Acoustic Doppler Current Profiler (ADCP): Principles of Operation and Setup

Christian Mohn & Martin White

Overview

- Principles of operation
- ADCP deployments, setup and systems
- From an acoustic ping to a velocity profile
- Biological measurements
- Trade-offs
Part 1: Principles of Operation

Physical Processes in the Ocean: A Myriad of Time and Space Scales

White et al 2016
Why ADCP?

- Measuring currents is fundamental to understand ecosystem dynamics, nutrient and organic matter cycling.
- High-resolution and ability to sample deep within the ocean interior.
- Measures currents at more than one location at the same time.

### Common ADCP specs and ocean processes

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<tr>
<th>Frequency</th>
<th>Range</th>
<th>Resolution</th>
<th>$\lambda$ (cm)</th>
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www.bornhoeft.de
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Profiling ADCP: Transducers

• Monostatic: Transmit and recieve sound waves
• Vibrating ceramic element protected by urethane

A Brief ADCP History

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<th>Description</th>
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<td>1970s</td>
<td>The first ADCP was produced as an adaptation of a commercial Doppler speed log (Rowe and Young, 1979).</td>
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<td>1980s</td>
<td>A range of commercial ADCPs becomes available (self-contained, ship-based, different frequencies).</td>
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<td>1990s</td>
<td>ADCPs become popular in the scientific community and environmental agencies.</td>
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<td>&gt; 2000s</td>
<td>Acoustic based instruments become the most common instrument type for flow measurements.</td>
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The Doppler Effect

Train approaches – Pitch higher than transmitted

Train recedes – Pitch lower than transmitted

The Basic Doppler Equation

\[ f_D = f_S \times \frac{V}{C} \]

- \( f_D \) = Doppler Shifted Frequency (measured)
- \( f_S \) = ADCP (Source) Frequency
- \( V \) = Water velocity
- \( C \) = Speed of Sound (dependent on water T/S)
ADCP: Water velocity from passive sound scatterers

**Assumption:** On average scatterers move at the same horizontal velocity as the water.

ADCP: Water velocity from sound scatterers

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<th>Scatterer is moving</th>
<th>Received signal $f_D$</th>
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<tr>
<td>toward</td>
<td>$f_D &gt; f_s$</td>
</tr>
<tr>
<td>away</td>
<td>$f_D &lt; f_s$</td>
</tr>
<tr>
<td>across/stationary</td>
<td>$f_D = f_s$</td>
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Transmitted pulse $f_s$
ADCP and Sound: Narrowband and Broadband

**Narrowband**: One simple tone burst – Doppler Frequency Shift of the return signal

**Broadband**: One phase coded pulse pair – Phase Shift of the return signals

ADCP and Sound: Broadband Technology

- Higher precision but lower range than Narrowband
Importance of Speed of sound ($C$)

$$V = \frac{f_D}{f_S} * C$$

Speed of sound ($C$) must be computed accurately by the ADCP.

- A temperature error of 2 °C or a salinity error of 5 ppt would result in a 1 % error in measured velocity.
- The ADCP must have an accurate temperature sensor and must be configured for a representative salinity.

When the scatter velocity may not be equal to the water velocity

**Fish:**

Water velocity measurement is biased toward the fish velocity

**Stationary objects:**

Water-velocity measurement is biased toward zero
Part 2: ADCP deployments and systems

ADCP deployments

http://rowetechinc.com/resources/
Vessel mounted systems

**S-ADCP**: Long-range profiling over ranges > 1000 m

**L-ADCP**: Long-range profiling over entire depth

**SV-ADCP**: Short-range profiling over entire depth

Self-contained, fixed position systems

Anchored surface/sub-surface **mooring**

Bottom mounted **lander/frame**

Horizontal **ADCP**
ADCP deployments: Advantages/disadvantages

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<th>Fixed position</th>
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<td>+</td>
<td>3D currents</td>
<td>Time series</td>
</tr>
<tr>
<td>+</td>
<td>Transport, discharge, flux measurements</td>
<td>Near-bottom, near-surface currents</td>
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<td>-</td>
<td>Ship/vessel motion</td>
<td>Battery life</td>
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Part 3: From an acoustic ping to a velocity profile
Profiling ADCP: What is measured?

- Doppler frequency shift between ADCP and scatterer
- Strength of the acoustic backscatter (echo amplitude)
- Water temperature at the ADCP
- Orientation of the ADCP
- Ancillary data (position, orientation and speed of the vessel)

Profiling ADCP: What is derived?

- Water velocity (east, north, up) in ADCP coordinates (attention: the coordinate system of the ADCP might be different from earth coordinates)
- Quality statistics (beam correlation, error velocity)
- Relative movement (speed) of the ADCP over ground (bottom track)
Profiling ADCP: Multiple Beams

- ADCP only sees velocity of scatterers parallel to the beam.
- But: Beam is tilted - Water velocity in the horizontal from trigonometric relationships.
- One beam is required for each velocity component (east, north, up)

Why four beams? – Error velocity

- Assumption: Water layer seen by the ADCP is homogenous
- Error velocity: Difference of vertical velocity between 2 beams
Error Velocity

- Differences in vertical velocities caused by malfunctioning equipment, small-scale turbulence, moving objects (fish, litter, etc.)
- Should be randomly distributed

Behind bridge pier

Getting a velocity profile: Depth cells and range gating

- Transmitting
- Blanking
- Start
- End
- Gate 1
- Gate 2
- Gate 3
- Gate 4
- Time
- Blank
- Bin 1
- Bin 2
- Bin 3
- Bin 4

Distance from ADCP
Unmeasured parts of the water column

- Blanking distance (recovery time after ping)
- Side lobe (lower sound intensity)
- Main beam (higher sound intensity)
- Area of side lobe interference

"good" velocity profile

ADCP velocity profile

- Blank Distance + Transducer Depth
- Depth Bin
- Loss of Data
- Side Lobe Interference Distance: \((1-\cos(\text{beam angle})) \times \text{Depth}\)

- Benefit: Velocity averaged over entire depth cell
- Trade-off: 6 – 12% of the profile cannot be used
Part IV: Biological measurements

Biological measurements

- The strength of the backscattered signal can provide very useful estimates of biological biomass, distribution and behaviour or suspended particulate matter (SPM).

- Wavelength $\lambda$ of the acoustic signal (frequency, sound absorption) determines the minimum size of the sound scatterers ‘seen’ by the ADCP

- Minimum size ($m$) = $0.25 \lambda - 0.5 \lambda$

- Example: 75 kHz ADCP resolve scatterers > 0.01 m
Diel vertical migration about a tall isolated seamount

Senghor Seamount, Cape Verde, North Atlantic

Repeated transect across seamount summit, vessel mounted 75 kHz ADCP, scatterers > 1 cm (what?)

Diel vertical migration at a cold water coral reef

Tisler Reef, Skagerrak, Baltic Sea

Time series, stationary upward looking 300 kHz ADCP, scatterers > 0.15 -0.25 cm (microzooplankton)
Part V: Trade-offs
### ADCP setup and Trade-offs

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05/05/2016
Other Considerations

• **Ship Speed**: Slow speed reduces the mean error in flow calculation.

• **Dimension of the cells**: Cells with a small size reduce the profiling range but give velocity measurements closer to the surface, the bottom and the shore.

• **Environmental Factors**: Profiling range is enhanced by colder and fresher water and by more suspended material and scatterers.

A brief summary

• Water velocity is measured with respect to the ADCP (beam coordinates).
• Velocity is measured taking advantage of the suspended/passive particles in the water column.
• The velocity of the ADCP is also measured (bottom track).
• Measurement gaps at the surface and bottom.
Interesting online resources

- [www.rdinstruments.com](http://www.rdinstruments.com)
- [www.sontek.com](http://www.sontek.com)
- [www.nortek-as.com](http://www.nortek-as.com)
- [www.rowetechinc.com](http://www.rowetechinc.com)

Thanks a lot