Environmental geophysics

Giorgio De Donno

Marine acoustic and seismic methods:
Multi Beam Echo Sounder (MBES)
Sub-Bottom Profiler (SBP)

MBES images are kindly provided by
Dr. Alessandro Bosman - CNR-IGAG c/o DICEA

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

phone: +39 06 44 585 078
email: giorgio.dedonno@uniroma1.it

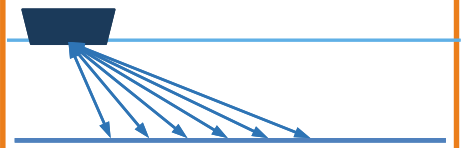
Marine seismics and acoustic

MARINE SEISMIC & ACOUSTIC METHODS

ACOUSTIC / SONAR

MBES

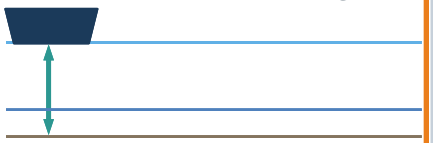
MultiBeam Echo Sounder



Bathymetry, seafloor morphology and texture, water column analysis

SBP

Sub-bottom profiling

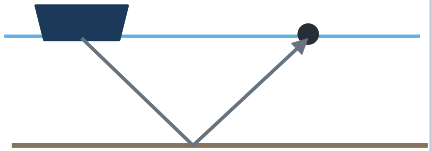


Shallow stratigraphy, high frequency → sediment layers, buried objects, gas

SEISMIC REFLECTION METHODS

Single-channel

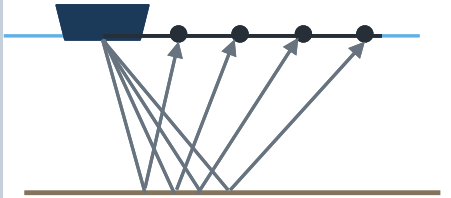
Seismic reflection



One receiver, lower frequencies → deeper imaging

Multi-channel

Seismic reflection



Streamer with many receivers → deeper imaging for oil&gas&mineral exploration

Marine seismic methods – Sub-bottom profiler (SBP)

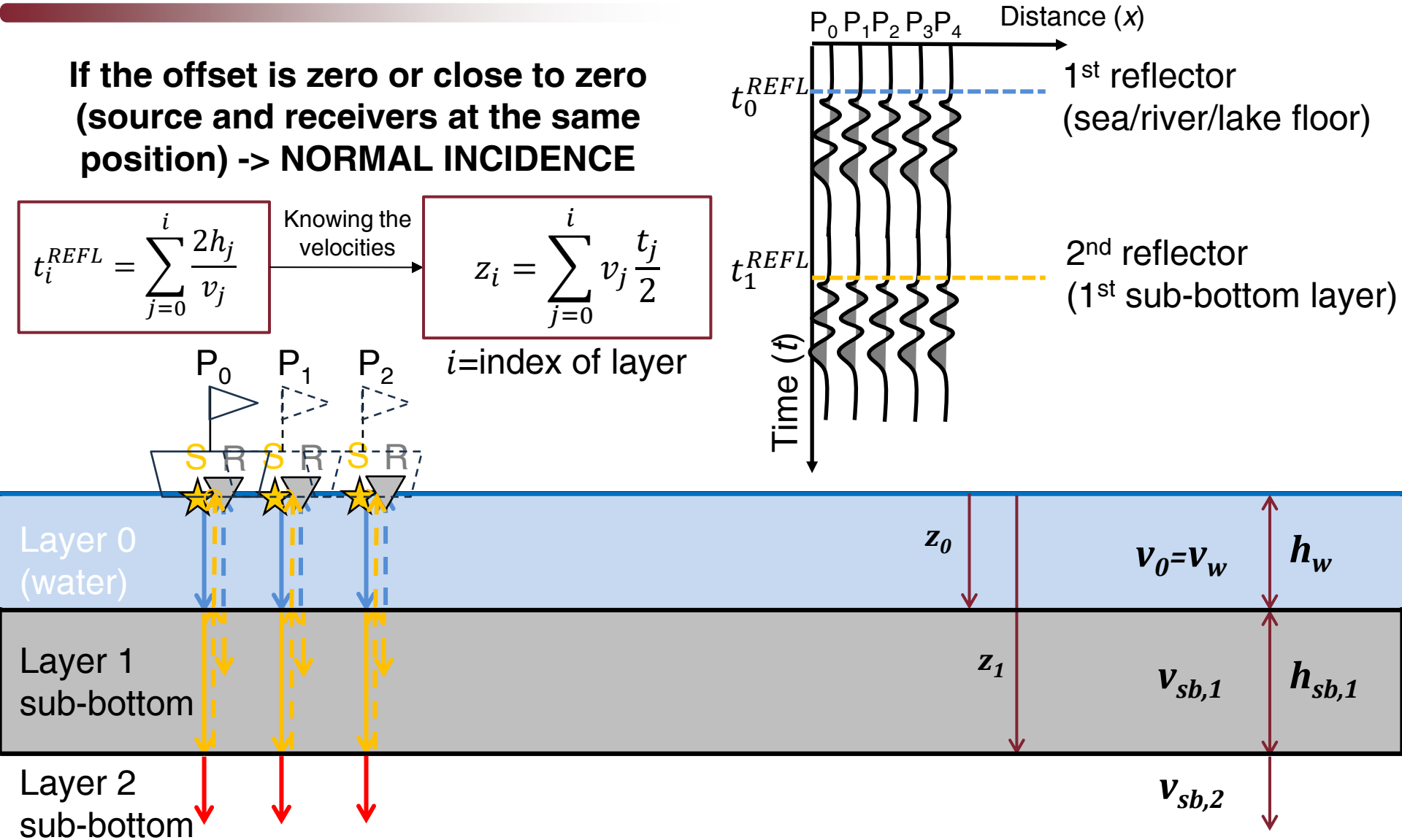
If the offset is zero or close to zero (source and receivers at the same position) -> NORMAL INCIDENCE

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

Knowing the velocities

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

i=index of layer



Marine seismic methods – Sub-bottom profiler (SBP)

First reflector
(sea/river/lake floor)

1st multiple (water)

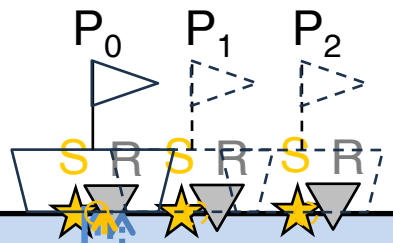
Second reflector
(1st-2nd sub-bottom layer)

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

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

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

Multiple reflections are periodic of *2h/v*



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

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



Marine seismic methods – Sub-bottom profiler (SBP)

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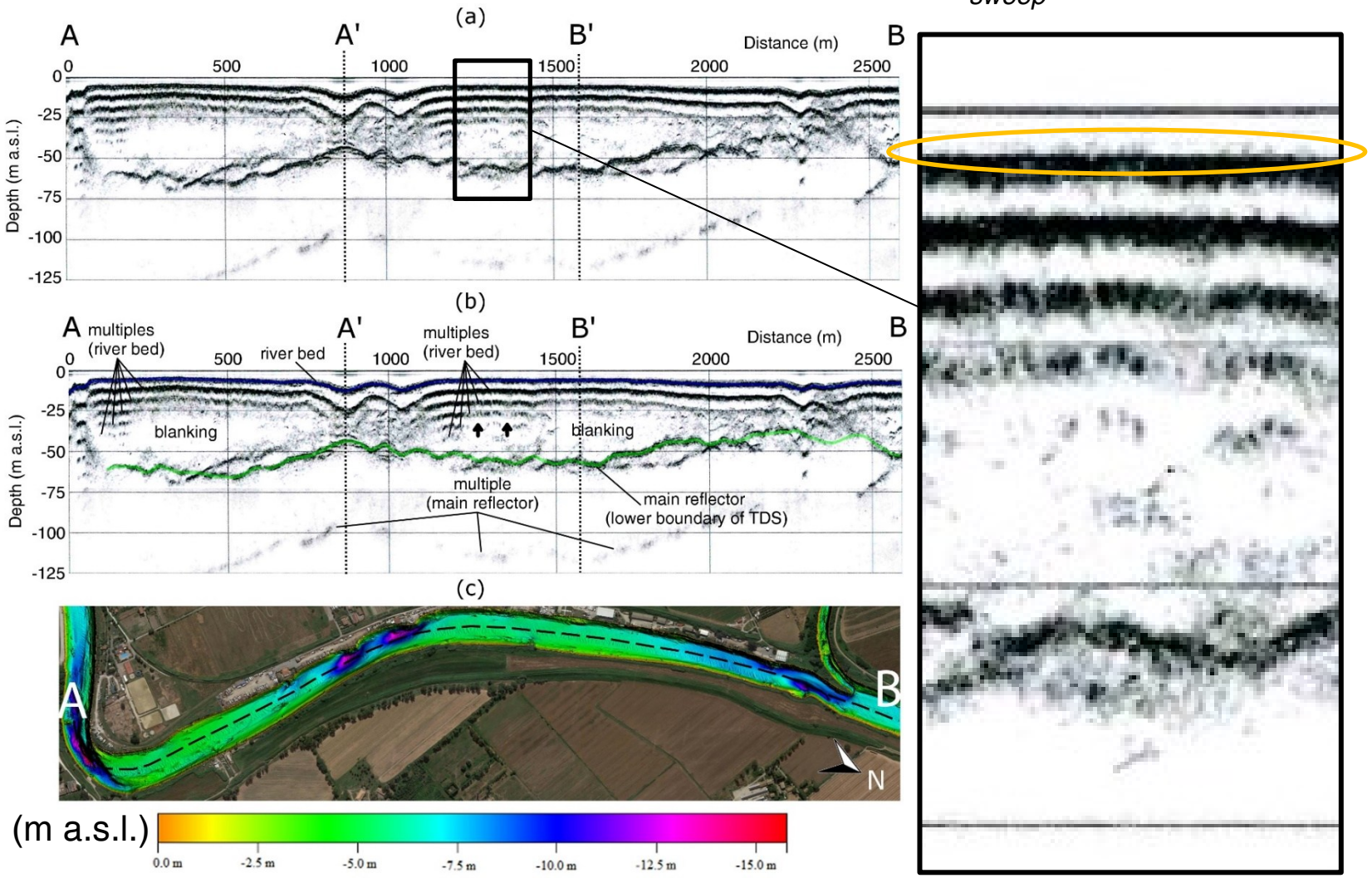
Tiber River – Capo due Rami (Rome)

Source: **Chirp** vibrating source
f_{sweep} = 2-8 KHz

SBP processed section

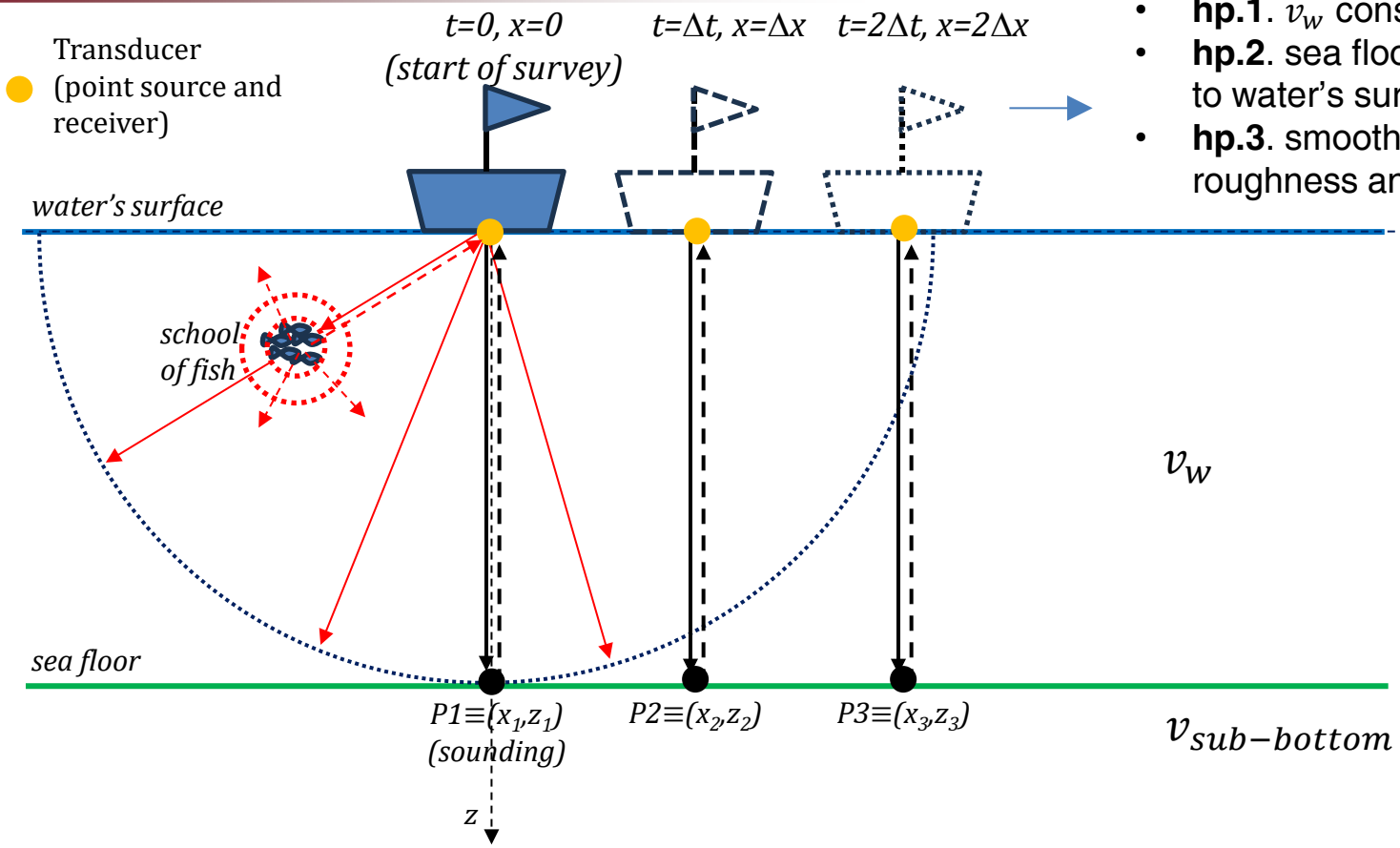
Interpretation

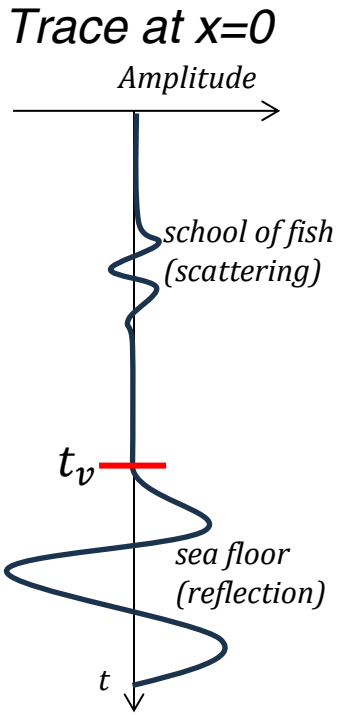
Multibeam data



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)





Depth of sea floor

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

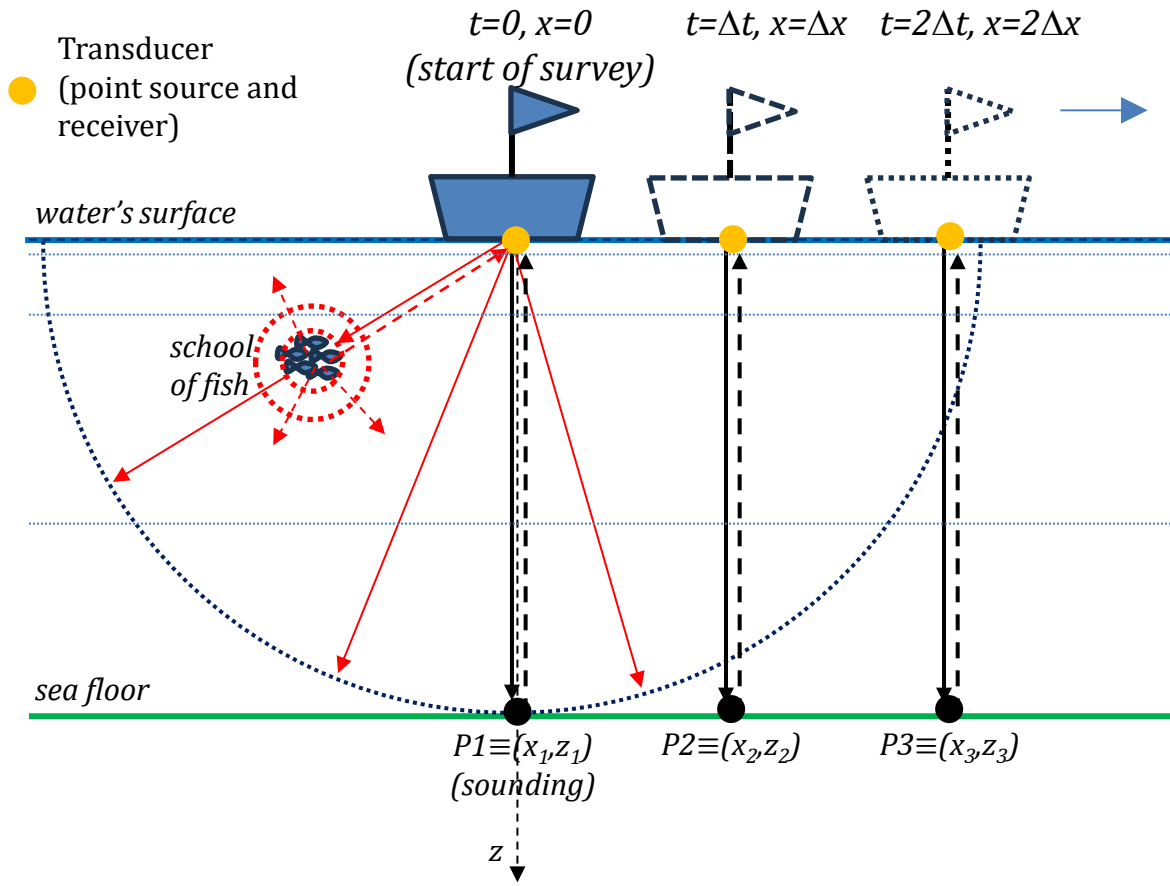
$v_w = \sqrt{\frac{K_w}{\delta_w}}$ *acoustic wave velocity (water)*

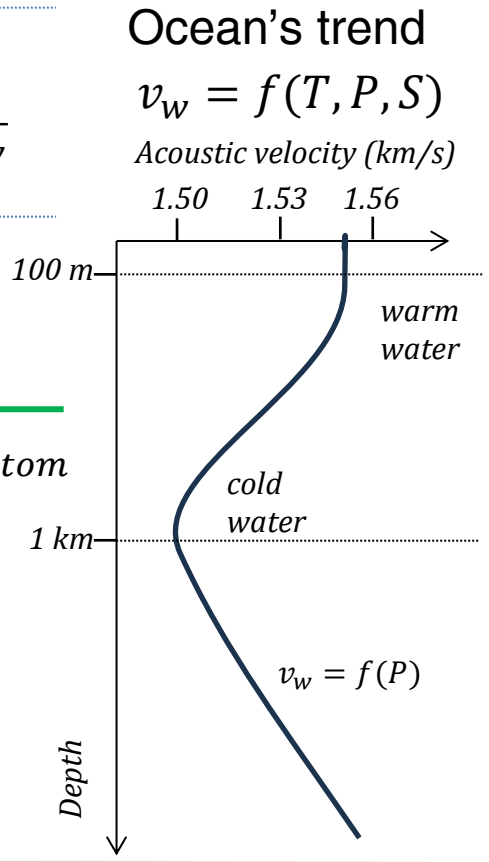
N_S: *number of soundings*

SONAR methods – Basic principles

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





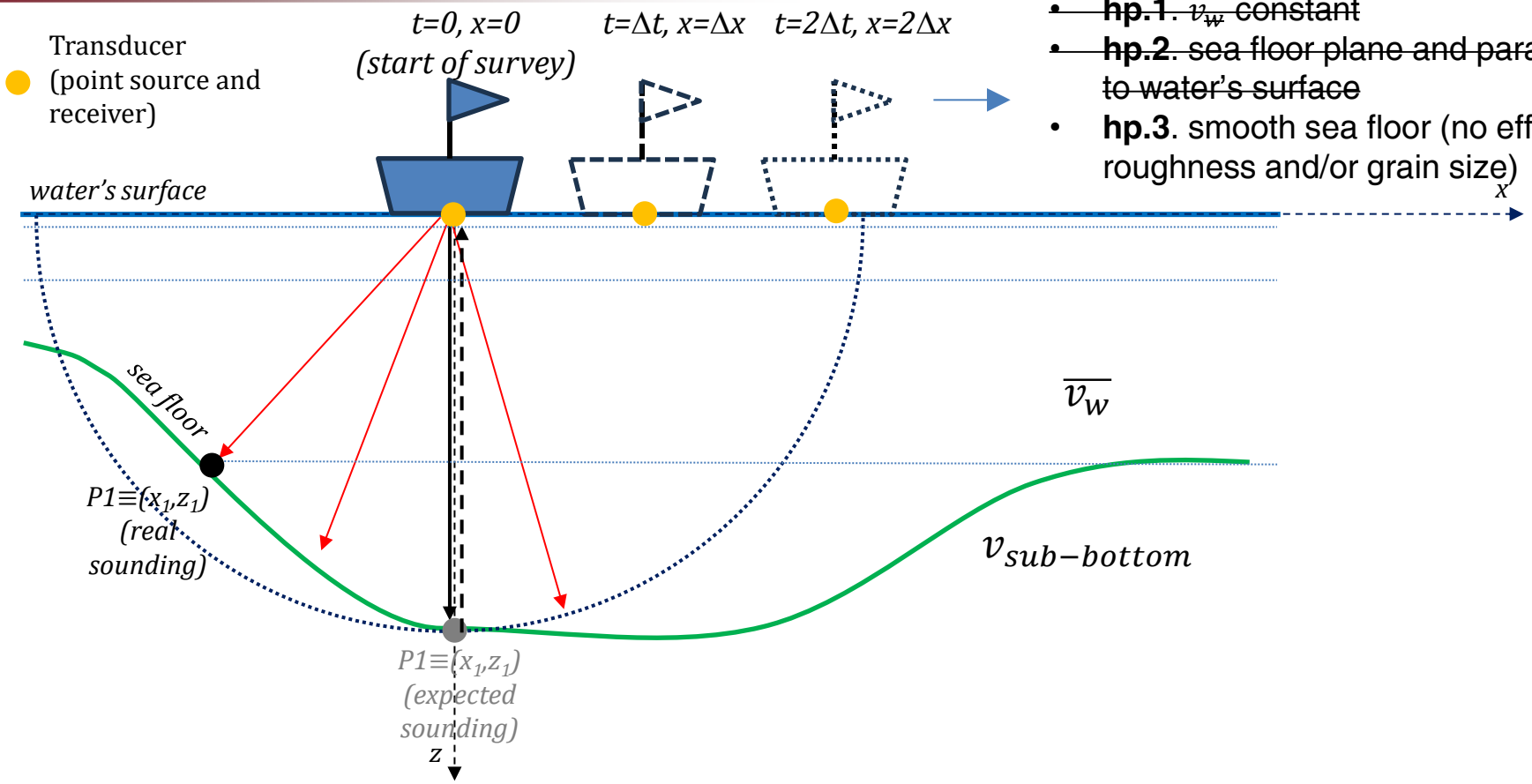
Depth of sea floor

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

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

N_S: *number of soundings*

SONAR methods – Basic principles



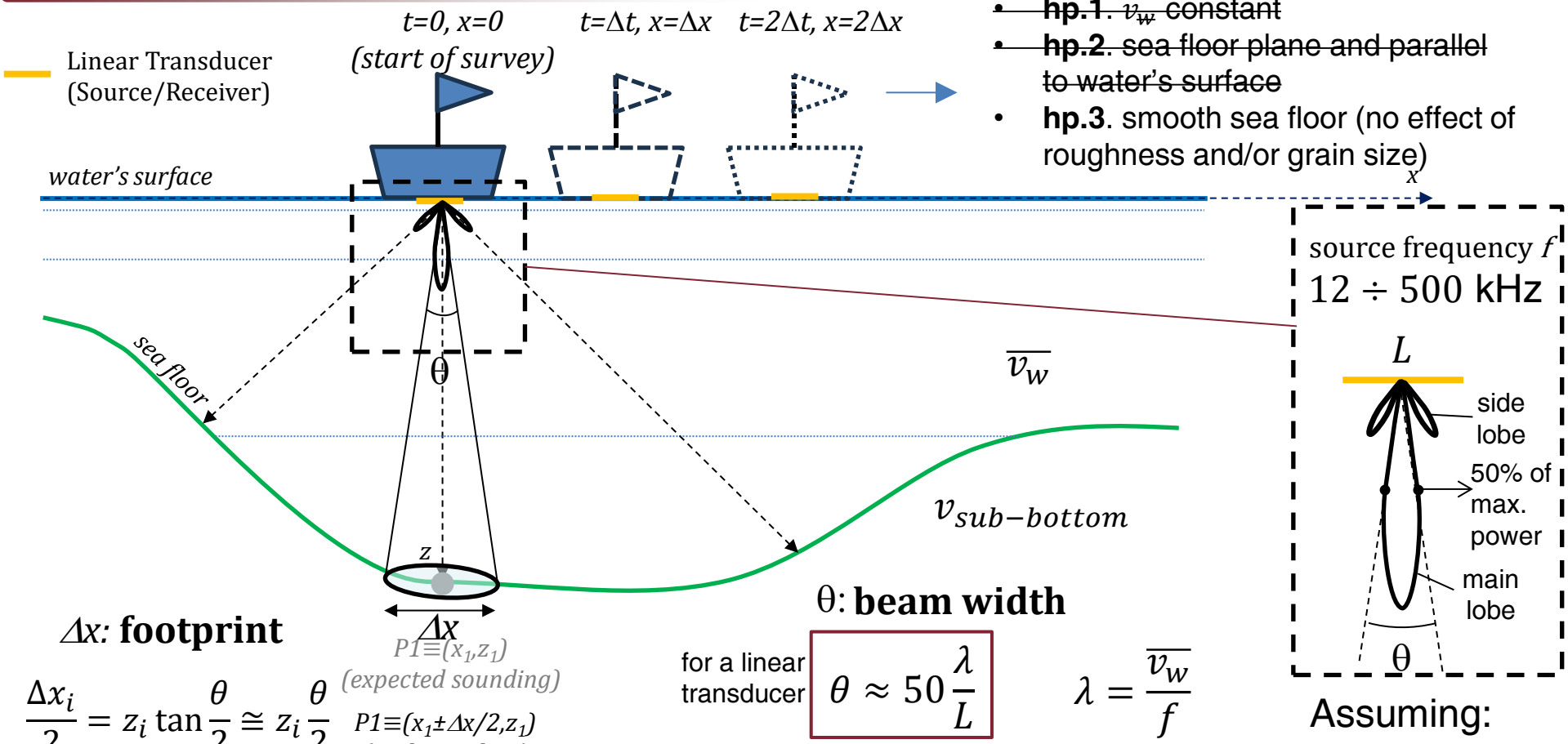
- ~~**hp.1**. v_w constant~~
- ~~**hp.2**. sea floor plane and parallel to water's surface~~
- **hp.3**. smooth sea floor (no effect of roughness and/or grain size)

Depth of sea floor?

SONAR methods – Basic principles

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



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 $\theta \approx 50\frac{\lambda}{L}$

$$\lambda = \frac{\overline{v_w}}{f}$$

Assuming:

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

$f = 12 \div 500$ kHz

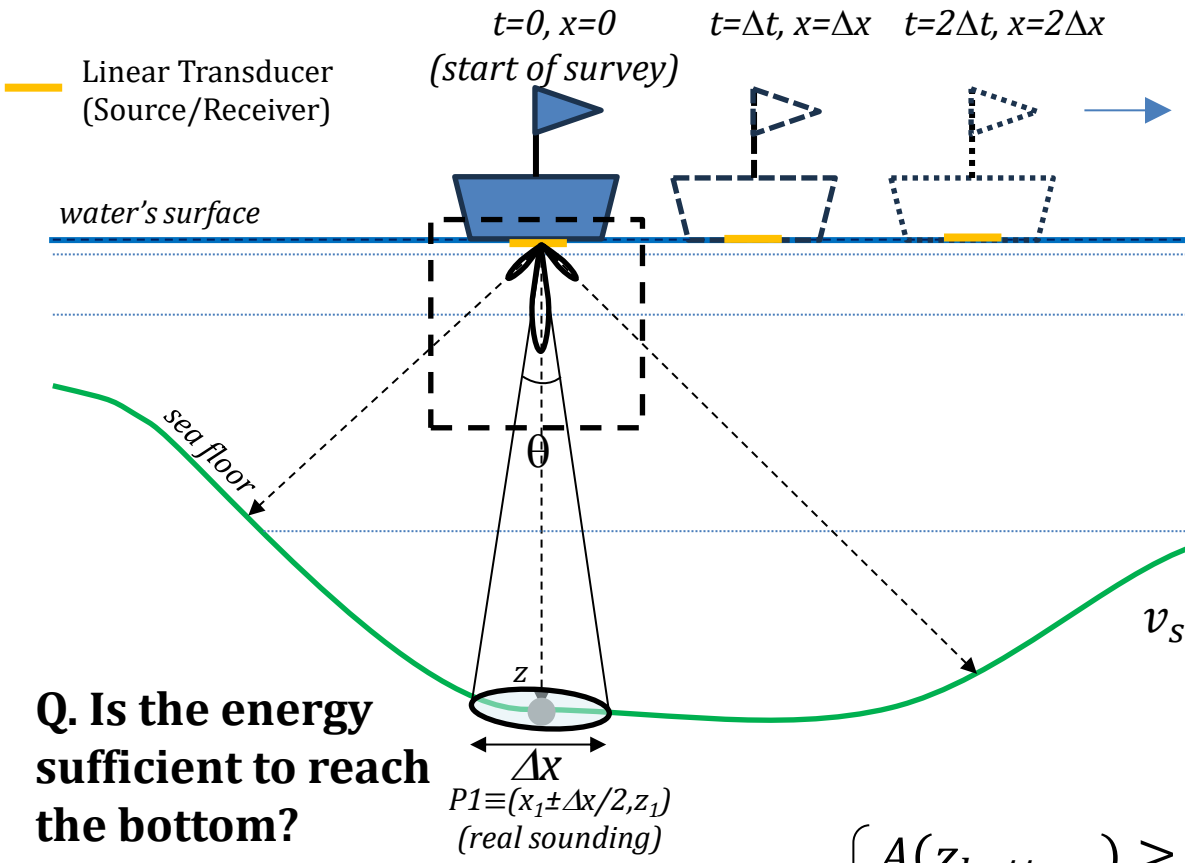
λ = **3 mm - 15 cm**

$\Delta x_i \cong z_i\theta$ **RESOLUTION**

$\Delta x \leq d_{object} \rightarrow OK$

$\Delta x > d_{object} \rightarrow NO$

SONAR methods – Basic principles



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

We have intrinsic attenuation with depth (exponential)

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

γ = attenution coefficient

$$\gamma \propto f^2$$

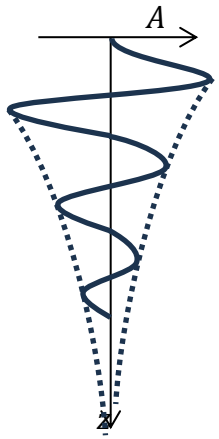
Q. Is the energy sufficient to reach the bottom?

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

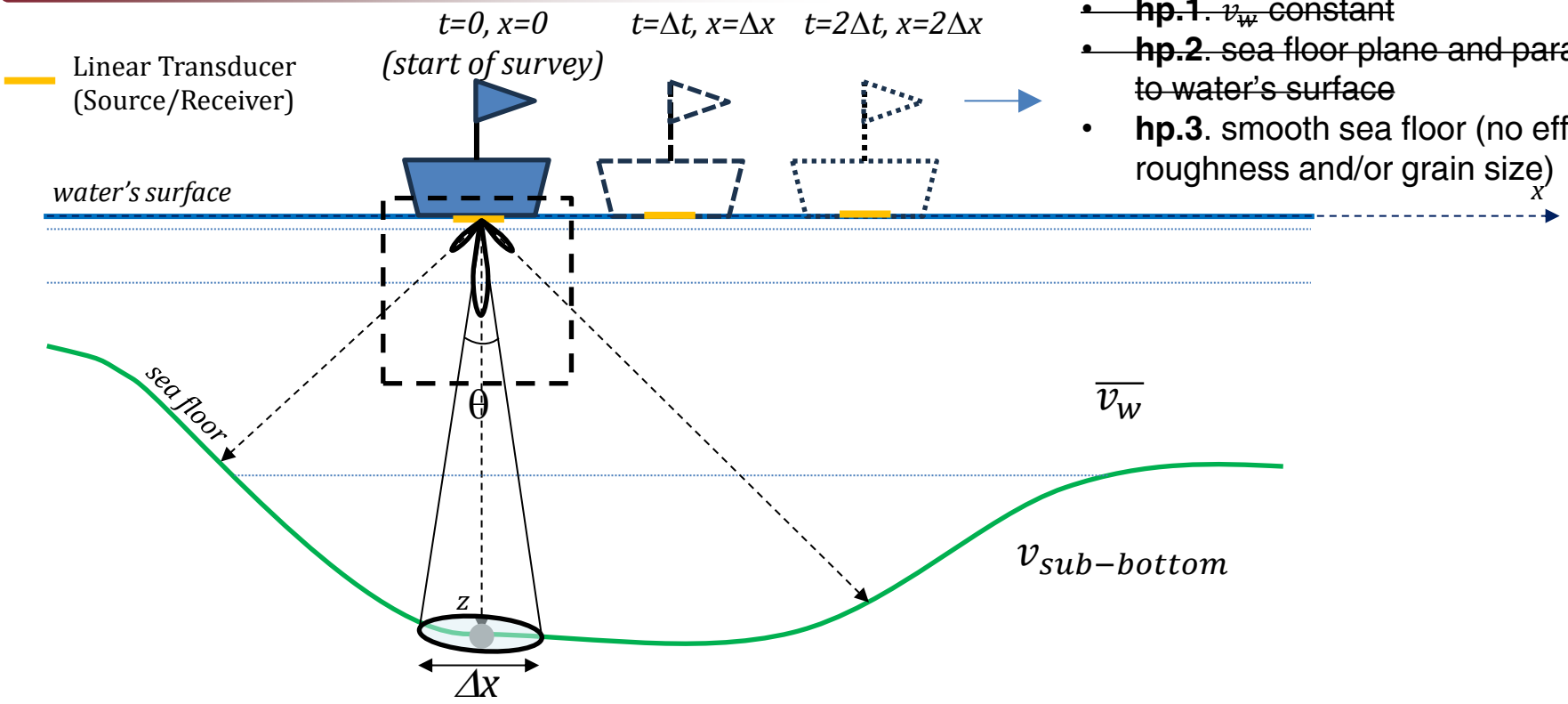
DOI
$$\begin{cases} A(z_{bottom}) \geq 37\% A_0 \rightarrow OK \\ A(z_{bottom}) < 37\% A_0 \rightarrow NO \end{cases}$$

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

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



SONAR methods – Basic principles



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

RESOLUTION

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

DOI

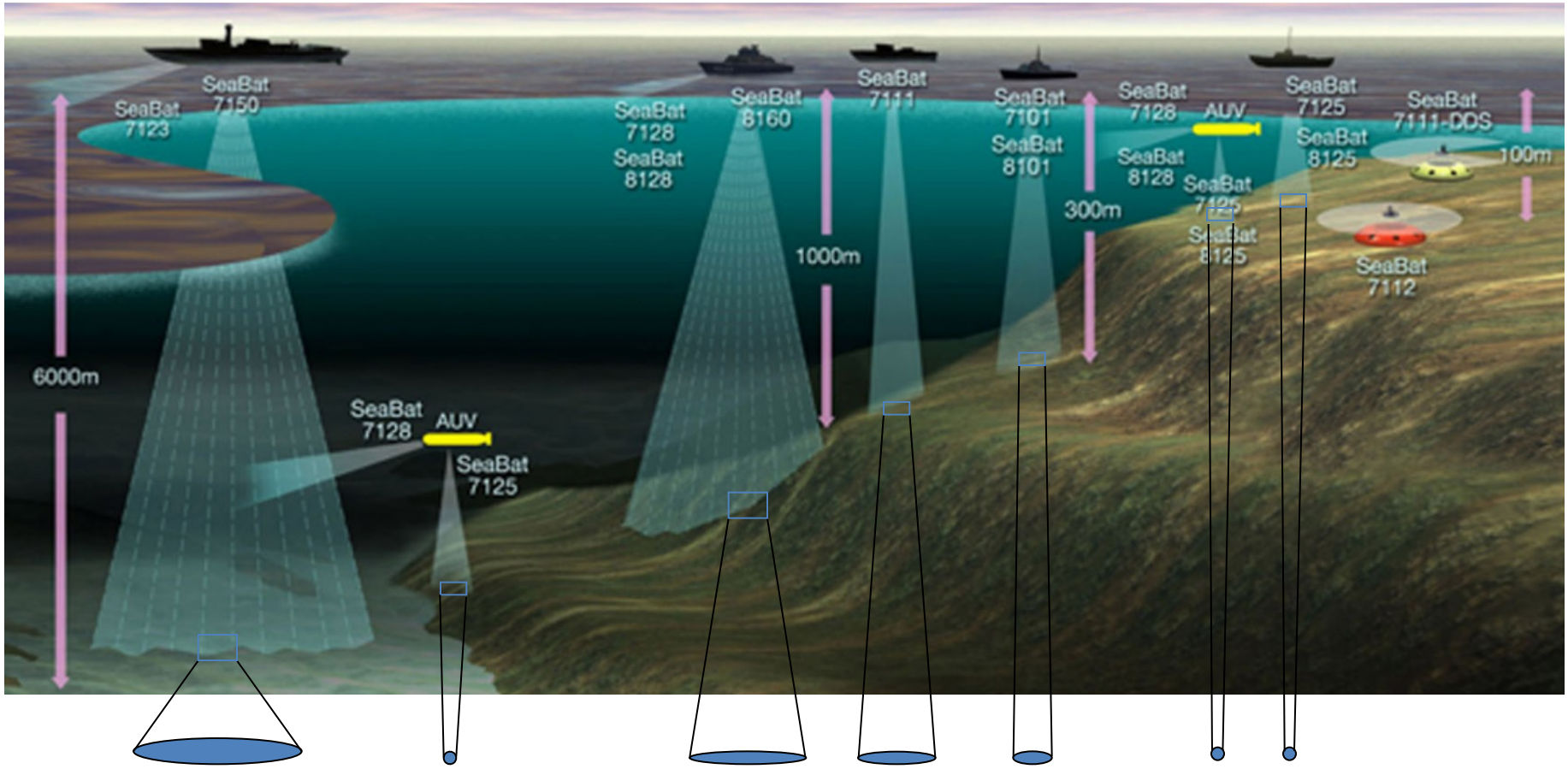
$$\begin{cases} A(z_{bottom}) \geq 37\% A_0 \rightarrow OK \\ A(z_{bottom}) < 37\% A_0 \rightarrow NO \end{cases}$$

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

SONAR methods - Resolution

Comparison between different frequencies and vessels

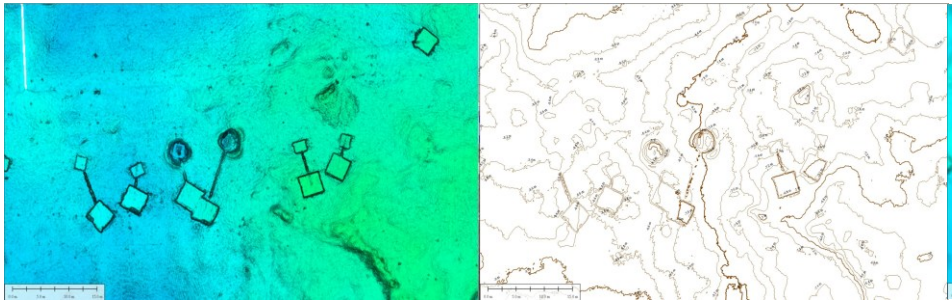
12- 24 kHz | 50 kHz | 100 kHz | 200 kHz | 400 kHz



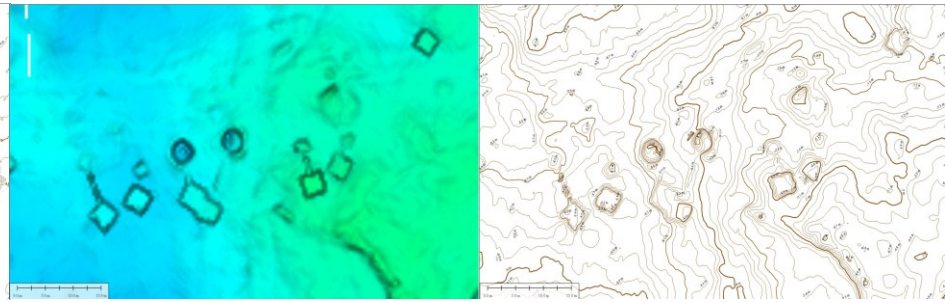
SONAR methods - Resolution

Example of comparison between different resolutions

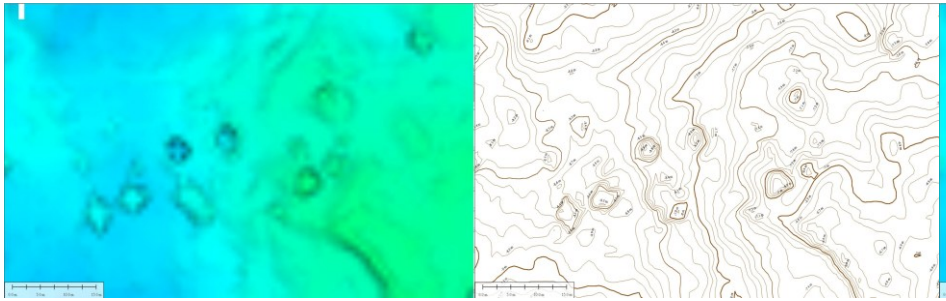
Resolution : 0.1 m



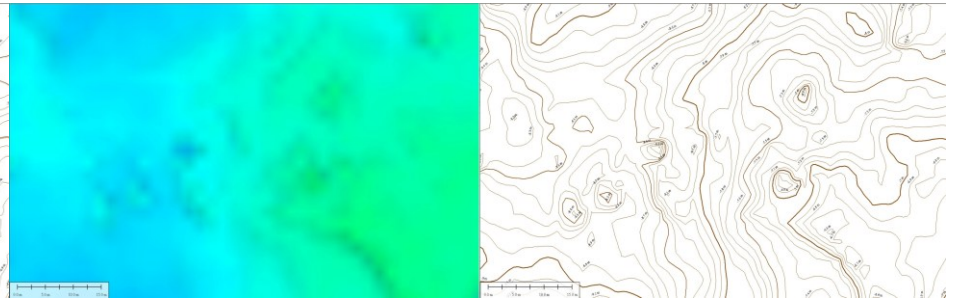
Resolution: 0.5 m



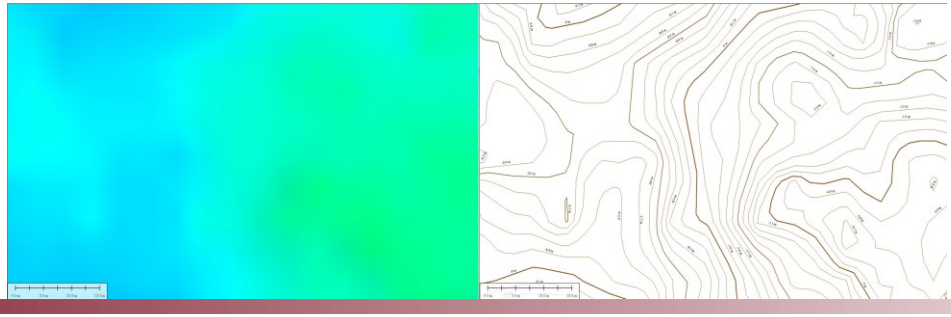
Resolution : 1 m



Resolution : 2 m



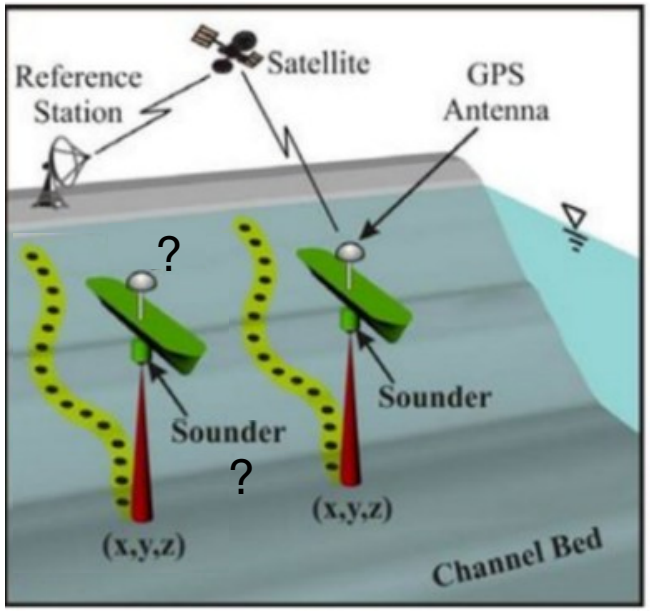
Resolution : 5 m



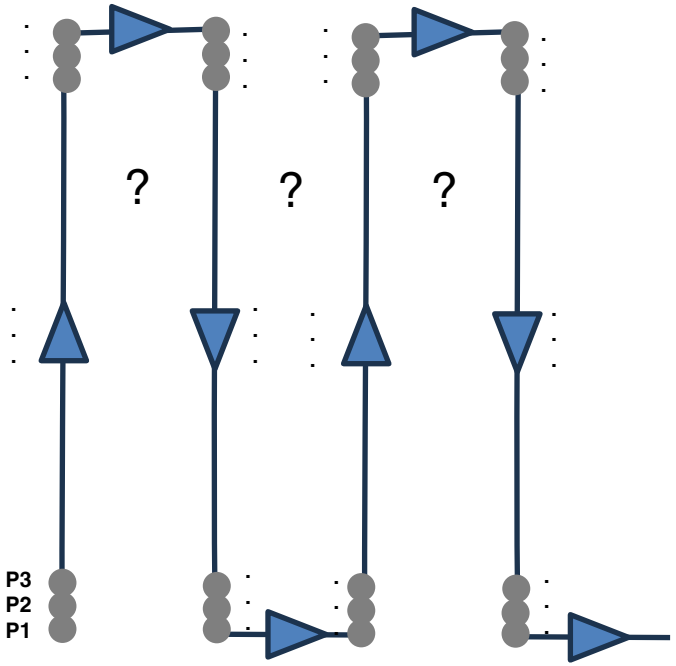
SONAR methods – From Single- to Multi-Beam

Single-Beam (SBES)

3D view



Plan view

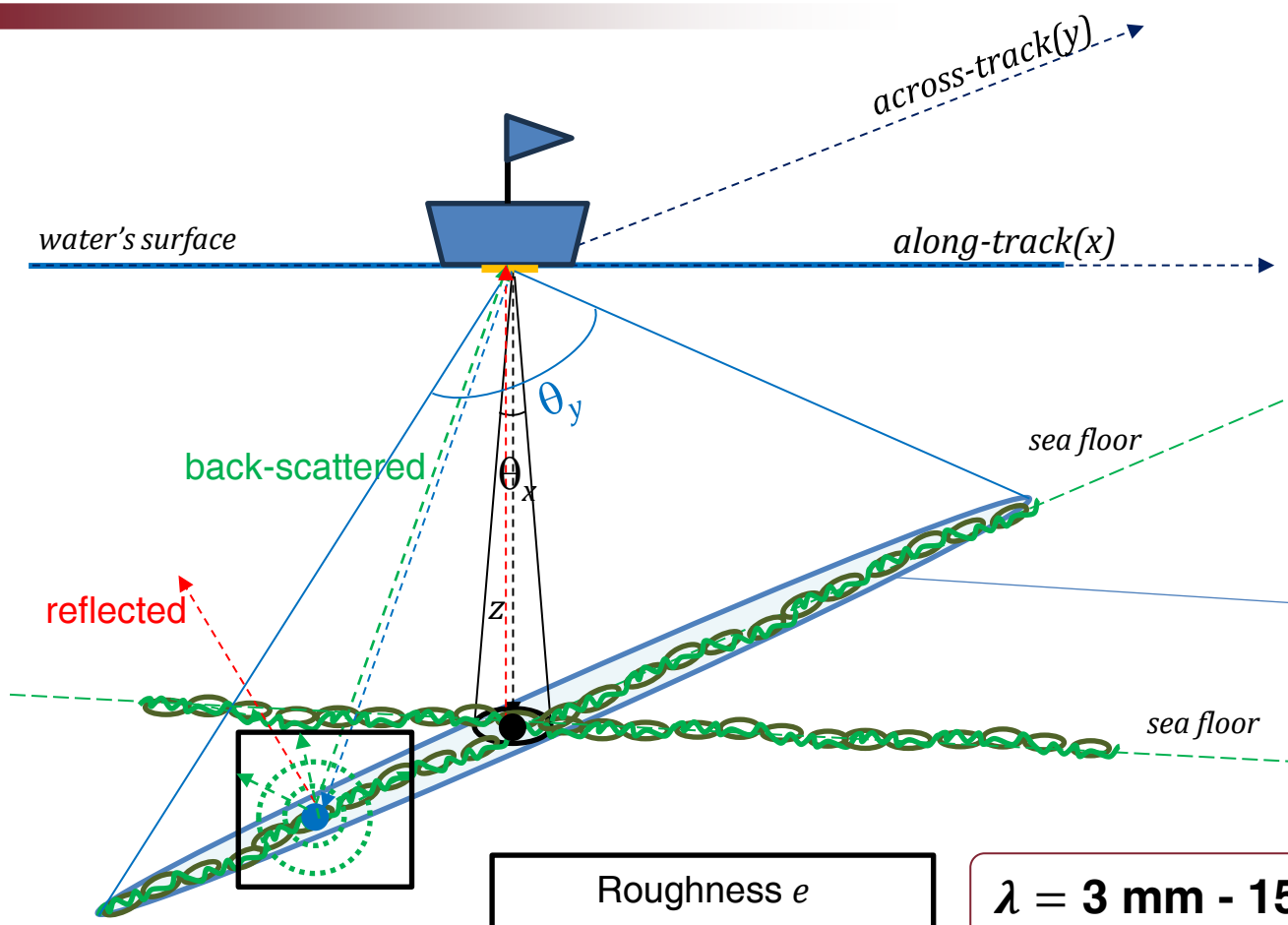


SBES method has a poor lateral coverage (across-track)

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

SONAR methods – From Single- to Multi-Beam

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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
$L_x = 1$ m
$L_y = 1$ cm
$\lambda = 3$ 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)

Roughness e

e

Grain coarseness d_{GR}

d_{GR}

λ = 3 mm - 15 cm

If $\lambda \sim e$

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

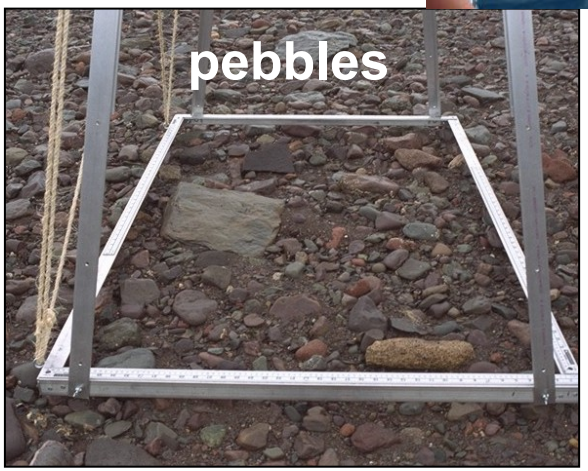
Scattering
Signals coming laterally can be back-scattered to the transducer

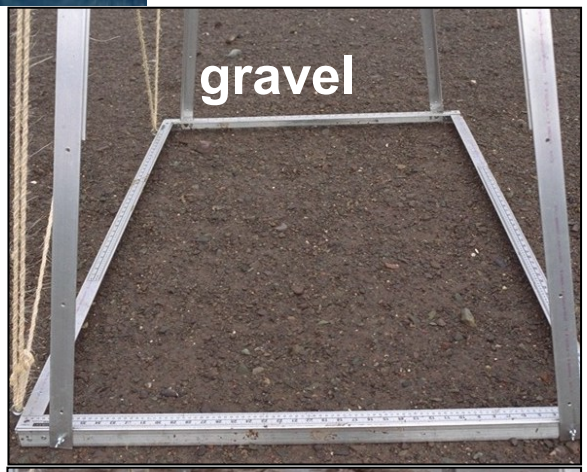
SONAR methods – From Single- to Multi-Beam

Roughness and coarseness
Direct inspections

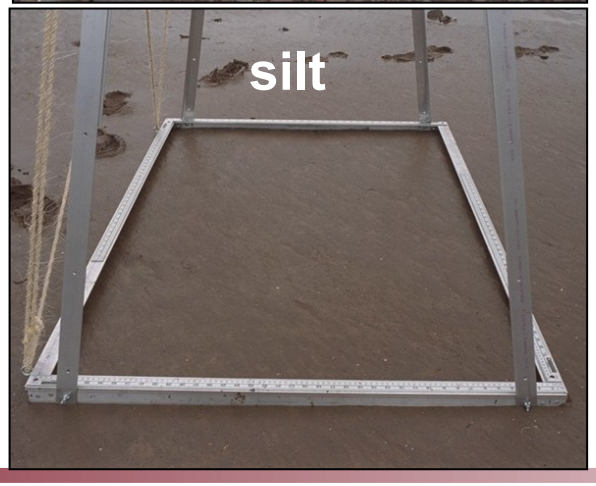


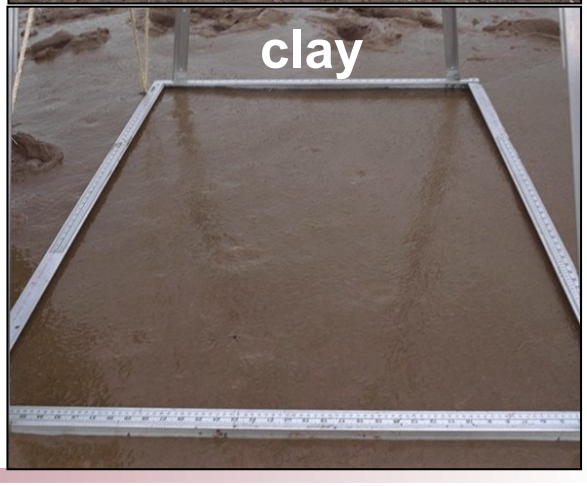










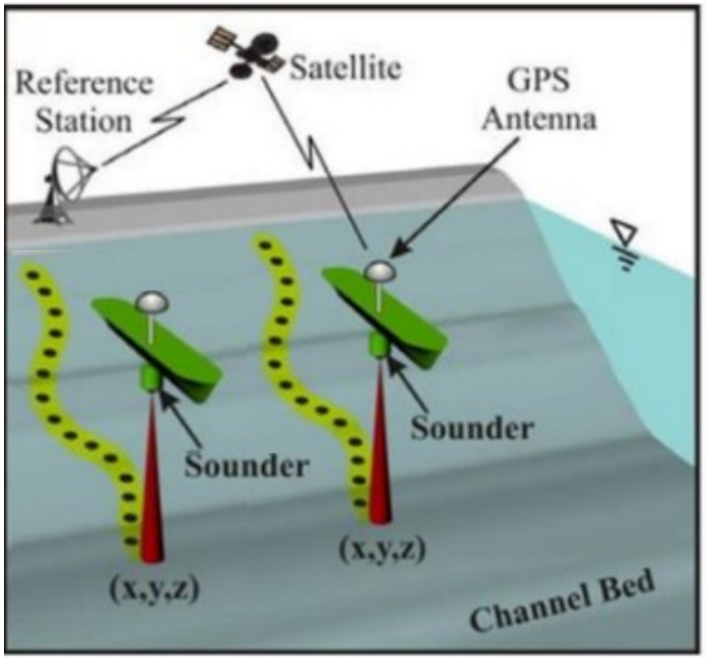


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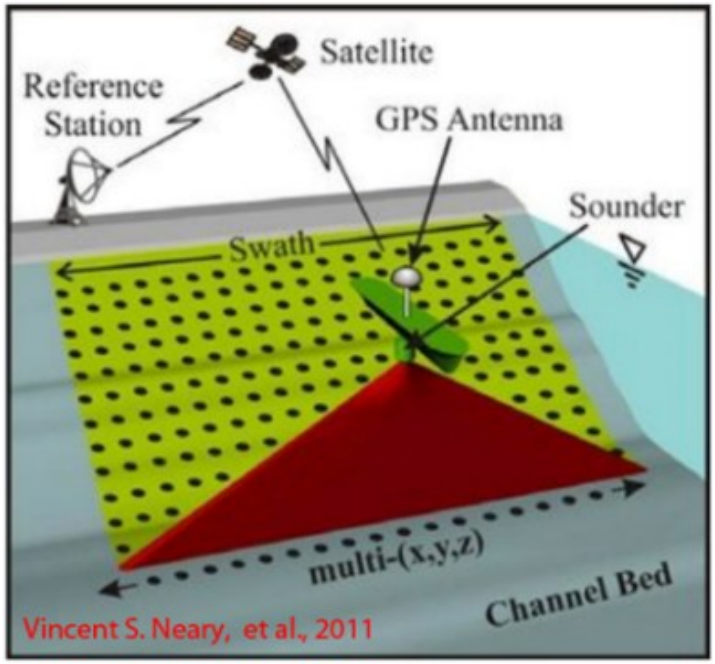
Q. Can the back-scattered echoes coming from lateral directions (y-dir) be detected?

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

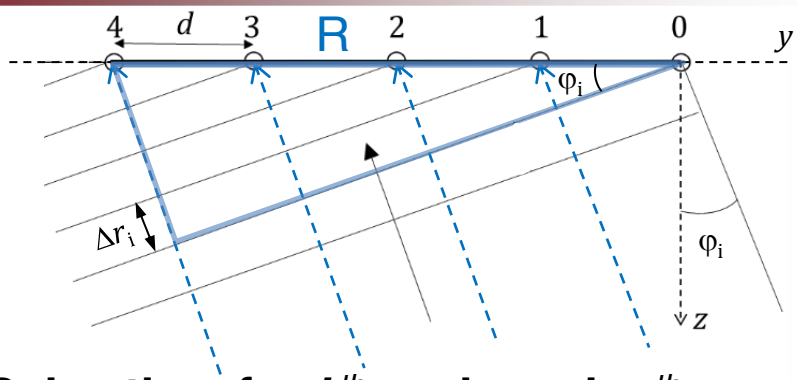
Single-Beam (SBES)

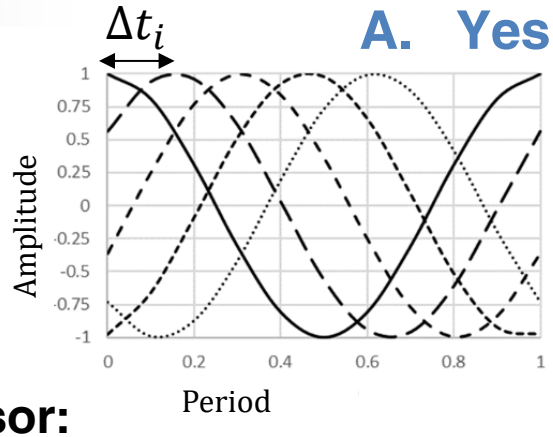


Multi-Beam (MBES)

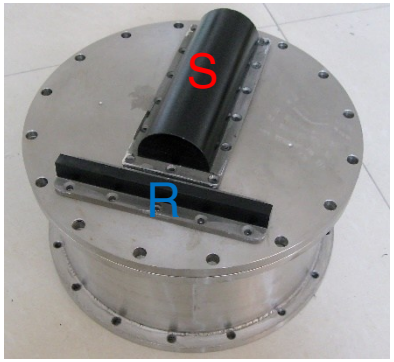


SONAR methods





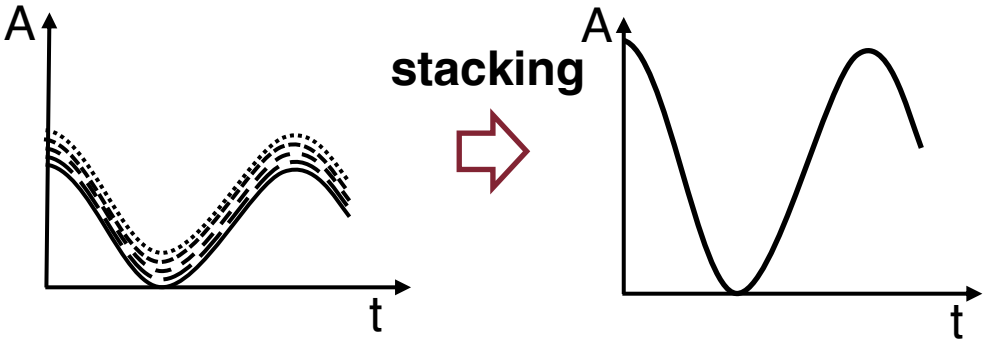
A. Yes, with a Mills' cross

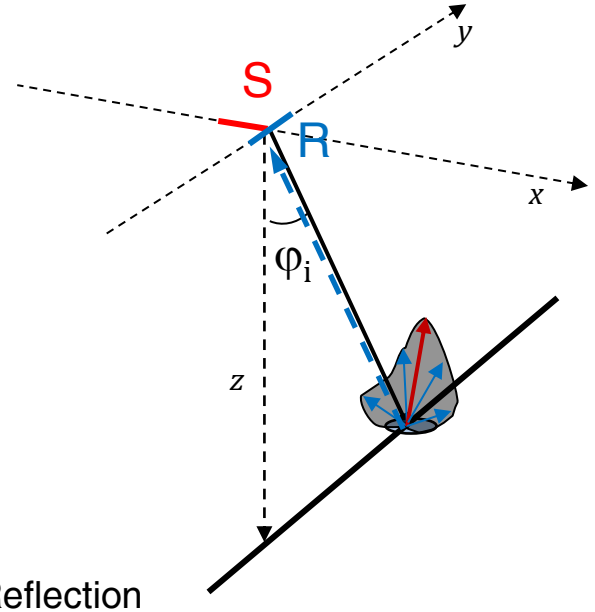


Delay time for *i*-*th* angle and *n*-*th* sensor:

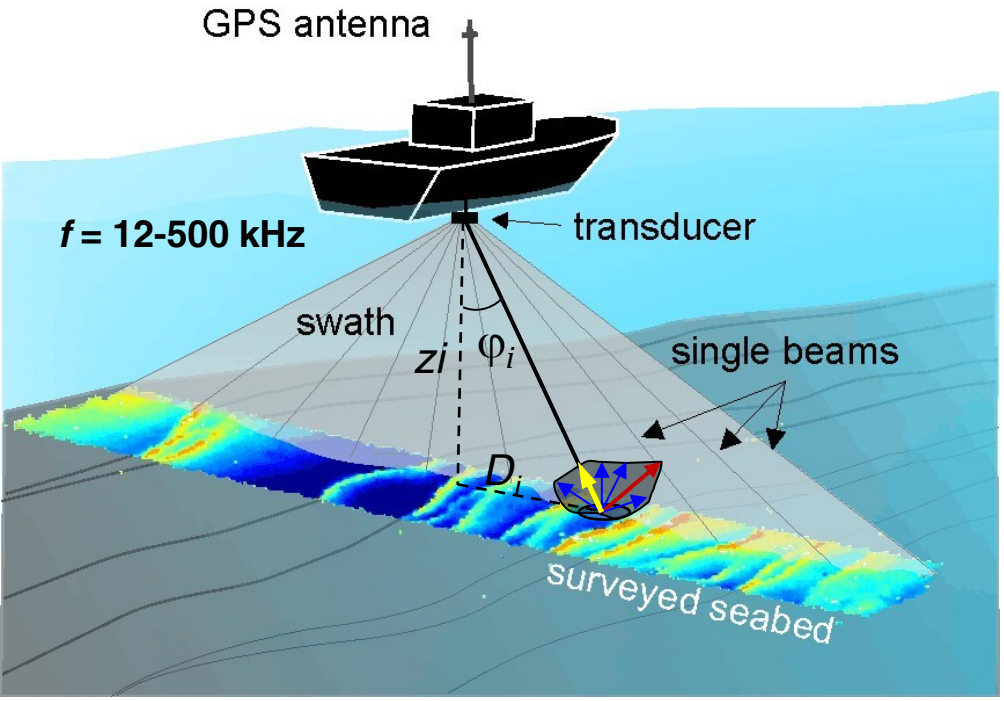
$$\Delta t_{n,i} = n\Delta t_i = \frac{n\Delta r_i}{v_w} = \frac{nd\sin\varphi_i}{v_w}$$

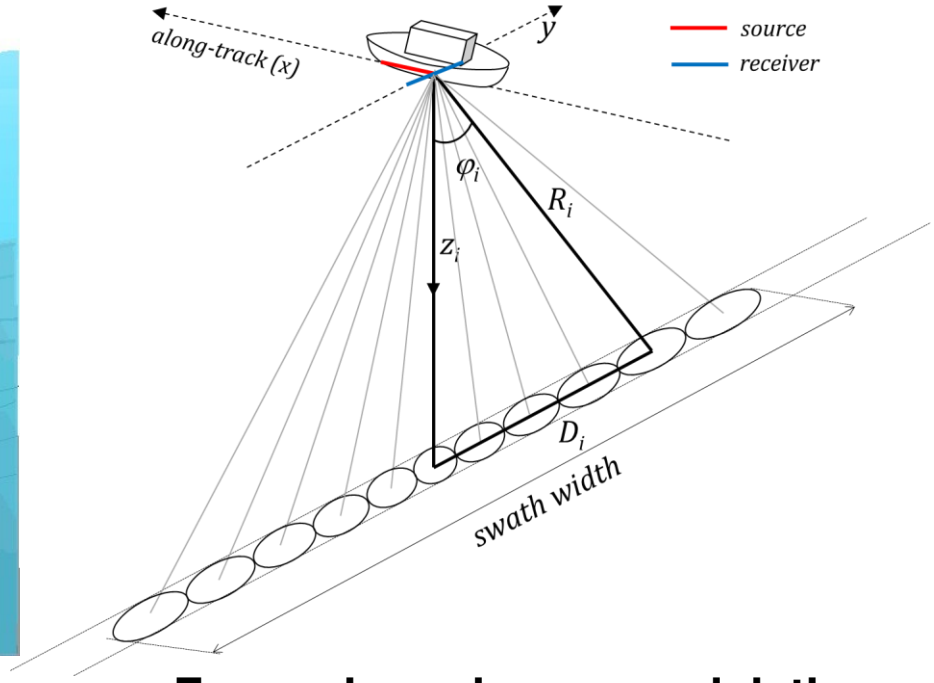
After applying the delay time (for each angle φ_i)
BEAMFORMING: 100% constructive interference - one stacked trace from each beam angle φ_i





SONAR methods





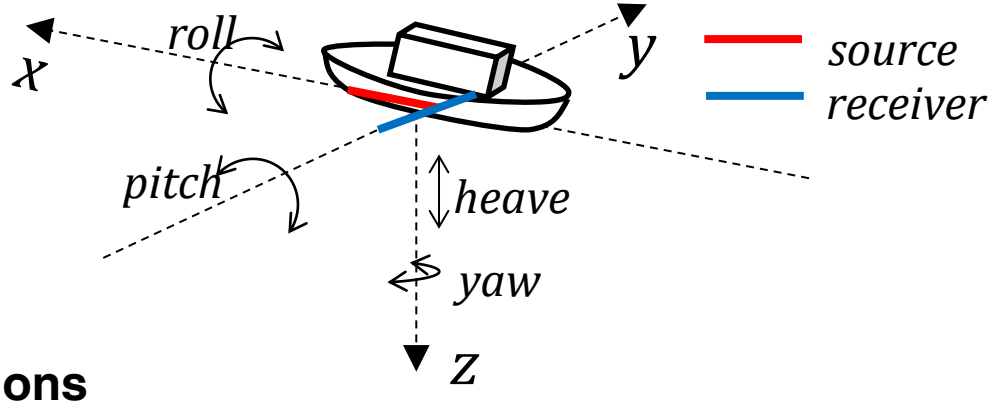
- Reflection
- Back-scattering (morphology & granulometry)
- Back-scattered signal at φ

For each angle φ_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

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

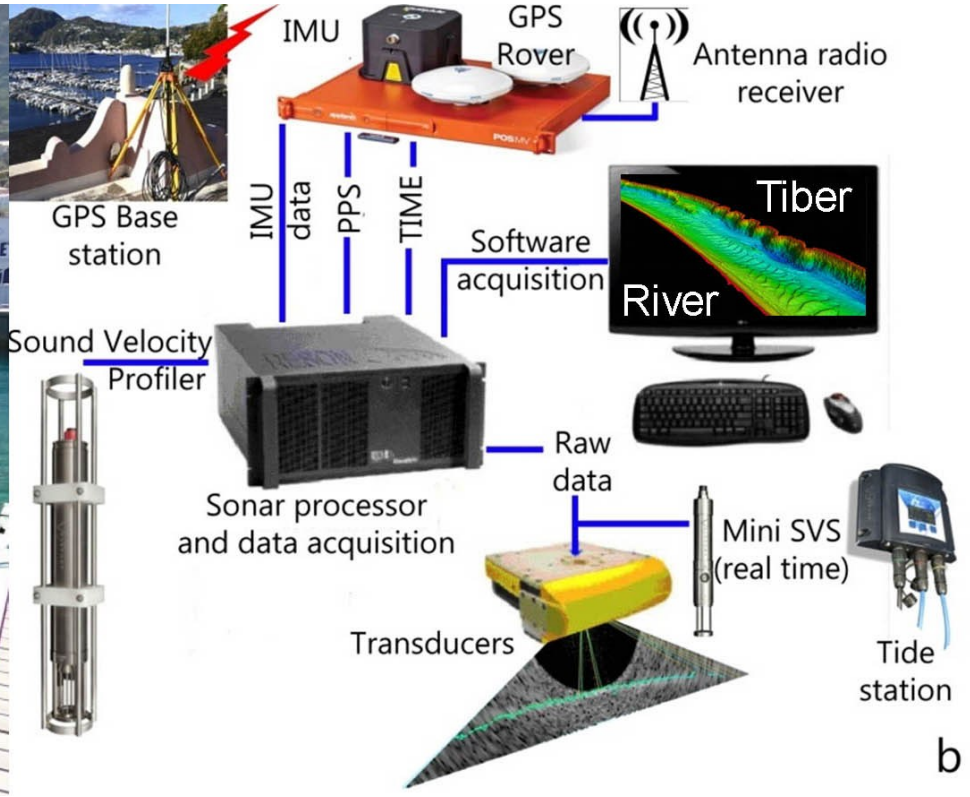


Positioning and corrections

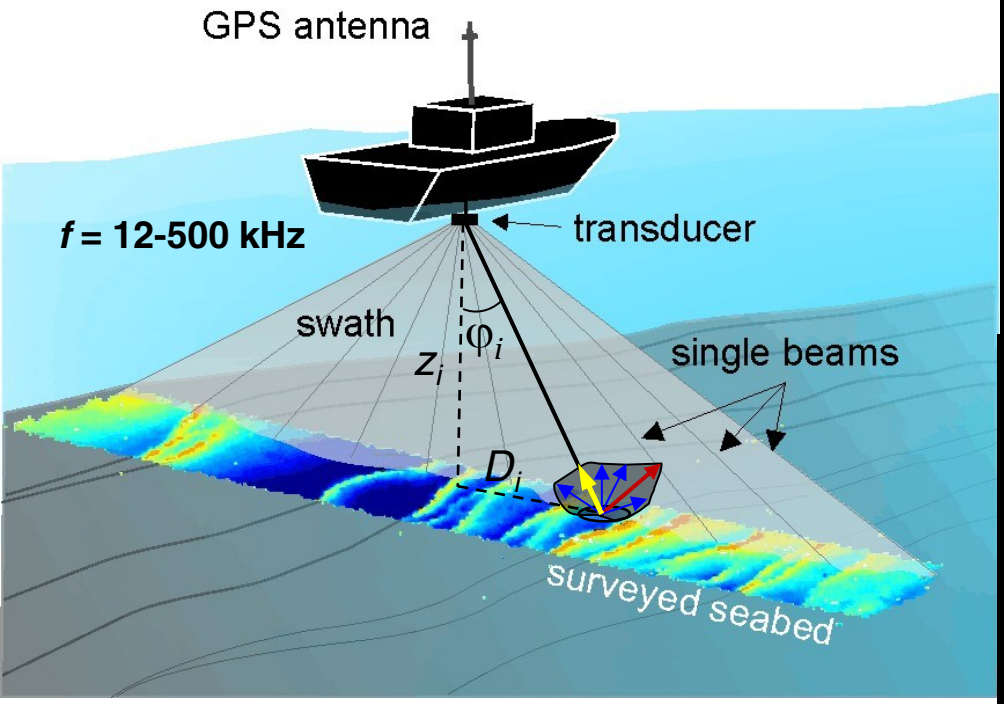
1. positioning LAT/LONG/HEIGTH via GNSS system with differential correction (e.g., RTK, DGPS)
2. motion of the ship (roll, pitch and heave) through an inertial sensor (IMU)
3. orientation (yaw) by a gyrocompass
4. tide correction (tide station)
5. direct measurement of the ultra-shallow water velocity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

SONAR methods - Instruments

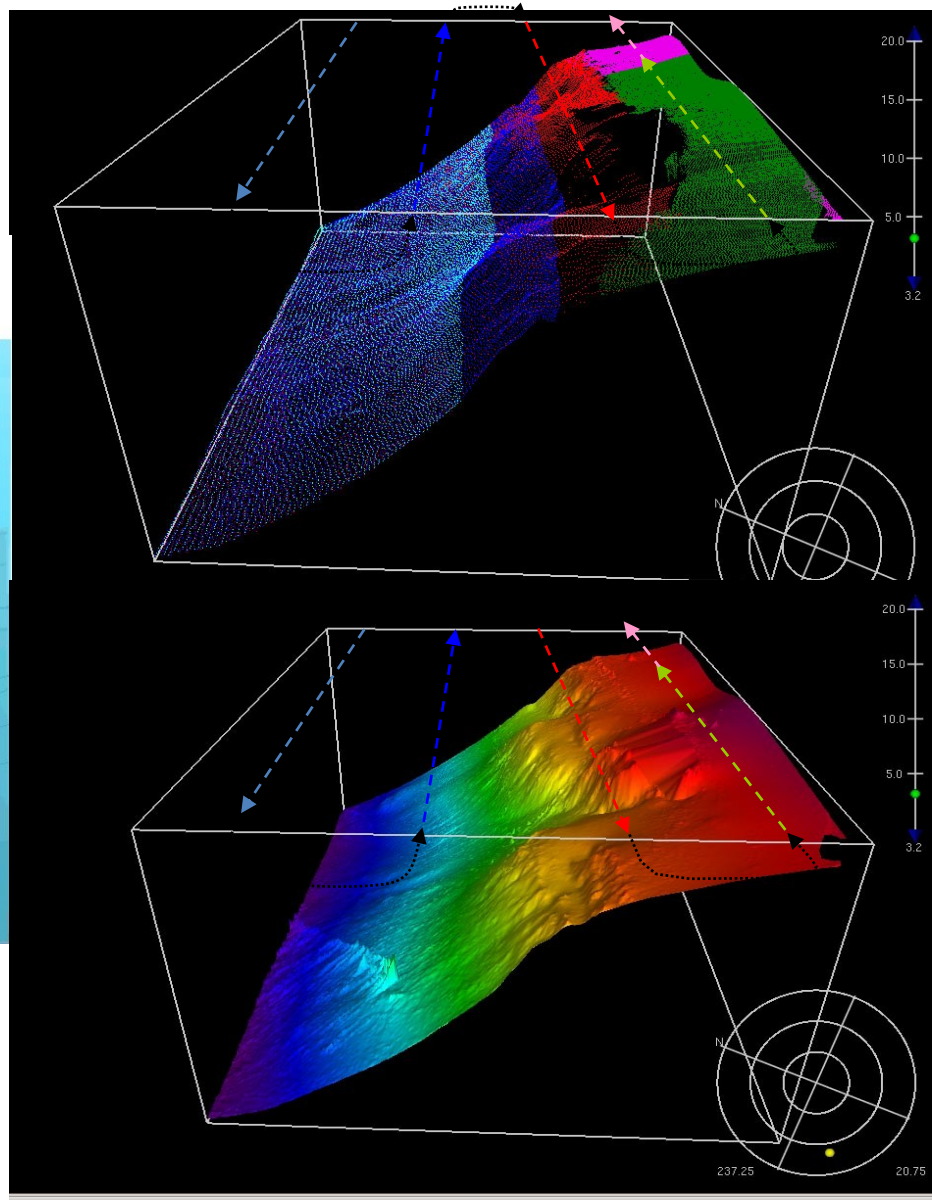




SONAR methods

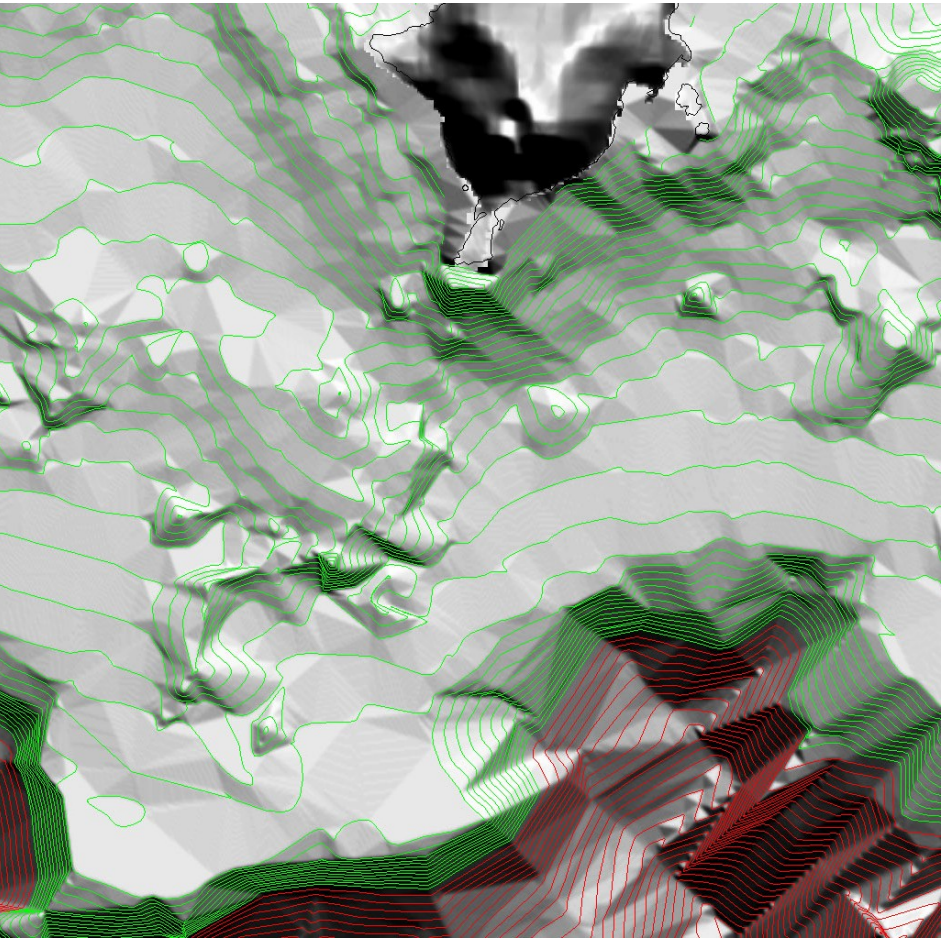


- Reflection
- Back-scattering
- Back-scattered signal at φ

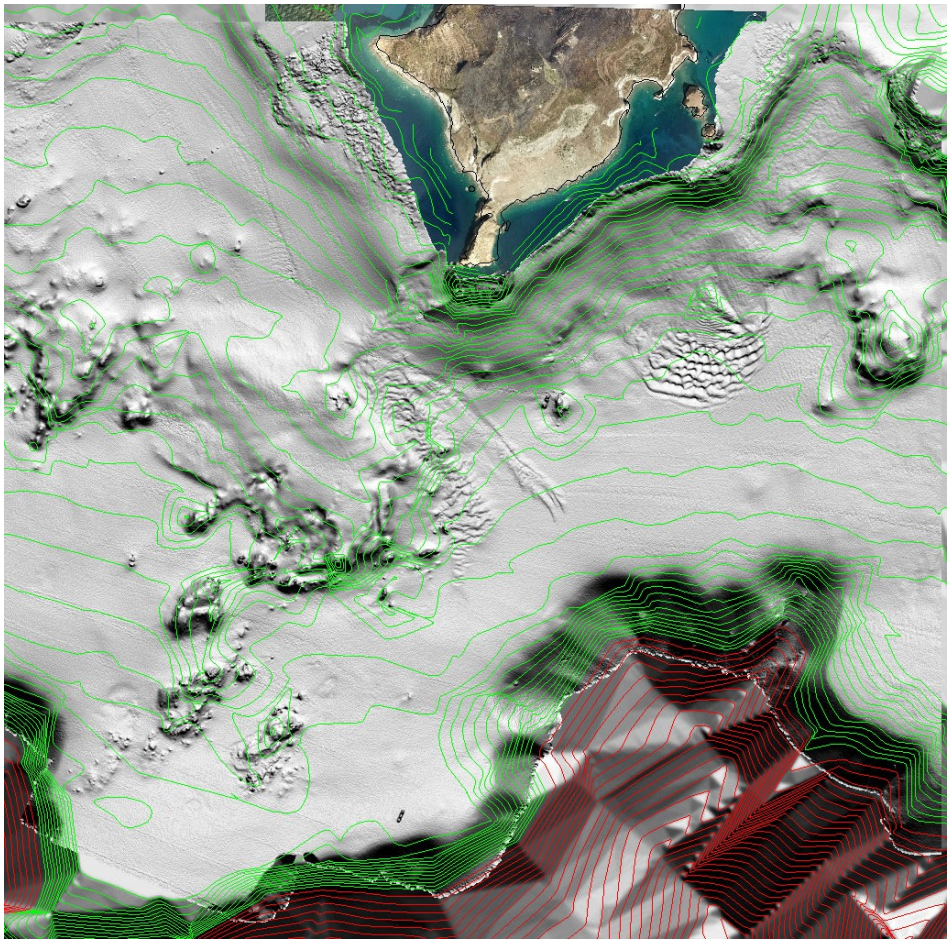


SONAR methods – SBES vs. MBES

SBES



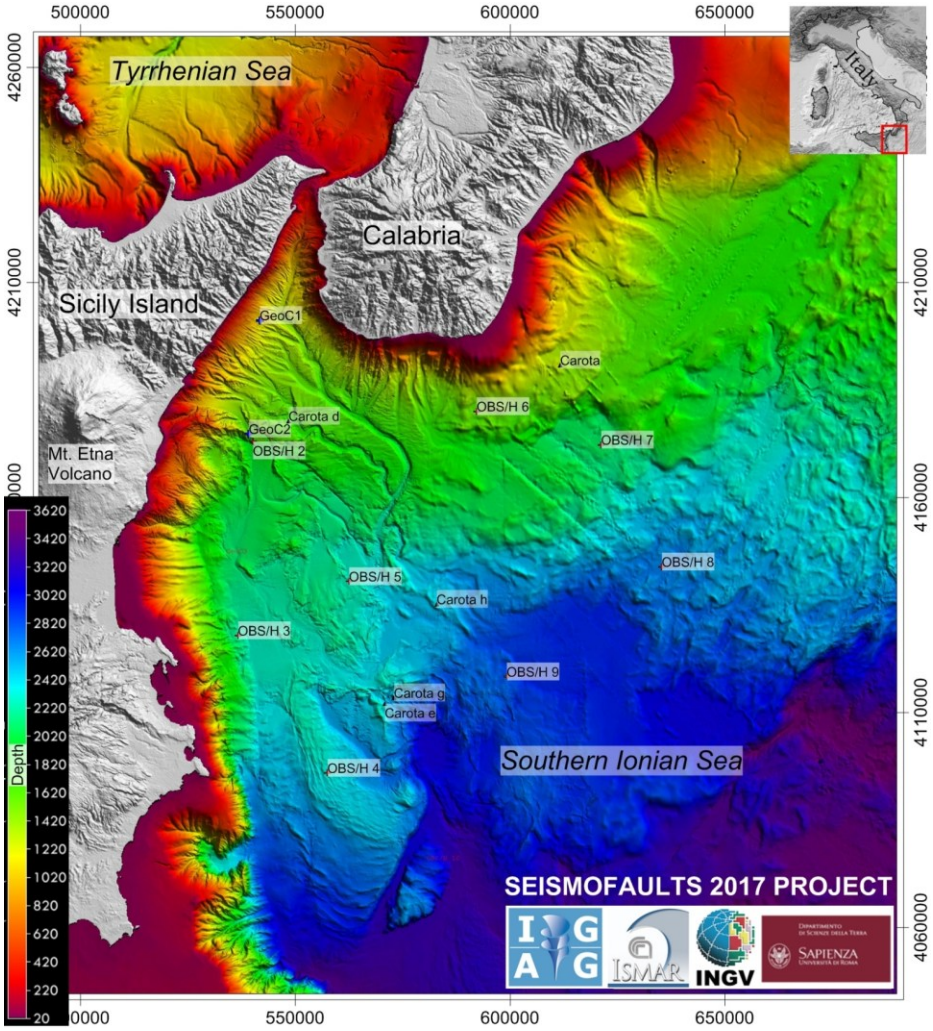
MBES



SONAR methods - Applications

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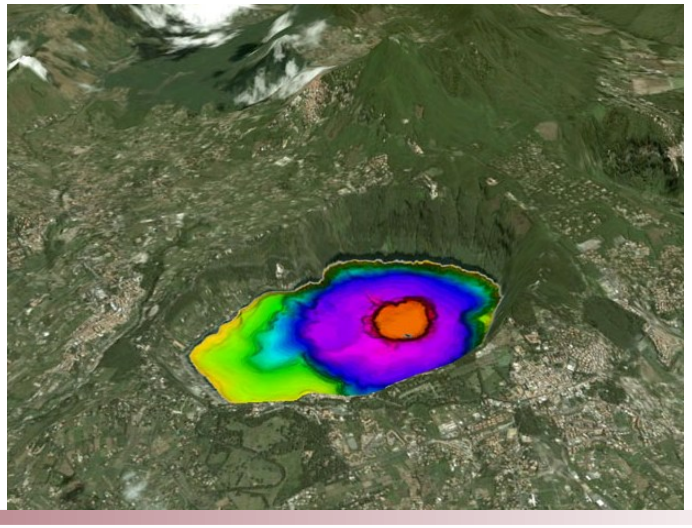
Sea



River



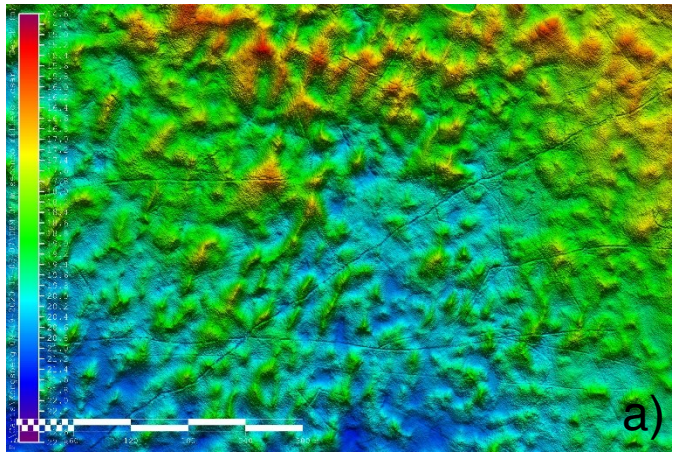
Lake



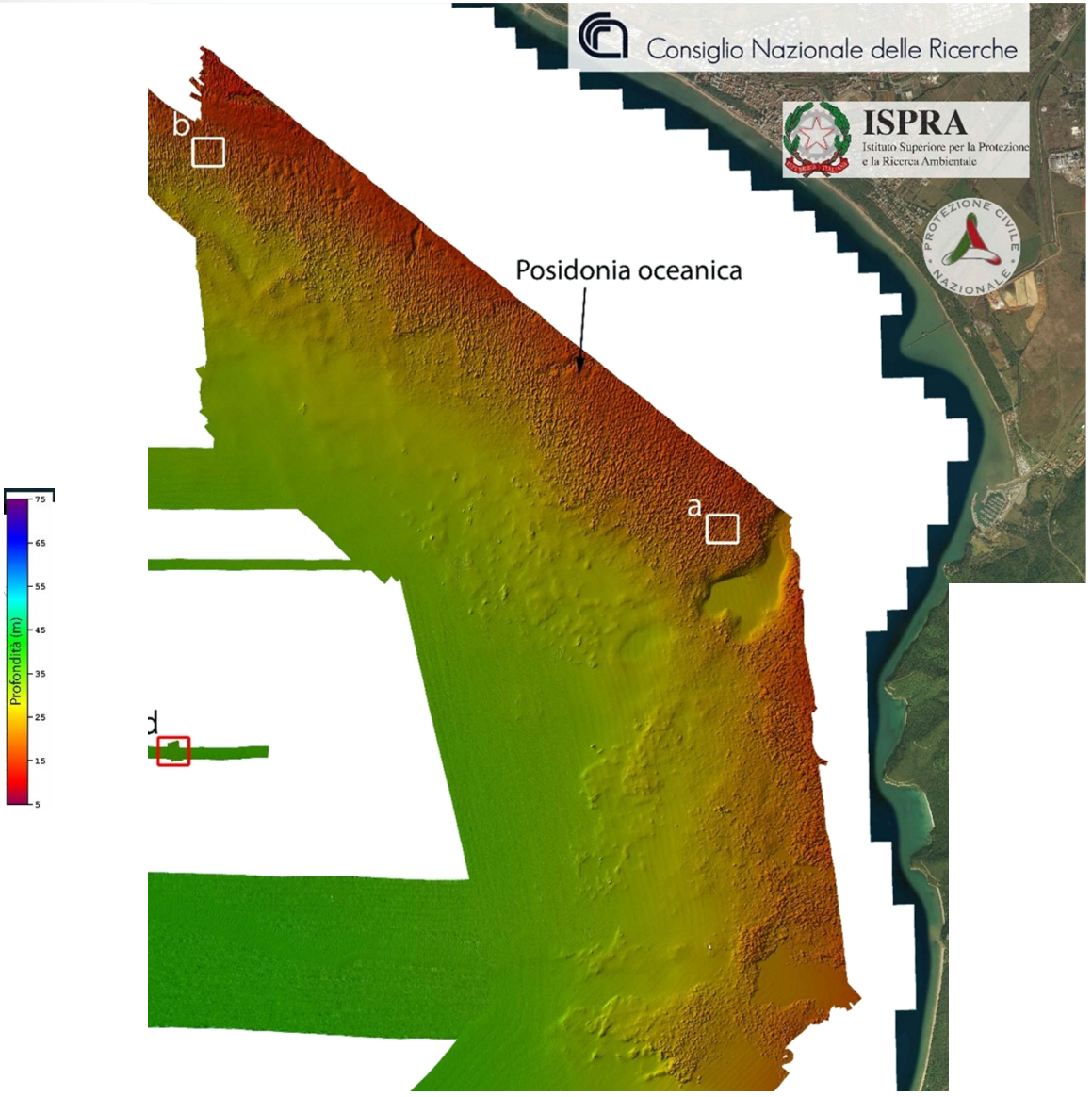
SONAR methods – Applications

- **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

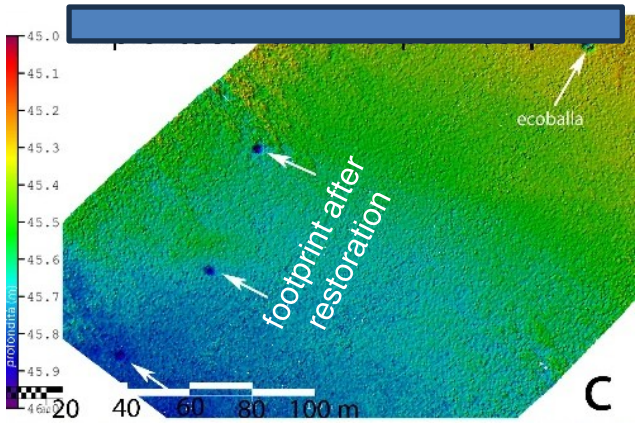
SONAR methods – Marine habitat (*Posidonia O.*)

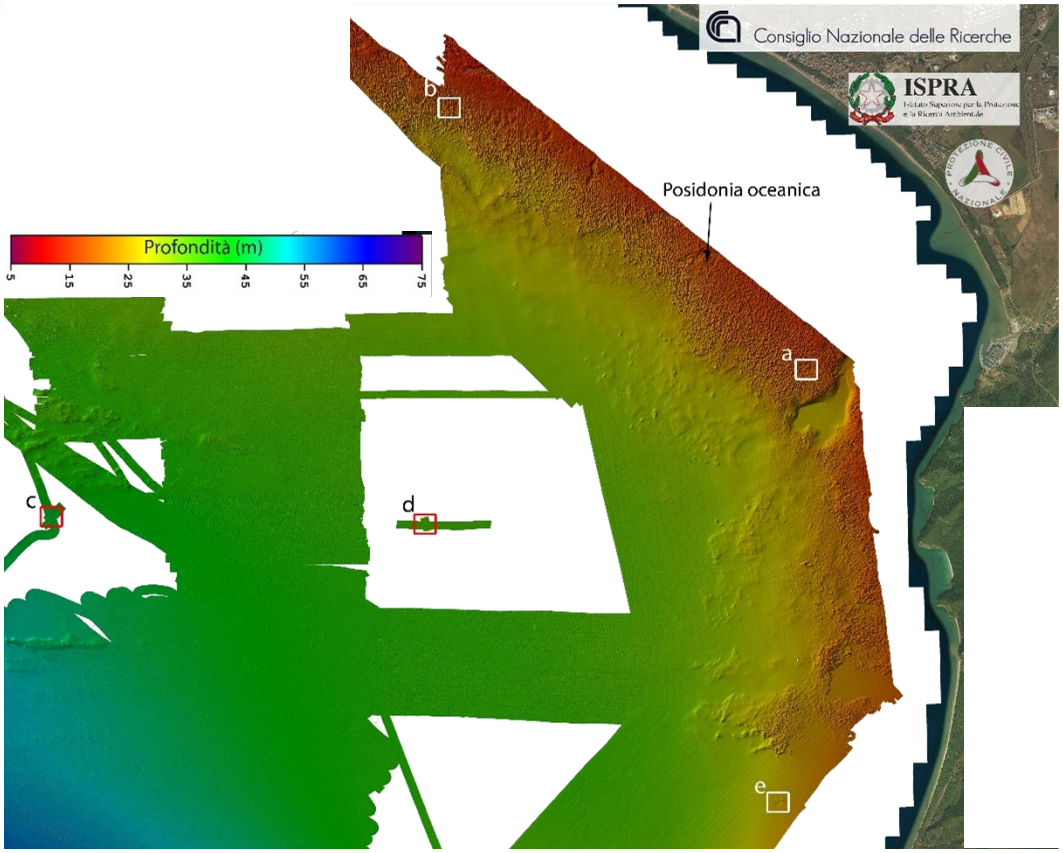




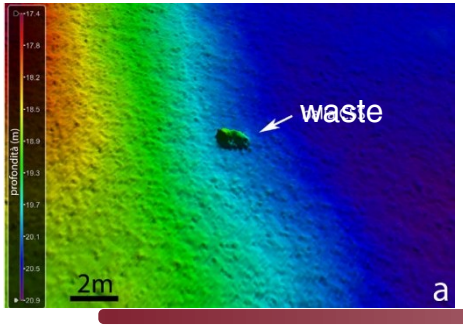


SONAR methods – Waste disposal







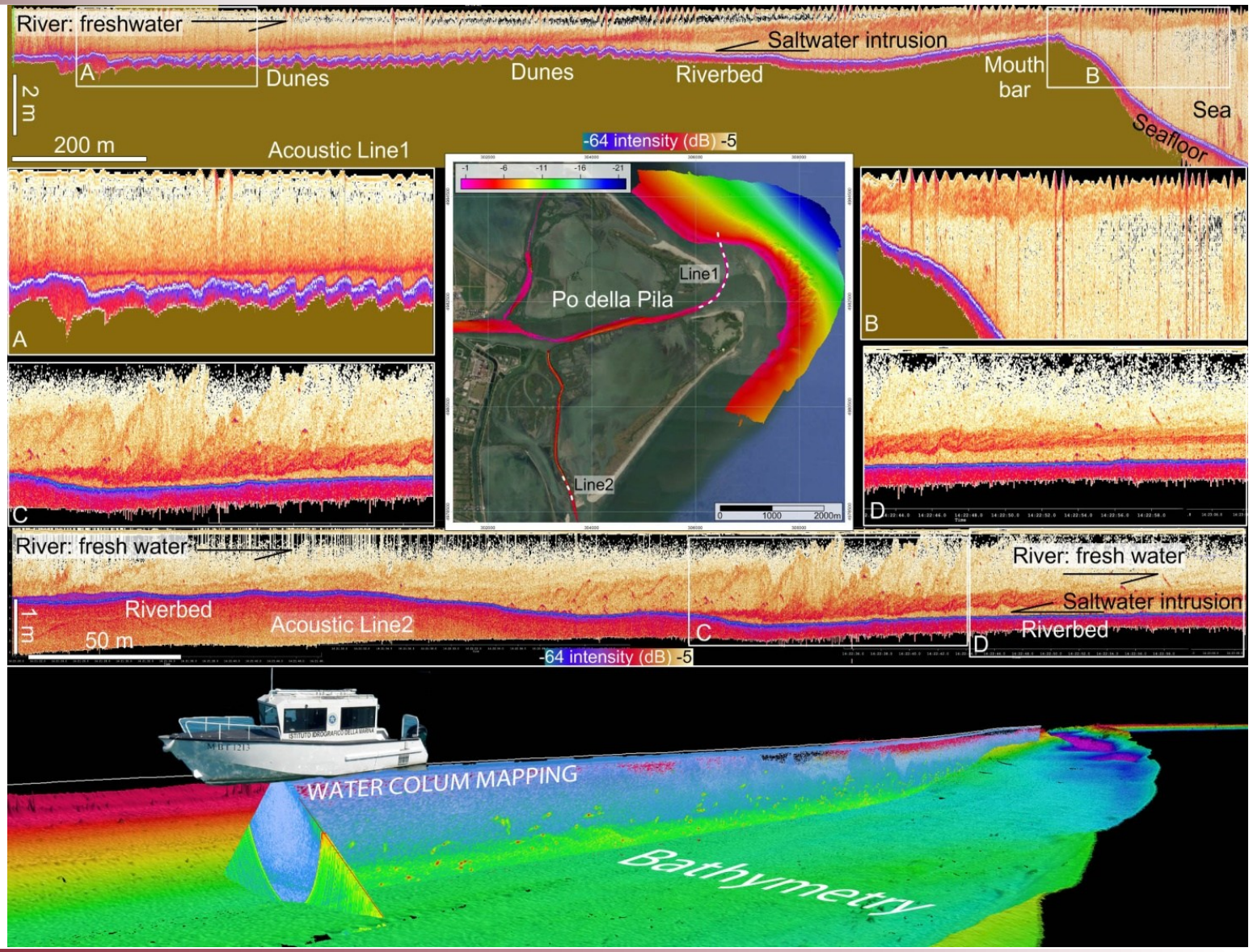




SONAR methods – Saline intrusion

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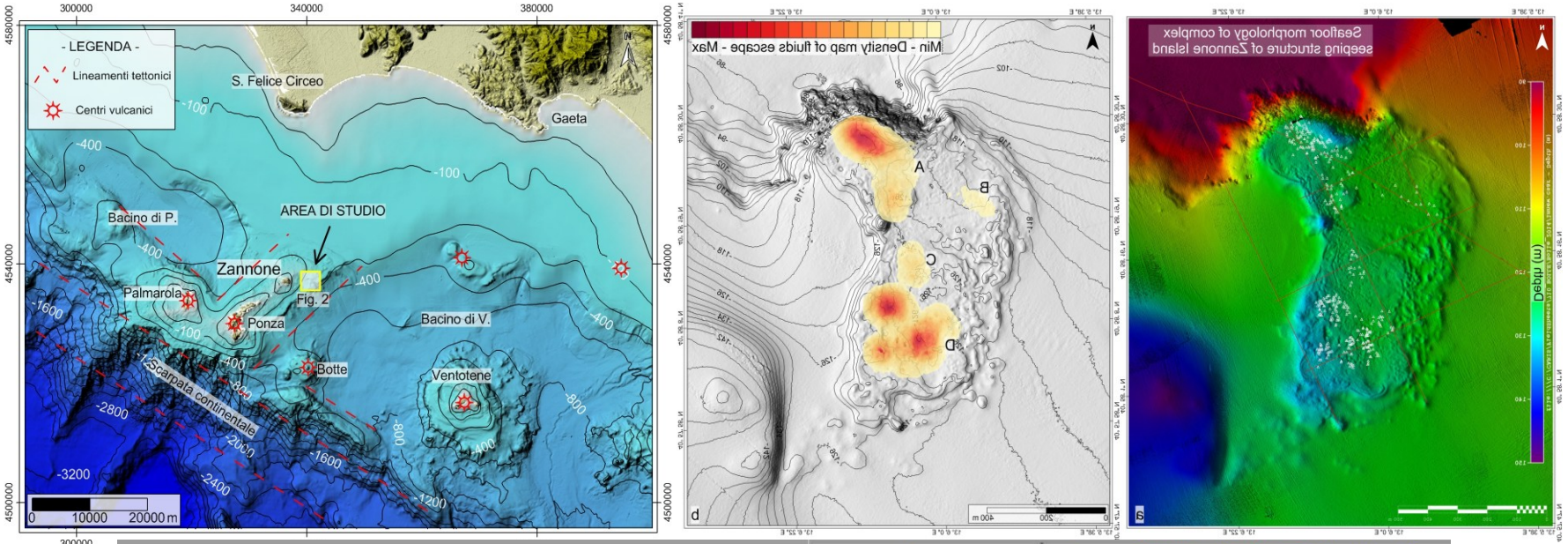
Water Column Data (WCD) to detect saline intrusion at the Po River mouth

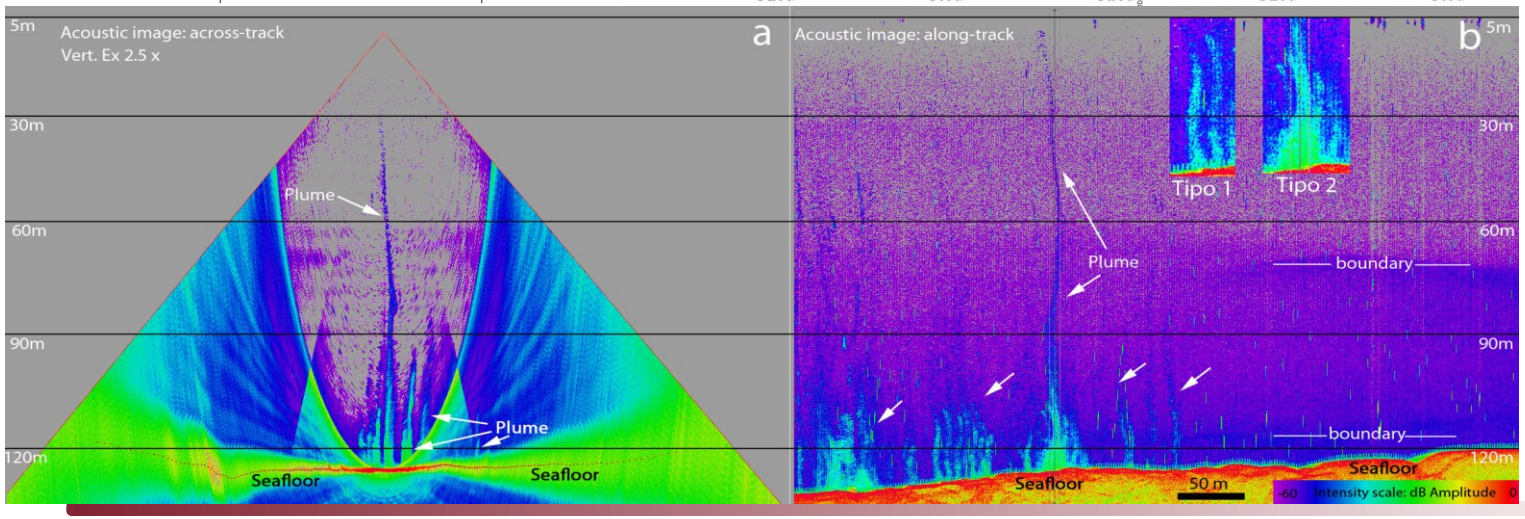


SONAR methods – Hydrothermal fluids

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Upwelling flows of hydrothermal fluids at the Zannone Island

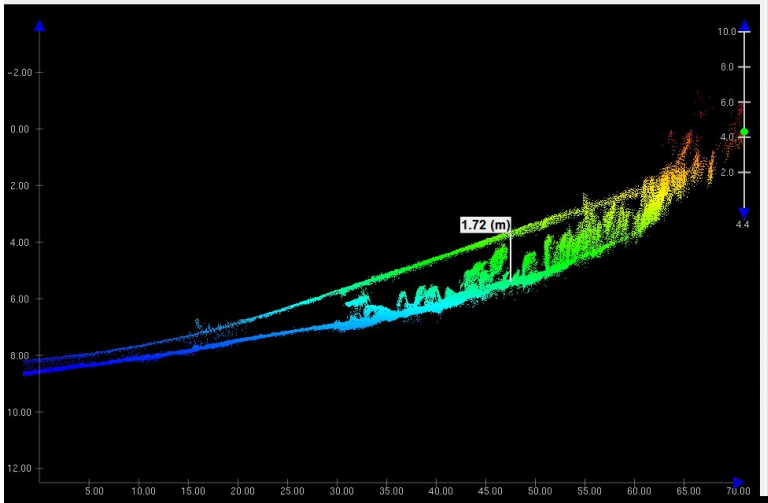


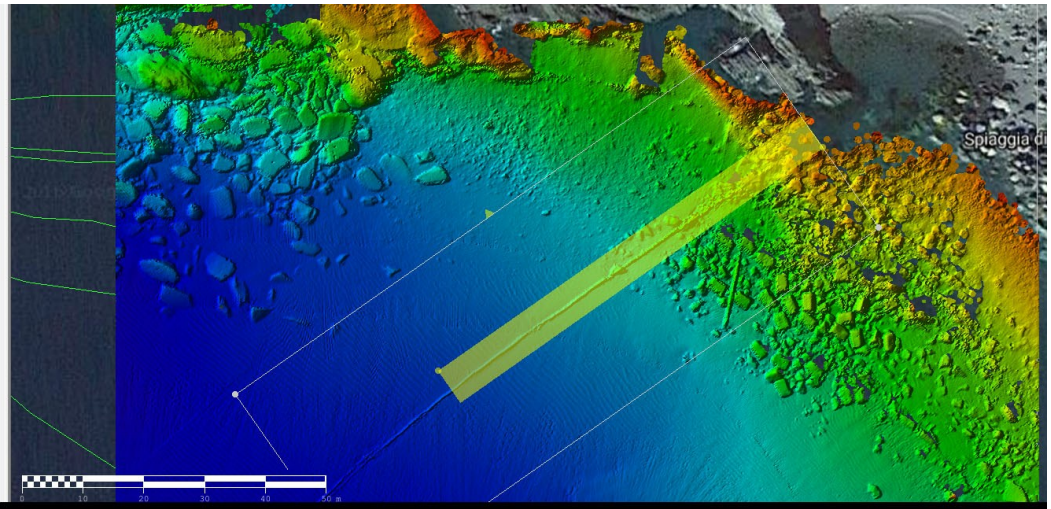


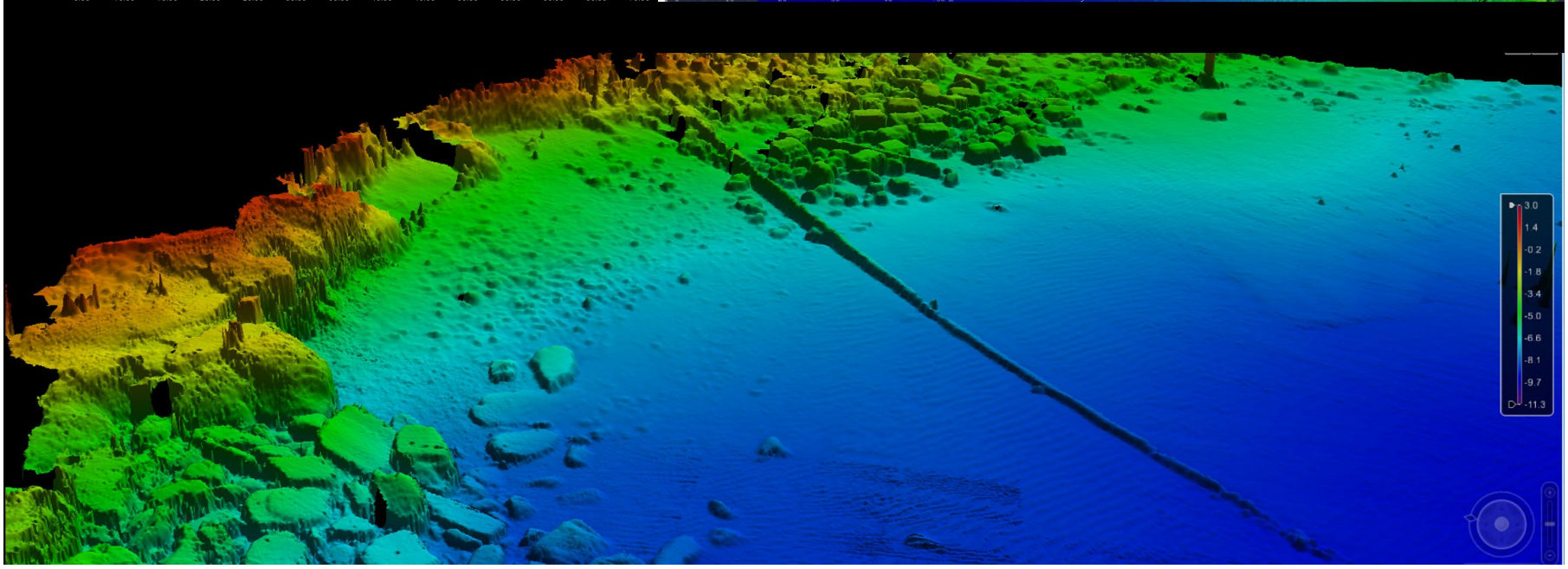
SONAR methods – Pipelines

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2014 Lipari Island



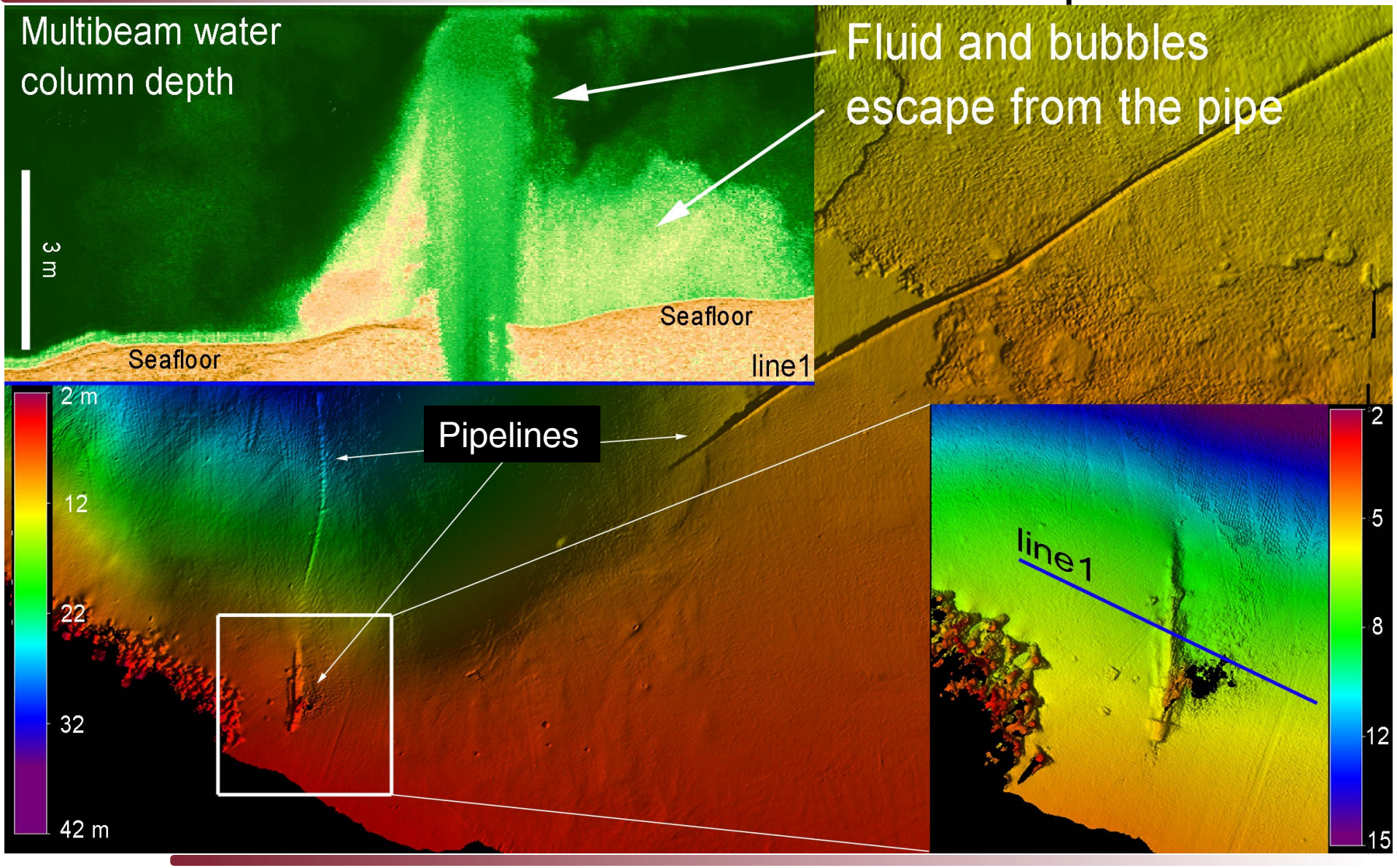




SONAR methods – Pipelines

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2014 Lipari Island

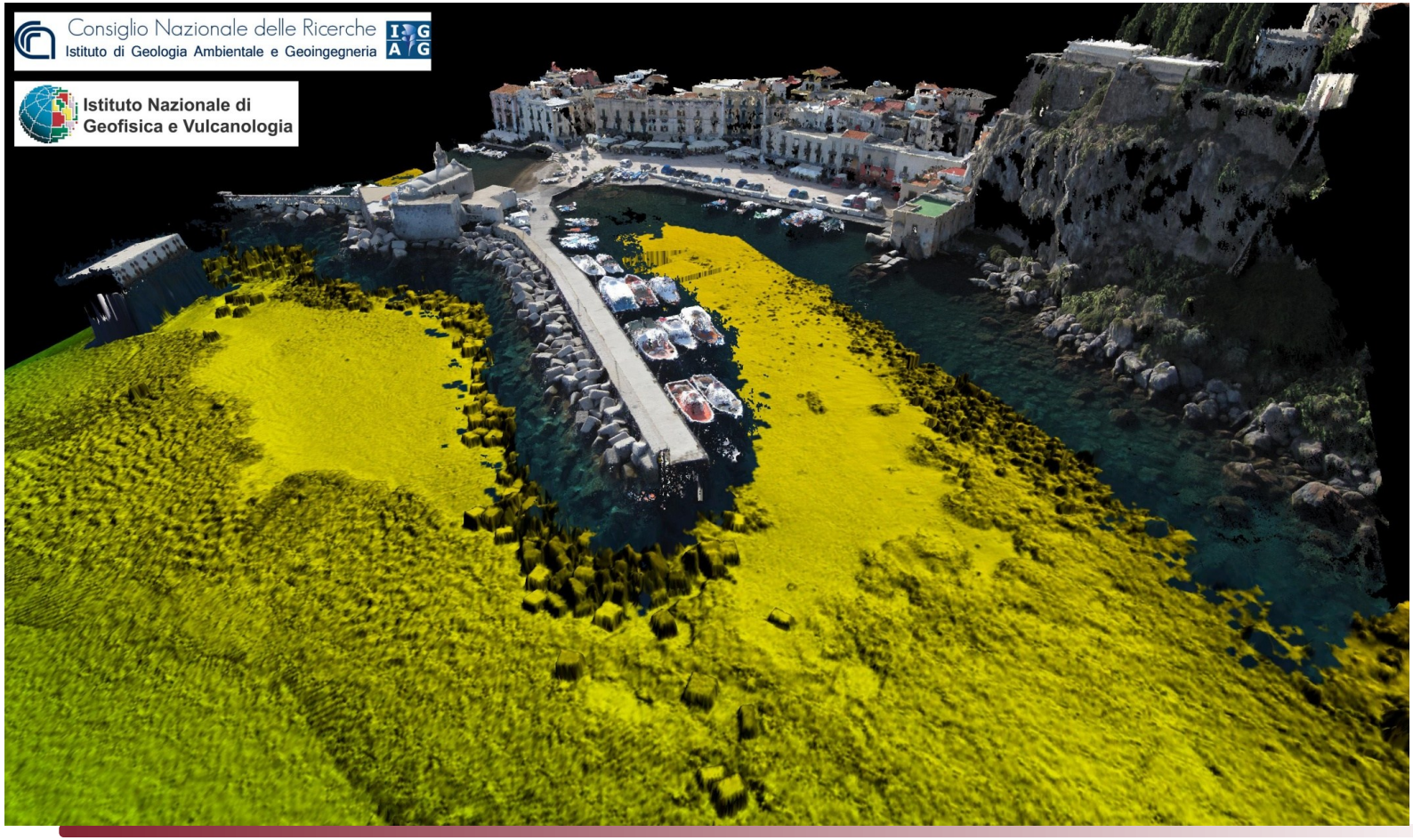


SONAR methods – Climate change

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

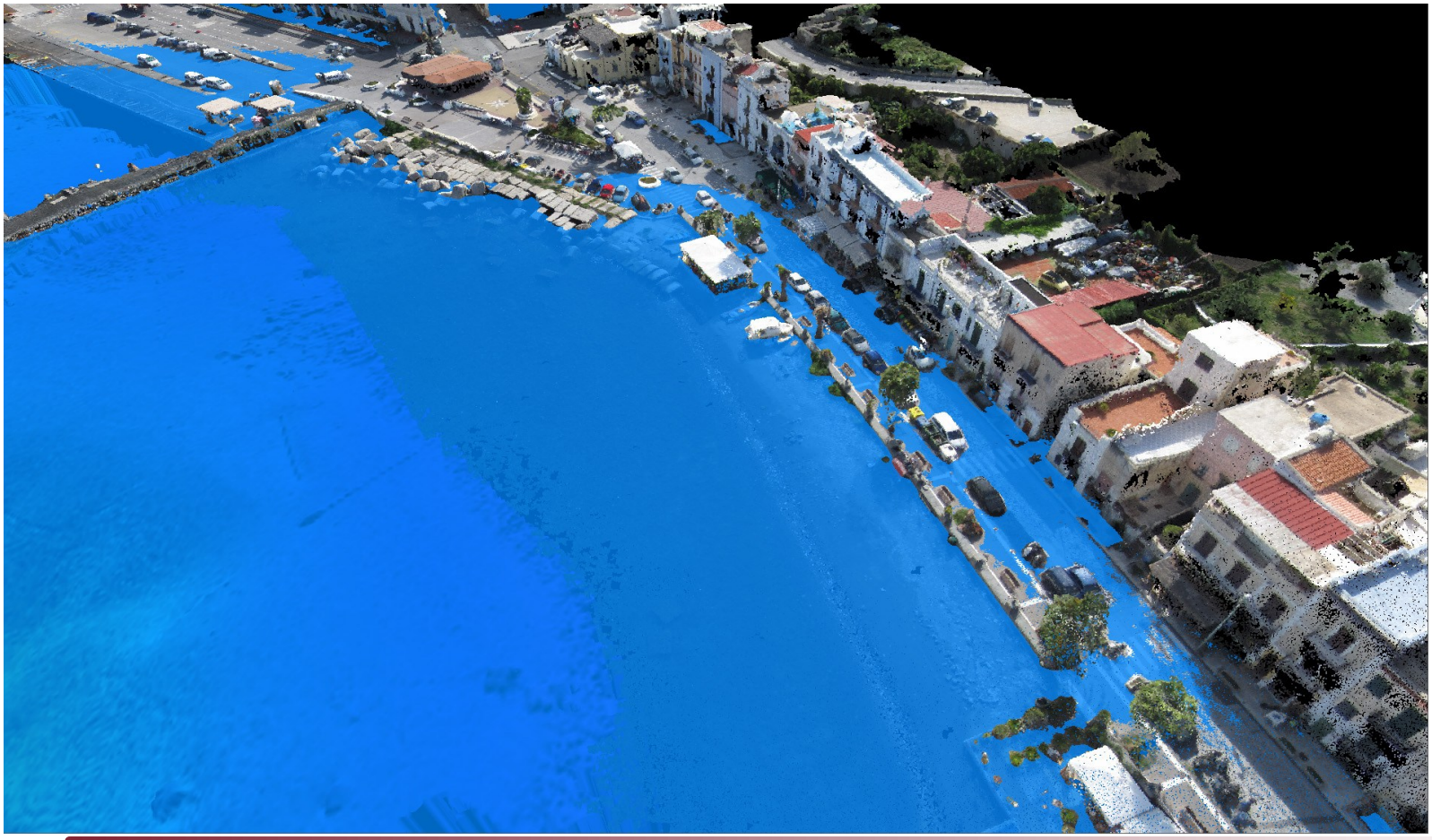
Simulation of sea level rise at a local scale- Marina Lunga Lipari (today)



SONAR methods – Climate change

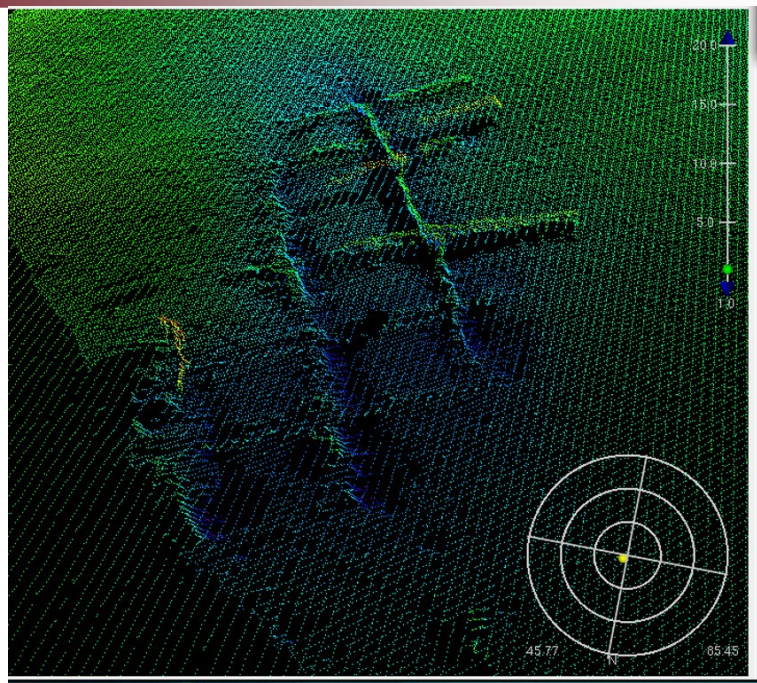
Sea (**MBES**) - shore (**Drone**) high-resolution data for climate change simulation

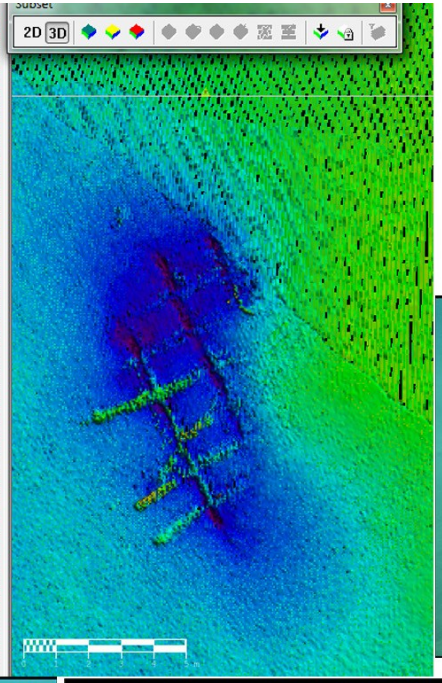
Simulation of sea level rise at a local scale - Marina Lunga Lipari (2100)

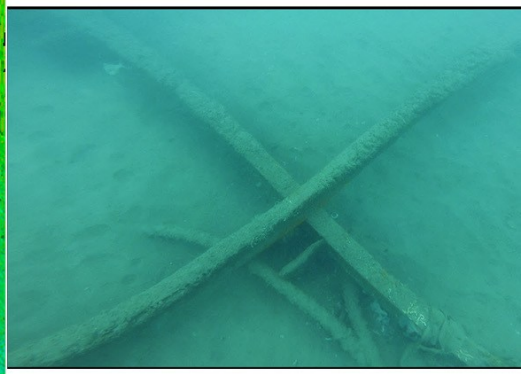


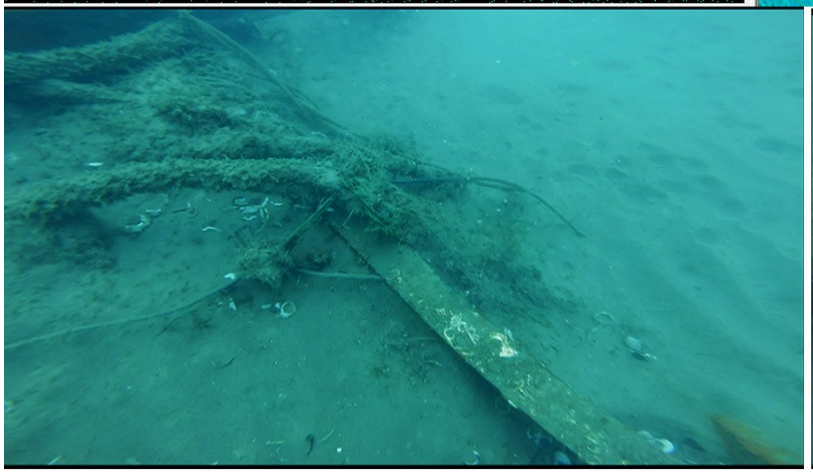
SONAR methods – Submerged strctures

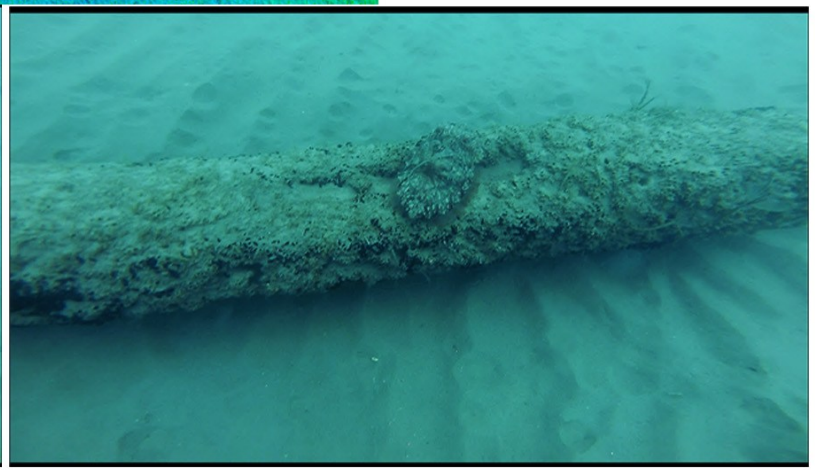
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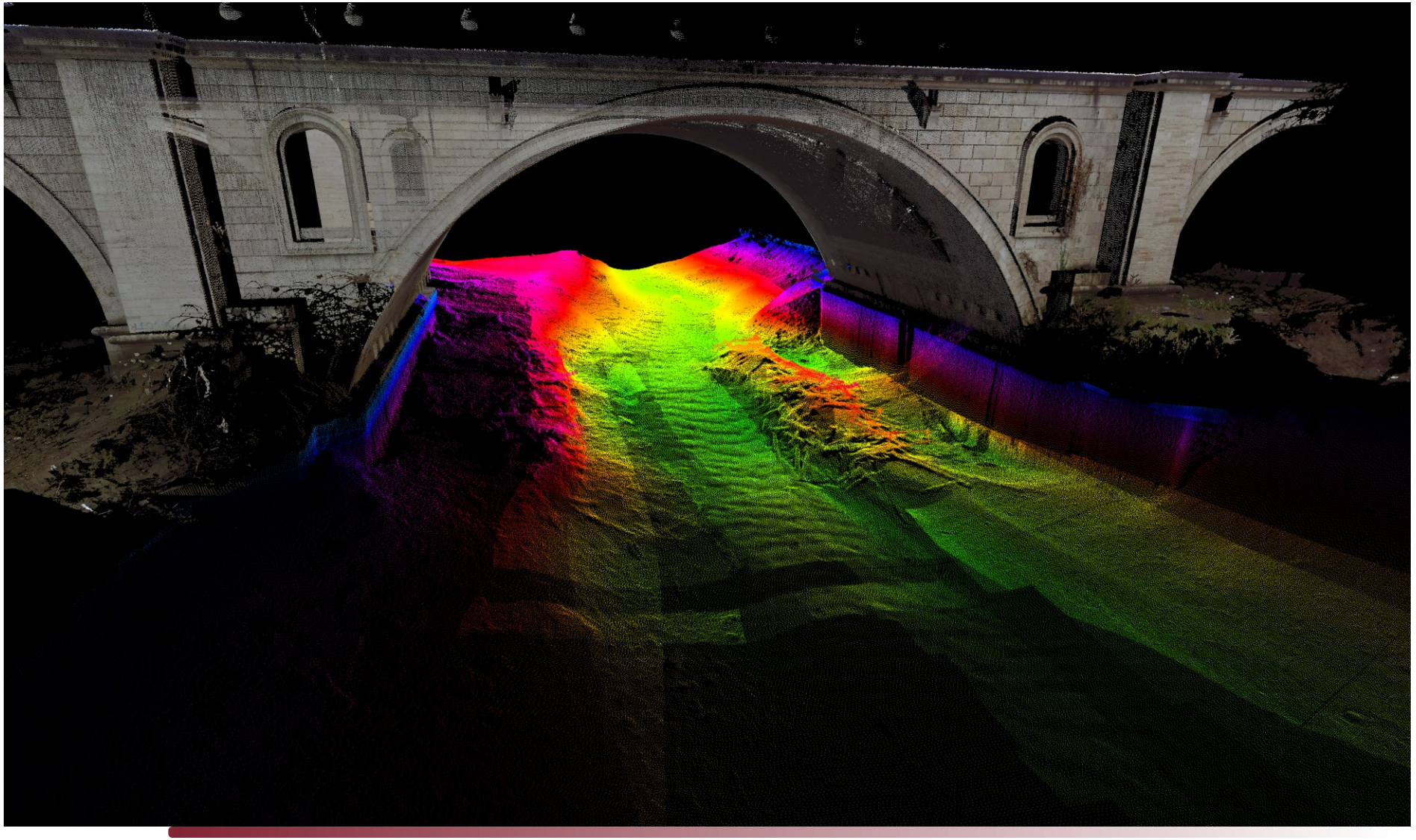






SONAR methods – Bridges

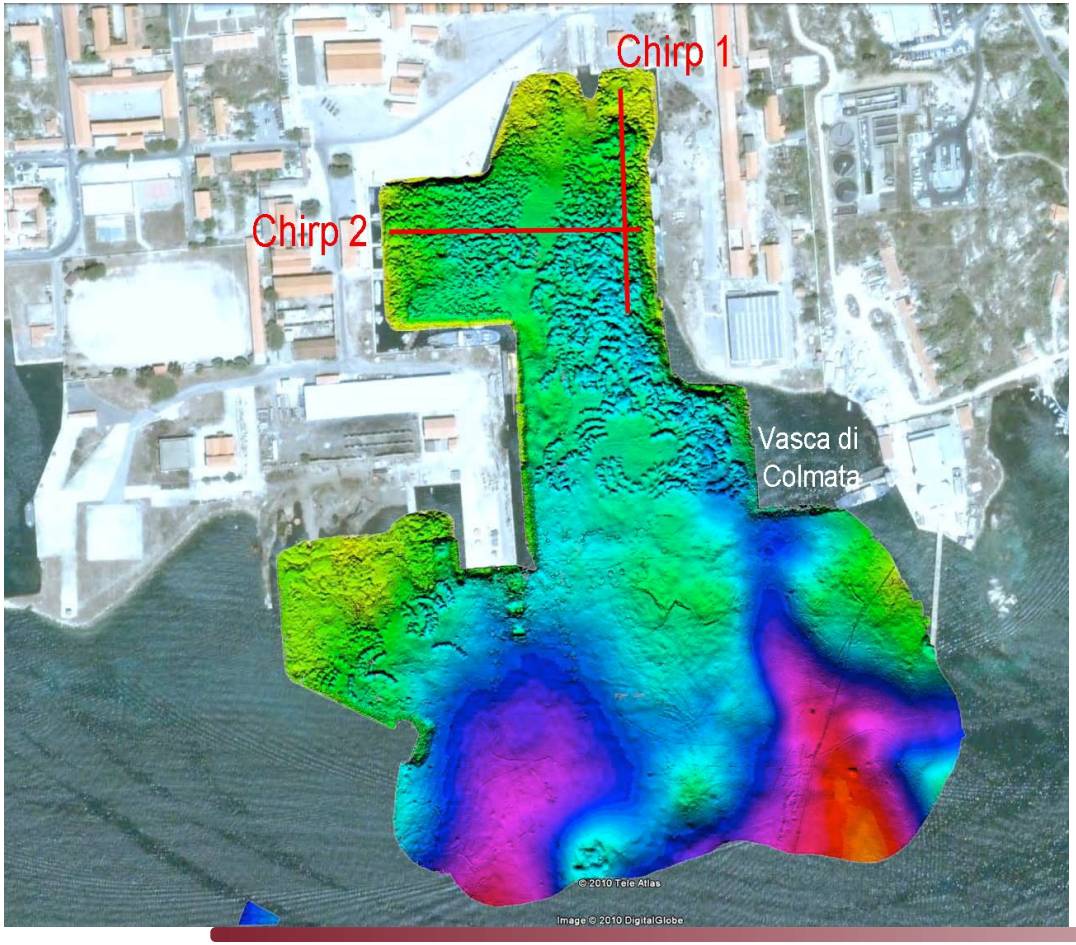
Tiber River: MBES e Laser Scan data



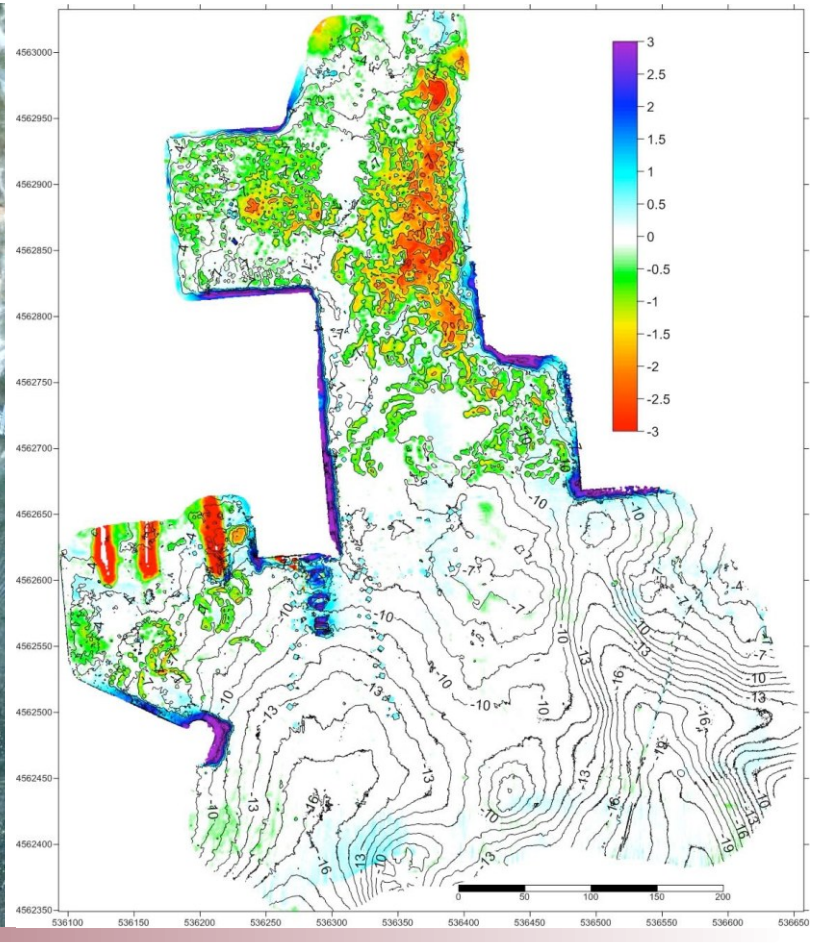
SONAR methods – Dredging

MBES to detect signatures on sea bottom caused by dredging activities

MBES 2008



Differential bathymetry
MBES 2010 – MBES 2008

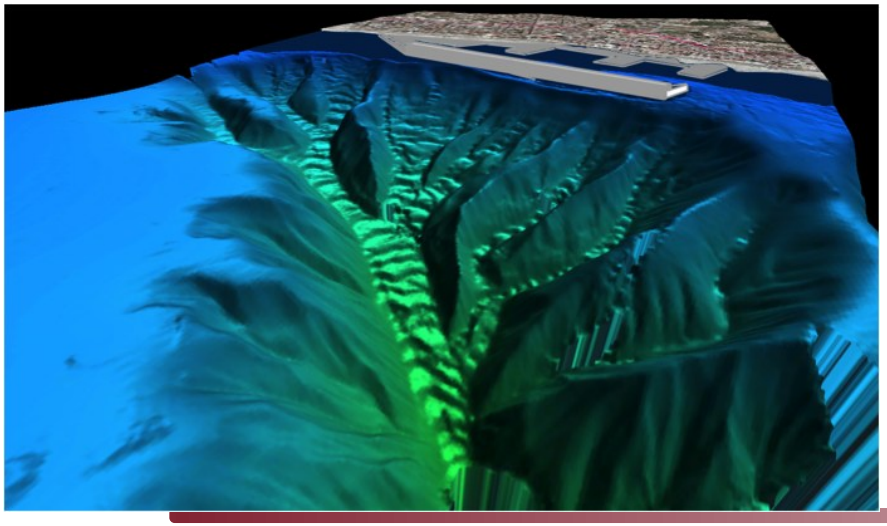


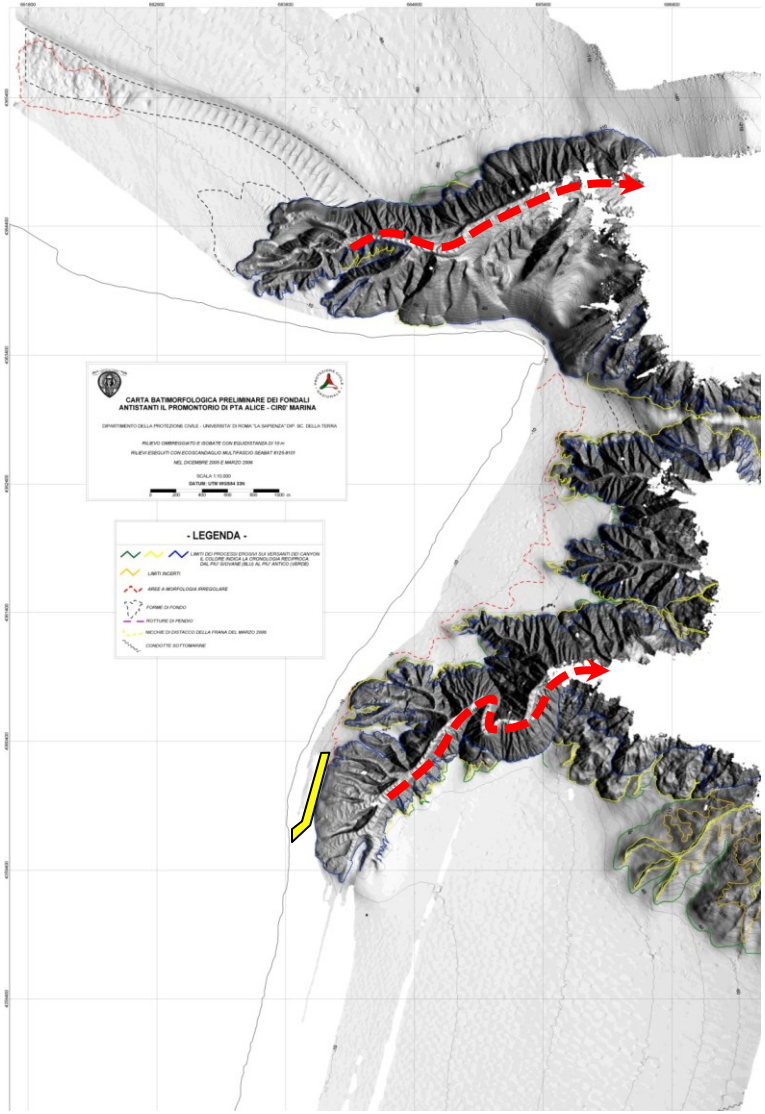
SONAR methods – Coastal engineering

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Monitoring the Cirò Marina port (canyons triggering slope instability)

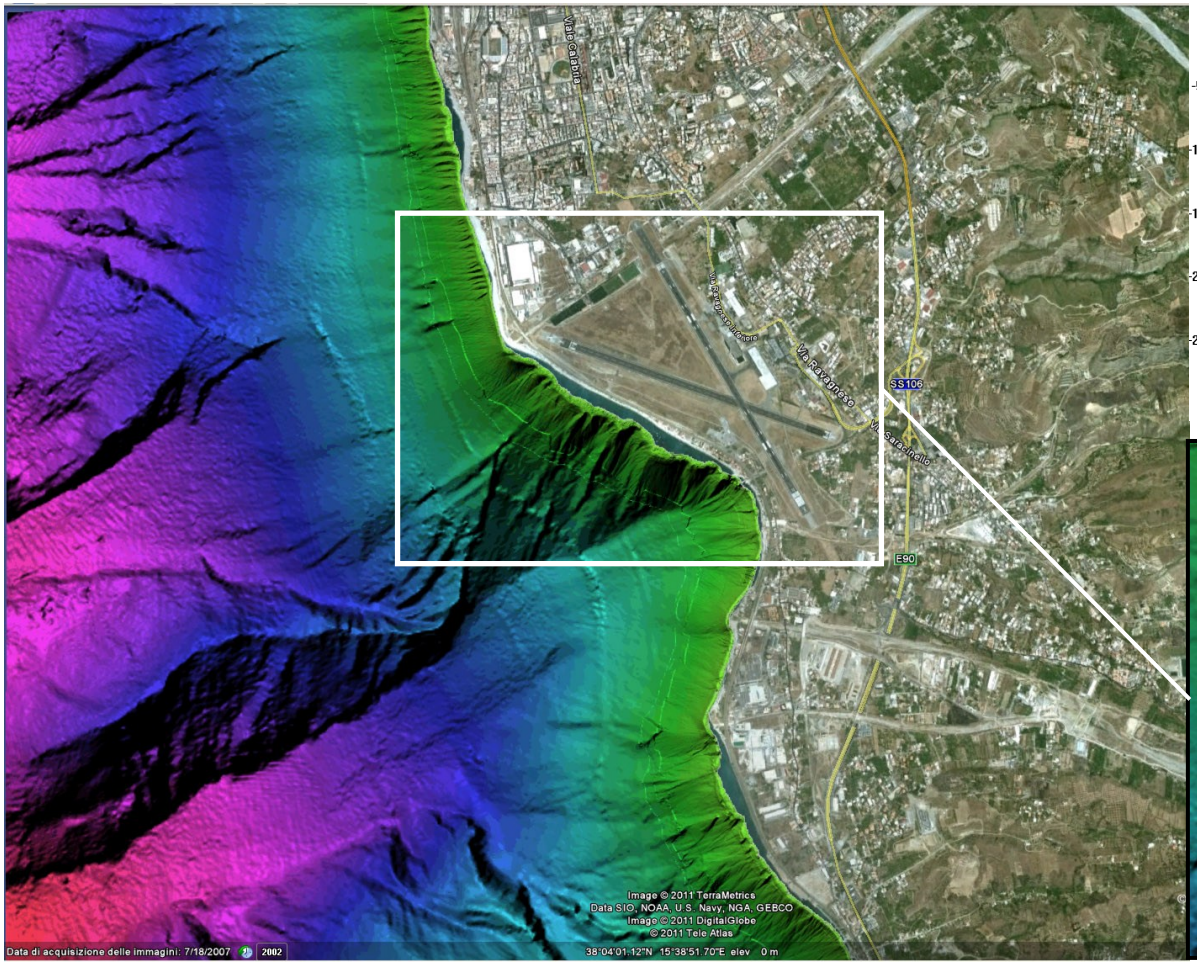


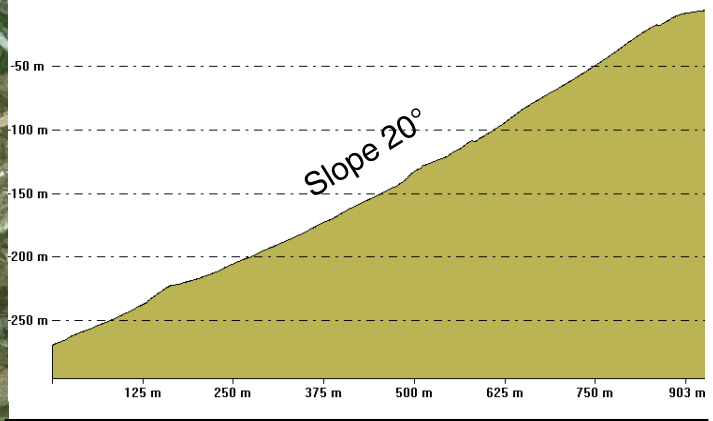




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Monitoring the Reggio Calabria airport (canyons)







SONAR methods – Archaeology

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Archaeological remains at the Tiber River (Rome)

