Currents

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DIY Oceanography BZH

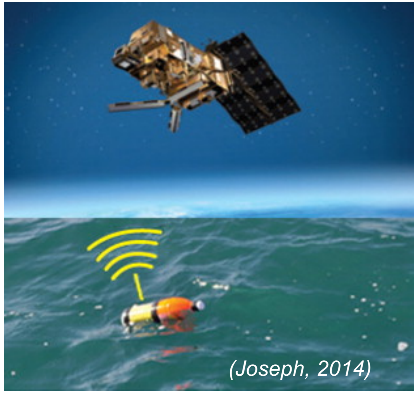
Currents

Determining a marine current involves measuring its speed, depth and direction. The velocity of the flow represent the movements/advection of oceanic water masses which are responsible for the transport of water, heat, salt, nutrients, particles, carbon, contaminants, biology...

Some historical background – lagrangian measurements

Very ancient: drift bottles were dropped at sea to evaluate favorable routes, mostly near coastal regions.

1847: Matthew Fontaine Maury (US) compiled mariners observations in « Wind and Currents charts », after 1855 emerged a joint action to evaluate currents using observations (difference between a ship's dead reckoning and its true position) and driftwoods....



(Joseph, 2014)

1885-1887: Prince of Monaco studied the surface currents of the Middle Atlantic, launching more than 1000 floats (weighted copper spheres) and 500 bottles.

1950: Drift card by F.C. Olson (printed card rolled hermetically in a polyethylene envelope), sensitive to wind forcing, time consuming.

1955: First neutrally buoyant float to track water movements at a given depth (J. Swallow).

... 2011: Satellite-tracked drift bottles by Koki Nishizawa and CLS (drifter with a drogue).

Currents

Some historical background – eulerian measurements

1787: First current meter by Reinhard Woltmann, consisting of a horizontal axis and a propeller in a shape of vane wheel with two angled vanes. A revolution counter was a mechanical one and was an integral part of the meter. In 1820, modification of the previous current meter by Trevianos, the shape of the propeller being changed from the vane wheel into a helical screw blades.

1903: Ekman current meter, a mechanical flowmeter.

1906: Nansen pendulum current meter.

1950: Roberts radio current meter (meter, buoy, transmitter). A speed signal derived from an impeller and a direction signal derived from a magnetic compass are electrically transmitted to the surface and recorded on a shipboard deck unit.

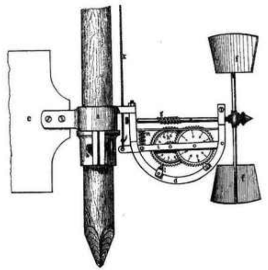
1960s: Savonius rotor current meter, known as Anderaa current meter, which is a mechanical instrument deployed on moorings. It is made of recording unit, a propeller to detect the water velocity and vane to determine the direction of the flow. Evolved through time (RCM8 with internal battery pack, analog-to-digital converter, internal compass and a micro-controller).

1960s-70s: Ultrasonic current meters for weak currents and turbulence, acoustic Doppler current meters.

1980s: RDI 3D water current sampling, current profiles along the water column at given cell depths.

1990s: Measurement of waves orbital velocities with ADPs.

Original Woltmann Current Meter



Ekman Current Meter

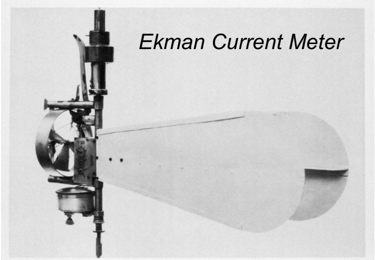
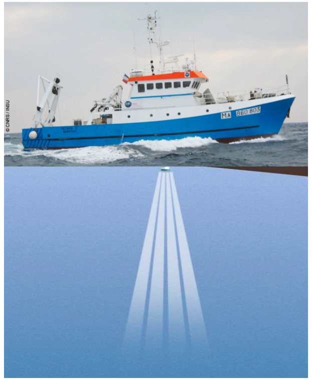


Figure 31. – Mesureur de courant de V.W. Ekman (n° 99 0613) (photo Y. Berard)

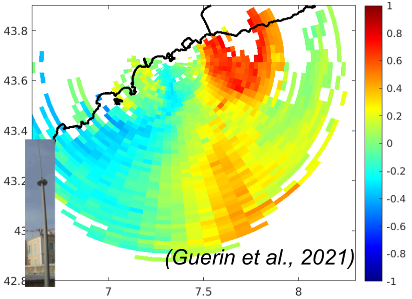
Nansen pendulum current meter

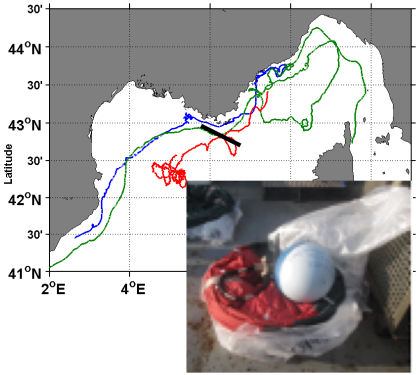
Overview of sensing principles available

In situ sensors:
Drifers (lagrangian)
Current meters (eulerian) :
suspended drag, propeller revolution registration by mechanical counters, unidirectional impeller current meters, Savonius rotor current meters, ultrasonic acoustic methods, thermal sensors for measurements of turbulent motions, laser Doppler sensors, and **acoustic Doppler current meters**



Remote sensors:
HF Radar
HF camera
Satellites





Overview of sensing principles available

Tilt current meter

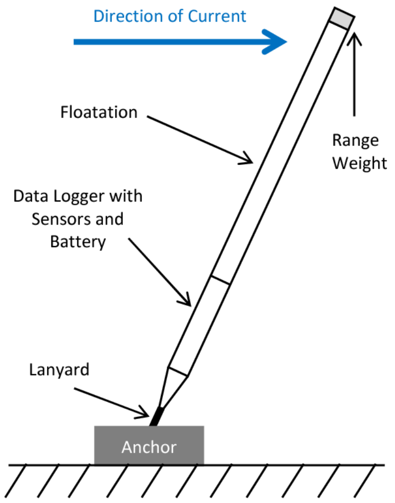
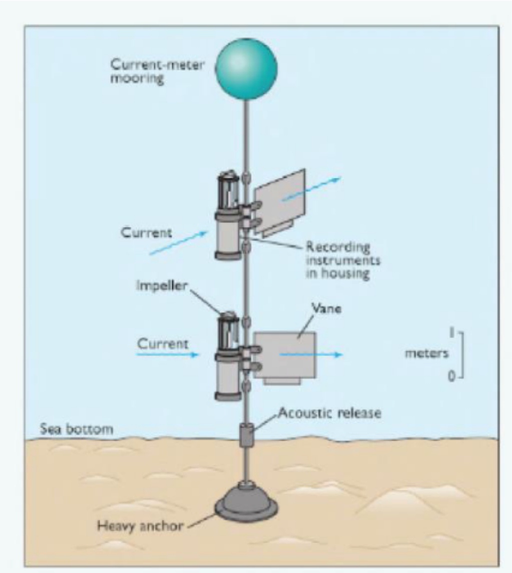


Fig. 1: Drawing of TCM-1 tilt current meter showing basic elements.

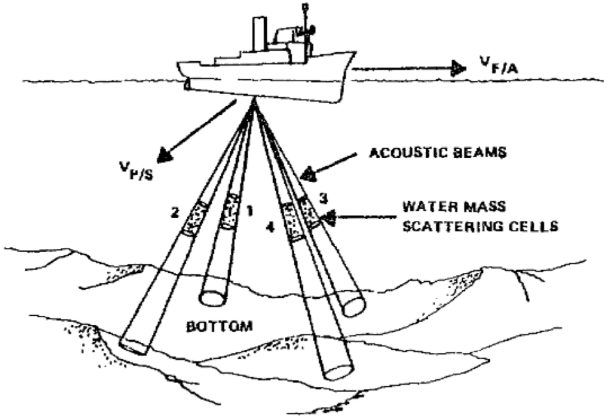
(Lowell, 2015)

Rotor current meter



(a) TWO IMPELLER METERS *(Pinet, 2014)*

Acoustic doppler current meters



(Rowe, 1979)

Tilt current meter

TCM-1 tilt current meter (Lowell Instrument)

- measures current using the drag-tilt principle.

The data logger is buoyant and is anchored to the bottom via a short flexible tether. Moving water tilts the data logger in the direction of flow. The TCM-1 contains a 3-axis accelerometer and 3-axis magnetometer for measuring tilt and bearing. The resulting orientation data is converted to current by applying calibration coefficients..

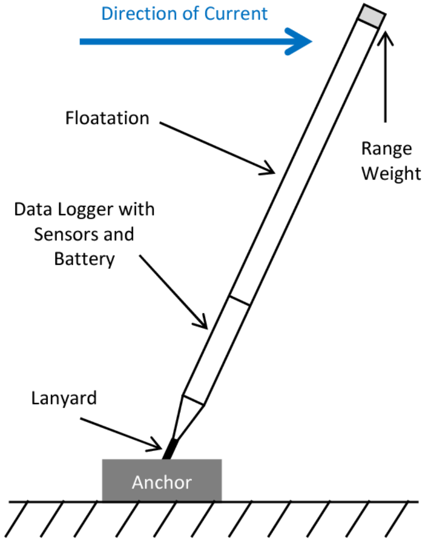


Fig. 1: Drawing of TCM-1 tilt current meter showing basic elements.

Tilt current meter

TCM-1 tilt current meter (Lowell Instrument)

- Depth <= 300 m; range 0-80 cm/s
- Size 73 cm long, 2,7cm diameter
- Tilt compensated compass for bearing measurements
- Simple, rugged, low maintenance design
- Seaweed snag-resistant
- Change range in the field without software
- 8 GB memory card
- Lithium battery : continuous 4Hz sampling for more than 1 year

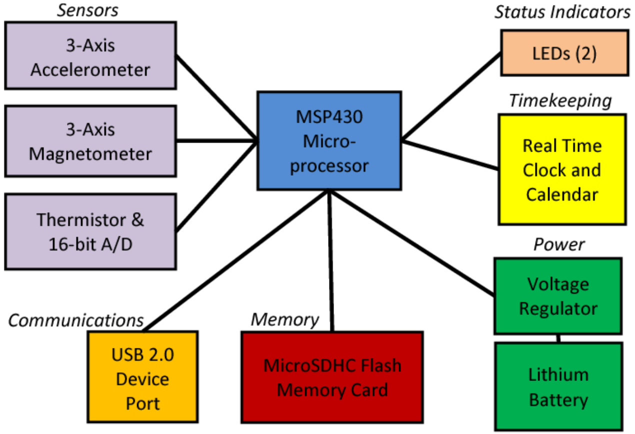


Fig. 2: Block diagram of the tilt current meter's electronics.

	Range	Accuracy	Resolution
Speed (Low Range)	0-40 cm/s	2 cm/s + 3% of reading	0.1 cm/s
Speed (High Range)	0-80 cm/s	3 cm/s + 3% of reading	0.1 cm/s
Direction	0-360°	5° (for speed >5 cm/s)	0.1°
Temperature	-5 to 30 °C	0.1 °C	<0.005 °C
	-20 to -5, 30 to 50°C	0.2 °C	<0.01 °C

Tilt current meter

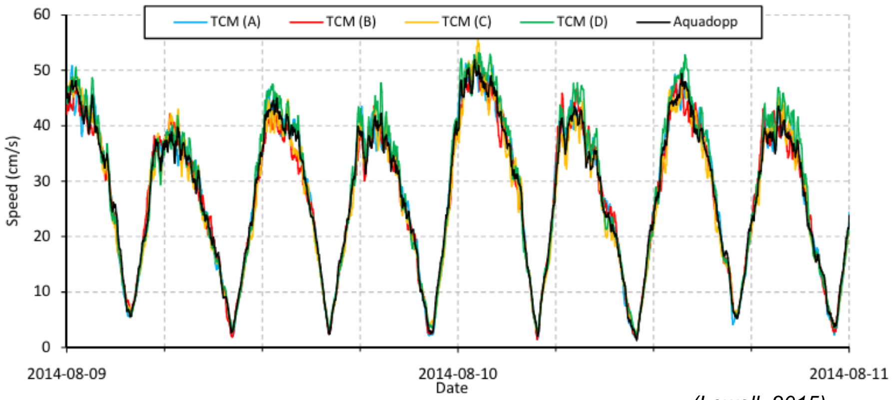


Fig. 4: Two-day representative time series of current speed with the results of each TCM-1 and the Aquadopp overlaid. *(Lowell, 2015)*

Advantages:

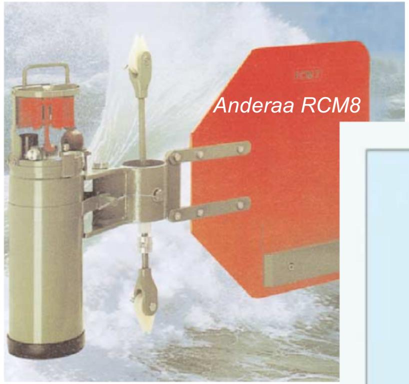
- Low technology
- Low price
- Low power
- Easy to deploy in coastal areas
- Validated in coastal areas

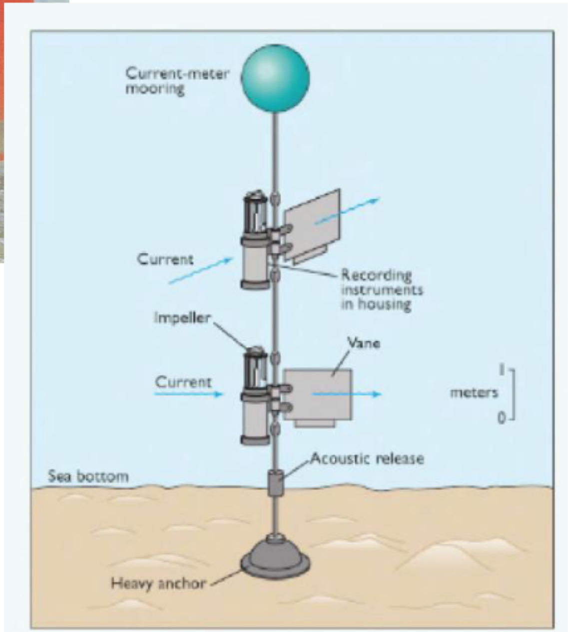
Drawbacks:

- Not extensively tested
- Only for bottom currents or surface currents (downward orientation)
- Limited range: 0-80 cm/s (70° inclination), not very precise under 10 cm/s
- Recovery by divers limits the depth deployment
- The sensitivity and range of the instrument have to be adjusted by adding and removing a range weight from the top of the meter (ranges 0-40 cm/s and 0-80 cm/s).
- Difficult to get the tilt-to-speed conversion curve
- Seaweed, or other debris fouling, can increase the drag on a TCM, resulting in an overestimation of current => antifooling option is provided => limits the dpeloyment duration

Rotor current meter

RCM rotor current meter (Anderaa)





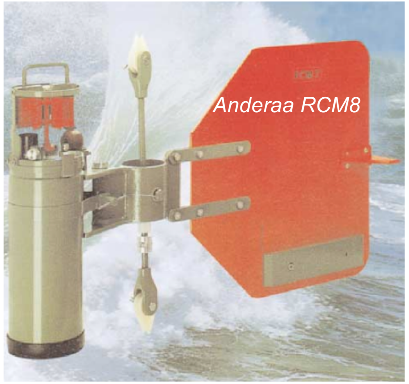
(a) TWO IMPELLER METERS *(Pinet, 2014)*

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.

Intensively used until 1990.

Rotor current meter

RCM rotor current meter (Anderaa)



Ch. 2. Temperature:

Sensor type:	Thermistor (Fenwall GB32JM19).
Resolution:	0.1% of selected range.
Accuracy:	±0.05°C.
Response time:	12 seconds (63%).
Selectable Ranges:	
Low range:	−2.4 to 21.4°C.
Wide range:	−0.3 to 32.1°C.
High range:	10.1 to 36.0°C.
Optional:	
Arctic range:	−2.6 to 5.6°C in channel 4.

Ch. 5. Direction:

Sensor Type:	Magnetic compass with needle clamped onto potentiometer ring.
Resolution:	0.35°.
Accuracy:	±5° for speeds from 5 to 100 cm/s. ±7.5° for current speeds 2.5 to 5 and 100 to 200 cm/s.

Ch. 6. Speed:

Sensor Type:	Rotor with magnetic coupling.
Range:	2 to 295 cm/s.
Accuracy:	±1 cm/s or ±4% of actual speed whichever is greater.
Starting Velocity:	2 cm/s.

Ch. 4. Pressure: (optional)

Part number:	RCM 7: 3239 or RCM 8: 3249
Sensor Type:	silicon piezoresistive bridge.
Ranges:	700, 3500, 7000 KPa, 14, 20, 35 and 60 MPa. 35 and 60 MPa is for RCM 8 only.
Accuracy:	±0.5% of range.
Resolution:	0.1% of range.

Rotor current meter

Advantages:

- Robust, well known instrument used for years
- Low power consumption: 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

Drawbacks:

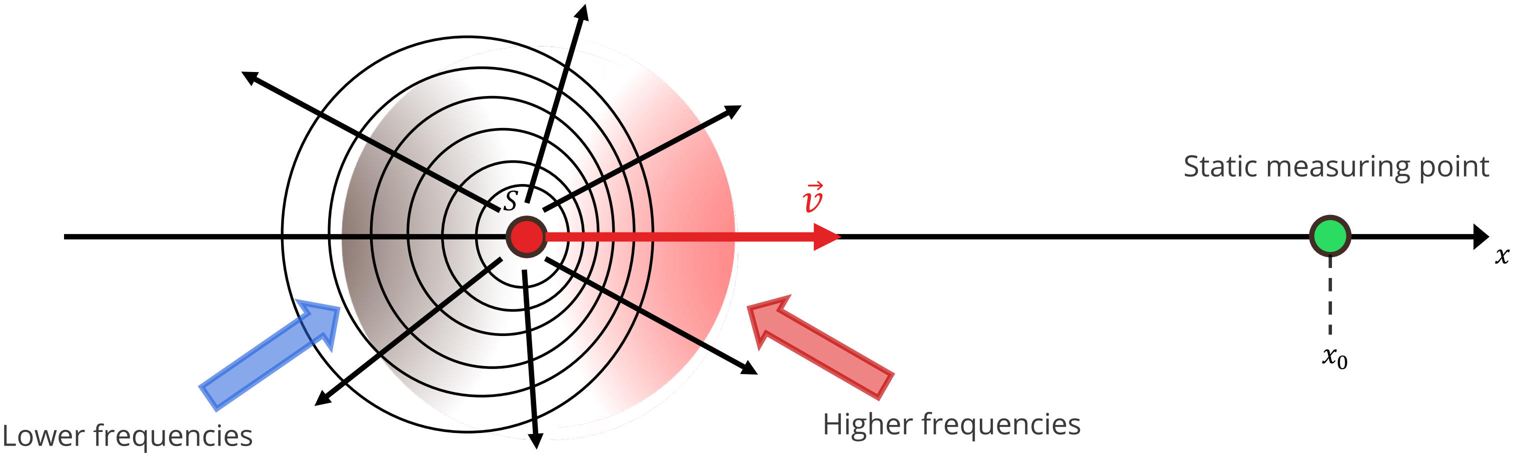
- Measures the current at a given depth, in a nearby cell close to the sensor : need for several current meters along the water column for profiling
- Mecanical bearings: threshold of speed below which they no longer turn
- Problem with Savonius rotors through their response (overestimation of water speed) to vertical flow and oscillatory (especially reversing) flow (Hamilton et al., 1997); vane time response: the vane has a length-scale to which it can respond that causes directional errors in oscillatory flow or mooring vibrations => the Anderaa RCM8 deals with these drawbacks by using a paddle-wheel rotor enclosed in a semsemicylindrical shield so that only half the rotor is exposed to flow along the vane instead of the Savonius rotor, the vane itself is small and has a fast response, and vectors are averaged.

Acoustic **D**oppler **C**urrent **P**rofiler (ADCP) – Doppler effect

ADCP principle

One measure a frequency shift Δf which is directly related to the relative speed v between the source and the reflector, this is the Doppler effect :

$$\Delta f = \propto v$$

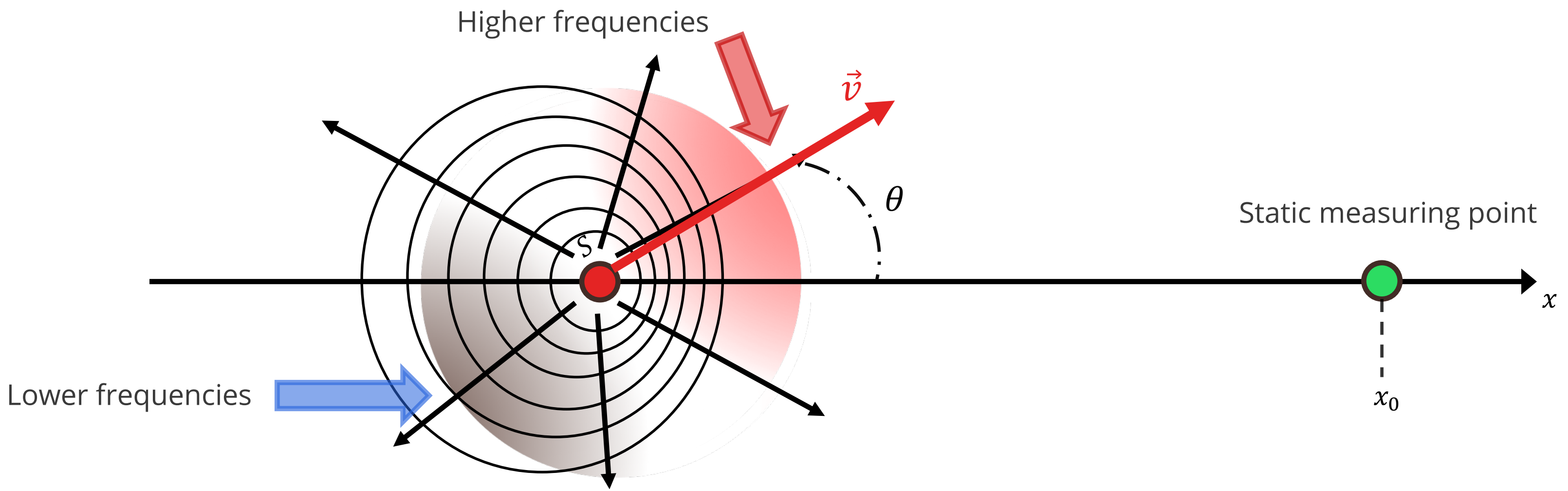


Acoustic **D**oppler **C**urrent **P**rofiler (ADCP) – Doppler effect

The Doppler effect is directional so the only measurable one is along the wave propagation axis (= beam axis) :

$$\Delta f = \propto \cos\theta \, v$$

Hence the need to combine several beams with different orientations, to reconstruct the three components of the velocity vector.



ADCP – sensor geometry

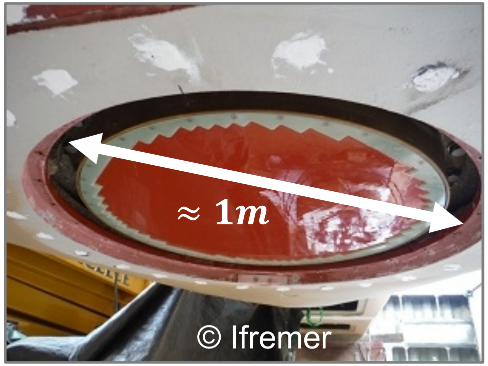
Most ADCP sensors feature 4 beams oriented in a so-called *Janus* configuration, at 90° to each other in the horizontal plane, and at an angle of about 25° to the vertical. Some have also a fifth vertical beam.

There are two main technologies :

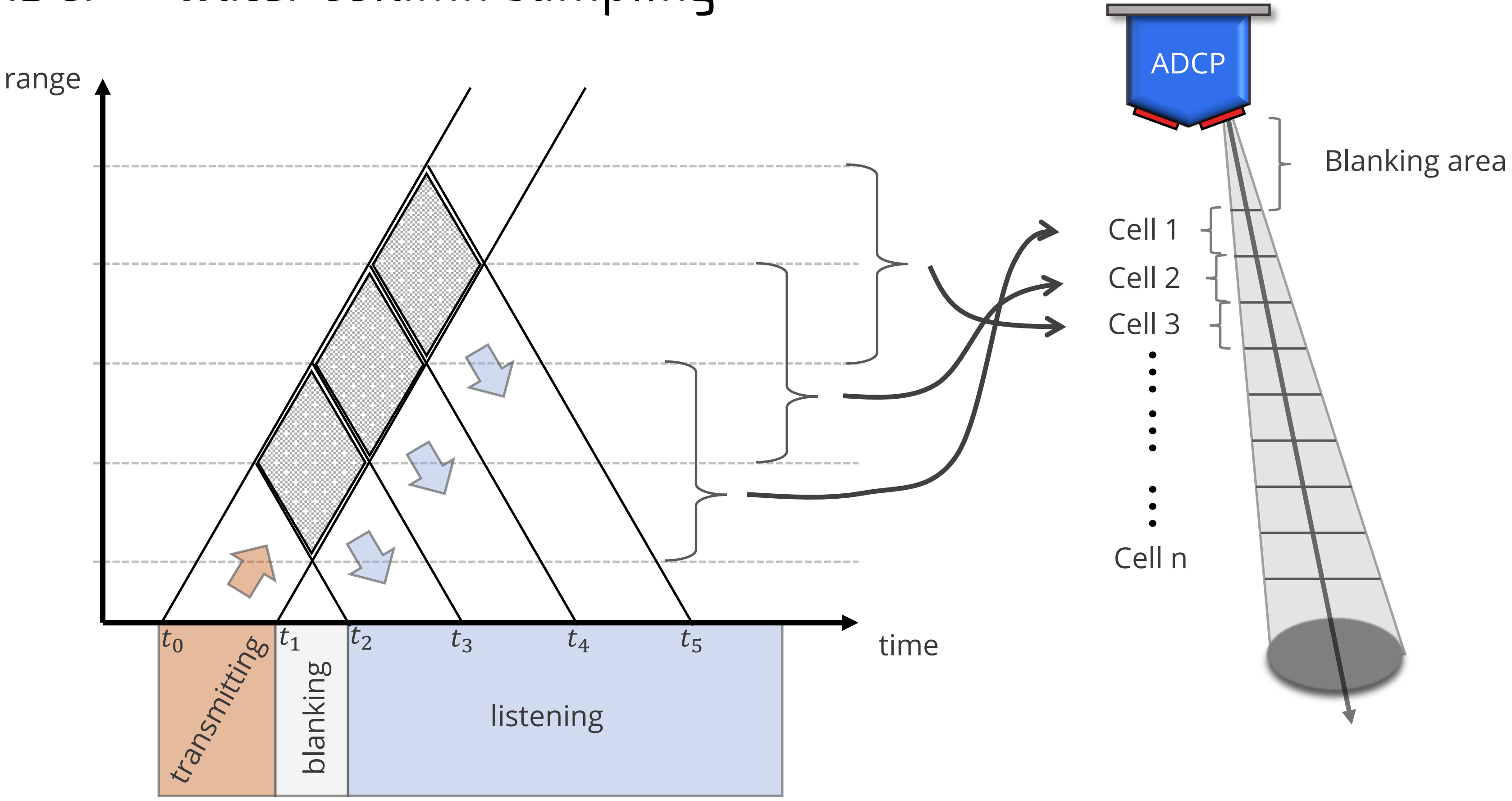
- piston-type transducers with physically separate transducers for each beam,
- phased-array antenna, electronically forming the beams, leading to more compact systems.

Nortek 250kHz ADCP

RDI 38kHz ADCP



ADCP – water column sampling



ADCP – effect of frequency on performance

Disclaimer : Performance is strongly dependent of ensonified medium properties (scatterers, …)

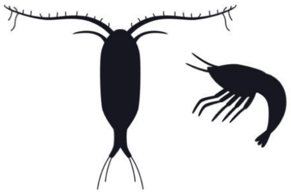
Order of magnitude

Frequency (kHz)	Range (m)	Resolution (m)
600	60	1
300	100	2
150	400	8
75	700	16
38	1000	24

ADCP – what is actually measured ?

Indirect measurement of currents

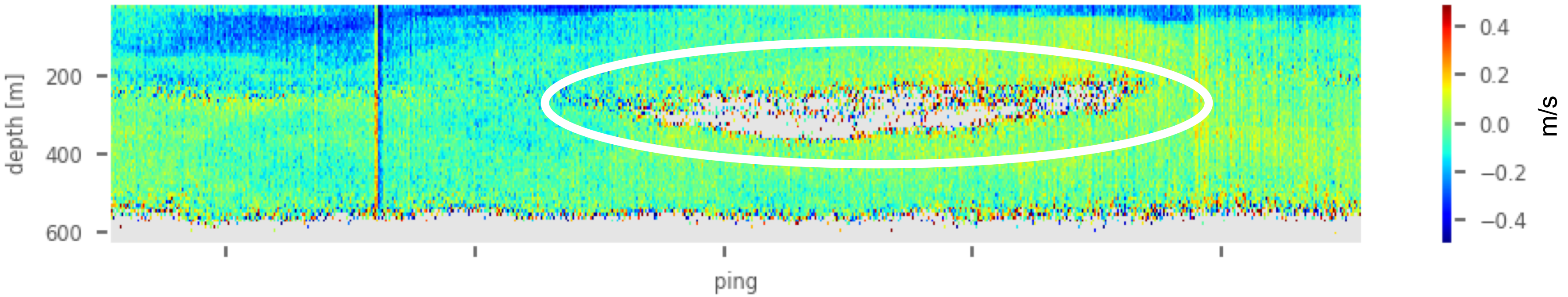
from mm to cm



We actually measure the velocity of micro-organisms (phytoplankton, zooplankton) or inert particles (sediment).

No scatterers = no current measurements

Currents data from mediterranean sea



ADCP – key assumptions

Assumption of no self-movement of scatterers relative to water mass

- This is the case with plankton, which are organisms that have no movement of their own in relation to currents.
- The frequency of the sensor determines which particles will be observed.

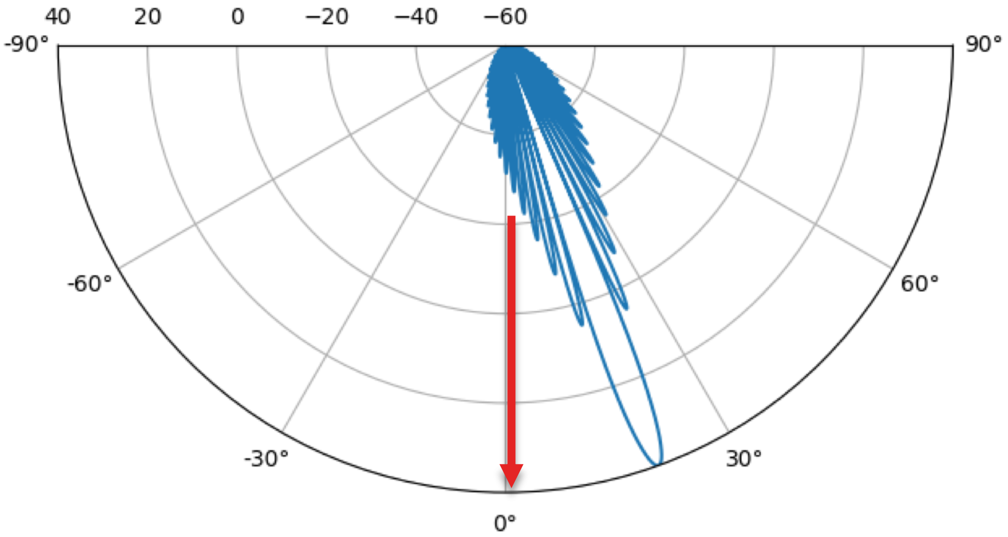
Assumption of horizontal homogeneity of the water mass

- This can be checked when the beams are recombined, as …
- …the ADCP generally operates 4 beams, so there is redundancy to reconstruct the current profile in 3 dimensions (4 equations for 3 unknowns).
- For example, you can calculate the velocity vertical-component in different ways and check that you find a similar result (also used to reject fish echoes).

ADCP – effect of true beam pattern on range

Depending on the sensor, the main lobe is a few degrees wide (typ. 3°) and is oriented at 20° to 30° to the vertical.

<u>Beam pattern of an ADCP beam oriented at 20° to the vertical</u>



Part of the energy propagates vertically

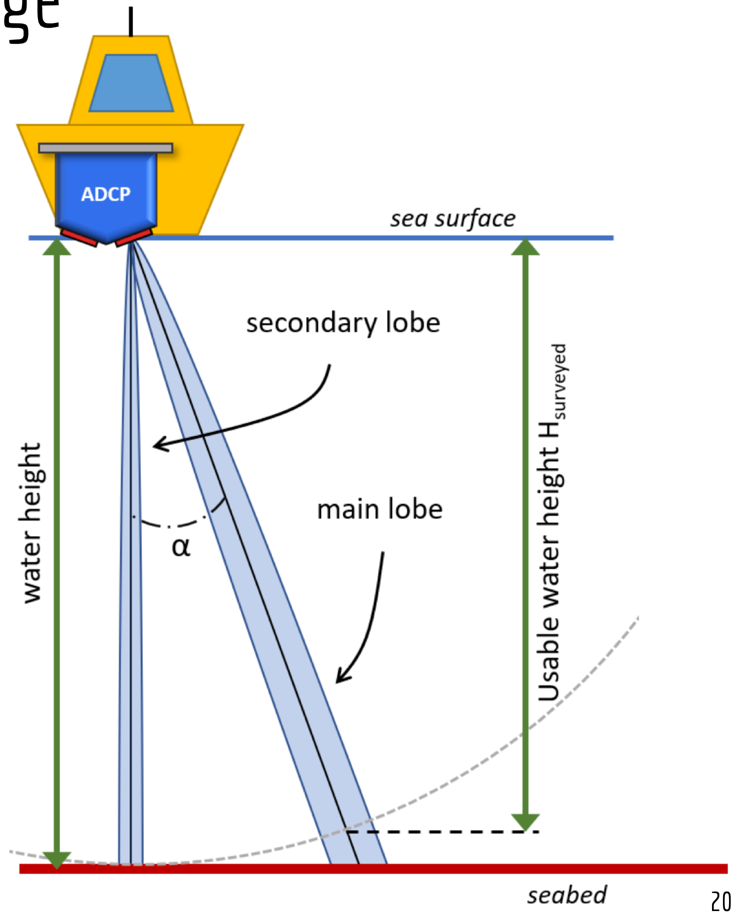
ADCP – effect of true beam pattern on range

Beam angle α to the vertical

It determines the ADCP ability to measure near-bottom (or other interfaces) currents.

Beam angle to the verticale α	Usable water height* $H_{surveyed}$
20°	~94%
25°	~90%
30°	~86%

**if an interface (e.g. bottom) is within ADCP maximum range.*



ADCP – effect of sound speed

Sound speed at transducer

Classically, only the speed of sound at transducer is measured and used by ADCP sensors. This is the most critical parameter for correctly estimating the Doppler effect (excluding phased-array antennas).

Both way Doppler effect :

$$\boxed{\vartheta = \vartheta_0 \left(\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}} \right) \approx \vartheta_0 \left(1 + 2\frac{v}{c} \right)}$$

$v \ll c$

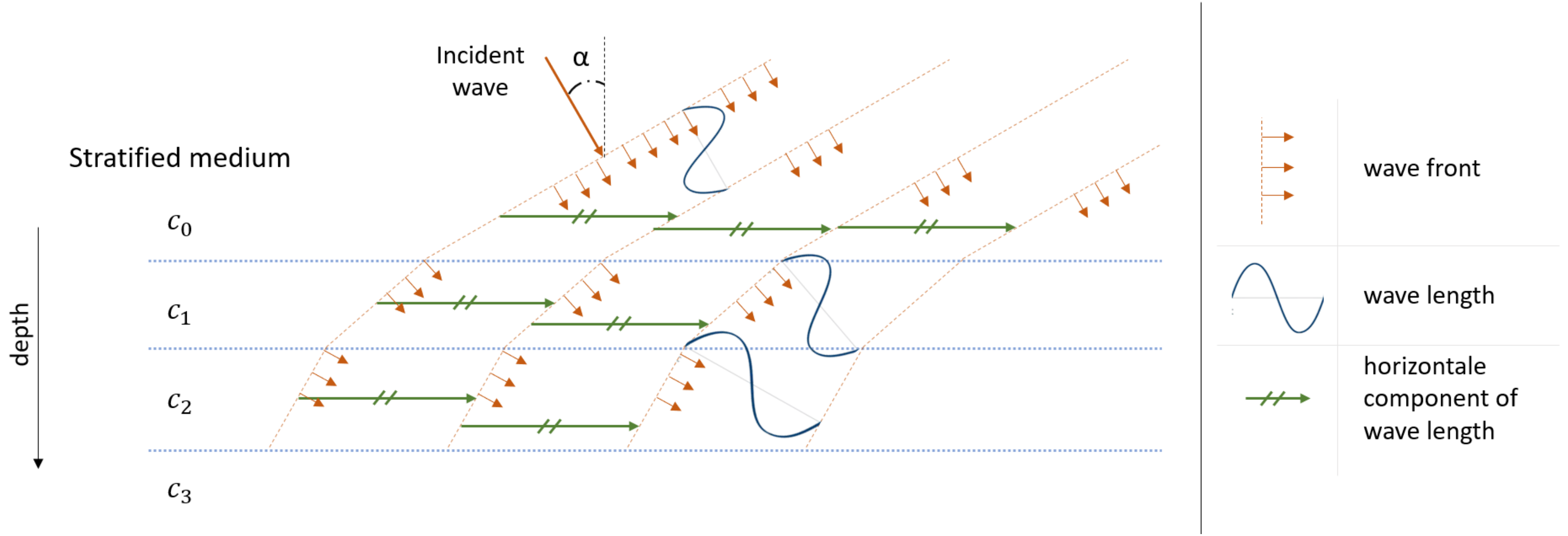
v : relative velocity

c : sound speed at transducer

ADCP – effect of sound speed

Sound speed profile

- No impact on the horizontal components of the current, as the wavenumber is conserved.
- On the other hand, it allows cells to be positioned at the correct depth.
- Impact on the vertical component of the current…
- … but many studies scope are limited to horizontal currents.



ADCP – main sources of uncertainty

Uncertainty sources

- Beam pointing errors
- Scatterers (number and reflectivity level : cell size, medium characteristics)
- Validity of key assumptions (locale homogeneity, no self-movement of particles)
- Sound speed at transducer
- Sound speed profile
- Sensor dynamic compensation
- Transform the data in a geographic frame

ADCP – 600kHz - single ping standard deviation (1σ)

Cell size	RDI theoretical charts	Tank trials	At sea trials
1m	~30 mm/s	~50 mm/s	~110 mm/s
2m	~15 mm/s	~30 mm/s	~60 mm/s

Depending on the horizontal spatial scale of the phenomena studied, averaging over a large number of pings can significantly reduce measurement uncertainty of a factor $^1/_{\sqrt{N}}$. (N: number of pings)

ADCP – advantages & drawbacks

Advantages

- ability to measure a 3D current profile in a very short time, at great range,
- wide range of systems available, offering various vertical resolution and range according to the application,
- good single-ping accuracy,
- knowing the speed of sound at transducer is sufficient to accurately estimate horizontal currents,
- quite a compact system.

Drawbacks

- sampling the water column in cells means that each measurement represents an averaging of currents over a certain depth, and is therefore not a measurement at a discrete point,
- key ADCP principle requires a locale horizontal homogeneity, condition that is not always met, specifically in the study of very fine-scale phenomena,
- need to know the sound velocity profile to estimate the vertical component of currents,
- a technologically advanced and therefore costly solution.

Conclusion & Perspectives

Not covered:

- Electromagnetic Sensors
- Radars
- Lagrangian drifters
- Particle Imaging Velocimetry…

Are there any sensors available over the counter that are relevant to oceanographic applications ?

- yes but mostly high performance sensors (ADCP, mostly RDI and Nortek)
- low cost sensor: tilt current meter (Lowell)

Is there work remaining in order to evaluate these sensors ?

- a lot of work deals with the sensor's accuracy, but more is needed to evaluate them when located on different platforms for underway measurements

Is there interest in developing DIY sensors that are not available over the counter ?

- yes in the low/medium range, the benefits being a better understanding of the technology and to get cheaper instruments (e.g. to deploy in risky areas or to increase the spatial sampling)
- certainly not in the high performance range

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