

Measurements of hydrographic properties

This section gives an overview of sensors and instrument packages for the measurement of temperature, salinity, oxygen, nutrients and tracers.

Reversing thermometers

In the earliest, temperature measurements at some depth below the surface were made by bringing a water sample up to the deck of a ship in an insulated bucket and measuring the sample temperature with a mercury thermometer. Although these measurements were not accurate, they gave the first evidence that below the top 1000m the ocean is cold even in the tropics. They also showed that highly accurate measurements are required to resolve the small temperature differences between different ocean regions at those depths.

The first instrument that (through the use of multiple sampling and averaging) achieved the required accuracy of 0.001°C was the [reversing thermometer](#). It consists of a mercury filled glass pipe with a 360° coil. The pipe is restricted to capillary width in the coil, where it has a capillary appendix. The instrument is lowered to the desired depth. Mercury from a reservoir at the bottom rises in proportion to the outside temperature. When the desired depth is reached the thermometer is turned upside down (reversed), but the flow of mercury is now interrupted at the capillary appendix, and only the mercury that was above the break point is collected in the lower part of the glass pipe. This part carries a calibrated gradation that allows the temperature to be read when the thermometer is returned to the surface.

To eliminate the effect of pressure, which compresses the pipe and causes more mercury to rise above the break point during the lowering of instrument, the thermometer is enclosed in a pressure resistant glass housing. If such a “protected [reversing thermometer](#)” is used in conjunction with an “unprotected [reversing thermometer](#)” (a thermometer exposed to the effect of pressure), the difference between the two temperature readings can be used to determine the pressure and thus the depth at which the readings were taken. The [reversing thermometer](#) is thus also an instrument to measure depth. Reversing thermometers require a research vessel as platform and are used in conjunction with Nansen or Niskin bottles or on multi-sample devices.

Nansen and Niskin bottles

The measurement of salinity and oxygen, nutrients and tracer concentrations requires the collection of water samples from various depths. This essential task is achieved through the use of “water bottles”. The first water bottle was developed by Fritjof Nansen and is thus known as the Nansen bottle. It consists of a metal cylinder with two rotating closing mechanisms at both ends. The bottle is attached to a wire. When the bottle is lowered to desired depth it is open at both ends, so the water flows through it freely. At the depth where the water sample is to be taken the upper end of the bottle disconnects from the wire and the bottle is turned upside down. This closes the end valves and traps the sample, which can then be brought to the surface.

In an “oceanographic cast” several bottles are attached at intervals on a thin wire and lowered into the sea. When the bottles have reached the desired depth, a metal weight (“messenger”) is dropped down the wire to trigger the turning mechanism of the uppermost bottle. The same mechanism releases a new messenger from the bottle; that messenger now travels down the wire to release the second bottle, and so on until the last bottle is reached.

The Nansen bottle has now widely been displaced by the Niskin bottle. Based on Nansen’s idea, it incorporates two major modifications. Its cylinder is made from plastic, which eliminates chemical reaction between the bottle and the sample that may interface with the measurement of tracers. Its closing mechanism no longer requires a turning over of the bottle; the top and bottom valves are held open by strings and closed by an elastic band. Because the Niskin bottle is fixed on the wire at two points instead of one (as is the case with the Nansen bottle) it makes it easier to increase its sample volume. Niskin bottles of different sizes are used for sample collection for various tracers.

Nansen and Niskin bottles are used in conjunction with [reversing thermometers](#). On the Nansen bottle

the thermometers are mounted in a fixed frame, the reversal being achieved by the turning over of the bottle. On Niskin bottles thermometers are mounted on a rotating frame.

Conductivity, Temperature and Depth System(CTDs)

Today's standard instrument for measuring temperature, salinity and often also oxygen content is the CTD, which stands for conductivity, temperature, depth. It employs the [principle](#) of electrical measurement. A platinum thermometer changes its electrical resistance with temperature. If its incorporated in an electrical oscillator, a change in its resistance produces a change of the oscillator frequency, which can be measured. The conductivity of seawater can be measured in a similar way as a frequency change of a second oscillator, and a pressure change produces a frequency change in a third oscillator. The combined signal is sent up through the single conductor cable on which the CTD is lowered. This produced a continuous reading of temperature and conductivity as functions of depth at a rate of up to 30 samples per second.

Electrical circuits allow measurements in quick succession but suffer from "instrumental drift", which means that their calibration changes with time. CTD systems therefore have to be calibrated by comparing their readings regularly against more stable instruments. They are therefore always used in conjunction with [reversing thermometers](#) and a multi-sample device.

Multiple water sample devices

Multiple water sample devices allow the use of Niskin bottles on electrically conducting wire. Different manufacturers have different names for their products, such as rosette or carousel. In all products the Niskin bottles are arranged on a circular frame, with a CTD usually mounted underneath or in the centre.

The advantages of multi-sample devices over the use of a hydrographic wire with messengers is that the water bottles can be closed by remote control. This means that the sample depths do not have to be set before the bottles are lowered. As the device is lowered and data are received from the CTD, the bottle can be closed by remote control. As the device is lowered and data are received from the CTD, the operator can look for layers of particular interest and take water samples at the most interesting depth levels.

Thermosalinographs

Continuous readings of temperature and salinity at the surface can be found out through CTDs. Water from the cooling water intake of the ship's engines is pumped through a tank in which a temperature and a conductivity sensor are installed. Such a system is called a thermosalinograph. In which the parameters are observed and are graphically represented called thermosalinograph.

Remote sensors

Most oceanographic measurements from space or aircraft are based on the use of radiometers, instruments that measure the electro-magnetic energy radiating from a surface. This radiation occurs over a wide range of wavelengths, including the emission of light in the visible range of heat in the infrared range, and at shorter wavelengths such as Radar and X-rays. Most oceanographic radio meters operate in several wavelength bands.

Radiometers that operate in the infrared are used to measure sea surface temperature. Their resolution has steadily increased over the years; the AVHRS (Advanced Very High Resolution Radiometer) has a resolution that comes close to 0.2°C.

Multi-spectral radiometers measure in several wavelength bands. By comparing the radiation signal received at different wavelengths it is possible to measure ice coverage and ice age, chlorophyll content, sediment load, particulate matter and other quantities of interest to marine biology.

Measurements of dynamic properties

The Dynamic properties includes surface expressions of [internal waves](#), the effect of rainfall on surface [waves](#), the effect of bottom topography on currents and [waves](#), and a range of other phenomena. Many instruments are designed to measure the above properties.

DRIFTERS:

An elementary way of observing oceanic movement is the use of drifters. As mentioned above drifters are platforms designed to carry instruments. But all measurements obtained from drifters are of little use unless they can be related to positions in space. A geolocation (GPS) device which transmits the drifter location to a satellite link is therefore an essential instrument on any drifter, and this turns the drifter into an instrument for the measurement of [ocean currents](#). Whether it does that job well or not depends on its design, and in particular the size and shape of its sea anchor.

Current meters

[Ocean currents](#) can be measured in two ways. An instrument can record the speed and direction of the current, or it can record the east-west and north-south components of the current. Both methods require directional information. All current meters therefore incorporate a magnetic compass to determine the orientation of the instrument with respect to magnetic north. Four classes of current meters can be distinguished, based on the method used for measuring current magnitude.

Mechanical current meters use a propeller-type device, a Savonius rotor or a paddle-wheel rotor to measure the current speed, and a vane to determine current direction. Propeller sensors often measure speed correctly only if they point into the current and have to be oriented to face the current all the time. Such instruments are therefore fitted with a large vane, which turns the entire instrument and with it the propeller into the current.

Propellers can be designed to have cosine response with the angle of incidence of the flow. Two such propellers arranged at 90° will resolve current vectors and do not require an orienting vane.

The advantage of the Savonius rotor is that its rotation rate is independent of the direction of exposure to the current. A Savonius rotor [current meter](#) therefore does not have to face the current in any particular way, and its vane can rotate independently and be quite small, just large enough to follow the current direction reliably.

With the exception of the [current meter](#) that uses two propellers with cosine response set at 90° to each other, mechanical current meters measure current speed by counting propeller or rotor revolutions per unit time and current direction by determining the vane orientation at fixed intervals. In other words, these current meters combine a time integral or mean speed over a set time interval (the number of revolutions between recordings) with an instantaneous reading of current direction (the vane orientation at the time of recording). This gives only a reliable recording of the ocean current if the current changes slowly in time. Such mechanical current meters are therefore not suitable for current measurement in the oceanic surface layer where most of the oceanic movement is due to [waves](#).

The Savonius rotor is particularly problematic in this regard. Suppose that the [current meter](#) is in a situation where the only water movement is from [waves](#). The current then alternates back and forth, but the mean current is zero. A Savonius rotor will pick up the wave current irrespective of its direction, and the rotation count will give the impression of a strong mean current. The paddle-wheel rotor is designed to rectify this; the paddle wheel rotates back and forth with the wave current, so that its count represents the true mean current.

Mechanical current meters are robust, reliable and comparatively low in cost. They are therefore widely used where conditions are suitable, for example at depths out of reach of surface [waves](#).

Electromagnetic current meters exploit the fact that an electrical conductor moving through a magnetic field induces an electrical current. Sea water is a very good conductor, and if it is moved between two electrodes the induced electrical current is proportional to the ocean current velocity between the electrodes. An electromagnetic [current meter](#) has a coil to produce a magnetic field and two sets of electrodes, set at right angle to each other, and determines the rate at which the water passes between both sets. By combining the two components the instrument determines speed and direction of the ocean current.

Acoustic current meters are based on the [principle](#) that sound is a compression wave that travels with the medium. Assume an arrangement with a sound transmitter, and let receiver B located downstream. If a burst of sound is generated at the transmitter it will arrive at receiver B earlier than at receiver A, having been carried by the ocean current.

A typical acoustic [current meter](#) will have two orthogonal sound paths of approximately 100mm

length with a receiver/transmitter at each end. A high frequency sound pulse is transmitted simultaneously from each transducer and the difference in arrival time for the sound travelling in opposite directions gives the water velocity along the path.

Electromagnetic and acoustic current meters have no moving parts and can therefore take measurements at a very high sampling rate (up to tens of readings per second). This makes them useful not only for the measurement of [ocean currents](#) but also for wave current and turbulence measurements.

Acoustic Doppler current profilers (ADCPs) operate on the same [principle](#) as acoustic current meters but have transmitter and receiver in one unit and use reflections of the sound wave from drifting particles for the measurement. Seawater always contains a multitude of small suspended particles and other solid matter that may not all be visible to the naked eye but reflects sound. If sound is transmitted in four inclined beams at right angle to each other, the Doppler frequency shift of the reflected sound gives the reflecting particle velocity along the beam. With at least 3 beams inclined to the vertical the three components of flow velocity can be determined. Different arrival times indicate sound reflected at different distances from the transducers, so an ADCP provides information on current speed and direction not just at one point in the ocean but for a certain depth range; in other words, an ADCP produces a current profile over depth.

Different ADCP designs serve different purposes. Deep ocean ADCPs have a vertical resolution of typically eight meters (they produce one current measurement for every eight meters of depth increase) and a typical range of up to 400m. ADCPs designed for measurements in shallow water have a resolution of typically 0.5m and a range of up to 30m. ADCPs can be placed in moorings, installed in ships for underway measurements, or lowered with a CTD and multi-sample device to give a current profile over a large depth range.

Wave measurements

The parameters of interest in the measurement of surface [waves](#) are wave height, wave period and wave direction. At locations near the shore wave height and wave period can be measured by using the [principle](#) of the stilling well described for tide gauges below, with an opening wide enough to let pass surface wave unhindered. Wave measurements on the shelf but at some distance from the shore can be obtained from a pressure gauge.

An instrument suitable for all location including the open ocean is the wave rider, a small surface buoy on a mooring which follows the wave motion. A vertical accelerometer built into the wave rider measures the buoy's acceleration generated by the [waves](#). The data are either stored internally for later retrieval or transmitted to shore. Wave riders provide information on wave height and wave period. If they are fitted with a set of 3 orthogonal accelerometers they also record wave direction.

Remote sensors

Sea level can also be measured from satellites. An altimeter measures the distance between the satellite and the sea surface. If the satellite position is accurately known this results in a sea level measurement. Modern altimeters have reached an accuracy of better than 5cm. The global coverage provided by satellites allows the verification of global tide models. When the [tides](#) are subtracted, the measurements give information about the shape of the sea surfaces and, through application of the [principle](#) of geostrophy, the large scale oceanic circulation.

Shear probes

This extremely brief overview of oceanographic measurement techniques can only cover the essentials of the most important platforms and instruments. Special equipments exist, and new special equipment is being designed every day, to address specific problems. The shear probe may serve as an example. It is designed to give insight into oceanic turbulence at the centimeter scale. Turbulence is characterized by currents which vary over short distances and short time intervals, so an instrument designed to measure turbulence has to be able to resolve differences in current speed and direction over a vertical distance of not more than a meter or so.

One such shear probe is a cylindrical instrument of less than 1m length with two electromagnetic or acoustic [current meters](#) at its two ends. By measuring current speed and direction at two points less than 1m apart it allows the determination of the current shear over that distance. To allow a reliable measurement not influenced by the heaving motion of the ship the probe falls slowly and freely through the ocean. Its maximum diving depth is programmed before the experiment , and the probe returns to the surface when that depth is reached. It is then picked up by the ship, and the internally recorded data are retrieved.

Another type of free-fall instrument used microstructure sensors that measure velocity fluctuations on a special scale of about 10mm. It used a piezo-electric beam that generates small voltages as the turbulent velocity varies the lift and thus the bending force on an aerofoil as it moves through the water.