WMO / OMM

Niger Basin Authority

Niger-HYCOS and Volta-HYCOS projects

Training programme on flow measurements

3rd partie : Flow measurement using ADCP – Principles and practice

IRD - Unite OBHI (*Observatoires Hydrologiques et Ingenierie*)

3rd partie : Flow measurement using ADCP – Principles and practice

1. Meaning of ADCP
2. History of development
3. Principles of operation :
   - The Doppler effect
   - Velocity profile
   - Three dimension current velocity vectors
   - Limitations
   - Bottom track
4. The different modes of operation
5. Some models of ADCP

1. Definition of ADCP

What is ADCP?

- Acoustic – Use of a sound wave
- Doppler –Doppler Effect is applied to measure velocity
- Current - Measurement of water velocity
- Profiler - Measurement of a velocity profile, not of a velocity at a point

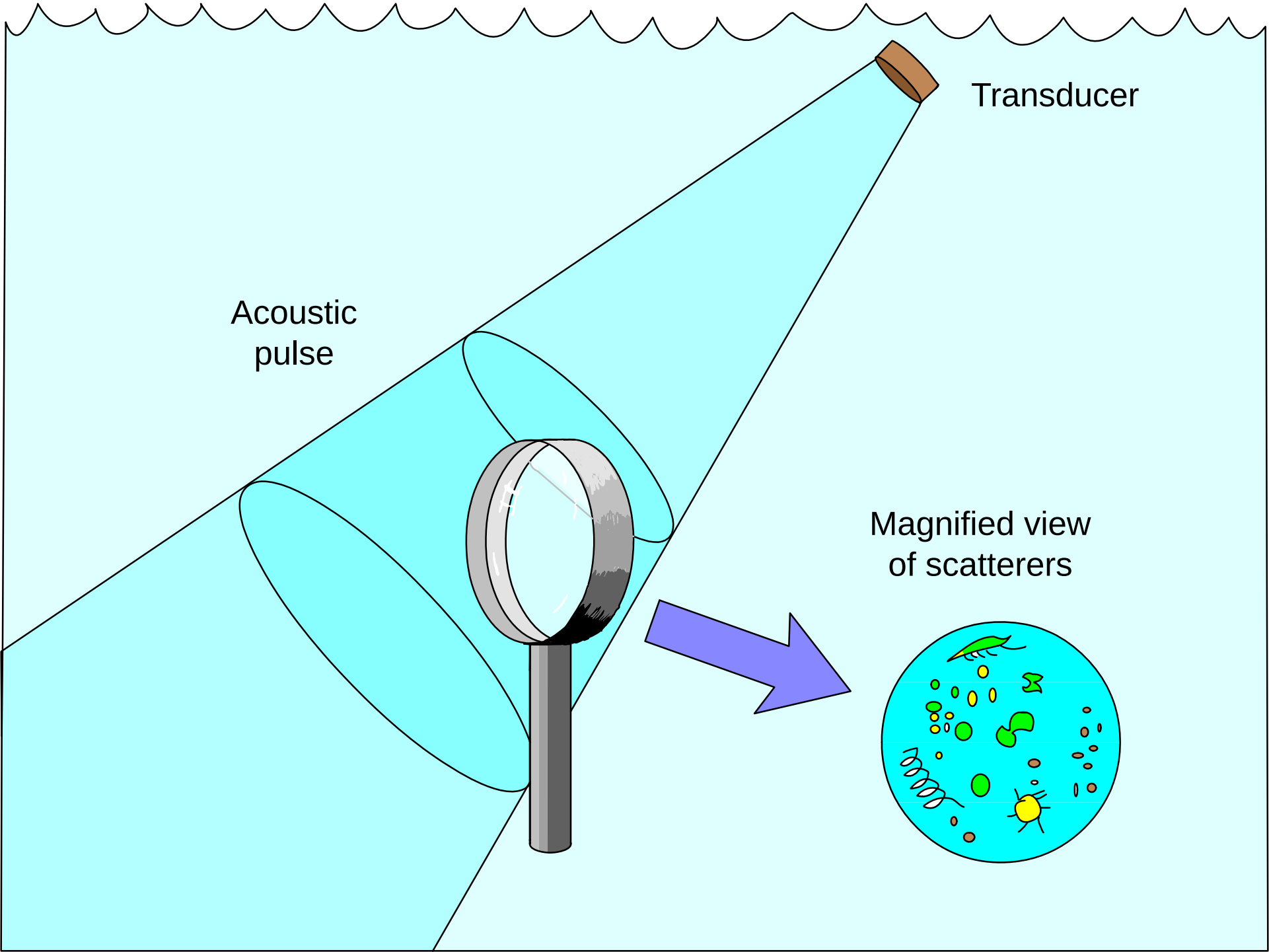
2 . History of ADCP

- Used in the 70’s to measure the speed of ships
- 1982 : first ADCP was commercialized by RDI (USA)
- 1991 : RDI developes the Broadband technology
- 1997 : ‘Workhorse’ is introduced

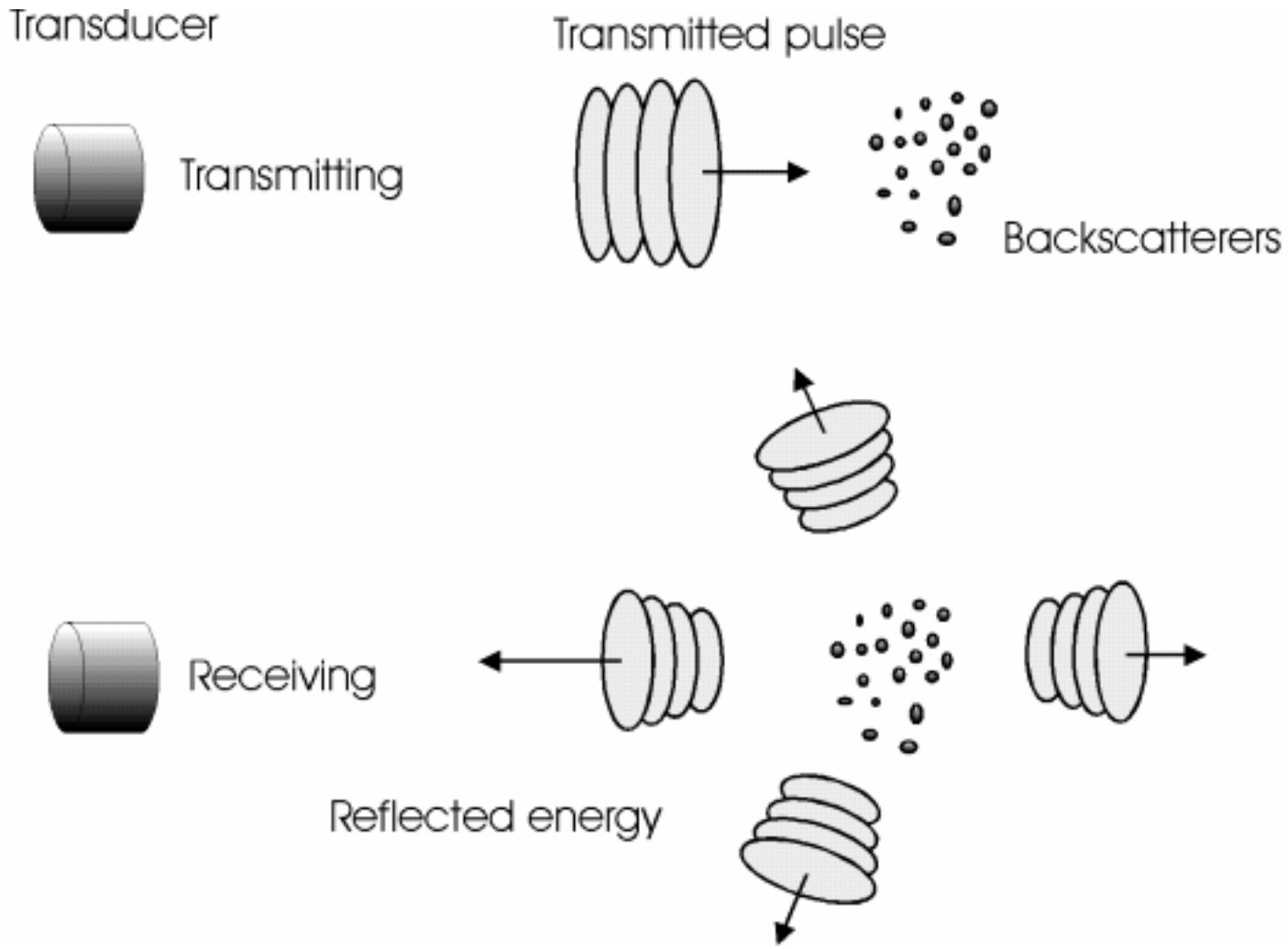
2 . Principles of operation of ADCP: the Doppler effect

- The ADCP sends ultrasonic waves which are reflected by **suspended particles**, which move with the current
- The particles receive the sound with a shifted **frequency** because of their velocity (**Doppler effect**).
- They reflect the sonic wave (=emitters)

➡ Doppler effect is applied 2 times

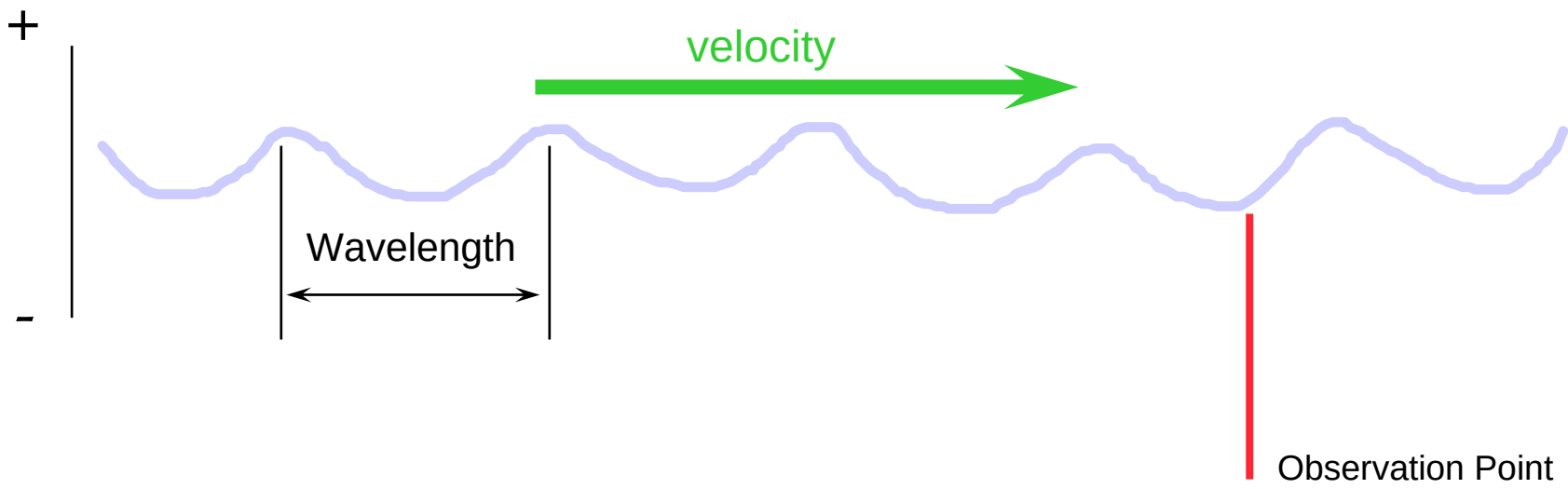

Transducer
Acoustic
pulse
Magnified view
of scatterers

2 . Principles of operation of ADCP: the Doppler effect



2 . Principles of operation of ADCP: the Doppler effect

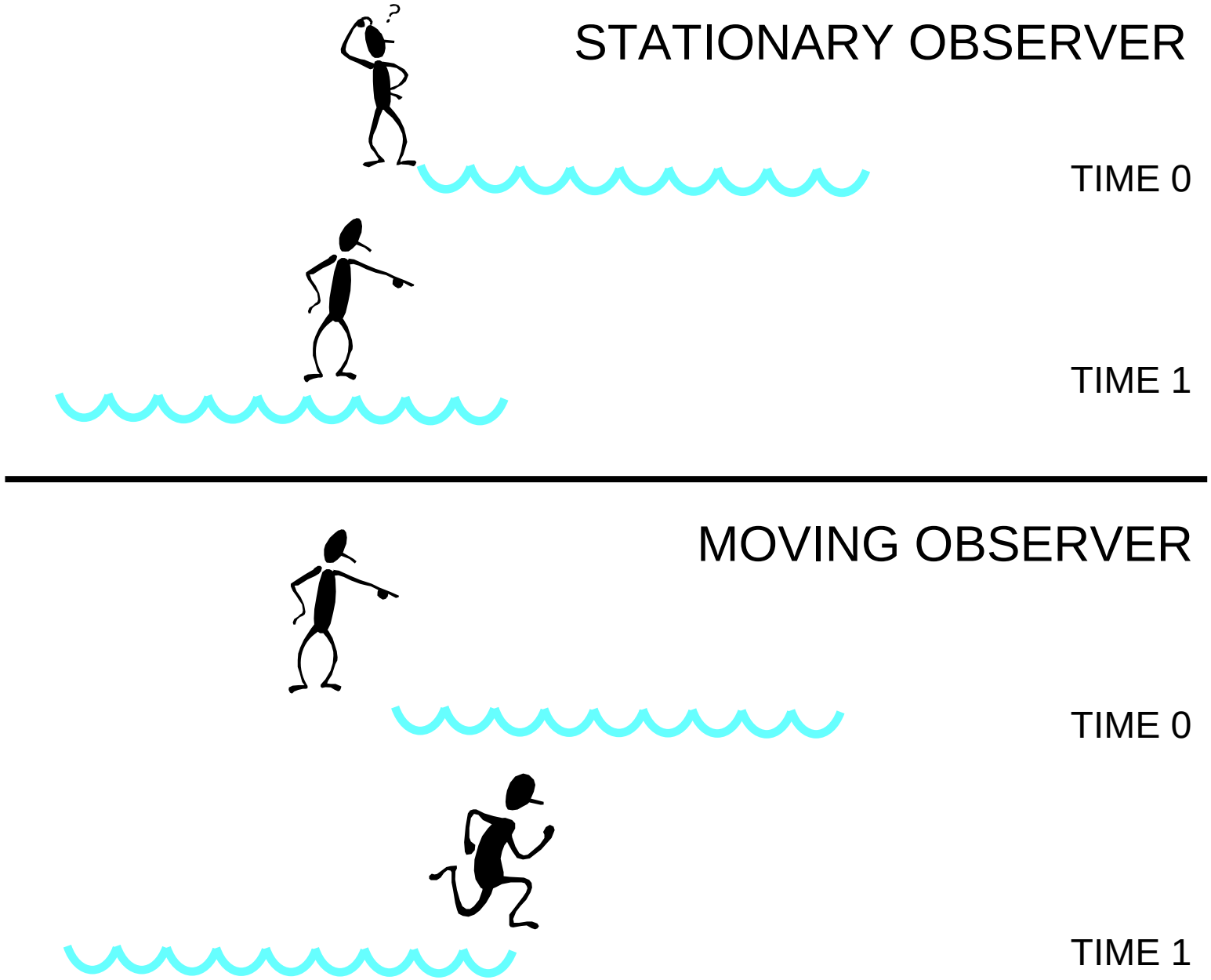
- Sound waves - bands of high and low pressure
- Water waves - crests and troughs of high and low water elevations



Speed = Frequency X Wavelength

$C = f X \lambda$

2 . Principles of operation of ADCP: the Doppler effect



2 . Principles of operation of ADCP: the Doppler effect

Summary

- The ADCP emits a sound and then listens
- The difference between the frequency of emitted wave and reflected echo : velocity of the particule

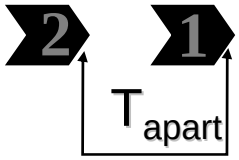
The Broadband technology

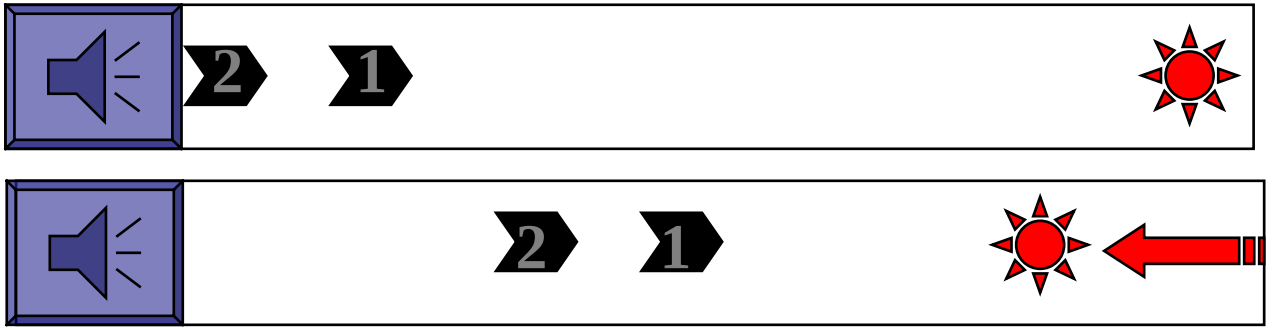
- ADCP does not send a single wave but **several pulses** which form a code
- It is not the difference of frequency between the emitted wave and the reflected wave that is measured but the **variation of phase beween the several relected pulses**.
- The obtained accuracy is 10 to 50 times better.

2 . Principles of operation of the ADCP

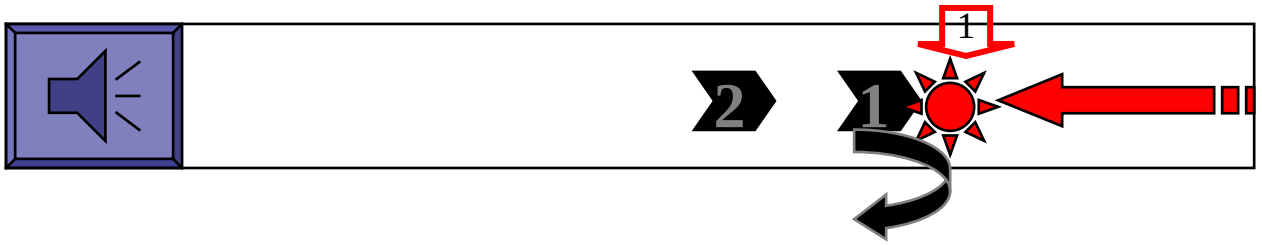
La technology Broadband

- 2 pulses are separated by a time T_{apart}
- They travel along the beam away from the ADCP





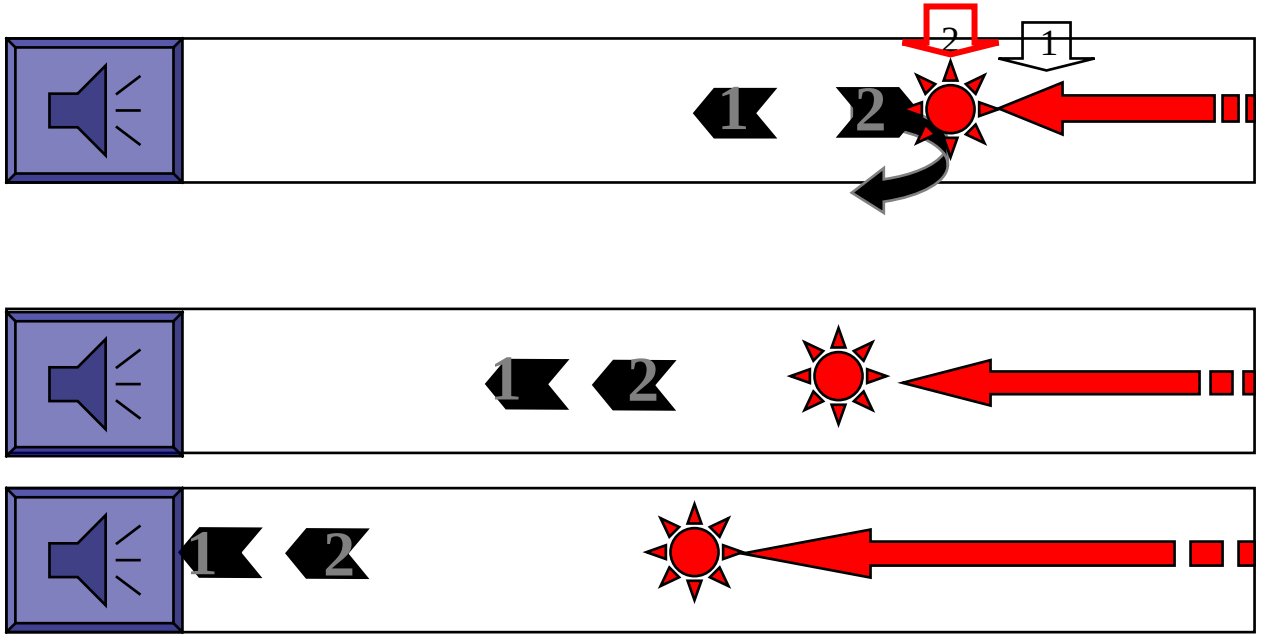
- The suspended particles move towards the ADCP
- When it meets the first pulse, an echo is sent towards the ADCP



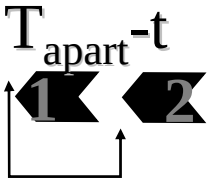
2 . Principles of operation of the ADCP

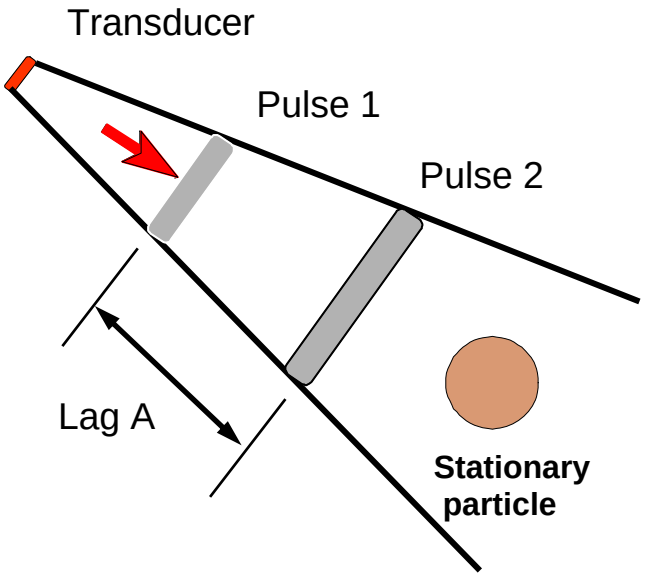
La technology Broadband

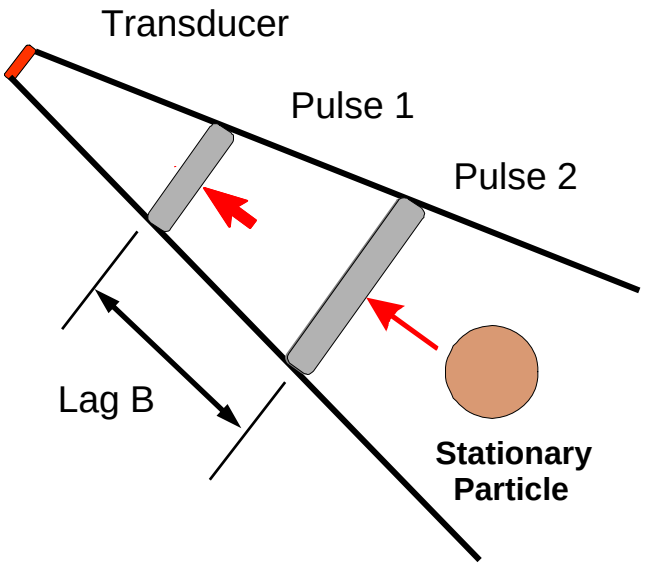
- Particles continue to move along the beam towards the ADCP. When they meet the 2nd pulse, a 2nd echo is created.

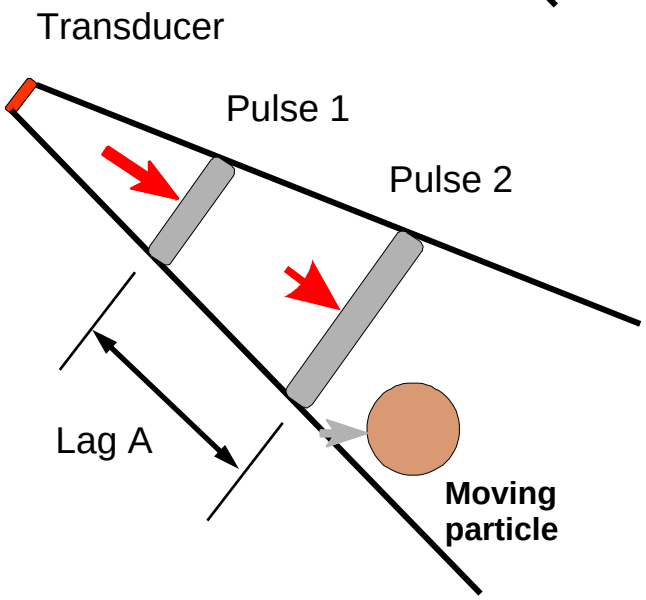


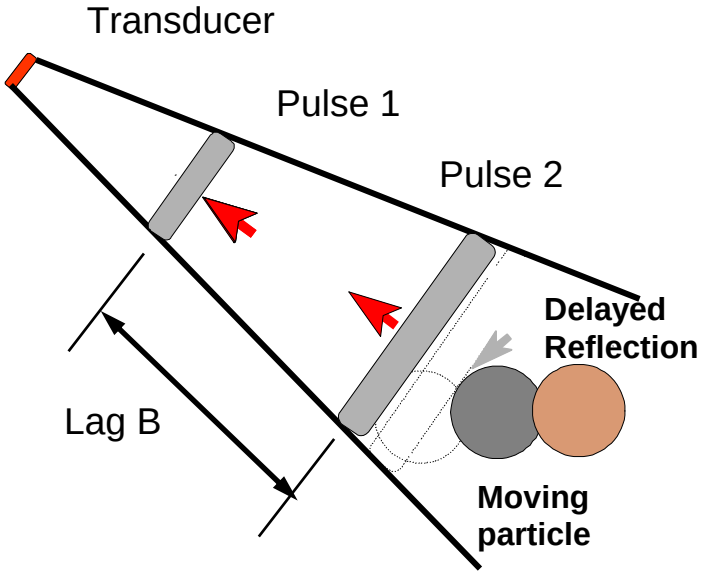
- The echos are detected by the ADCP. The difference between their time of arrival is lower than the difference between the 2 pulses emitted




Transducer
Pulse 1
Pulse 2
Lag A
Stationary
particle

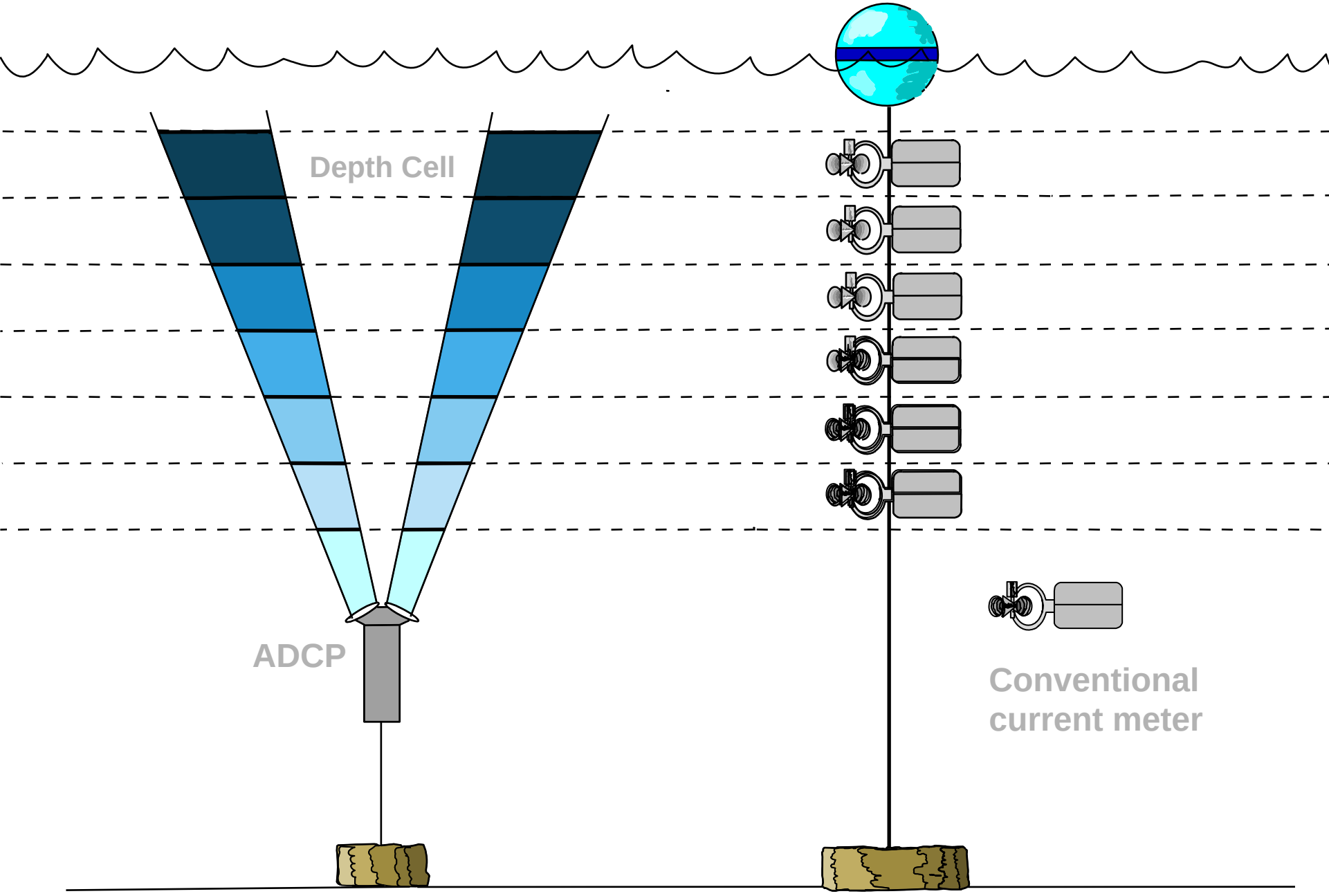

Transducer
Pulse 1
Pulse 2
Lag B
Stationary
Particle

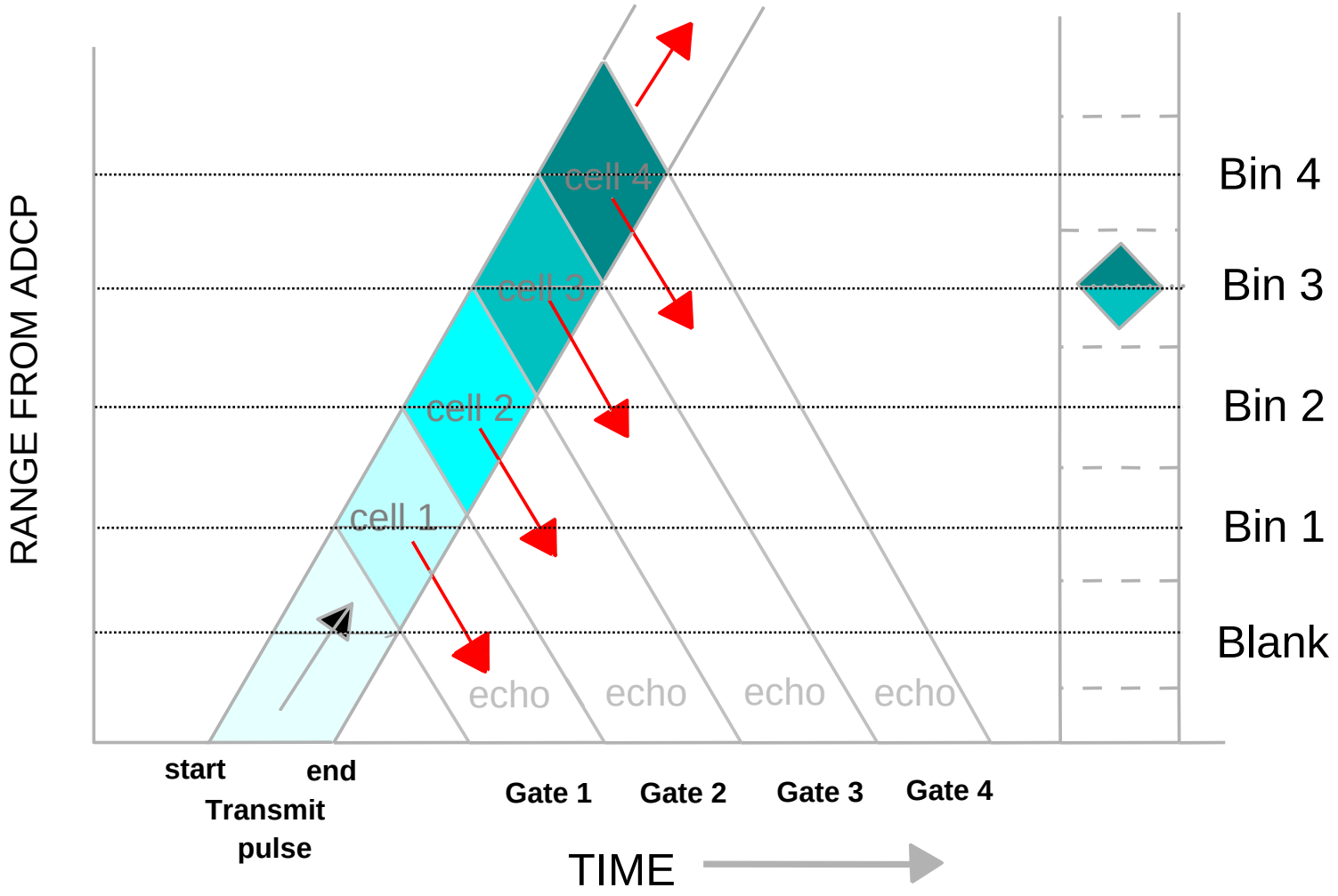

Transducer
Pulse 1
Pulse 2
Lag A
Moving
particle


Transducer
Pulse 1
Pulse 2
Delayed
Reflection
Lag B
Moving
particle

Velocity profile

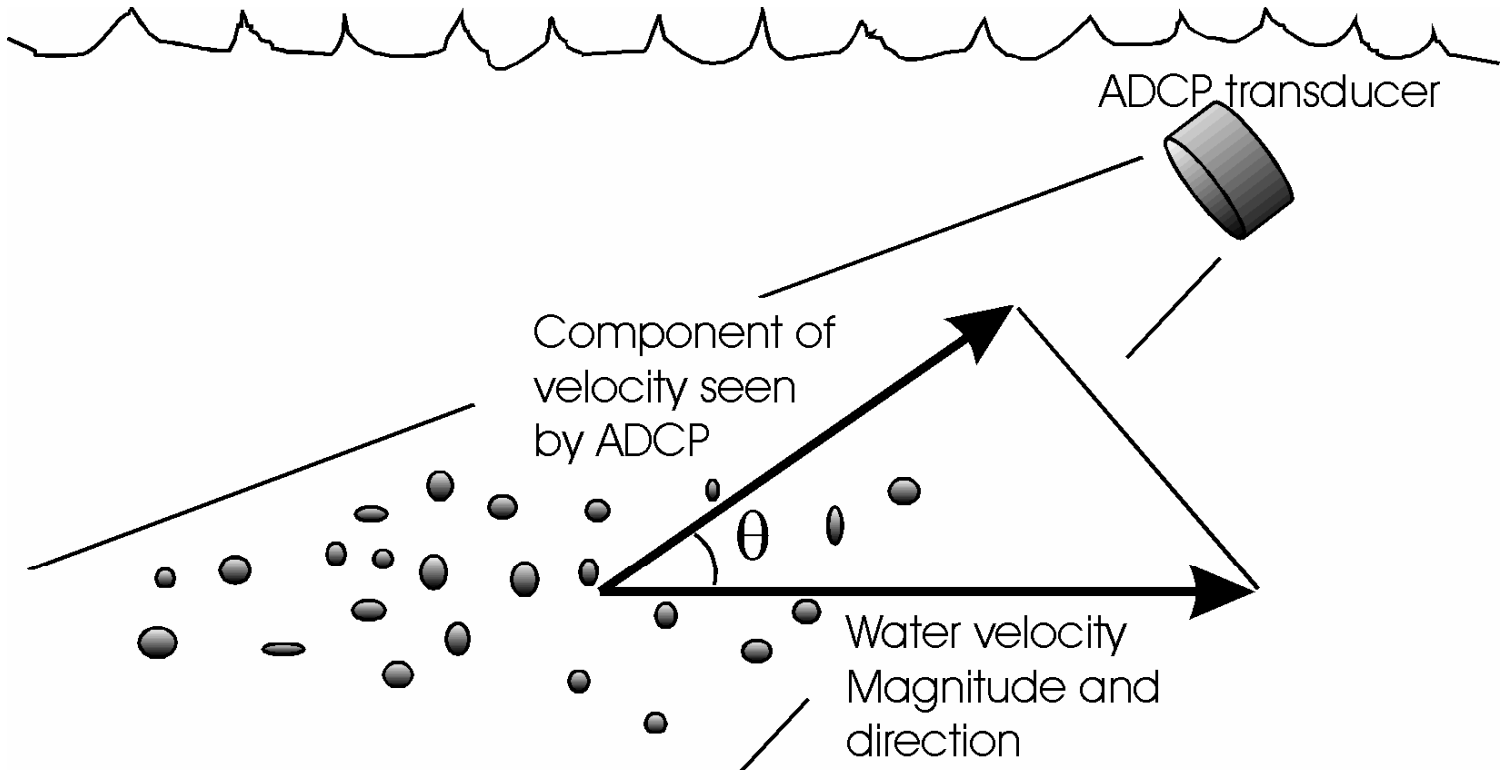
- On a vertical : emission of a ping (=pulse)
  - One part is reflected towards the ADCP
  - The other part continues its trajectory
- **ADCP determines the depth of the particle** knowing the time of return of the wave and the speed of sound (v=d/t)
- **The column of water is partitioned into vertical elements** : the ADCP listens to the reflected echos at different time intervals, which correspond to given depths


Depth Cell
ADCP
Conventional
current meter


RANGE FROM ADCP
cell 4
cell 3
cell 2
cell 1
echo
echo
echo
echo
Bin 4
Bin 3
Bin 2
Bin 1
Blank
start
Transmit
pulse
end
Gate 1
Gate 2
Gate 3
Gate 4
TIME

2 . Principles of operation of the ADCP

Three dimension current velocity vectors



The velocity of the particle is measured along the axis of a beam

2 . Principles of operation of the ADCP

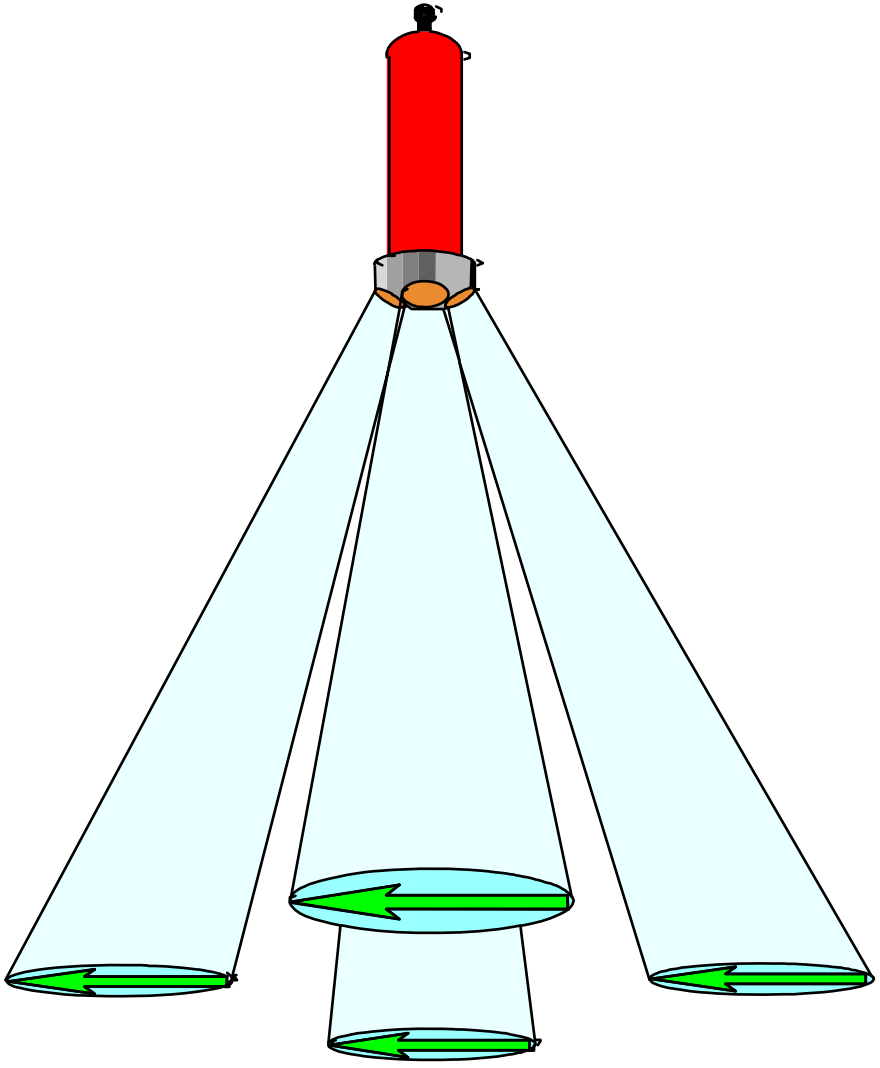
Three dimension current velocity vectors

- 2 opposite beams enable to calculate the horizontal component and the vertical component of velocity. At the same time, the 2 other beams will calculate the other horizontal component and the same vertical component.

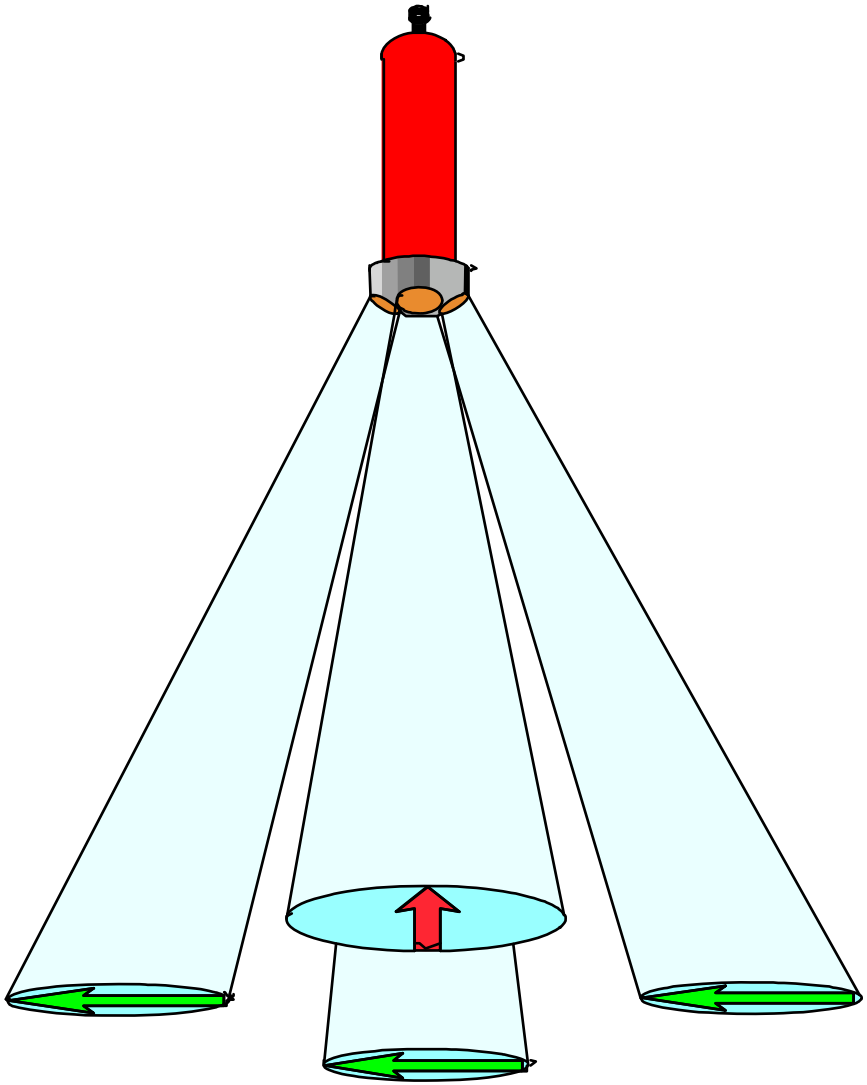
  ➡ Comparison of the 2 vertical component gives the **"error velocity".**

- **homogenous** medium: the 4 current vectors courant are equivalent.

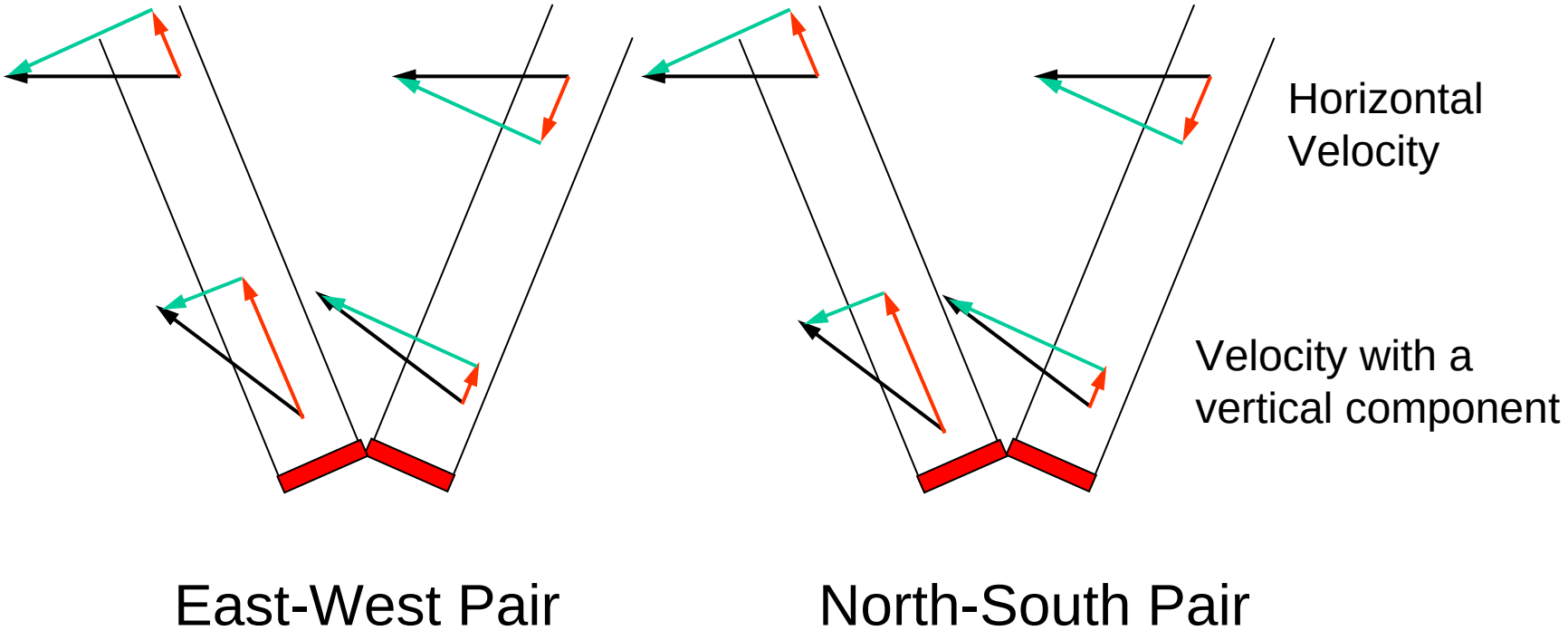
  turbulent medium : if one of the beam detects a different current, the error velocity bcames important

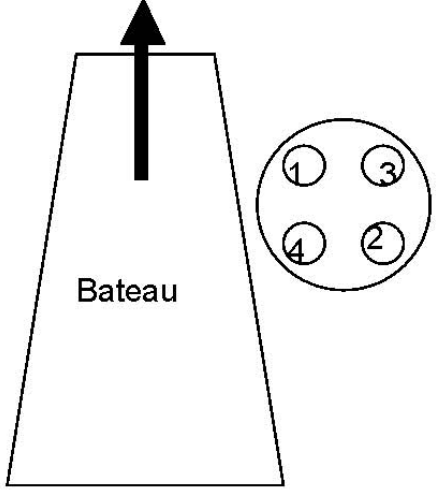


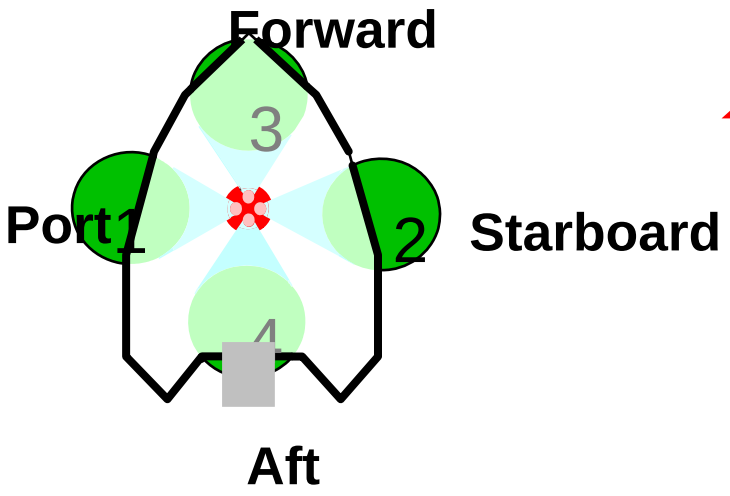
HOMOGENEOUS



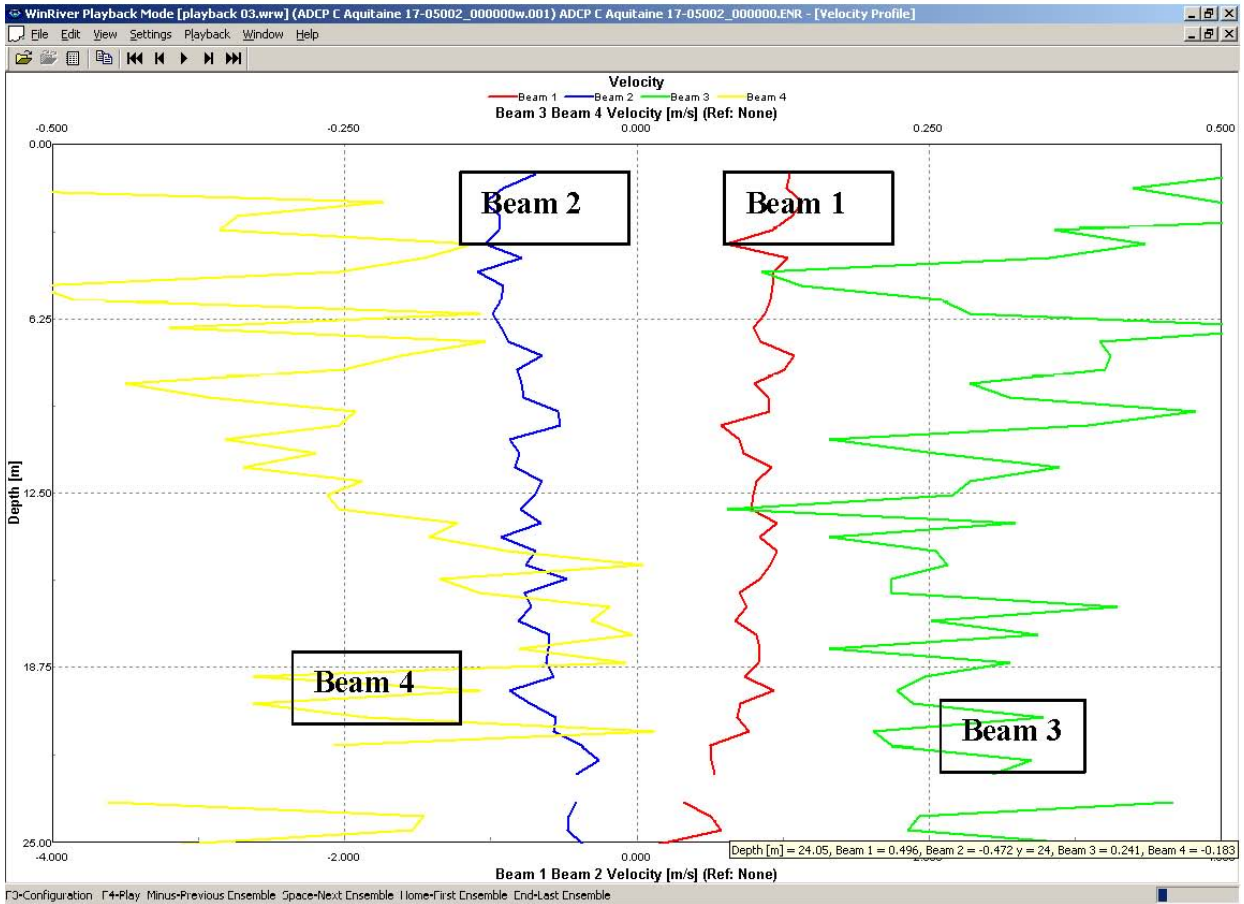
NON HOMOGENEOUS


Horizontal
Velocity
Velocity with a
vertical component
East-West Pair
North-South Pair
Water velocity vector
Measured component
Unmeasured component


Bateau
1
3
4
2


Forward
3
Port
1
2
Starboard
4
Aft


Trajectory
of boat


WinRiver Playback Mode [playback 03.wrw] (ADCP C Aquitaine 17-05002_000000w.001) ADCP C Aquitaine 17-05002_000000.ENR - [Velocity Profile]
File Edit View Settings Playback Window Help
Velocity
Beam 1 Beam 2 Beam 3 Beam 4
Beam 3 Beam 4 Velocity [m/s] (Ref: None)
-0.500 -0.250 0.000 0.250 0.500
0.00
6.25
12.50
18.75
25.00
Depth [m]
Beam 2
Beam 1
Beam 4
Beam 3
-4.000 -2.000 0.000
Beam 1 Beam 2 Velocity [m/s] (Ref: None)
Depth [m] = 24.05, Beam 1 = 0.496, Beam 2 = -0.472 y = 24, Beam 3 = 0.241, Beam 4 = -0.183
F3-Configuration F4-Play Minus-Previous Ensemble Space-Next Ensemble Home-First Ensemble End-Last Ensemble

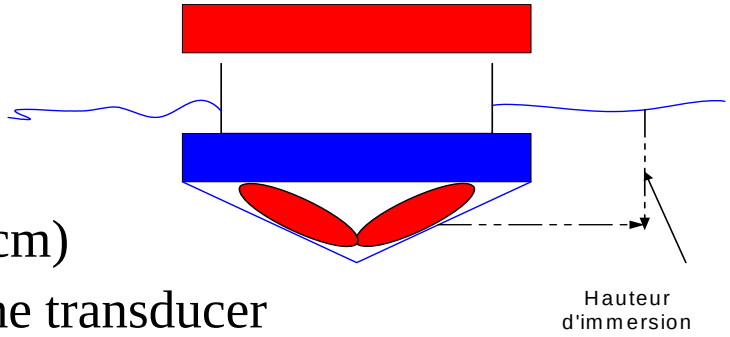
Accuracy of the velocity measurement

Accuracy of the velocity measurement depends on several factors including :

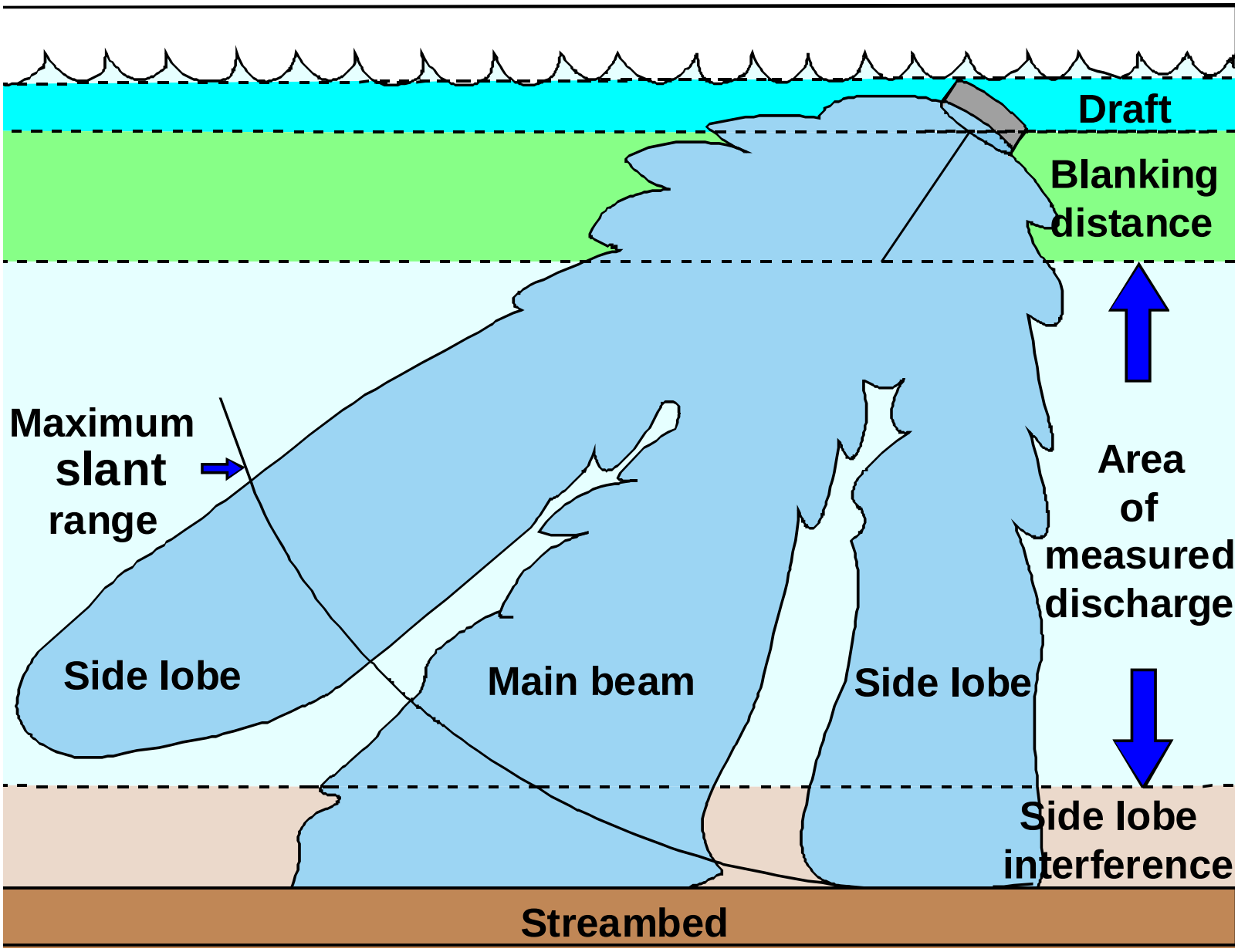
- **Boat speed** : slow speed reduces the mean error in flow calculation
- **Dimension of the cells** : cells with a small height have a high systematic error but gives velocity measurements closer the the surface, the bottom and the shore
- **Salinity** : velocity of sound in water is dependent on the salinity of water

  A 3 % error in the velocity of sound can result in a 9 % error in the total flow calculation. Default value for the ADCP = 35ppm (sea & ocean)

Limitations of ADCPs



- **No measurements in the superficial zone**
  - Depth of immersion of the ADCP (~25 cm)
  - Blank : blind zone immediately below the transducer
  - Ex : The first 1m below the water surface is not measured for the Workhorse model (1200 kHz, with bins size = 25cm)
- **Effects due to the river bed :** ADCP does not measure the entire column up to the river bed, because of acoustic reflection from the bottom
  - Side lobes : reflection of side lobes from the stream bed interfers avec with the reflections from the particles : thickness of the polluted layer : 6 % of the distance transducer- streambed
  - The last cell is not used to measure the flow
- **Problems with moving beds**


Draft
Blanking distance
Maximum slant range
Area of measured discharge
Side lobe
Main beam
Side lobe
Side lobe interference
Streambed

2 . Principles of operation of the ADCP

ADCP extrapolates the flow values for the following areas :

- **Upper and bottom layers** :

  different methods for extrapolation:

  – Constant or linear method

  – Power method

- **Banks :** minimum depth necessary for the acquisition of good measurements

Bottom track

- Bottom track
- Measurement of ADCP’s velocity with respect to the river bed (Doppler effect)
- Beware of moving beds

Principles of operation of the ADCP : summary…

- Water velocity is measured with respect to the ADCP
- Velocity is measured taking advantage of the suspended particles in the water column
- The velocity of the ADCP is also measured (bottom track)
- Extrapolation of velocities at the surface, bottom and banks

3 . The different modes of operation of ADCP

ADCP can use different types of codes for emission and analysis of the signal :

- ***Mode 1*** : Standard mode, very robust for all applications
- ***Mode 8*** : Precision mode for shallow depth (3.5 m for 1200 kHz model et 7.5 m for 600 kHz model) and low velocity (Vmax = 2 m/sec).
- ***Mode 5*** : High precision mode for slow currents (V max = 1 m/sec) and shallow depth (idem mode 8) .
- ***Mode 11*** : Mode 8 improved (Vmax =1 m/s)
- ***Mode 12*** : Mode 5 improved ; velocity < 1m/s

3 . The different modes of operation of ADCP

	Mode 1	Mode 5	Mode 8	Mode 11
Minimum recommanded cells size	10cm	10cm	10cm	Improved version of Mode 5. Very high precision and very shllow depth (Vmax ~ 1 m/s)
Systematic error For one emission (Ping)	60 cm/s	1 cm/s (vitesse d'écoulement de 50cm/s)	15 cm (vitesse d'écoulement de 100cm/s)	
Minimum water depth	1.00 m	2.00 m	1.00 m	
Maximum depth for water velocity < 50cm/s)	20 m	4 m	4 m	
Maximum velocity	10 m/s	1 m/s	2 m/s	
typical use	High velocity at all depth. Difficult situation. Excellent with too fast or too deep rivers	For slow velocity and shallow water. Low turbulence	For average rivers with velocity inferior to 2 m/, but with turbulences. Satisfying in shallow water	

4. Some models of ADCP

- WorkHorse Rio Grande (600 kHz ou 1200 kHz)
- WorkHorse Monitor : continuous flow measurements (possibility of permanent installation)
- Zedhed : for low water level (range of measurement from 30 cm up to 20 m, with a resolution of 1 cm)

Terminology

Ping	• Impulsion sonic de frequency connue
Cellule, Bin	• Definition d'un intervalle verticale
Ensemble	• Ensemble de donnees fournies par the ADCP
Transect	• Groupement d'ensemble constituant une Measurement du debit
Bottom tracking	• Suivi de fond utilise pour Measurement r la velocity de deplacement de the ADCP