MEASUREMENT TOOLS: WATER SYSTEMS (OCEANS)

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Contents

Summary

The ocean properties at a given point in space and time can be divided into (i) mechanical motion (velocity), (ii) thermodynamic state (density, temperature), (iii) dissolved substances (salt, gases), and (iv) suspended matter (bubbles, plankton). Various techniques have been developed to measure such properties in situ, in vitro, or remotely. The water transport speed can be recorded by means of mechanical rotors or acoustic Doppler measurements. The fundamental thermodynamic properties of a water parcel are pressure, temperature, and salinity. Highly reliable electronic sensors have been developed to measure them with accuracy sufficient to compute the water density with errors below 0.01 grams per kg. Thermodynamic theory enables to compute a large variety of different water properties from these three fundamental ones, based on mathematical so-called potential functions (the “equation of state”). Several optical properties can be measured for additional information of the water contents.

1. Introduction

Oceans, continents and atmosphere define the surface of the Earth, interactively control the climate and form a refuge for all life, as we know it. The thermodynamically most important role of the oceans in this regard is that of a vast buffer and transportation medium for energy. The very specific physical properties of water made the oceans the preferred environment for many life forms. The second significant function is their capability as the source and sink of fresh water due to the evaporation, precipitation, freezing, and river discharge processes. The relevant physical processes are very complex and are linked to each other in various ways. Oceanography is a relatively young scientific discipline that tries to better understand these interacting physical, chemical, biological and geological dynamic phenomena.

The ocean waters appear both in the liquid (sea water) and in the solid phase (sea ice), with the latter being the much less important and the much less investigated state. A ‘parcel’ of sea water is physically characterized by just a few different properties;

- its three-dimensional motion (velocity, or momentum);
- its thermodynamic conditions (pressure and temperature);
- its dissolved chemical compounds (salts, gases);
- its suspended matter (bubbles, dust, mud, living and dead organisms).

Numerous further properties like sound speed, heat capacity, energy, conductivity, light absorption, etc. can—at least in principle—be computed theoretically as soon as the basic data are known. For sea ice, transport velocities are very small and much less variable in space and time. The solid state “ice” depends not only on temperature and applied pressure, but additionally, in a complicated way, on the primary ice formation process and on the time history of that particular piece of ice. Sea ice contains “brine pockets,” these are cavities filled with seawater with high salt concentration, while the solid ice itself is fresh water ice only. The mechanical, thermal and optical properties vary with a much wider range than those of seawater.Ocean currents, even at the water surface, are normally almost invisible to the human eye. The water motion is driven by winds, tides, and, even less obvious, by spatial density differences similar to low and high pressure systems in the atmosphere. The knowledge of ocean transport mechanisms and their variability in space and time is a key to understanding important phenomena, for example, in climate and fishery.

2. Current Measurements for Oceans

To measure the current velocity of water in the ocean, we have to distinguish first between *direct* and *indirect methods.* The latter try to determine currents by physical laws after measuring the distribution of water density and pressure, and we will look at these questions in the next section. The direct methods can be further divided into **Lagrangian methods** on the one hand, where instruments or substances drift with the water and their displacement is recorded (see *Field Techniques: Water Systems (Oceans)*), and **Eulerian methods** on the other hand, where measuring instruments—current meters—are mounted at fixed positions and measure the temporal change in speed and direction of the local flow. Three different physical principles are the base for the most common current meters: electromagnetic devices, mechanical devices, and acoustical devices.

Electromagnetic flow meters make use of the fact that seawater is an electrically conducting liquid. When a magnetic field is applied to water, the streaming water induces electrical voltages dependant on the strength and direction of the flow. Although this principle is rather robust even under maritime conditions, its main drawback is a high power consumption, so that these instruments have played only a minor role in oceanography. A special instrument, however, was the ship-towed electro-kinetograph (compare *Field Techniques: Water Systems (Oceans)*)which used the geomagnetic field

Mechanical current meters are equipped with a rotor (measuring the current speed), with a vane and a compass such that the instrument can turn into the flow like a wind mill (measuring the horizontal current direction), with a pressure sensor to determine the depth, and optionally with an inclinometer to measure deviations from vertical and additional sensors for temperature and conductivity.

They have internal data storage media for working periods of several months or even years; their energy consumption is sufficiently economical. Stall speed of the rotor is typically about 2 cm/sec, such that slow currents cannot be observed. The rotor is sensitive to seaweed and mussel growth. Therefore, applications in the bright near-surface zone are very restricted in duration. Over several decades, mechanical current meters were dominating the research, but presently the acoustic devices are taking over.

Acoustical devices make use of the time needed for a sound pulse to travel upward from a bottom-mounted source to be reflected at the sea surface and its return to the source. They can be used to study patterns within the stratification of an overlying water column. This concept was used to construct inverted echo sounders to record, among other things, sea level fluctuations in the open ocean.

The basic problem with such an electronically operating transducer design lies in the detection of very small travel time differences, highly precision frequency measurements, and phase detection depending on the mode of operation. If one aims at a resolution of 0.1 cm/s using a distance of 10 cm and assumes a sound velocity of 1500 m/s, then travel times less than 1 μs have to be resolved. In order to achieve a fast transducer response, piezoelectric transducers with resonant frequencies in the MHz range are used. A typical transducer with a resonant frequency at 3.5 MHz has a diameter of 10 mm and is about 1 mm thick.

Acoustic Doppler current profiler (ADCP, or ADP, acoustic Doppler profiler) applies the physical Doppler effect (named after the discovery by Christoph Doppler in 1842), which is the frequency shift of a sound wave if source and receiver are moving relative to each other. They use specifically designed acoustic sources and receivers to measure the three velocity components along the beam by detecting the Doppler shift of the acoustic frequency released in the range between 90 kHz and 600 kHz. The principle of such an ADCP is depicted in Figure 1.

Controlled by a crystal oscillator, an acoustic transducer generates sound waves into the flowing water. The directional sensitivity of the related receiver overlaps with that of the transducer within a small water volume forming the measuring zone. Particles with acoustic impedances, which are different from those of seawater, are transported by currents into this measuring zone. Oceanic currents carry such particles virtually everywhere. Particles are used as passive reflectors.

The receiver sees such reflectors as moving sound sources when the sizes are at least greater than half the wavelength of the emitted sound. Sound waves are partly reflected into the direction of the receiver. The higher the frequency the smaller the reflecting particle can be in size. For instance, a sound frequency of 5 MHz realizes a characteristic length of about 0.15 mm. The sweep between emitted and received signals (that is, the Doppler effect) is proportional to the current velocity. In reality, size and particle concentration vary within a large range. Therefore, a Doppler frequency band rather than a single frequency appears at the receiver and registered signals fluctuate considerably. Again, this problem is solved by suitable filter procedures. Finally, recorded time series are stored by memory units with a large capacity.

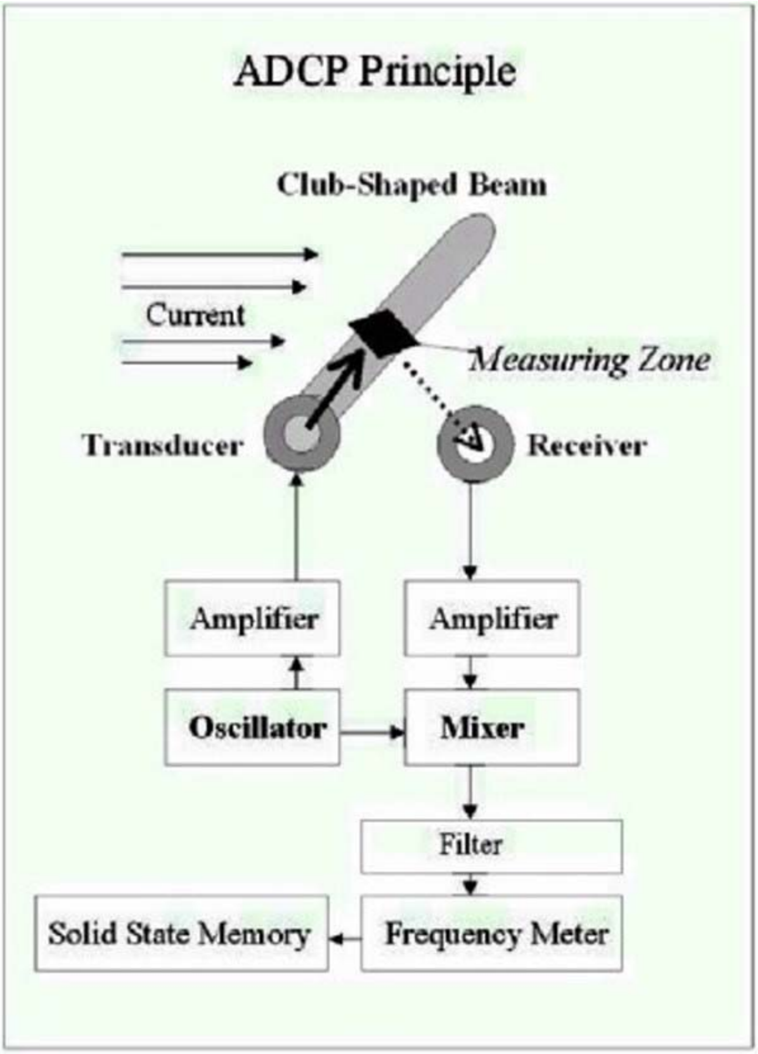

Figure 1. Working principle of the acoustic doppler current profiler (ADCP)

Several configurations of ADCPs are used. More recently, commercial ADCP units are mounted directly in the hull of research vessels to obtain rapidly repeated underway velocity profiles of the upper few hundred meters. Other constructions have been combined with usual CTD probes or are used autonomously, either mounted on the seabed (upwards looking) or beneath subsurface moorings (downwards looking), [*Schott*, 1986]. Some professionial ADP instruments are shown in Figure 2.

Figure 2. Different acoustic Doppler profilers ADP (with kind permission of SonTek Inc., San Diego).

The principle arrangement of transmitter and receiver to detect Doppler signals in flowing water is the same in acoustics as in optics. The optical method has become feasible after the emergence of the Laser light source. Temporal and spatial coherence of its light allows a concentration in very small volumes in the order of 1 mm³ at a certain distance away from the housing of the instrument. This technique is mainly used to study high frequency fluctuations of the motion field (turbulence), especially within oceanic boundary layers. Again, the Doppler shift is proportional to the particle velocity. However, there is no need for calibration in a towing tank as it is the case for most of other velocity sensors. The basic configuration is determined by the location of the detector in that system. It selects which velocity component is measured. That means, the detector constellation is important for the practical design of such a current meter under field conditions. Typical scattering functions of seawater suggest the use of forward scattering methods because 50–60% of the total scattered intensity falls into the range of ±5° in the forward direction. This forward scattering mode is named 'differential mode'. Adopting this mode, all backward intensities are lowered by a factor between 10^{-3} and 10^{-4}. The two crossing beams generate a system of interference stripes. When a particle crosses this system of dark and bright stripes it is illuminated by a certain frequency. The detected signal is recorded. Subsequent data processing is done on board of the ship. Compared to other current meters, the application of Laser Doppler Anemometers (LDA) is still in an experimental stage. Principles were discussed 25 years ago by *Kullenberg and Buchhave*, 1974. Generally, such a system measures the velocity in two orthogonal directions in a plane perpendicular to the axis of the instrument. Two sets of beams are used, for instance with frequencies of 38 MHz and 42 MHz. The scattered light is recorded by one photodetector. Thereafter, both components are separated by filters and the velocity is obtained by frequency trackers. The related measuring volume is about 0.5 mm³. Associated current fluctuations can be detected down to the order of 0.01 cm/s with frequencies up to several kHz. Therefore, such instruments are also called **"turbulence meter."**

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Biographical Sketches

Eberhard Hagen is a university lecturer in applied physics at Rostock University and senior scientist in physical oceanography at the Institute for Baltic Sea Research Warnemuende (IOW), Germany. He studied geophysics and meteorology at the Leipzig University. His scientific career started with experimental studies on energetic exchange processes between atmosphere and ocean in coastal zones of the Baltic Sea. During the last twenty years, his particular interest focused on both descriptive investigation and numerical modeling of circulation dynamics in coastal upwelling regions along African coasts as well as on spreading of dense water flow in deep Baltic basins. He participated several international field programs like that of the World Ocean Circulation Experiment (WOCE) and was principal oceanographer of distinct national contributions. Related field campaigns were carried out in the Indian Ocean (Channel of Mozambique), the equatorial Atlantic Ocean, along west African coasts, the North Sea, and the Baltic Sea. He was member of several working groups of the Scientific Committee on

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