



Robotique d'Exploration Karstique Lez 2020



Séminaire

Gestion Intégrée des Ressources en Eau,
Montpellier le 22/06/2023



PEOPLE INVOLVED

○ LIRMM

- Lionel Lapierre
- Didier Crestani
- René Zapata
- Jean Triboulet
- Sébastien Druon
- Gilles Trombettoni
- K. Godary-Déjean
- Dang Huu Tho
- Quentin Massone
- Rodolfo Villalobos
- Verlein Radwan
- Yohan Breux

○ ENSTA

- Simon Rohou

○ HSM

- Hervé Jourde
- Pierre Fischer
- Pascal Brunet
- M. Aliouache

○ BRGM

- J.C. Maréchal

○ IES

- Franck Augereau
- Didier Laux
- Arnaud Véna
- Mohammad Alarab

○ IMAG

- Bijan Mohammadi
- André Mas

○ LEM/MRM

- Saïd Yami
- Gérald Naro

○ 3M

- Arnaud Vestier
- Lionel Villa

○ Céladons

- Frank Vasseur
- Mathieu Foulquié

○ PlongéeSout

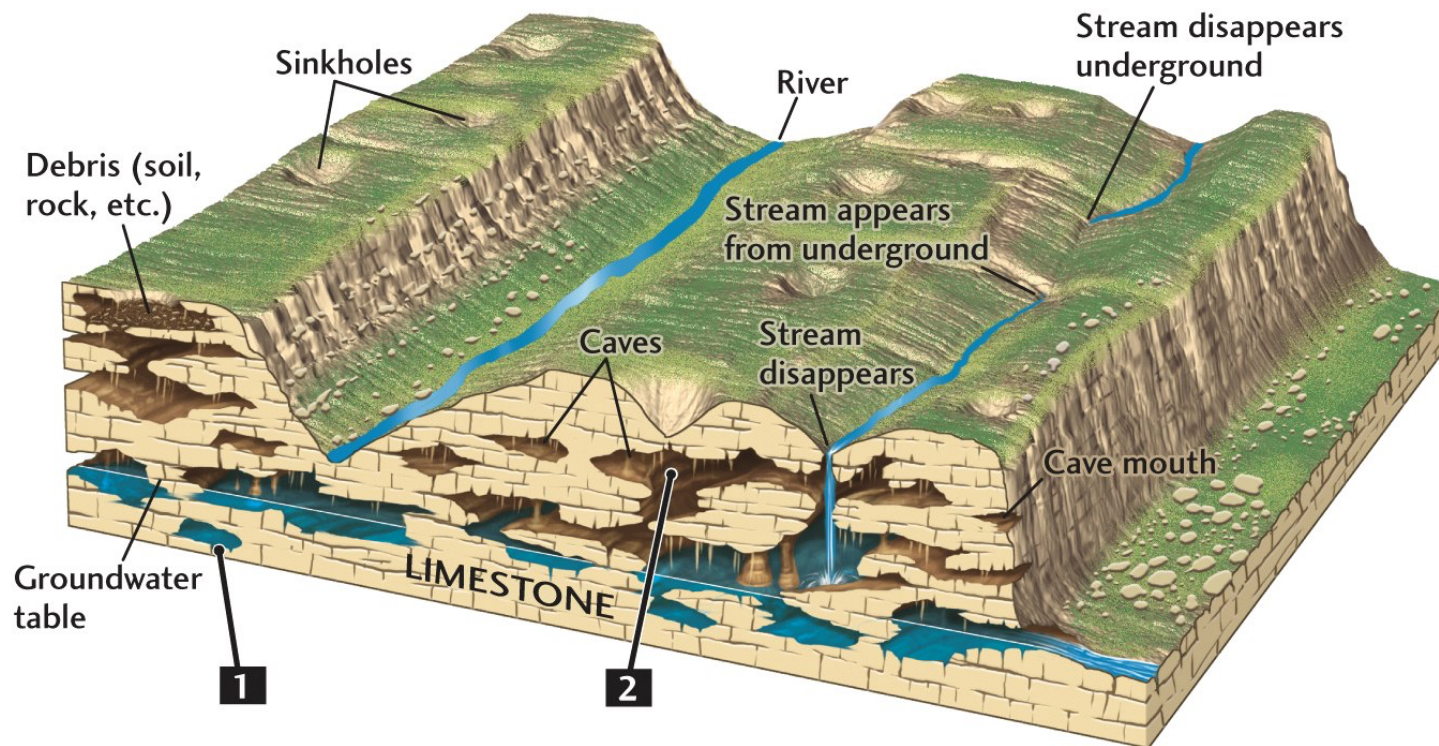
- Rémi Bouchard

○ Companies

- Luc Rossi (Syera)
- Benoit Ropars (Reeds)

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



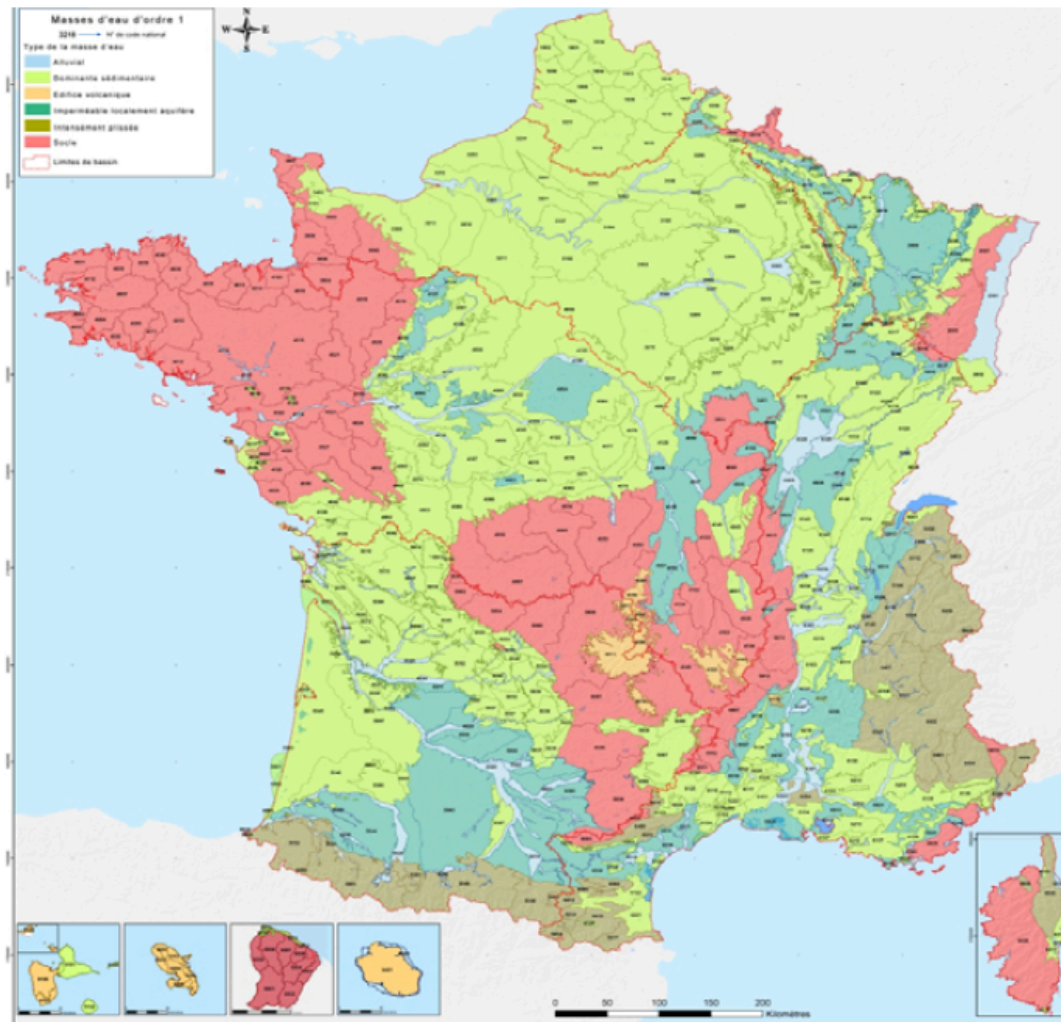
*Eclairage : Cédrik Bancarel
Dominique François
Photo.: Frank Vasseur*

KARST : GROUNDWATER RESERVOIR



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

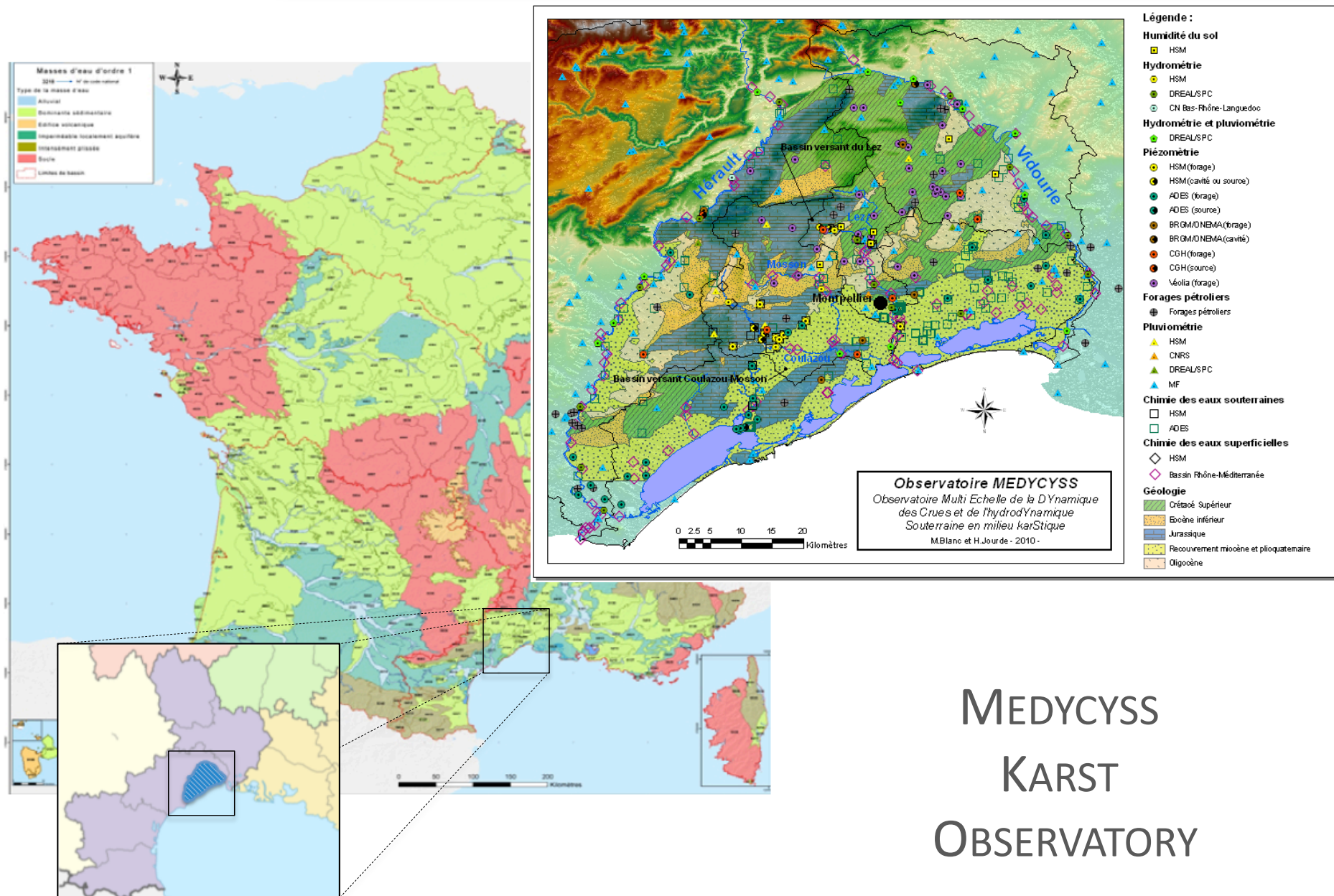
KARST : GROUNDWATER MANAGEMENT, A NATIONAL ISSUE



+ 50% of Drinking Water Supply

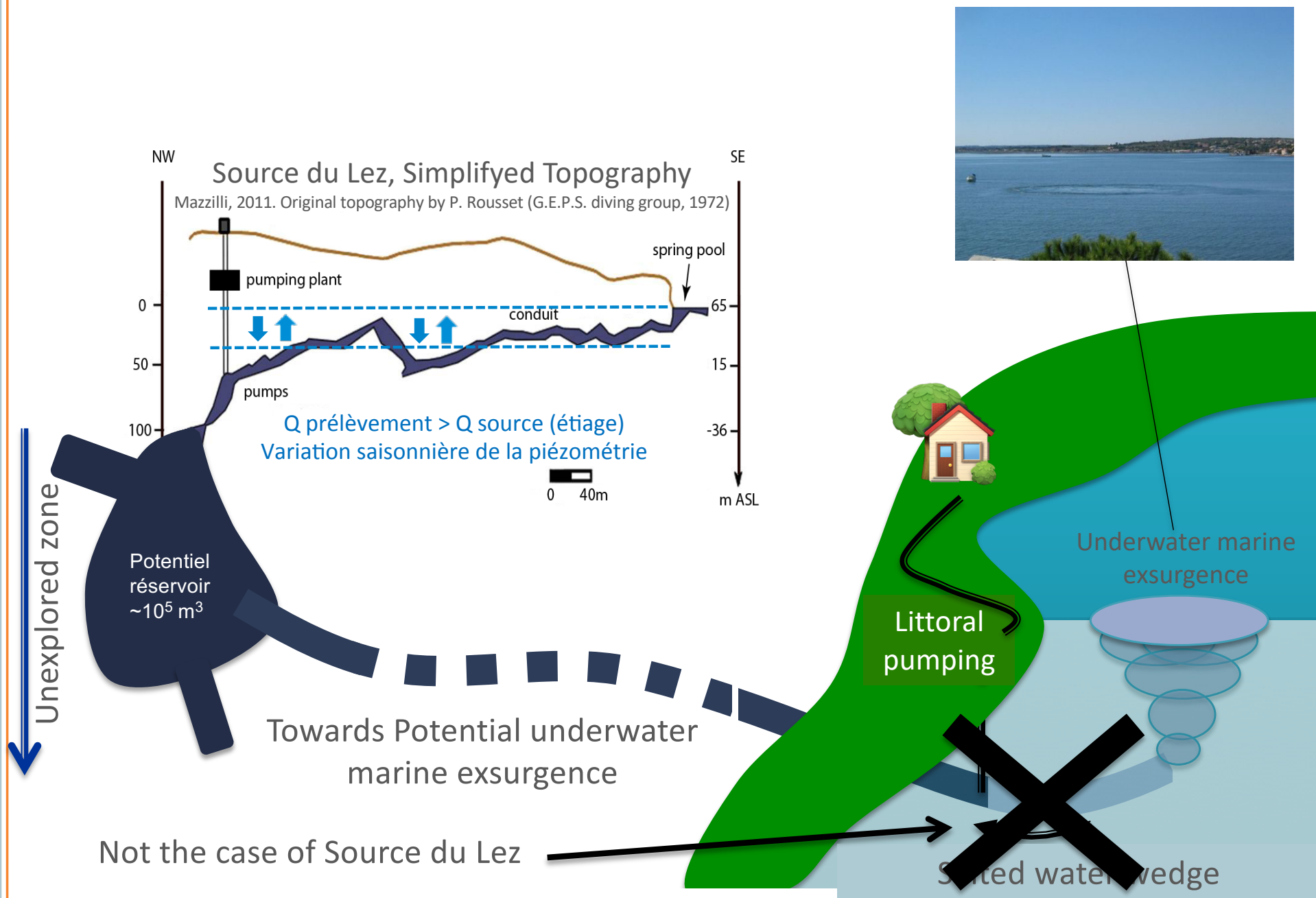
Service National d'Observation
du KARST,
SNO INSU/CNRS
OSU OREME (UM)
Coordinator H. Jourde

MONTPELLIER'S CATCHMENT BASIN : A SEMINAL CASE STUDY

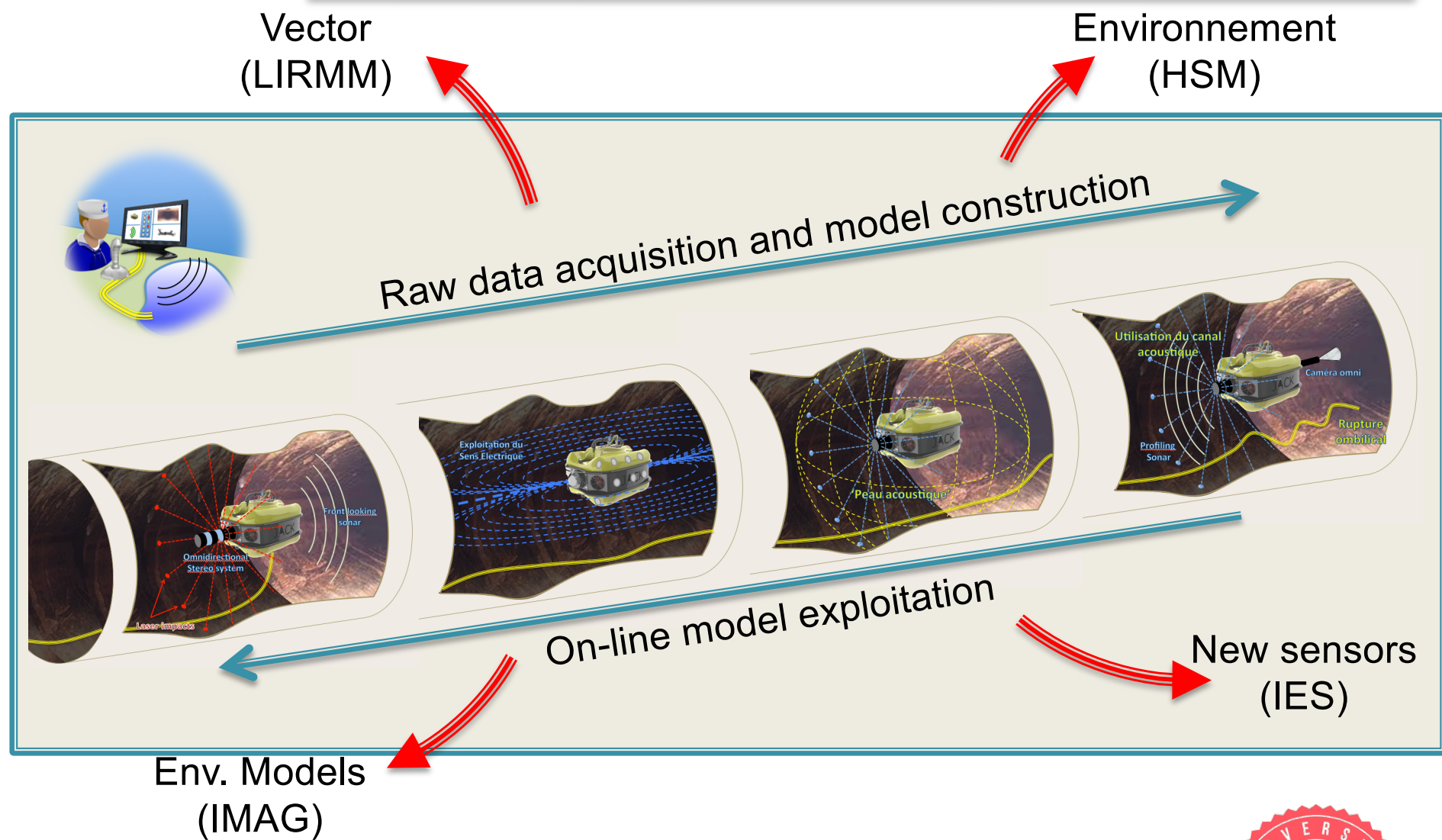


MEDYCYSS
KARST
OBSERVATORY

SOURCES DU LEZ : ACTIVE MANAGEMENT OF GW RESOURCE



RKE : GLOBAL PRINCIPLES



THE RKE INITIATIVE : THE CHALLENGES

○ New Sensors Development

- Acoustic Skin
- Active Umbilical

○ Navigation

- Glob. Nav. System
- n-D Acoustic 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

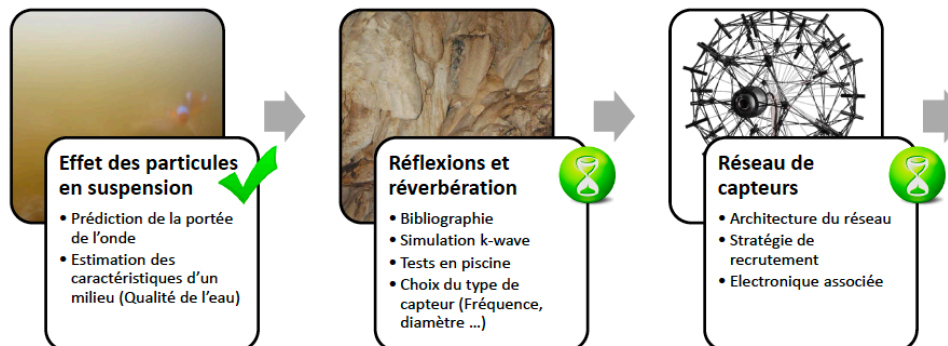
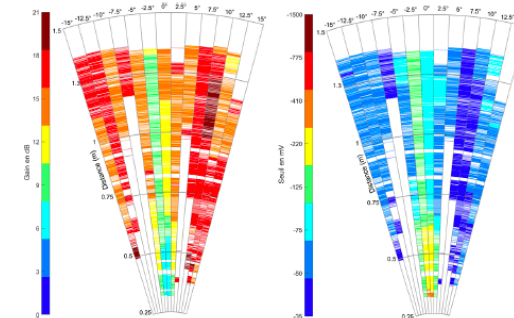
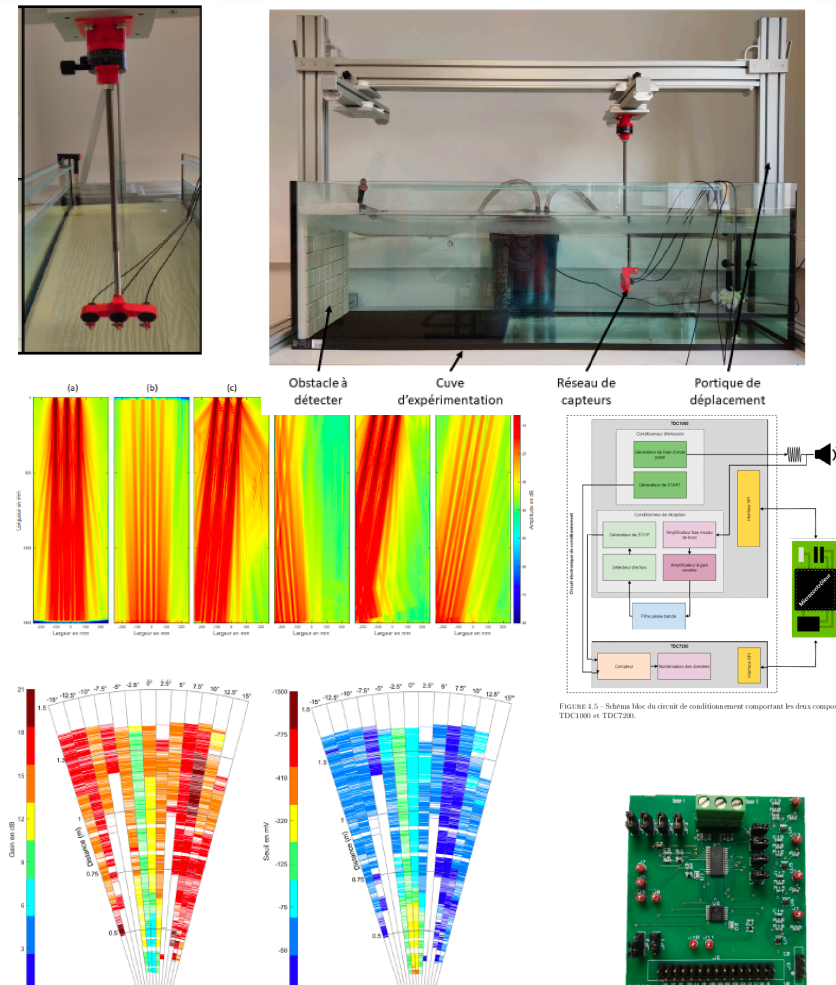
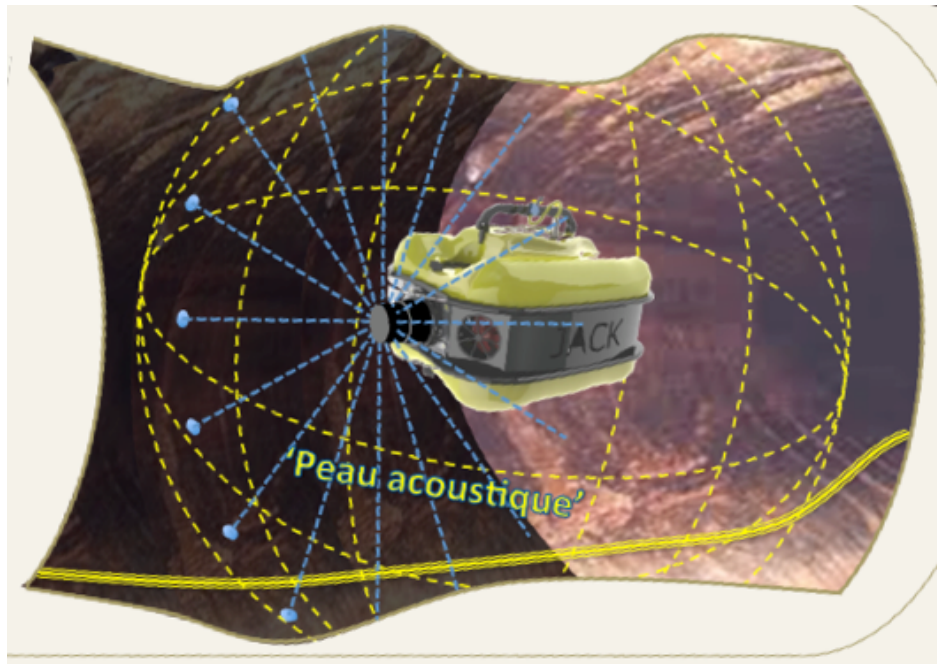
- Active Truncanner, NRJ opt.

○ Economic

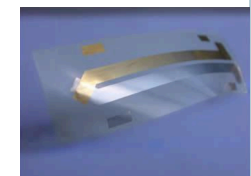
- Evangelization of a Blue Ocean

○ New Sensors Development

• Acoustic Skin



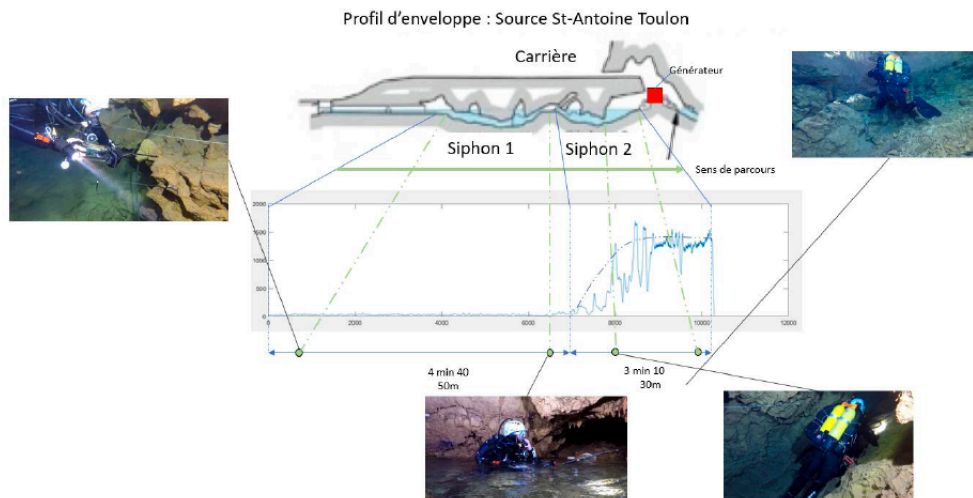
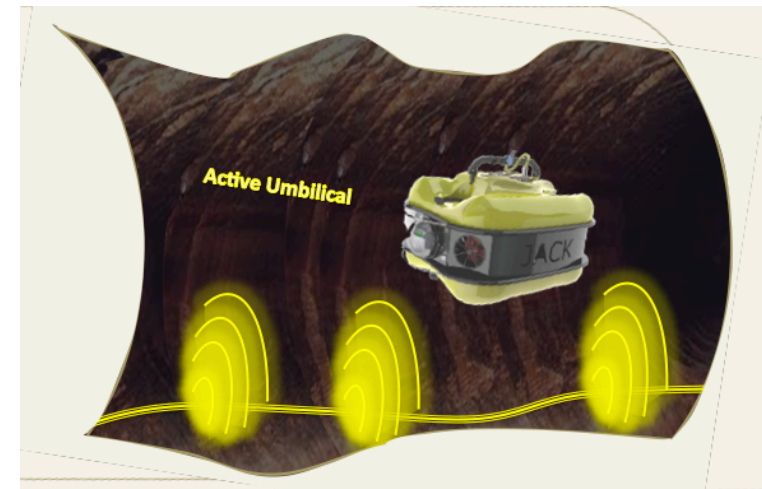
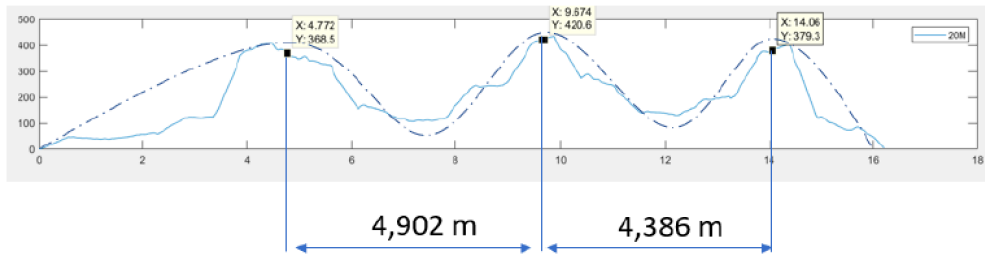
Stimulation
Protocol



Time of Arrival Sensor (piezotech)

○ New Sensors Development

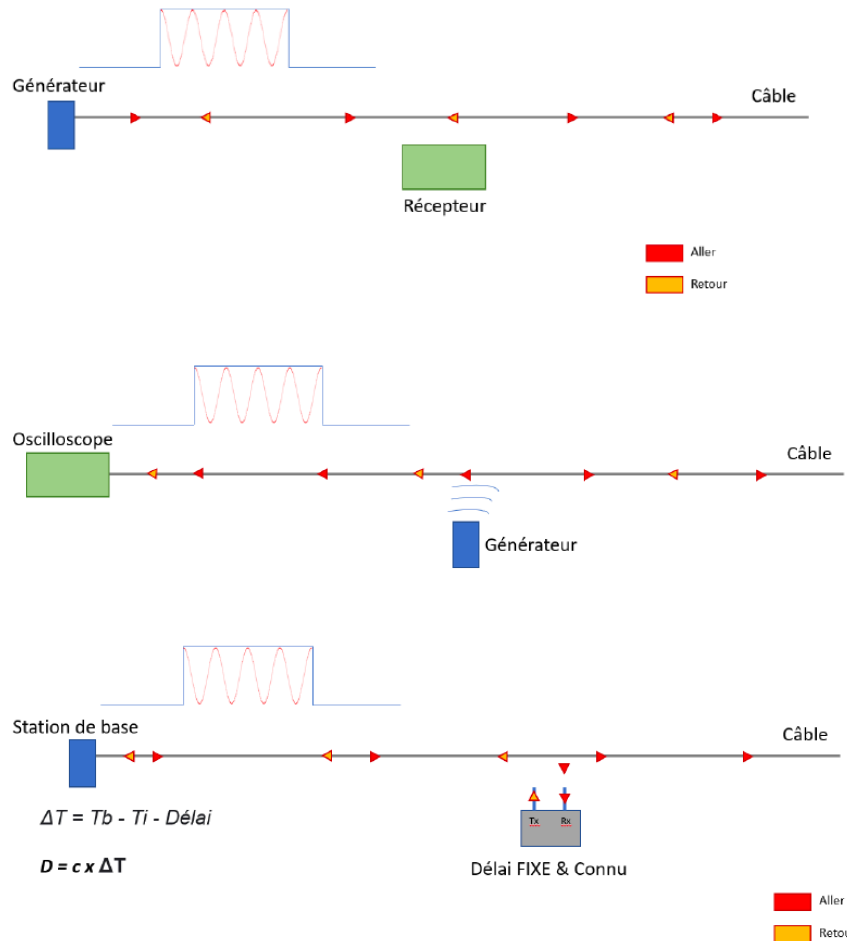
- Active Umbilical (localisation and communication)
 - Détection of Stationnary waves in single wire (fil d'ariane)



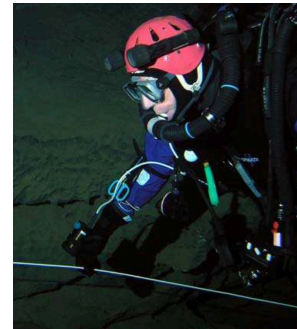
Experimentation in the St Antoine spring (Toulon)

○ 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)

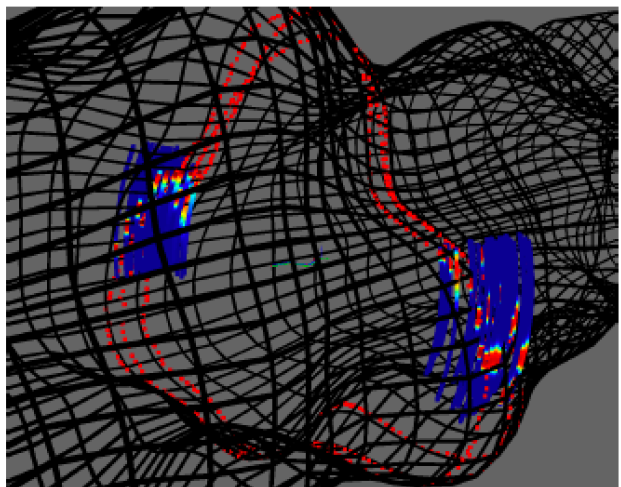
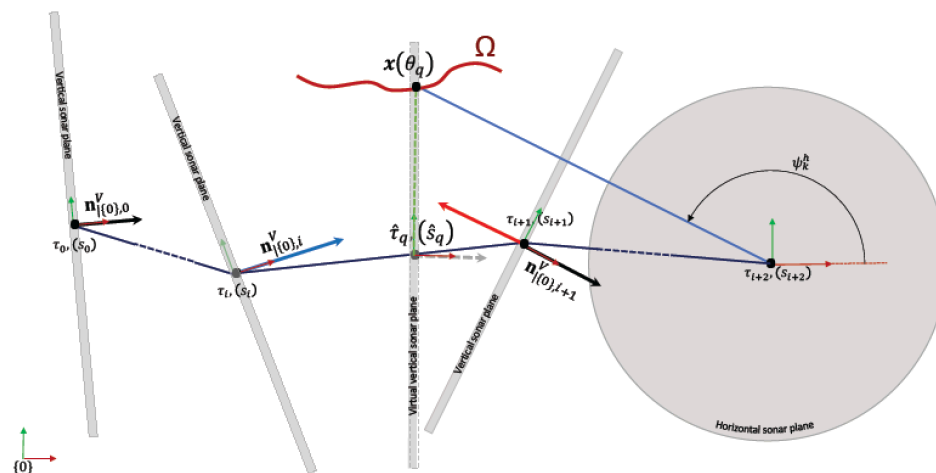
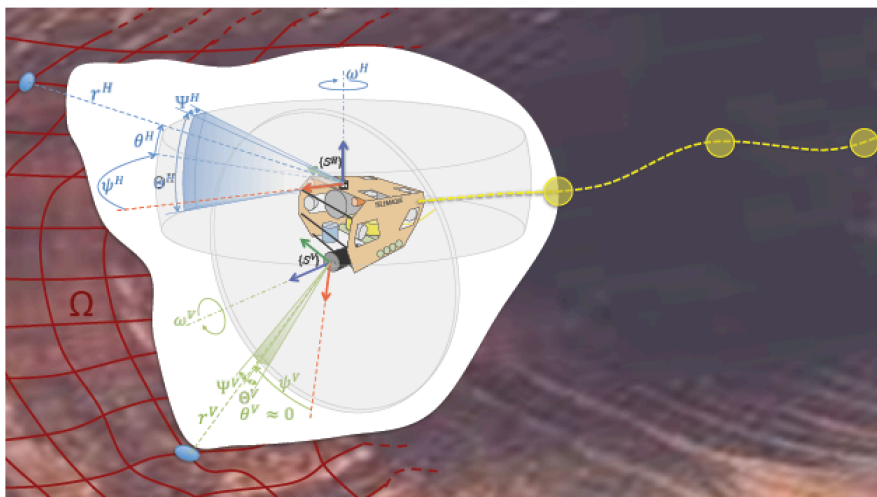


THE RKE INITIATIVE : FORCES AT WORK

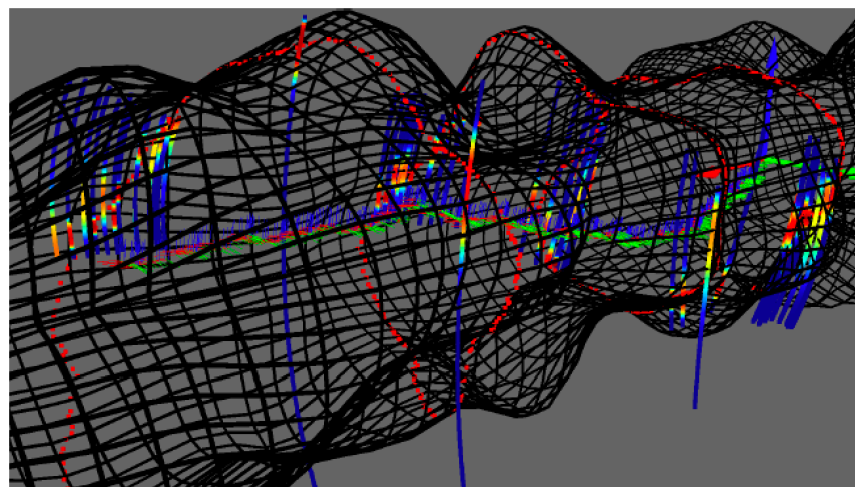
Y. Breux (LIRMM/IMAG)
B. Mohammadi (IMAG)
A. Mas (IMAG)
L. Lapierre (LIRMM)

Navigation

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



(a) Dense case.



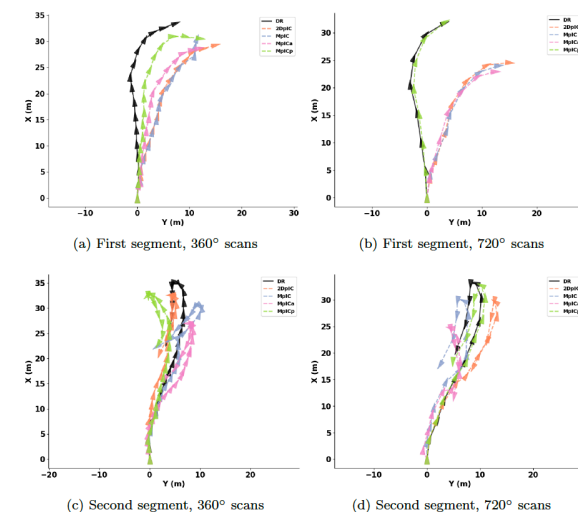
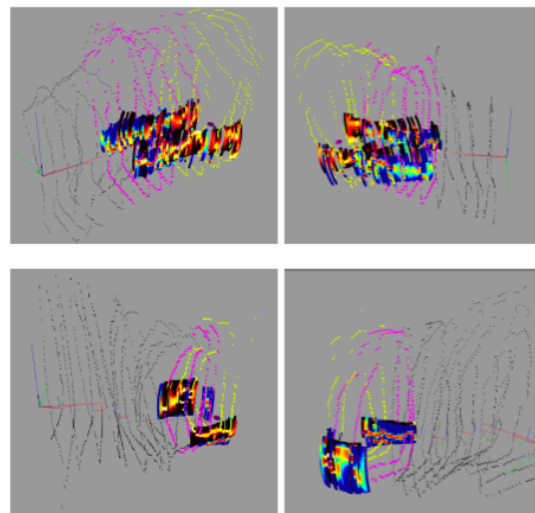
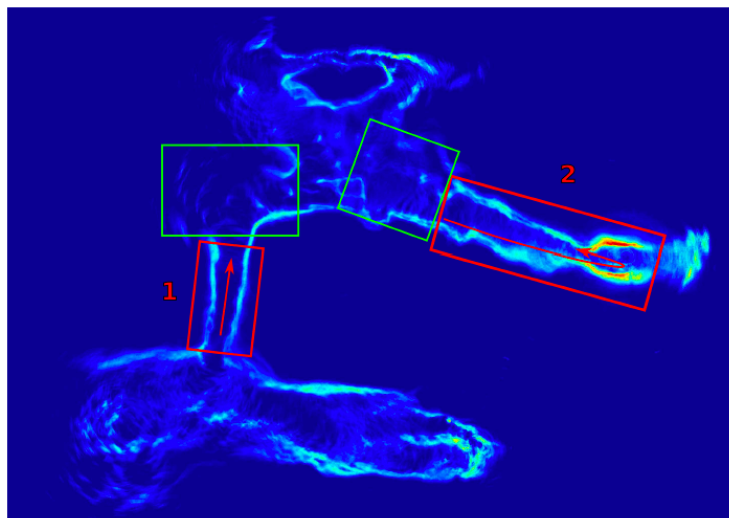
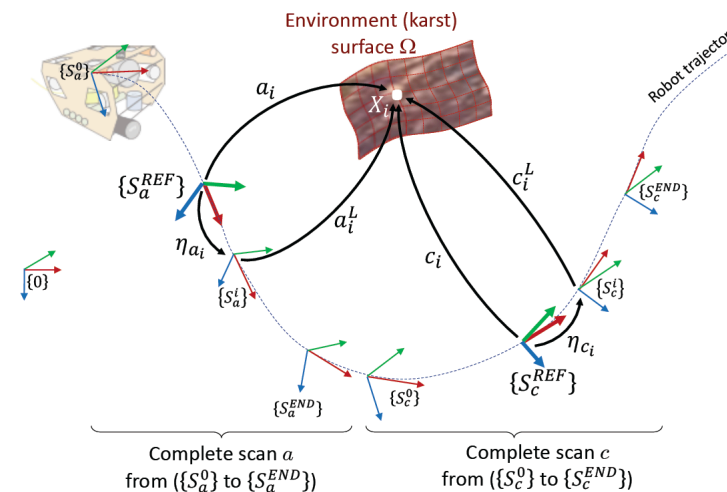
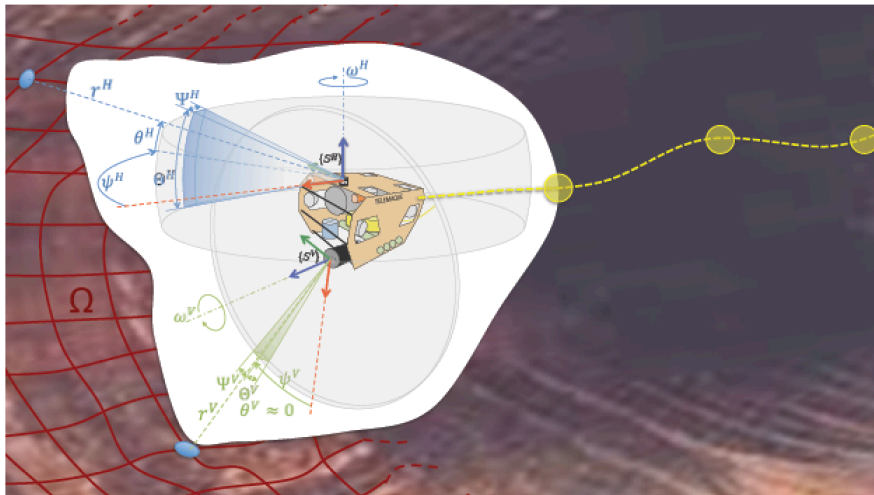
(c) Sparse case.

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...

Navigation

- Vacancy Evidence Grids
- Advance vector

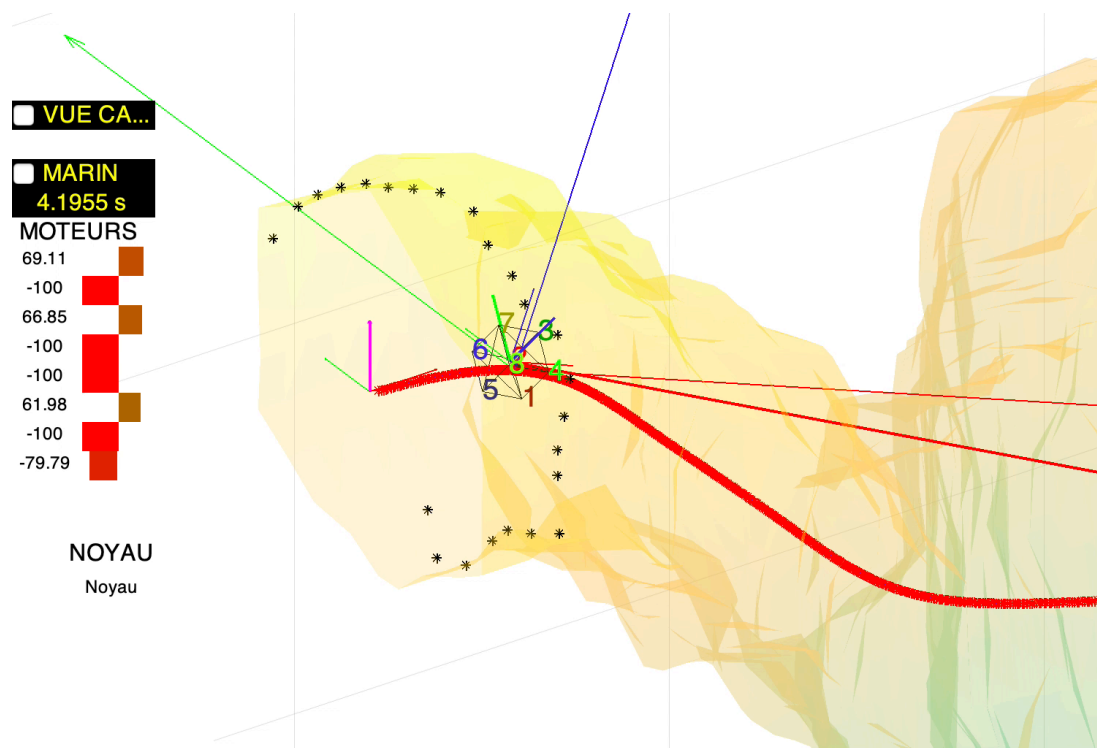
Local Path-planning

Guidance

- Autonomous Centring
- Path Following
- Obstacle Avoidance

Control

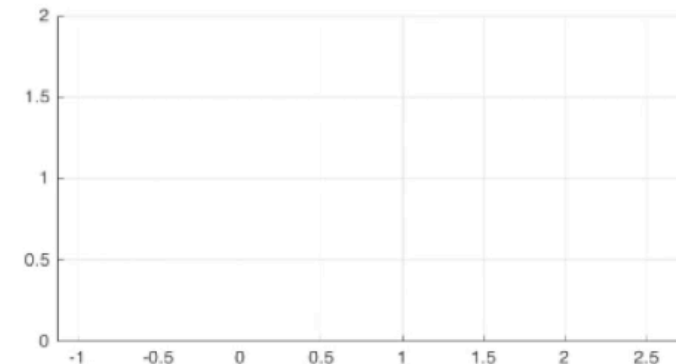
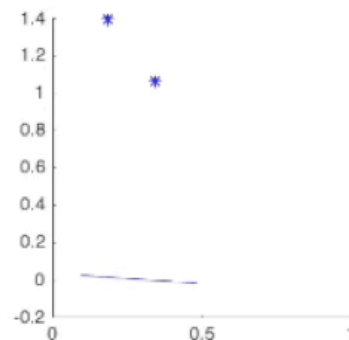
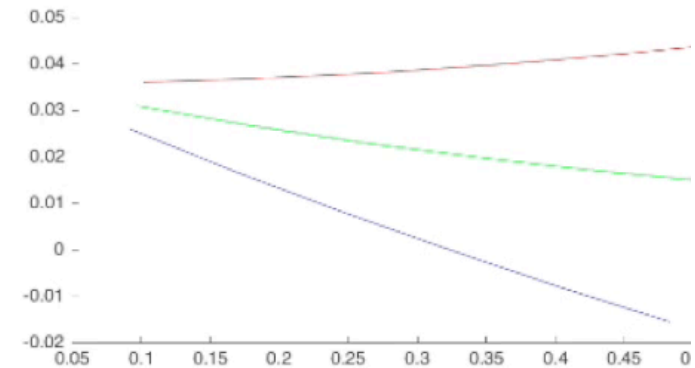
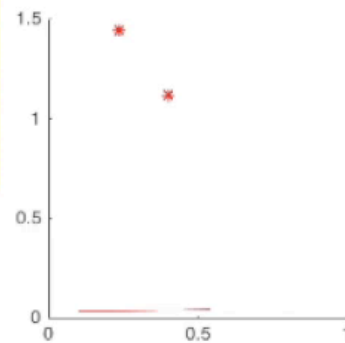
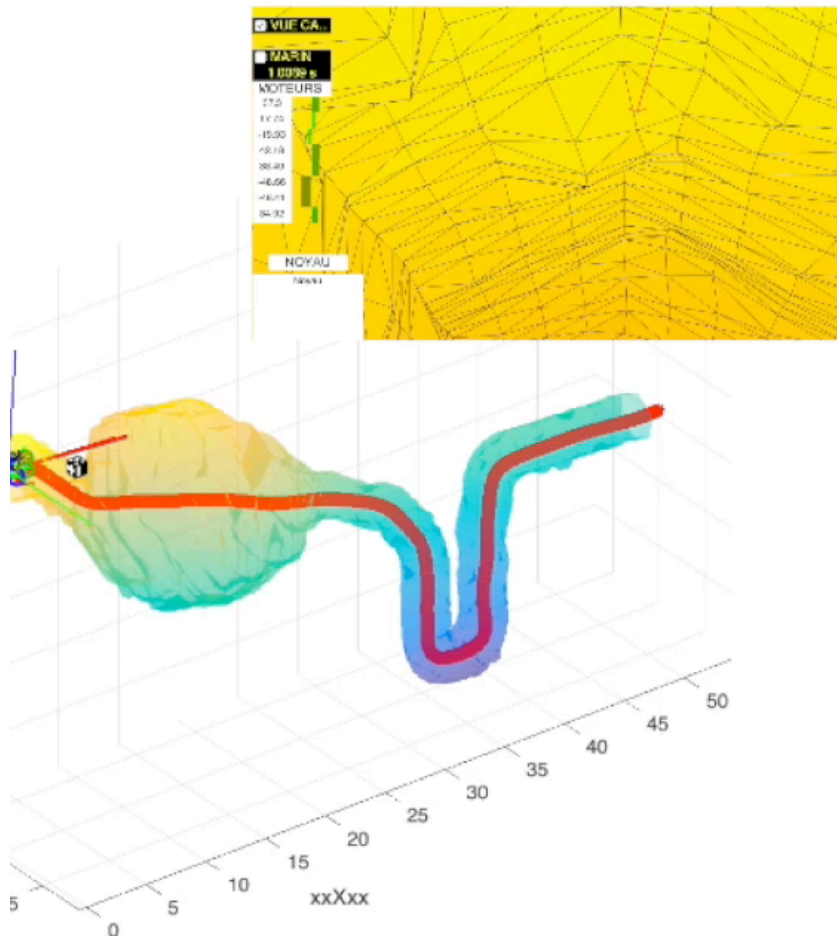
- Robustness
- Co-control
- Open-loop stability



THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

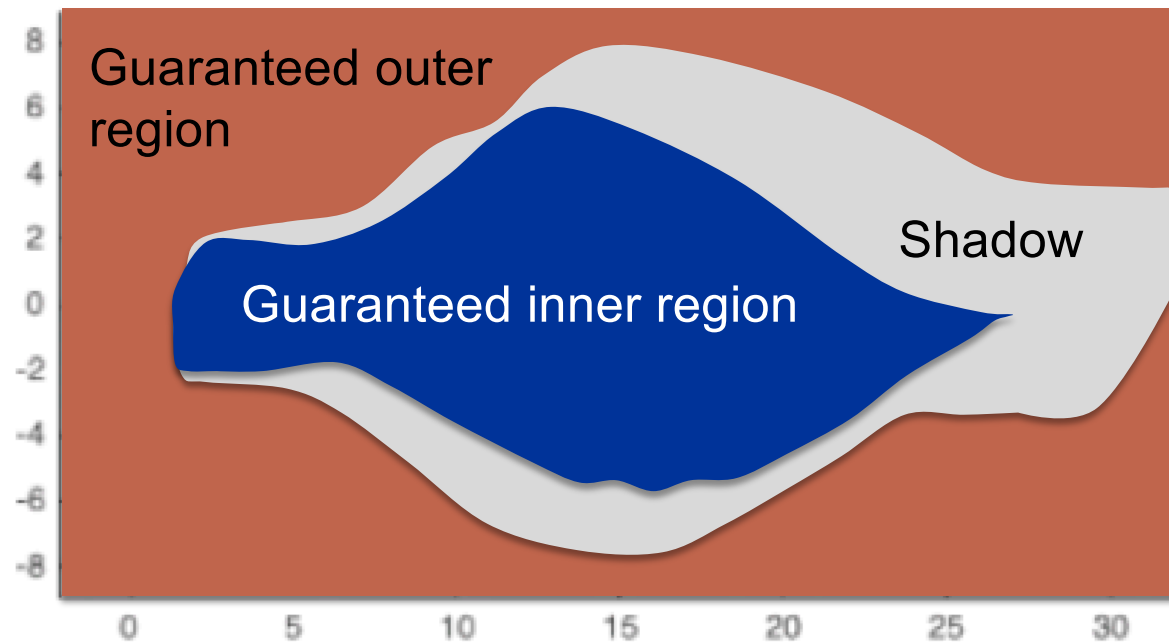
- Cartographie garantie, analyse par intervalles

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



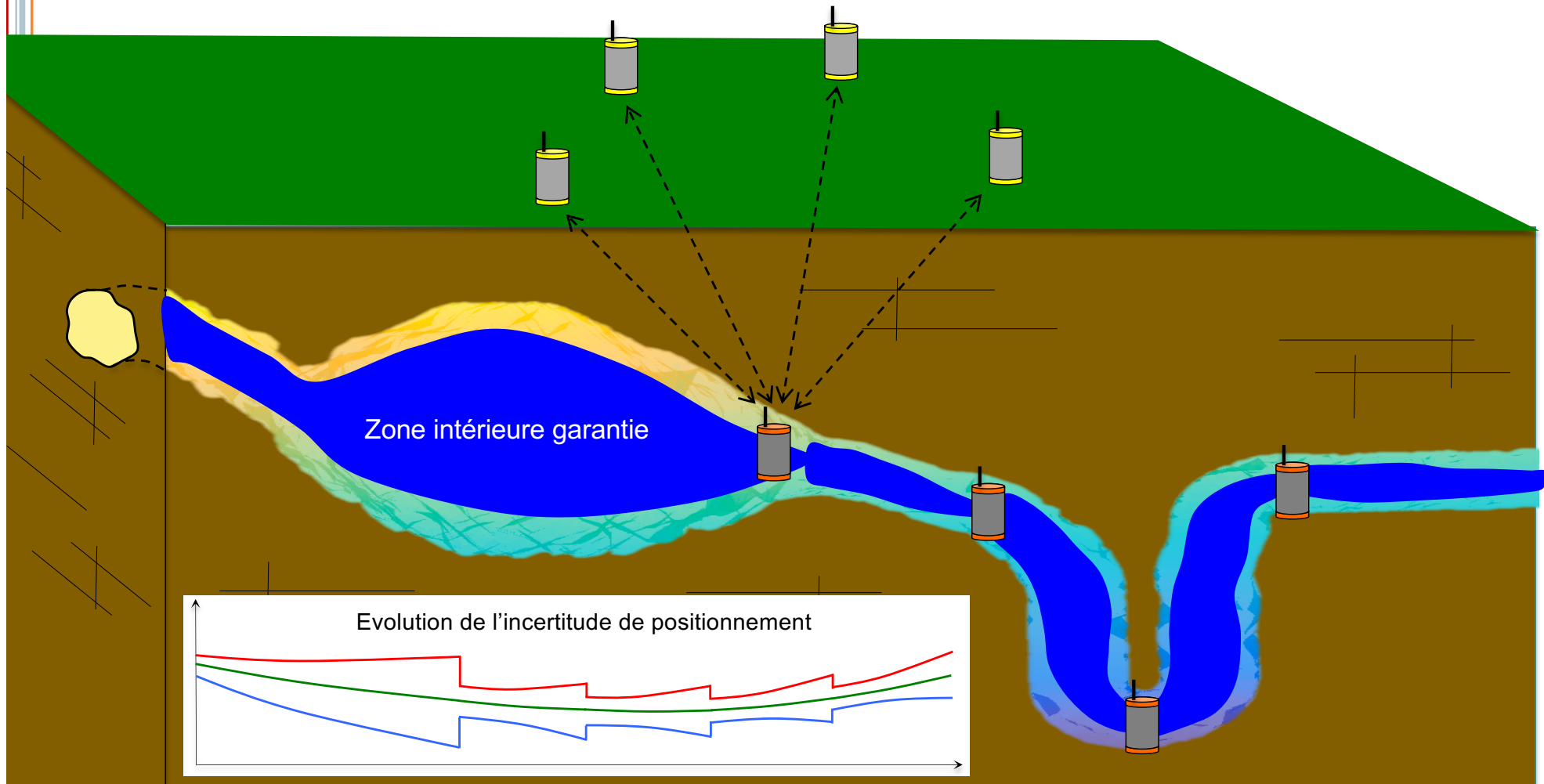
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

- Cartographie garantie, analyse par intervalles



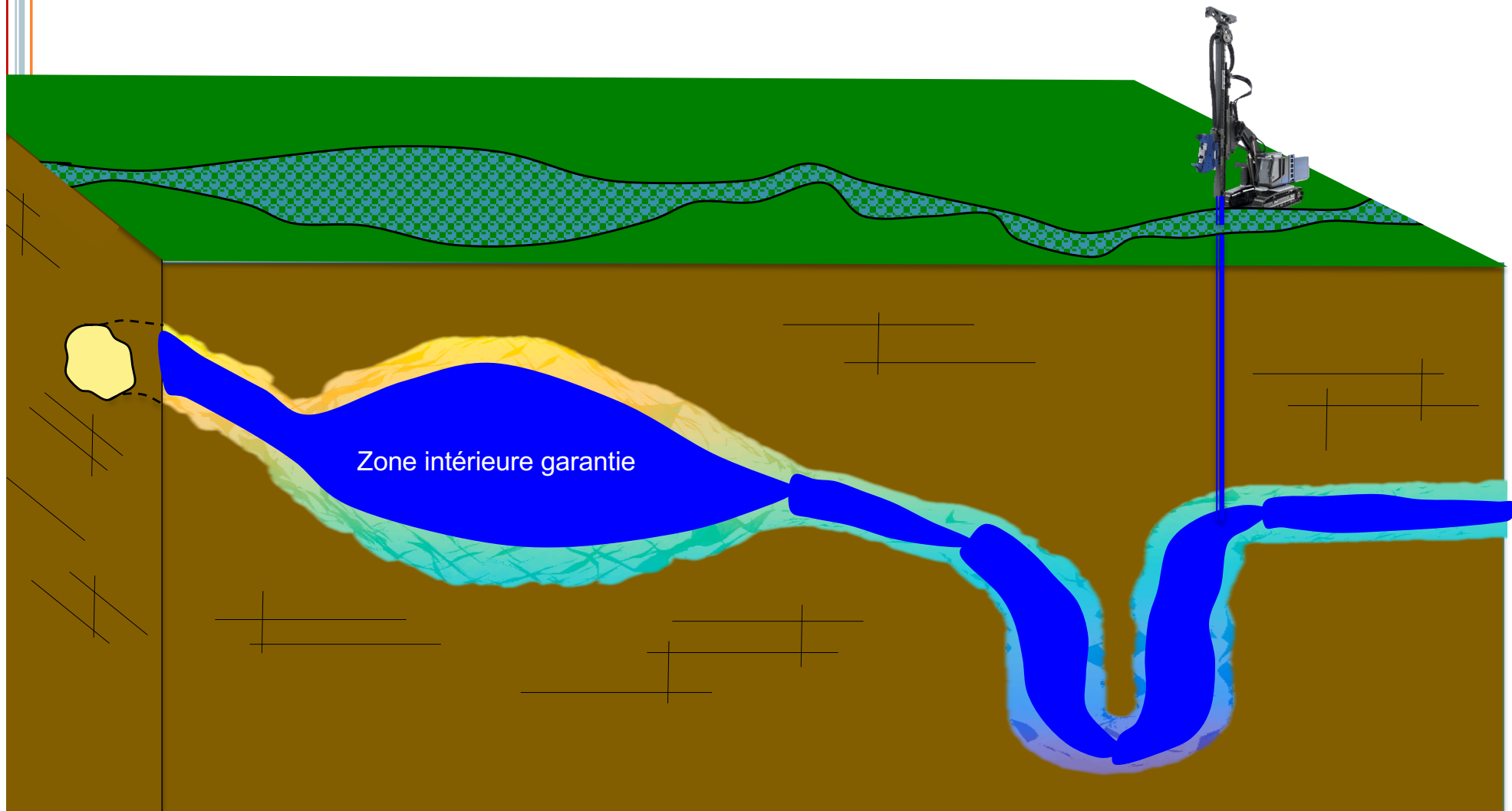
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

- 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

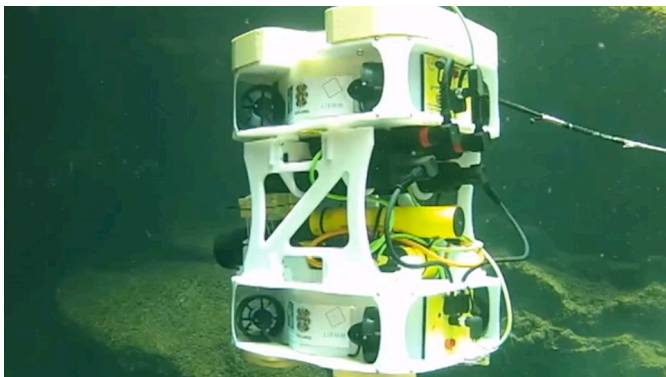


THE RKE INITIATIVE : FORCES AT WORK

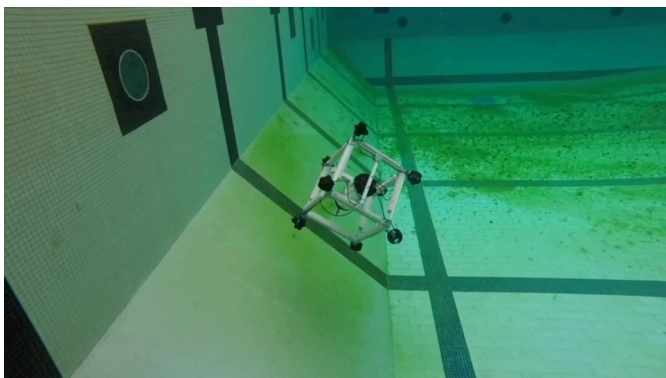
Actuation

- Reactive management of actuation redundancy,
- Variable Geometry A.S.

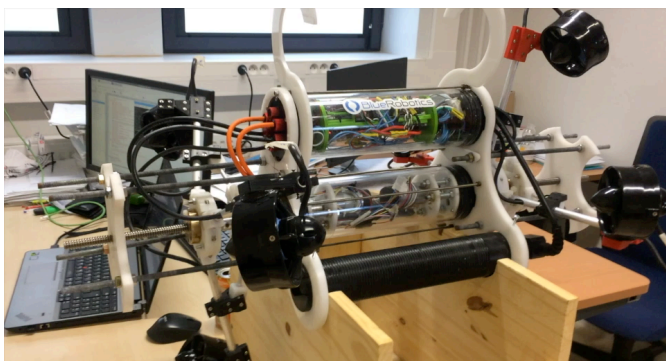
R. Zapata (LIRMM)
L. Lapierre (LIRMM)
B. Ropars (Reeds)
D. Huu Tho (Thèse)
Luc Rossi (Syera)
R. Bouchard (PlongeeSout)
F. Vasseur (PlongeeSout)



Ulysse



Cube



Umbrella



NavScoot



HammerHead



NavScoot 2

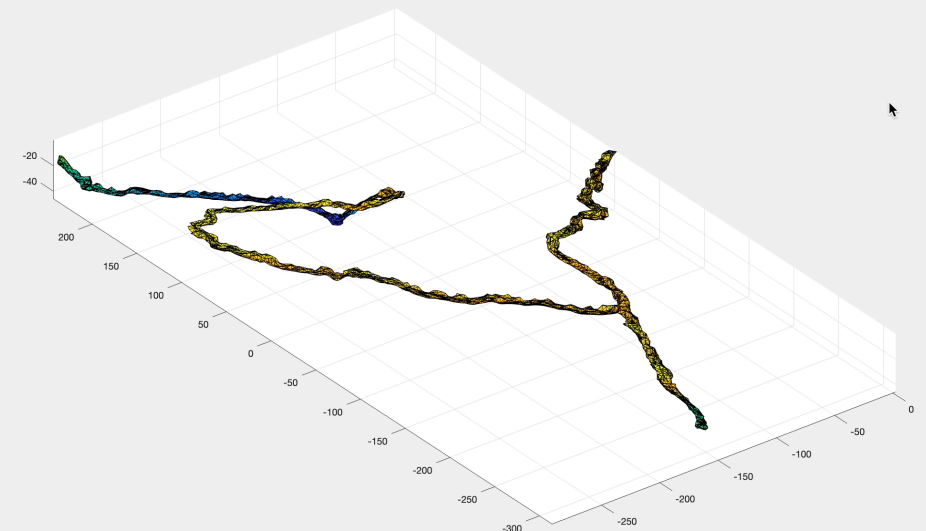
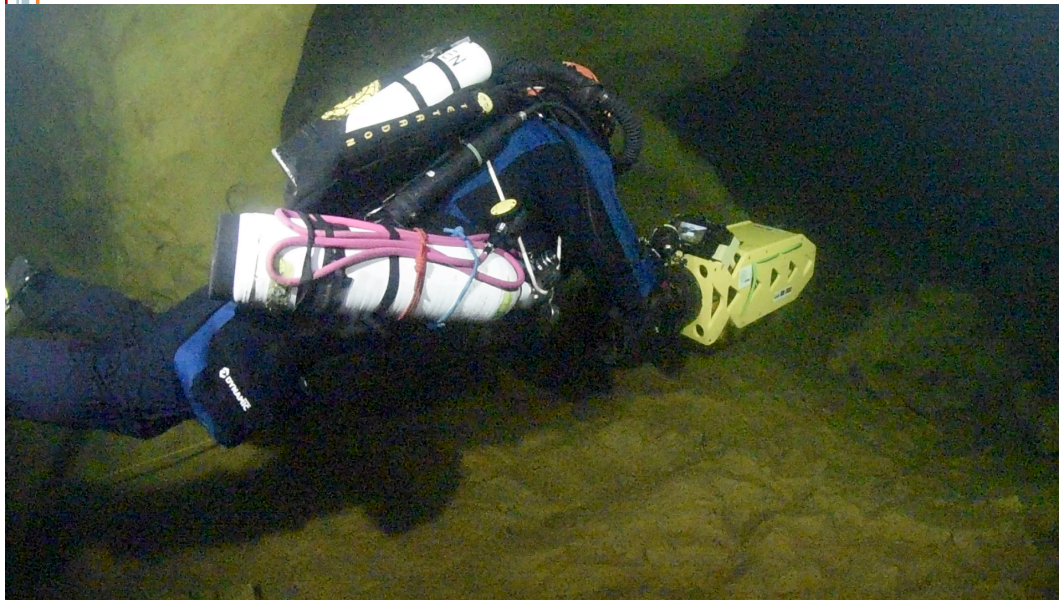
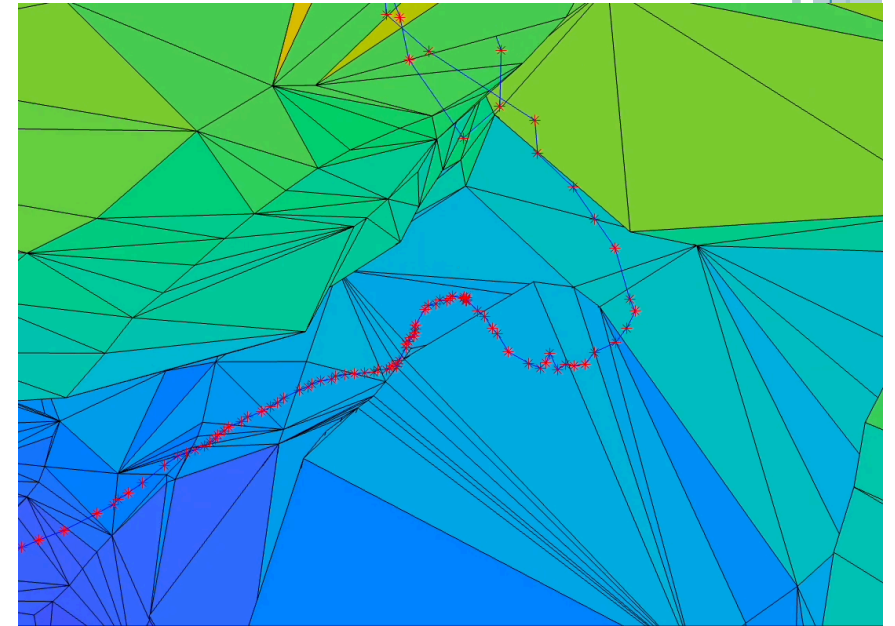
TERRAIN RESULTS: FONTAINE DE NÎMES, 8/03/2023



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

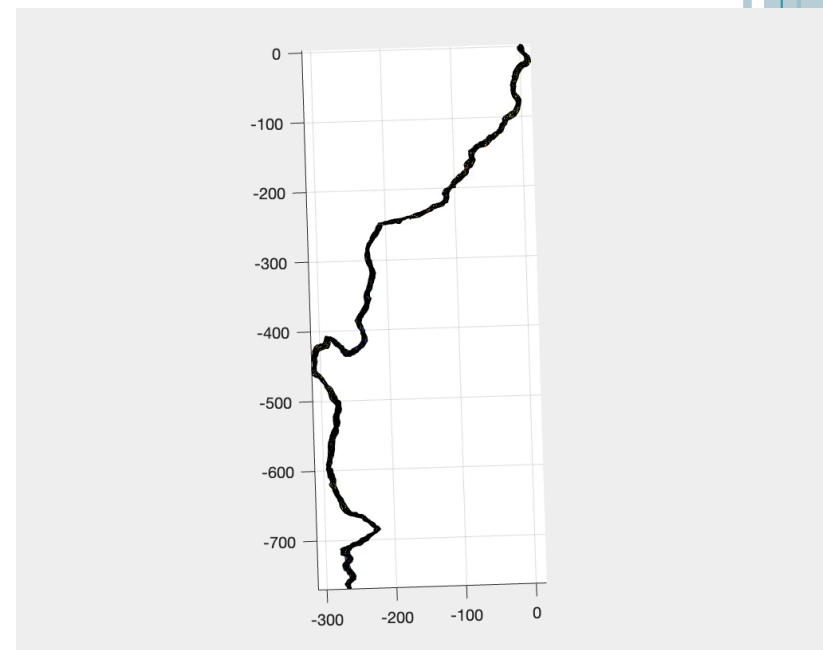
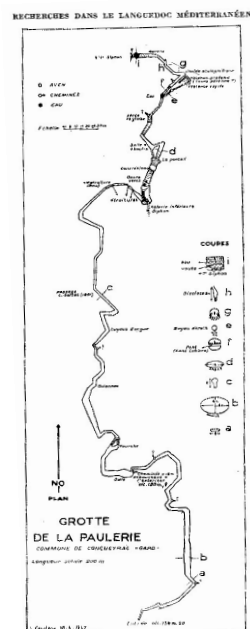
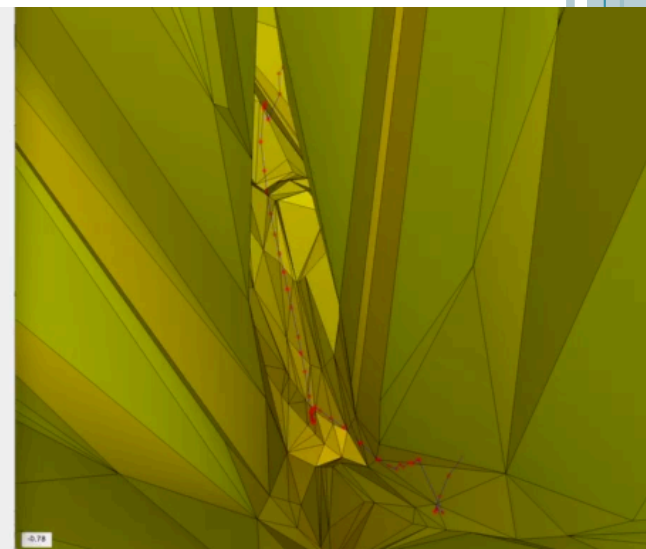
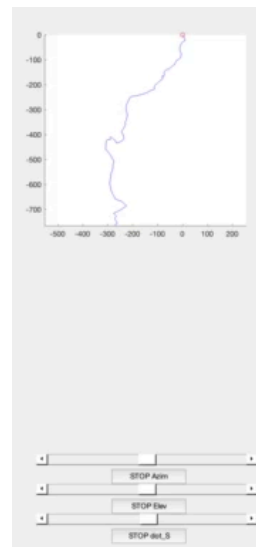


TERRAIN RESULTS: FONTAINE DE SAUVE, 24/05/2023



PLONGEURS
Frank VASSEUR
Doriane MORATA
Dominique VIGNOLE

Eq. TECHNIQUE
Benoit ROPARS

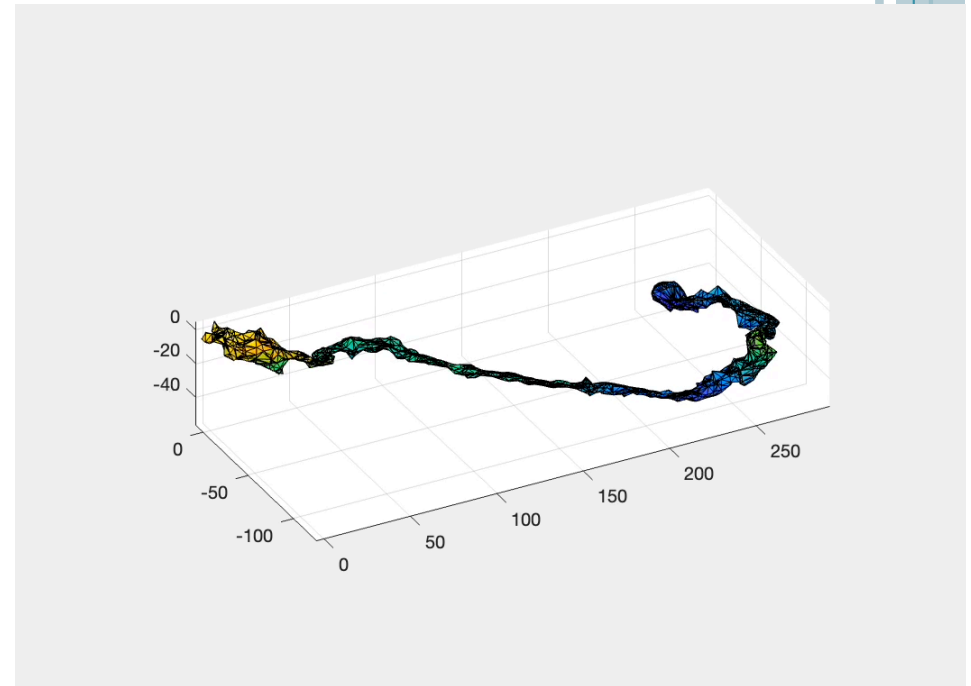
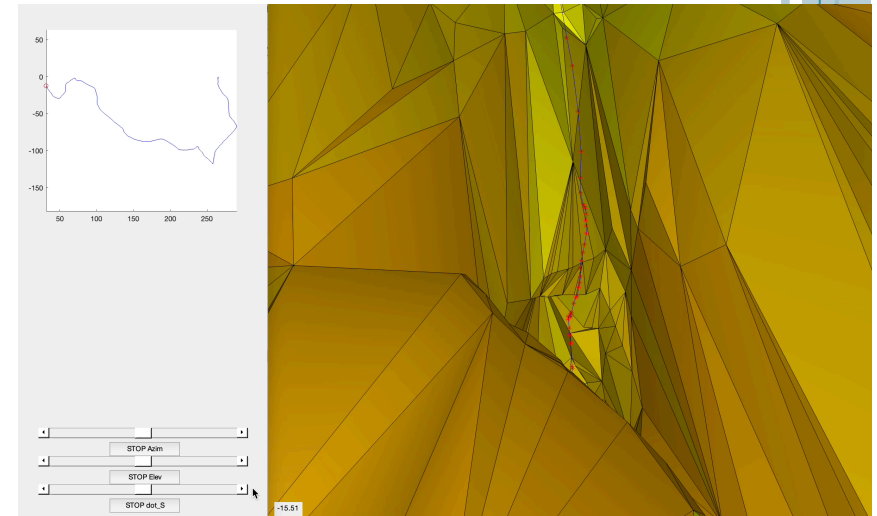


TERRAIN RESULTS: SOURCE DU LEZ, 15/03/2023



PLONGEURS
Frank VASSEUR
Mathieu FOULQUIE
Doriane MORATA
Dominique VIGNOLE
Denis PAILLO

Eq. TECHNIQUE
Lionel LAPIERRE
Hervé JOURDE
Benoit ROPARS
Mohammed ALIOUACHE



ON GOING ACTIVITIES

○ Sources du LEZ

- 2/4 dives to conclude the project, September / October 2023

Vigilance accrue à la source du Lez où les niveaux sont au plus bas

ENVIRONNEMENT

Le déficit pluviométrique est marqué depuis des mois. L'enjeu est important car l'usine de captage alimente, au quotidien, plus de 83 000 foyers abonnés sur quatorze communes de la Métropole.

Frédéric Mayet
fmayet@midilibre.com

Saint-Clément de Rivière, la bien nommée. C'est ici, au milieu d'un sous-bois luxuriant, que commence à couler le fleuve Lez. « La zone est ouverte au public mais on la protège, notamment en rétablissant les berges. C'est un poumon. » Pascale Le Neouannic, de la Régie des eaux de la Métropole, se félicite, au passage, « que les gens aient désormais bien compris l'enjeu de la préservation de l'eau et de son cycle. » Voilà bien le cœur du sujet qui préoccupe. Plus que jamais. « L'arrêt préfectoral vient de tomber. Le niveau du Lez et des nappes ne sont pas bons cette année. Nous l'avions dit, les spécialistes l'avaient prédit. Sans pluie, on manque d'eau. Le bassin-versant du Lez vient de basculer en vigilance jaune. » Soit la mise en place de premières restrictions au

quotidien : interdiction d'arroser le jardin, de laver les véhicules hors des stations et de remplir les piscines. Effectivement, à quelques centaines de mètres de là, le spectacle de la résurgence du Lez fait comprendre l'état de manque actuel. « Ce n'est pas bon. Nous avons la crainte que plusieurs phénomènes jouent, y compris le vent qui assèche plus vite les végétaux, accentue l'évaporation naturelle. Sans parler de la canicule et de l'irrégularité des pluies. »

« L'eau ne connaît pas les limites administratives » Pascale Le Neouannic rappelle le constat, fait ces trente dernières années : « Les pluies de mi-août se sont progressivement décalées à fin septembre. En 2021 et l'an dernier nous avons été en sécheresse hivernale. » Résultat : ces jours-ci le niveau de la résurgence du Lez est très très bas. « Mi-mars l'eau débordait. » Au-delà de cette résurgence na-



Le niveau de la résurgence du Lez est actuellement très bas. Il débordait pourtant à la mi-mars. R. DE HULLESEN

tuelle, depuis 1982, grâce au travail du géologue Jacques Avias, alors professeur à l'université des sciences et techniques du Languedoc, le choix a été fait de creuser pour retrouver la nappe souterraine du Lez. « L'usine de captage est au droit de cette nappe, sur la commune des Matelles, avec trois pompes qui descendent 80 mètres sous la terre. » Impossible, cependant, d'estimer plus ou moins précisément

le volume d'eau de cette nappe. « La Régie a des partenariats avec des chercheurs montpelliérains pour connaître notre réservoir naturel. On connaît bien la résurgence jusqu'au droit des pompes. Après c'est plus compliqué. » Reste, comme le souligne avec malice Pascale Le Neouannic, que « l'eau ne connaît pas les limites administratives mais des bassins-versants et des secteurs. Le réseau Lez principal

concerne Montpellier et Juvi-gnac. Aujourd'hui Grabels a ses propres ressources, sécurisées par le système Lez. Lattes et Pérols sont alimentées exclusivement par l'eau du Bas Rhône. Parallèlement la Régie vend de l'eau au Pic Saint-Loup dans un schéma d'échange. »

> Lire également l'article sur les mesures de restriction en page Région de ce dimanche 14 mai.

Restrictions renforcées avec l'arrêt préfectoral

MESURES Le Préfet a décidé, ce vendredi 12 mai, de « renforcer les restrictions sur les usages de l'eau dans le département. » Ainsi le bassin-versant de la Mosson et du Lez bascule-t-il en alerte. Avec nouvelles restrictions d'usage de l'eau : interdiction du remplissage des piscines privées, du lavage des voitures à domicile et du fonctionnement des fontaines en circuit ouvert. L'irrigation agricole et des potagers est interdite entre 10 h et 18 h (sauf pour les modes d'irrigation économes en eau). Pour l'arrosage domestique (pelouses, jardins), des terrains de golf et des stades, l'interdiction s'étend de 8 h à 20 h. « Sur la source du Lez, explique Arnaud Astier, directeur environnement de la Régie des eaux, le cumul pluviométrique (141 mm) sur l'aire d'alimentation du captage représente toujours environ la moitié de la pluviométrie normale de la période. Les autres nappes exploitées par la Régie se situent à un niveau normal à modérément bas. »

ONGOING ACTIVITIES

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

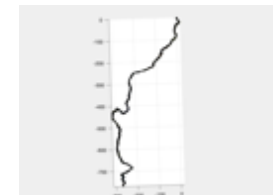
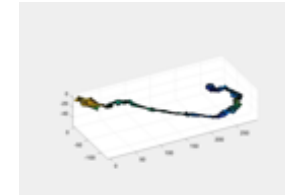
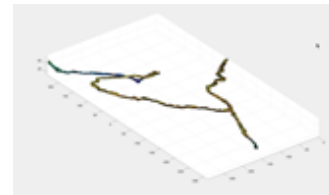
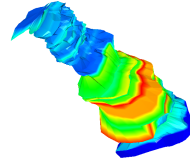
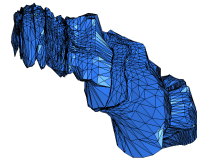
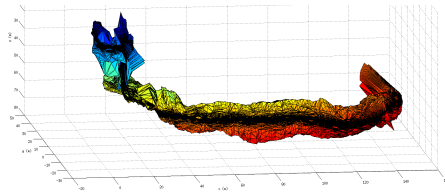


ONGOING ACTIVITIES

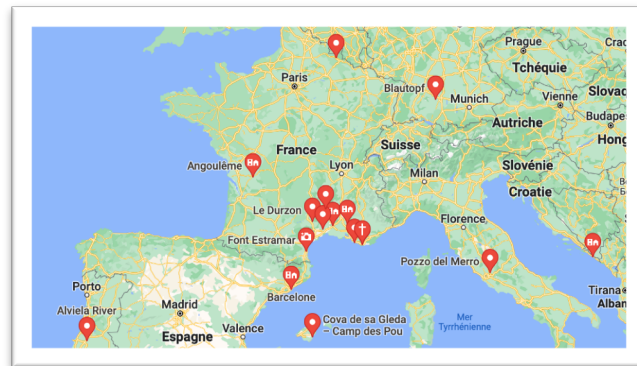
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EXPLOITATION / VALORISAT°

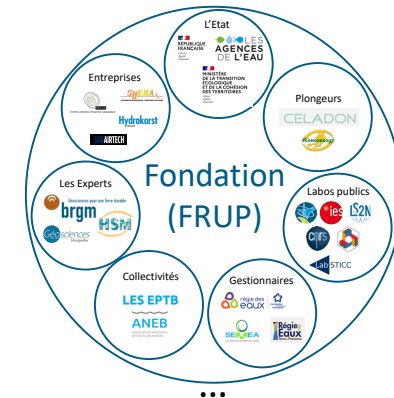
RECHERCHE



Cartographie des ressources en eaux souterraines (visitables)



NAVSCOOT 3



2015 - 2017

2017 - 2020

2020 - 2022

2023 - 2027

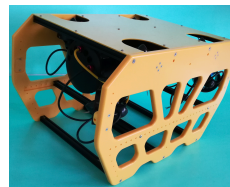
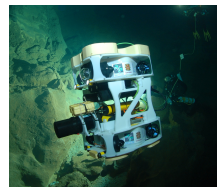
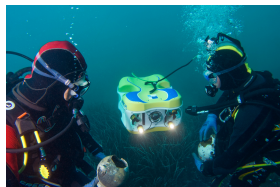
REEA

ALEYIN

LEZ 2020

ElectroKarst

ANZAR XX



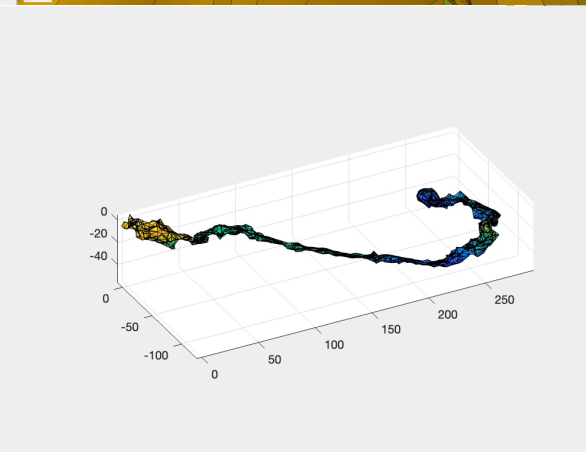
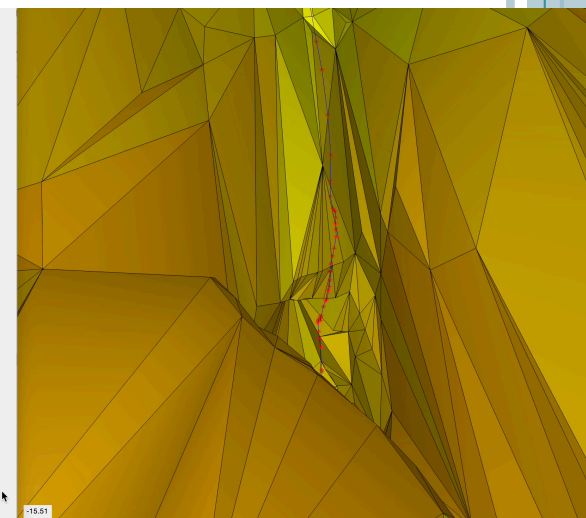
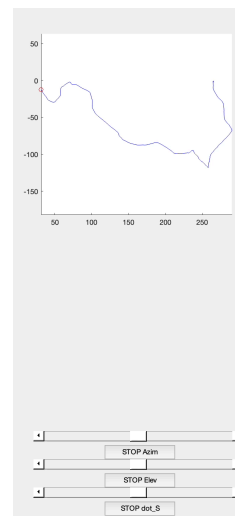


SOURCES DU LEZ, 15/03/2023



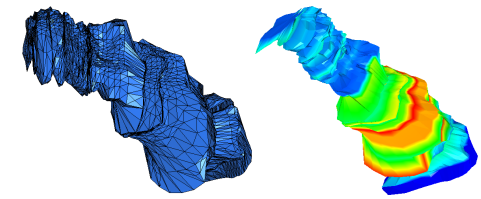
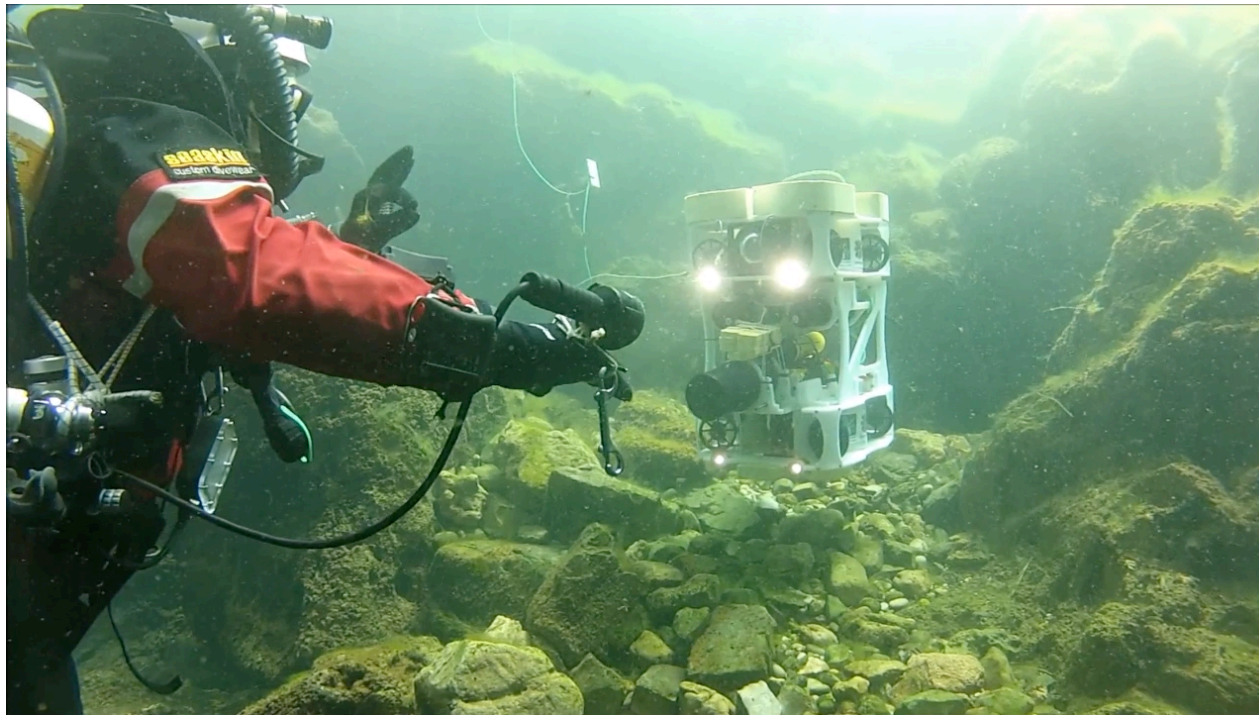
PLONGEURS
Frank VASSEUR
Mathieu FOULQUIE
Doriane MORATA
Dominique VIGNOLE
Denis PAILLO

Eq. TECHNIQUE
Lionel LAPIERRE
Hervé JOURDE
Benoit ROPARS
Mohammed ALIOUACHE

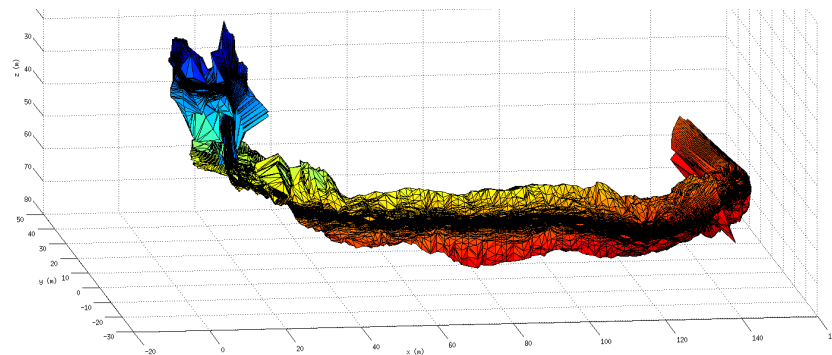
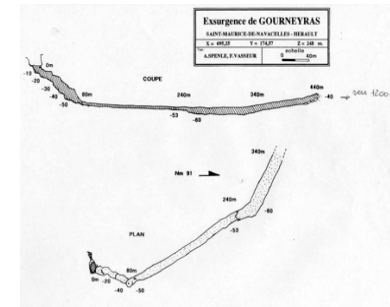


FISRT TERRAIN RESULTS

- Gourneyras, 11-14/07/2016 and 23/01/2017.

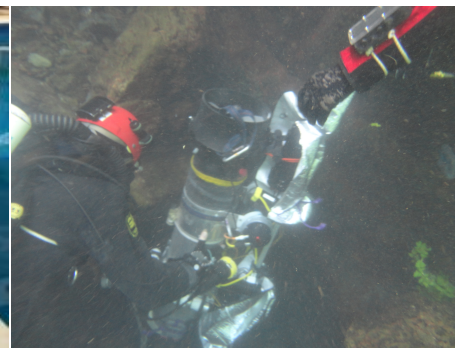
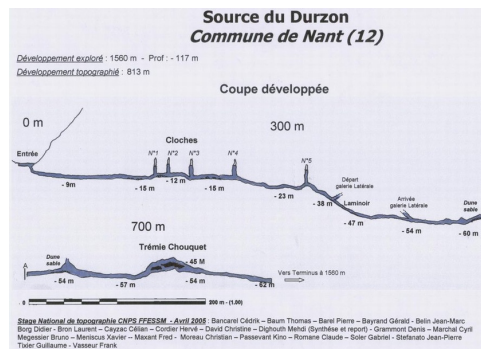


Volume (1187 m³)



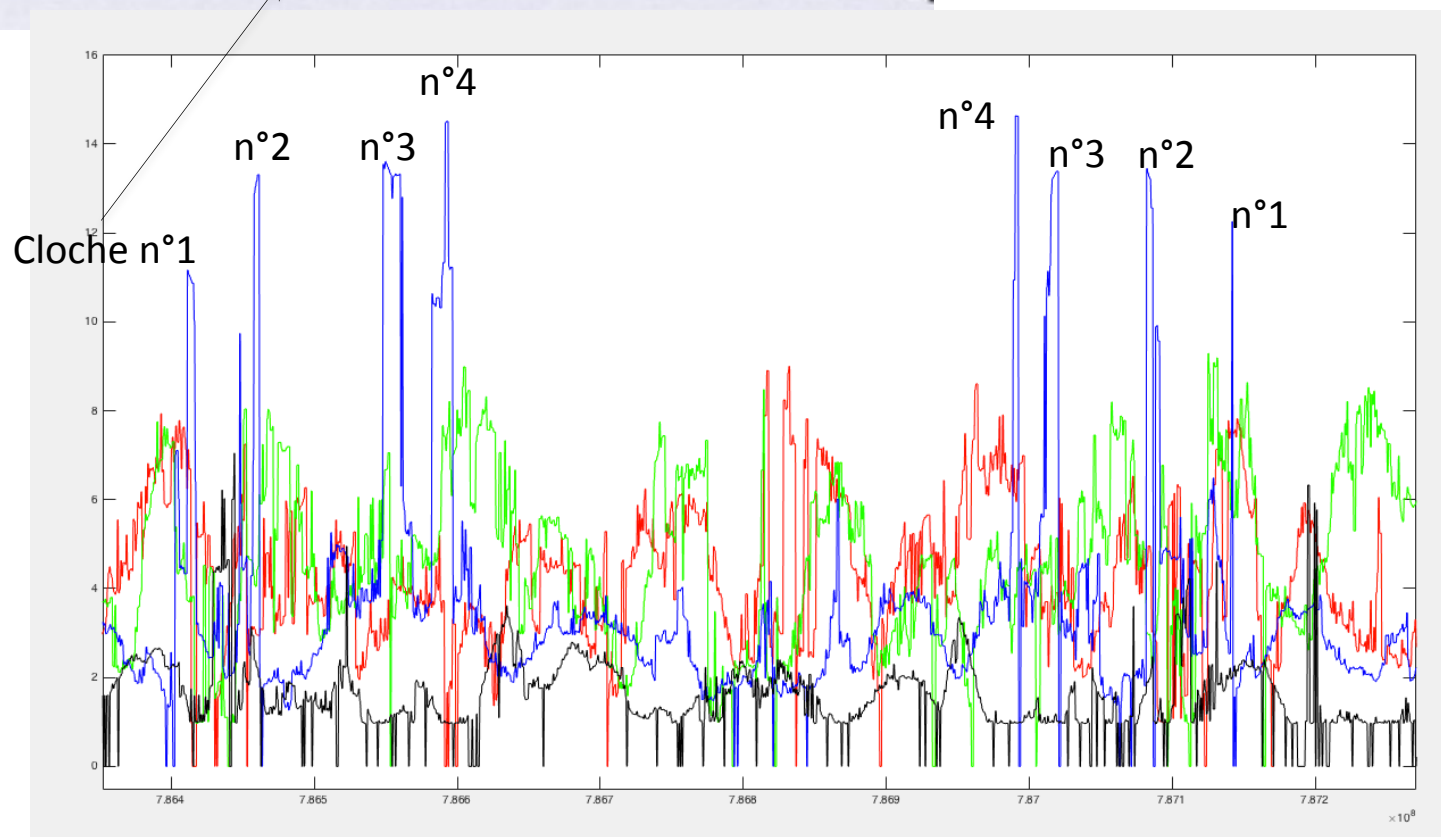
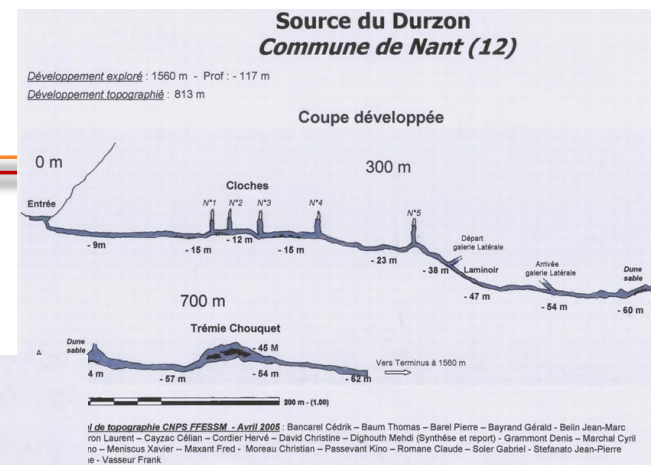
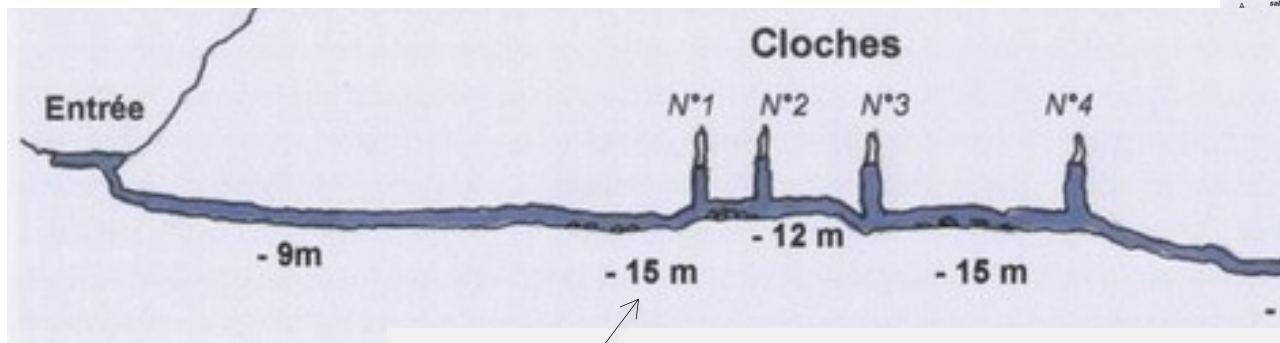
FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

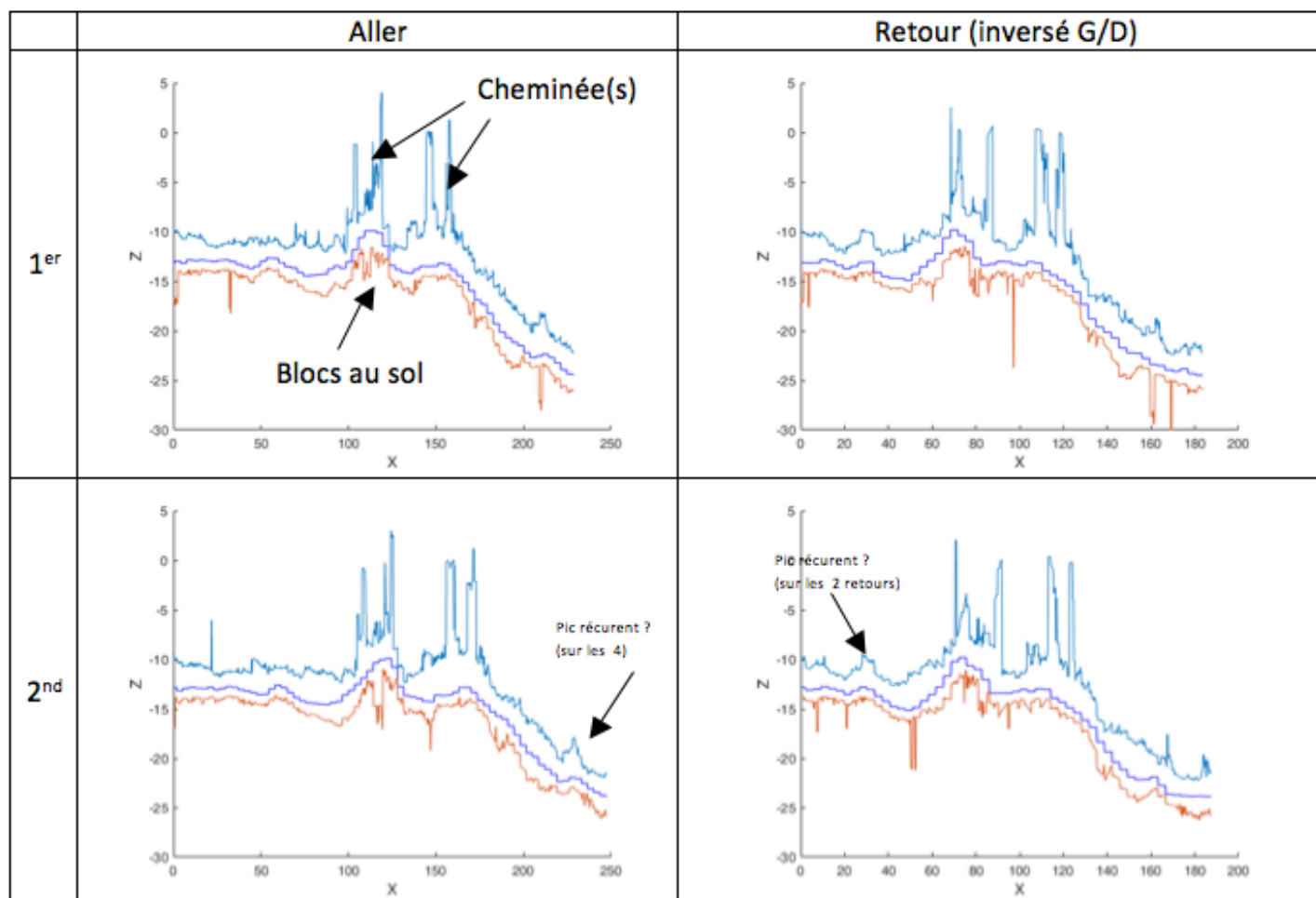


FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

« Vue de côté » (Echosondeurs Haut/Bas + Profondimètre)

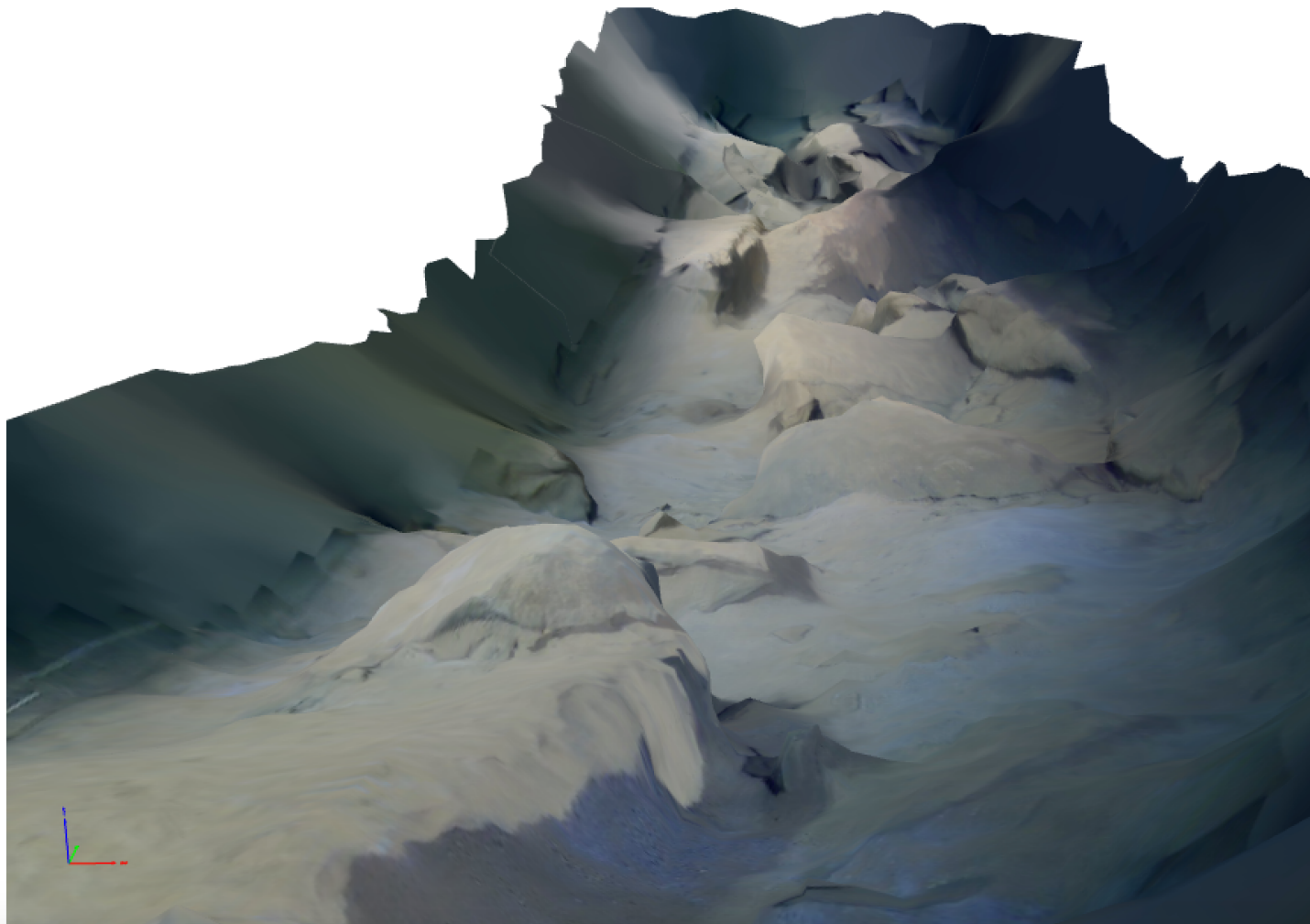
Données :



FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.

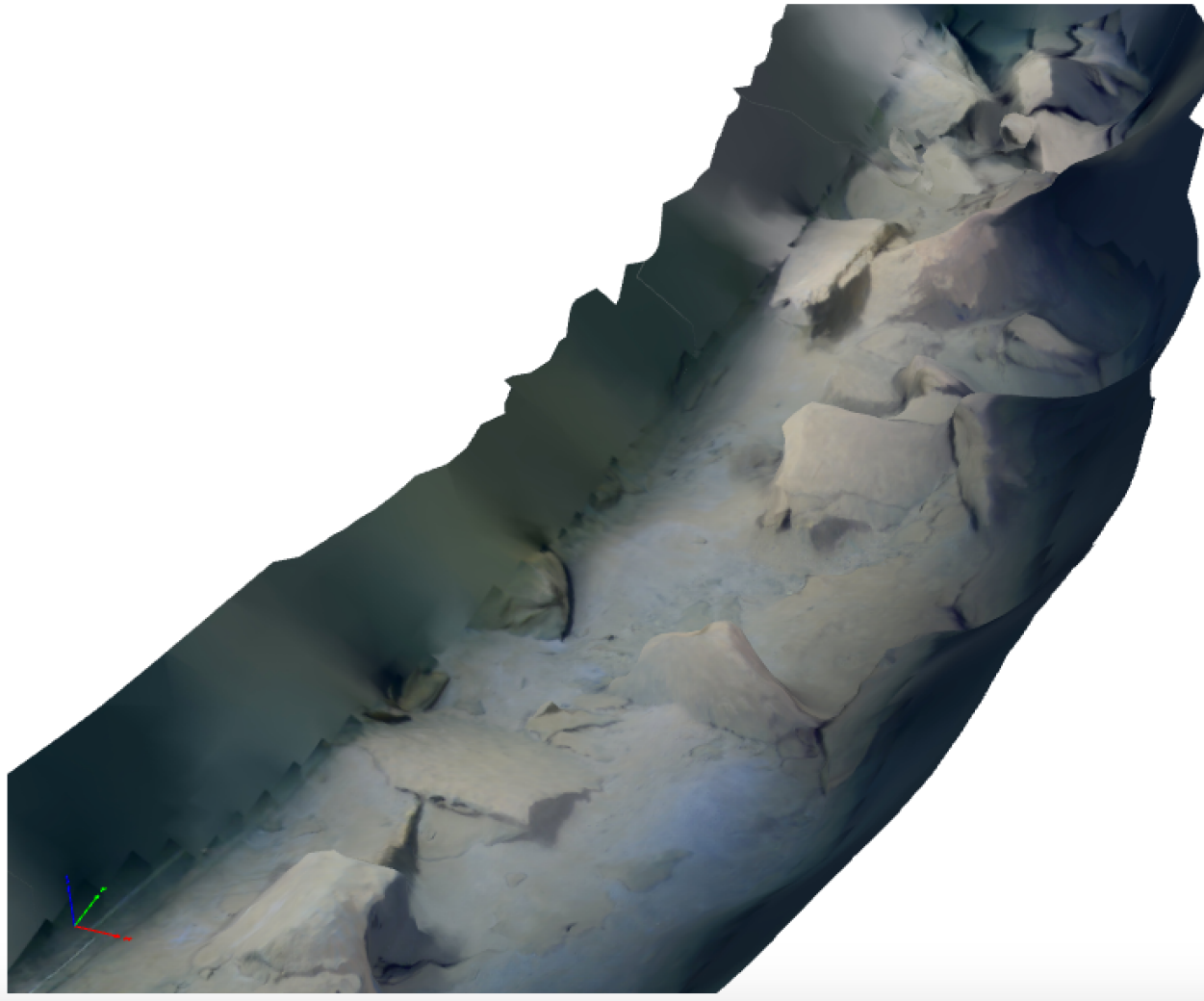
Photogrammetric reconstruction



FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.

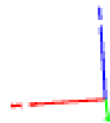
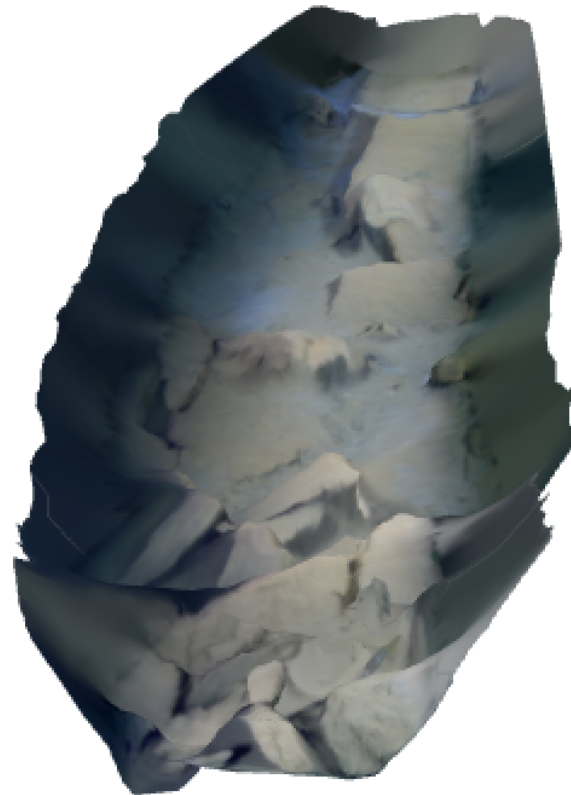
Photogrammetric reconstruction



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

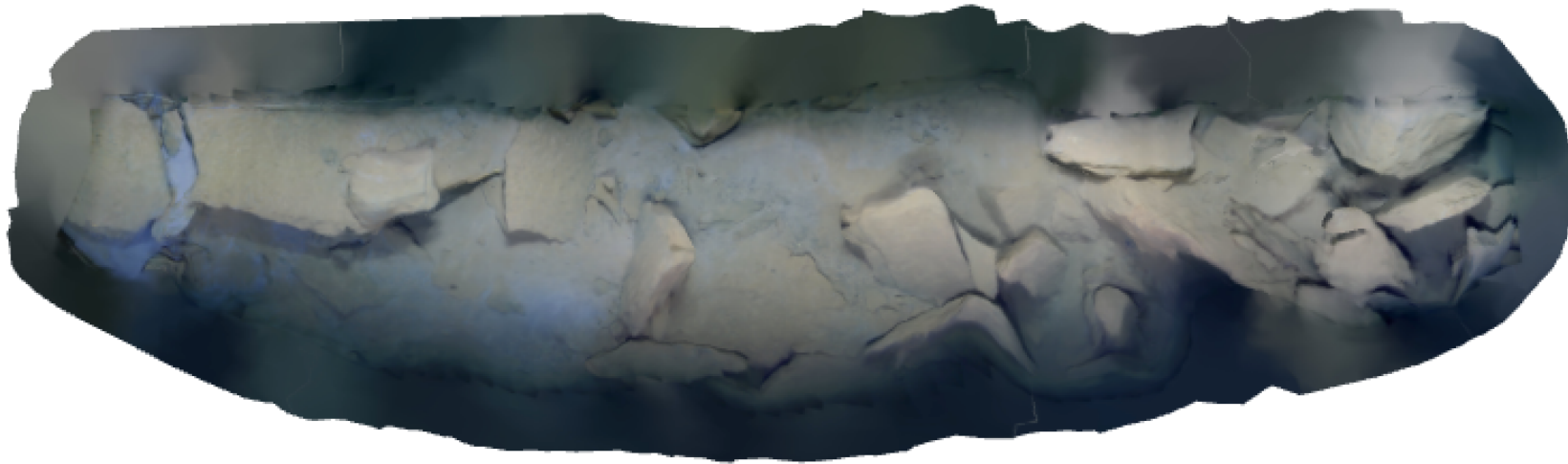
Photogrammetric reconstruction



FISRT TERRAIN RESULTS

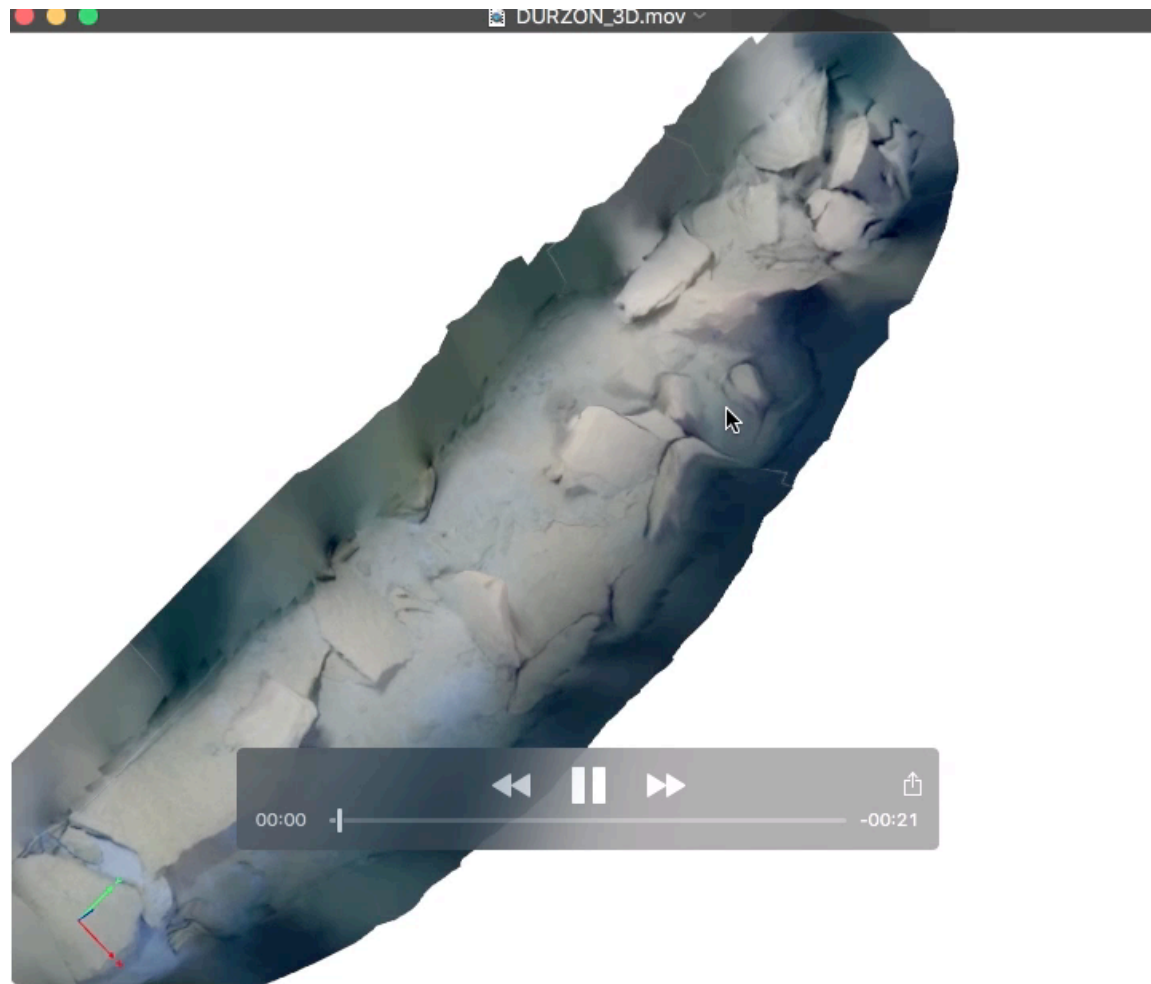
○ Durzon, Nant, 24/06/2018.

Photogrammetric reconstruction



FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.



Partial photogrammetric reconstruction

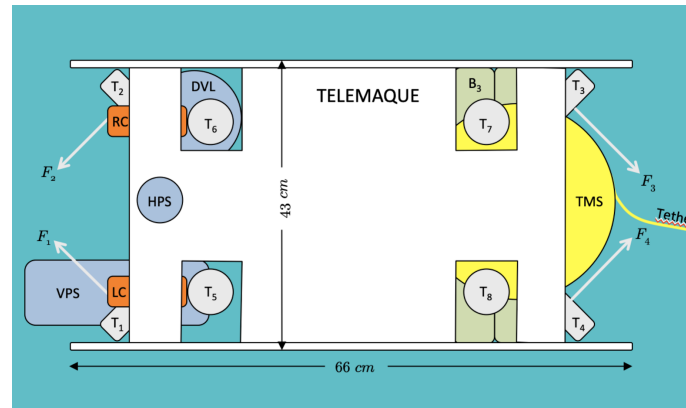
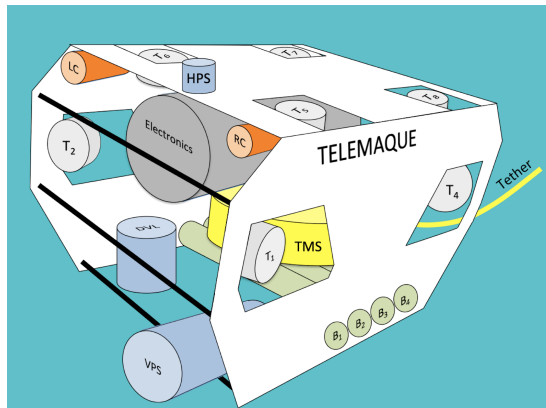
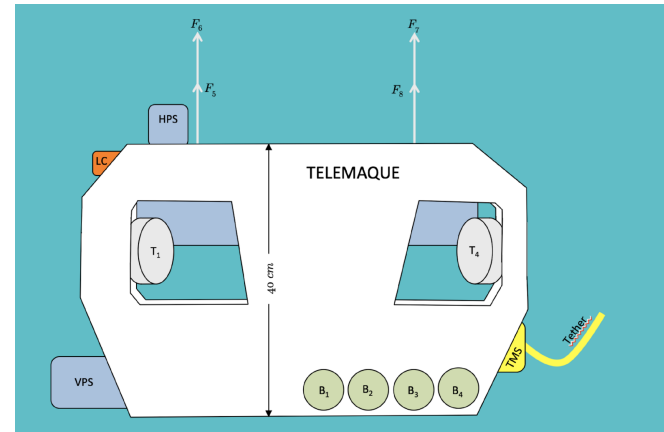
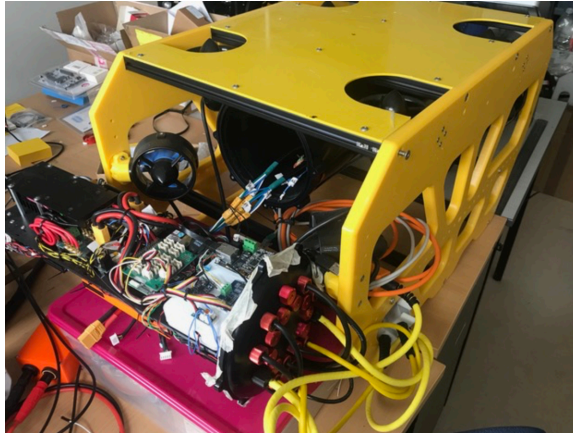


WHAT'S NEXT ?



NEW SYSTEMS

○ Télémaque



8 thrusters (T_1 to T_8) : T200 from BlueRobotics

4 batteries (B_1 to B_4) : 4x9Ah

IMU : cheap mems

Vertical Profiling Sonar (VPS) : Superseaking Tritech (or Subtop "DT360", Multibeam 360 Profiling Sonar)

Horizontal Profiling Sonar (VPS) : ping360, from BR

Doppler Velocity Log (DVL) : Nortek 1Mhz

2 cameras (Left and Right, LC and RC) :

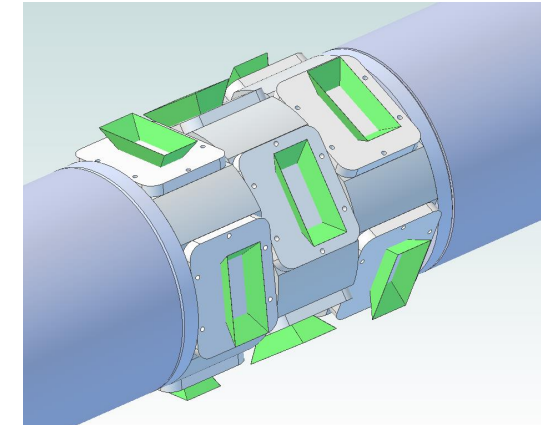
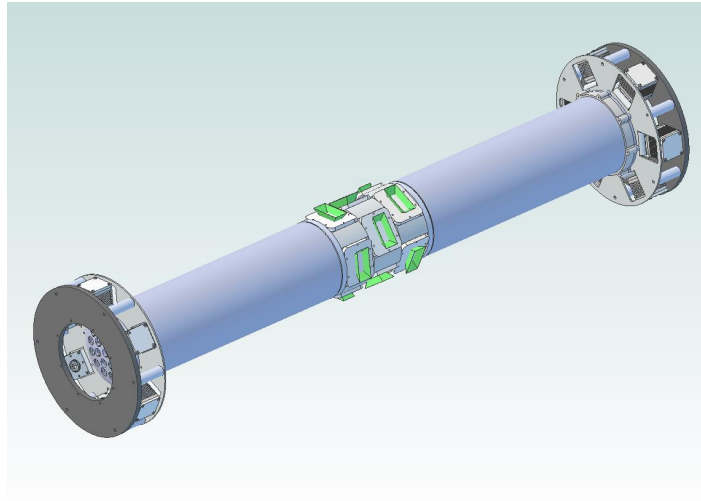
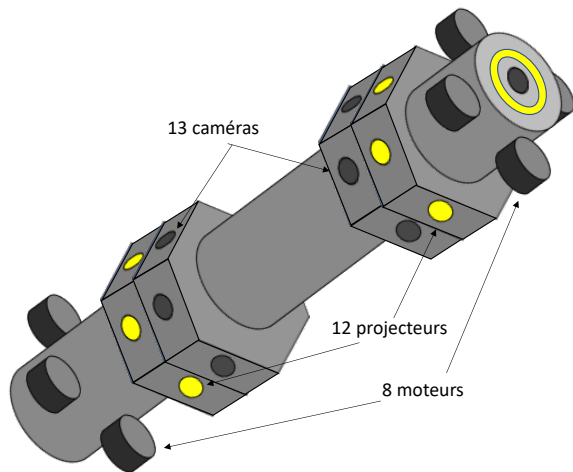
Tether Management System (TMS) : from Syera and Reeds

Water leaks detectors

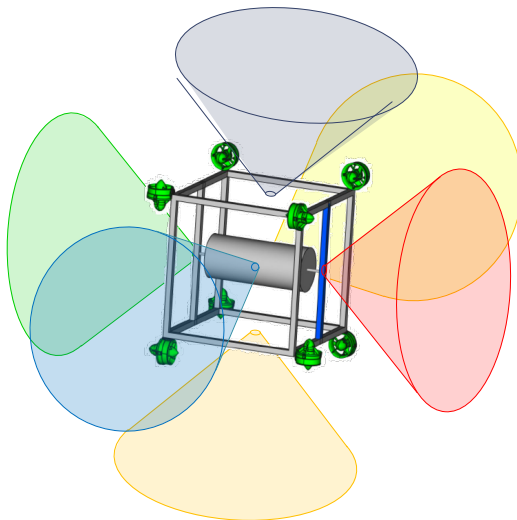
Batteries' consumption

NEW SYSTEMS

○ Dodécam : système photogrammétrique 12 caméras



○ Cube



■ VUE CA...

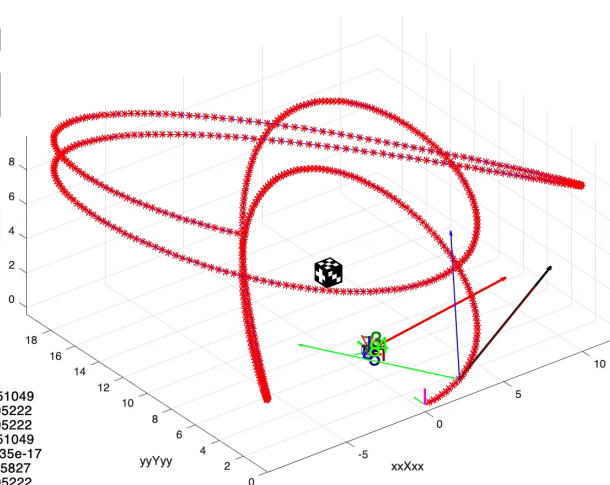
■ MARIN
0.3 s

MOTEURS

36.2
27.01
-22.17
-33.42
-100
21.32
-56.77
15.93

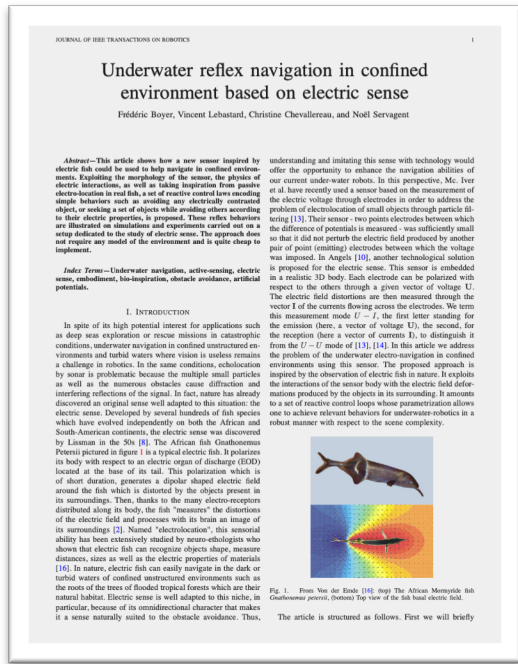
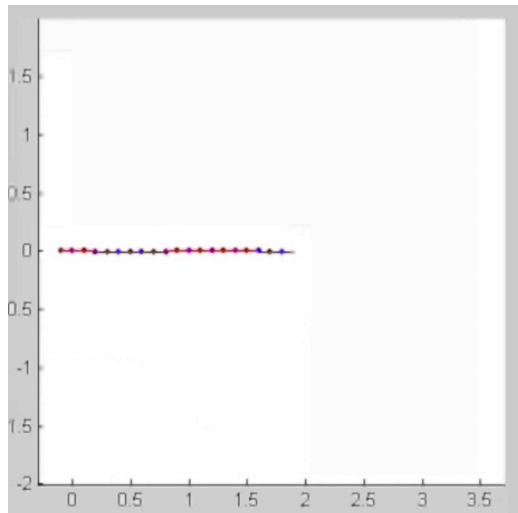
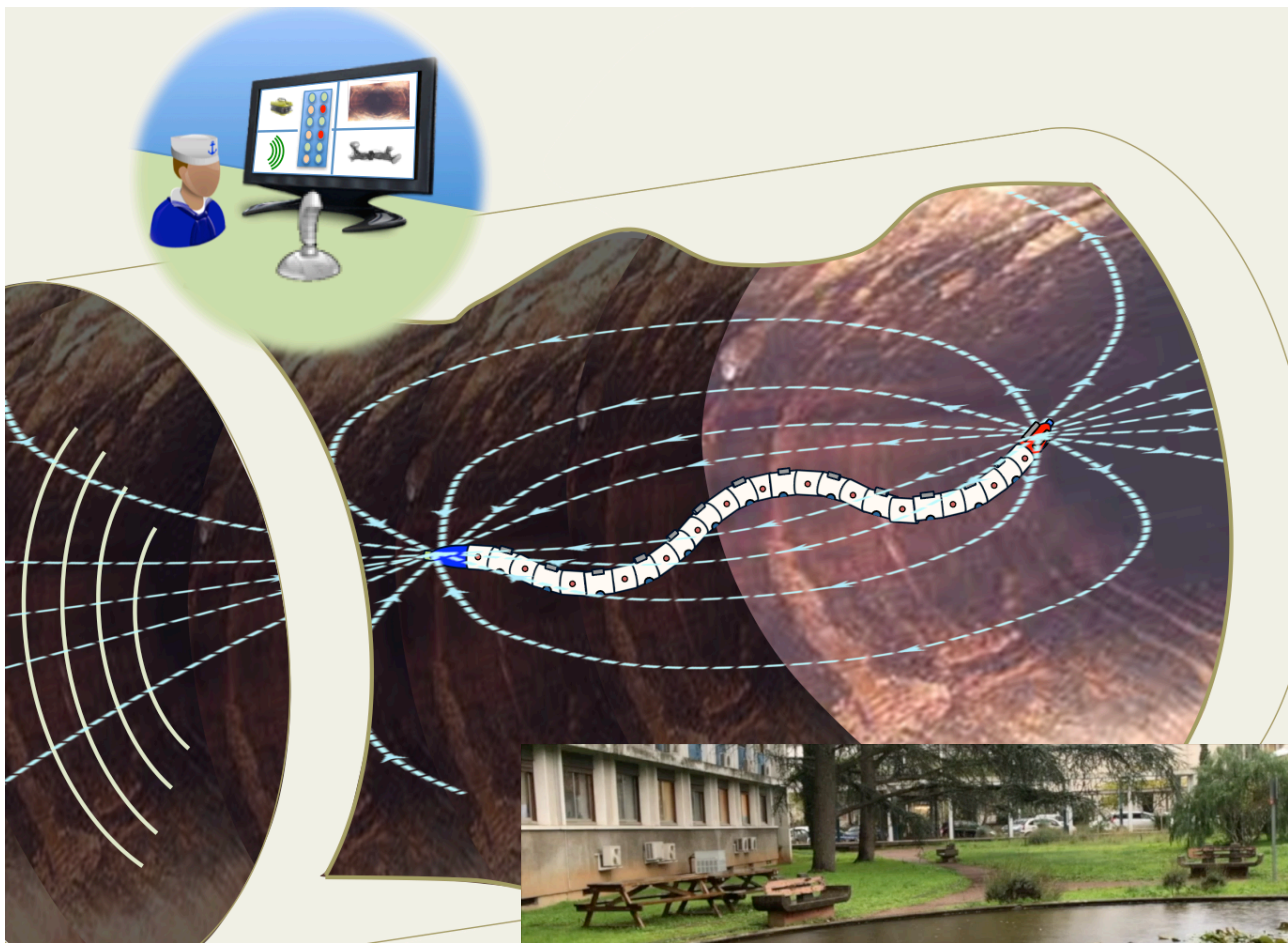
NOYAU

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0.51375 -0.05222
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-2.2135e-18 -5.2135e-17
0.43587 0.45827
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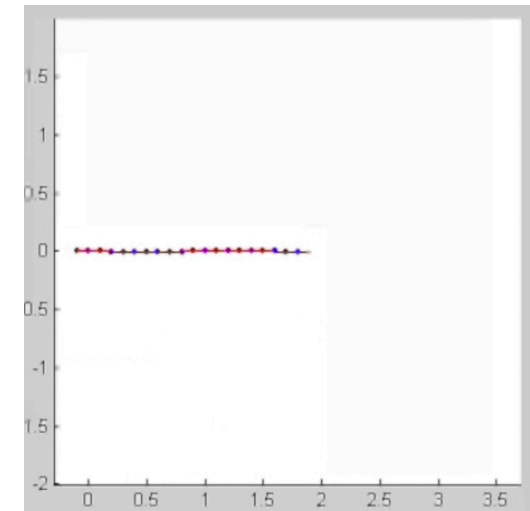
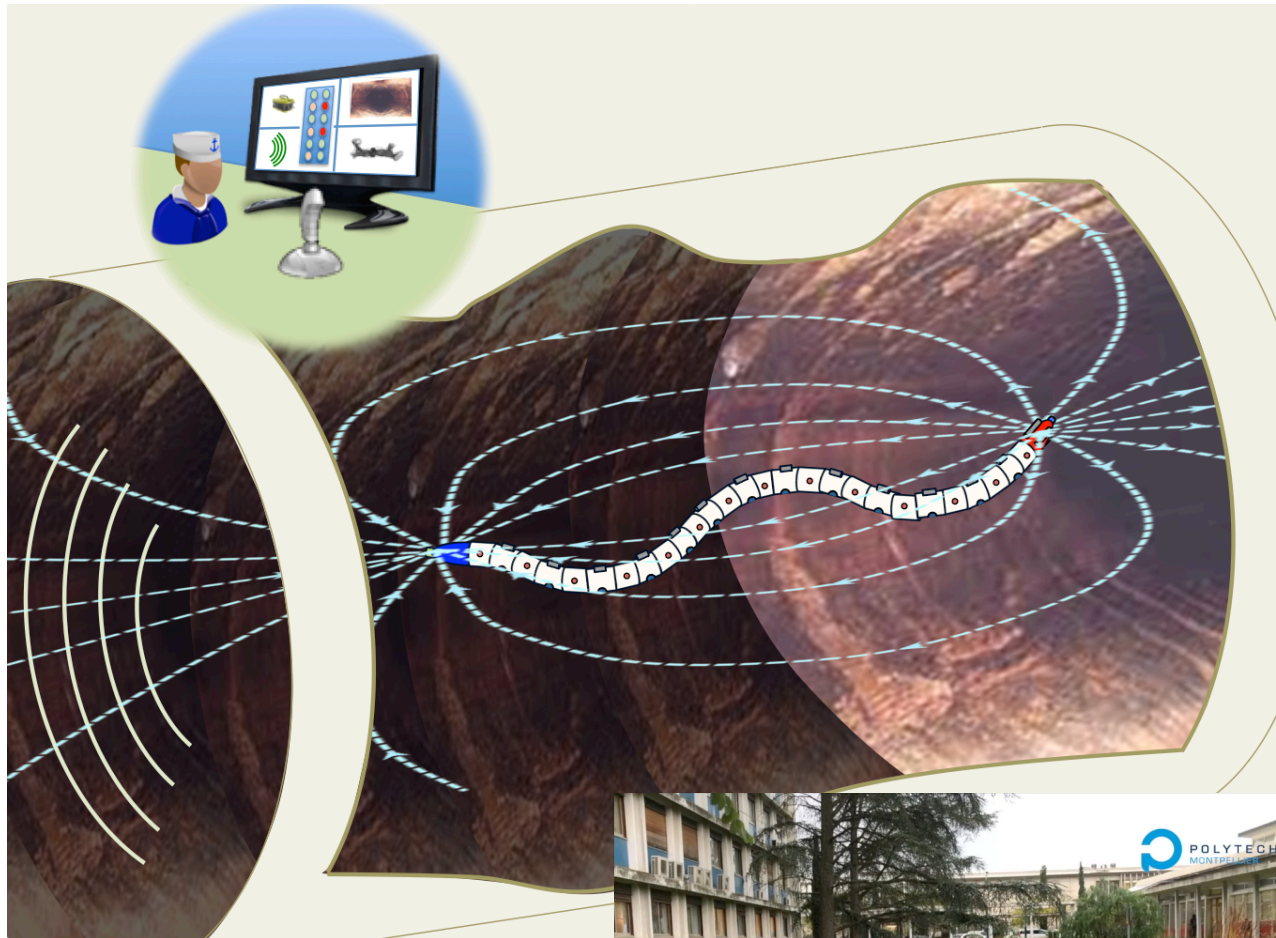
NEAR FUTURE : ANR LIRMM, LS2N, ENSTA, SYERA, REEDS

Locomotion anguilliforme et Sens électrique



NEAR FUTURE : ANR LIRMM, LS2N, ENSTA, SYERA, REEDS

Locomotion anguilliforme et Sens électrique



Underwater reflex navigation in confined environment based on electric sense

Fédéric Boyer, Vincent Lebastard, Christine Chevalereau, 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 interaction, 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, eel-like robot, bio-inspired, obstacle avoidance, artificial potentials.

I. INTRODUCTION

In spite of its high potential interest for applications such as deep sea 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, robot navigation by sensor 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 Liissman in the Sixties [1]. The African fish *Gnathostomus Pinnatus* 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 shows 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 underwater 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 Angeli [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 turn this measurement mode $I \rightarrow J$, 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 $U \rightarrow I$ 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 interaction 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 scene complexity.

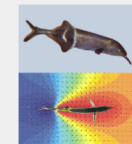
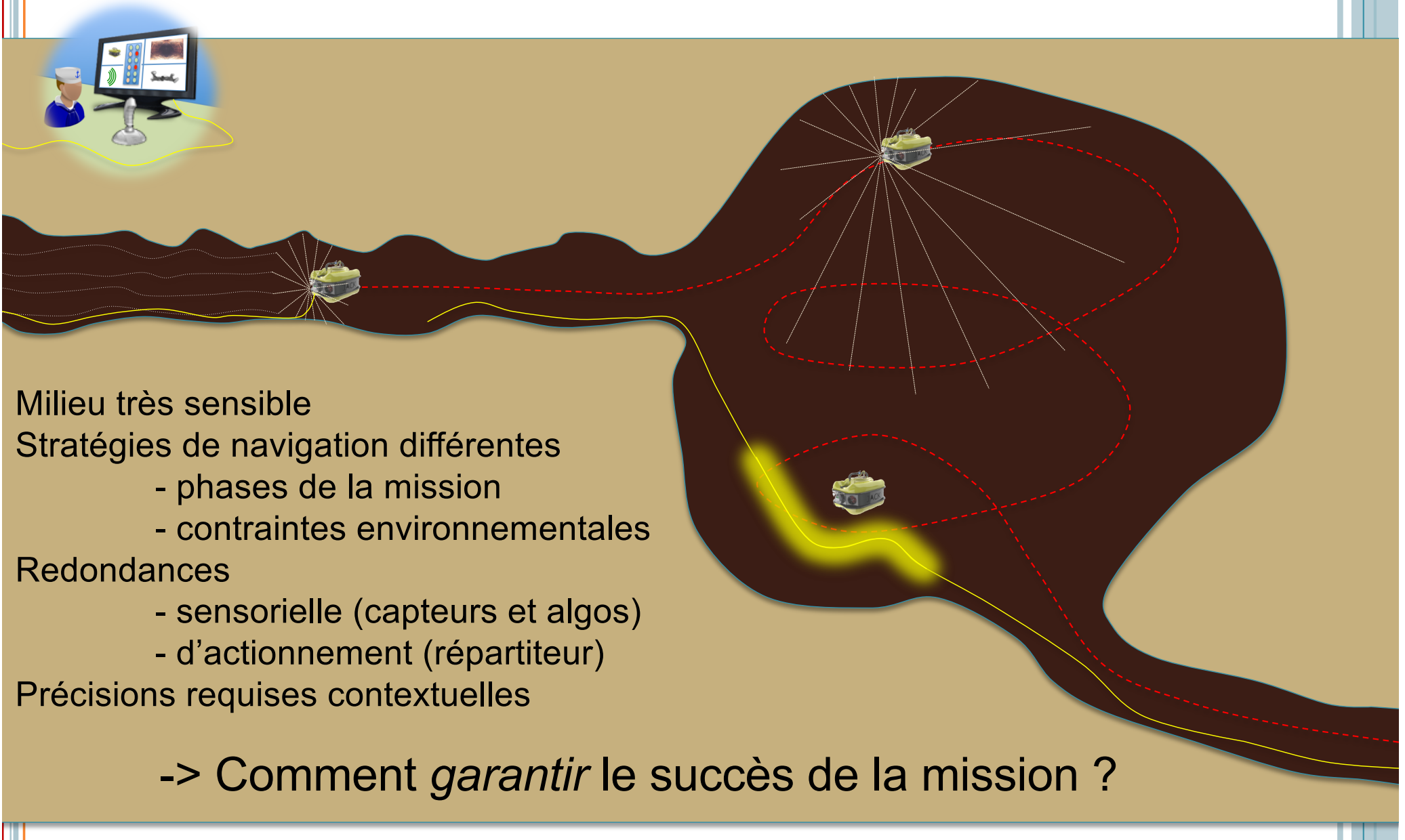


Fig. 1. From Van der Ende [16], top: The African Mormonete fish *Gnathostomus pinnatus*, bottom: Top view of the fish body electric field. The article is structured as follows. First we will briefly

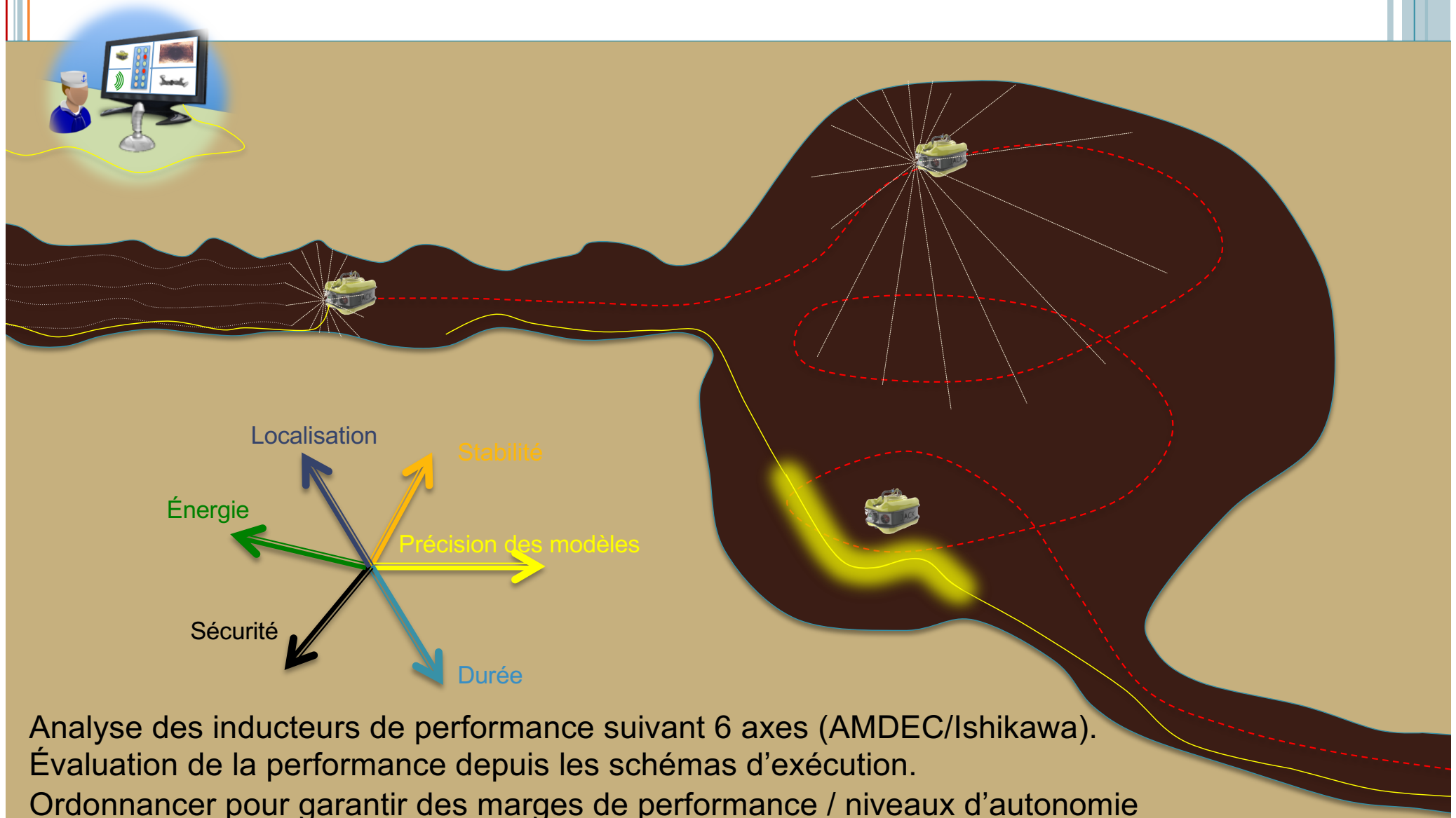
NEAR FUTURE : LIRMM, ENSTA

- Autonomie et *garanties* de performances



NEAR FUTURE : LIRMM, ENSTA

- Autonomie et *garanties* de performances



EUROPEAN PROJECT : ANZAR

