Ocean Current Measurements: a Review

Measurement of water motion permits us to predict transport of sediment, estimate drift of contaminates, understand mixing and transport processes and to report wave conditions. While these are only a few of the benefits conferred by current measurements, they serve to illustrate the demands made on current meters.

Current measurement techniques have progressed from mechanical sensors to electromagnetic, acoustic and optical sensors. A broad distinction can be made between single point sensors and profiling sensors. Transport of water may also be determined using drifters, tracked acoustically or positioned by radio/satellite transmission.

Point Sensors

These are among the most often used, illustrate many of the principles and trade-offs, and give the least ambiguous measurements. The mechanical Savonius rotor-and-vane current meter embodied in the Aanderaa RCM 5 and the Woods Hole Oceanographic Institution VACM (Vector Averaging Current Meter) has a venerable and important history. Most long-term, deep-sea measurements were obtained with these instruments until about 1990, and although no longer made they are still used. The rotor makes a revolution with the passage of a characteristic length of water, in principle independent of speed. The vane aligns with the instantaneous direction of flow and vane orientation is measured relative to a compass aligned with the horizontal component of the Earth’s magnetic field, a direction-finding technique that is nearly ubiquitous.
Power for turning the rotor and aligning the vane comes from the flow and only the counting, compass reading and data-recording circuitry requires electric power. With their mechanical bearings running in seawater, these have a threshold of speed below which they no longer turn. Above this stall speed, fluctuations in flow may make them stall and run intermittently and under-respond in a way that is unsuspected. A more noticeable problem with rotors is their response to vertical flow and oscillatory flow; and the vane has a length-scale to which it can respond that causes directional errors in oscillatory flow or mooring vibrations.

VMCM - Vector Measuring Current Meter

The fan-blade VMCM (Vector Measuring Current Meter) was developed to deal with near-surface current measurements, where the rotors behaved badly. Although no longer manufactured, these instruments are also still in use. While they have a dead band from bearing friction and possible imbalance of blades, this is lower than in VACMs. Both types of mechanical sensor (rotors and blades) are inherently low power. They have large sampling volumes compared to some point sensors and are not suitable for turbulence studies, but they are suited to transport studies.

EM Sensors - Electromagnetic Sensors

Electromagnetic sensors (EM) have no moving parts. The principle of measurement in EM sensors is the law of magnetic induction. Point sensors like the Marsh McBirney, Valeport and InterOcean S4 generate an oscillating magnetic field with electric current through a coil. A voltage is induced in a moving conductor, seawater, in this magnetic field and the oscillating voltage is measured. EM sensors are free of dead band or hysteresis, but the zero point must be determined by calibration. Sensitivity must also be determined by calibration, difficult in moderate-sized tow-tanks with their nearby walls.

Acoustic point measurements are replacing mechanical and EM techniques in most new applications. Doppler and travel-time techniques are used. A sensitive acoustic receiver detects the frequency shift of a transmitted acoustic pulse echoed from scattering particles. This Doppler frequency shift is linear in the velocity component of the scatterers along the angle bisector of the acoustic paths. By geometric or timing arrangements, the sensing volume can be made remote from the transducers and away from the flow obstruction of the sensor. In bistatic arrangements like the SonTek ADV (Acoustic Doppler Velocimeter) probe, three receive-beams intersect a single transmitted beam in a small volume, remote from the transducer array. Doppler shifted signals from scatterers in this volume can be tracked in three circuits to obtain a 3-D vector velocity in a volume only about one centimetre in diameter. Signals are continuous; so many realisations of Doppler shift can be made in short intervals, realising both high-frequency response and good velocity resolution. This has made the ADV attractive for turbulence measurements.

Monostatic Doppler Acoustic-point Current Meters

There are also monostatic Doppler acoustic-point current meters like the Aanderaa RCM 9 and 11 and the Nortek Aquadopp, where the same transducer is used to transmit and receive and the sensing volume, remote from the transducer head, is defined by timing. These do not have a precise scattering volume like the ADV and are not suitable for measuring turbulence. But they do have a compact shape and look rugged. Because a pulse is transmitted and later received by the same transducer, there must be some dead time before another measurement can be made. Again, this is not suitable for turbulence but might be useful for transport, mixing studies, or possibly for wave measurements.

Acoustic Doppler point sensors require scatterers to return a signal for measurment. Scatterers may be mineral particles, small bubbles or organic detritus, but frequently they are zooplankton capable of motion. This can introduce errors of as much as 10cm/s in the vertical and 30cm/s in the horizontal. However, the greatest concern with acoustic sensors is absence of scatterers in clear water.

MAVS - Modular Acoustic Velocity Sensor

A travel-time acoustic point sensor avoids this dependence on scatterers. An opposing pair of acoustic transducers defines an axis along which the component of flow is measured by the difference in travel time for oppositely directed pulses. The pulse propagating upstream takes longer to cross the volume than the pulse propagating downstream. While this makes the travel-time sensor equally effective in clear or turbid water, the transducers are physically at the ends of the measurement volume, possibly distorting the flow to be measured. Faired supports in Nobska's MAVS (Modular Acoustic Velocity Sensor) minimise this effect. FSI's ACM (Acoustic Current Meter) and MAVS current meter are linear through zero velocity and must be zero-offset calibrated, unlike Doppler sensors with their inherent zero point at zero-frequency shift. FSI uses phase shifts, where Nobska uses time of pulse arrival to resolve velocity to 0.2cm/s and 0.05cm/s respectively.

Doppler Profilers

Doppler backscatter from low-acoustic frequencies, permits long acoustic ranges which, when time gated to multiple bins, gave a profile of velocity. At 300kHz the range is 150 metres with good scatterers. Like all Doppler sensors, ADPs must average many pulses to reduce the Doppler ambiguity of a single pulse to an acceptable velocity uncertainty. For the higher frequency, where attenuation is greater, pulses can be transmitted at a higher repetition rate, and in the same interval of time higher-velocity resolution can be achieved. In general, Doppler profilers are limited to a constant product of time resolution with velocity resolution for any operating frequency. If operating frequency, which determines range, is included in the equation so that a greater range can be achieved with a lower frequency, the constant is maximum range × repetition rate × 1/standard deviation of velocity.

BBADCP - Broadband Acoustic Doppler Current Profiler

RDI in conjunction with WHOI recognised that multiple pulses could be in the water at the same time if they were encoded as pseudo-random phase reversal codes. This requires the transmitter to have more bandwidth to generate the high frequencies associated with phase reversals in only a few cycles, so RDI designates this version of its ADCP (Acoustic Doppler Current Profiler) the BBADCP: broadband ADCP. This scheme reduces the value of the constant by a factor equal to the number of coded pulses used. ADCP scattering volumes are large compared to single-point Doppler current meters, and loss of signal from clear water is not as troubling as for the smaller-volume, higher-frequency ADV and other point-measuring Doppler current meters.

Other Methods: PIV (Particle Imaging Velocimetry) and DPIV (Differential PIV)

PIV (Particle Imaging Velocimetry) and DPIV (Differential PIV) use natural or seeded particles in a flow to define instantaneous flow-fields around objects such as hull appendages or fish. A sheet of light scatters from particles in the plane of illumination and the scatterers are photographed with a camera viewing this plane. A time exposure several tens of milliseconds long, or two exposures several tens of milliseconds apart leave either streaks or pairs of spots, with PIV or DPIV, respectively. Length or separation in the two cases represents speed of flow, and angle represents direction of flow in the plane of illumination. Lagrangian drifters provide integrated current measurements. The Argos array of 1,500 drifting buoys, soon to be expanded to 3,000 floats, cover the oceans, signalling drift vectors on a large scale, while also reporting salinity and temperature profiles. Gliders add forward motion to similar floats as they move from the depths, where they measure T and S, to the surface, where they telemeter these profiles. Their position gives current drift, corrected for their own motion through water.

Conclusion

This review of ocean current measurements shows this to be a vigorous field of instrumentation and development. The Current Measurement Technology Committee of the Oceanic Engineering Society of IEEE holds working conferences every two to five years, the last one was held from 28th to 29th June 2005, at Southampton Oceanography Centre.