Robotique d'Exploration en milieu confiné noyé :

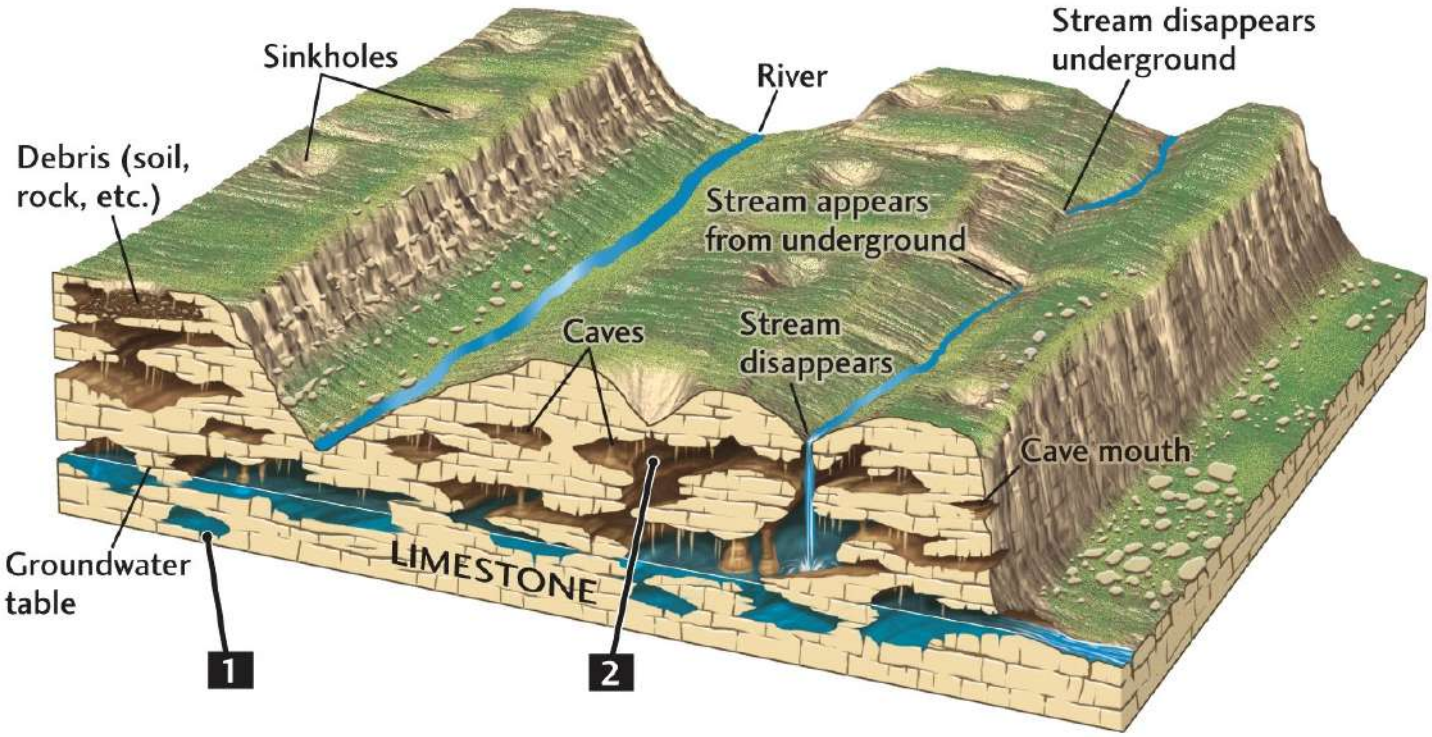
Exploration Karstique,

les besoins en nouveaux capteurs

lionel.Lapierre@ensta-Bretagne.fr

KARST : DEFINITION

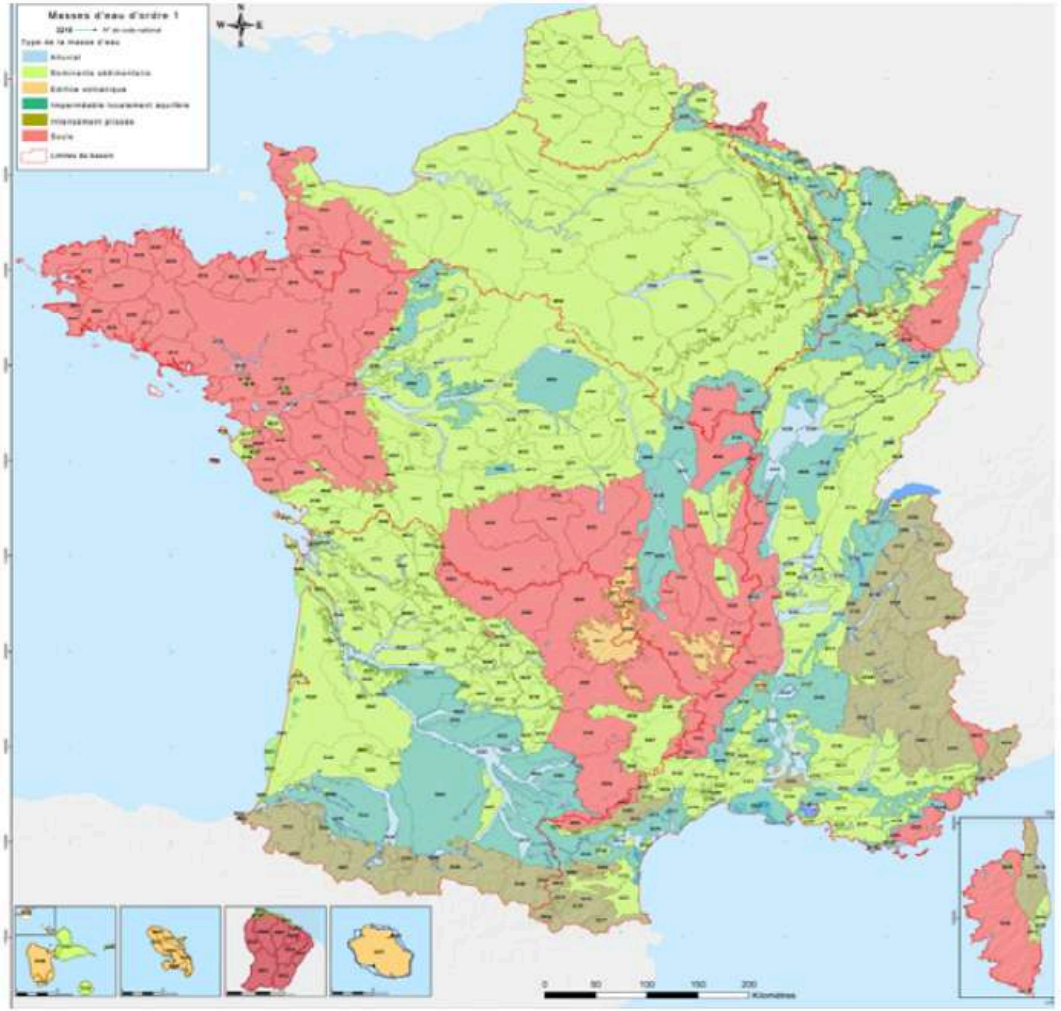
- A topography formed from the dissolution of soluble rocks such as limestone, dolomite, and gypsum,



- Characterized by **underground drainage hydrosystems** with sinkholes and caves.

KARST : GROUNDWATER RESERVOIR

KARST : GROUNDWATER MANAGEMENT, A NATIONAL ISSUE



+ 50% of Drinking Water Supply

Service National d'Observation
du KARST,
SNO INSU/CNRS
OSU OREME (UM)
Coordinator H. Jourde

Carte hydrogéologique des formations carbonatées karstifiables (EASAC report)

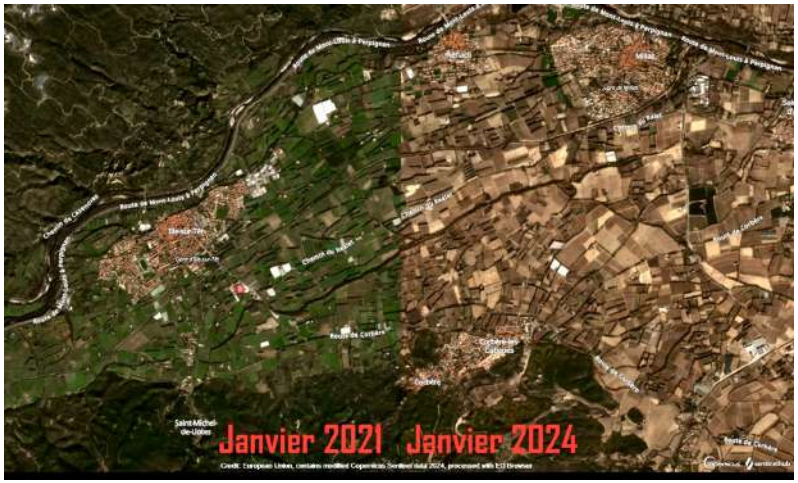
Le Monde

UNE SÉCHERESSE CRITIQUE S'INSTALLE DANS LE BASSIN MÉDITERRANÉEN

- Dans toute la région, le déficit de précipitations devient peu à peu la norme
- Les effets sur l'agriculture et l'alimentation en eau potable sont rapides et importants

PAGES 8-9

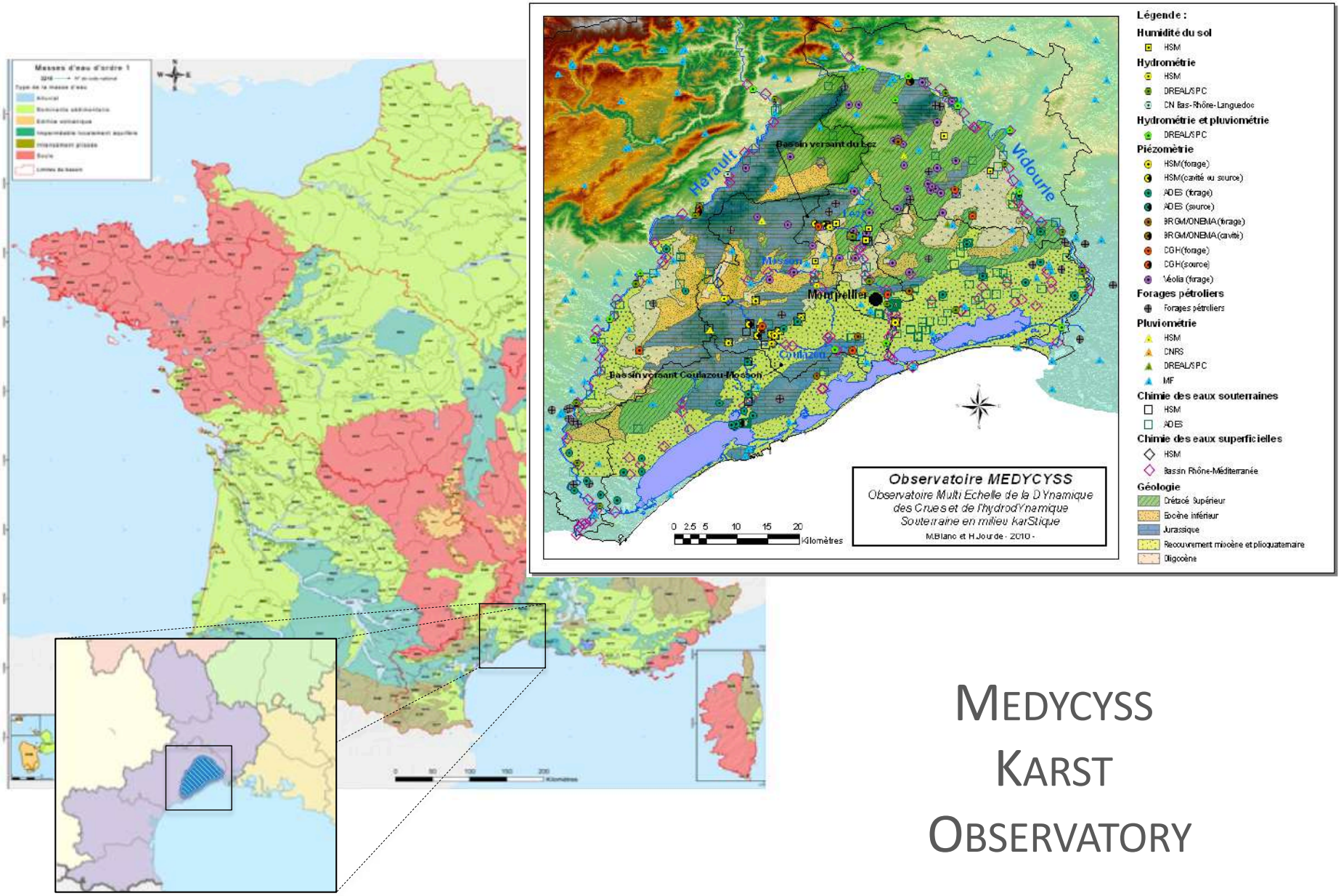
Edition du 19/03/2024



Les PO

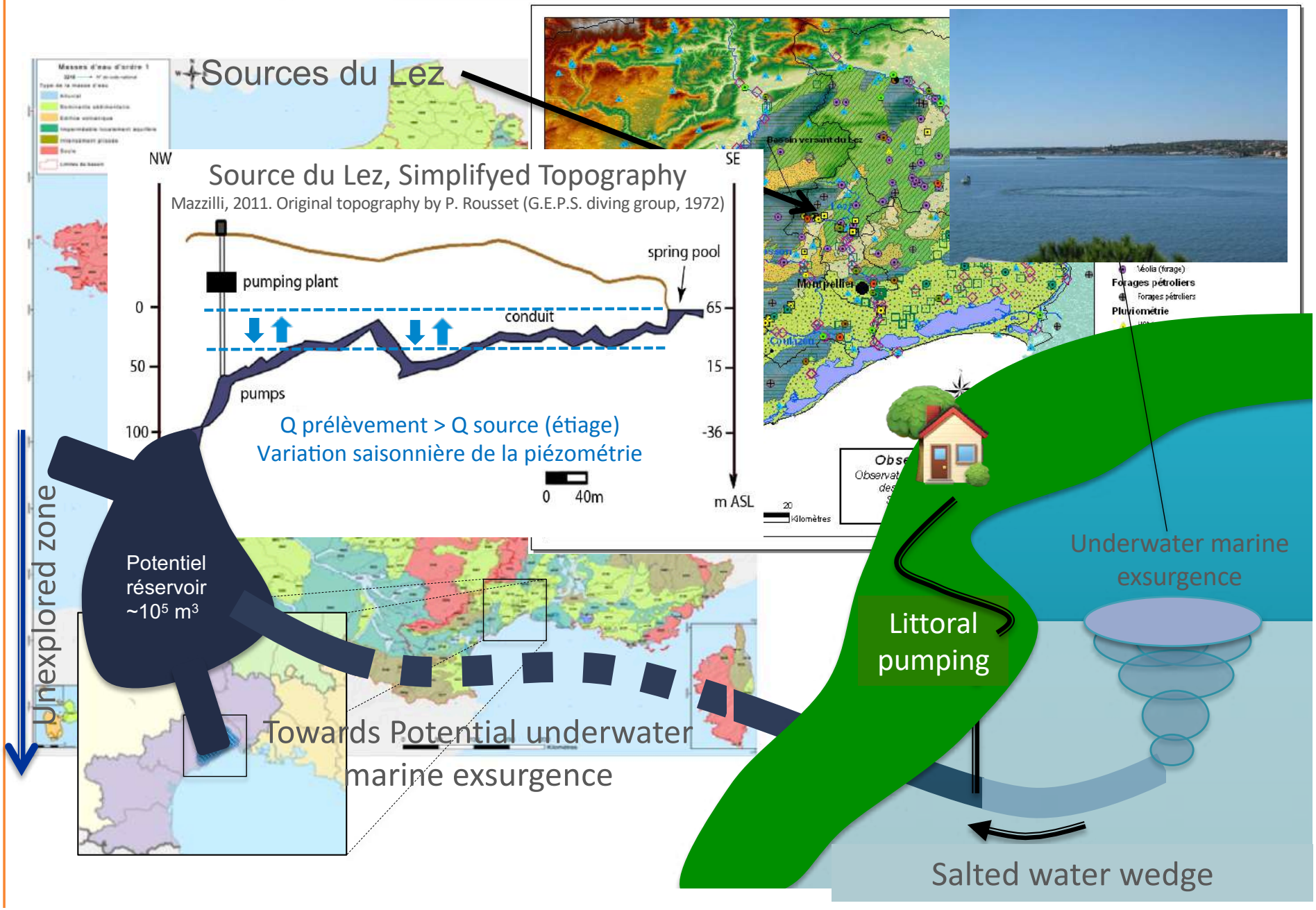
La Loire 21/10/2023

Montpellier's Catchment Basin : a Seminal Case Study

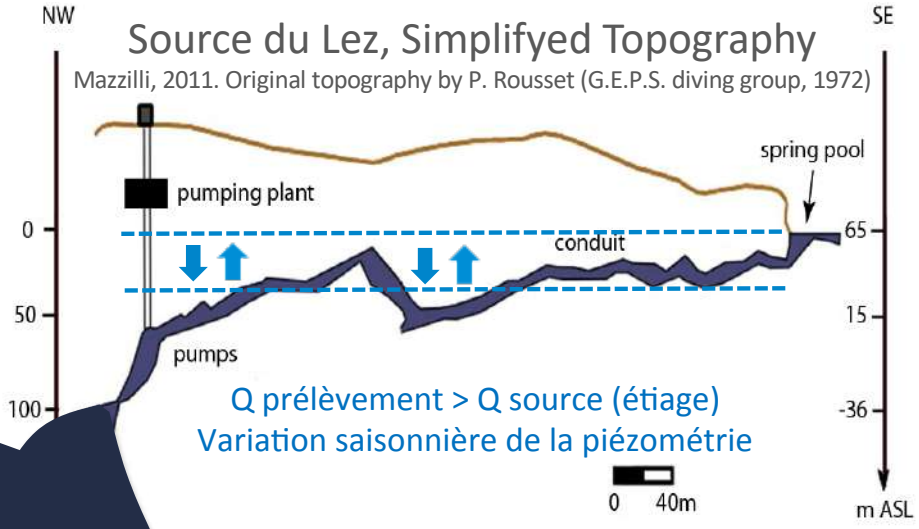


Medycyss
Karst
Observatory

Sources du Lez : a Seminal Case Study



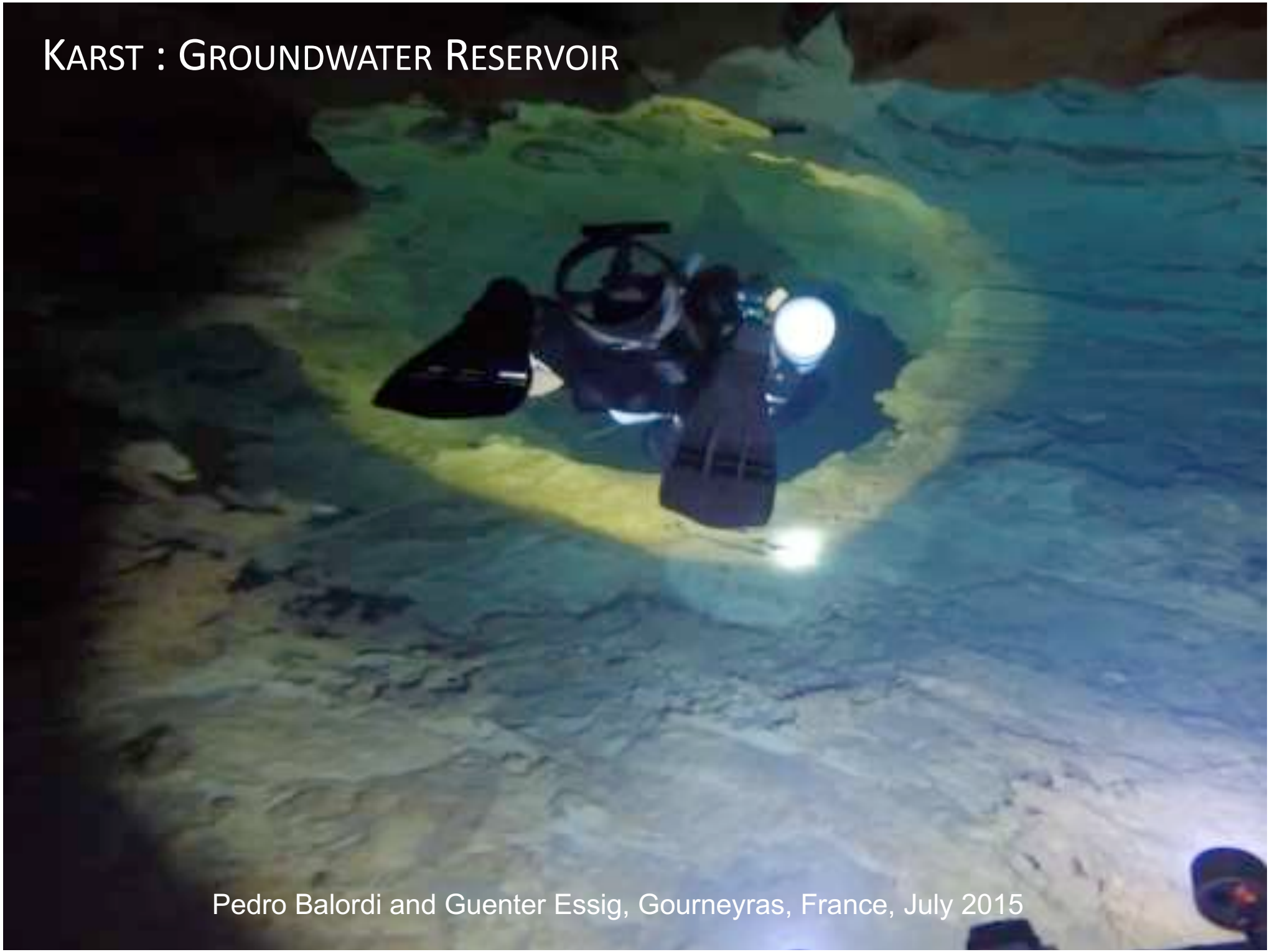
Sources du Lez : Active Management of GW Resource



A European Concern

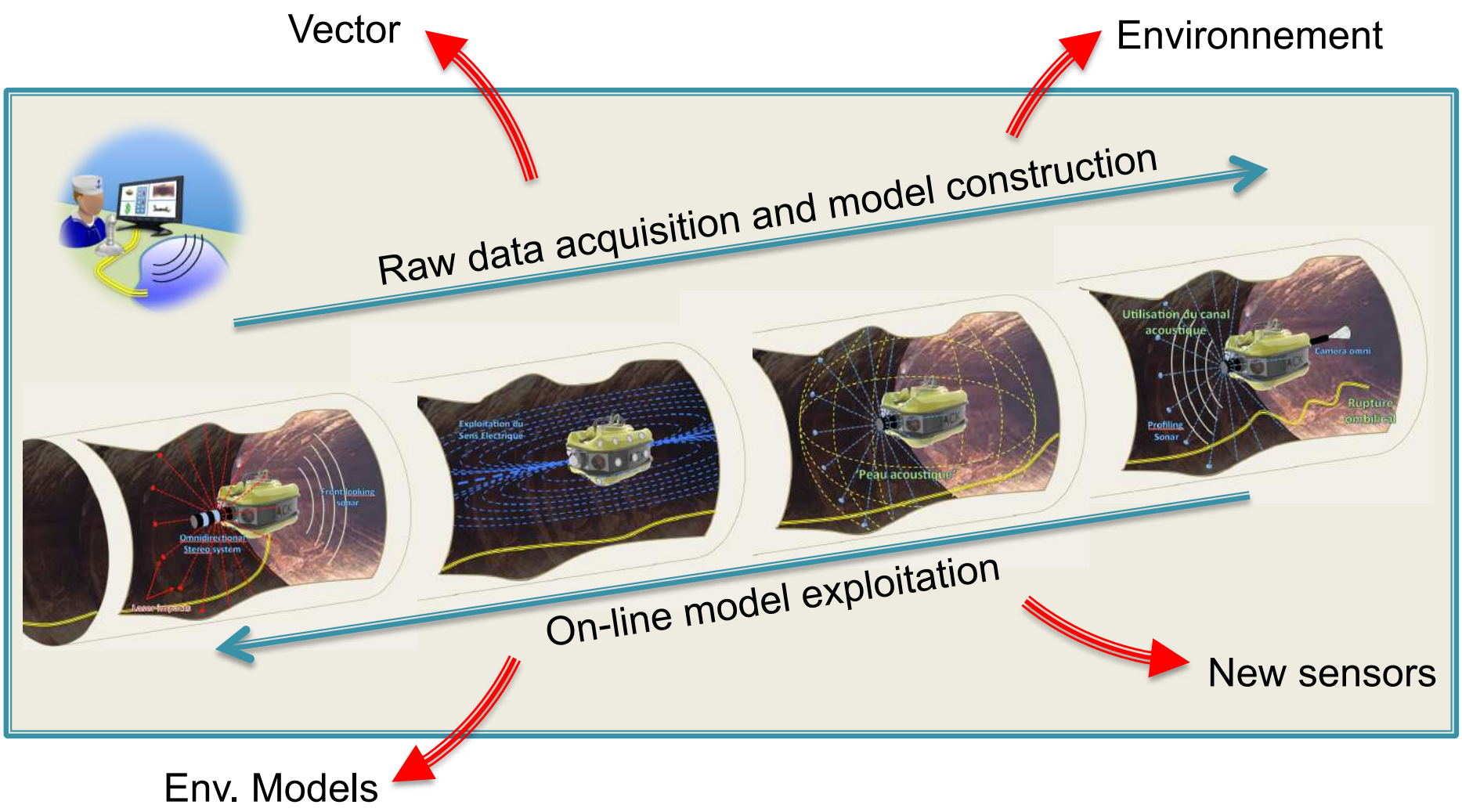
- **Sources du LEZ, Les Fontanilles, Gourneyrou, Fontaine de Nîmes, Source de la Touvre, Font Estramar, Fontaine de Vaucluse, *Ombla*, *La Falconera…***

KARST : GROUNDWATER RESERVOIR



Pedro Balordi and Guenter Essig, Gourneyras, France, July 2015

RKE : Global Principles



The RKE Initiative : The Challenges

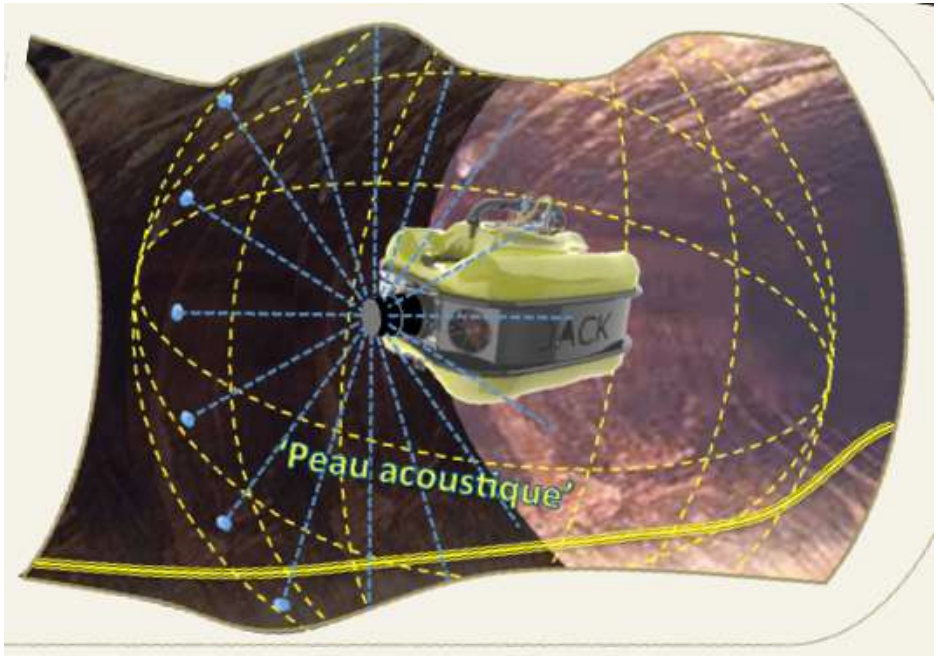
- **New Sensors Development**
  - Acoustic Skin
  - Active Umbilical
- **Navigation**
  - Glob Nav Syst
  - n-D Acoustic, Int. Grid SLAM
  - Vacancy Evidence Grids
- **Guidance**
  - Autonomous Centring
  - Autonomous Targeting
  - Env. Models inclusion
- **Control**
  - Robustness
  - Co-control
  - Open-loop stability
- **Actuation**
  - Reactive redundant A.S.
  - Variable Geometry A.S.
- **Software Architecture**
  - Management of sensors recruitment (acc. jamming)
  - Adaptive Autonomy
  - Dependability & GoP
- **Models**
  - Multi-modality & Scalability
  - Uncertainty Consideration
- **Technology**
  - Active Truncanner, NRJ opt.
- **Economic**
  - Evangelization of a Blue Ocean

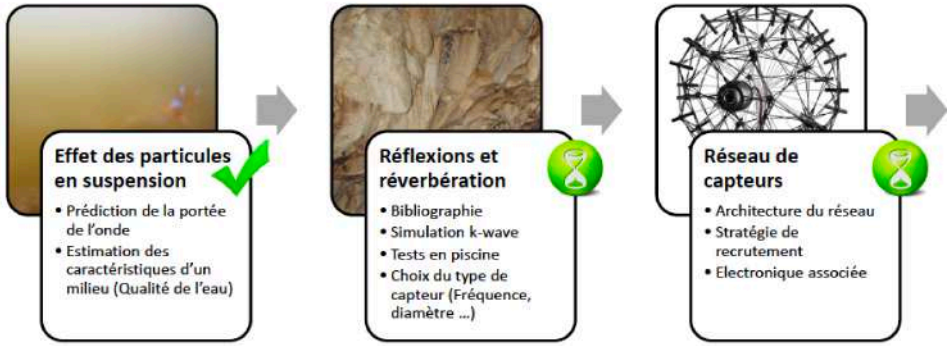
The RKE Initiative : Forces at Work

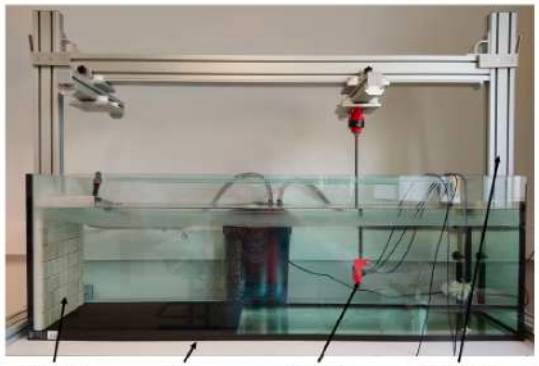
F. Augereau (IES)
D. Laux (IES)
M. Alarab (Thèse)

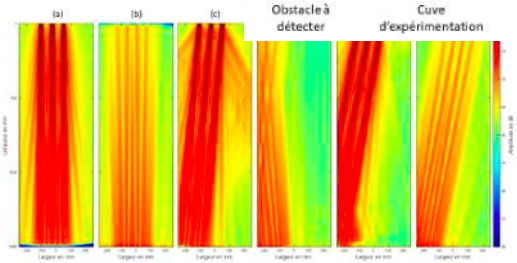
New Sensors Development

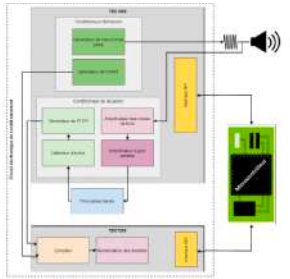
- Acoustic Skin

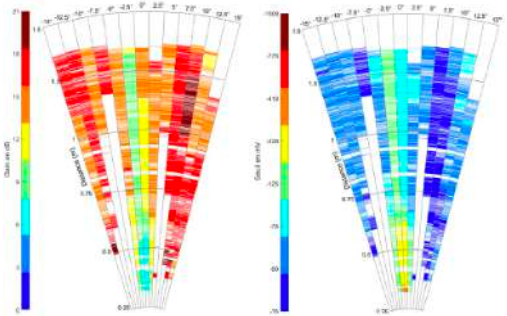






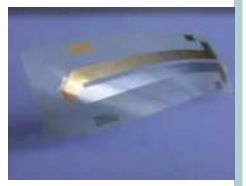






IGURE 5.12 – Variation du gain (à gauche) et du seuil (à droite) de détection de
cuit de conditionnement en fonction de la distance de détection et l'angle d'incidence.
onfiguration : 3 transducteurs émetteurs espacés de 5 cm, réflexion contre le paroi de
quarium en verre. Représentation des variations sur le transducteur centrale.

Stimulation Protocol

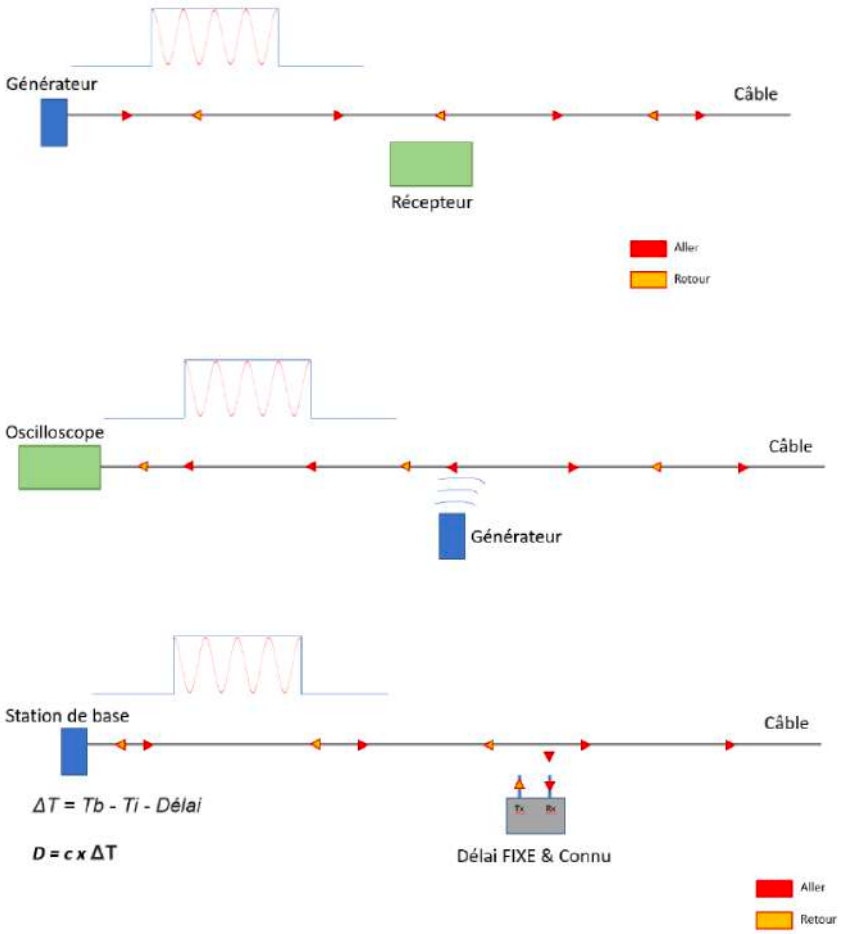


Time of Arrival Sensor (piezotech)

THE RKE INITIATIVE : FORCES AT WORK

A. Vena (IES)
N. Troesch (PFE EPUM)

- **New Sensors Development**
  - Active Umbilical (localisation and communication)
    - Détection of Stationnary waves in single wire (fil d'ariane)
    - Communication/localisation with Burst / Ping

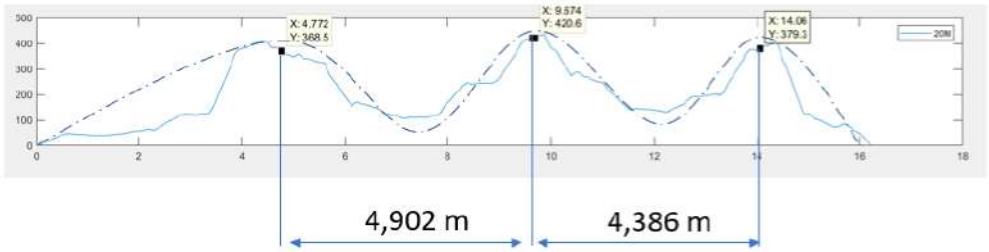


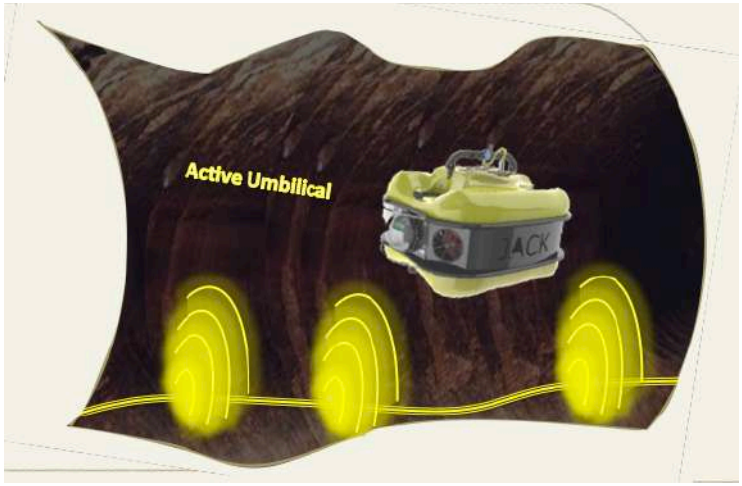
amperometric clamp
(pince ampèremétrique)

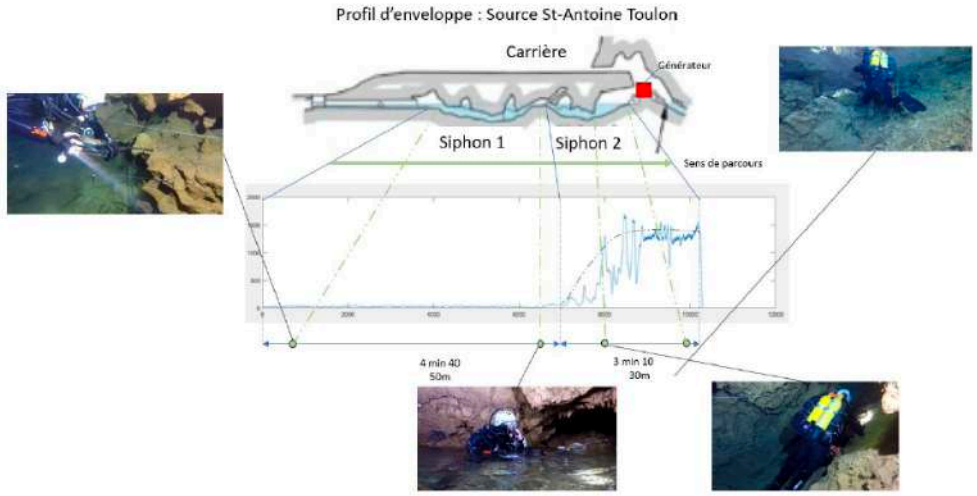
The RKE Initiative : Forces at Work

A. Vena (IES)
N. Troesch (PFE EPUM)

- **New Sensors Development**
  - Active Umbilical (localisation and communication)
    - Détection of Stationnary waves in single wire (fil d'ariane)





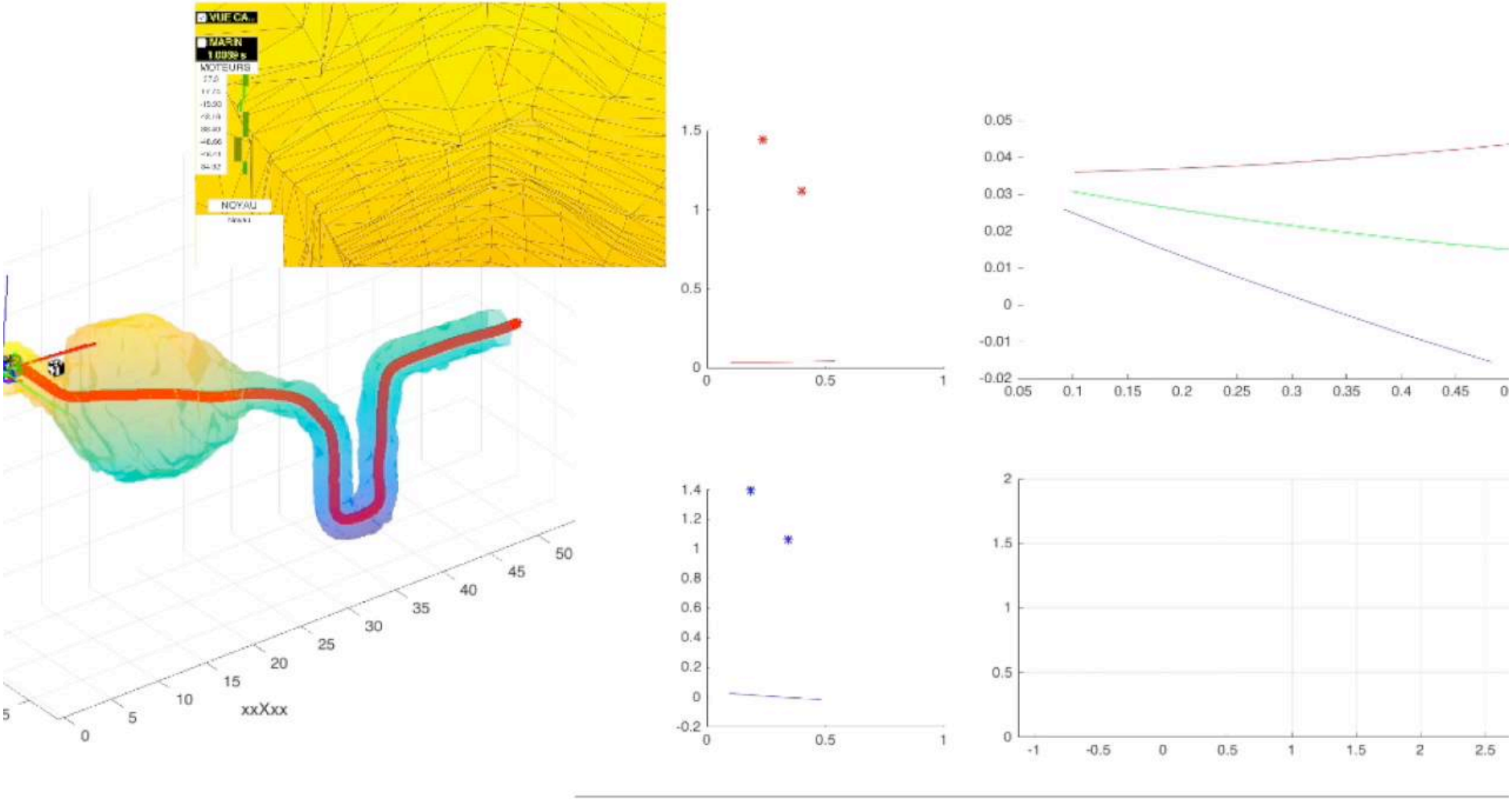


Experimentation in the St Antoine spring (Toulon)

The RKE Initiative : Forces at Work (LIRMM, ENSTA B)

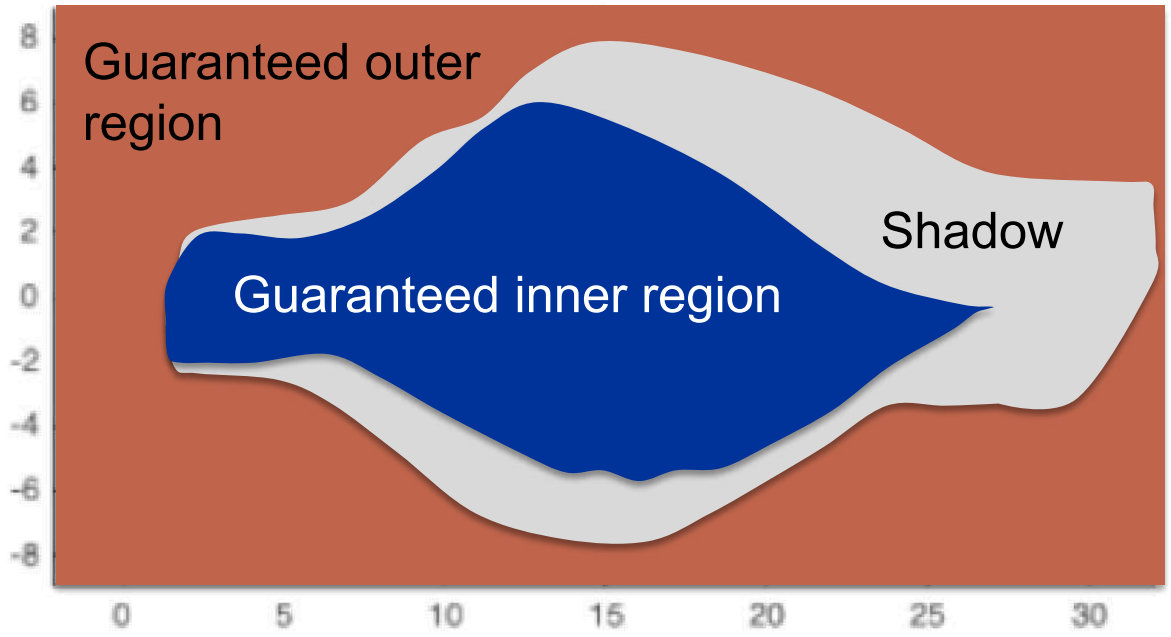
- Cartographie garantie, analyse par intervalles

$$X, \tilde{X} \rightarrow [X]$$



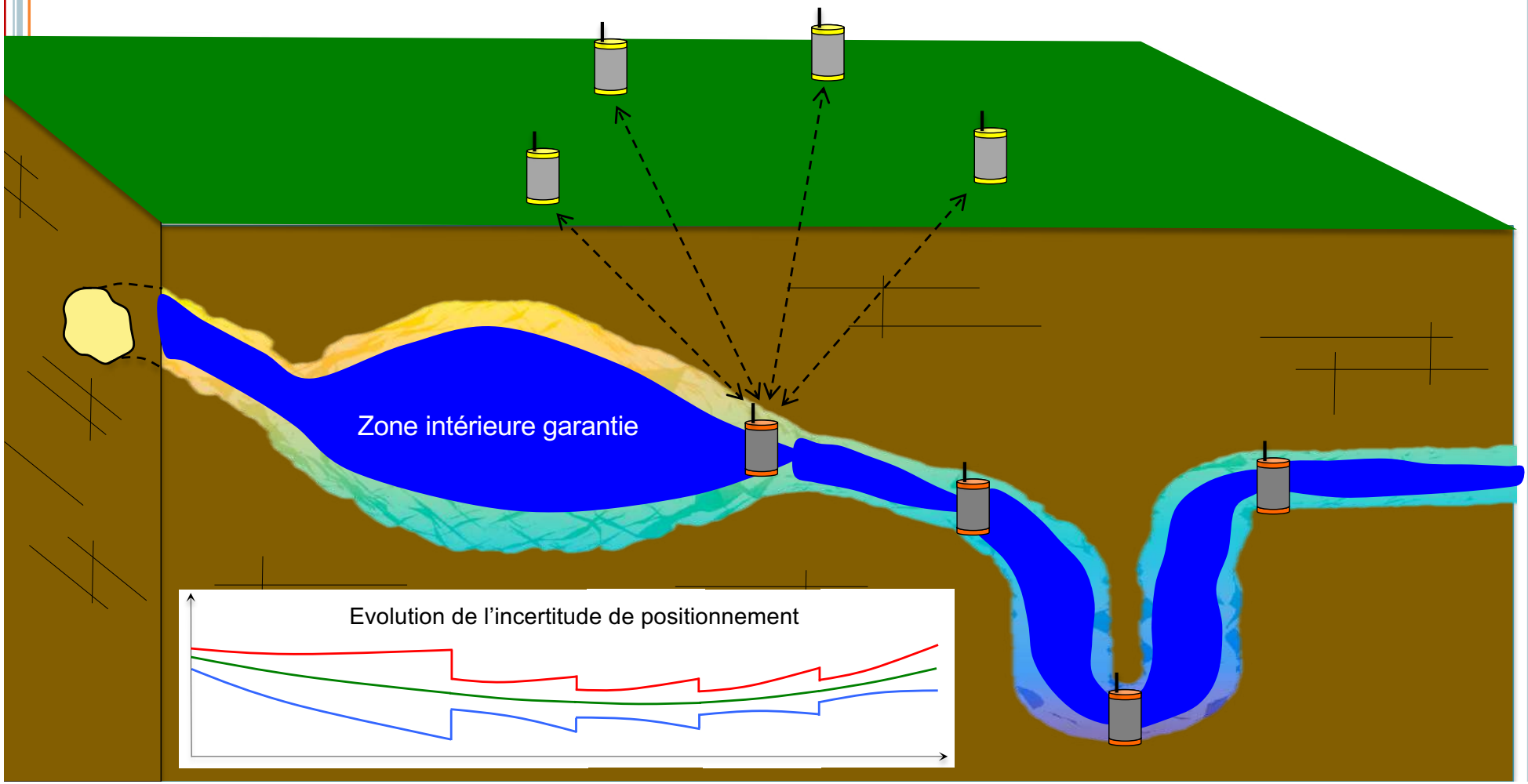
The RKE Initiative : Forces at Work (LIRMM, ENSTA)

- Cartographie garantie, analyse par intervalles



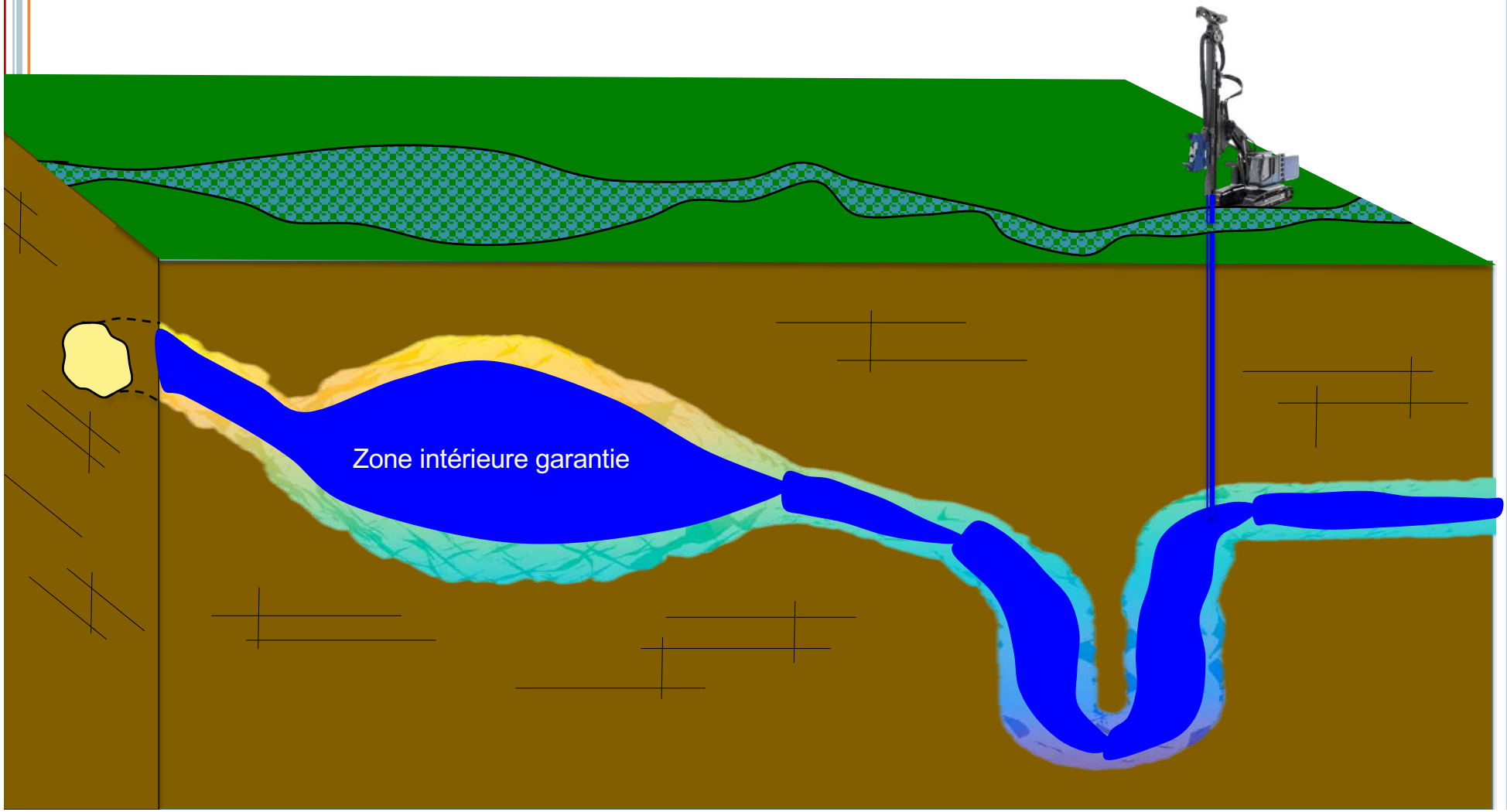
The RKE Initiative : Forces at Work

- Cartographie garantie, analyse par intervalles
- Recalage par UG-GPS (ISSKA, localisation magnétique)



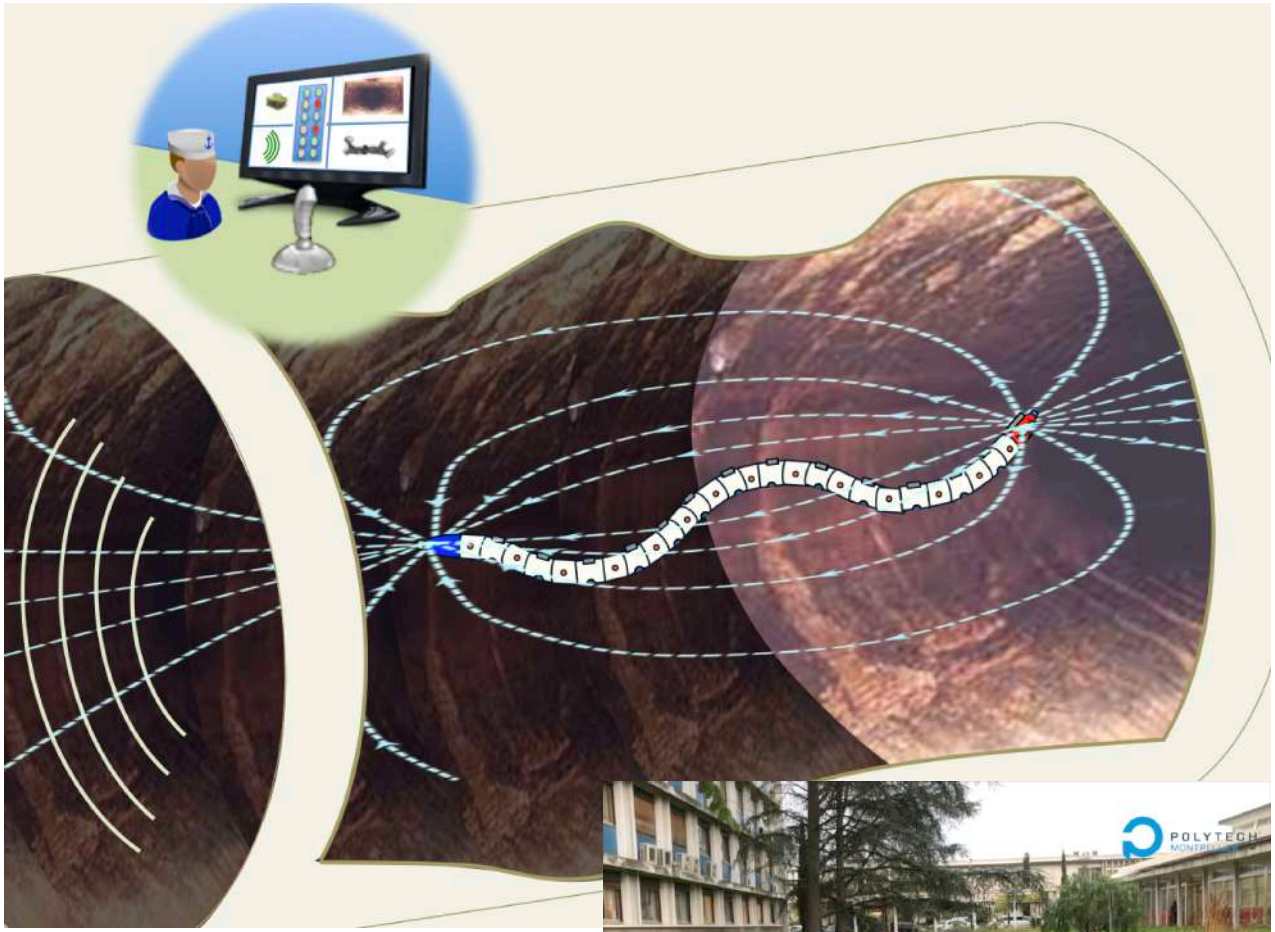
The RKE Initiative : Forces at Work (LIRMM, ENSTA)

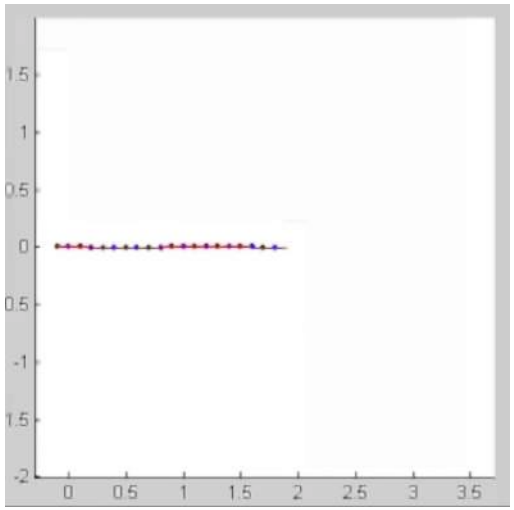
- Cartographie garantie, analyse par intervalles
- Recalage par UG-GPS (ISSKA, localisation magnétique)
- Application au forage hydraulique

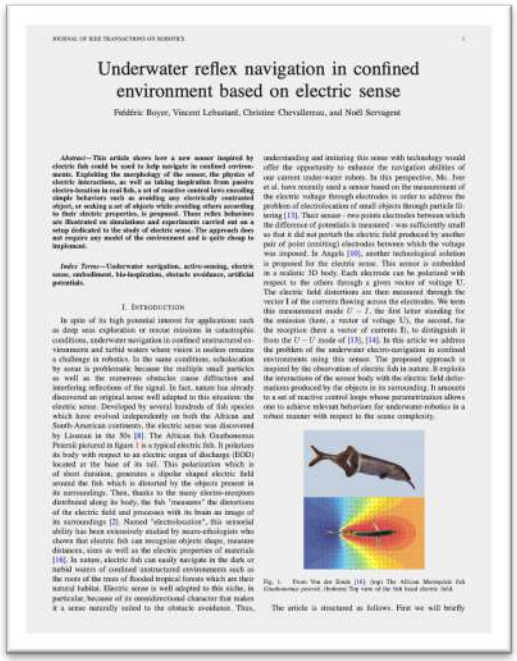


Near Future : ANR LIRMM, LS2N, ENSTA, Syera, Reeds

- Locomotion anguilliforme et Sens électrique







Underwater reflex navigation in confined environment based on electric sense

Frédéric Boyer, Vincent Lebastard, Christine Chevallereau, and Noël Servagent

Abstract—This article shows how a new sensor inspired by electric fish could be used to help navigate in confined environments. Exploiting the morphology of the sensor, the physics of electric interactions, as well as taking inspiration from passive electro-location in real fish, a set of reactive control laws encoding simple behaviors such as avoiding any electrically contrasted object, or seeking a set of objects while avoiding others according to their electric properties, is proposed. These reflex behaviors are illustrated on simulations and experiments carried out on a setup dedicated to the study of electric sense. The approach does not require any model of the environment and is quite cheap to implement.

Index Terms—Underwater navigation, active-sensing, electric sense, embodiment, bio-inspiration, obstacle avoidance, artificial potentials.

I. Introduction

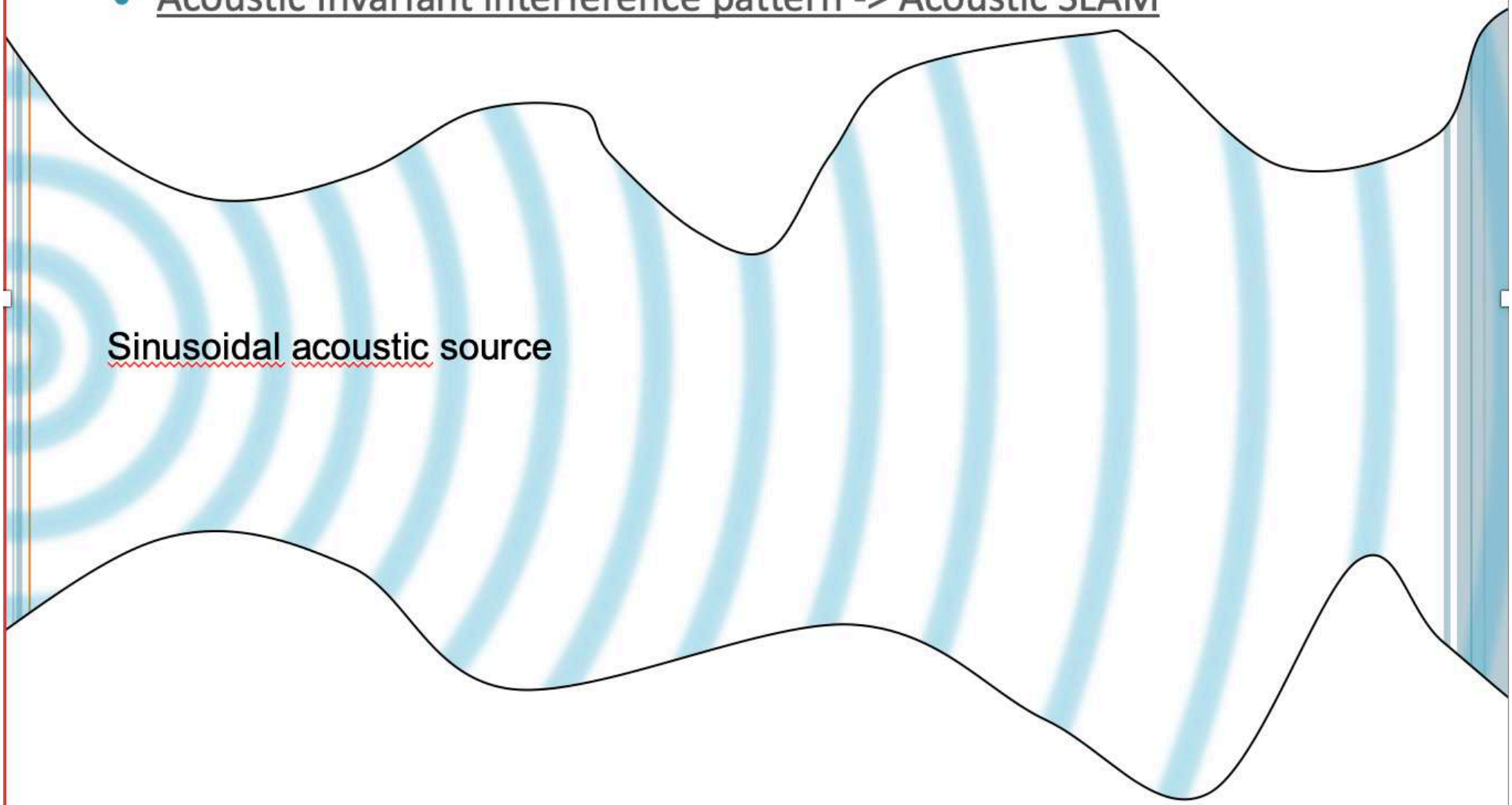
In spite of its high potential interest for applications such as deep seas exploration or rescue missions in catastrophic conditions, underwater navigation in confined unstructured environments and turbid waters where vision is useless remains a challenge in robotics. In the same conditions, echolocation by sonar is problematic because the multiple small particles as well as the numerous obstacles cause diffraction and interfering reflections of the signal. In fact, nature has already discovered an original sense well adapted to this situation: the electric sense. Developed by several hundreds of fish species which have evolved independently on both the African and South-American continents, the electric sense was discovered by Lissman in the 50s [8]. The African fish Gnathonemus Petersii pictured in figure 1 is a typical electric fish. It polarizes its body with respect to an electric organ of discharge (EOD) located at the base of its tail. This polarization which is of short duration, generates a dipolar shaped electric field around the fish which is distorted by the objects present in its surroundings. Then, thanks to the many electro-receptors distributed along its body, the fish "measures" the distortions of the electric field and processes with its brain an image of its surroundings [2]. Named "electrolocation", this sensorial ability has been extensively studied by neuro-ethologists who shown that electric fish can recognize objects shape, measure distances, sizes as well as the electric properties of materials [16]. In nature, electric fish can easily navigate in the dark or turbid waters of confined unstructured environments such as the roots of the trees of flooded tropical forests which are their natural habitat. Electric sense is well adapted to this niche, in particular, because of its omnidirectional character that makes it a sense naturally suited to the obstacle avoidance. Thus, understanding and imitating this sense with technology would offer the opportunity to enhance the navigation abilities of our current under-water robots. In this perspective, Mc. Iver et al. have recently used a sensor based on the measurement of the electric voltage through electrodes in order to address the problem of electrolocation of small objects through particle filtering [13]. Their sensor - two points electrodes between which the difference of potentials is measured - was sufficiently small so that it did not perturb the electric field produced by another pair of point (emitting) electrodes between which the voltage was imposed. In Angels [10], another technological solution is proposed for the electric sense. This sensor is embedded in a realistic 3D body. Each electrode can be polarized with respect to the others through a given vector of voltage U. The electric field distortions are then measured through the vector I of the currents flowing across the electrodes. We term this measurement mode $U - I$, the first letter standing for the emission (here, a vector of voltage U), the second, for the reception (here a vector of currents I), to distinguish it from the $U - U$ mode of [13], [14]. In this article we address the problem of the underwater electro-navigation in confined environments using this sensor. The proposed approach is inspired by the observation of electric fish in nature. It exploits the interactions of the sensor body with the electric field deformations produced by the objects in its surrounding. It amounts to a set of reactive control loops whose parametrization allows one to achieve relevant behaviors for underwater robotics in a robust manner with respect to the sense complexity.

Fig. 1. From Von der Emde [16]. (top) The African Mormyrids fish *Gnathonemus petersii*. (bottom) Top view of the fish based electric field.

The article is structured as follows. First we will briefly

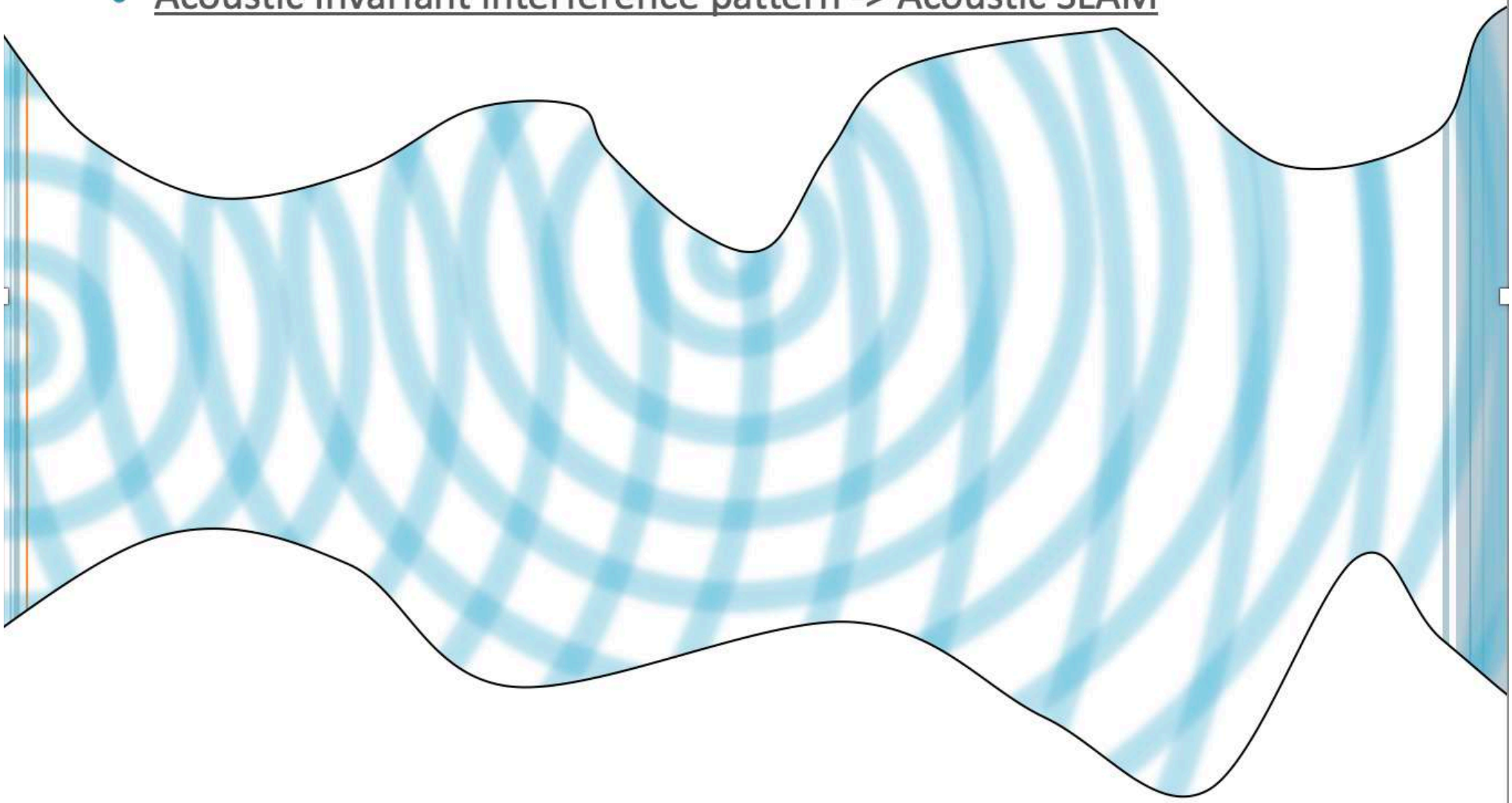
The RKE Initiative : Forces at Work

- **New Sensors Development**
  - Acoustic Invariant interference pattern -> Acoustic SLAM



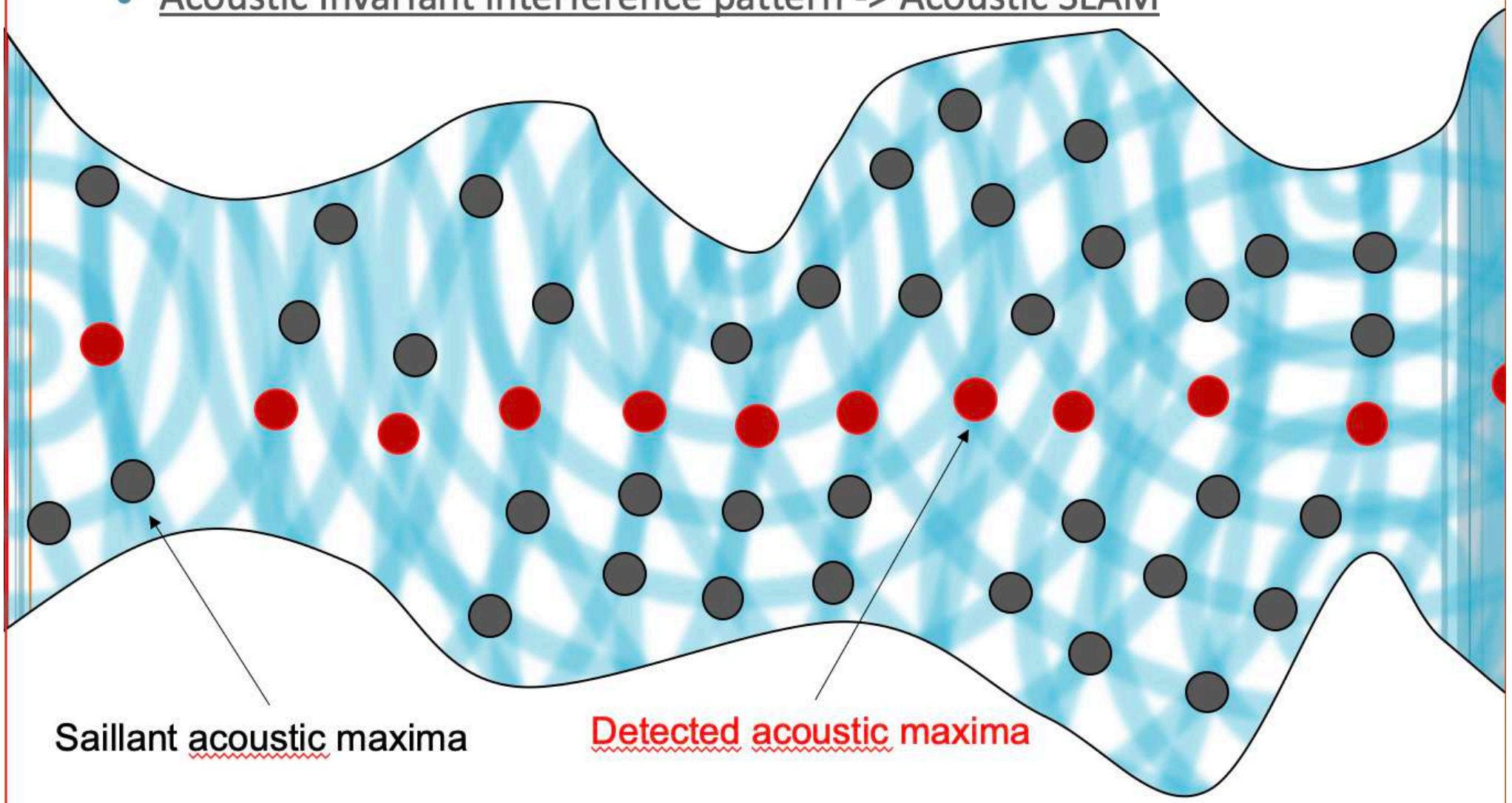
The RKE Initiative : Forces at Work

- **New Sensors Development**
  - Acoustic Invariant interference pattern -> Acoustic SLAM



The RKE Initiative : Forces at Work

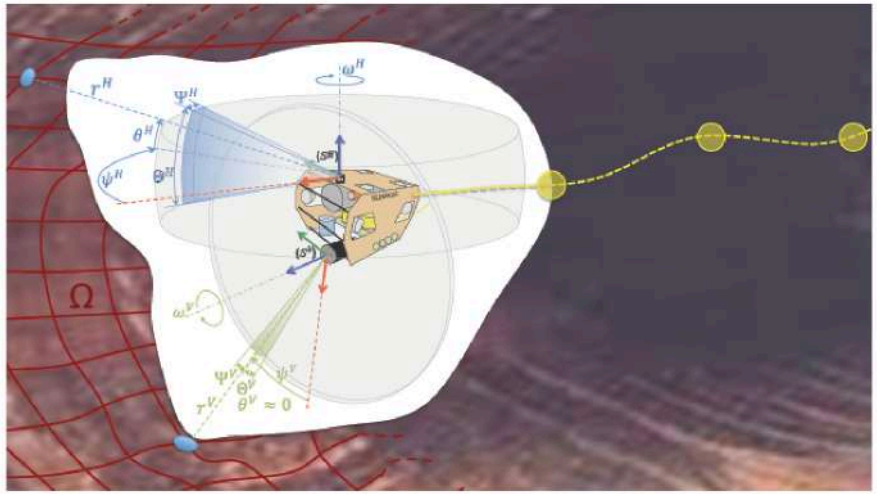
- **New Sensors Development**
  - Acoustic Invariant interference pattern -> Acoustic SLAM

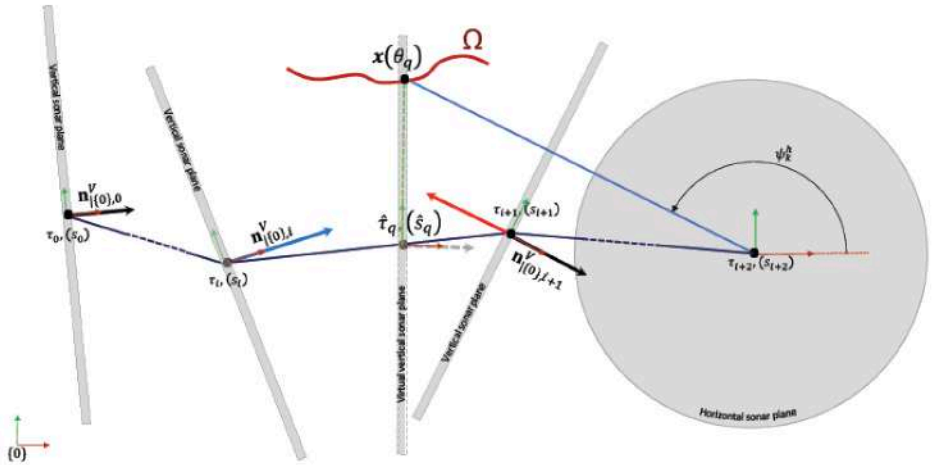


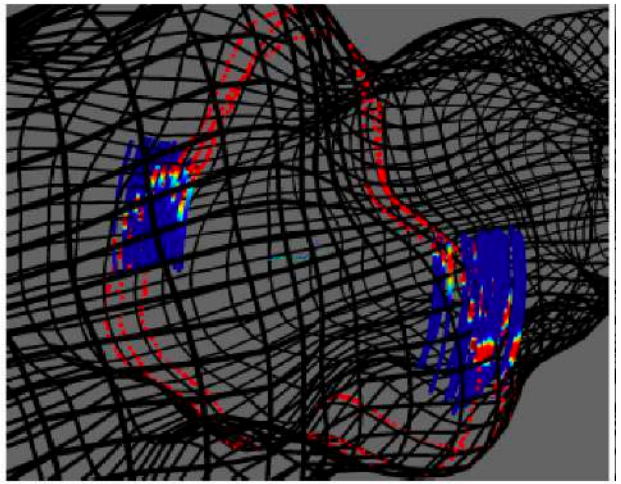
The RKE Initiative : Forces at Work

Y. Breux (LIRMM/IMAG)
B. Mohammadi (IMAG)
A. Mas (IMAG)
L. Lapierre (LIRMM)

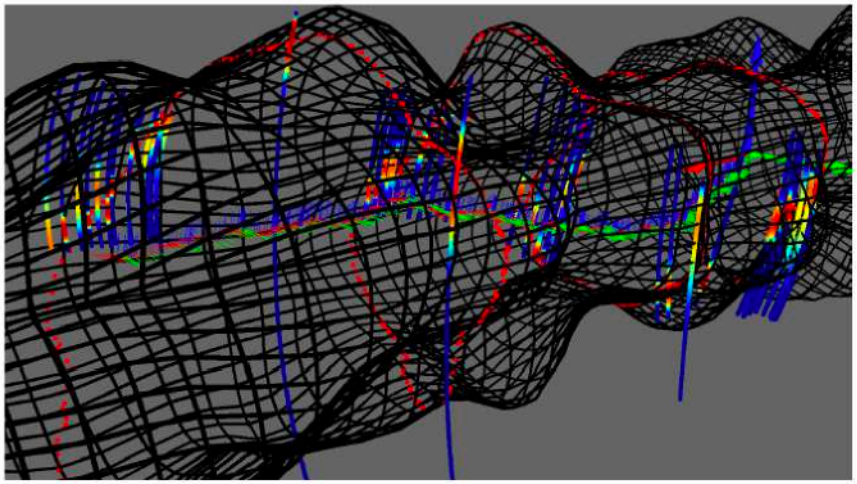
- **Navigation**
  - 3D Acoustic SLAM (1) : Estimation of the elevation angle of the large angle vertical profiling sonar.







(a) Dense case.

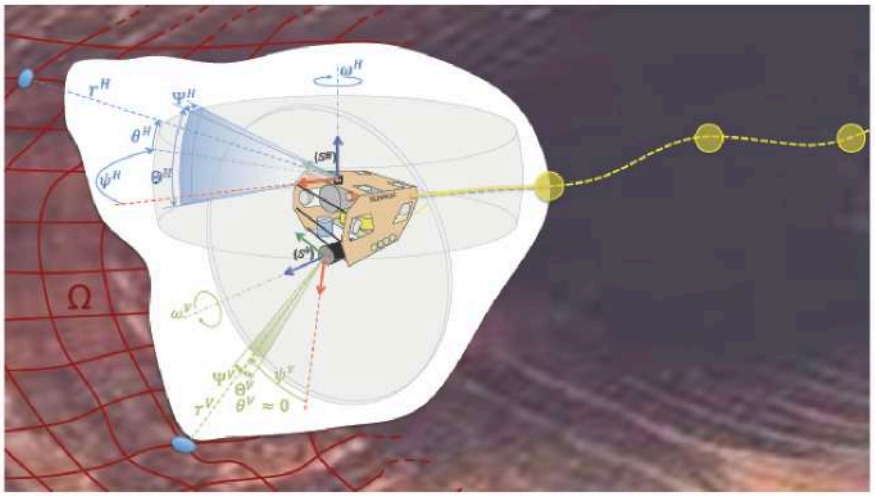


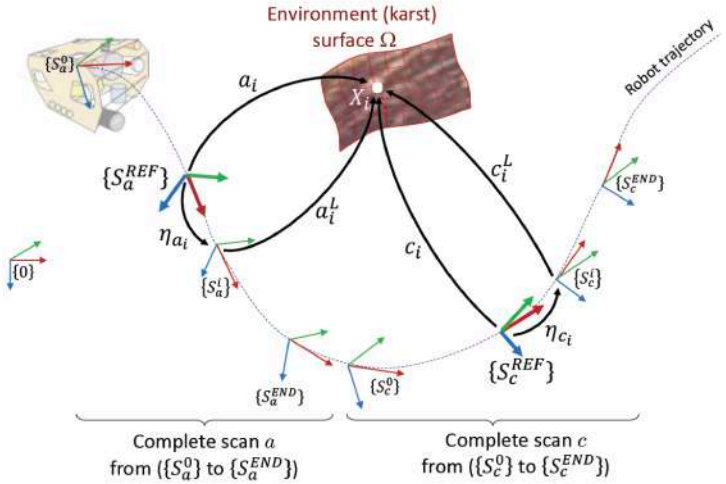
(c) Sparse case.

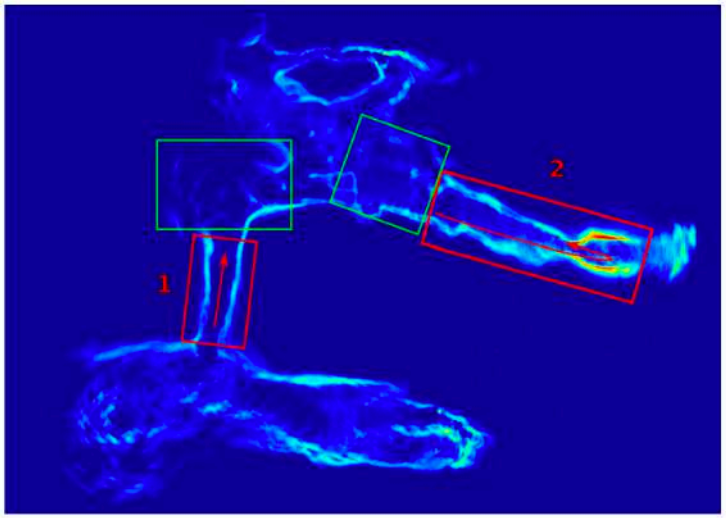
The RKE Initiative : Forces at Work

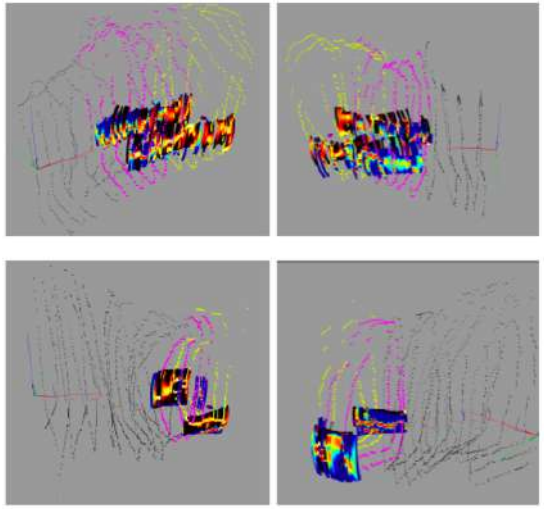
Y. Breux (LIRMM/IMAG)
B. Mohammadi (IMAG)
A. Mas (IMAG)
L. Lapierre (LIRMM)

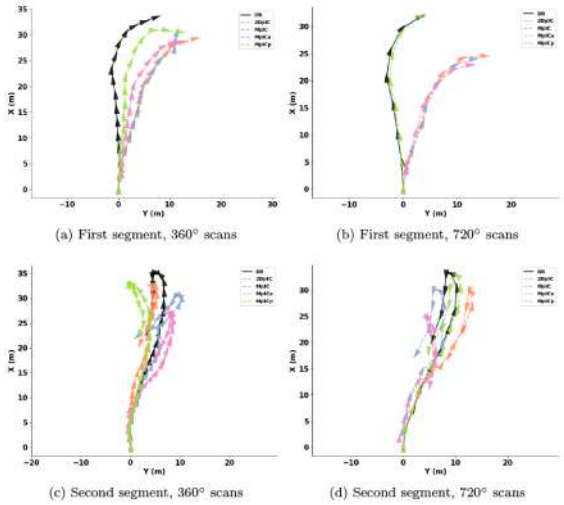
- **Navigation**
  - 3D Acoustic SLAM (2) : Scan Matching (point to point and point to plane).









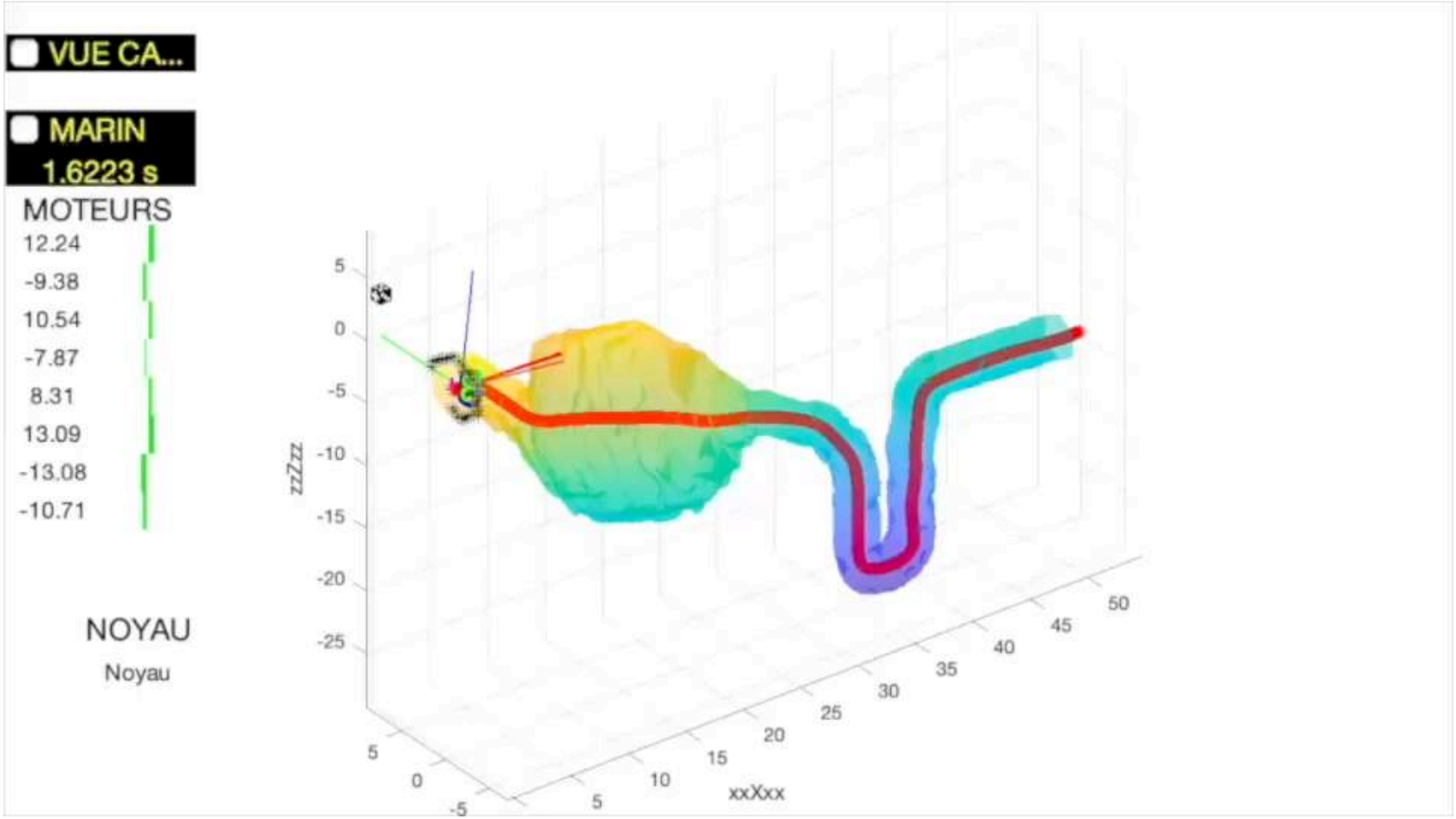


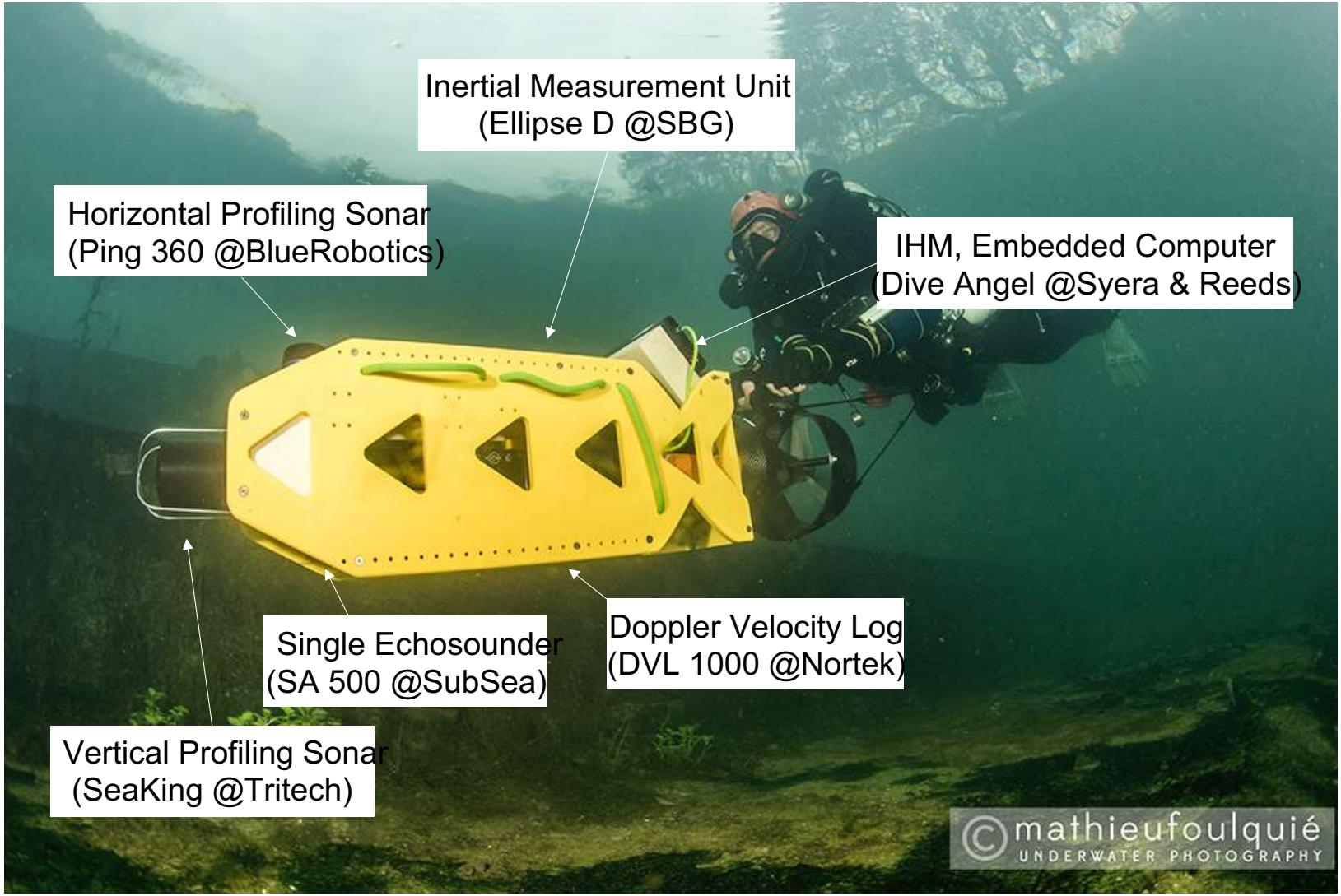
  - Acoustic SLAM (3) : Graph SLAM and loop closure detection...

THE RKE INITIATIVE : FORCES AT WORK

S. Rohou (ENTSA B)
L. Lapierre (ENSTA B)

- **Navigation**
  - Acoustic SLAM with helicoidal constraints



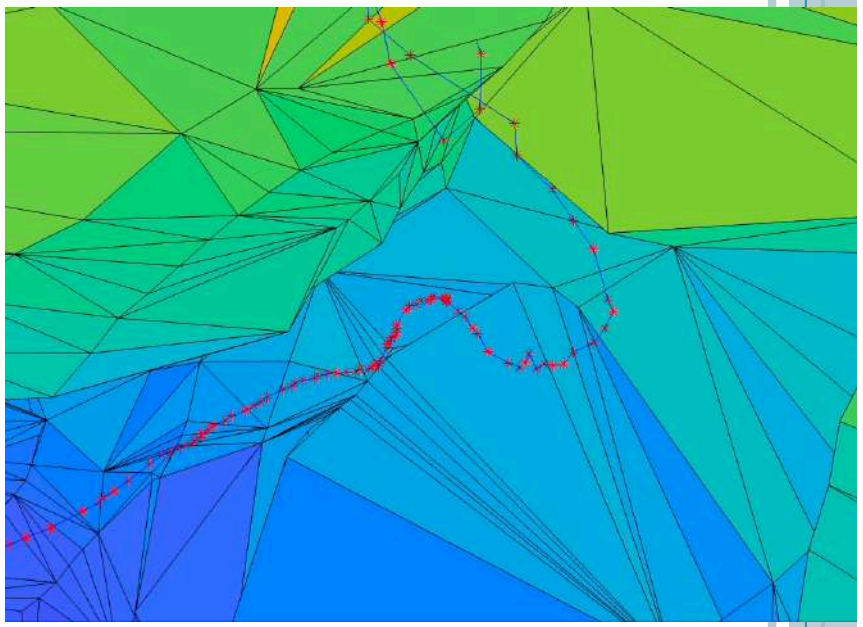

Inertial Measurement Unit
(Ellipse D @SBG)
Horizontal Profiling Sonar
(Ping 360 @BlueRobotics)
IHM, Embedded Computer
(Dive Angel @Syera & Reeds)
Single Echosounder
(SA 500 @SubSea)
Doppler Velocity Log
(DVL 1000 @Nortek)
Vertical Profiling Sonar
(SeaKing @Tritech)
©mathieufoulquié
UNDERWATER PHOTOGRAPHY

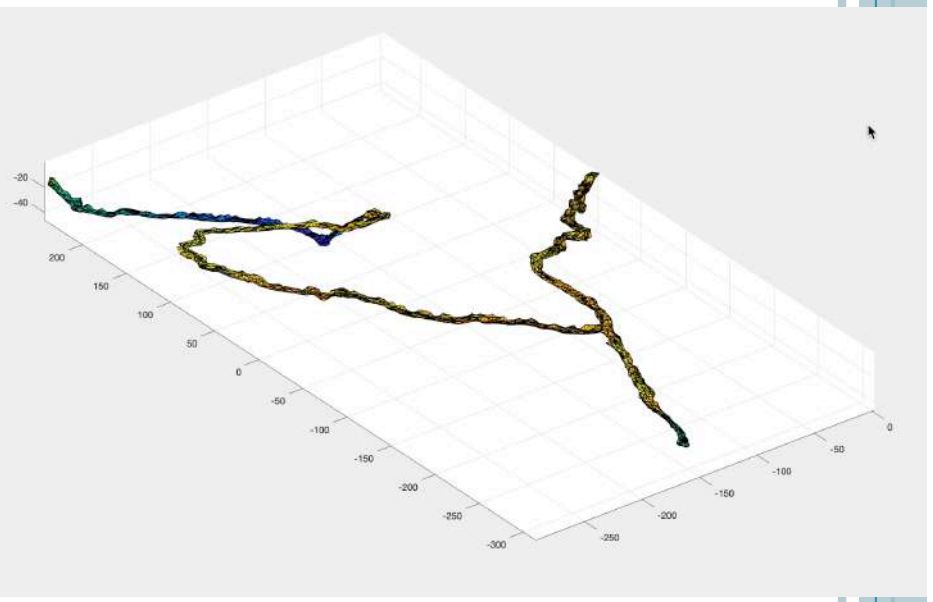
Terrain Results: Fontaine de Nîmes, 8/03/2023

PLONGEURS
Frank VASSEUR
Mathieu FOULQUIE
Doriane MORATE
Damien VIGNOLE
Denis PAILLO

Eq. TECHNIQUE
Lionel LAPIERRE
Hervé JOURDE
Pierre FISCHER
Benoit ROPARS
Mohammed ALIOUACHE

MAIRIE DE NIMES
Guillaume PLA

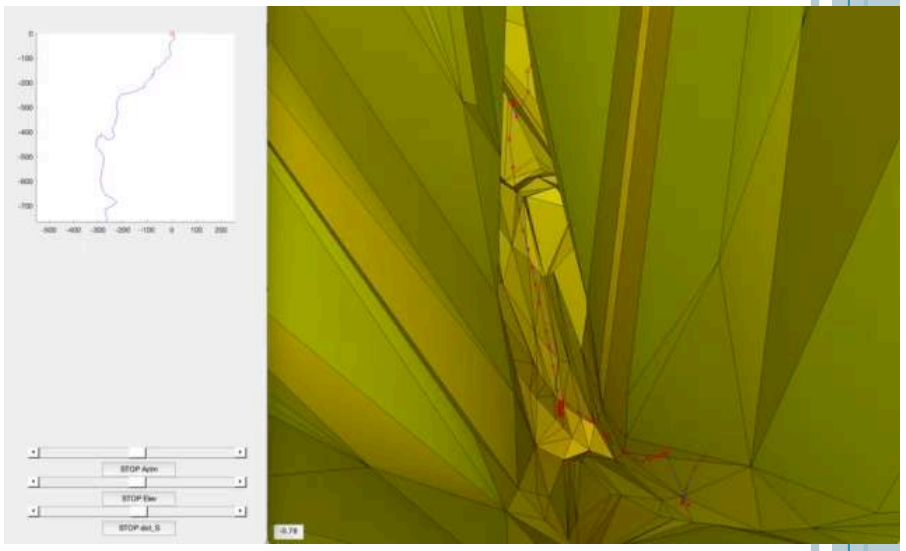


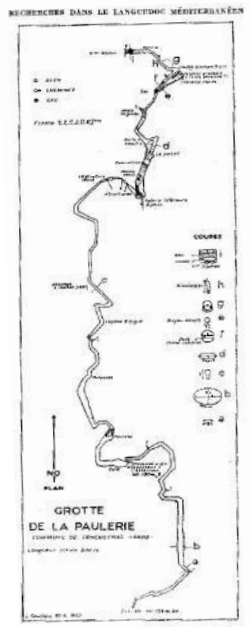


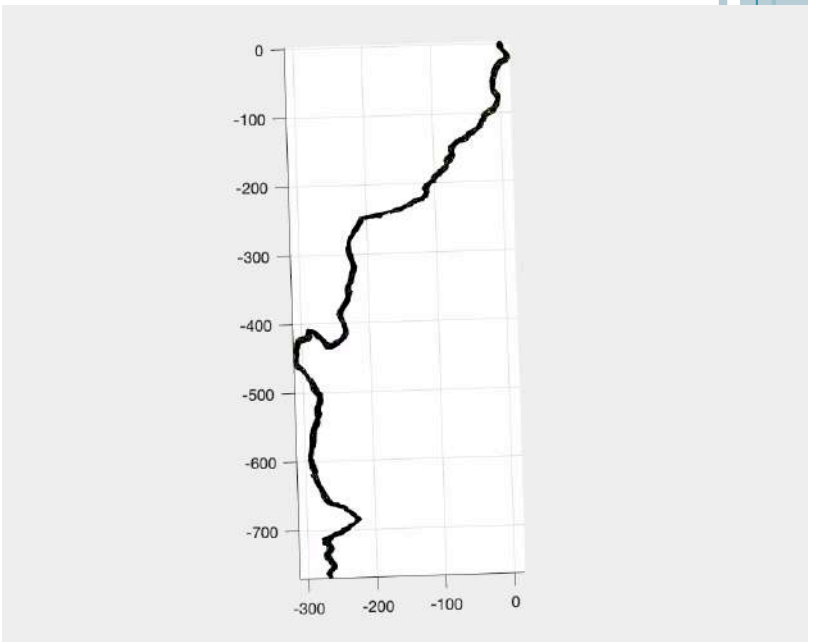
Terrain Results: Fontaine de Sauve, 24/05/2023

PLONGEURS
Frank VASSEUR
Doriane MORATA
Dominique VIGNOLE

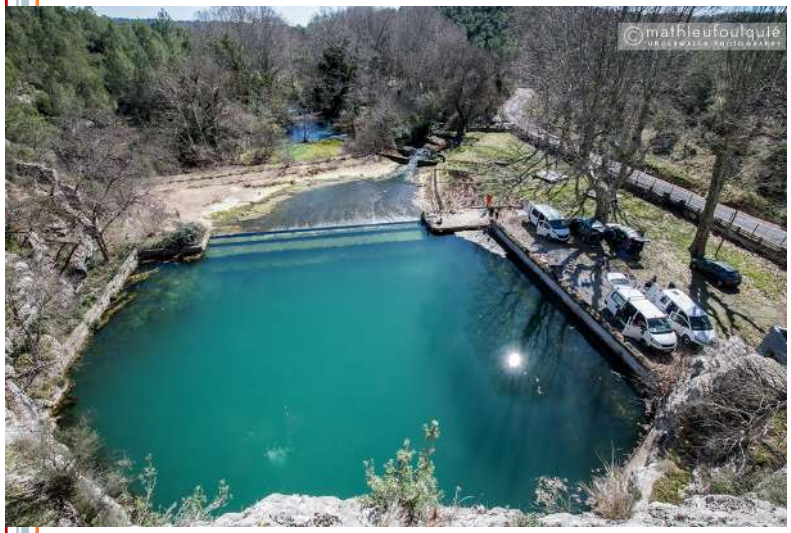
Eq. TECHNIQUE
Benoit ROPARS





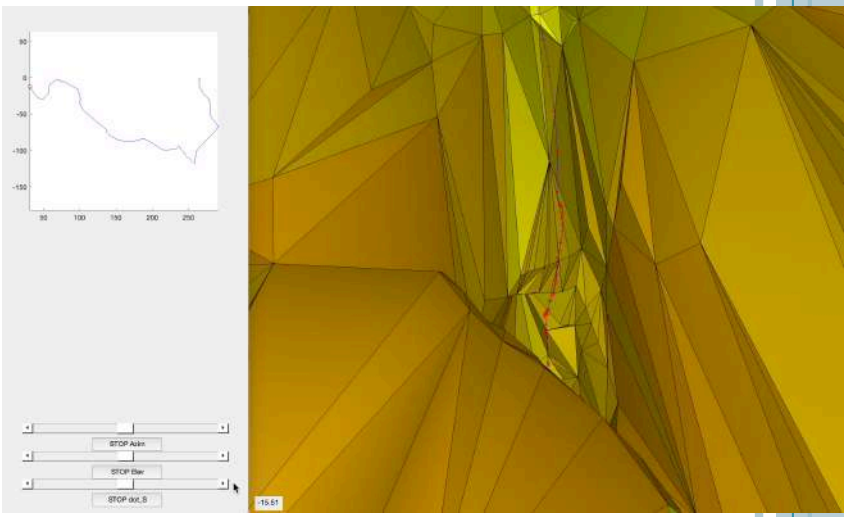


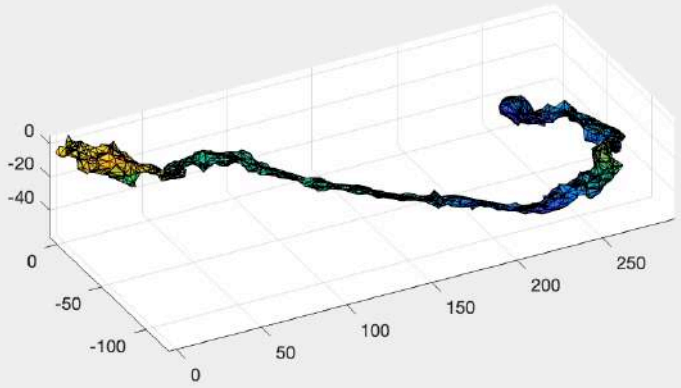
TERRAIN RESULTS: SOURCE DU LEZ, 15/03/2023



PLONGEURS
Frank VASSEUR
Mathieu FOULQUIE
Doriane MORATA
Dominique VIGNOLE
Denis PAILLO

Eq. TECHNIQUE
Lionel LAPIERRE
Hervé JOURDE
Benoit ROPARS
Mohammed ALIOUACHE

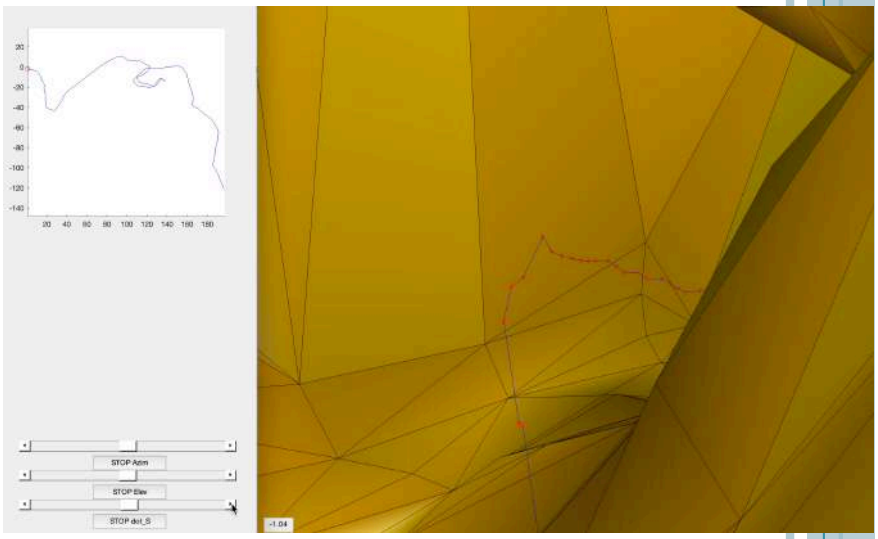


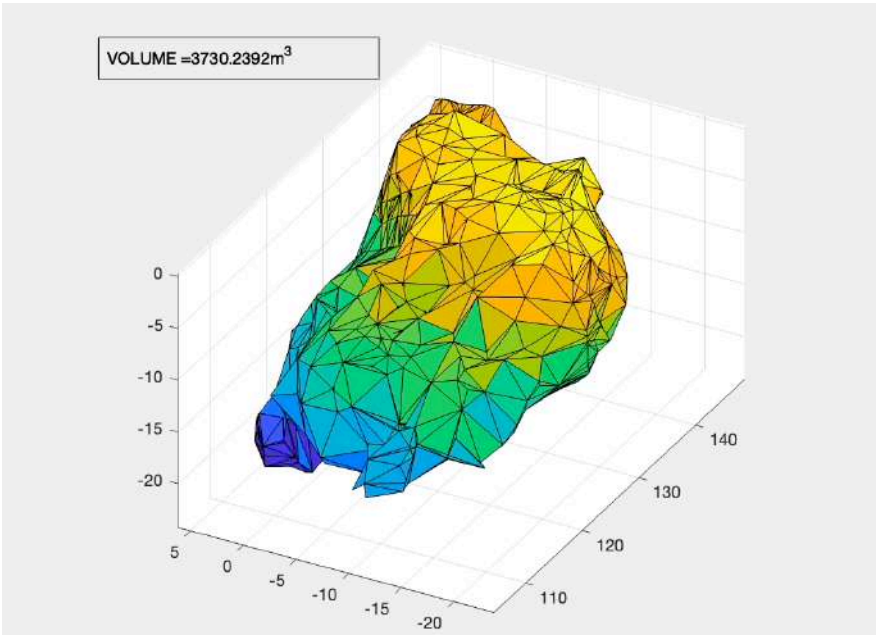


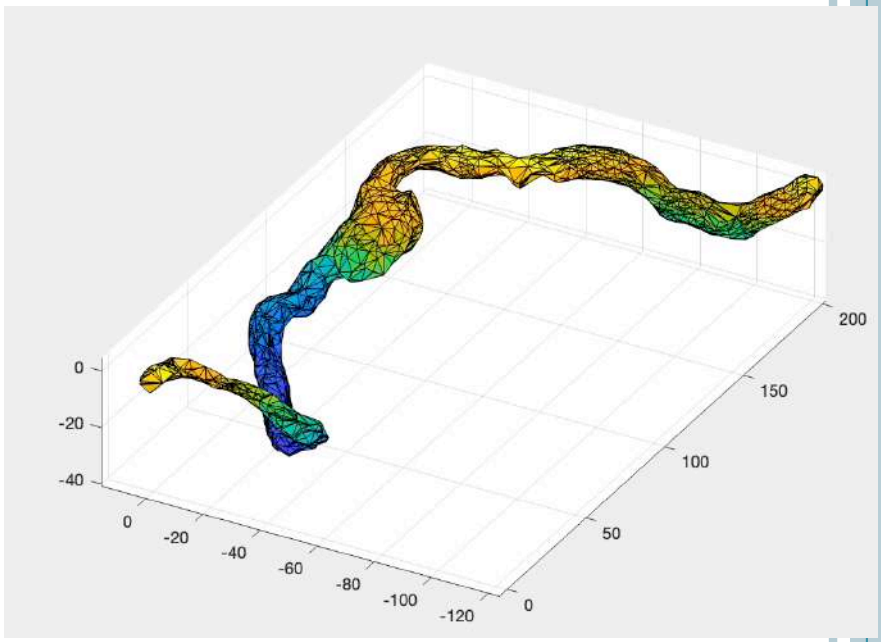
TERRAIN RESULTS: FONTANILLES, 15/03/2023

PLONGEURS
Frank VASSEUR
Mathieu FOULQUIE
Doriane MORATA
Dominique VIGNOLE
Denis PAILLO

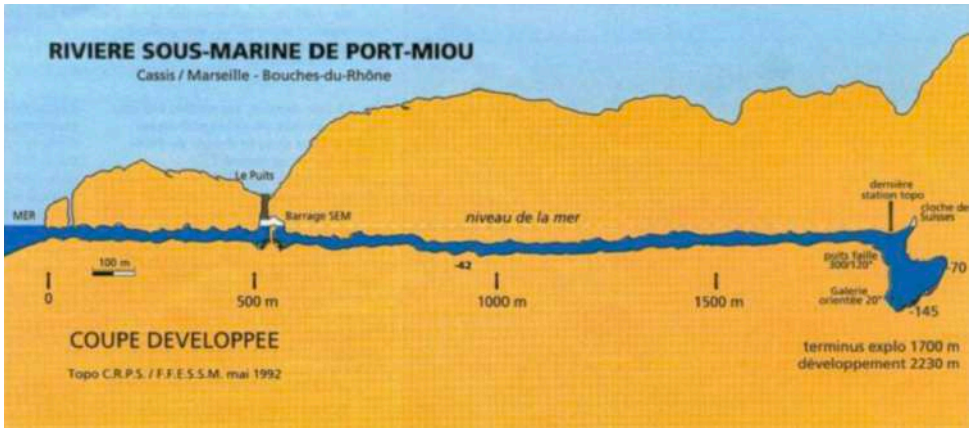
Eq. TECHNIQUE
Benoit ROPARS







A venir : Port Miou, un site Pilote



IngéBlue
institut
interdisciplinaire

ENSTA
BRETAGNE

UNIVERSITÉ DE
TOULON

CASSIS
rivières mystérieuses