

Workshop: A Practical Introduction to Marine
Monitoring Hardware and Procedures

Current Measurements. Current-meter and ADCP: principles of operation and applications.

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Current Measurements

Eulerian measurements (involve «fixed» point observation):

- Current-meter (punctual data)
- ADCP (Acoustic Doppler Current Profiler) (column data)
- ADCP-VM (ADCP Vessel Mounted)

Lagrangian measurements (involve following a parcel of fluid as it moves):

- Drifters (surface and sub-surface measurements)
- Floats (profiling device- surface and parking depth currents)



Example: E2M3A

Temperature

Salinity

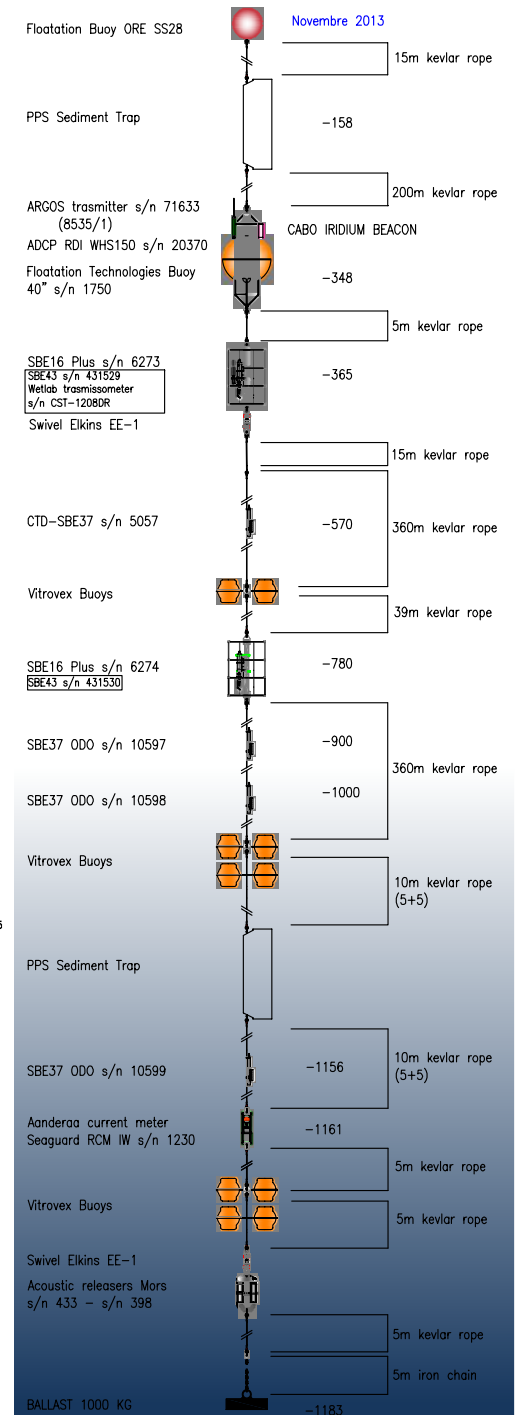
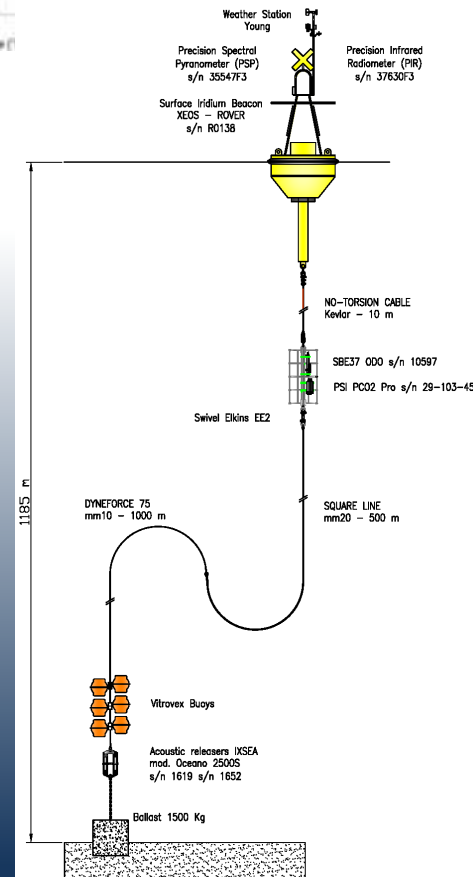
Currents:

Eulerian measurements:

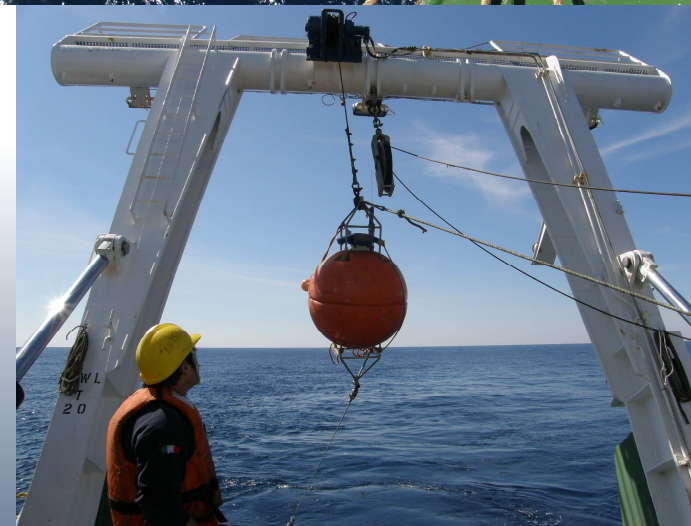
- ADCP
- RCM - Seaguard

Sedimentological
measurements

Meteorological
measurements



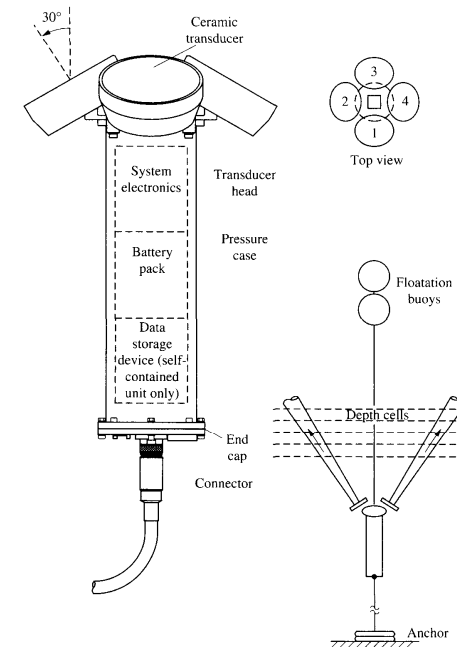
ADCP Operations



Principles of ADCP

- The standard narrow-band ADCPs employ four separate transducers oriented in a Janus configuration with beams pointing at an angle of 30° to the plane of the transducers.
- The broadband unit, the angle has been reduced to 20°.

The standard instruments are available at frequencies of 75, 150, 300, 600, 1200 and 2400 kHz



ADCP measures can be considered as a chain of currentmeters where the width of the cell corresponds to the distance between them.

Positioned: Upward or downward looking



The choice of frequency is dependent on the particular application



Principles of Operation:

The Doppler Effect

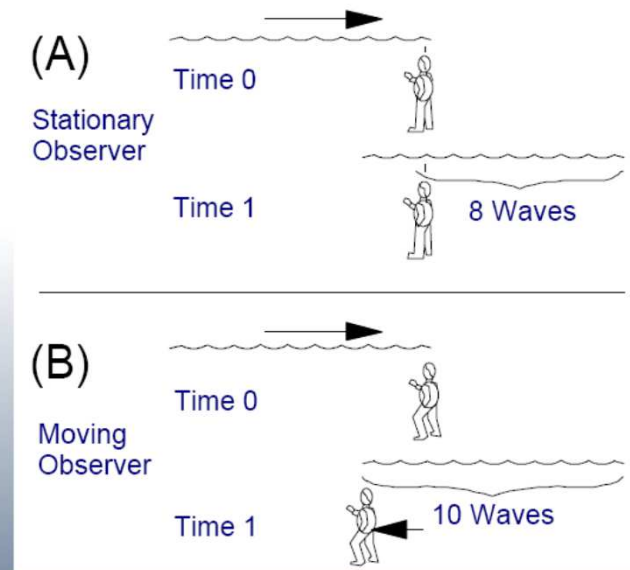
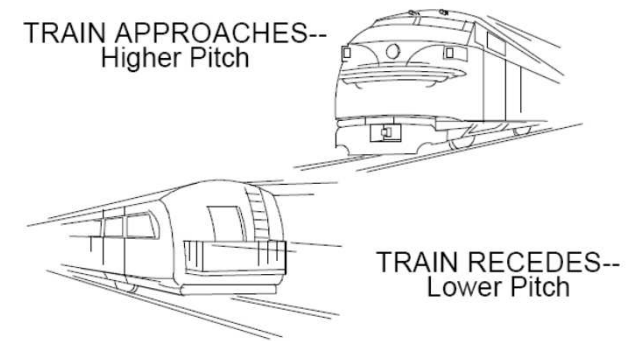
- Speed of sound = frequency × wavelength:

$$C = f \cdot \lambda$$

- The *Doppler effect* is a change in the observed sound pitch that results from relative motion. The *Doppler Shift* is the difference between the frequency you hear when standing still and what you hear when you move:

$$\Delta F = F_s (V/C)$$

- The *Doppler effect* measures only relative, radial motion.
- ADCP uses the Doppler effect by transmitting at a fixed frequency and listening to echoes returning from scatterers in the water

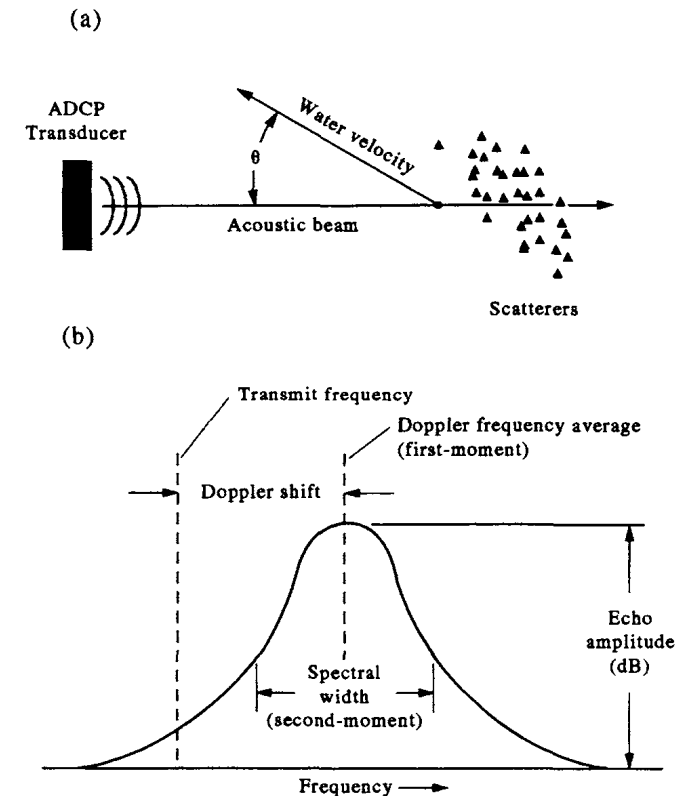


Principles of ADCP

For a narrow-band ADCP with a transmit pulse having a fixed length of a few milliseconds, the frequency shift, Δf , of the backscattered signal is proportional to the component of relative velocity, $v \cos \vartheta$, along the axis of the acoustic beam between the backscatterers and the transducer head. For a given source frequency, f , and bin k (depth range = D_k) we find

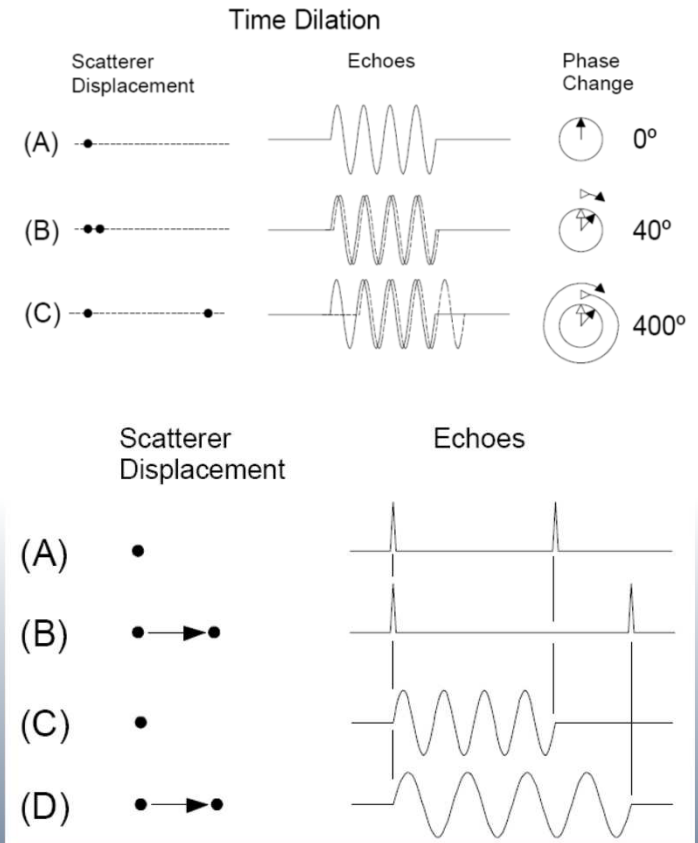
$$v_k = \frac{(\Delta f_k / f) c}{\cos \theta_k}$$

v_k is the relative current velocity for bin k at depth D_k , ϑ_k is the angle between the relative velocity vector and the line between the scatters and the ADCP beam, c is the speed of sound at the transducer and Δf is the frequency shift measured by the instrument.



Principles of Operation: BroadBand Doppler Processing

- If a particle moves away from the transducer, it would take longer time for the second echo to reach the transducer, than for the first. BroadBand ADCPs use phase differences to determine *time dilation*. The phase differences are exactly proportional to the particle displacement.
- BroadBand ADCPs use time dilation by measuring the change in arrival times from successive pulses
- Long time lags increase precision, but introduce ambiguity problems (B & C upper figure).
- RDI uses autocorrelation techniques for comparing echoes.



Scatters

The technique relies on the fact that:

- (1) sound is reflected and/or scattered when it encounters marked changes in density; and
- (2) the frequency of the reflected sound is increased (decreased) in direct proportion to the rate at which the reflectors are approaching (or receding from) the instrument.

Reflectors ensonified by ADCMs include "clouds" of planktonic organisms such as euphausiids, copepods and gellies, fish (with and without swim bladders), suspended particles, and discontinuities in water density.

gellies



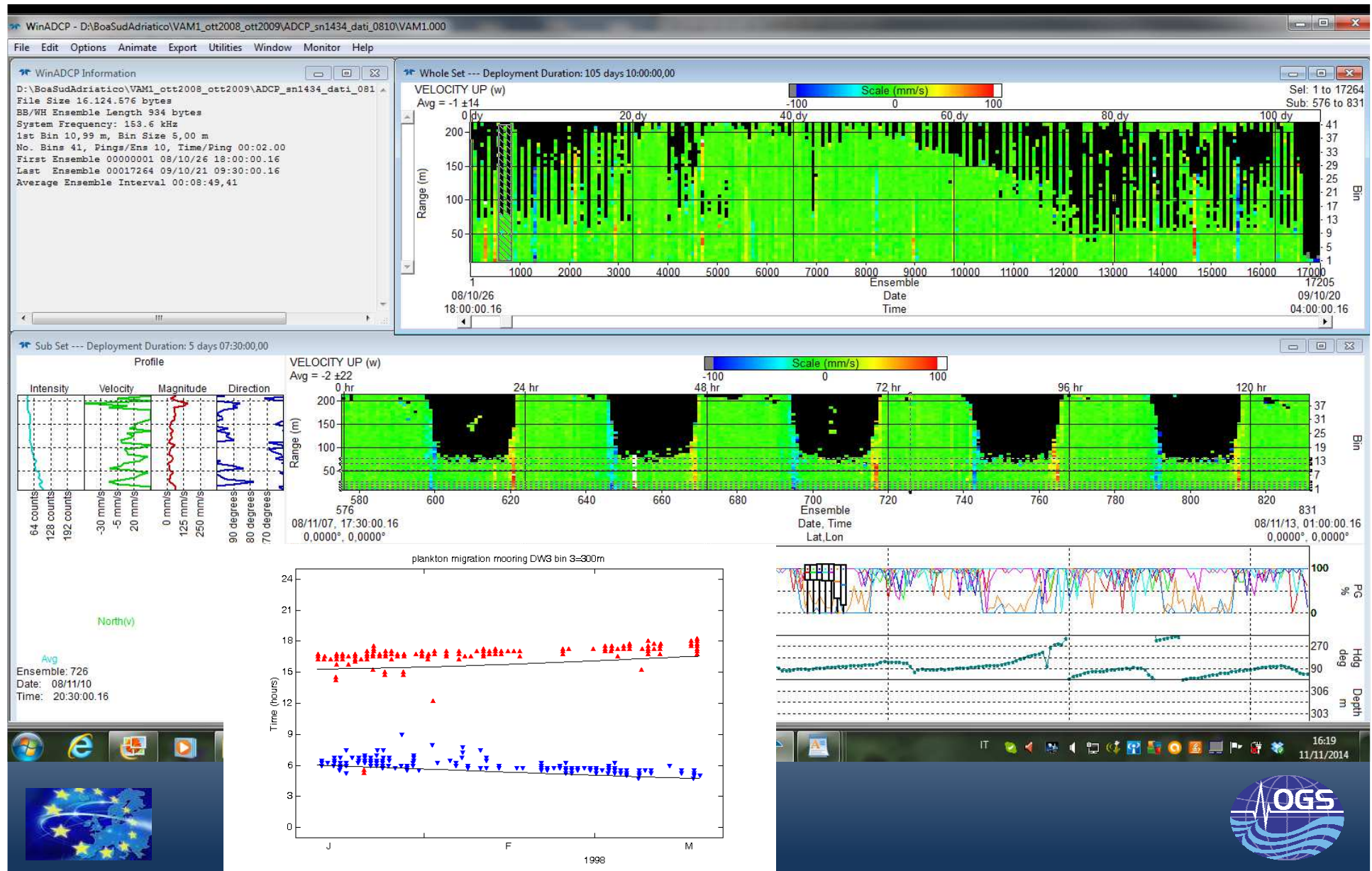
euphausiids



copepods

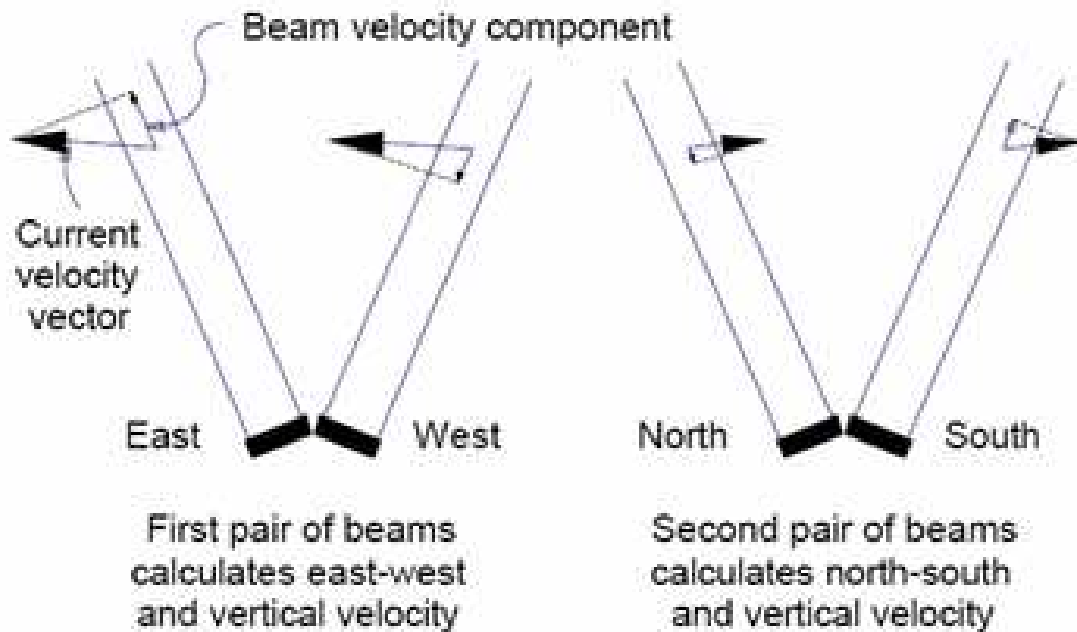


Example of lack of Scatters



Principles of Operation:

Three-dimensional Current Velocity and error



- Calculation of Velocity with the Four ADCP Beams:
 - ▶ from each pair of beams get 1 component of horizontal velocity + 1 component vertical velocity
- assumes current Homogeneity in a Horizontal Layer
 - ▶ really do not need 4 beams to compute U in 3-space
 - ▶ but it provides an estimate of **error velocity** as the difference in the w estimates
 - ▶ this can be used to detect:
 - ▶ a) inhomogeneity in measurement or maybe more importantly
 - ▶ b) bad ADCP beam

Calculation of Velocity with the Four ADCP Beams

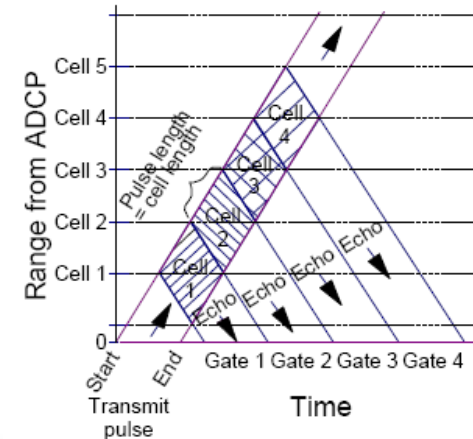
$$\begin{aligned} u_1 &= v \sin\theta + w \cos\theta & u_2 &= -v \sin\theta + w \cos\theta \\ u_3 &= u \sin\theta + w \cos\theta & u_4 &= -u \sin\theta + w \cos\theta \end{aligned}$$



Principles of Operation:

Velocity Profile

- Profiles are produced by range-gating the echo signal (→ Depth cells = Bins)
- The velocity is averaged over the depth of the entire depth cell



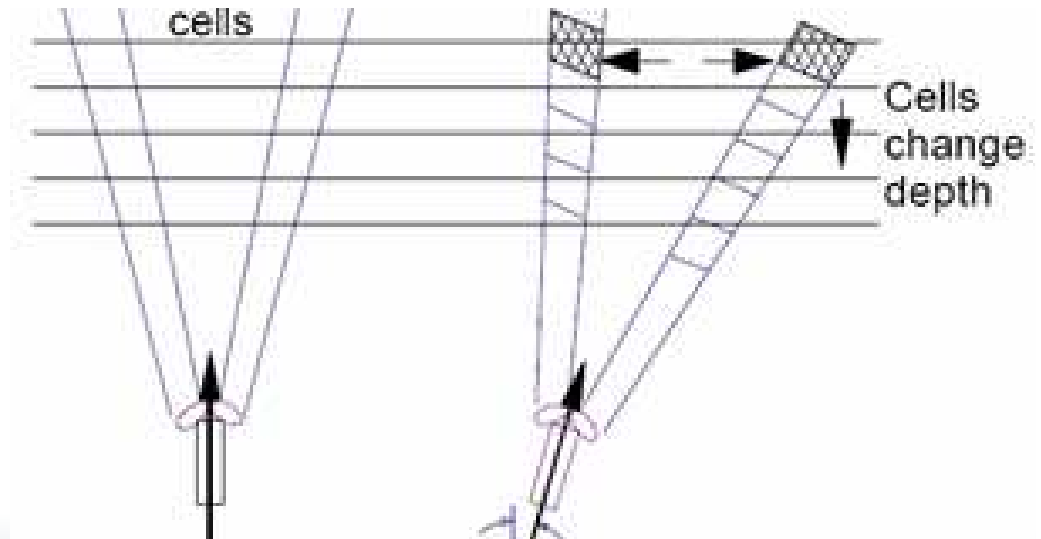
- The echo from the farthest part of a cell contributes signal only from the leading edge of the transmit pulse. The echo from the closest part of a cell contributes echo only from the trailing edge
- Each depth cell overlaps adjacent depth cell. This overlap causes a correlation between adjacent depth cells of about 15% if transmit pulse is equal to depth cell size



Principles of Operation:

ADCP Pitch, Roll and Heading

- ❑ Conversion from ADCP- to Earth Reference (trigonometry & depth cell mapping)

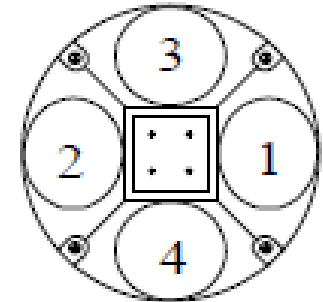


- ❑ Measuring ADCP Rotation and Translation
 - ▣ Rotation (heading): flux-gate and gyrocompass
 - ▣ Rotation (pitch and roll): inclinometers & vertical gyro
 - ▣ Translation: bottom-tracking, GPS, reference (“no-motion”) layer → ADCP-VM



ADCP Data what do we measure?

↑
Forward



Teledyne RDI VmDas - [VAM11000.000]

File View Options Control Chart Window Help

Profiles Ship Track 1 Ship Track 2

System configuration: C/C: Convex, Ens Length: 1154 bytes, Bin 1 dist: 9.32 m, Time/ping: 00:02:00, Sys freq: 153600 Hz, Up/down: Up, Bins: 50, Blank dist: 3.52 m, Pings/ens: 100, Oper Mode: Broad bandwidth, Bm angle: 20 deg, Coord sys: Earth, Bin length: 5.00 m, Time/ens: 00:02:00

Leader: Ens Num: 3, Date: 14 Sep 2014, Heading: 262.43 ± 1.0 deg, Pitch: 0.11 ± 0.20 deg, Temp: 14.19 C, Xdr Depth: 289.30 m, BIT Err: OK, Time: 02:00:00.00, Roll: 0.21 ± 0.10 deg, Salinity: 39 ppt, Sound Vel: 1514 m/s

BB B...	Depth (...)	East (m/s)	North (m/s)	Up (m/s)	Err (m/s)	RSSB (c...)	RSS2 (c...)	RSS3 (c...)	RSS4 (cts)	Cor1 (cts)	Cor2 (...)	Cor3 (cts)	Cor4 (...)	3 bm good (%)	Hi Verr (%)	2+ bm bad...	4 bm good (%)	BB B...
50	34.98	-0.030	0.064	-0.005	0.009	86	92	91	88	106	112	114	109	---	---	---	100	50
49	39.98	-0.014	0.066	-0.005	-0.009	81	88	87	85	99	105	108	104	1	---	---	99	49
48	44.98	-0.025	-0.004	-0.001	0.036	78	81	83	79	92	87	92	86	13	---	---	86	48
47	49.98	0.031	-0.008	-0.015	-0.002	80	79	78	78	96	87	90	88	14	---	---	86	47
46	54.98	0.032	-0.011	-0.001	0.040	78	79	82	80	90	87	100	97	11	---	---	89	46
45	59.98	0.076	0.035	0.000	0.026	78	80	81	81	91	94	92	94	6	---	---	94	45
44	64.98	0.067	0.047	-0.003	0.003	81	84	84	84	102	104	105	105	---	---	---	100	44
43	69.98	0.035	0.058	-0.006	0.003	87	86	87	85	112	103	111	106	---	---	---	100	43
42	74.98	0.052	0.057	-0.003	0.008	91	86	90	88	117	107	116	110	---	---	---	100	42
41	79.98	0.043	0.038	-0.005	0.000	90	90	92	95	111	118	116	124	---	---	---	100	41
40	84.98	0.030	0.018	-0.008	0.011	84	87	92	90	105	93	119	106	3	---	---	97	40
39	89.98	0.012	0.043	-0.002	-0.005	81	80	89	87	95	91	100	108	7	---	---	93	39
38	94.98	0.048	0.024	-0.003	0.008	82	81	80	85	106	100	90	110	3	---	---	97	38
37	99.98	0.057	0.020	0.002	0.014	80	82	81	82	94	93	96	88	10	---	---	89	37
36	104.98	0.050	0.031	-0.001	-0.017	79	83	79	83	88	103	89	110	13	---	---	87	36
35	109.98	0.046	0.094	-0.006	-0.008	78	80	84	85	101	83	104	97	15	---	---	85	35
34	114.98	0.068	0.058	0.000	0.004	82	83	82	83	92	109	98	108	6	---	---	94	34
33	119.98	0.065	0.048	-0.006	-0.019	78	83	87	90	91	85	111	111	9	---	---	91	33
32	124.98	0.081	0.085	-0.008	-0.016	83	81	82	86	111	97	81	105	11	---	---	88	32
31	129.98	0.055	0.088	-0.016	-0.008	88	81	81	83	111	92	106	102	4	---	---	96	31
30	134.98	0.049	0.056	-0.005	0.004	81	78	91	87	85	77	116	115	27	---	---	69	30
29	139.98	0.032	0.080	-0.006	0.013	78	80	90	92	90	100	113	109	8	---	---	92	29
28	144.98	0.049	0.076	-0.004	0.010	82	84	90	92	100	100	110	121	4	---	---	96	28
27	149.98	0.059	0.072	-0.010	0.000	92	103	96	90	121	130	124	96	2	---	---	98	27
26	154.98	0.079	0.102	-0.006	-0.021	95	100	94	95	122	117	111	127	2	---	---	98	26
25	159.98	0.048	0.032	-0.004	-0.040	103	94	102	100	126	123	129	118	---	---	---	100	25
24	164.98	0.059	0.090	-0.003	-0.030	100	98	99	93	120	121	121	114	---	---	---	100	24
23	169.98	0.076	0.081	0.002	-0.004	106	107	105	105	126	128	127	132	---	---	---	100	23
22	174.98	0.076	0.088	-0.002	-0.023	113	110	101	106	130	124	123	124	---	---	---	100	22
21	179.98	0.039	0.074	0.001	-0.024	112	113	114	113	126	128	129	132	---	---	---	100	21
20	184.98	0.070	0.106	-0.002	-0.006	117	119	116	116	136	131	129	125	---	---	---	100	20
19	189.98	0.071	0.068	0.007	-0.025	116	121	118	118	128	126	128	130	---	---	---	100	19
18	194.98	0.050	0.070	0.003	-0.010	113	126	122	114	126	135	135	131	---	---	---	100	18
17	199.98	0.062	0.087	-0.003	0.016	120	122	116	128	129	131	125	129	---	---	---	100	17
16	204.98	0.066	0.077	0.004	0.012	131	126	114	127	134	124	135	133	---	---	---	100	16

Ens IO closed NAV IO closed 10:57 11/09/2015

- Velocity: 3 components +error → earth reference
- Echo Intensity: Receiver Signal Strength (dB) → solid targets or insufficient scatters
- Correlation: measure of data quality → spatial variability of particle distribution
- Percent good: what fraction of pings passed the various error threshold



Variety of rejection criteria (correlation, error velocity, fish detection)

Principles of Operation:

Ensemble Averaging

- ADCP errors: random errors & bias
 - Random errors could be reduced by ensemble averaging: $\sigma \sim N^{-1/2}$
 - Bias depends on several factors: temperature, mean current speed, signal/noise ratio, beam geometry, etc.
- Averaging inside the ADCP vs. averaging later
 - Conversion of the data prior to averaging
 - Data transmission can slow down ping processing



Principles of Operation:

- **Echo intensity and Profiling Range :**
 - Sound absorption (exponential decay of echo intensity with increasing range) – increases in proportion to frequency
 - Beam spreading (range squared)
 - Transmit power (longer pulses put more energy into the water)
 - Scatterers
 - Bubbles
- **Sound Speed Corrections:**
 - ADCP automatically computes **sound speed** and corrects velocity based on measured temperature and assumed salinity:

$$V_{\text{corrected}} = V_{\text{uncorrected}} (C_{\text{real}} / C_{\text{ADCP}})$$



Principles of Operation: Measurements Near Surface or Bottom

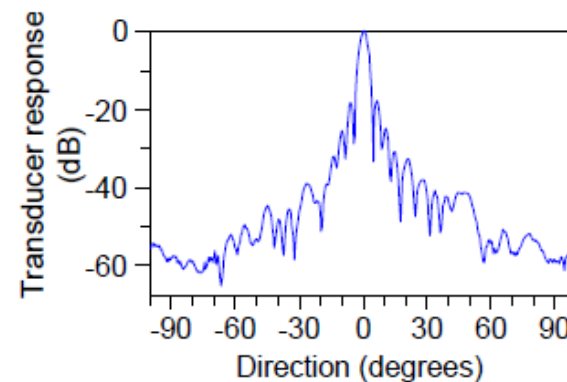
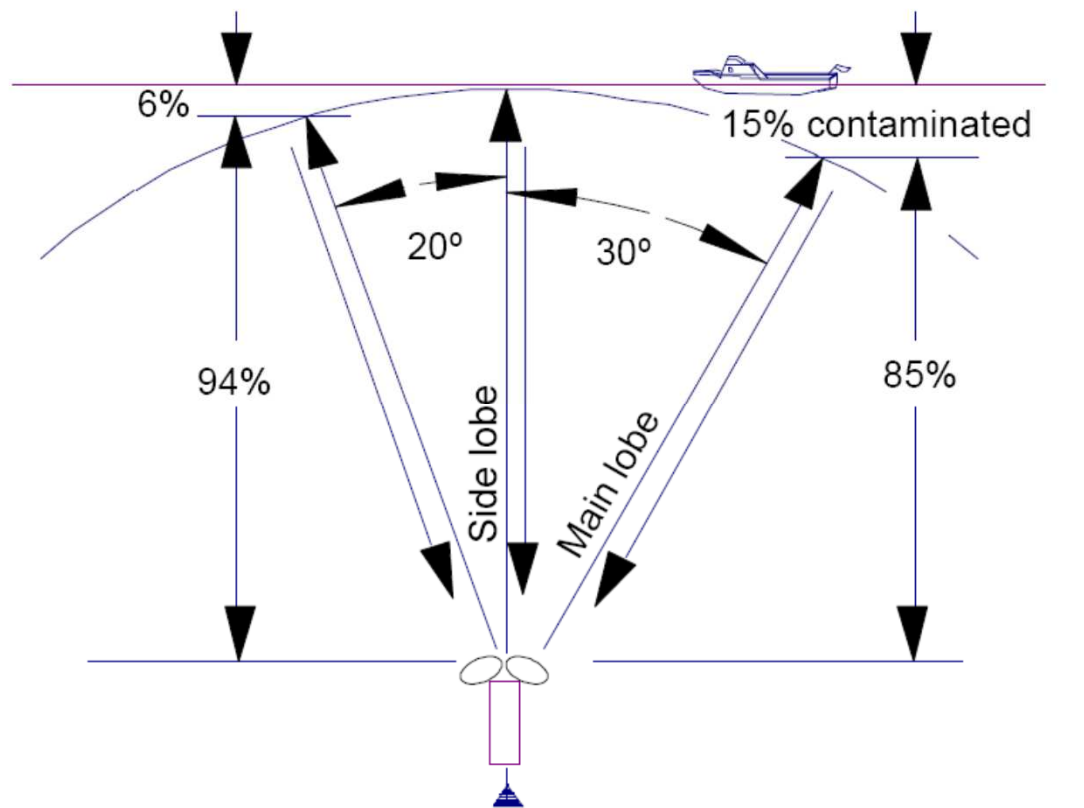


Figure 23. Typical beam pattern of a 150 kHz transducer. Transducer response is one-way, measured relative to the response at the transducer axis.

Table 3. Typical ringing times, expressed as distances in front of the transducer.

Frequency	Ringing distance
75 kHz	6 m
150 kHz	4 m
300 kHz	2 m
600 kHz	1 m
1200 kHz	0.5 m



Optimizing ADCP Setup

- ADCP Setup Parameters
- Trade-off Triangle:
 - Resolution
 - Range
 - Random Noise
- Operation Modes

(based on RDI technical note: http://www.rdinstruments.com/tips/tips_archive/optimize_setup_1203.html)



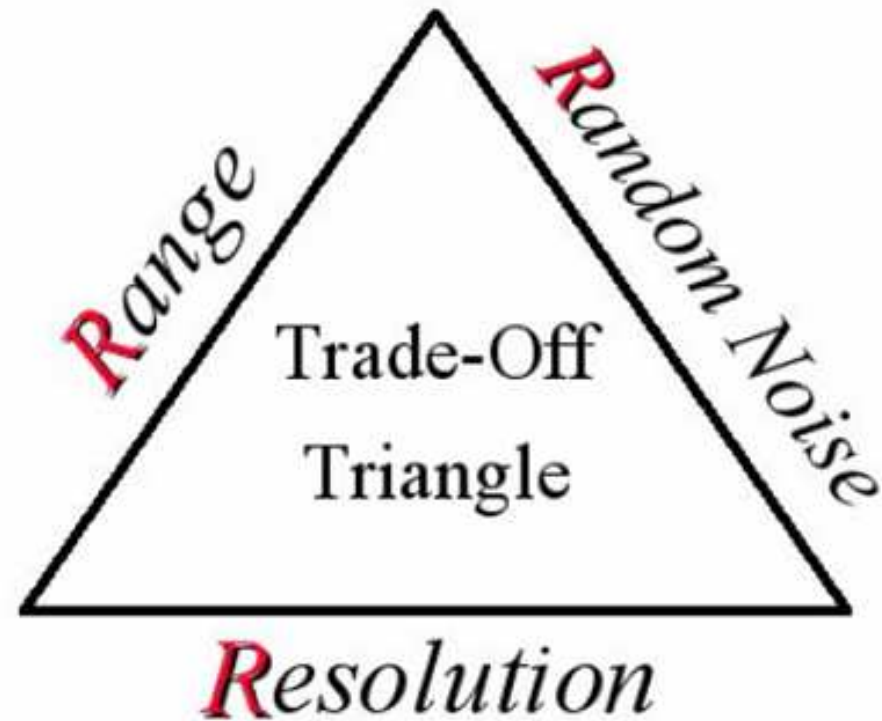
Optimizing ADCP Setup: Setup Parameters

- Depth range of measurements
- Spacing between measurements: in depth and time
- Data averaging
- Deployment duration



Optimizing ADCP Setup:

Trade-off Triangle



Optimizing ADCP Setup: Resolution

- Resolution (Depth) vs. Random Noise
 - Doubling depth resolution will double the random noise, and v.v.
- Resolution: Depth vs. Time
 - Doubling depth resolution without increasing the random noise will require 4 x the measuring period, and v.v.
- Resolution vs. Deployment Length
 - Doubling the number of depth cells doubles the power consumption



Optimizing ADCP Setup:

Range

- Range vs. Frequency
 - Twice the acoustic frequency will reach about half as far
- Resolution vs. Range
 - Doubling cell size injects more energy into the water – adding 10% to the profiling range and v.v.
- Range: external factors
 - Usually, profiling range is enhanced by colder and fresher water and by more suspended material



Optimizing ADCP Setup:

Random Noise

- Random Noise vs. Resolution
 - Velocity precision improves by $\sqrt{\text{No. pings} \times \text{Depth Cell size}}$
- Random Noise: Dynamic Conditions
 - Velocity precision degrades due to more turbulence, greater change in velocity across the depth cell, pitch and roll of the ADCP mounting
- Random Noise vs. Operating Modes
 - Operating modes are separated in two classes: short lag (1, 12) and long lag (11, 8, 5). Longer lags return more precise velocity data, but have limited profiling range and maximum measuring velocity



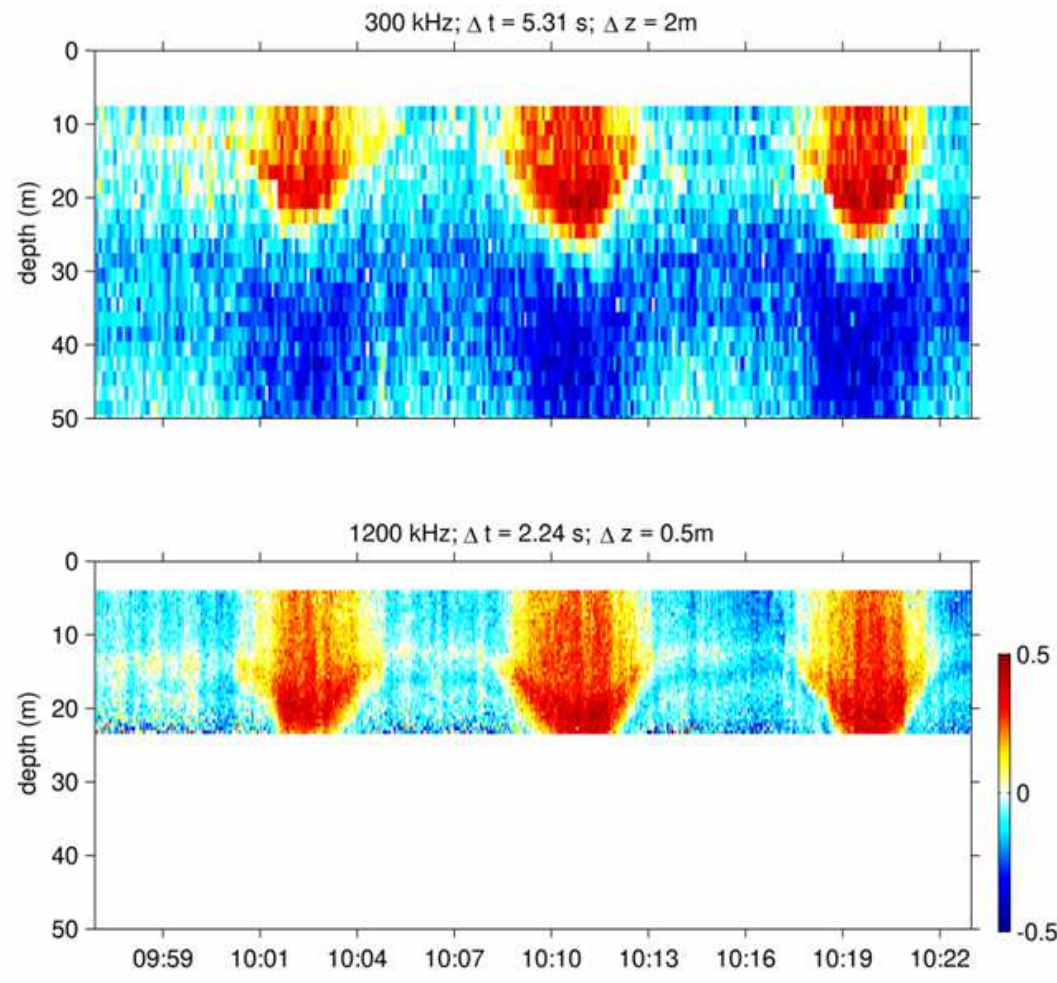
Optimizing Your ADCP Setup:

Operation Modes

Operating Mode	1	12	11
What it is?	A standard ping mode. All the sensors are examined each ping.	Each ping consists of a sequence of sub-pings, which are summed and then converted to earth coordinates. Orientation is checked once per sequence.	Transmits hundreds of narrow pulse pairs with pair members separated by a wide time lag. Fixes with greater time separation permit more precise velocity estimate.
Profiling Range	Highest	Mode 1 or less with smaller cells	Limited to a few meters
Advantage	Higher Speeds Robustness	Most flexible mode. Allows higher resolution and/or lower std than mode 1. Lower power consumption.	High Resolution (1 to a few centimeters, depending on acoustic frequency)
Precision	Few cm/s	Better	Highest (mm/s)
Limitations		Not applicable if orientation changes significantly during the ping sequence.	Limitations of mode 12; Slow flows (profiling range x maximum velocity < 1 m ² /s)



Data Example from SW06: Workhorse 300kHz vs. Workhorse 1200kHz



ADCP-VM

Additional requirements:

- problems related to positioning of the instrument on the boat, oscillations, etc....
- variability of data both in space and time
- necessity of accurately knowing the ship velocity (differential GPS, bottom tracking), pitch, roll.
- editing and processing with CODAS3 (University of Hawaii)



One point current measurements

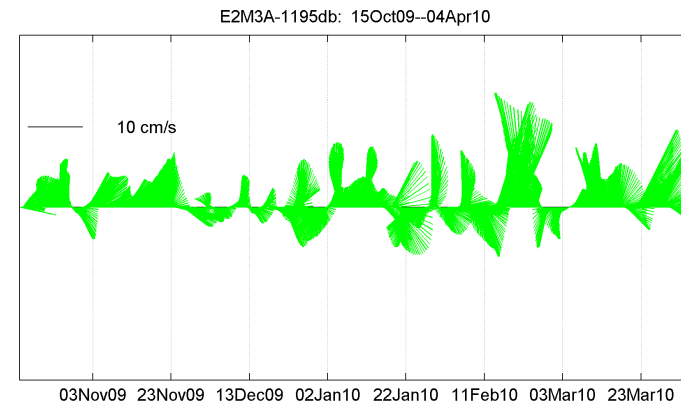
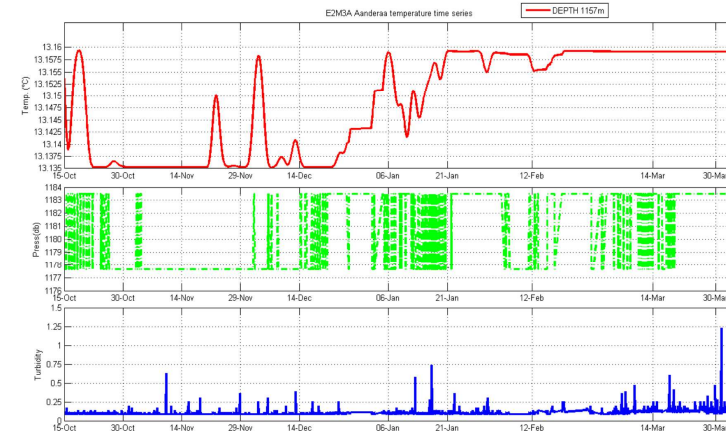
Aanderaa RCM series + Seaguard



Currentmeters: Aanderaa RCM series + Seaguard - single point measurements



RCM Series



Applications



Data Processing:

ADCP:

- Visualizing with WinADCP (or VMDAS)
- Each cell is treated as an independent time series
- Spike removal *
- Quality control * based on: percent good, thresholds for velocity components (u,v,w), threshold for error, maximum Dt with bad data, maximum number of bad data.

*performed also on punctual data (AD)

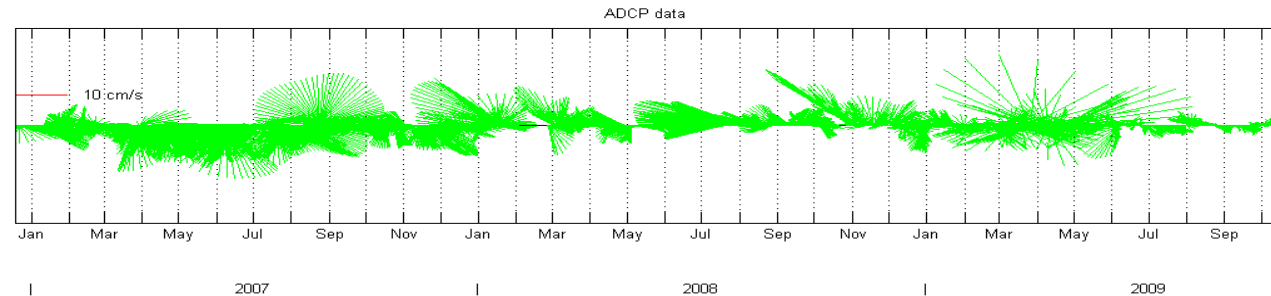
For both ADCP cells and current-meter time series:

- Spectral and harmonic analysis
- Low-pass filter with cut-off period at 33 hours to remove inertial oscillation → sub-inertial non-tidal flow

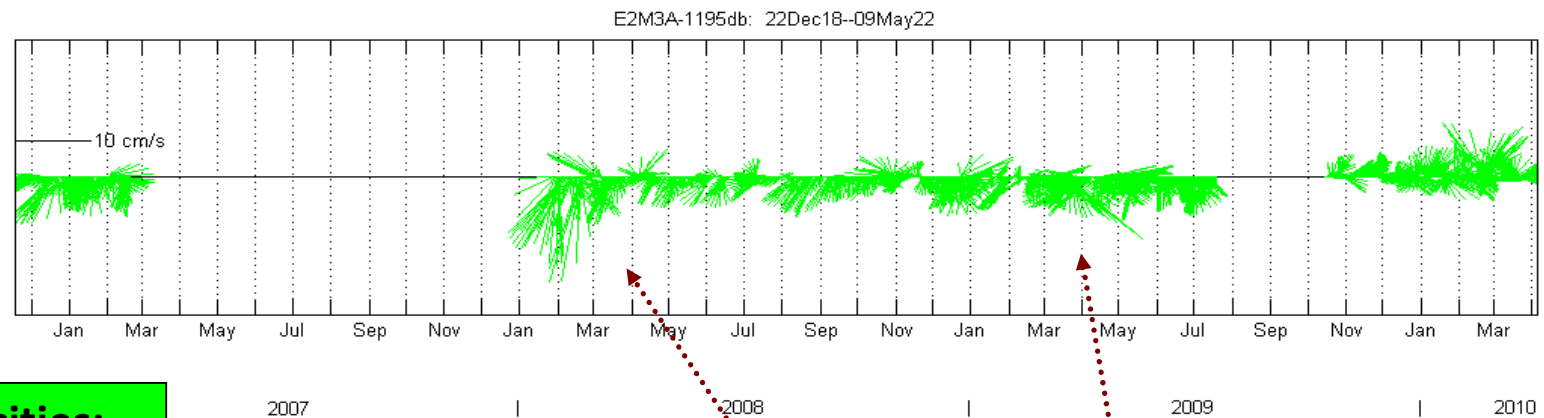


2006-2010 : hz. currents in the South Adriatic [Bottom Layer]

ADCP
~300m

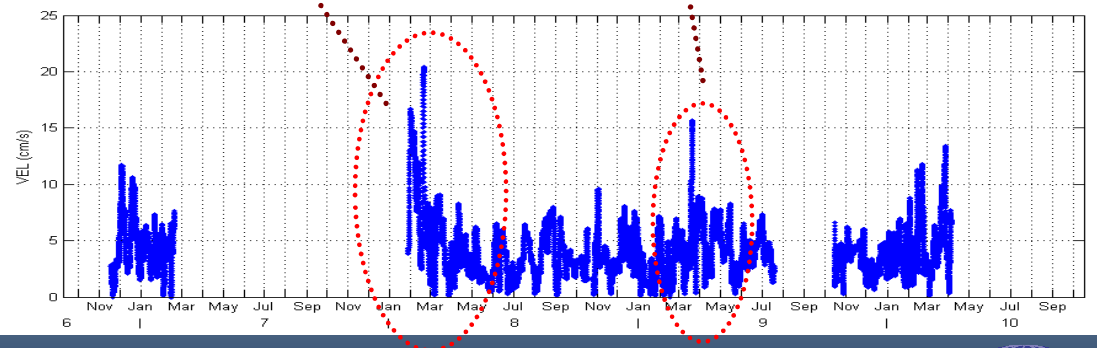


Aanderaa
~ 1150m



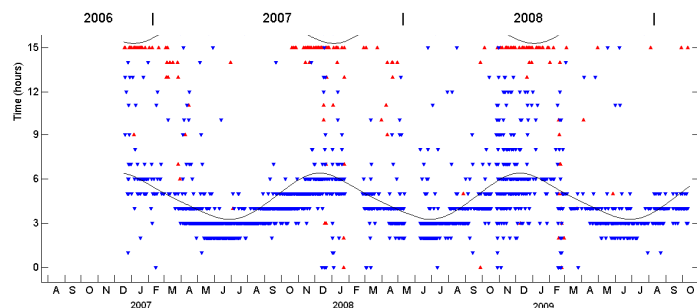
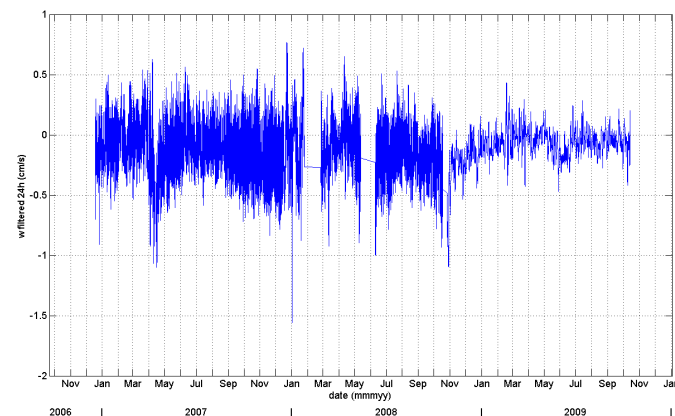
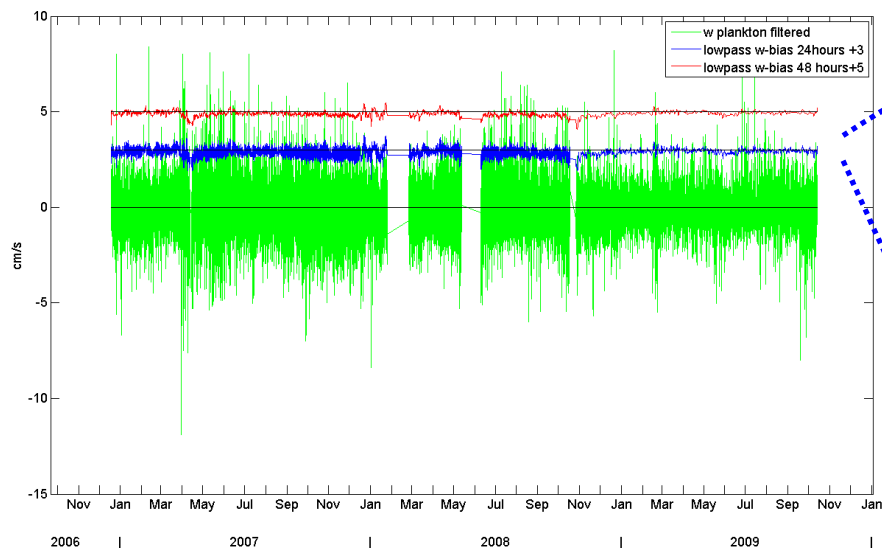
Bottom Velocities:

0 - 20.4 (cm/s)
are higher in winter
with main dir W-SW



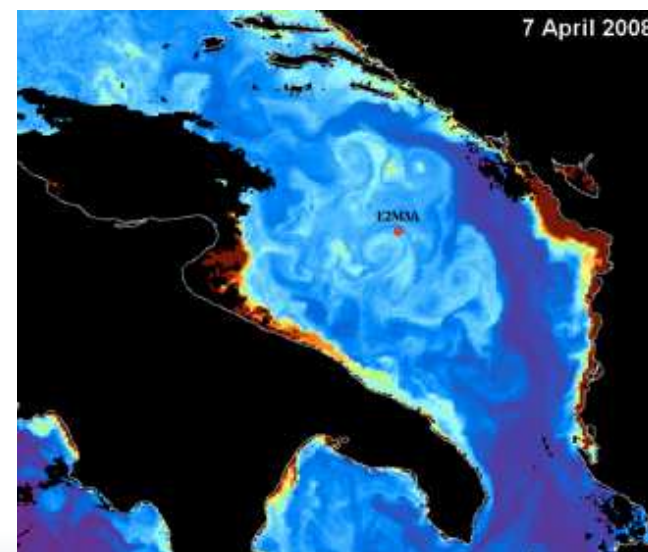
2006-2009 : vertical curr. in the South Adriatic

[Layer 100-300m]



- ✓ Diurnal vertical migration cycle at 300m depth. (Motion > 2.5 cm/s)
- ✓ Vertical motion cleaned by plankton diurnal migration





Passage of cyclonic eddy in the intermediate layer and the concurrent passage of an anticyclonic eddy at the bottom

From Bensi et al. 2012

