SAPIENZA
UNIVERSITÀ DI ROMA

Consiglio Nazionale delle Ricerche

Istituto di Geologia Ambientale e Geoingegneria

# Environmental geophysics

**Giorgio De Donno**

## *Sub-Bottom Profiler (SBP)*
## *Multi Beam Echo Sounder (MBES)*

***MBES images are kindly provided by***
***Dr. Alessandro Bosman - CNR-IGAG***

***"Sapienza" University of Rome*** **-** *DICEA Area Geofisica*

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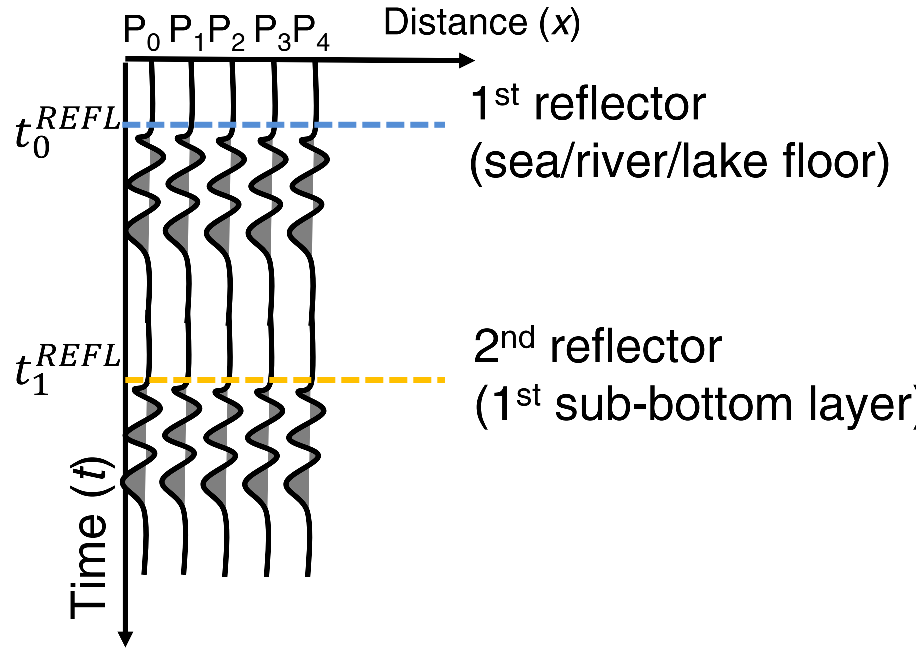
**If the offset is zero or close to zero (source and receivers at the same position) -> NORMAL INCIDENCE**

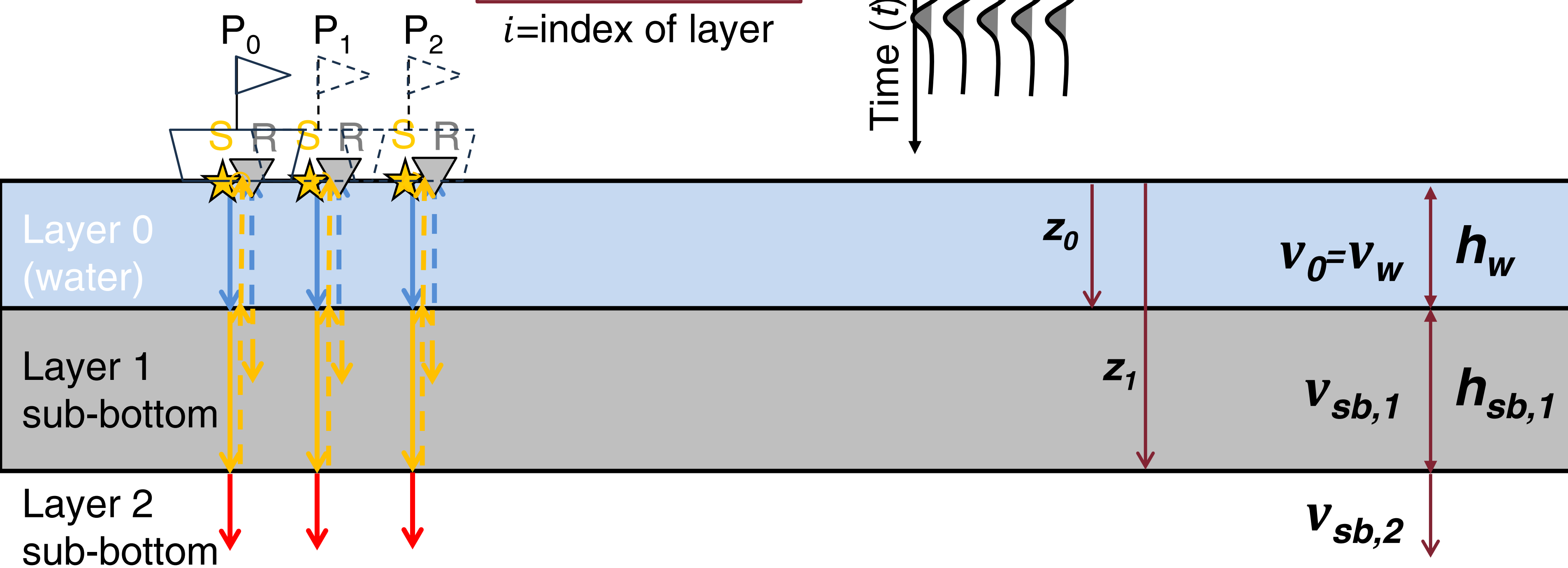
$$t_i^{REFL} = \sum_{j=0}^{i} \frac{2h_j}{v_j}$$

Knowing the velocities →

$$z_i = \frac{1}{2}\sum_{j=0}^{i} v_j t_j$$

$i$=index of layer



# Marine seismic methods – Sub-bottom profiler (SBP)

**First reflector**
**(sea/river/lake floor)**

**1st multiple (water)**

**Second reflector**
**(1st-2nd sub-bottom layer)**

$$t_w = \frac{2h_w}{v_w}$$

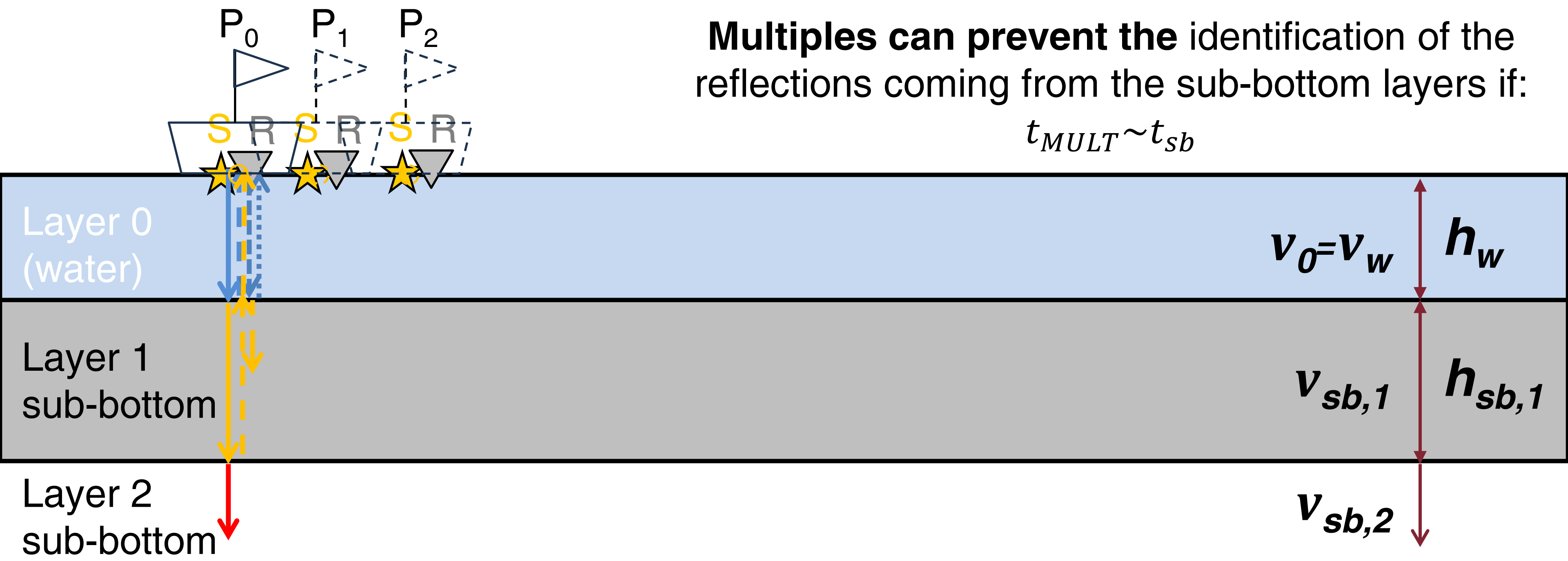
$$t_{w,MULT} = 2\frac{2h_w}{v_w} = \frac{4h_w}{v_w}$$

$$t_{sb,1} = \frac{2h_w}{v_w} + \frac{2h_{sb,1}}{v_{sb,1}}$$

**Multiple reflections are periodic of $2h/v$**

**Multiples can prevent the** identification of the reflections coming from the sub-bottom layers if:

$$t_{MULT} \sim t_{sb}$$



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## Tiber River – Capo due Rami (Rome)

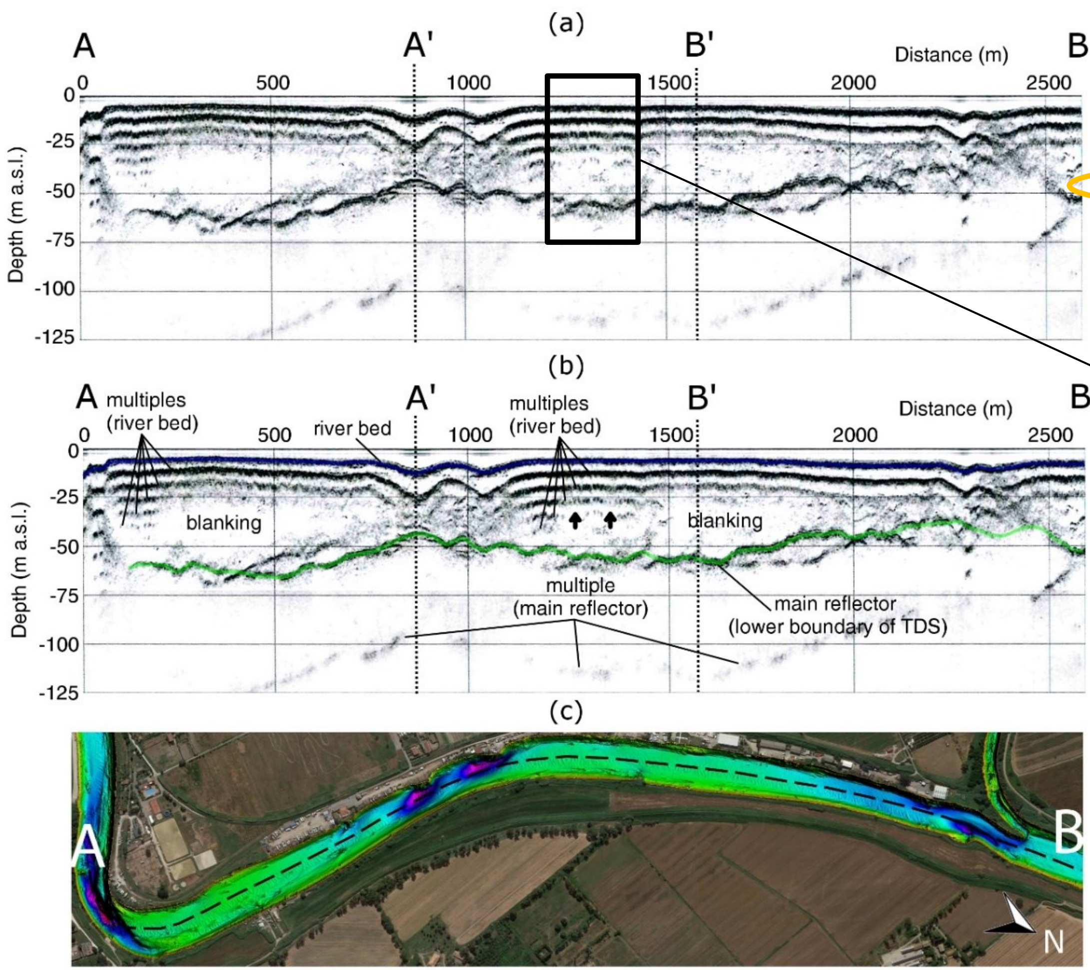
Source: **Chirp** vibrating source

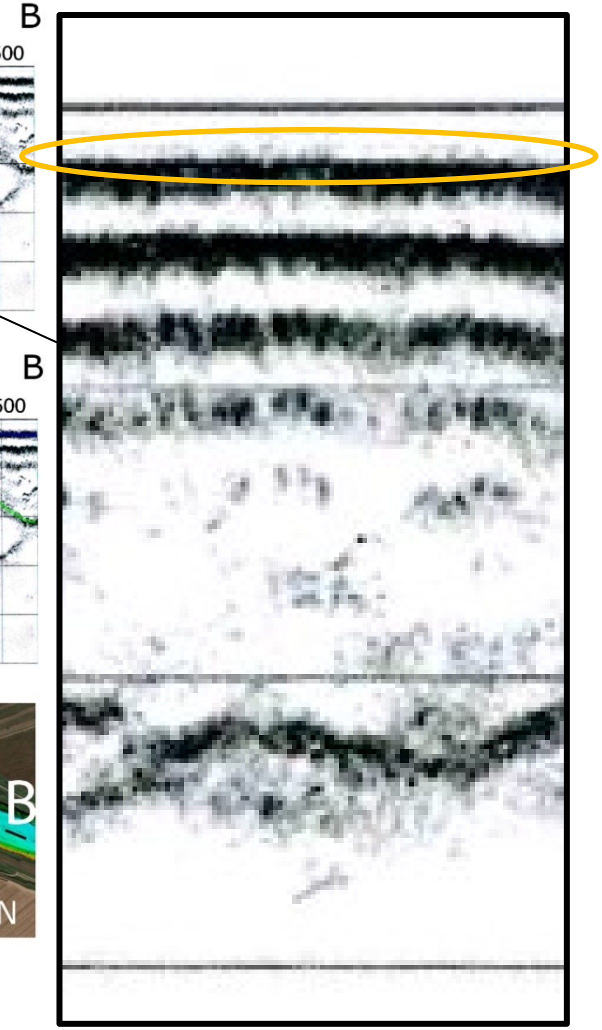
$f_{sweep}$ = 2-8 KHz

SBP processed section

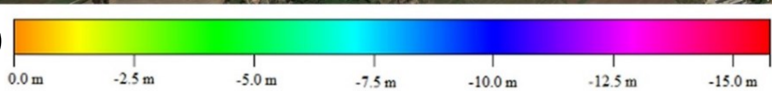
Interpretation

Multibeam data



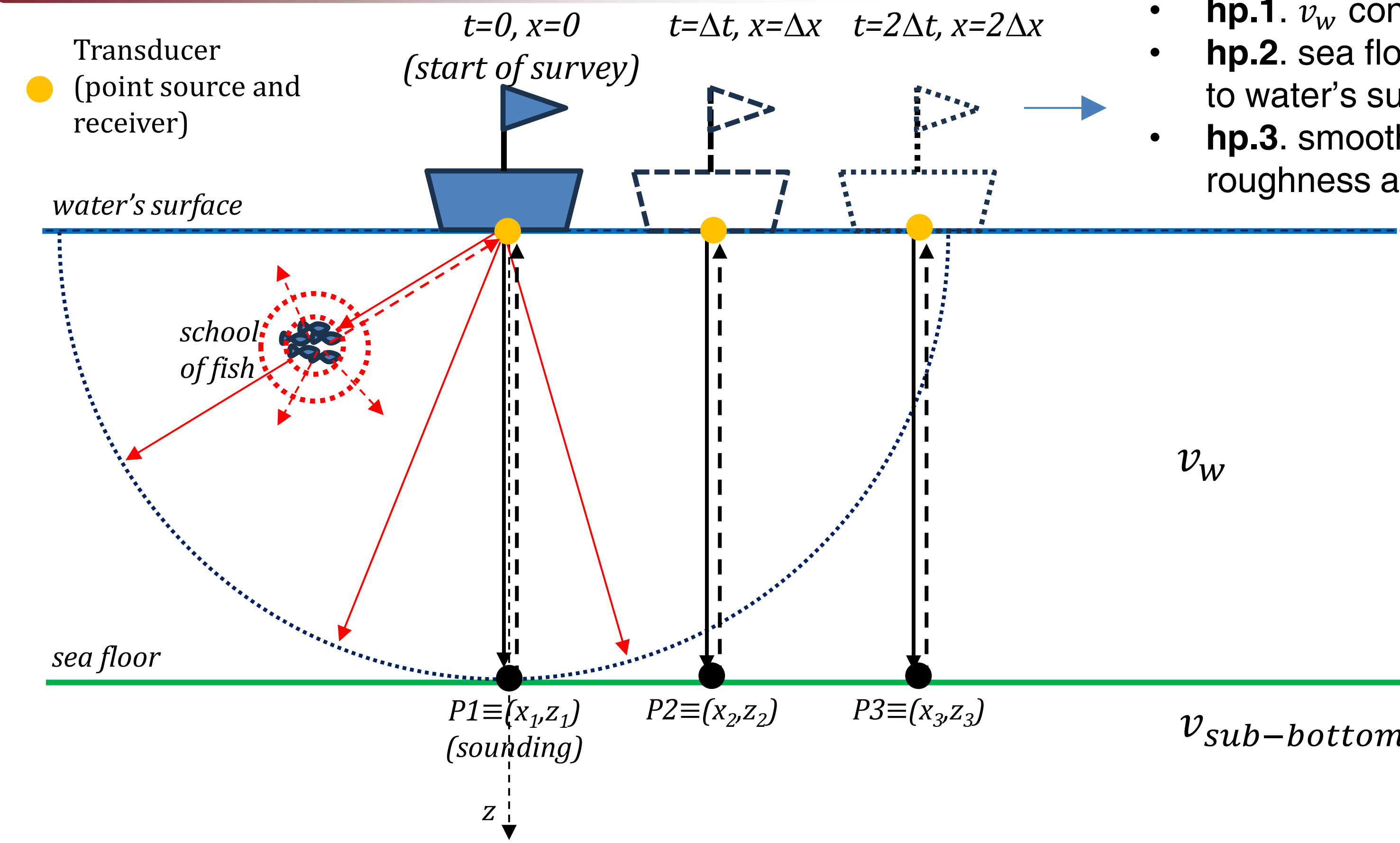
Depth (m a.s.l.)



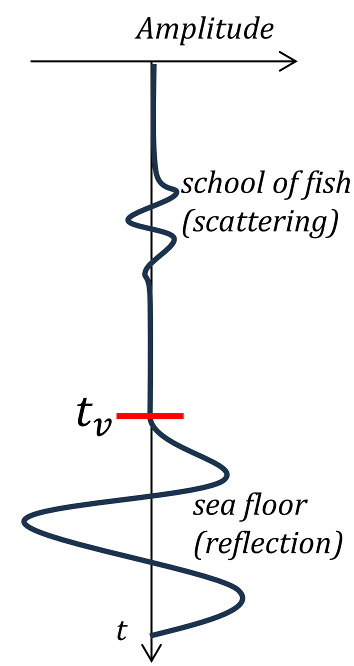
# SONAR methods – Basic principles



- **hp.1**. $v_w$ constant
- **hp.2**. sea floor plane and parallel to water's surface
- **hp.3**. smooth sea florr (no effect of roughness and/or grain size)




*Trace at x=0*




## Depth of sea floor

$$z_i = \frac{v_w t_{v,i}}{2} \quad i = 1,2,\ldots,N_S$$

$$v_w = \sqrt{\frac{K_w}{\delta_w}}$$ *acoustic wave velocity (water)*

$N_S$: *number of soundings*

# SONAR methods – Basic principles

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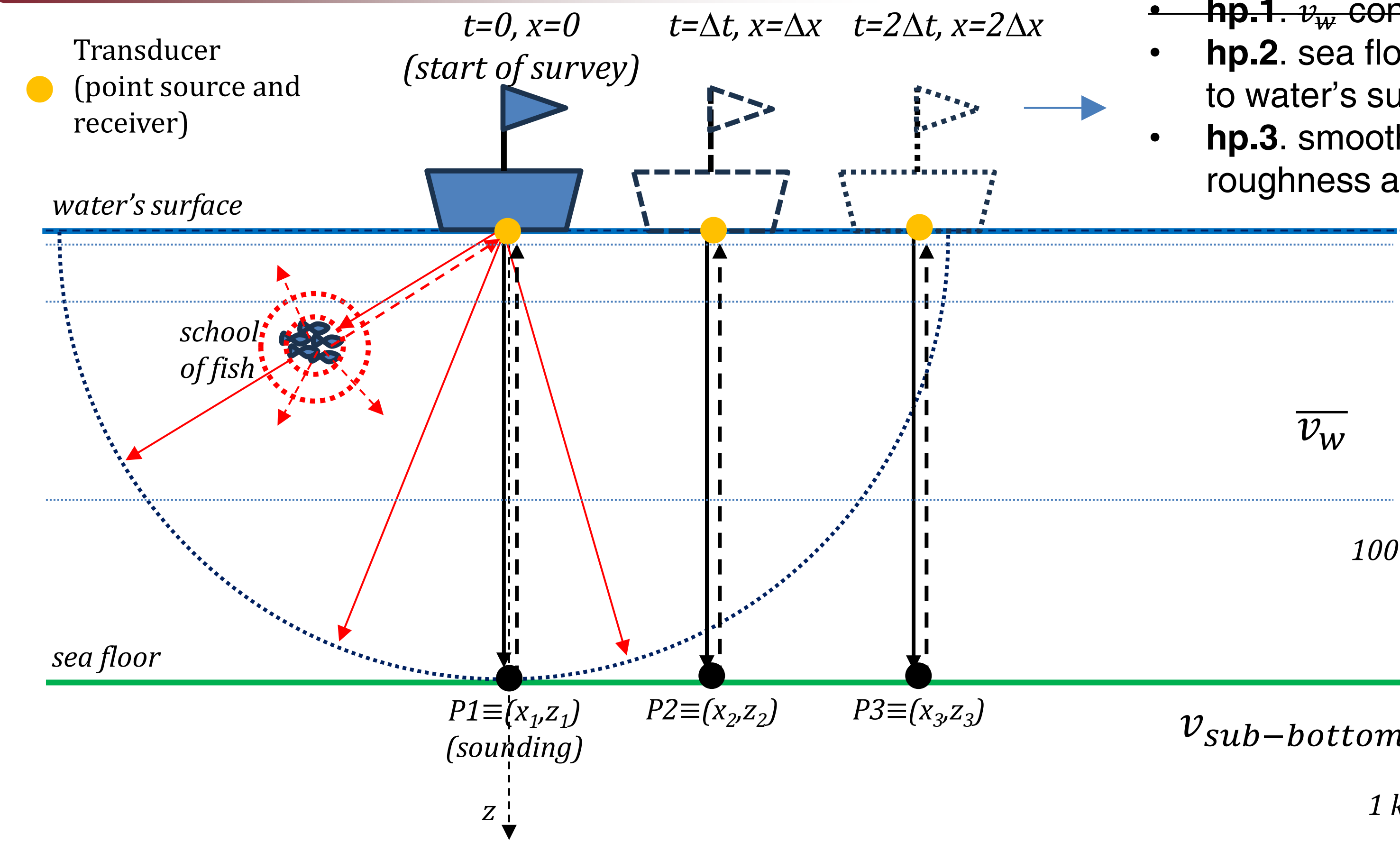
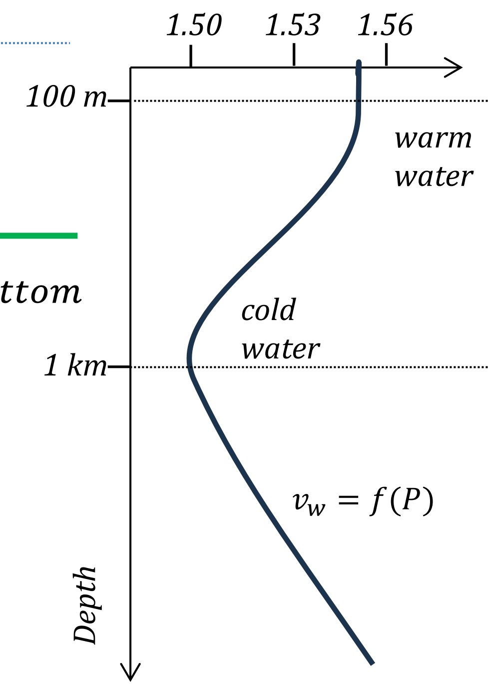



## Ocean's trend

$$v_w = f(T, P, S)$$




## Depth of sea floor

$$z_i = \frac{\overline{v_w} t_{v,i}}{2} \quad i = 1,2,\dots,N_S$$

$\overline{v_w}$ *weigthed average (on thickness of each layer) acoustic wave velocity*

$N_S$: *number of soundings*

# SONAR methods – Basic principles

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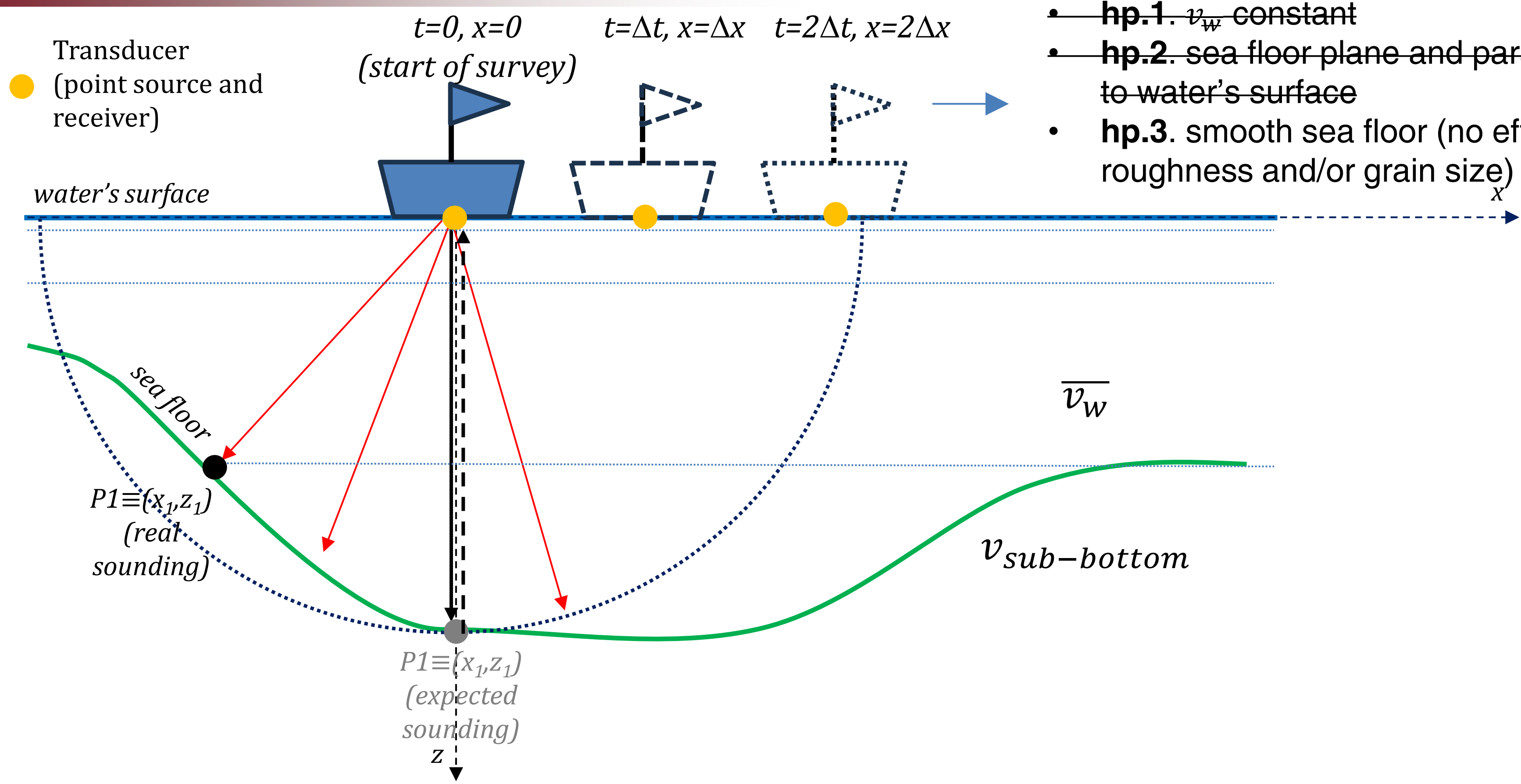


**Depth of sea floor?**

# SONAR methods – Basic principles



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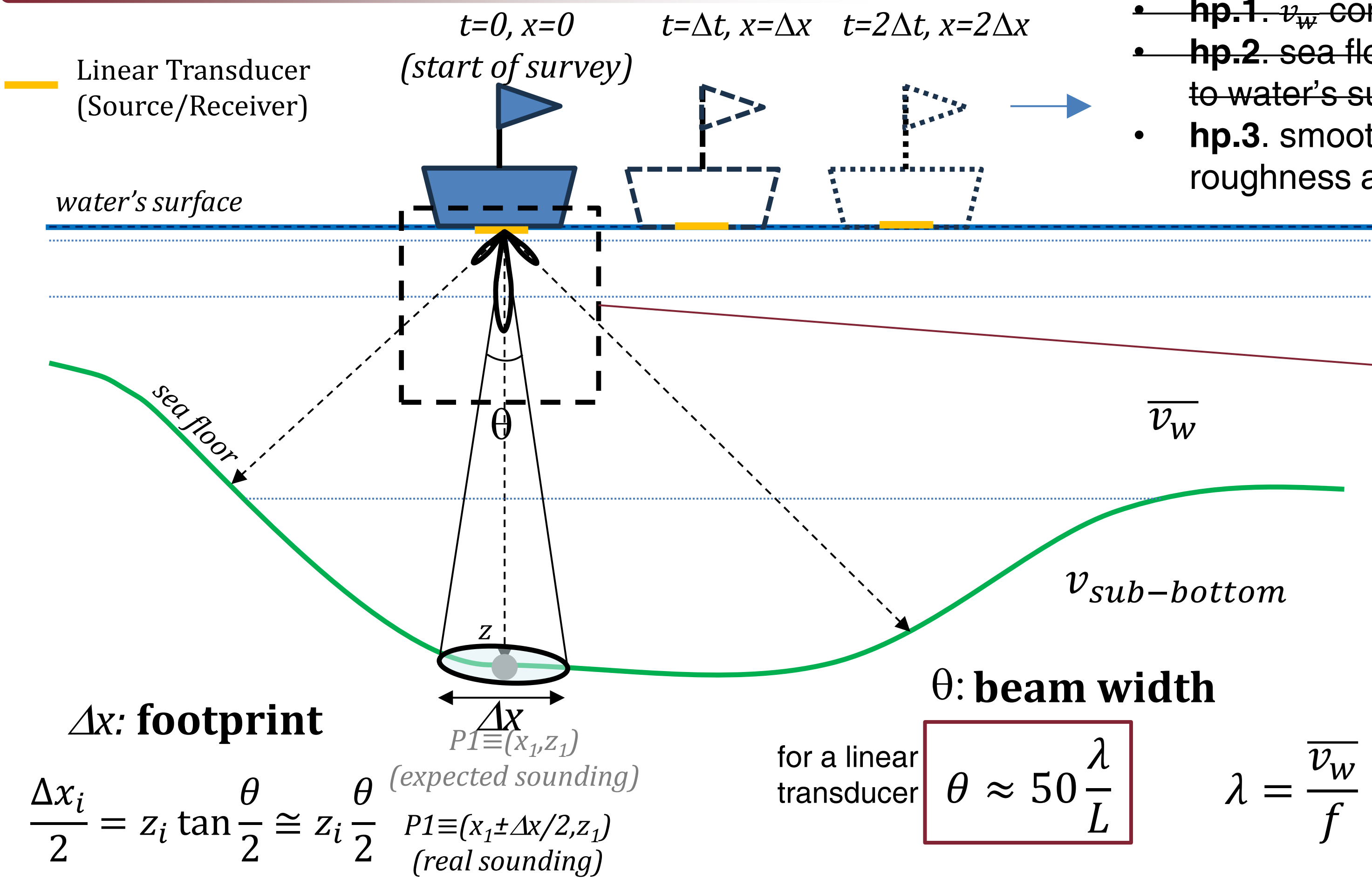


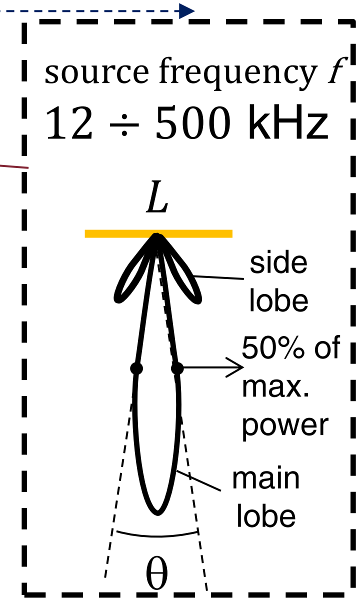


***Δx*: footprint**

$$\frac{\Delta x_i}{2} = z_i \tan\frac{\theta}{2} \cong z_i \frac{\theta}{2}$$

**θ: beam width**

for a linear transducer $\theta \approx 50\frac{\lambda}{L}$ $\quad \lambda = \frac{\overline{v_w}}{f}$

$\Delta x_i \cong z_i\theta$ **RESOLUTION** $\begin{cases} \Delta x \le d_{object} \rightarrow OK \\ \Delta x > d_{object} \rightarrow NO \end{cases}$

Assuming:

$\overline{v_w} = 1500$ m/s

$f = 12 \div 500$ kHz

$\lambda =$ **3 mm - 15 cm**

# SONAR methods – Basic principles

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- ~~**hp.1**. $v_w$ constant~~
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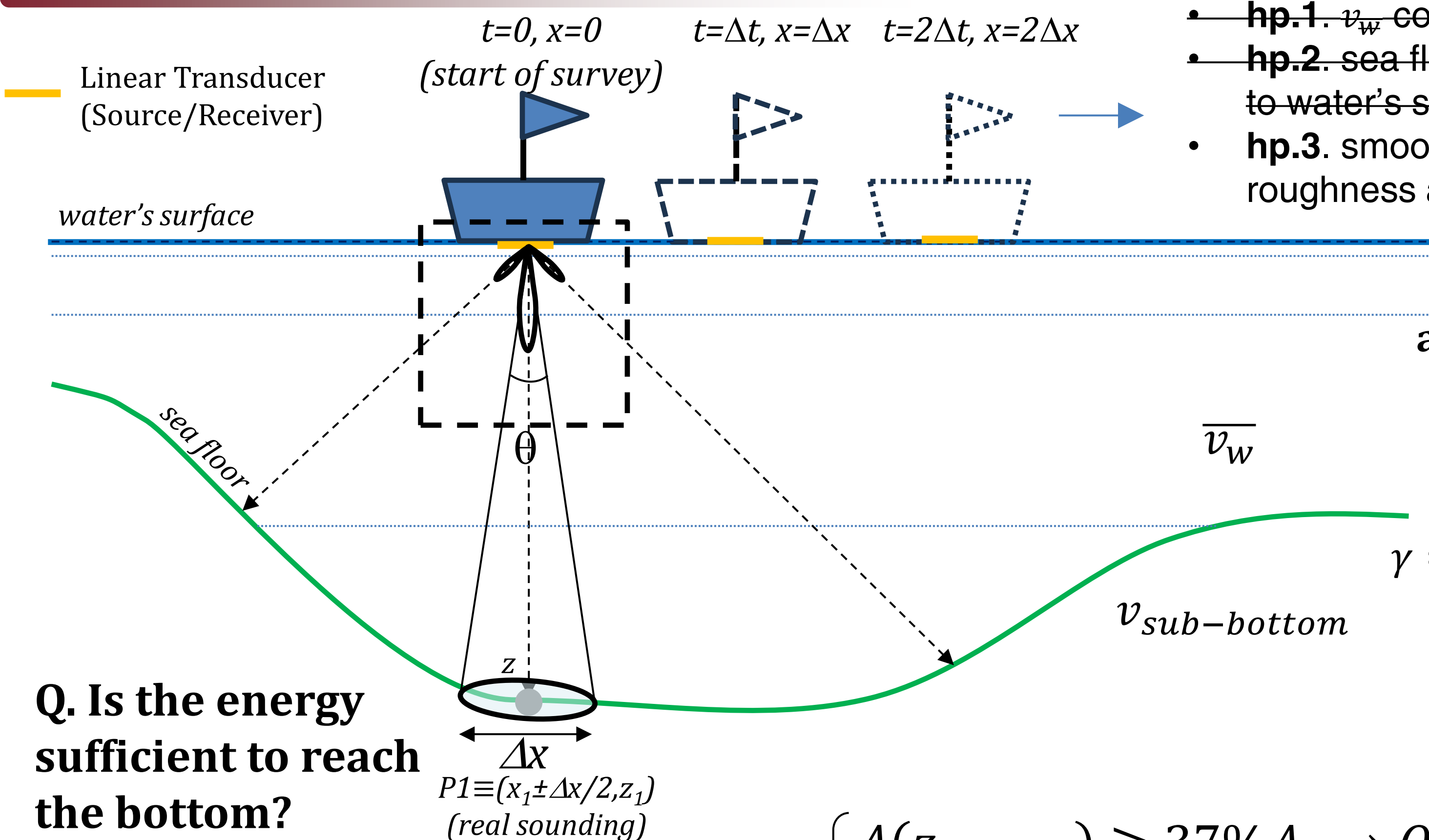
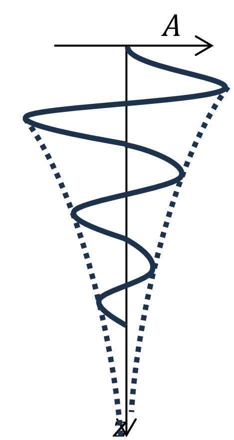



**We have intrinsic attenuation with depth (exponential)**

$$A(z) = \exp(-\gamma z)$$

$\gamma$ = attenution coefficient

$$\gamma \propto f^2$$




**Q. Is the energy sufficient to reach the bottom?**

**A. Yes, if the signal amplitude at the bottom is at least equal to the 37% of the original amplitude**

$$\text{DOI} \begin{cases} A(z_{bottom}) \geq 37\% A_0 \rightarrow OK \\ A(z_{bottom}) < 37\% A_0 \rightarrow NO \end{cases}$$

$$A_{min} = 1/e \cong 0.37$$

$$e = \exp(1) = \text{Euler's number}$$

# SONAR methods – Basic principles

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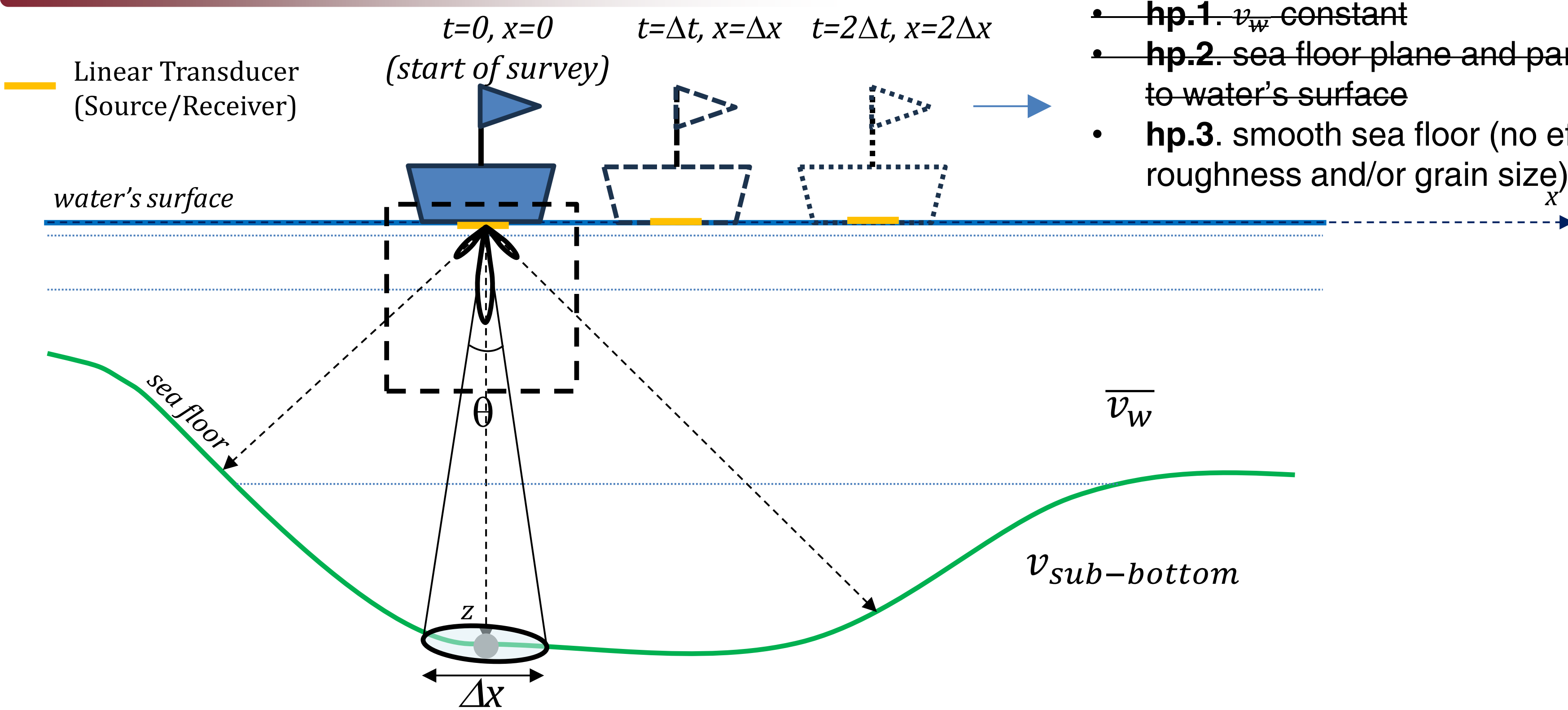



**RESOLUTION**

$$\begin{cases} \boldsymbol{\Delta x \leq d_{object} \rightarrow OK} \\ \Delta x > d_{object} \rightarrow NO \end{cases}$$

**DOI**

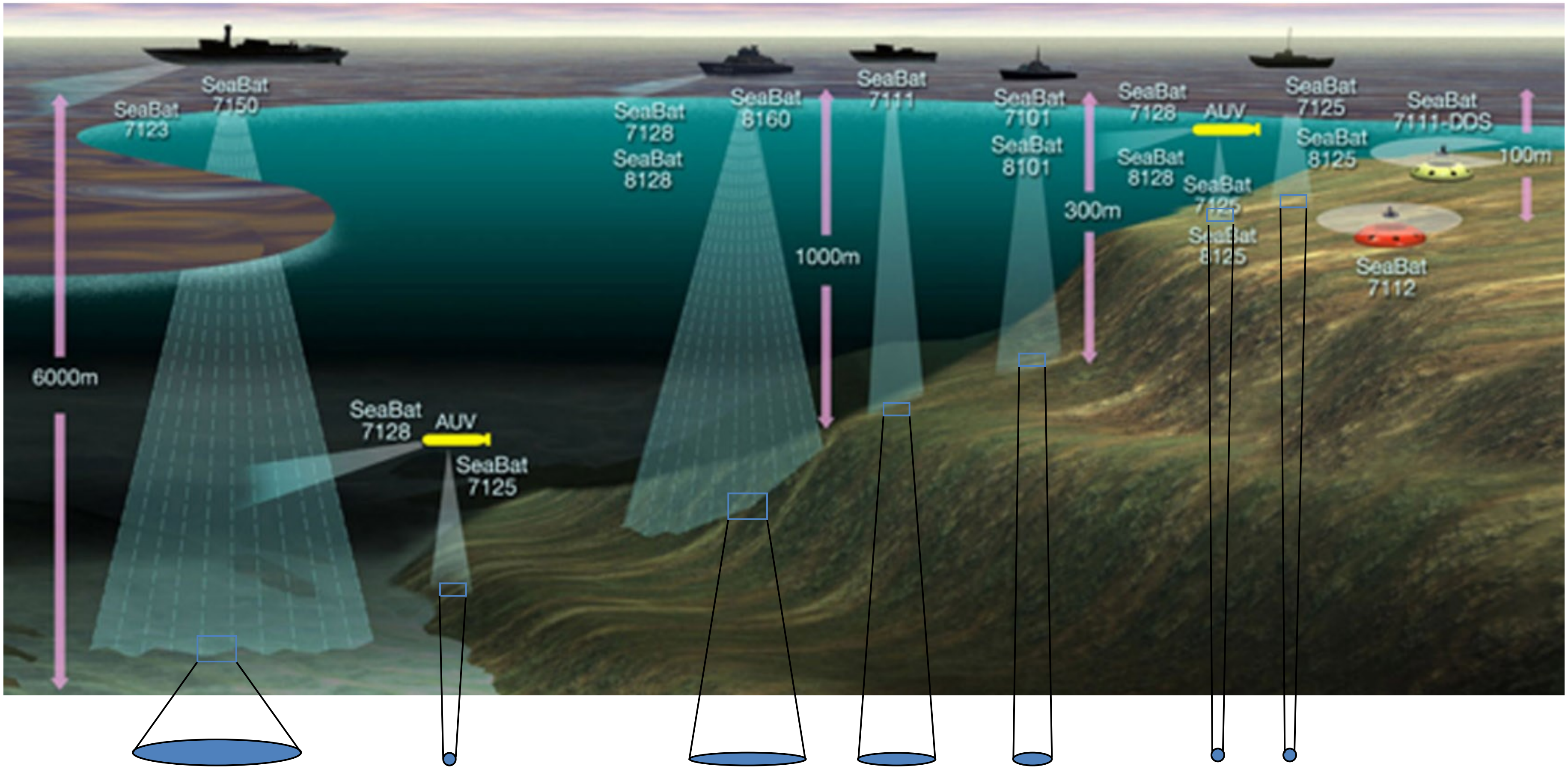
$$\begin{cases} \boldsymbol{A(z_{bottom}) \geq 37\% A_0 \rightarrow OK} \\ A(z_{bottom}) < 37\% A_0 \rightarrow NO \end{cases}$$

Only if **both** conditions are satisfied a transducer is effective for the target detection

# SONAR methods - Resolution

## Comparison between different frequencies and vessels

12- 24 kHz 50 kHz 100 kHz 200 kHz 400 kHz



# SONAR methods - Resolution

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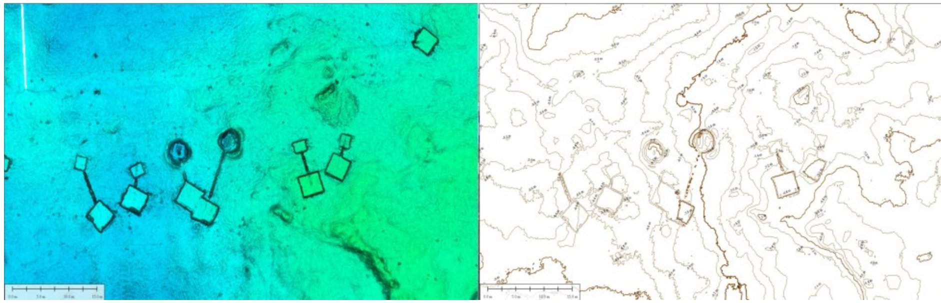
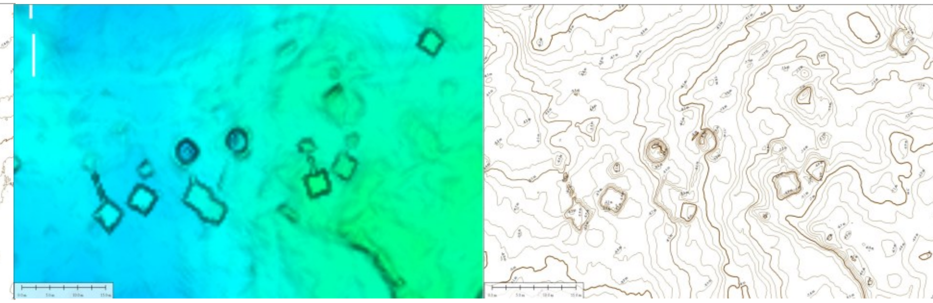
## Example of comparison between different resolutions

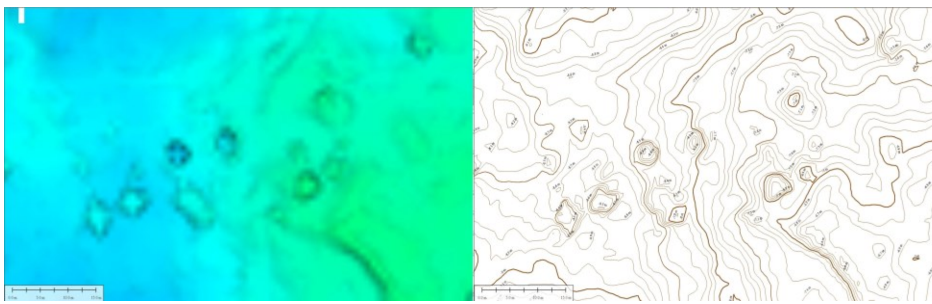
Resolution : 0.1 m



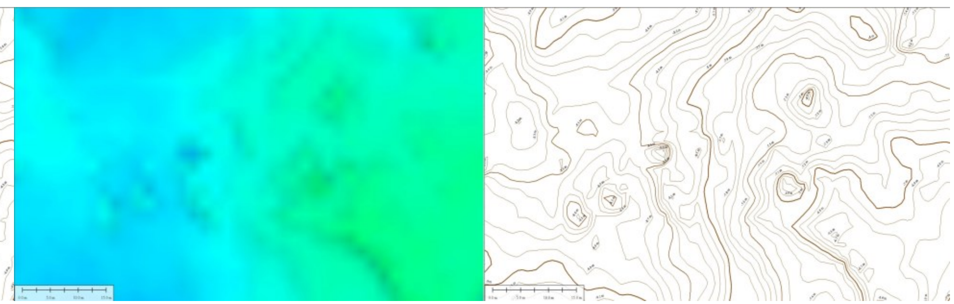
Resolution: 0.5 m



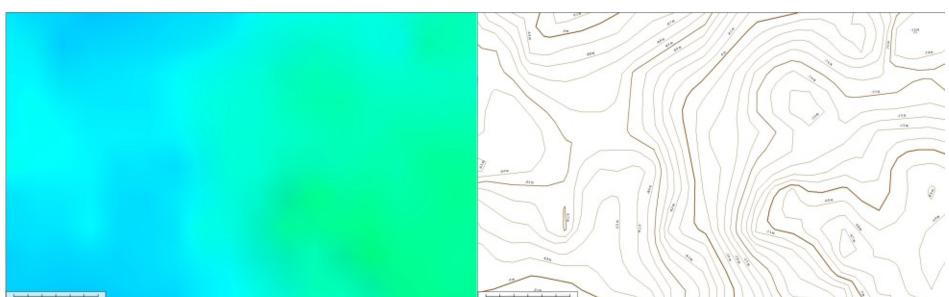
Resolution : 1 m



Resolution : 2 m



Resolution : 5 m



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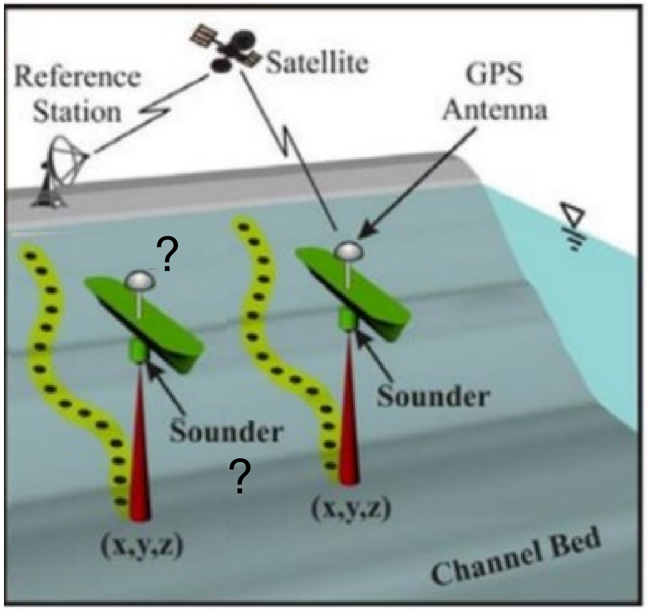
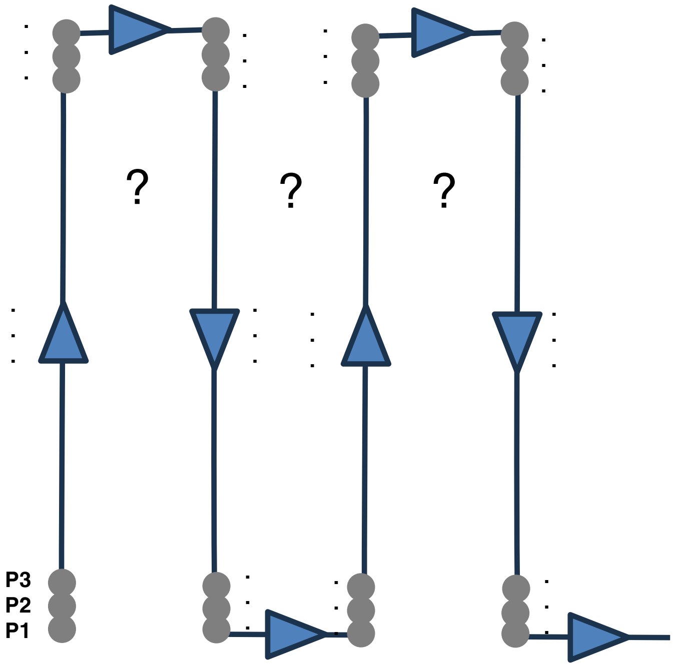
**Single-Beam (SBES)**

**3D view**




**Plan view**

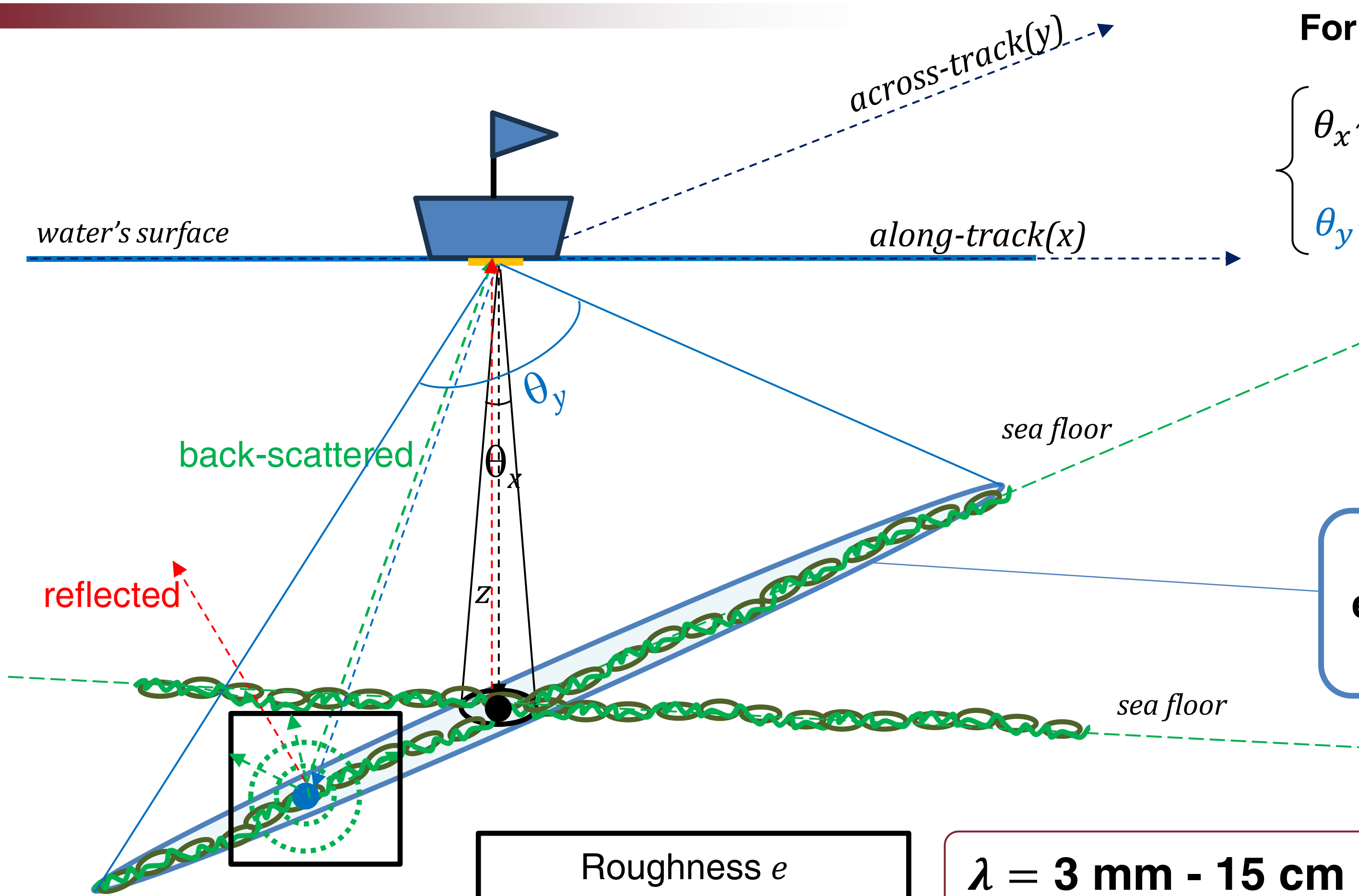



**SBES method has a poor lateral coverage (across-track)**

**Q. How the 100% lateral coverage can be accomplished?**

# SONAR methods – From Single- to Multi-Beam





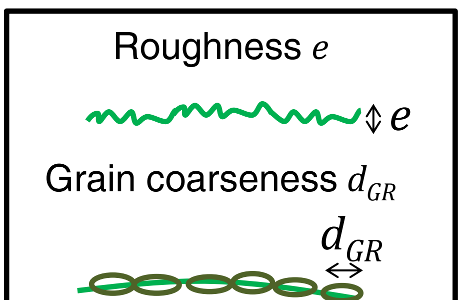

**For a linear transducer**

$$\begin{cases} \theta_x \sim 50 \dfrac{\lambda}{L_x} \\ \theta_y \sim 50 \dfrac{\lambda}{L_y} \end{cases}$$

Ex.1
$L_x = 1\ \text{m}$
$L_y = 1\ \text{cm}$
$\lambda = 3\ \text{cm}$

$$\begin{cases} \theta_x \sim 50 \dfrac{0.03}{1} = 1.5° \\ \theta_y \sim 50 \dfrac{0.03}{0.01} = 150° \end{cases}$$

**A linear transducer ensonifies also a wide angle laterally (y-dir)**




$\lambda = $ **3 mm - 15 cm**

If $\lambda \sim e$

and/or $\lambda \sim d_{GR}$

**Scattering**
Signals coming laterally can be back-scattered to the transducer

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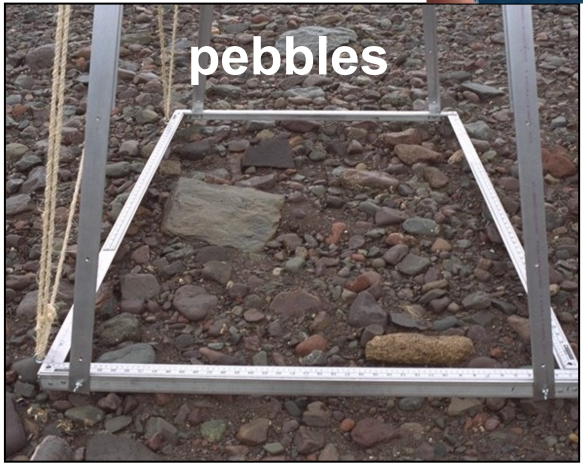
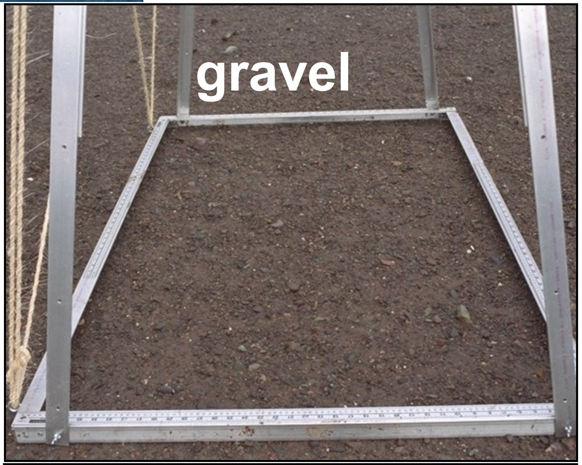
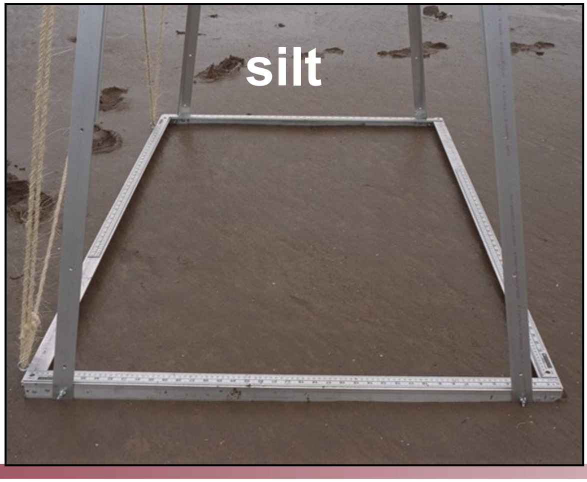
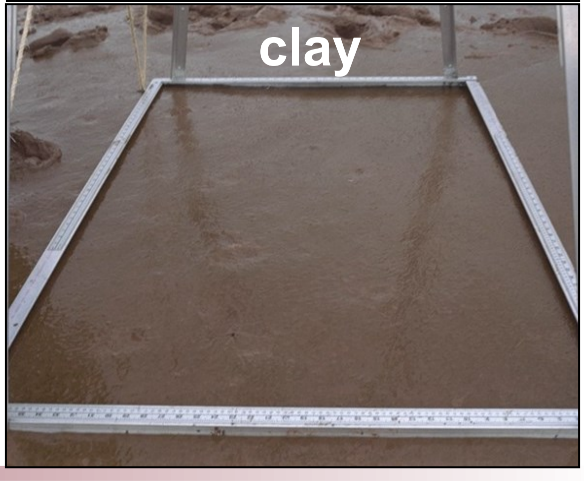
**Roughness and coarseness**
**Direct inspections**



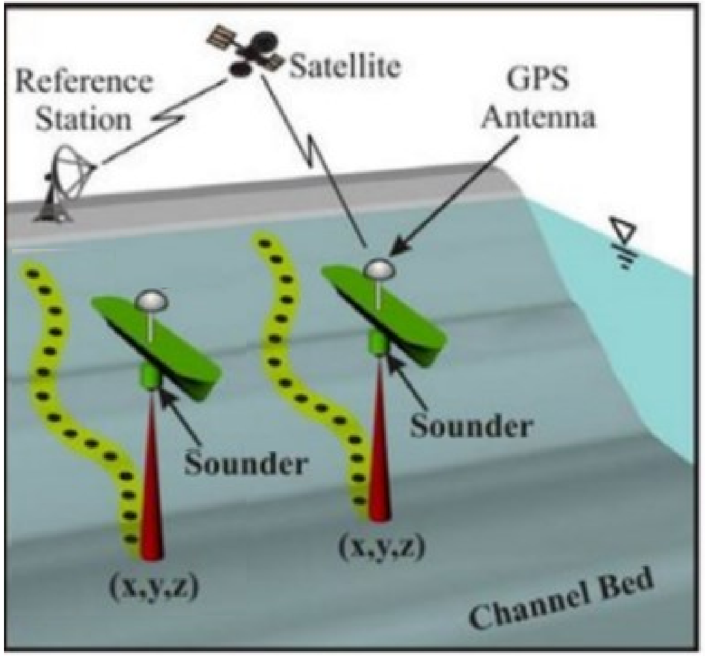


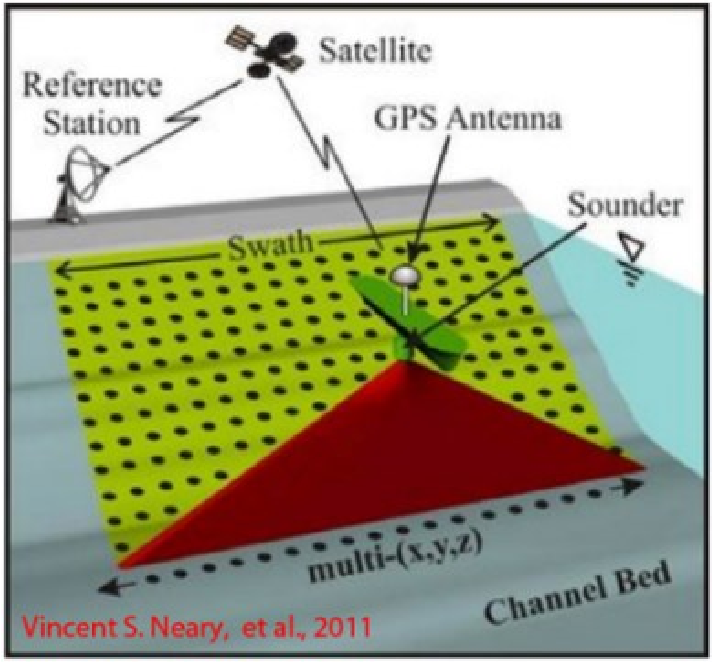
**Q. Can the back-scattered echoes coming from lateral directions (y-dir) be detected?**

If yes, when moving I can achieve a good coverage also for lateral zones…

**Single-Beam (SBES)**



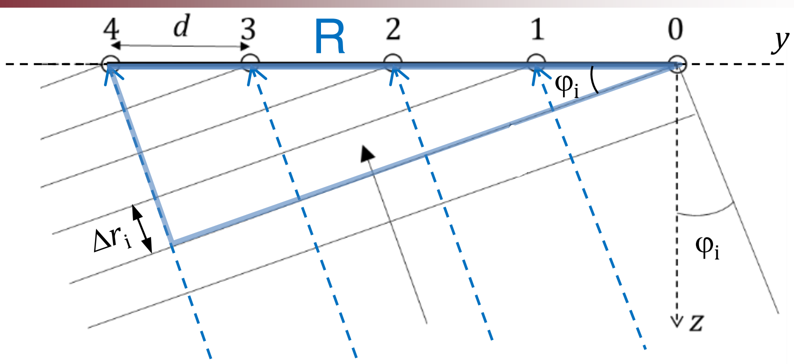

**Multi-Beam (MBES)**

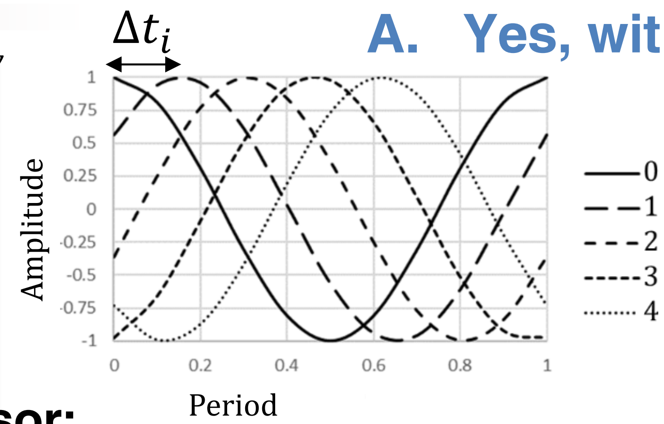


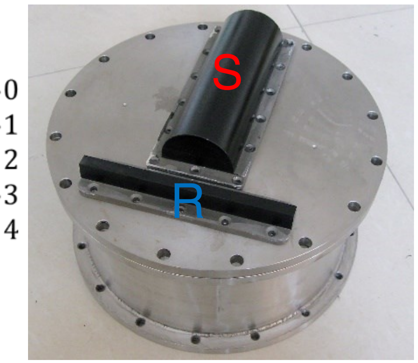
# SONAR methods



## A. Yes, with a Mills' cross



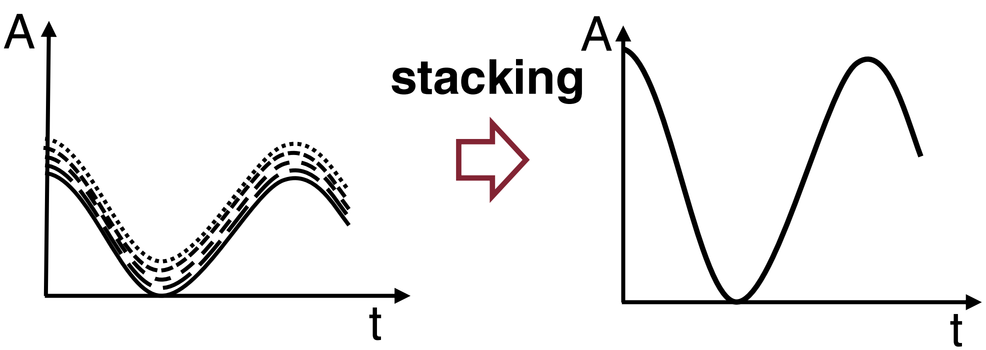



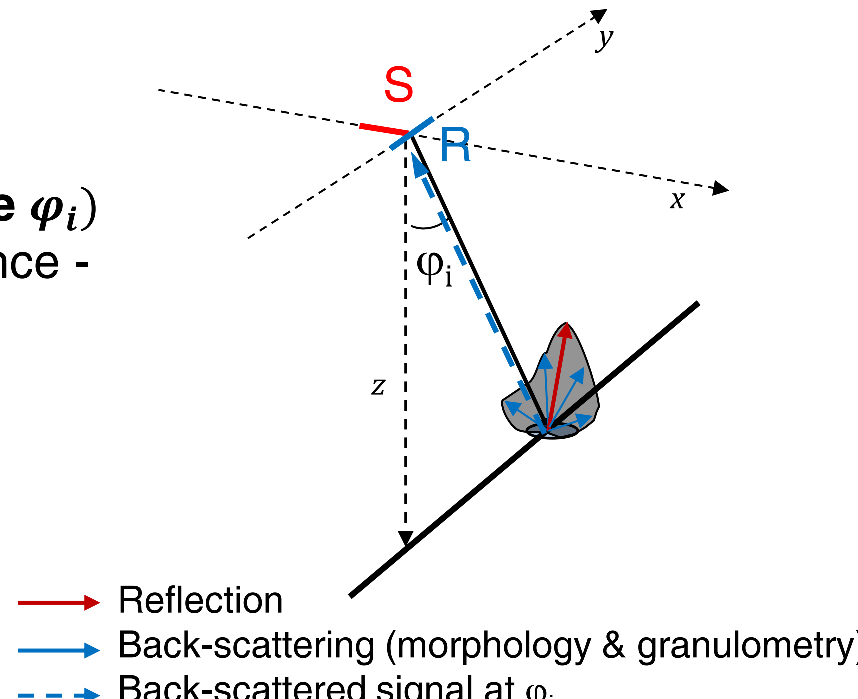




**Delay time for *i*-*th* angle and *n*-*th* sensor:**

$$\Delta t_{n,i} = n\Delta t_i = \frac{n\Delta r_i}{\overline{v_w}} = \frac{nd\sin\varphi_i}{\overline{v_w}}$$

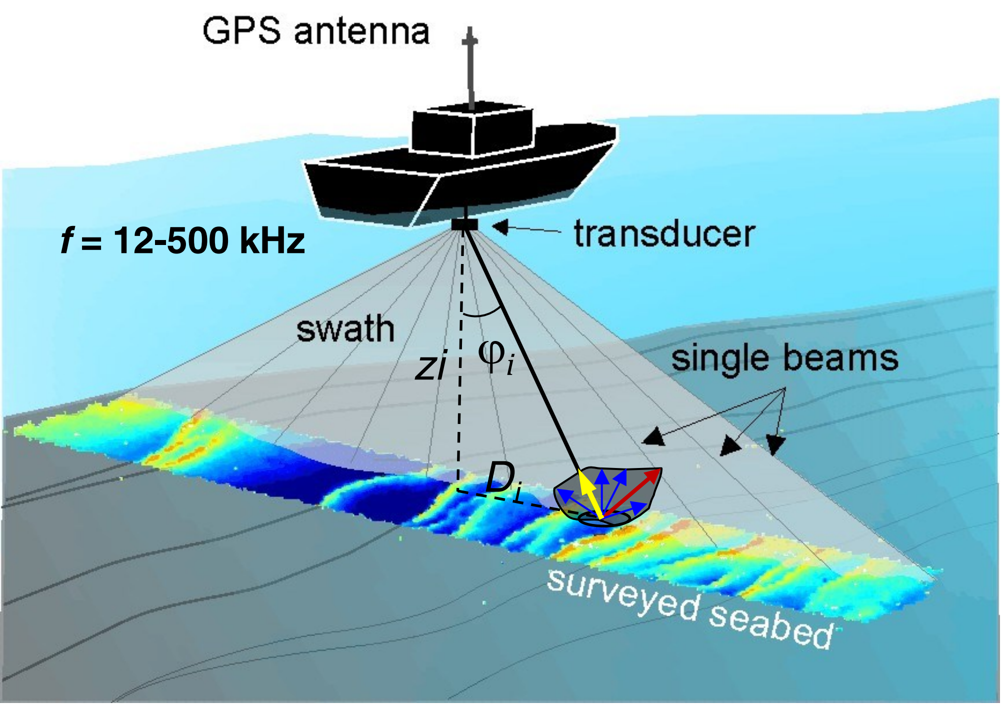
**After applying the delay time (for each angle $\varphi_i$)**
**BEAMFORMING:** 100% constructive interference - one stacked trace from each beam angle $\varphi_i$



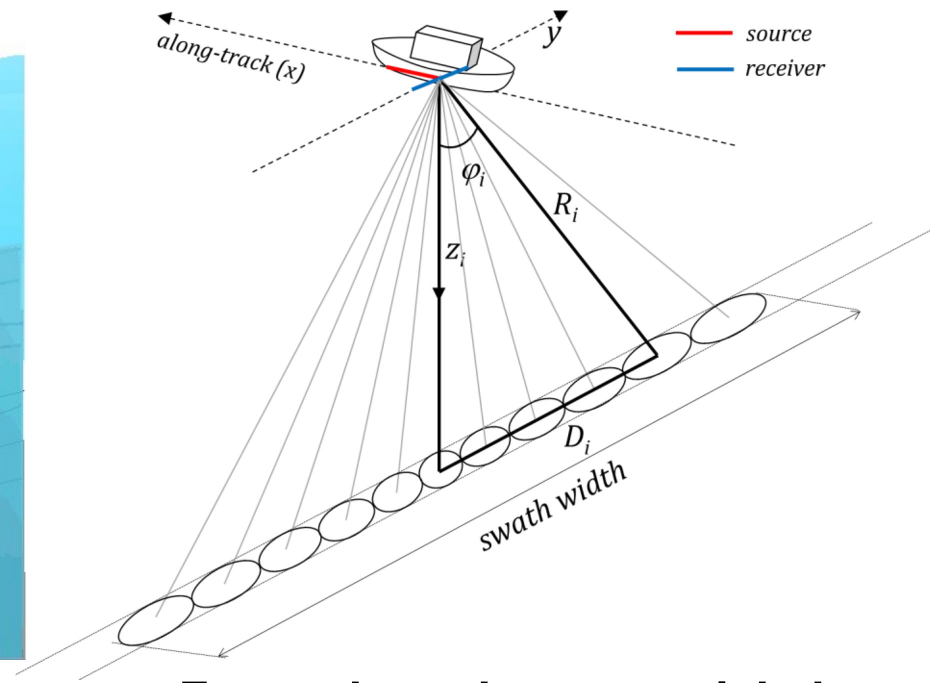



# SONAR methods






Reflection
Back-scattering (morphology & granulometry)
Back-scattered signal at φ




**For each angle $\varphi_i$, we pick the Time Of Arrival (TOA)**

$$R_i = \frac{\overline{v_w}\,TOA_i}{2}$$
$$D_i = R_i \sin\varphi_i$$
$$z_i = R_i \cos\varphi_i$$

**Slant range and its projections**

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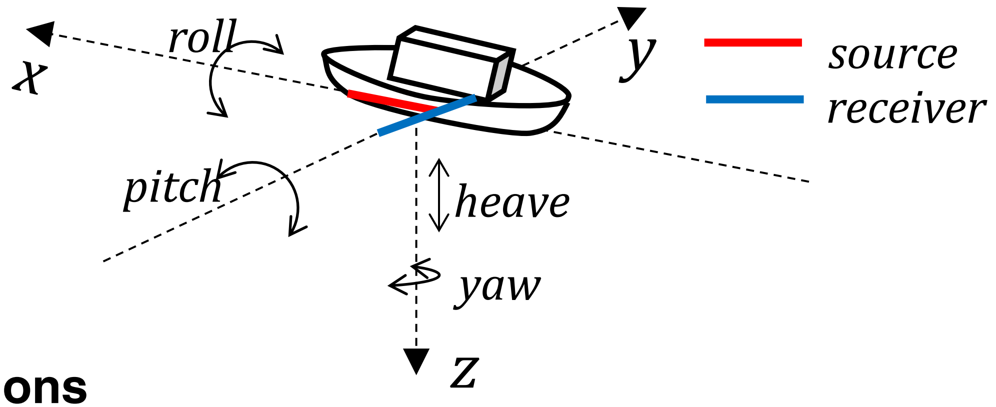
## Then, *D* and *z* have to be positioned and corrections are needed

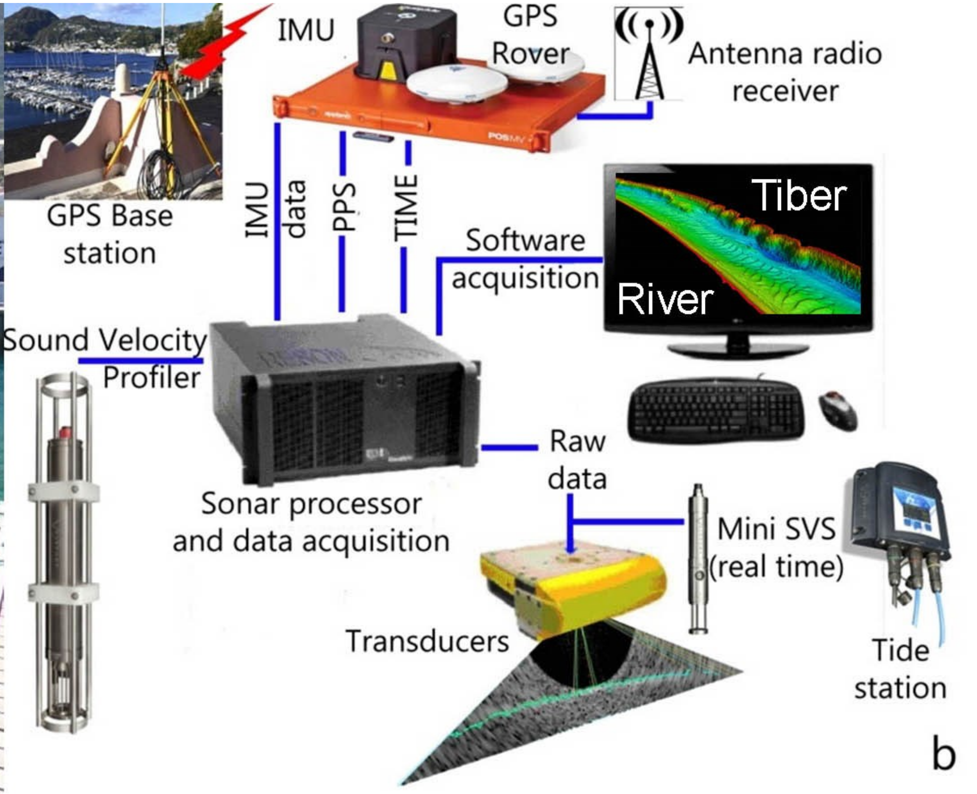



**Positioning and corrections**

1. positioning LAT/LONG/HEIGTH via GNSS system with differential correction (e.g., RTK, DGPS)
2. motion of the ship (roll, pitch and heave) through an inertial sensor (IMU)
3. orientation (yaw) by a gyrocompass
4. tide correction (tide station)
5. direct measurement of the ultra-shallow water velocity (continuous) and of the whole velocity profile $v_w(z)$ (at some stations)

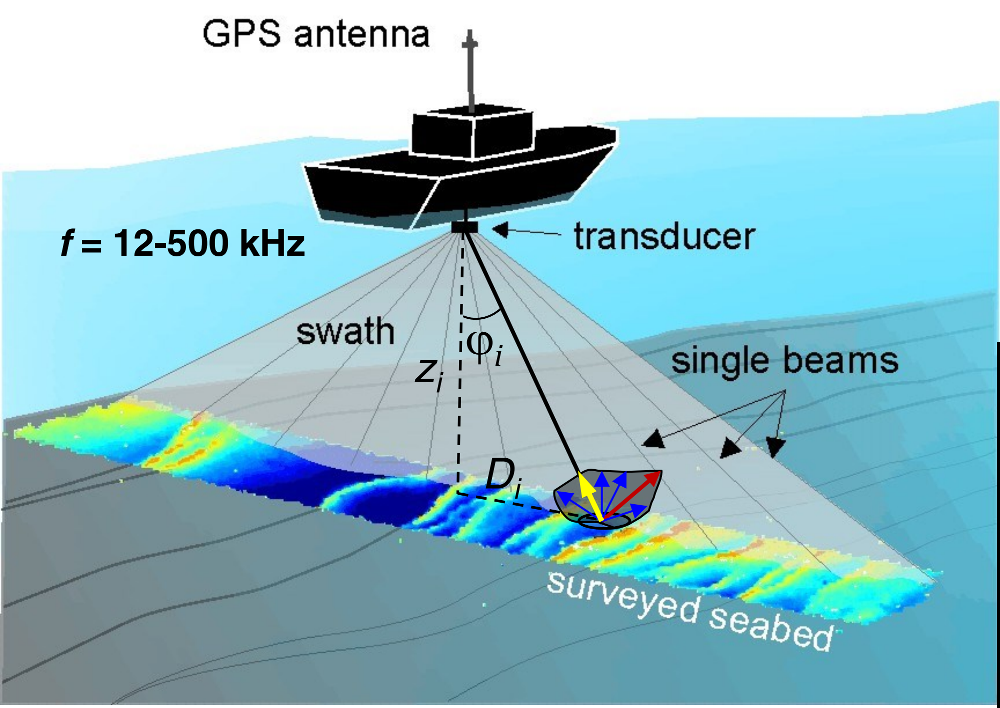
# SONAR methods - Instruments

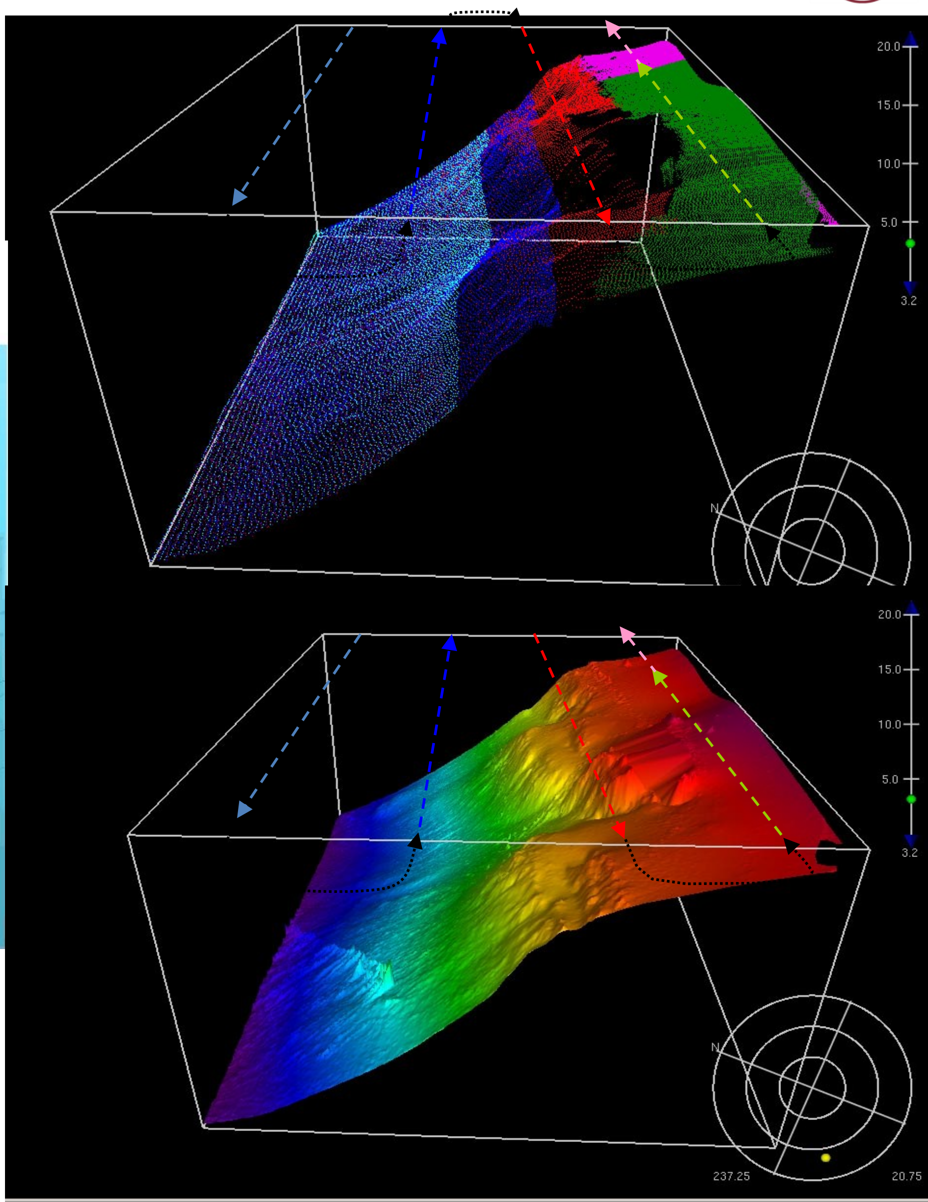


# SONAR methods





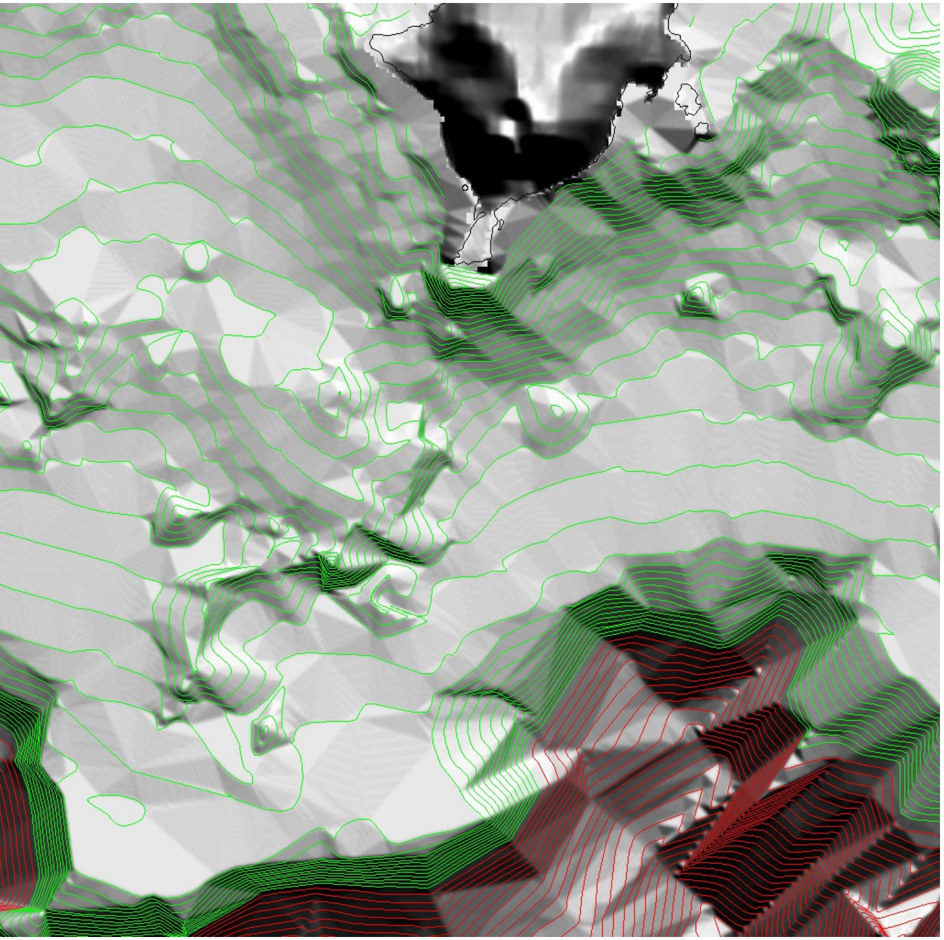



→ Reflection
→ Back-scattering
→ Back-scattered signal at φ

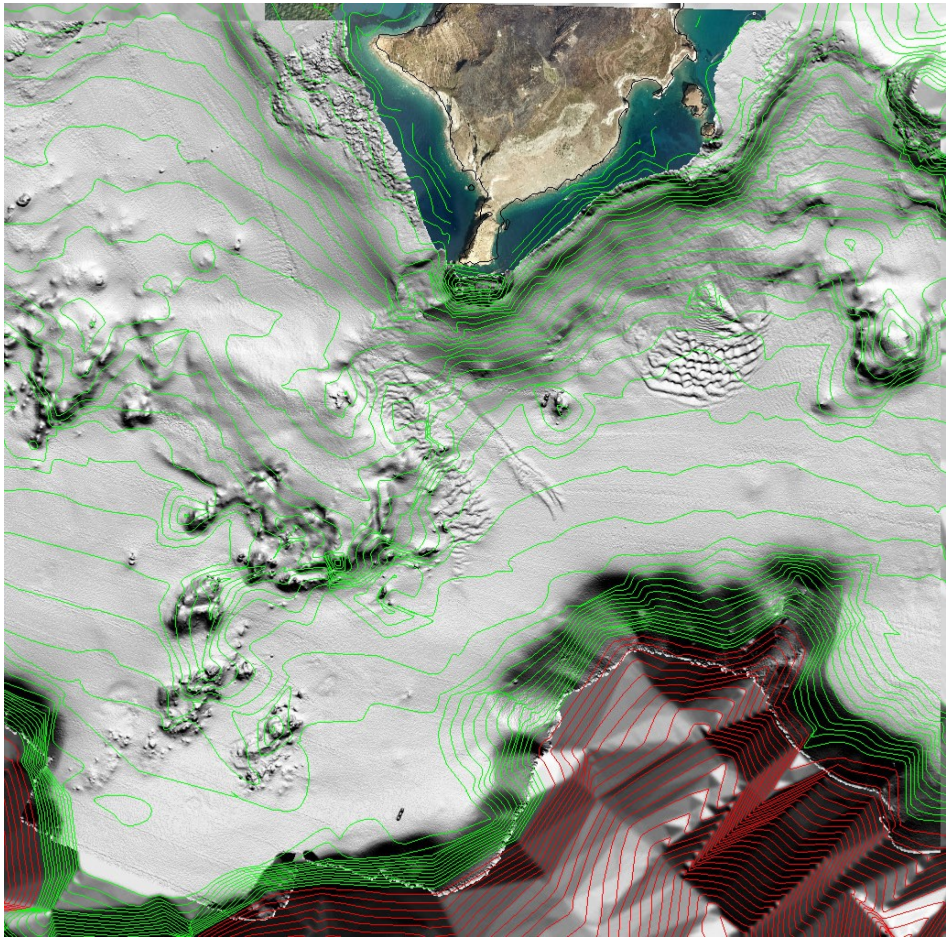
# SONAR methods – SBES vs. MBES



**SBES**



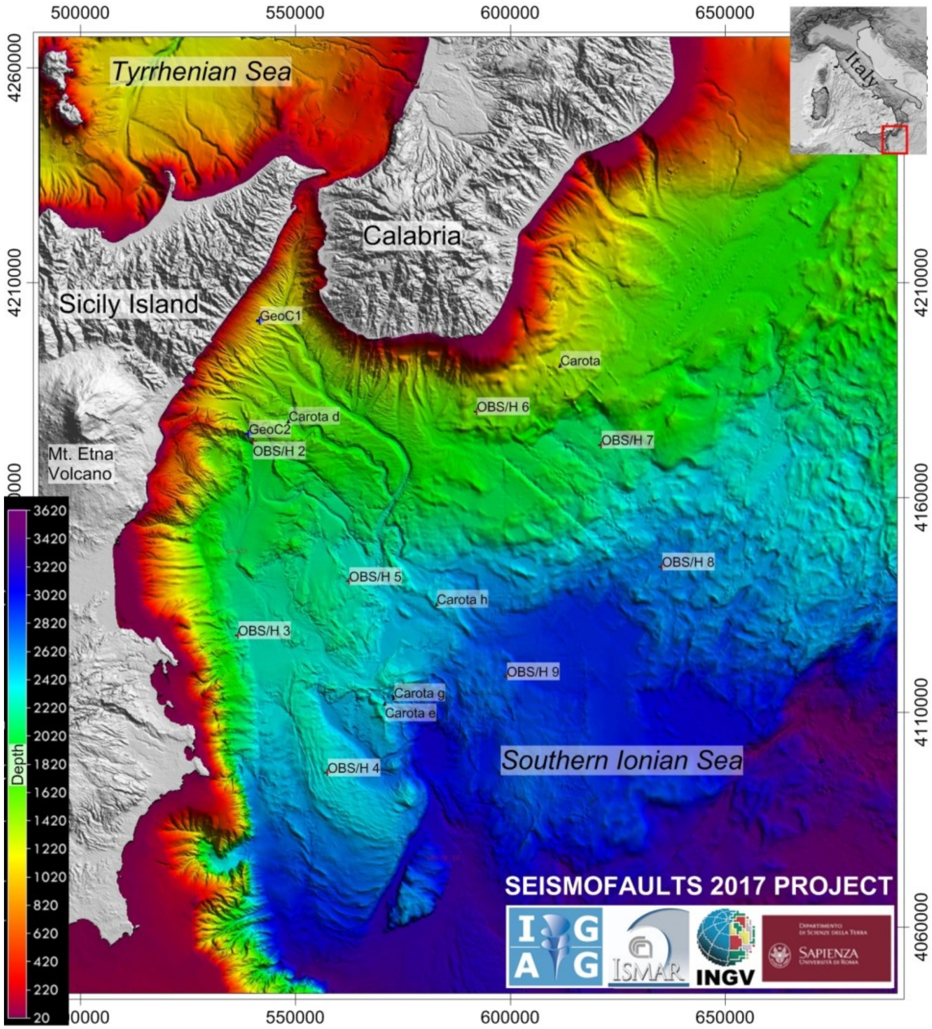
**MBES**



# SONAR methods - Applications

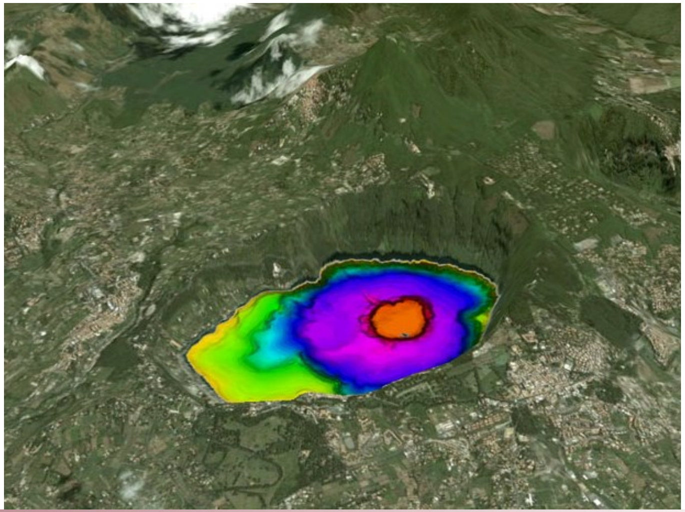


## Sea




## River

## Lake

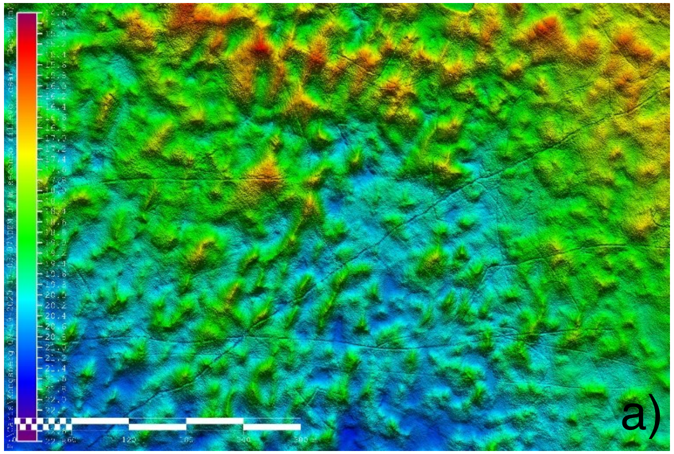


# SONAR methods – Applications

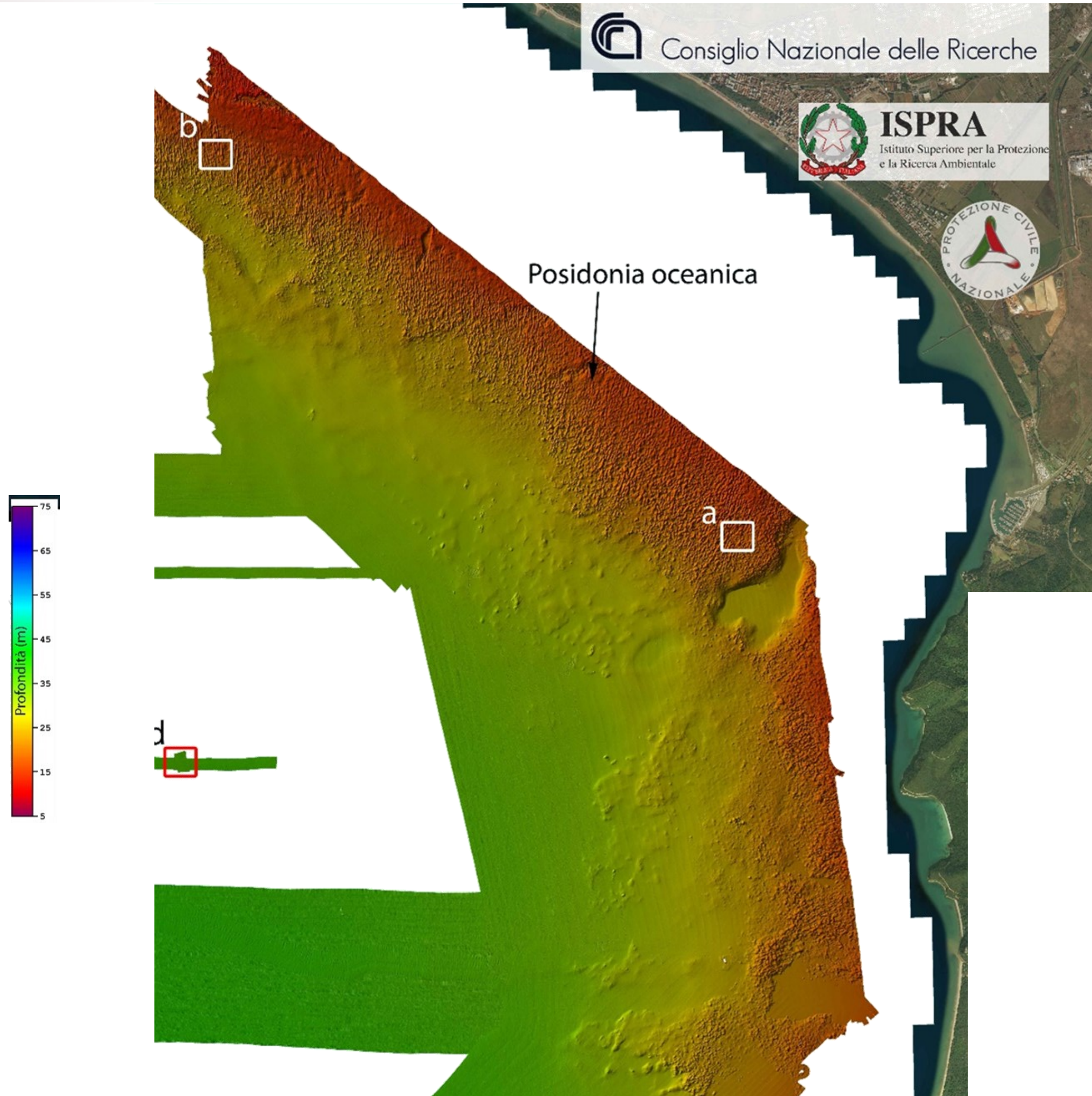


- **Environmental engineering**
  - ✓ Mapping and monitoring marine habitat (i.e. Posidonia Oceanica - *Neptune grass*)
  - ✓ Mapping and monitoring underwater waste disposal
  - ✓ Assisting simulation of sea level rise for climate change studies
  - ✓ Mapping and monitoring pollutant (solids) or suspensions or fluid emissions
  - ✓ Mapping and monitoring saline intrusion
- **Civil engineering**
  - ✓ Mapping and monitoring utilities (cables, pipelines, etc.)
  - ✓ Mapping and monitoring coastal structures and infrastructures (ports, dams, etc.)
- **Geology**
  - ✓ Geomorphology
  - ✓ Mapping and monitoring volcanoes
  - ✓ Mapping and monitoring landslides or tsunami
  - ✓ Mapping and monitoring seabed lithotypes (rock, sand, silt)
- **Cartography**
  - ✓ Bathymetry
  - ✓ Sea maps
- **Archaeology**
  - ✓ Underwater bodies or remains

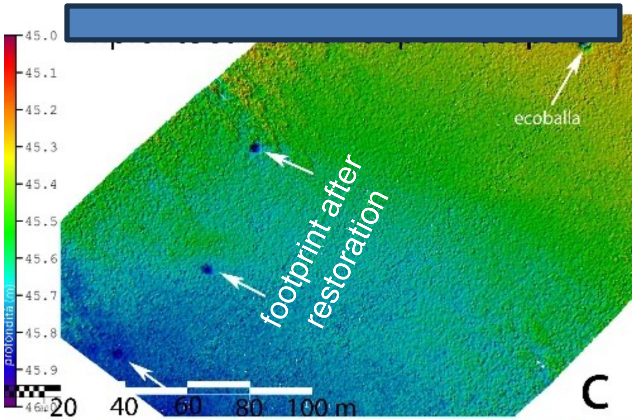
# SONAR methods – Marine habitat (*Posidonia O.*)



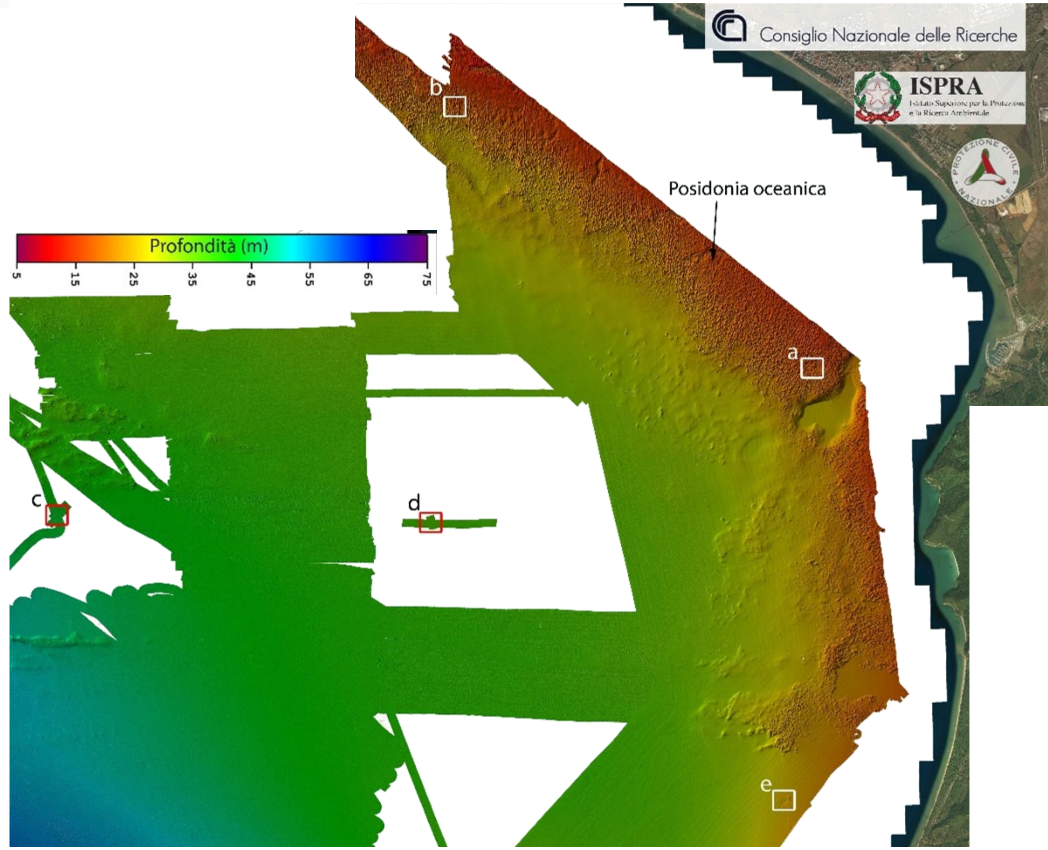




# SONAR methods – Waste disposal






# SONAR methods – Saline intrusion

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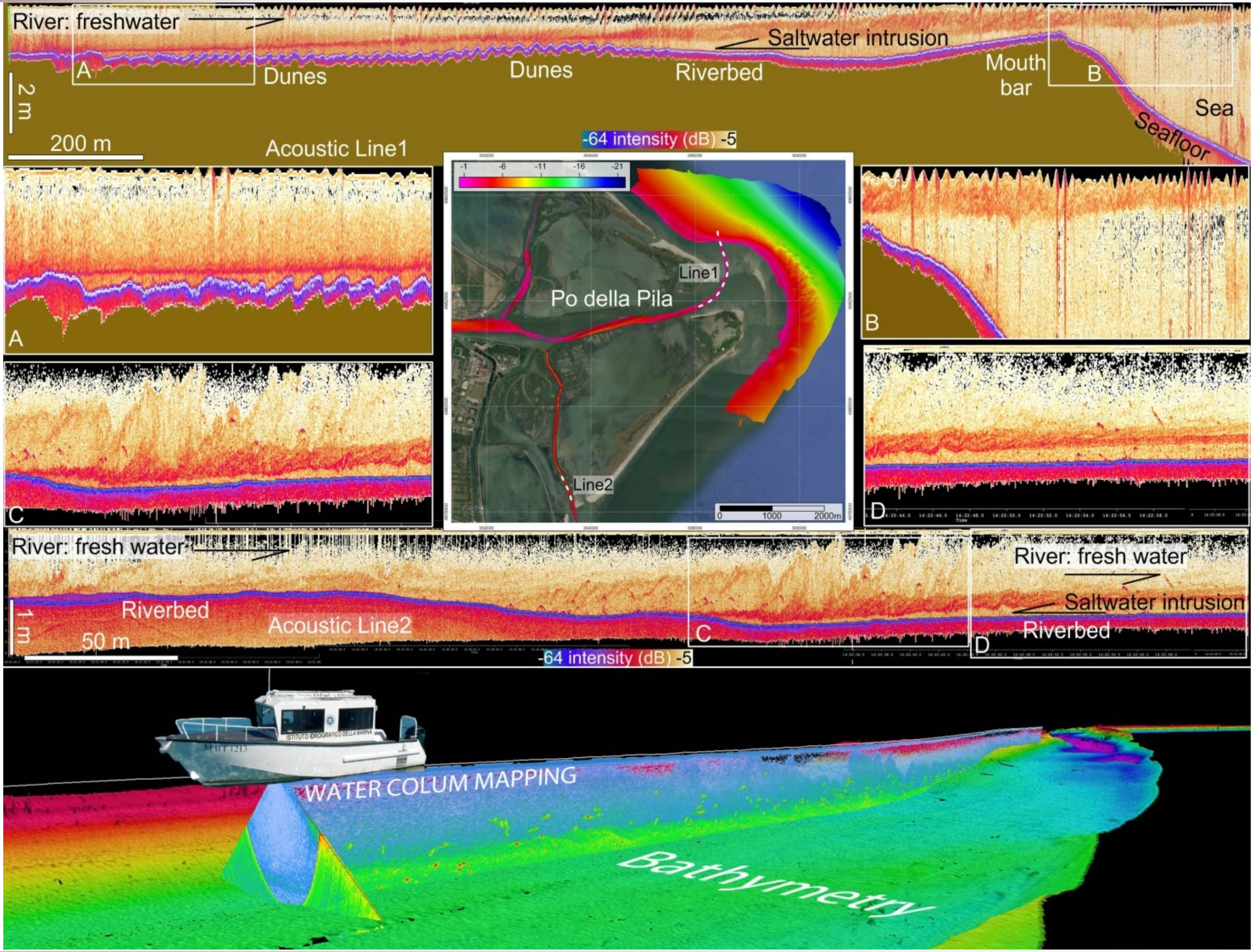
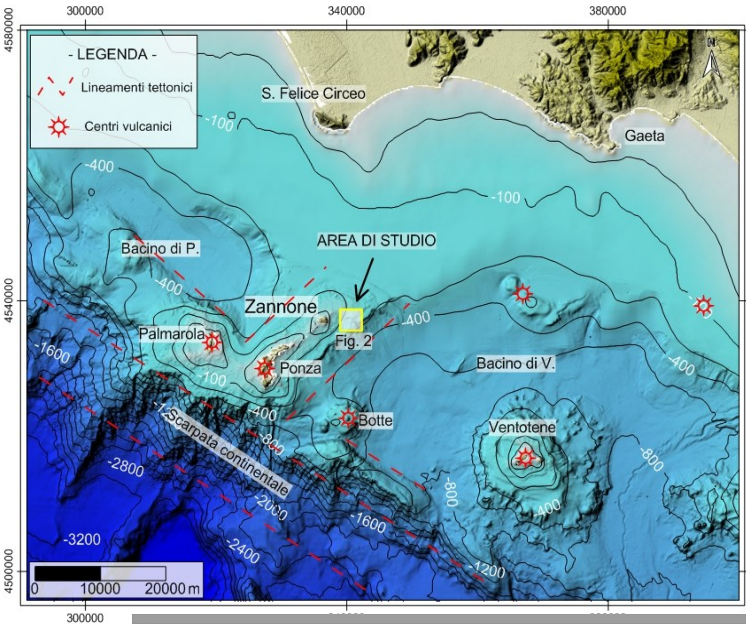
**Water Column Data (WCD) to detect saline intrusion at the Po River mouth**

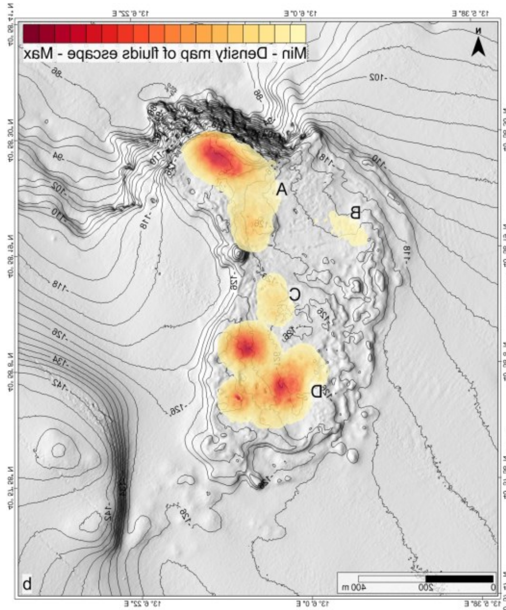


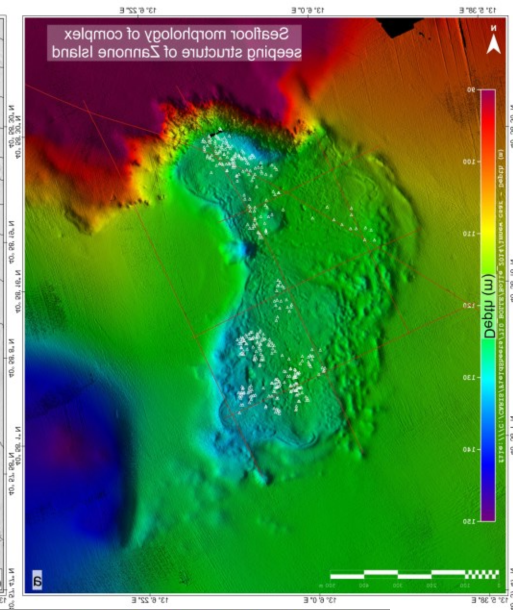
# SONAR methods – Hydrothermal fluids

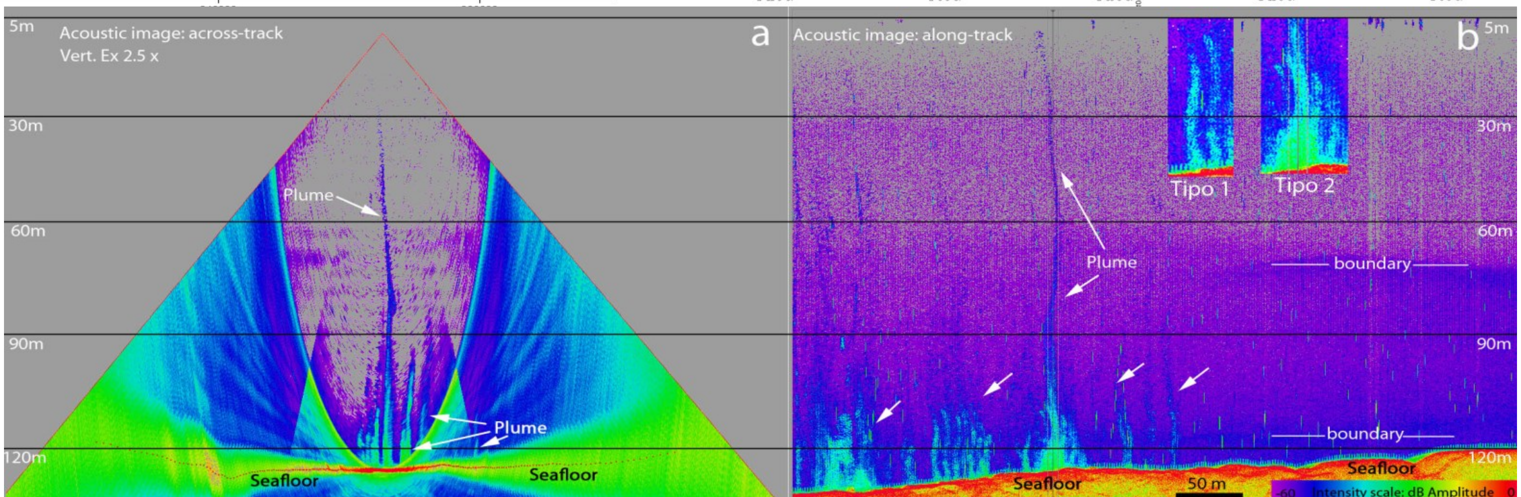


## Upwelling flows of hydrothermal fluids at the Zannone Island



# SONAR methods – Pipelines

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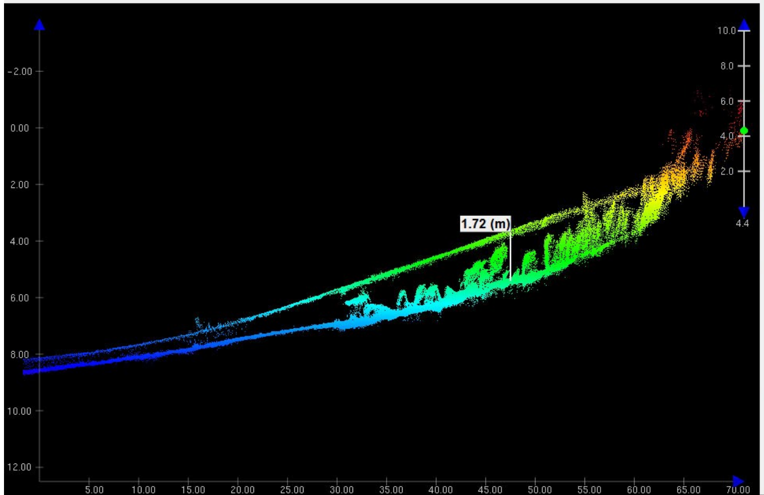
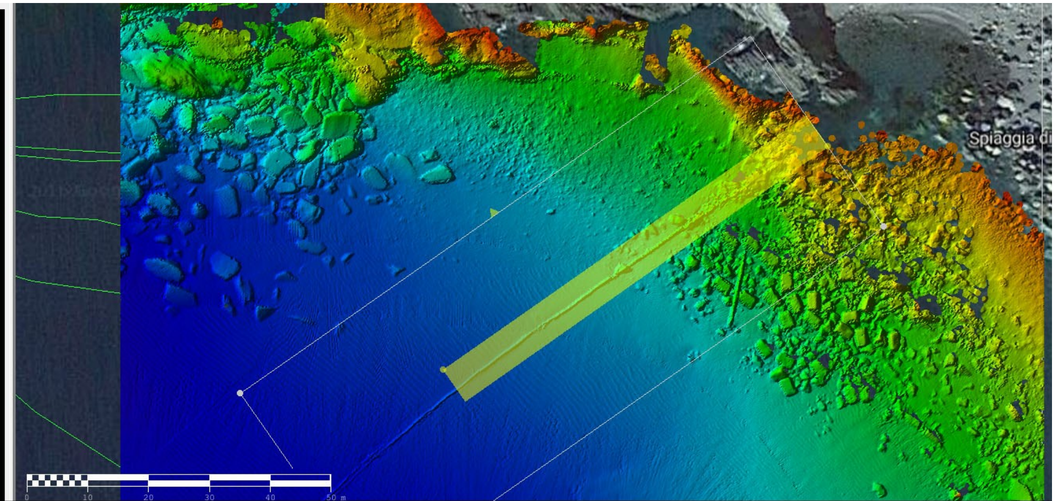
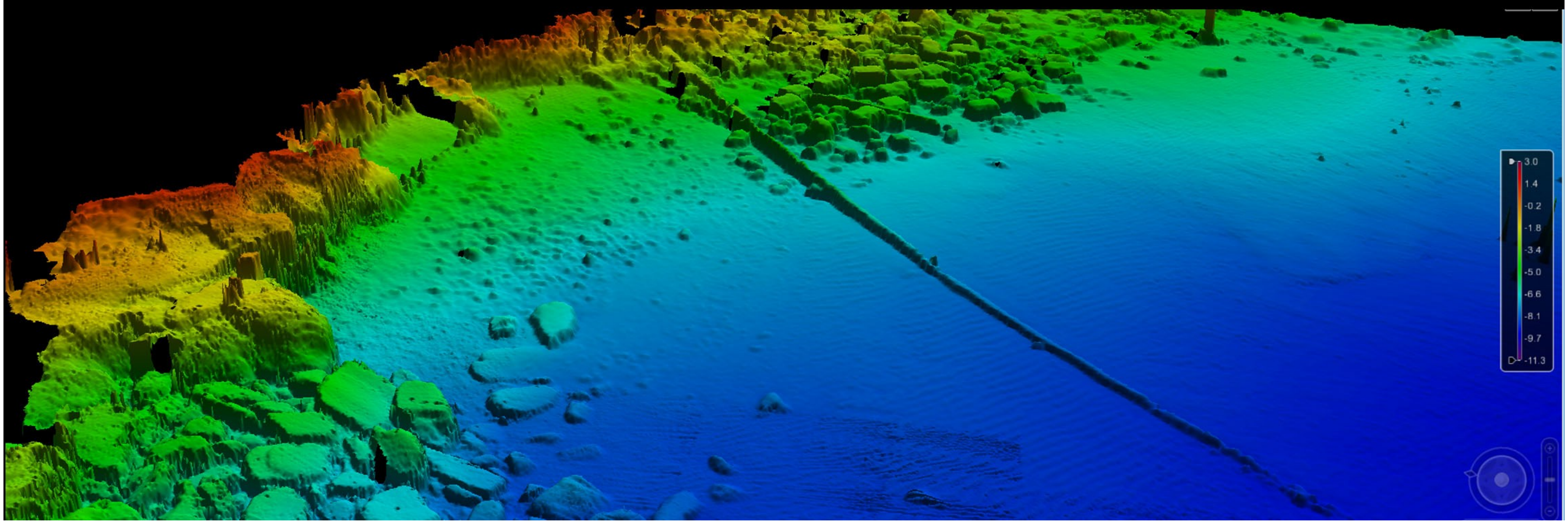
## 2014 Lipari Island

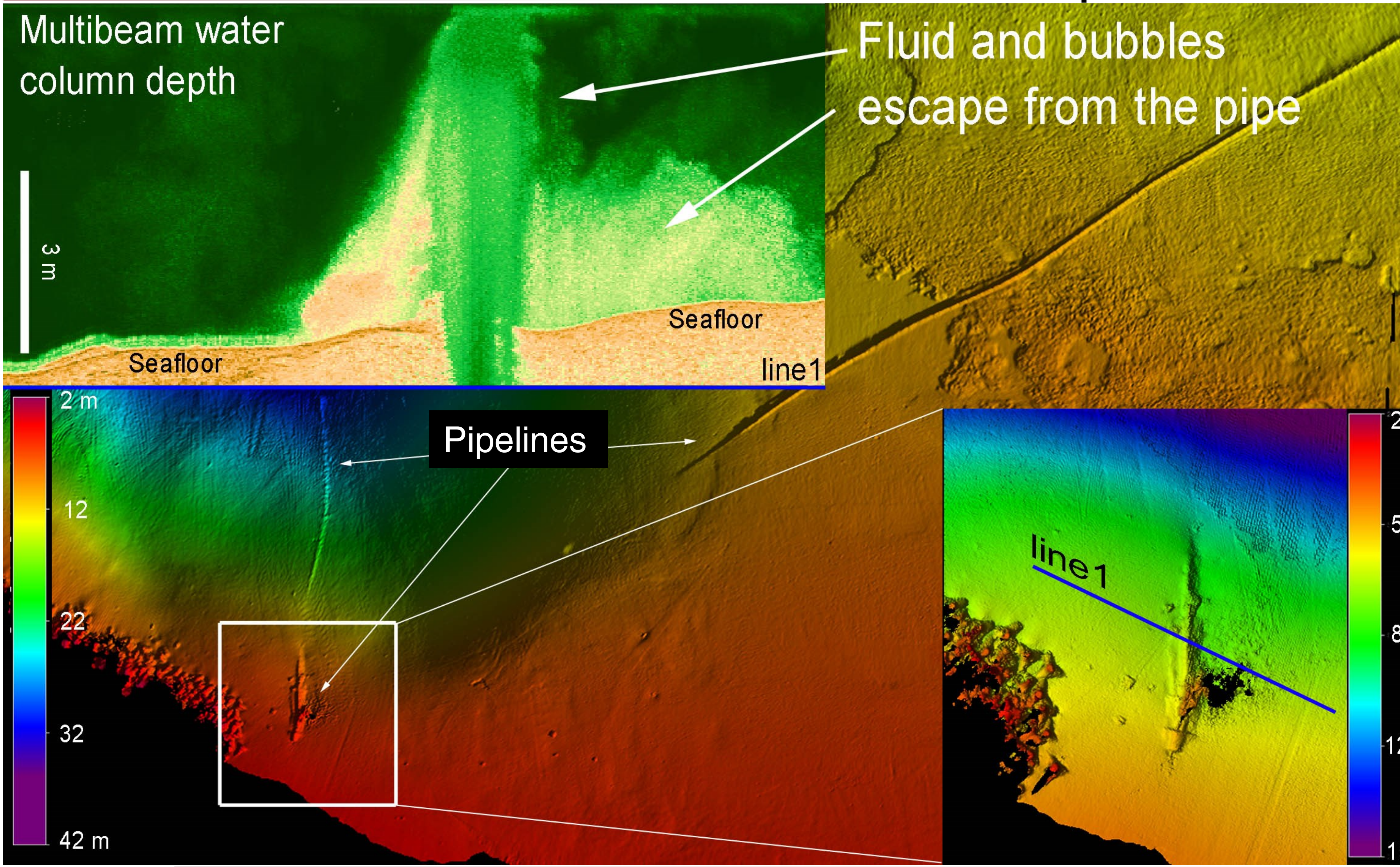


# SONAR methods – Pipelines

2014 Lipari Island



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Sea (**MBES**) - shore (**Drone**) high-resolution data for climate change simulation

**Simulation of sea level rise at a local scale- Marina Lunga Lipari (today)**

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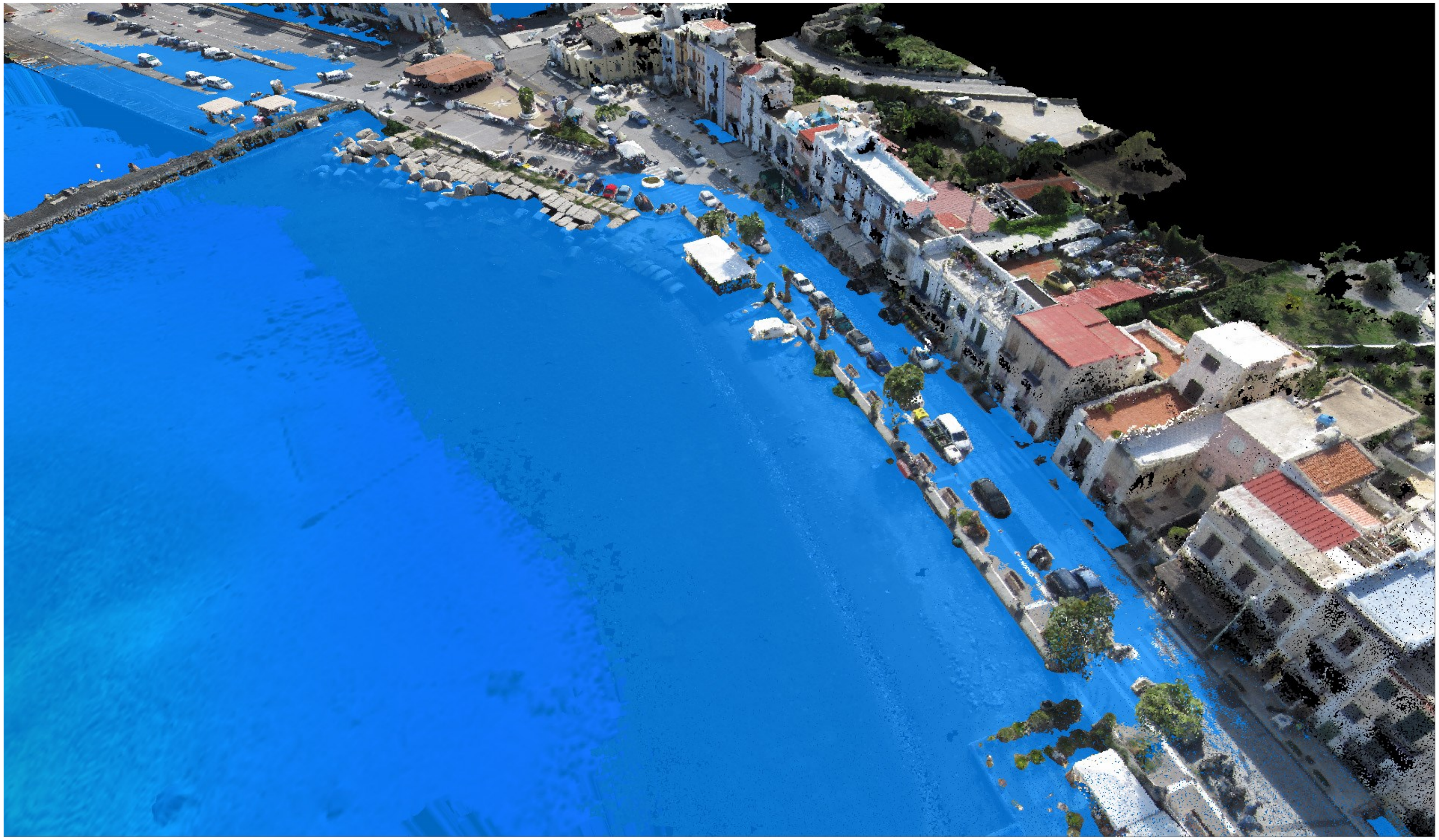
Sea (**MBES**) - shore (**Drone**) high-resolution data for climate change simulation

**Simulation of sea level rise at a local scale - Marina Lunga Lipari (2100)**



# SONAR methods – Submerged strctures

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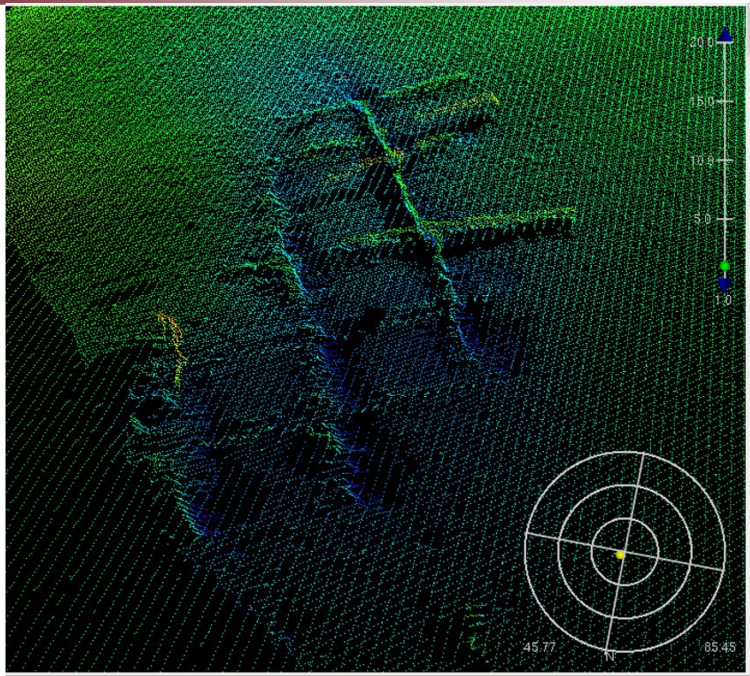
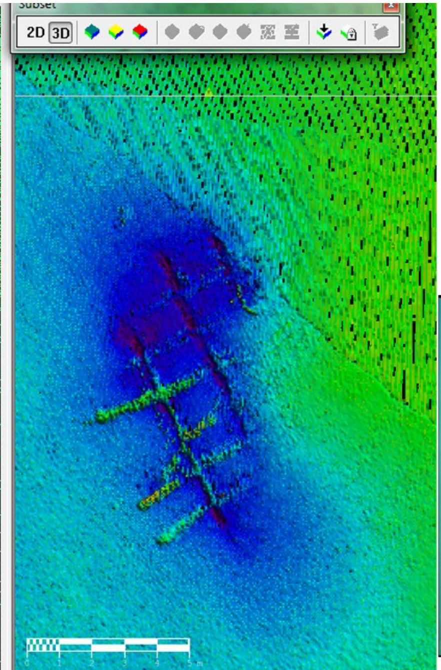
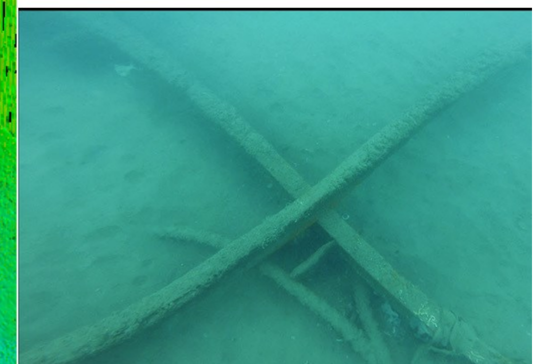
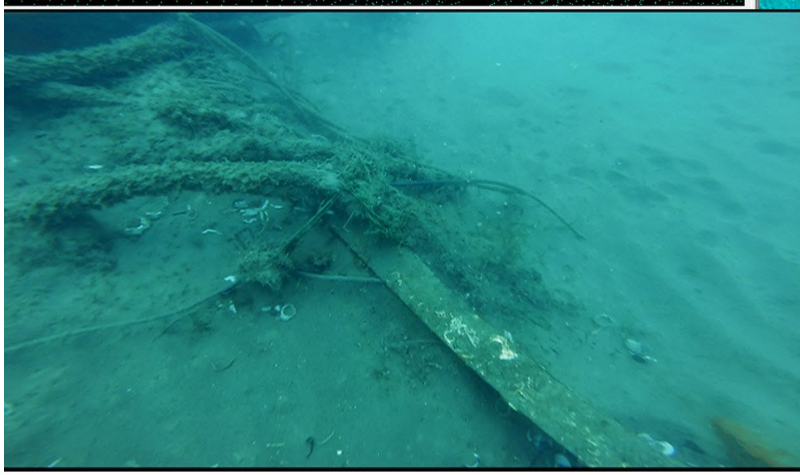
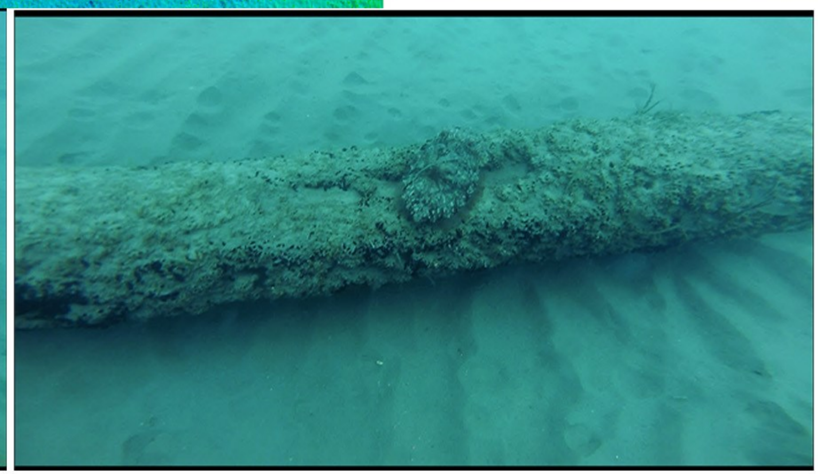


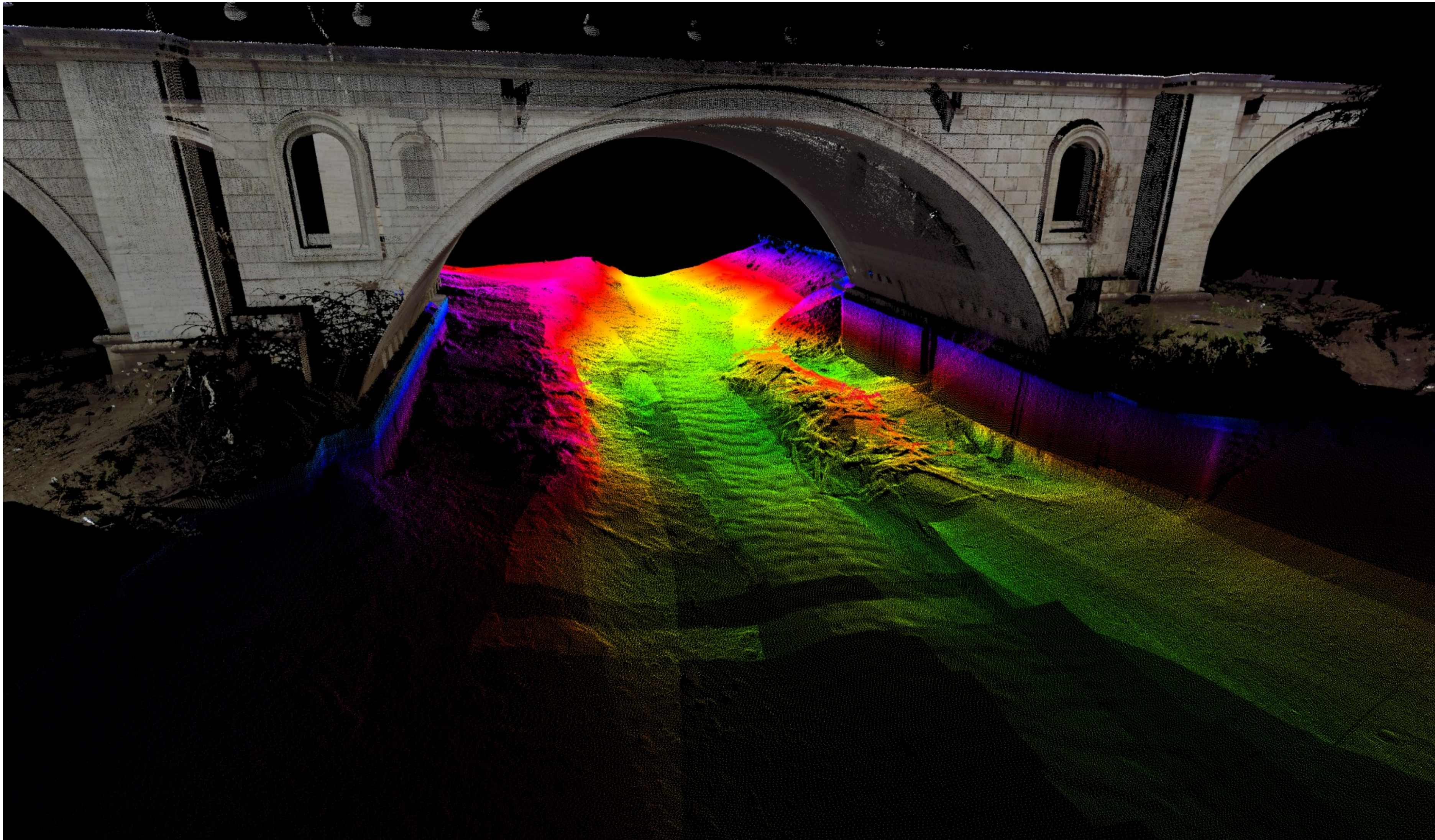







## Tiber River: MBES e Laser Scan data



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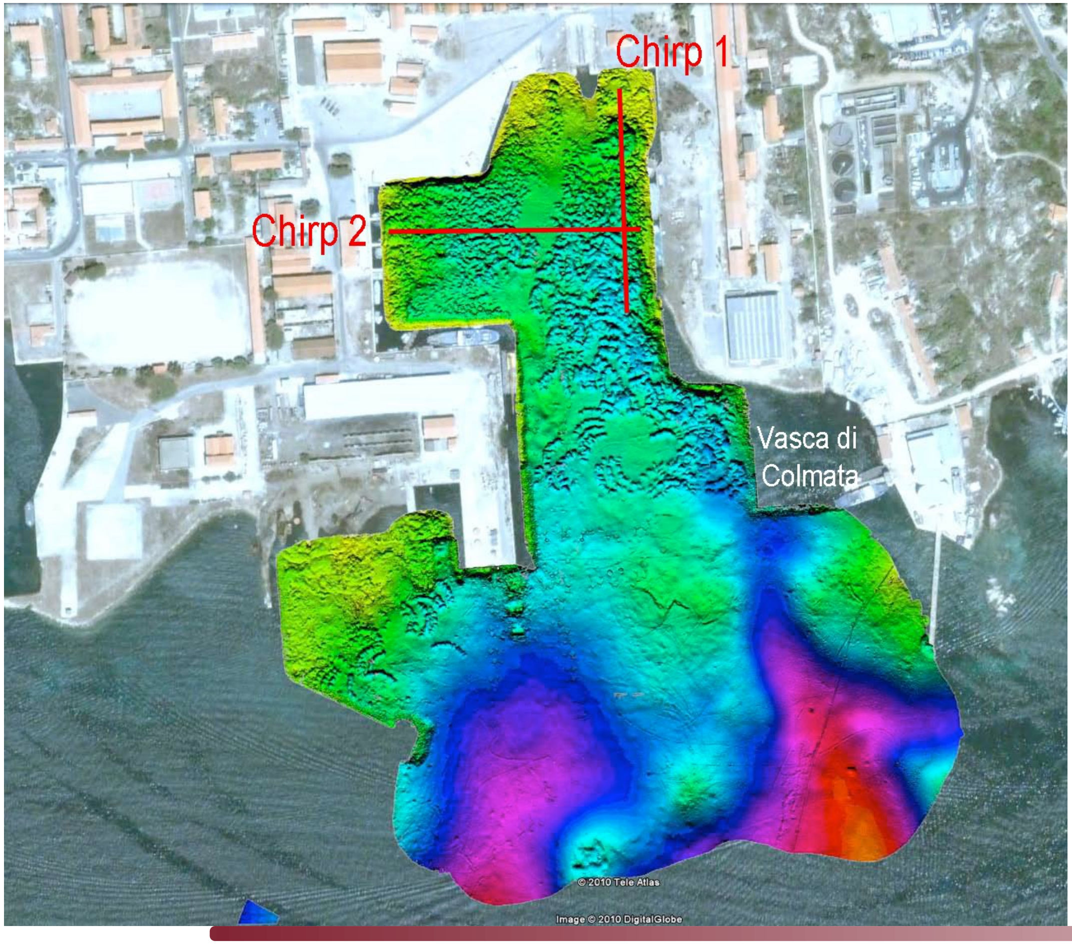
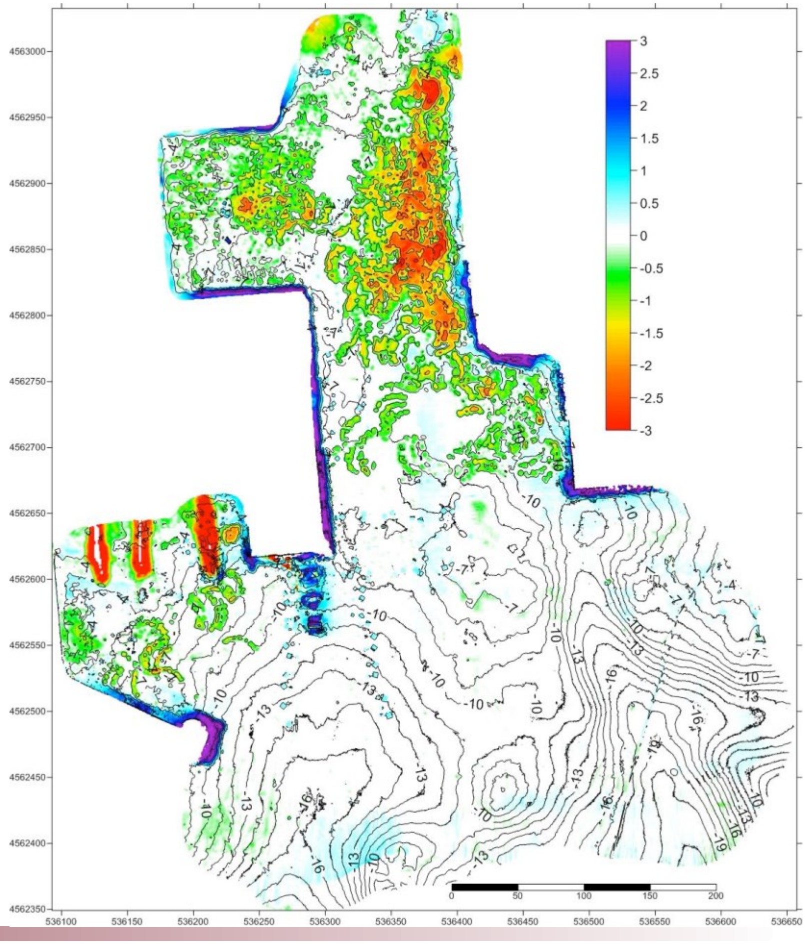
**MBES to detect signatures on sea bottom caused by dredging activities**

**MBES 2008**

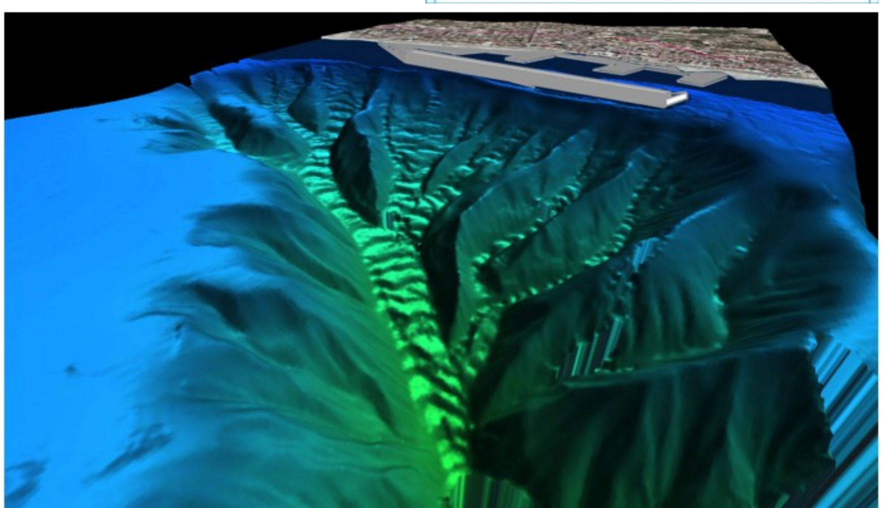


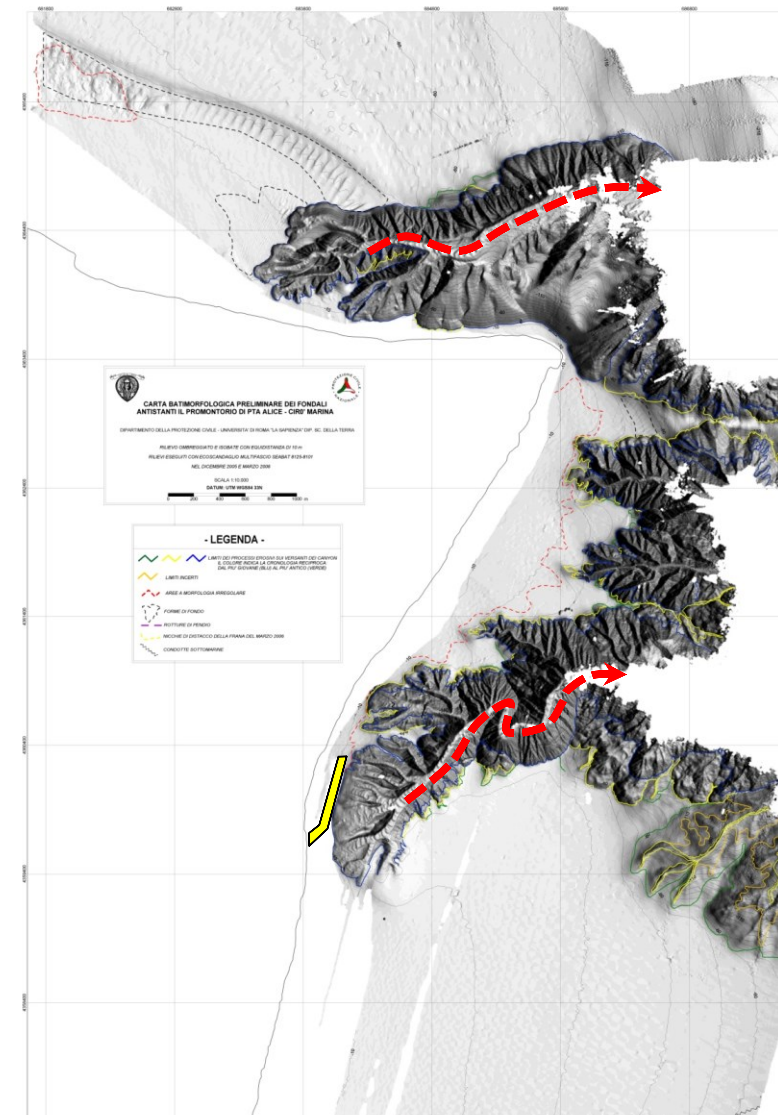

**Differential bathymetry**
**MBES 2010 – MBES 2008**



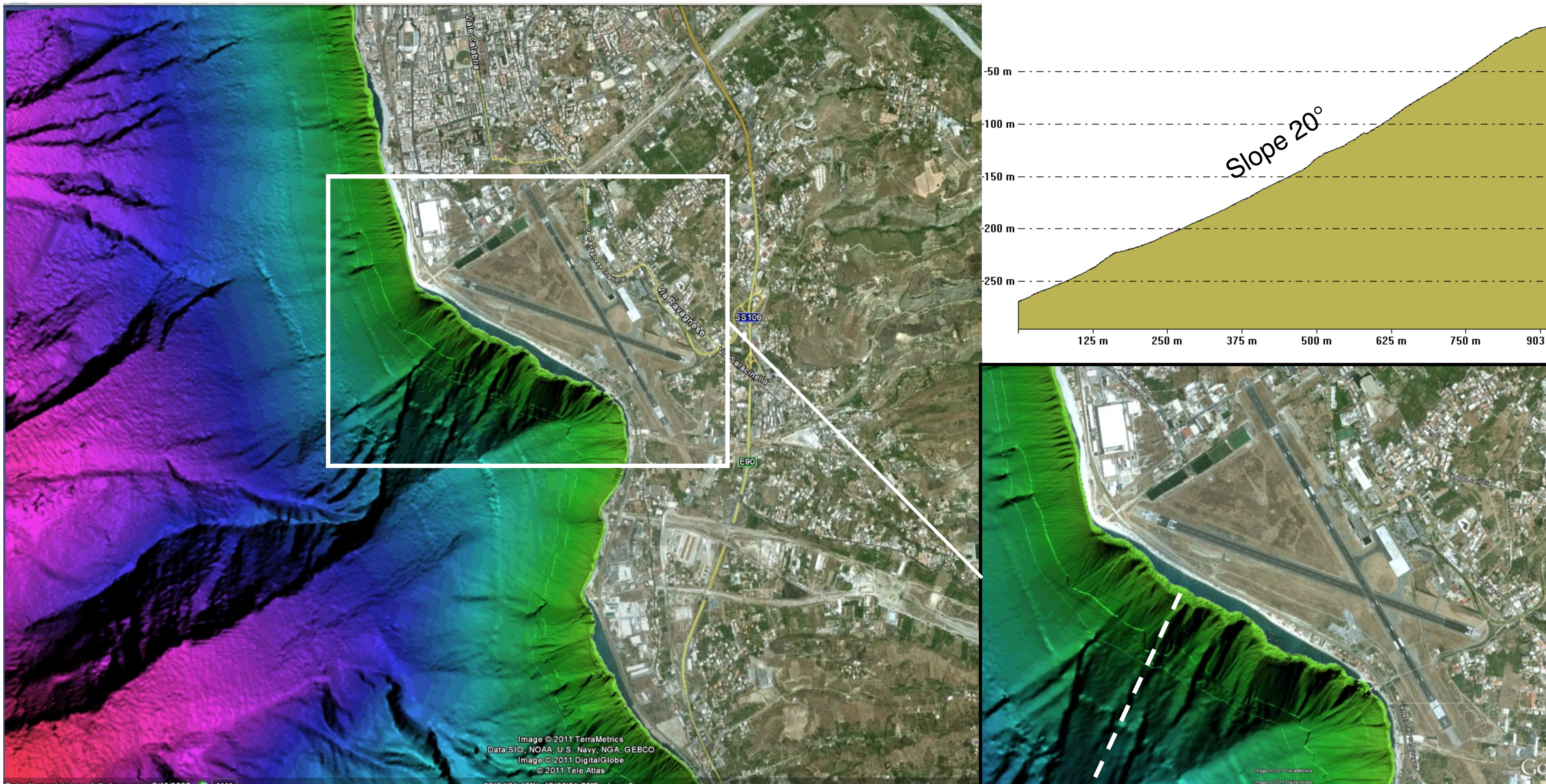
# SONAR methods – Coastal engineering

**Monitoring the Cirò Marina port (canyons triggering slope instability)**



## Monitoring the Reggio Calabria airport (canyons)



## Archaeological remains at the Tiber River (Rome)