

Subaquatic robotics, Robots for Karstic Exploration:

REEA
ALEYIN
LEZ 2020



BTS meeting, 27/09/2021



PEOPLE INVOLVED

○ LIRMM

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

○ ENSTA

- Simon Rohou

○ HSM

- Hervé Jourde
- Pierre Fischer
- Pascal Brunet

○ BRGM

- J.C. Maréchal
- V. Bailly-Comte

○ IES

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

○ IMAG

- Bijan Mohammadi
- André Mas

○ LEM/MRM

- Saïd Yami
- Gérald Naro

○ 3M

- Arnaud Vestier
- Adélaïde Kasolter

○ Céladons

- Frank Vasseur

○ PlongéeSout

- Rémi Bouchard

○ Companies

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

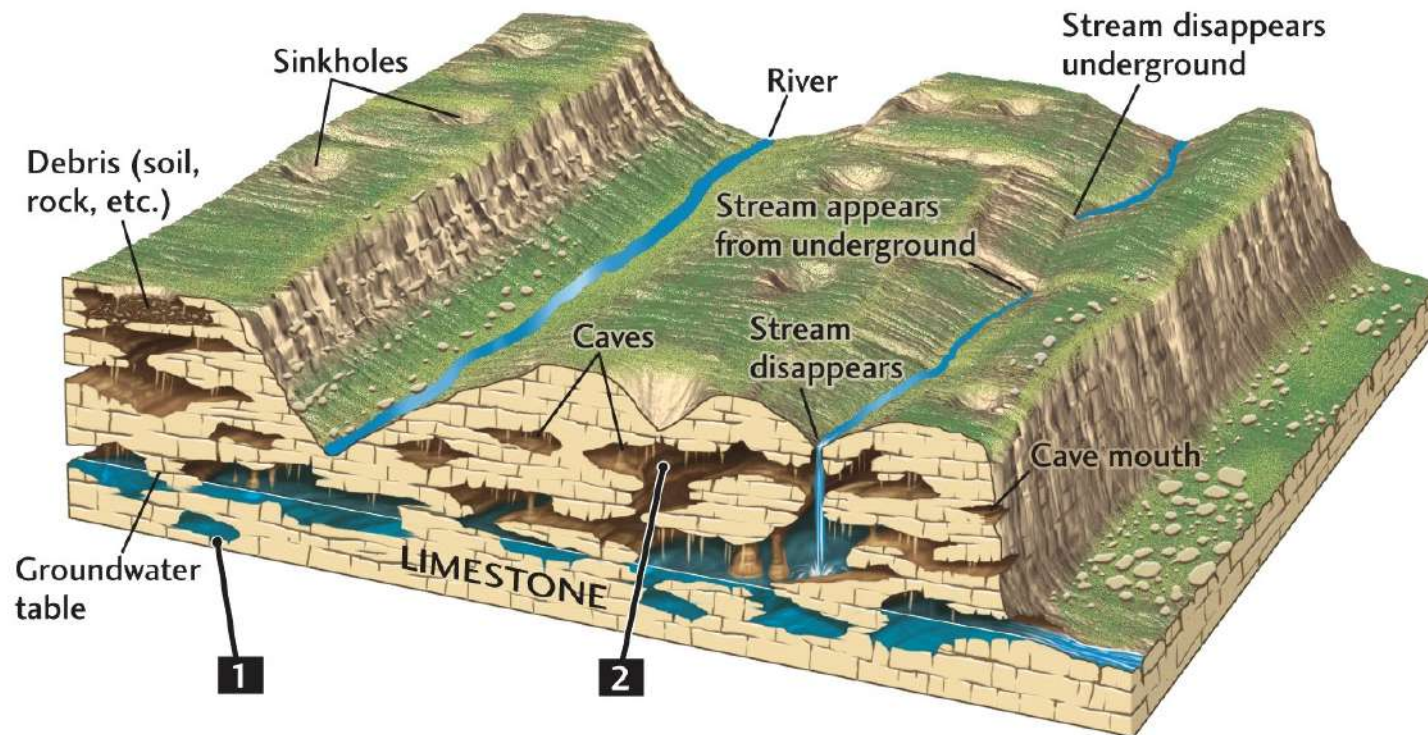


ROBOTS FOR KARSTIC EXPLORATION: OBJECTIVES



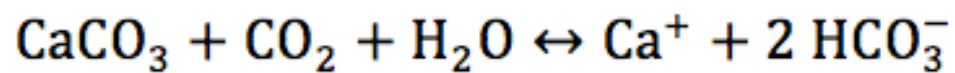
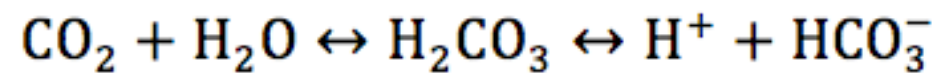
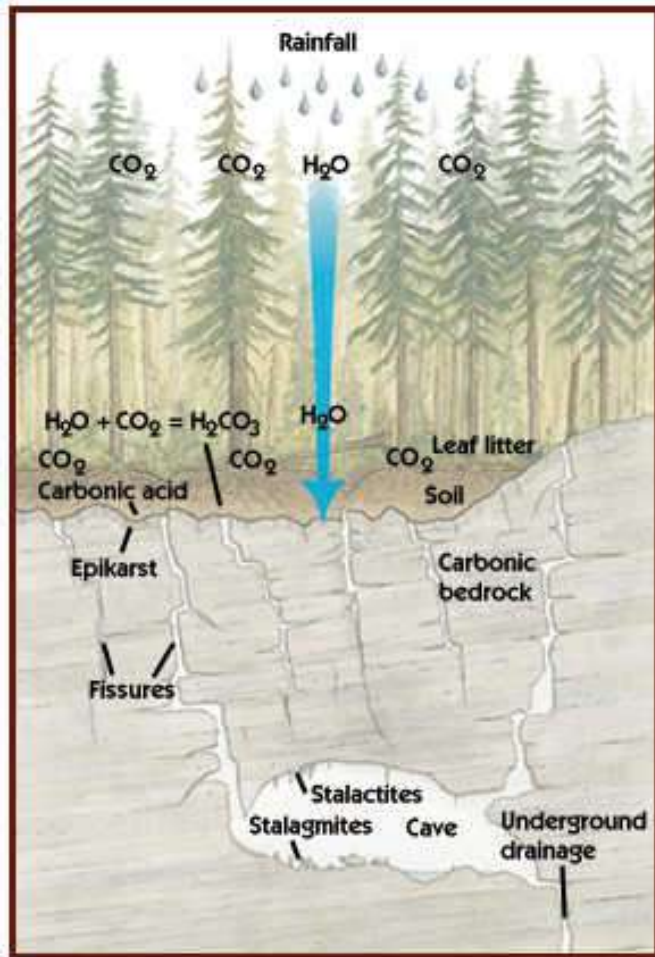
KARST : DEFINITION

- 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 : DEFINITION



Tsingy de Bemaraha, Madagascar

KARST : SURFACE STIGMATA



Balaa, Tannourine, Lebanon



Stone Forest, Shilin Yi, Yunnan, China

KARST : SURFACE STIGMATA



Cetina Spring, Croatia



Blue cave, Croatia



Pazin cave, Croatia

KARST : UNDERGROUND CONTINUATION



Ruby Falls ,Chattanooga, Tennessee, USA



Cueva de los Cristales, Naica,, Mexico



Furong Cave, Wulong District, Chongqing, China

KARST : GROUNDWATER RESERVOIR



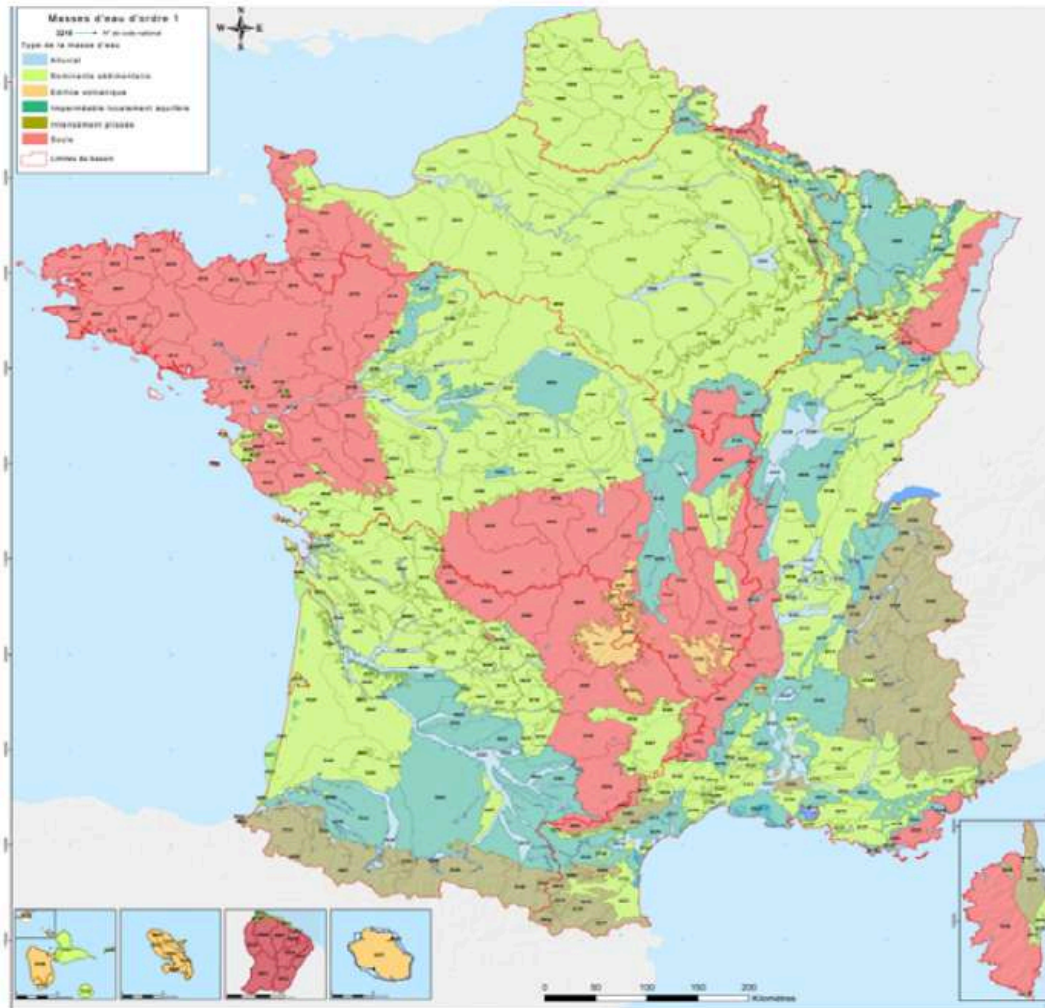
*Eclairage : Cédrik Bancarel
Dominique Françoise
Photo.: Frank Vasseur*

KARST : GROUNDWATER RESERVOIR



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

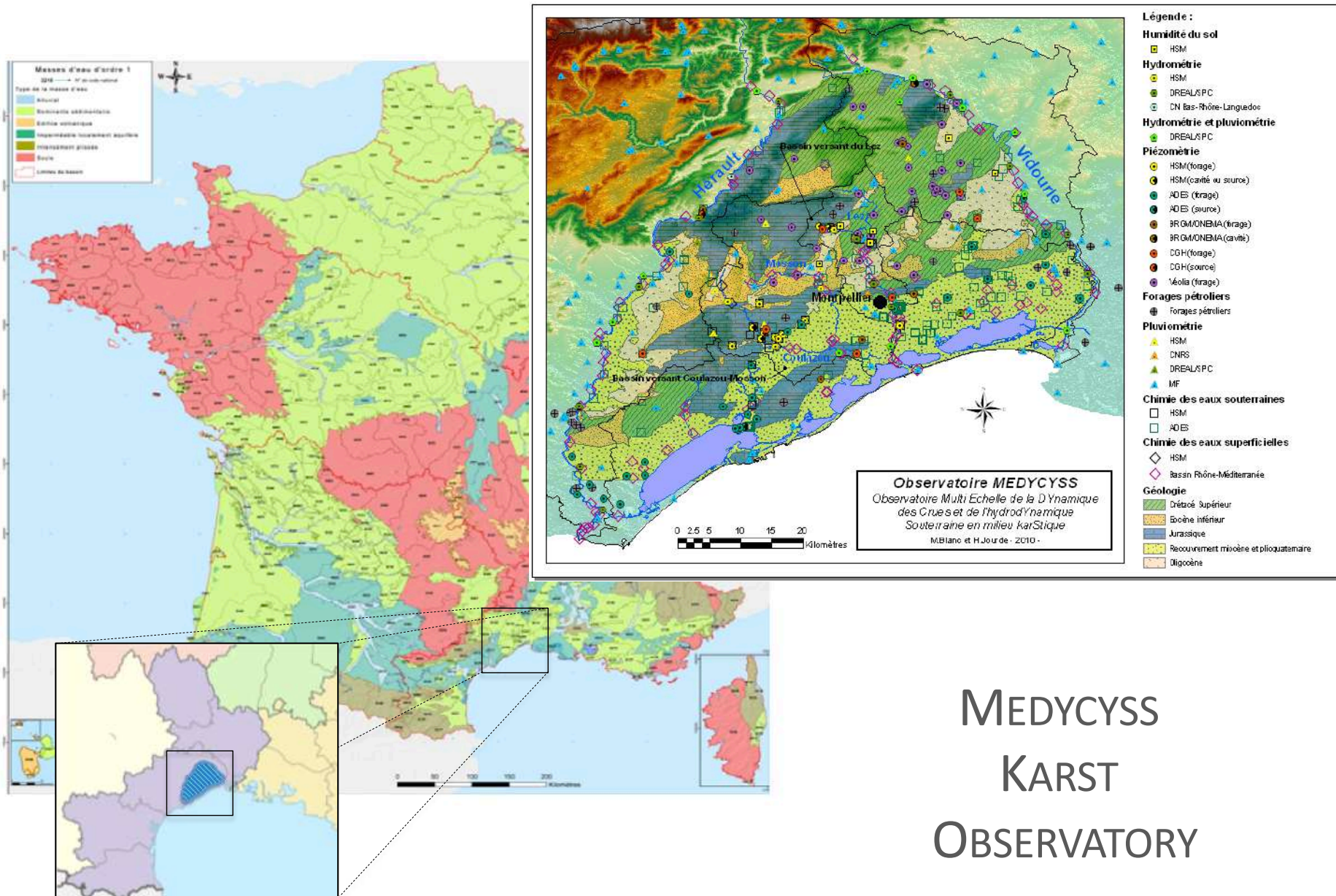
KARST : GROUNDWATER MANAGEMENT, A NATIONAL ISSUE



+ 50% of Drinking Water Supply

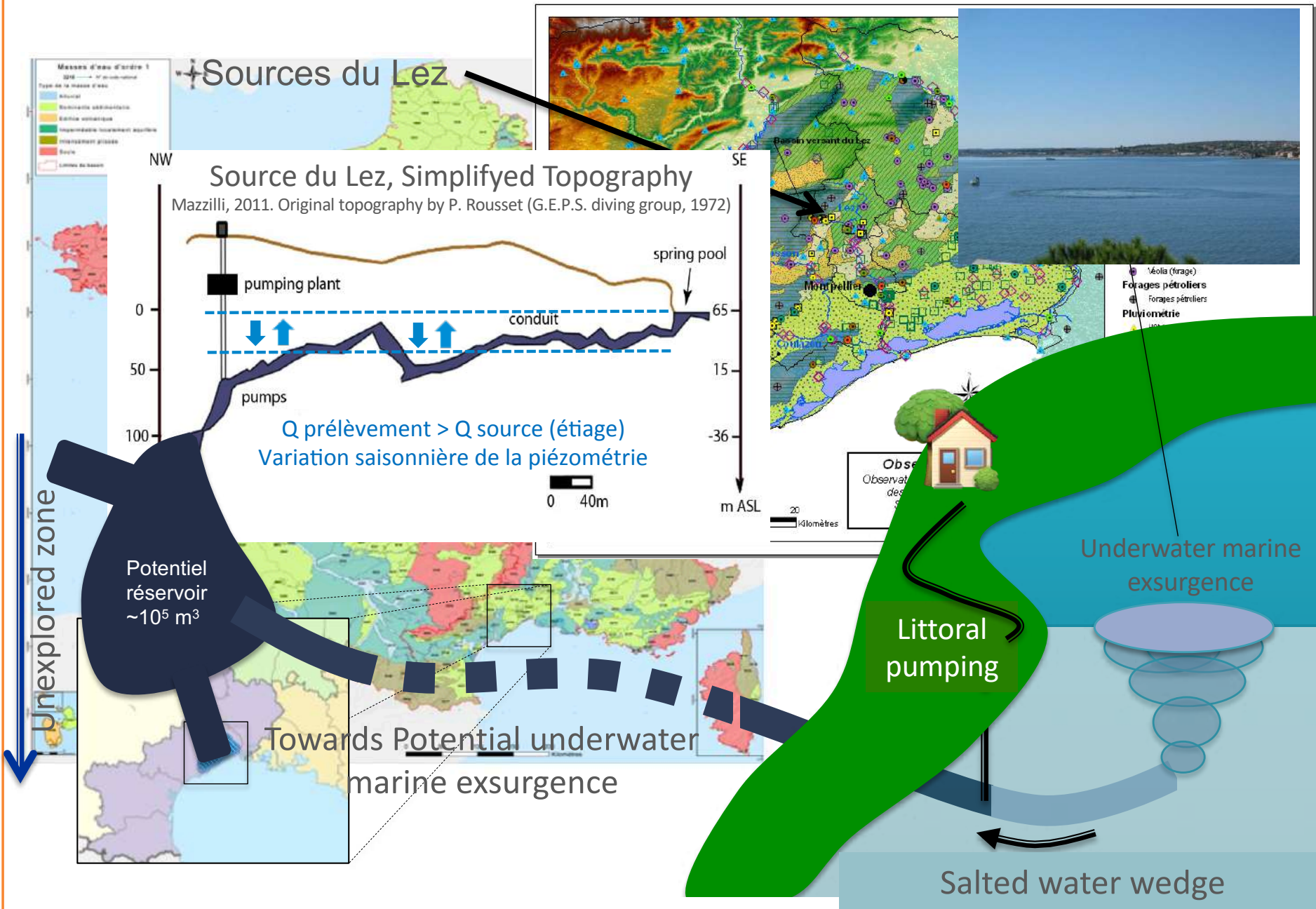
Service National d'Observation
du KARST,
SNO INSU/CNRS
OSU OREME (UM)
Coordinator H. Jourde

MONTPELLIER'S CATCHMENT BASIN : A SEMINAL CASE STUDY

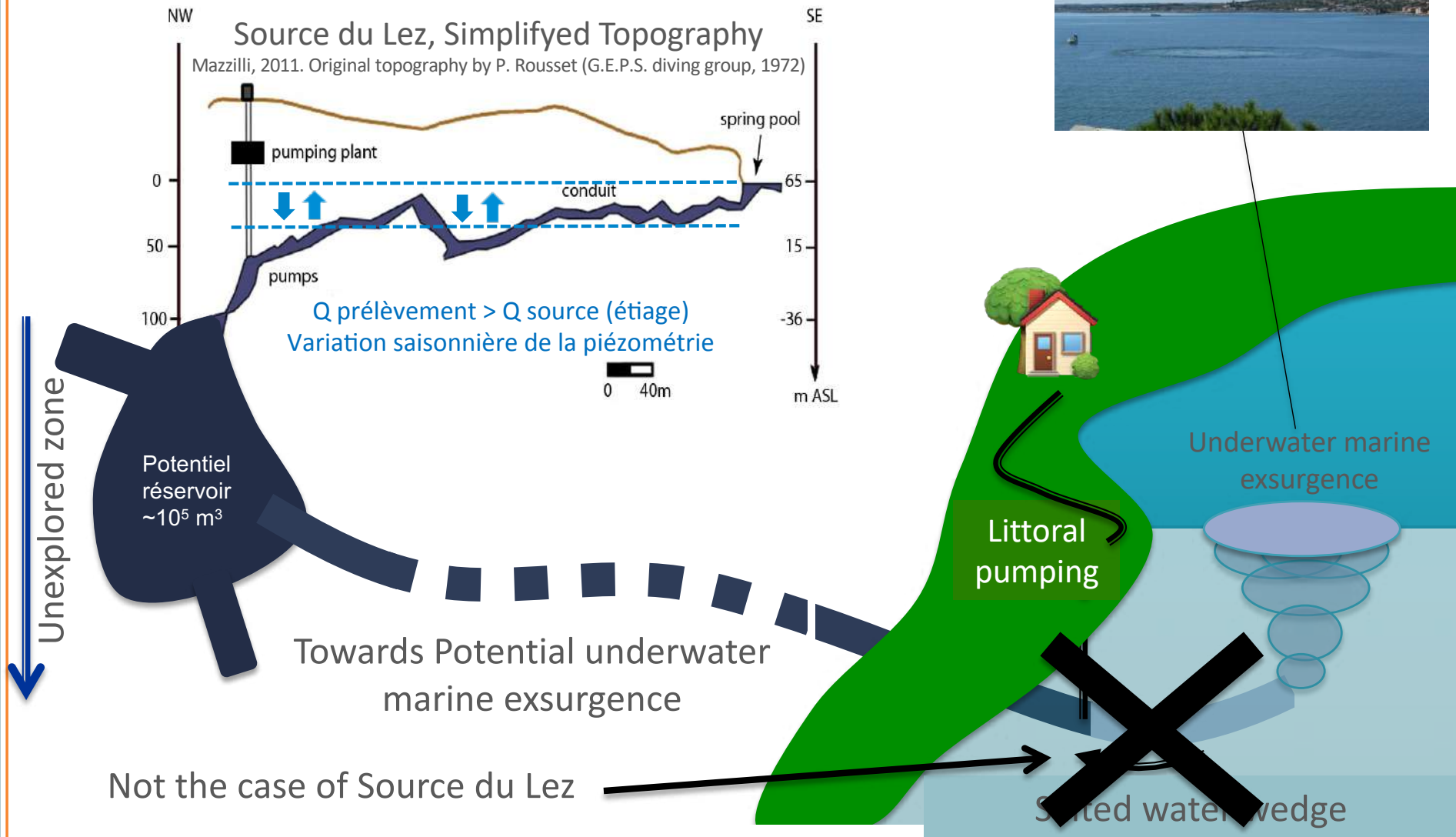


MEDCYSS
KARST
OBSERVATORY

SOURCES DU LEZ : A SEMINAL CASE STUDY

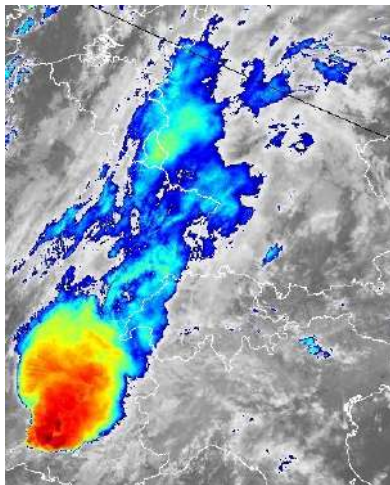
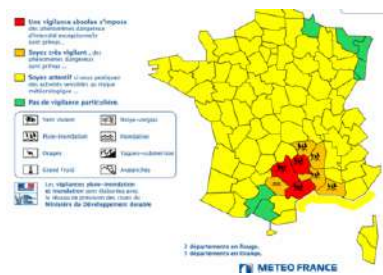


SOURCES DU LEZ : ACTIVE MANAGEMENT OF GW RESOURCE



MONTPELLIER'S CATCHMENT BASIN : A SEMINAL CASE STUDY

Hydrogeological Risk Assessment



Floods of Coulazou River, December 2002



Floods of Lez River
6 Septembre 2005, Prades le Lez







HYDROGEOLOGICAL RISK : SINKHOLES



Harbin, Heilongjiang province, China.



Guatemala City, Guatemala



Orlando, Florida, USA



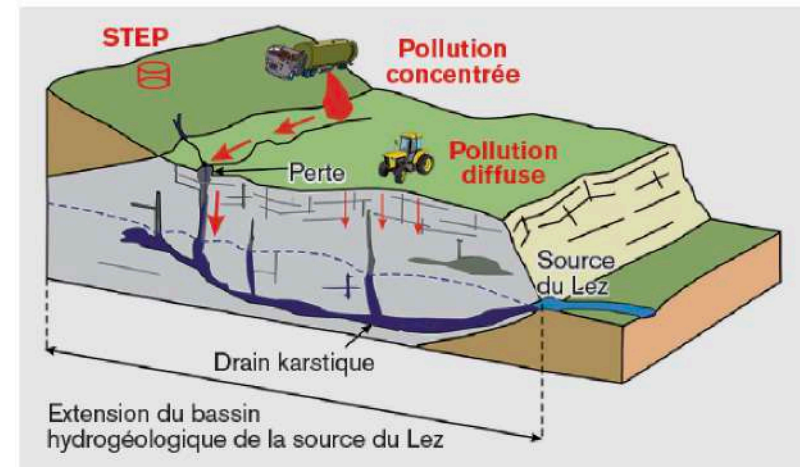
Dead-Sea shore, Israel

THE STAKES

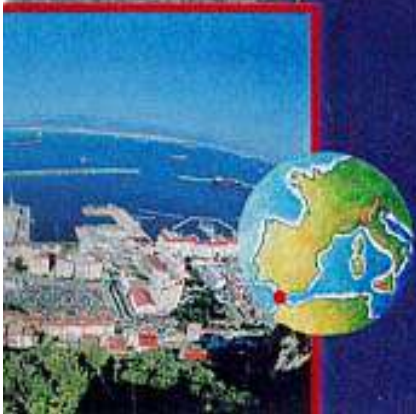
- Prospection / Preservation/ Management of Water Resource
 - Pumping and drilling regulation and guidance
 - Management of supply redundancy in case of massive contamination

- Hydrological and pollution Risk Assessment

- Forecasting and Decision Aids
- Skinholes detection
- Karst as flood control dam: regulation and strategic positioning of pumping stations -> Active management of the resource



CLOSURE OF THE GILBRALTAR STRAIT

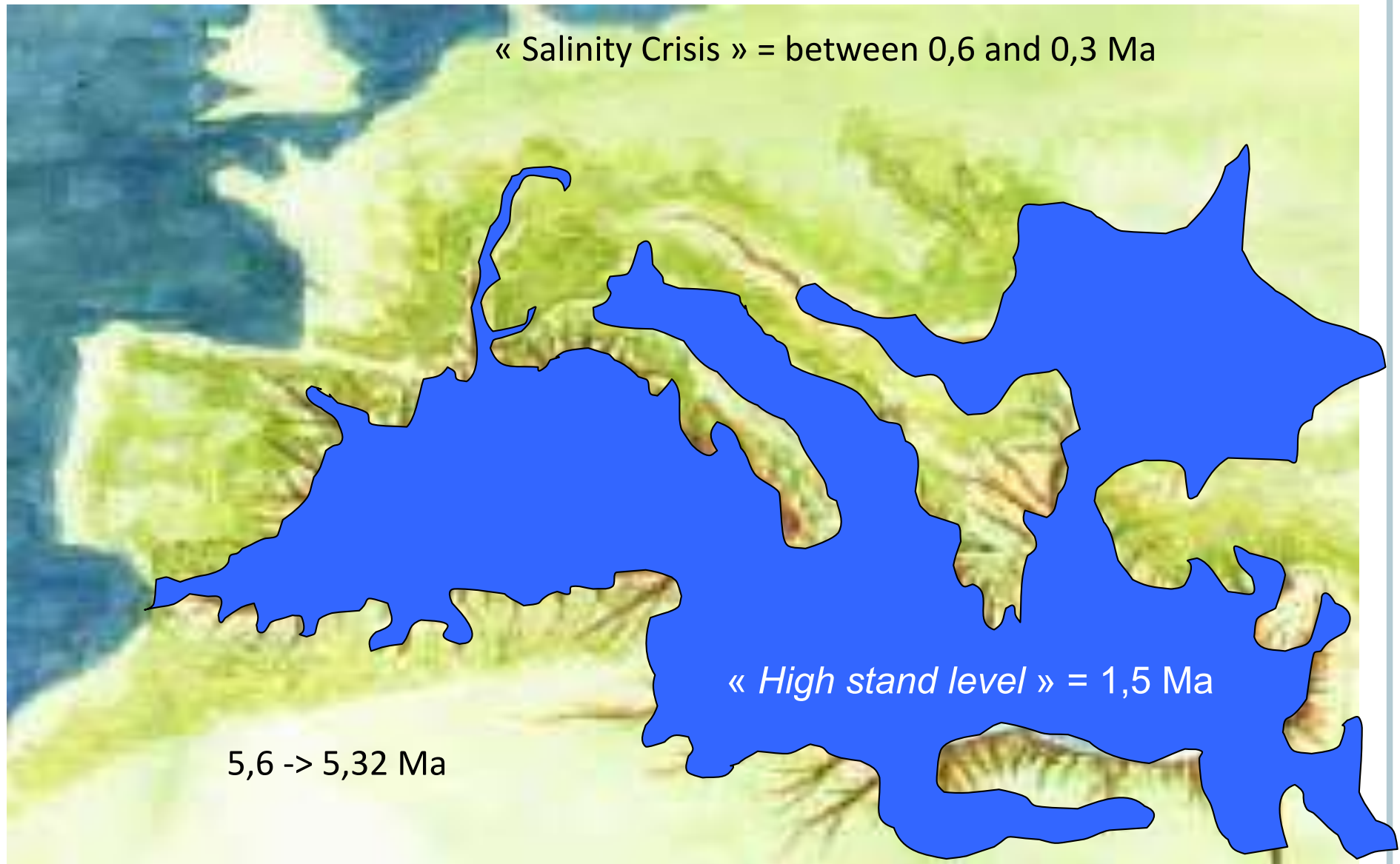


Messinian events : 2 salinity crisis

1/ 5.95 - 5.6 Ma 100 m

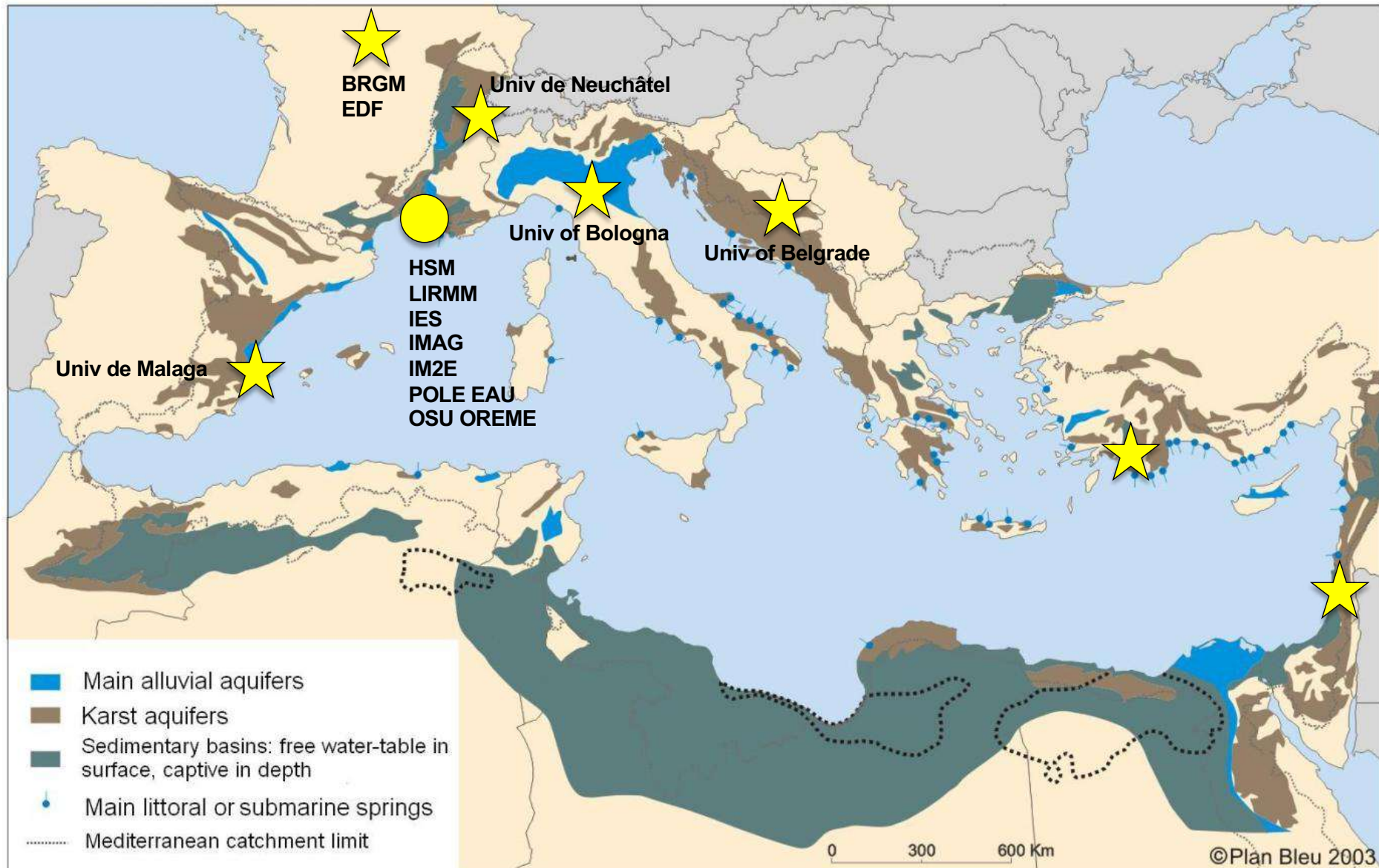
2/ 5.6 - 5.32 Ma 1500 m

MEDITERRANEAN KARSTS DURING MESSINIAN SALINITY CRISIS

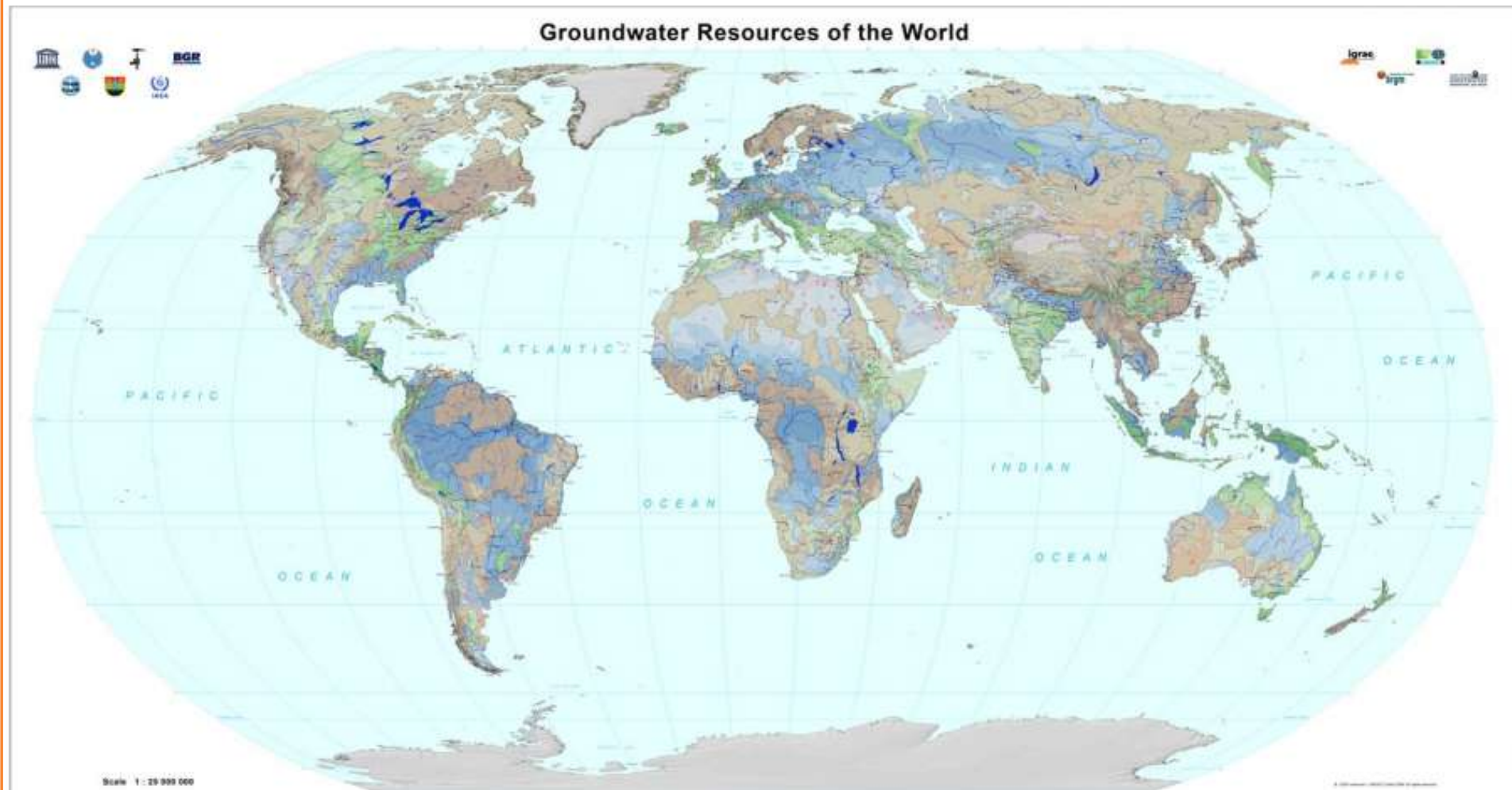


Deep Karstification

MEDITERRANEAN KARSTS



WORLD KARSTIC REGIONS



IAH : International Association of Hydrogeology, société savante.

EXPLORE FLOODED KARST : CHARACTERIZATION OF THE KARST DYNAMIC



Network cartography beyond physiological limitations.

Seasonal measurements and Reproducible protocols.

Environment Instrumentation, specific marker drop.

Geomorphology of the flooded zone (volumes) : new sensors, new models.

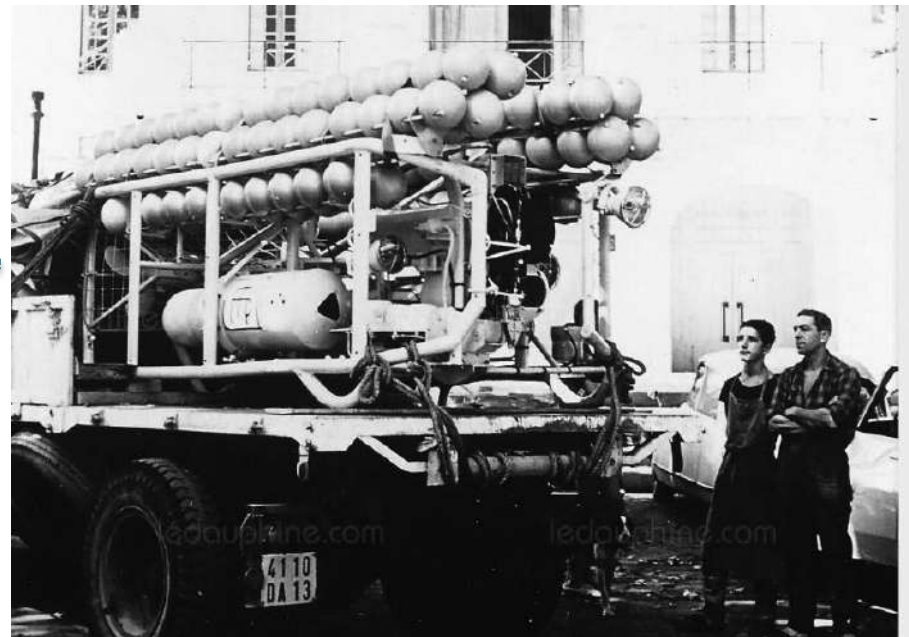
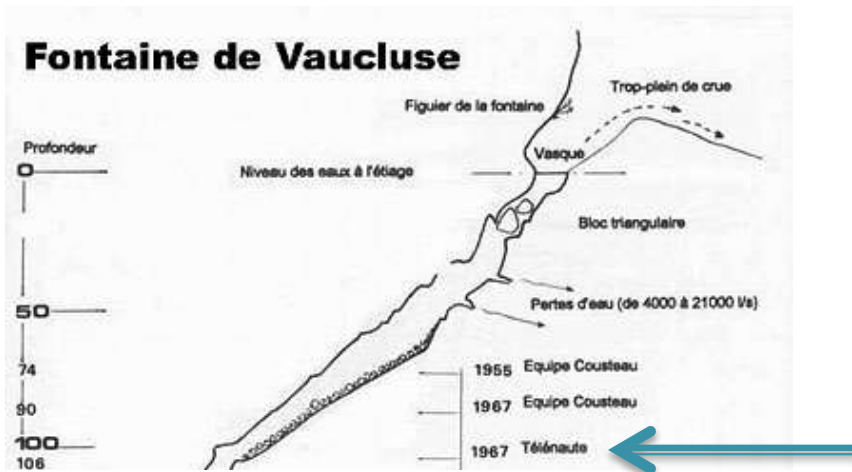
N-D geomorphological models

Karst Dynamics



A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

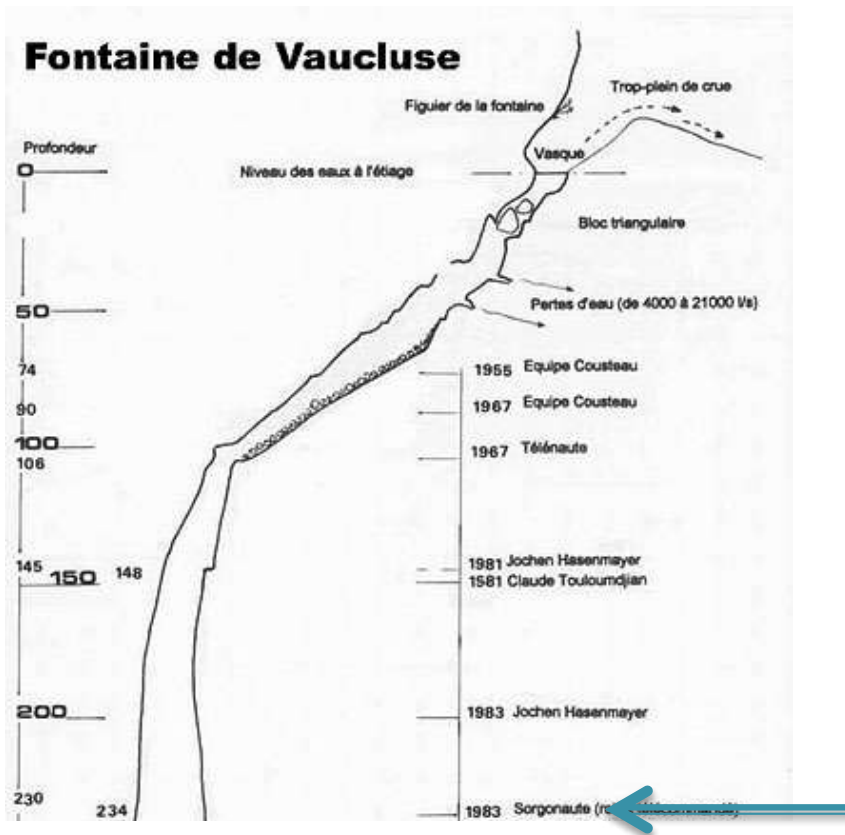
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1967, Télénauts (Cdt Cousteau)
106m

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

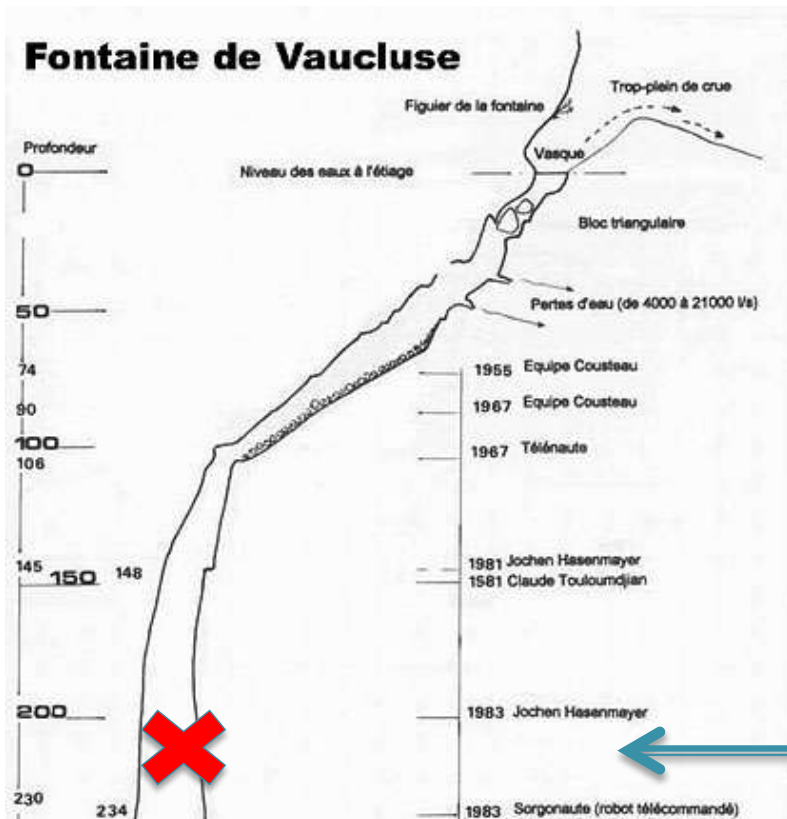
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1983, Sorgonaute (Renault)
243m
(stopped by cable length)

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

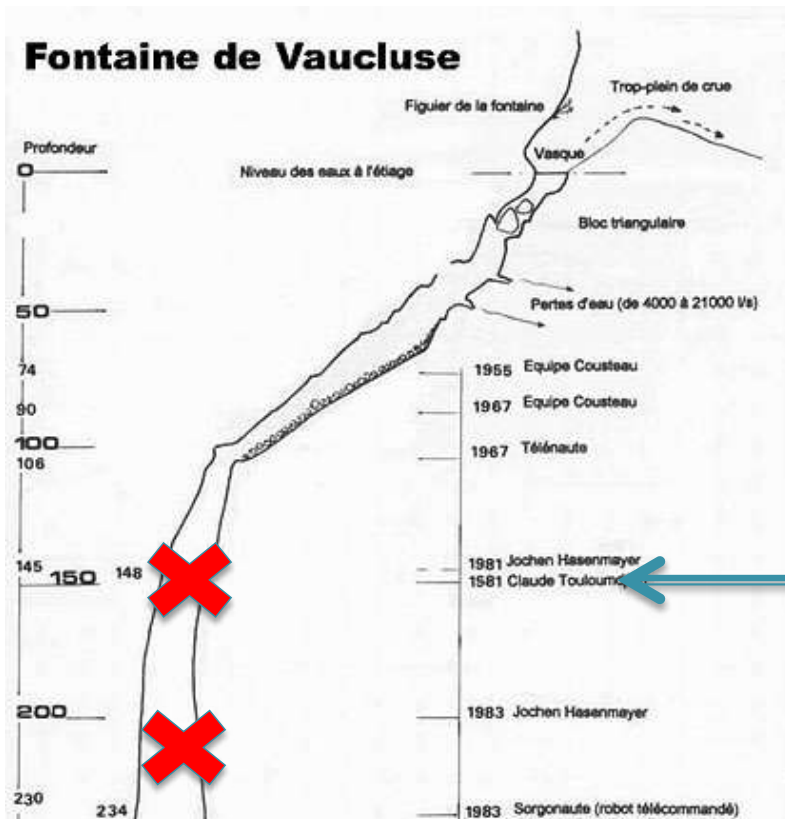
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1984, Sorgaunote II (Renault)
Lost at 233m
(Trapped in a remaining lifeline)

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

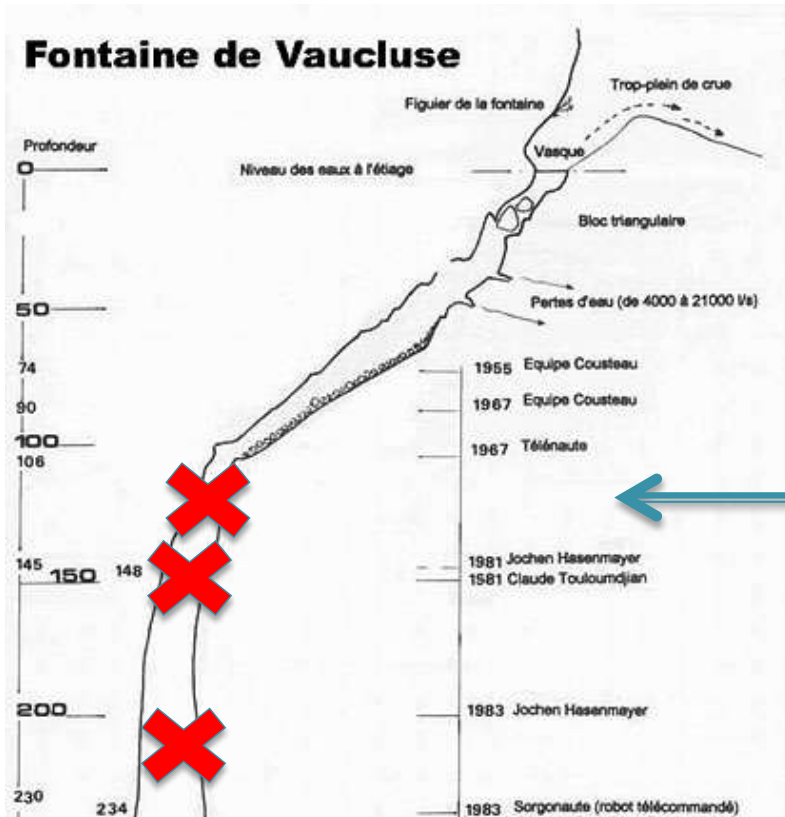
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1986, Sorgaunote III (Renault)
Lost at 150m
(Trapped in the cable of Sorgonaute II)

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

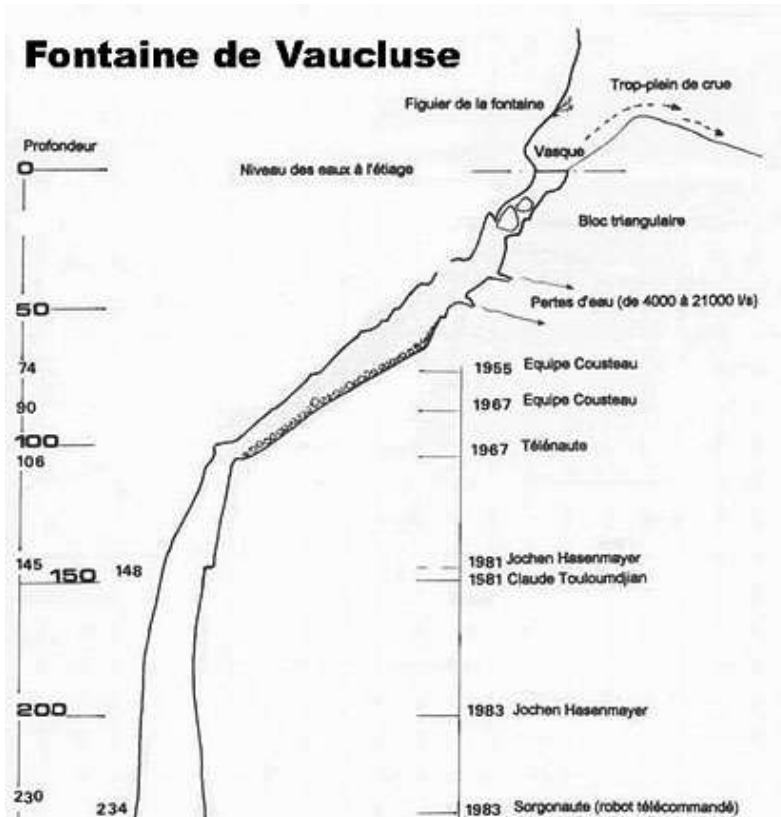
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1983, Sorgonaute IV (Renault)
Failure
(Unable to recover SI and SII)

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

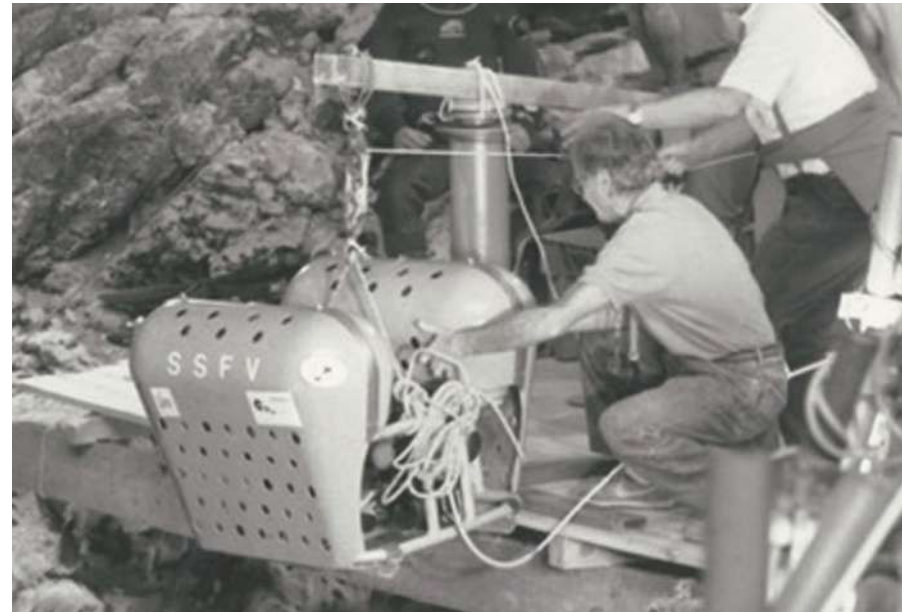
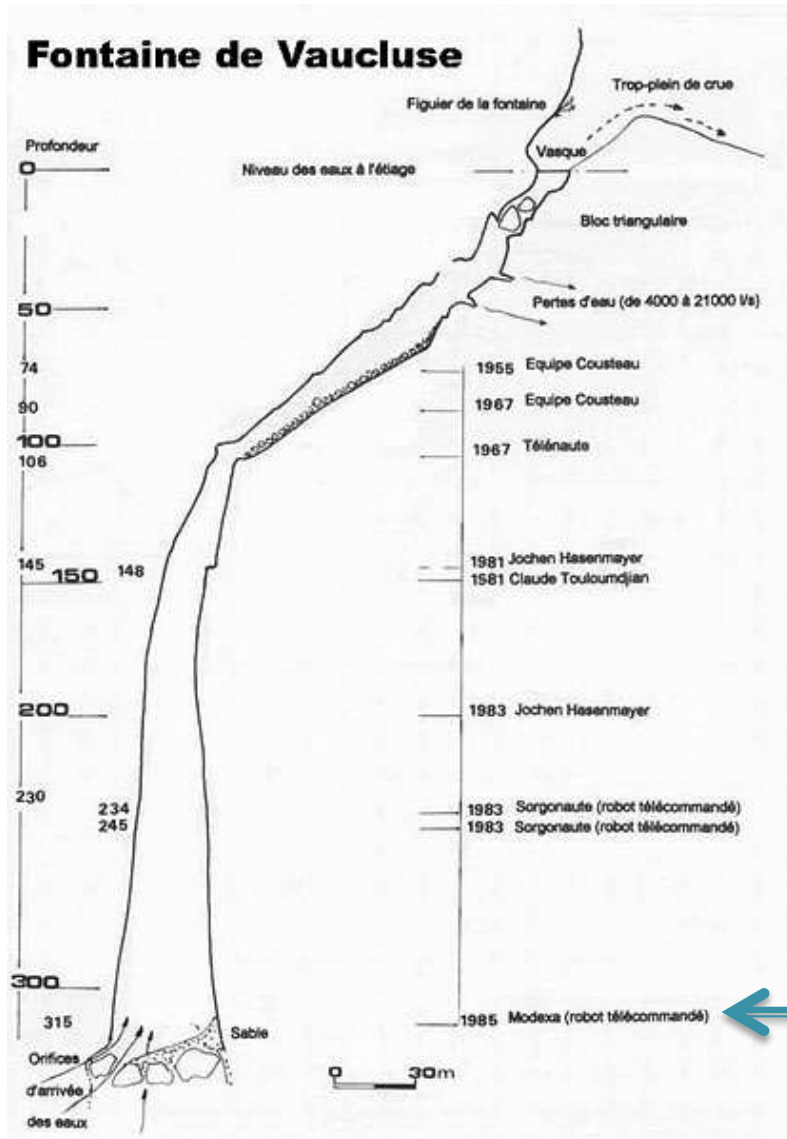
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1984, The chasm was cleared by divers

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

○ Fontaine de Vaucluse : A magnificent Robotic Failure

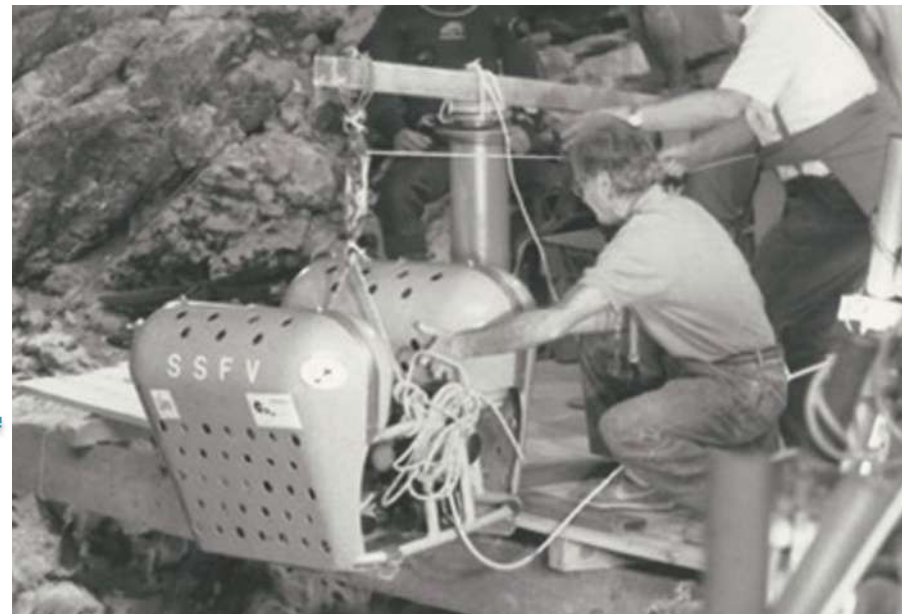
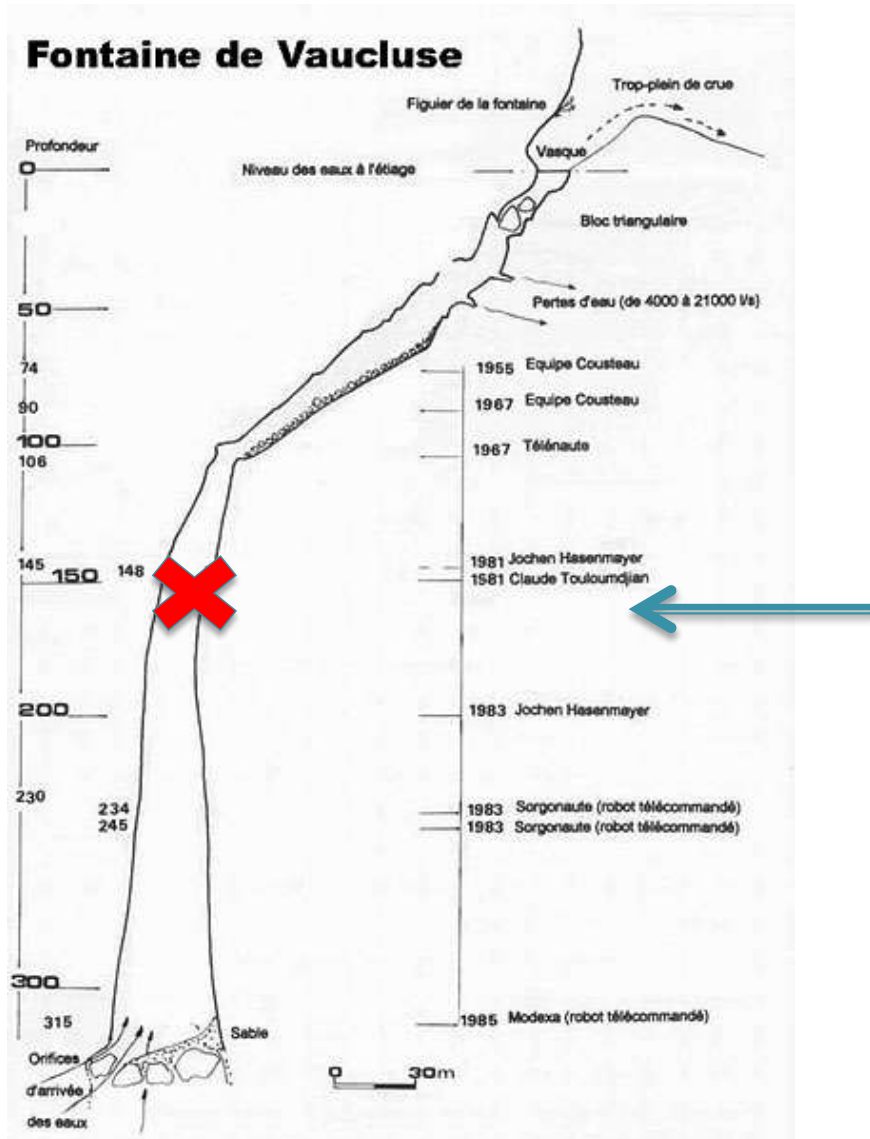


1989, Spélénaute (S.S.F.V.)
Touch-down : 315m

1985, Modexa (M.I.C), Touch-down : 315m

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

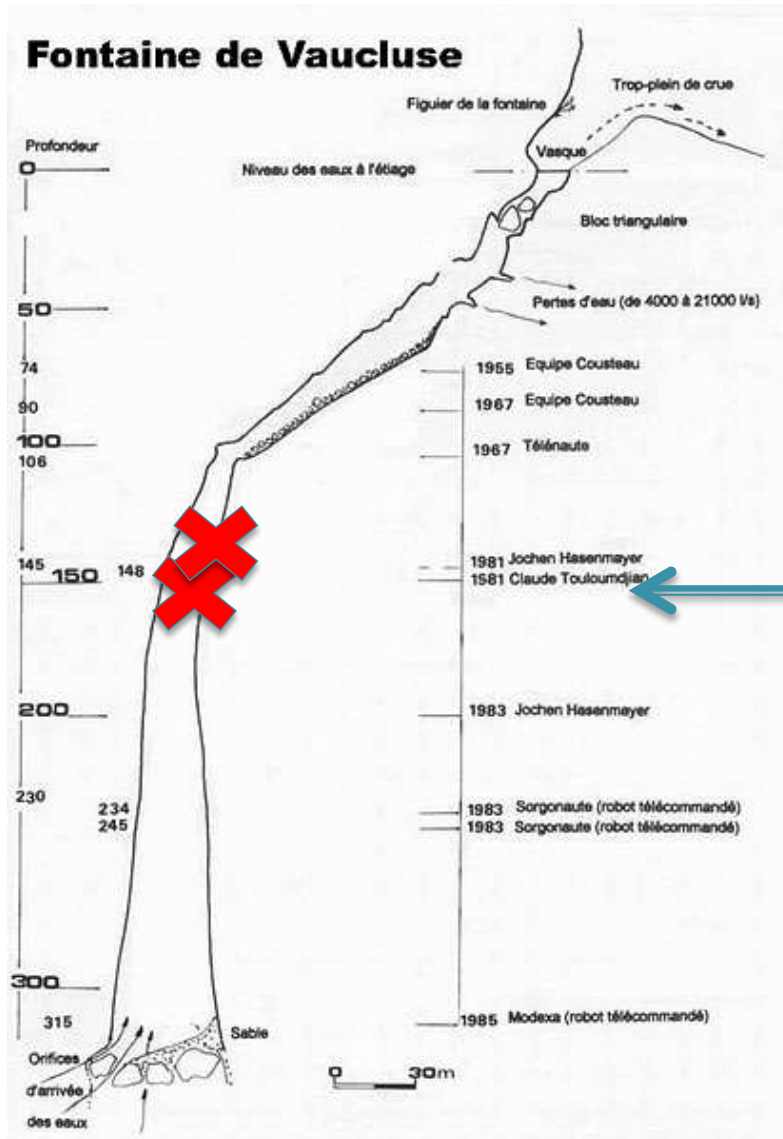
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1996, Spélénaute III (S.S.F.V.)
Lost at 164m
(Trapped in a remaining lifeline)

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

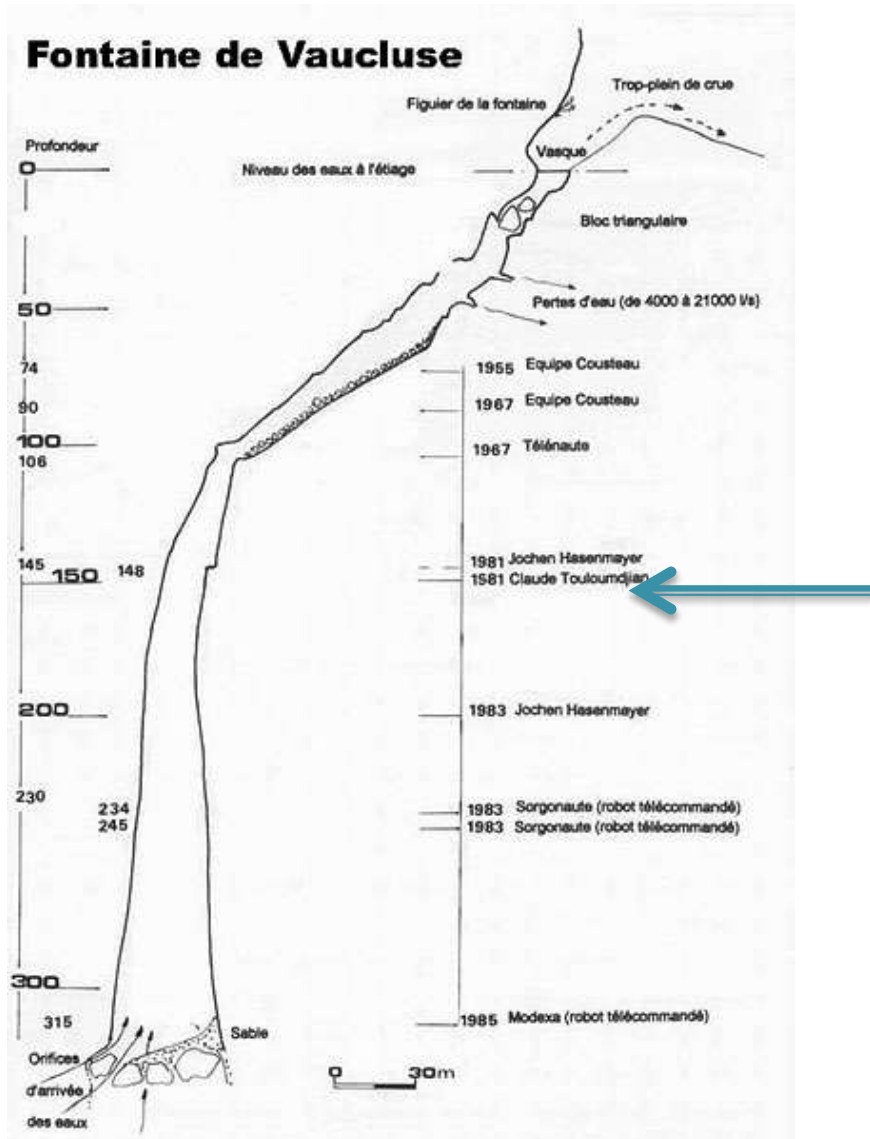
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1996, ROV COMEX
Lost at 164m
(Trapped in the cable of Spélénaute III)

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

○ Fontaine de Vaucluse : A magnificent Robotic Failure



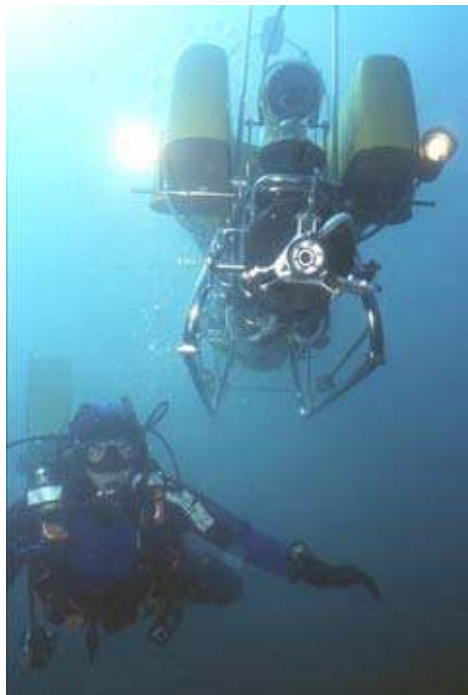
1996, Chasm cleared by divers

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

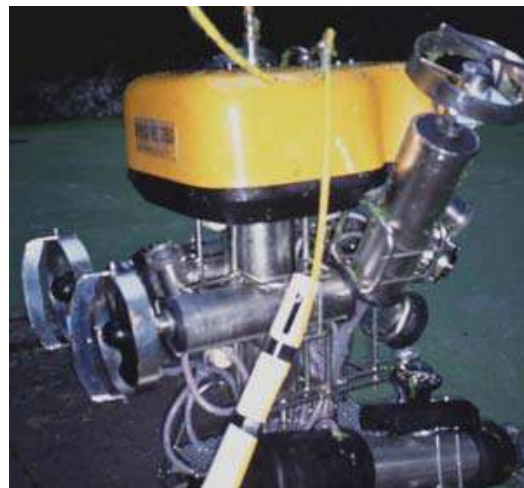
- Exploration of the Pozzo Del Merro (Italy)



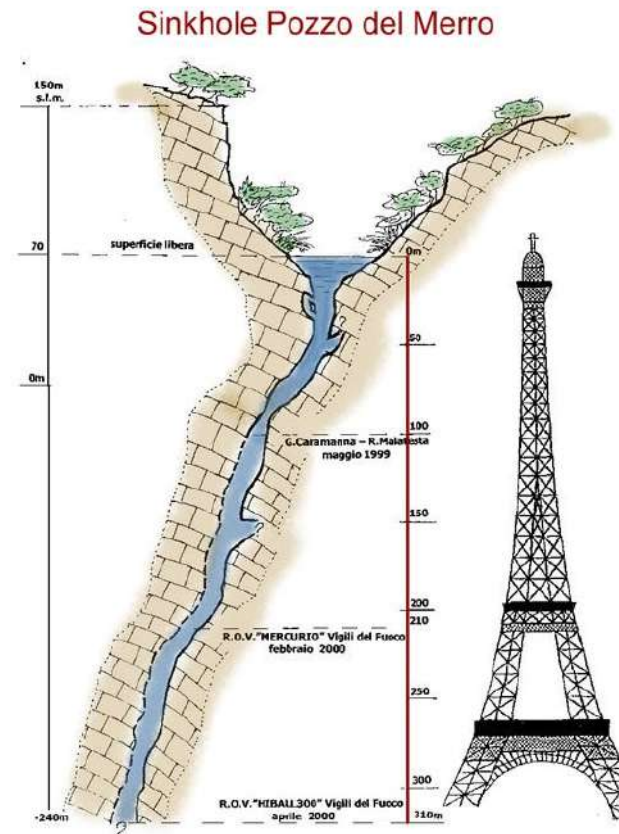
2001, Hyball, 310m



2000, Mercury, 210m

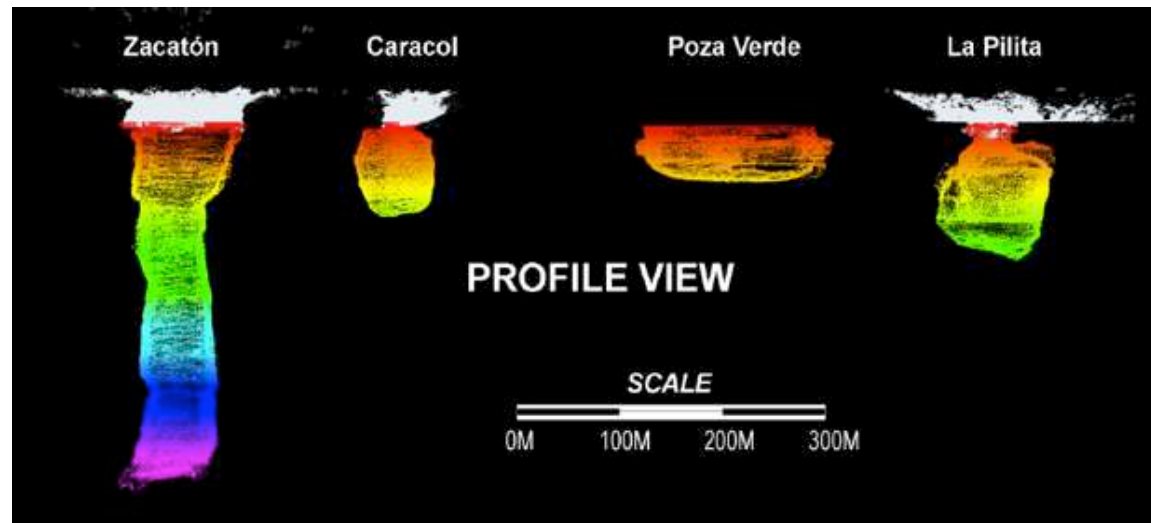
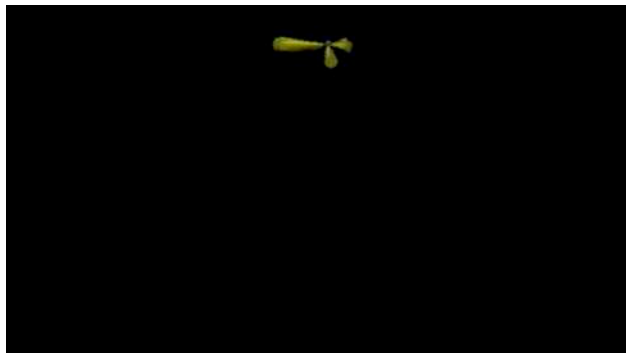
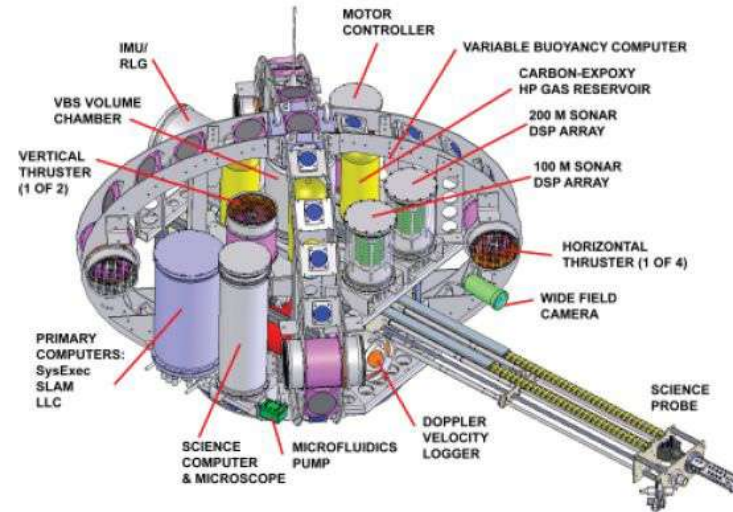


2002, Prometheus, 392m



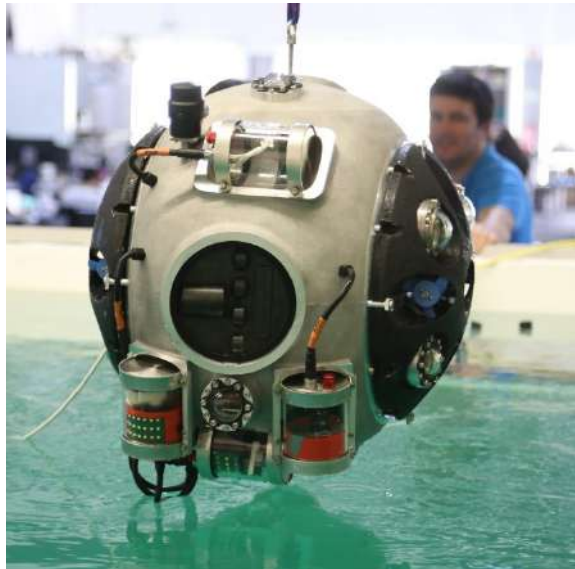
A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

○ DepthX (DEep Phreatic THERmal eXplorer)



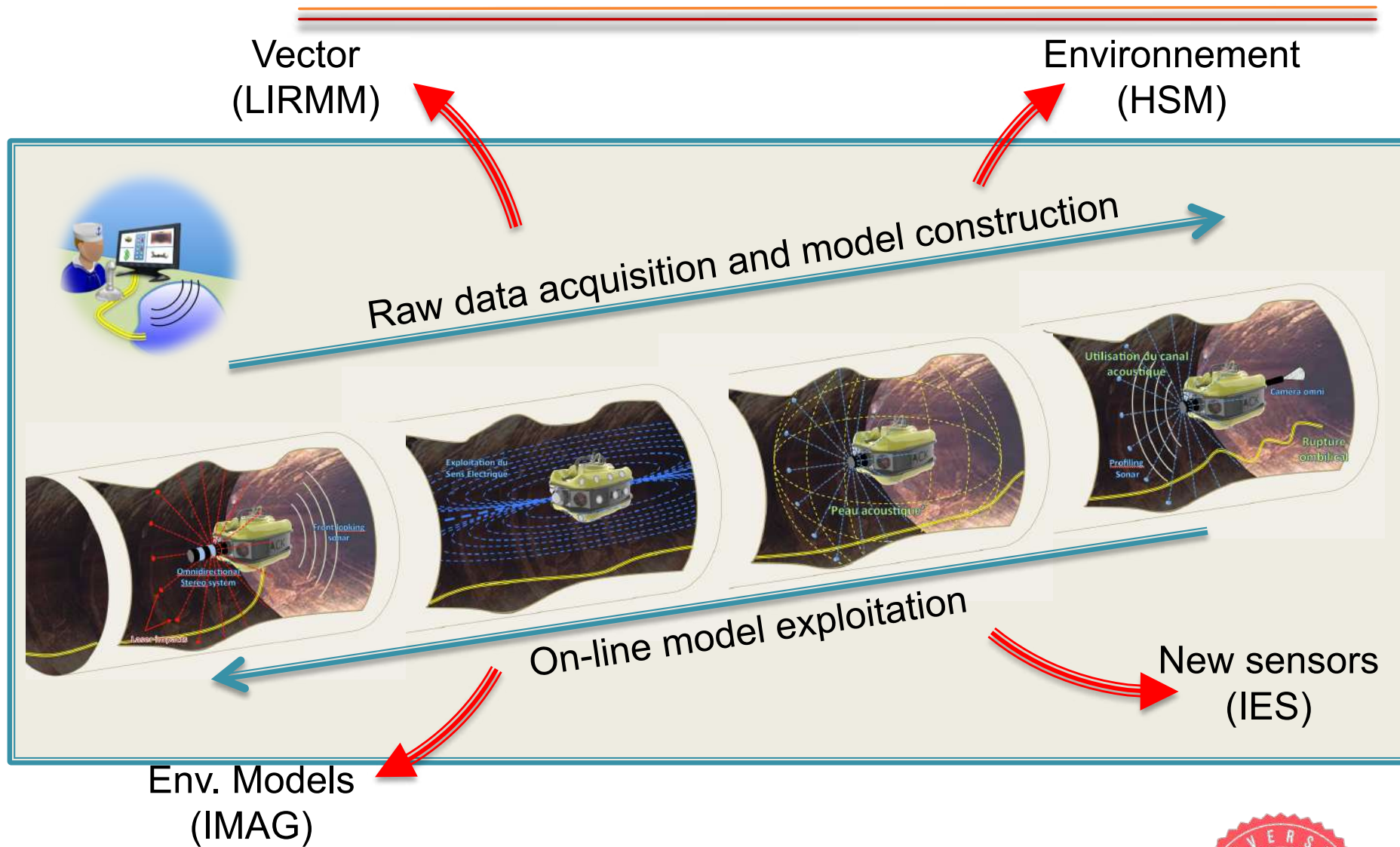
A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

○ Unexmin (UX-1 : AUV explorer for flooded mines)



- Water sampler
- Conductivity and pH measuring units
- Sub-bottom profiler
- Magnetic field measuring unit
- UV and SLS imaging units
- Multispectral camera
- Acoustic cameras
- Laser scanners
- Thrusters
- SONARs
- Pendulum and buoyancy control system
- Rechargeable batteries
- Protective pressure hull

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

FORCES AT WORK

THE RKE INITIATIVE : FORCES AT WORK

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

○ New Sensors Development

● Acoustic Skin

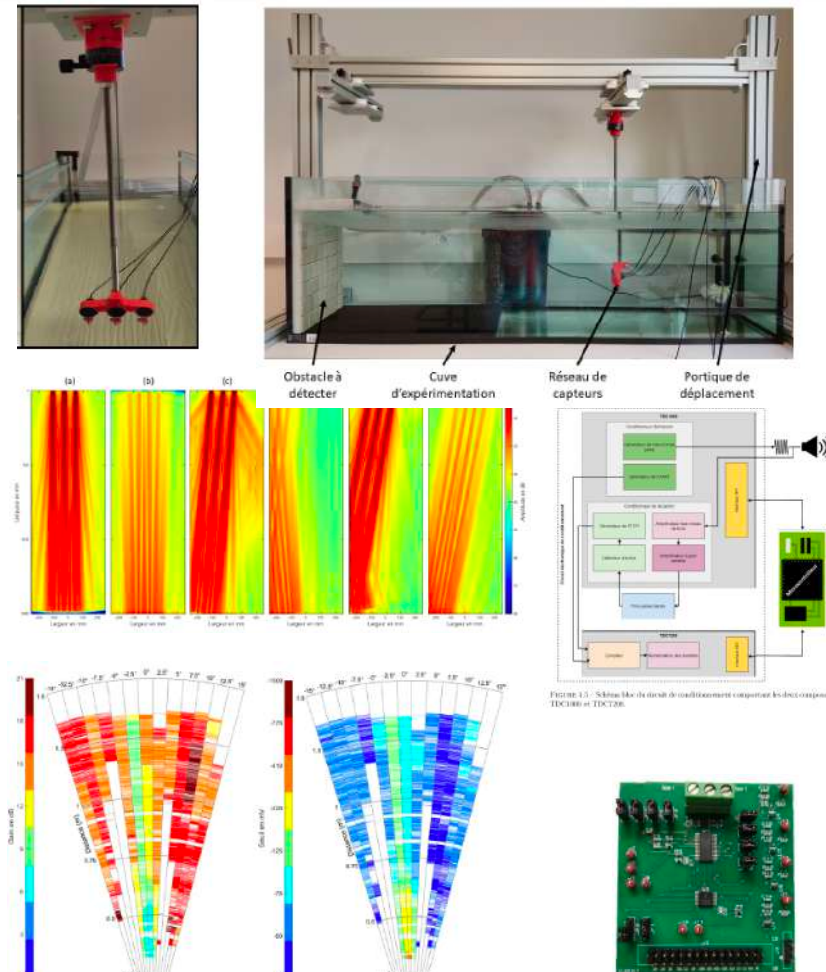
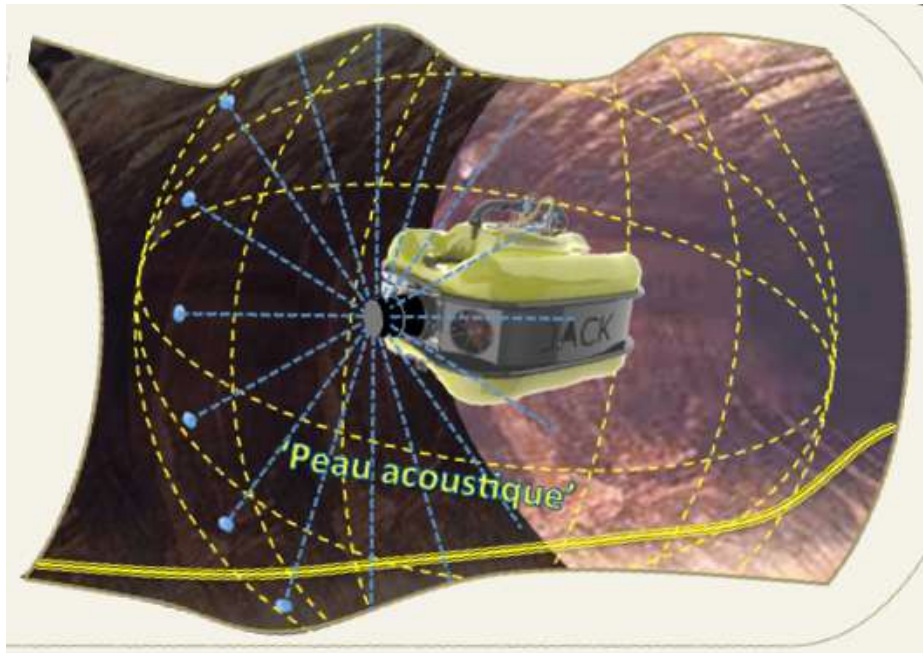
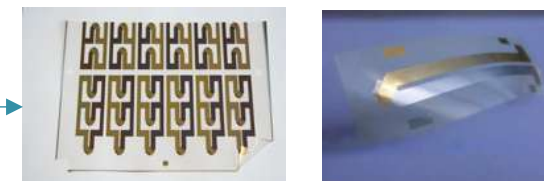


FIGURE 5.12 - Variation du gain (à gauche) et du seuil (à droite) de détection de rovit de conditionnement en fonction de la distance de détection et l'angle d'incidence. Configuration : 3 transducteurs émetteurs espacés de 5 cm, réflexion contre le paroi de aquarium en verre. Représentation des variations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



Stimulation
Protocol

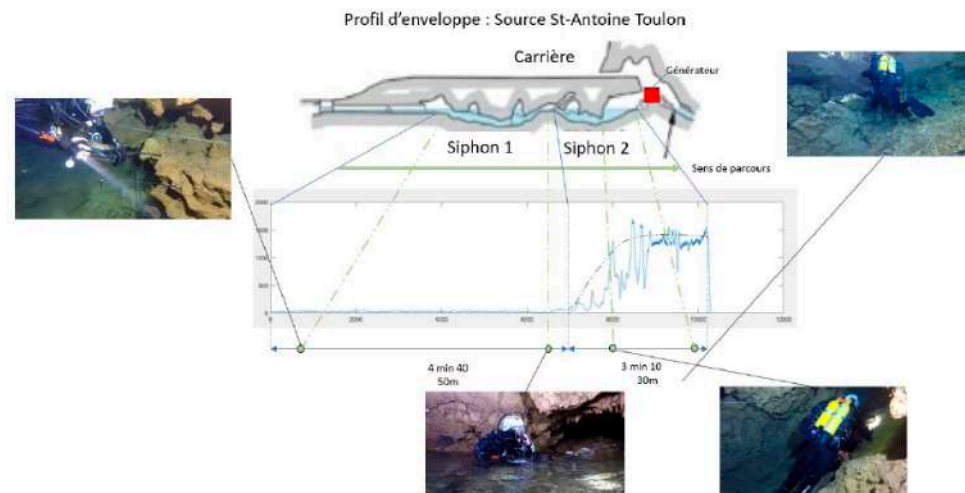
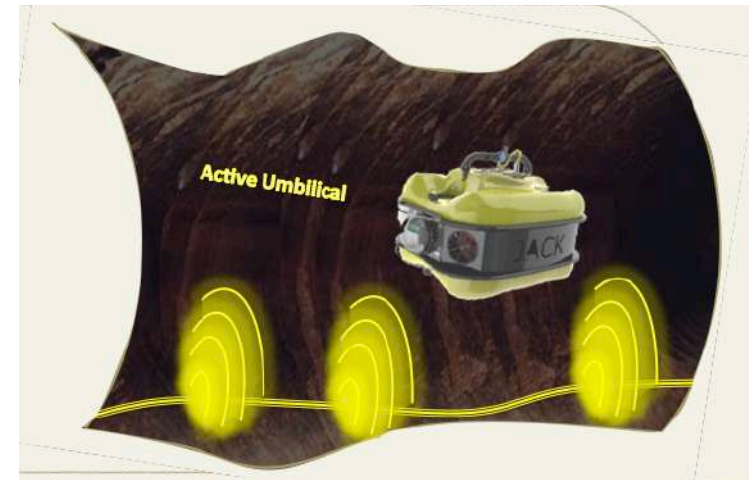
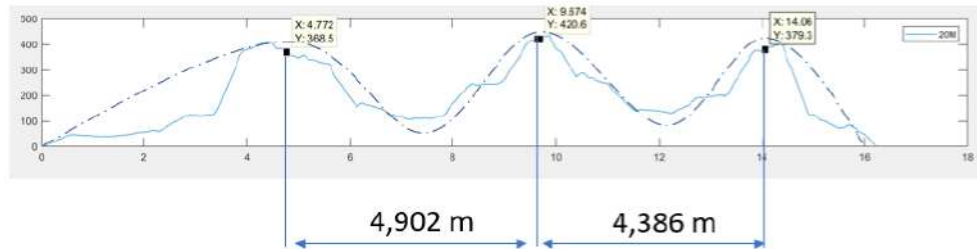


Time of Arrival Sensor (piezotech)

○ New Sensors Development

- Active Umbilical (localisation and communication)

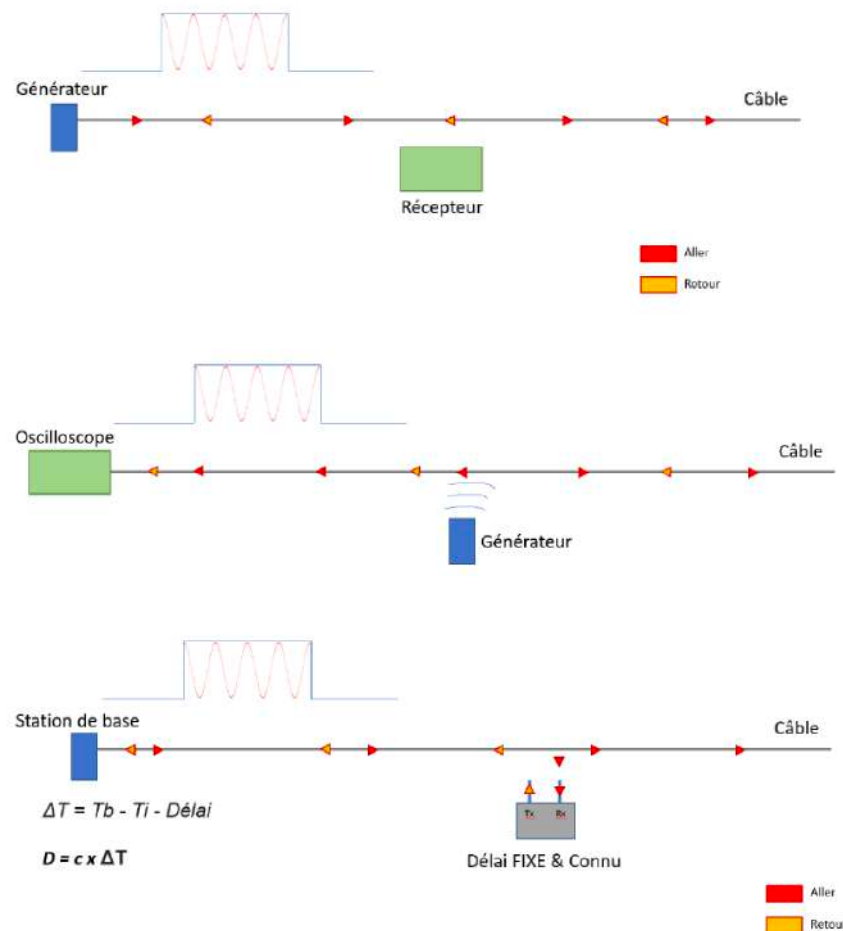
- Détection of Stationnary waves in single wire (fil d'ariane)



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)

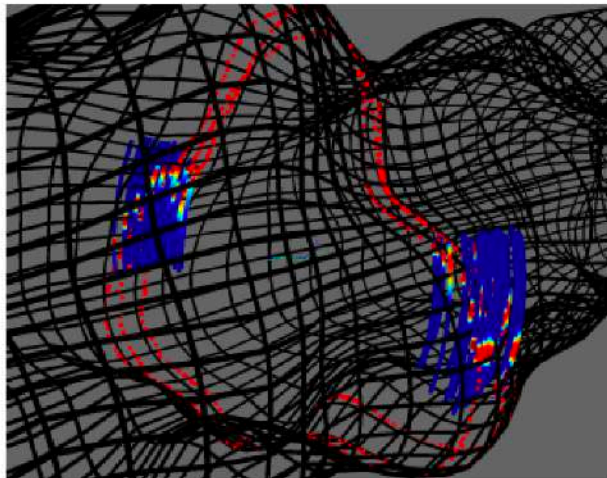
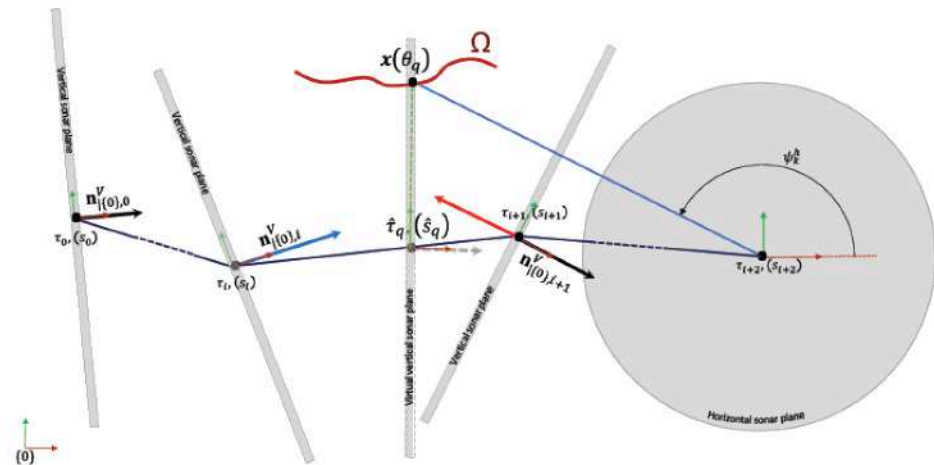
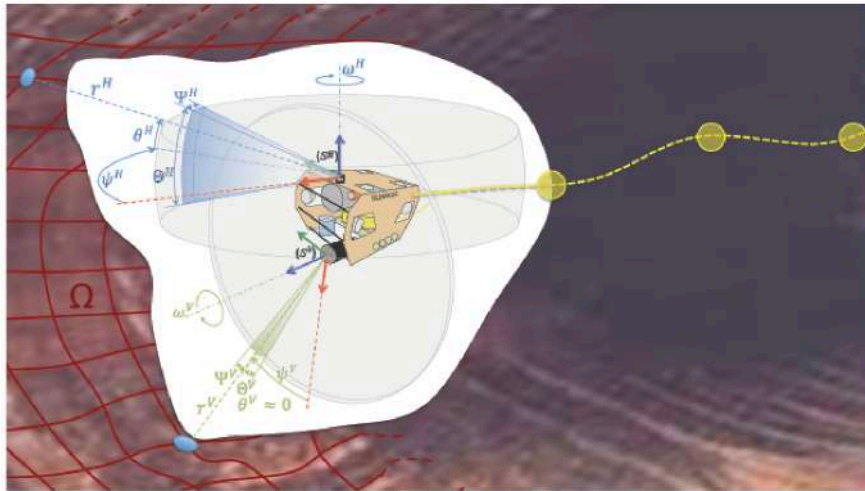


THE RKE INITIATIVE : FORCES AT WORK

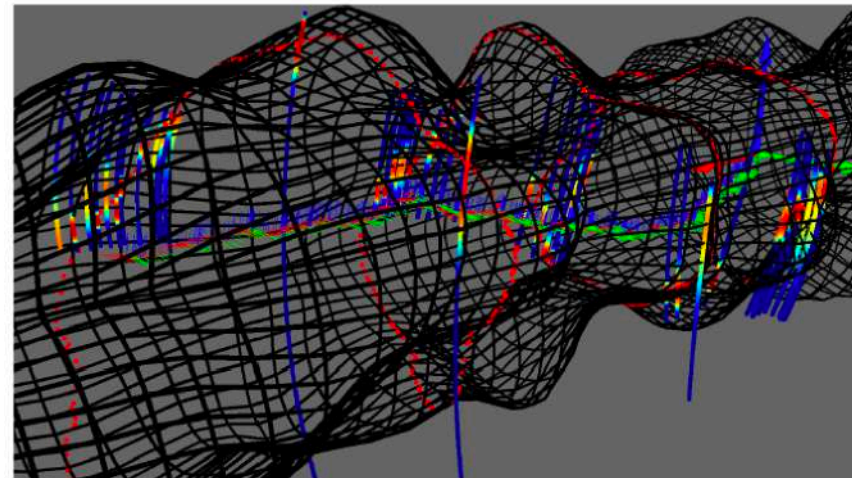
Y. Breux (LIRMM/IMAG)
B. Mohammadi (IMAG)
A. Mas (IMAG)
L. Lapierre (LIRMM)

Navigation

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



(a) Dense case.



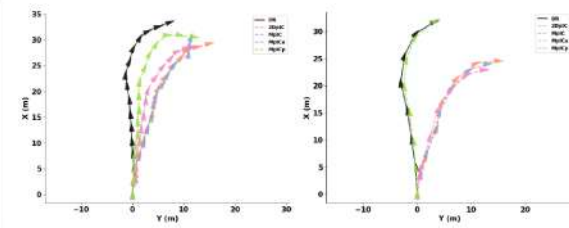
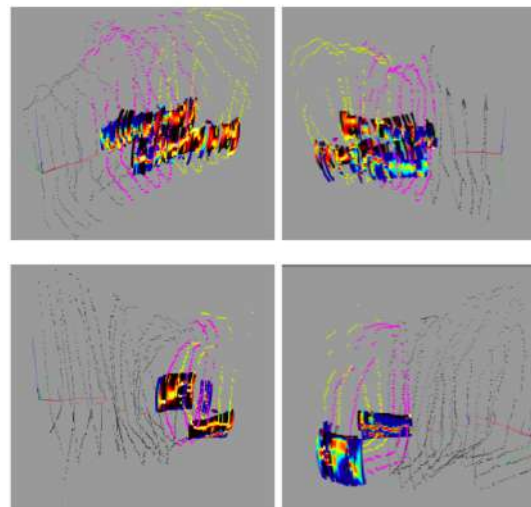
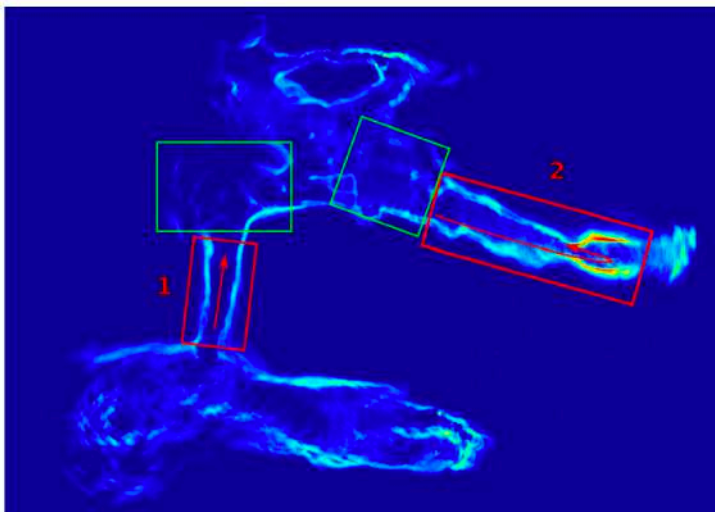
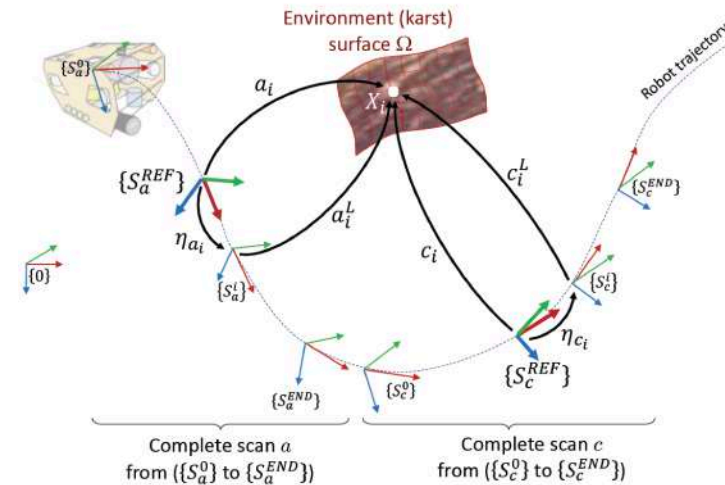
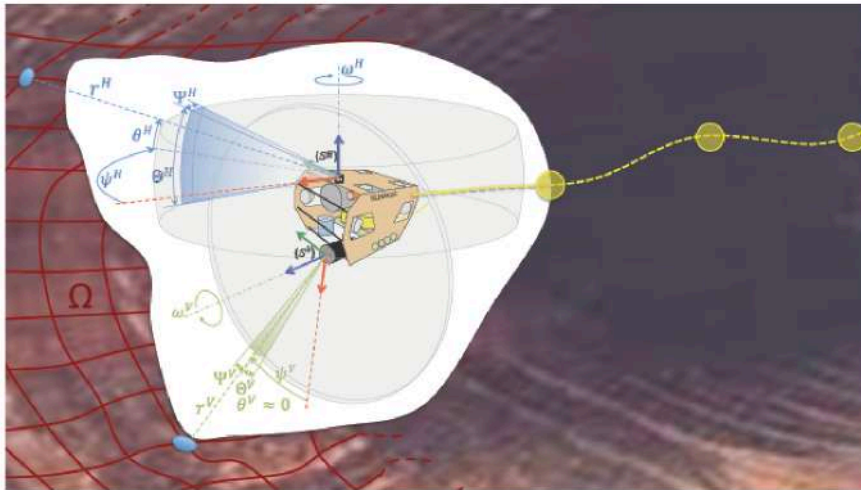
(c) Sparse case.

THE RKE INITIATIVE : FORCES AT WORK

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

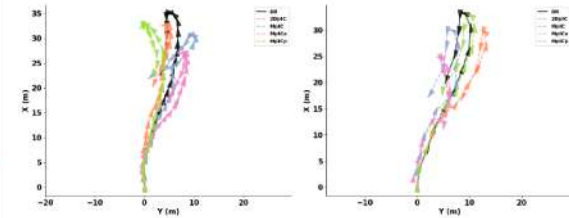
Navigation

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



(a) First segment, 360° scans

(b) First segment, 720° scans



(c) Second segment, 360° scans

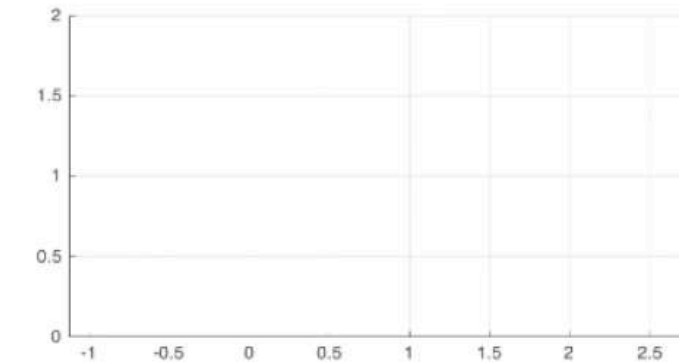
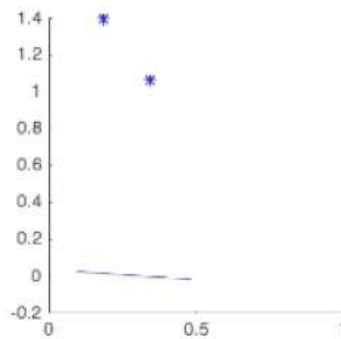
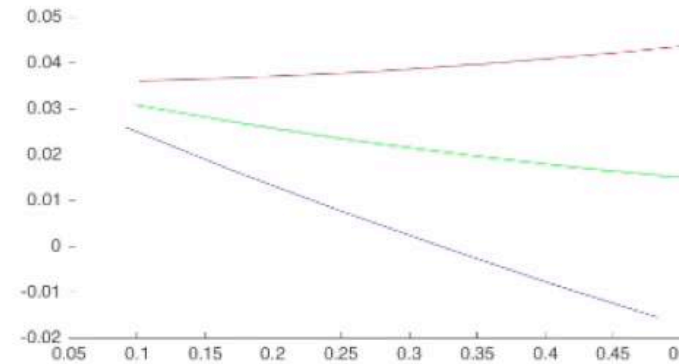
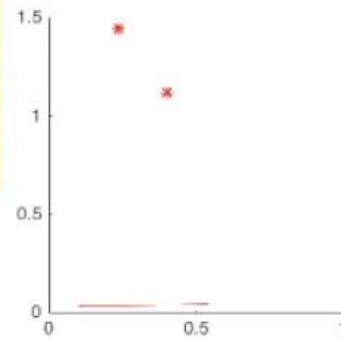
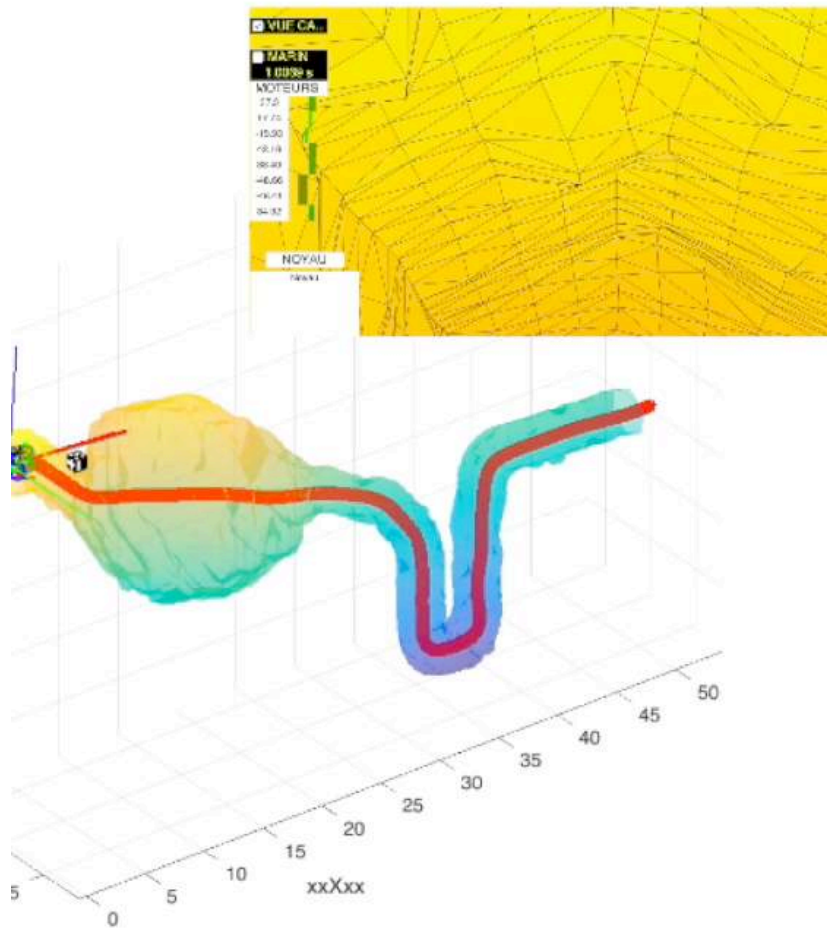
(d) Second segment, 720° scans

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

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

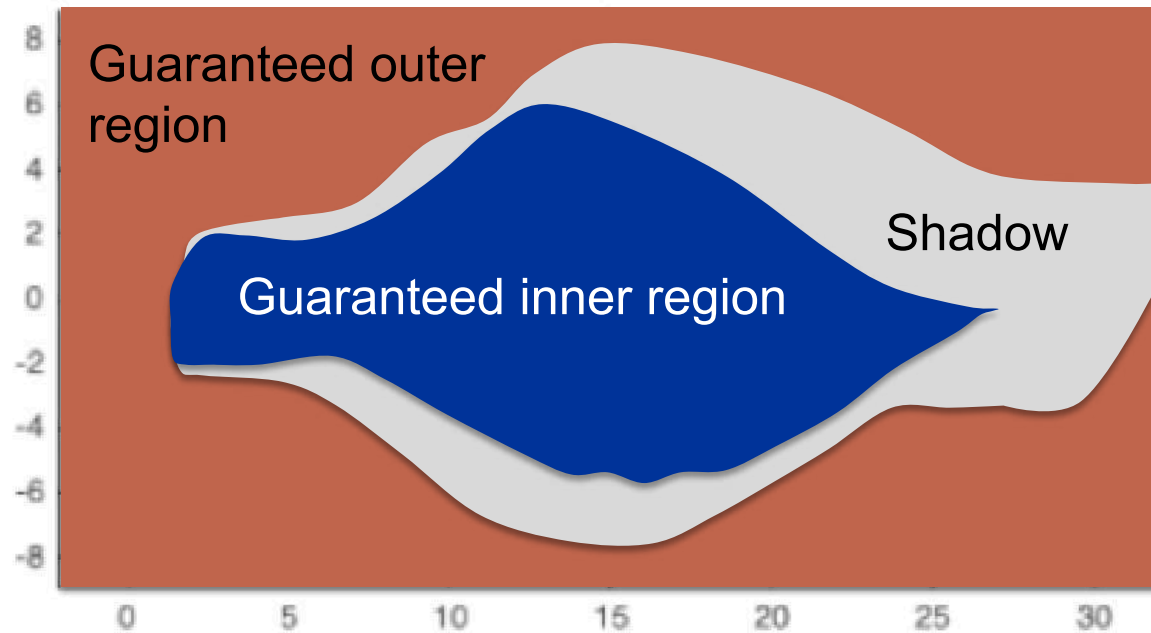
- Cartographie garantie, analyse par intervalles

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



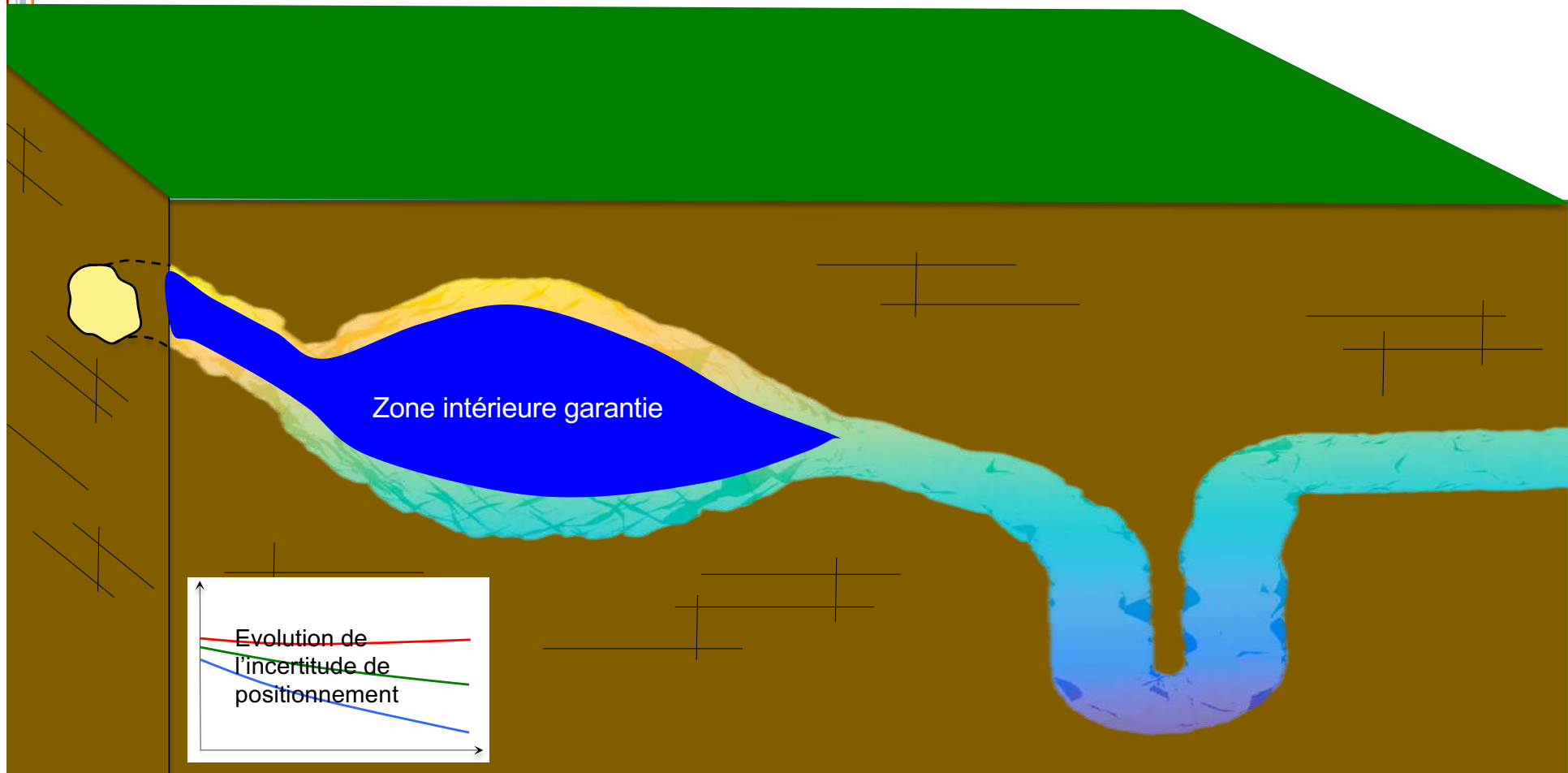
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

- Cartographie garantie, analyse par intervalles



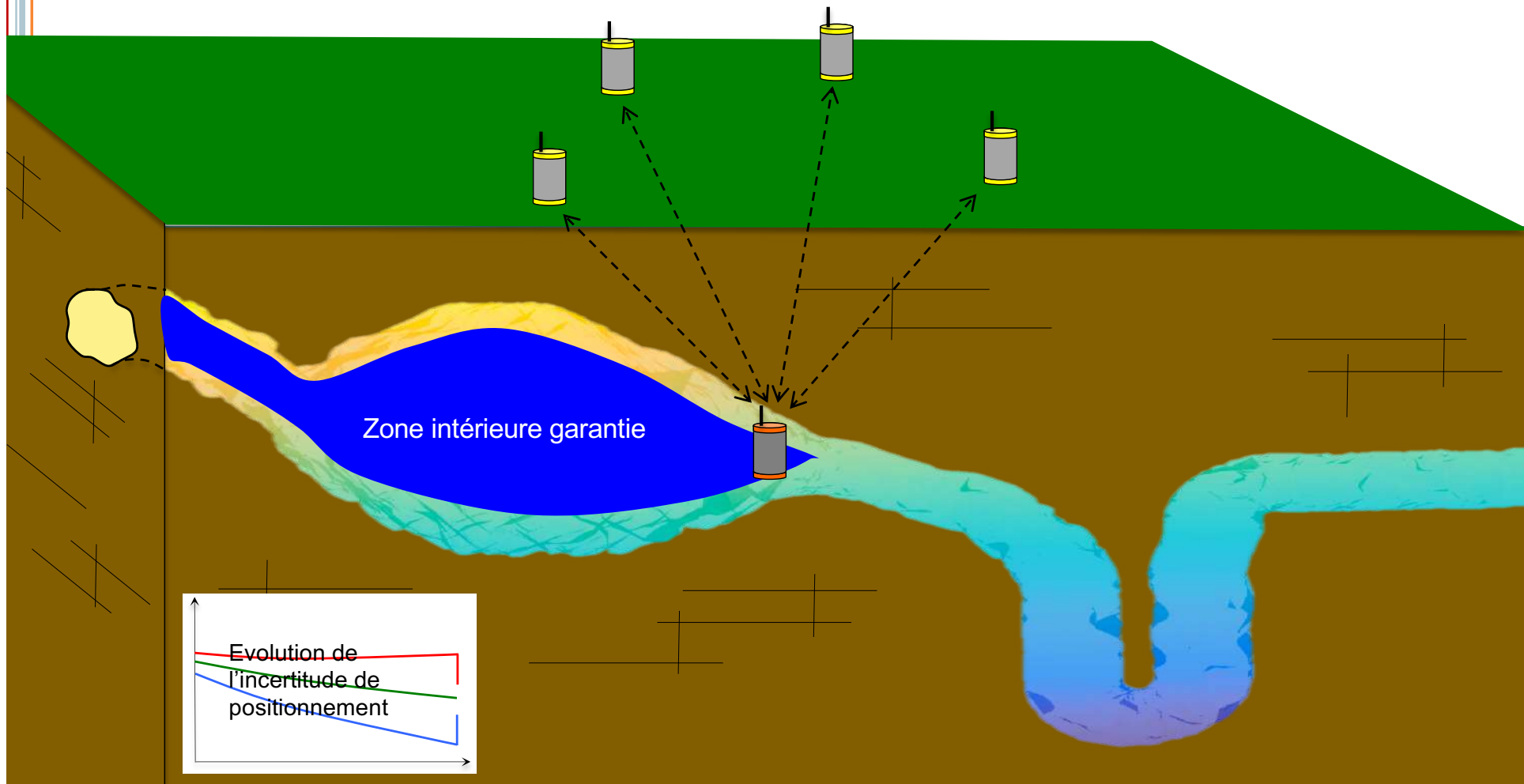
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

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



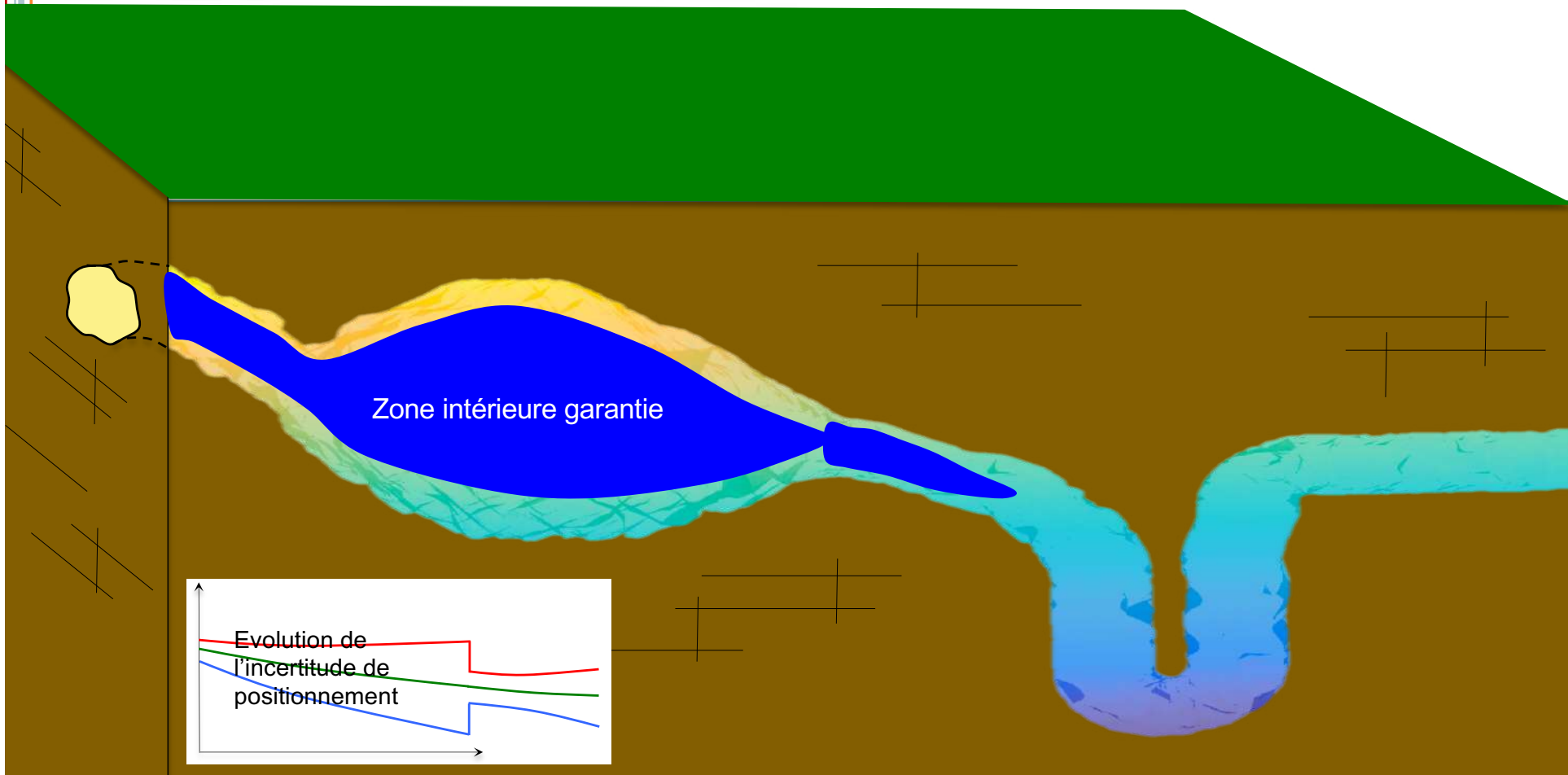
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

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



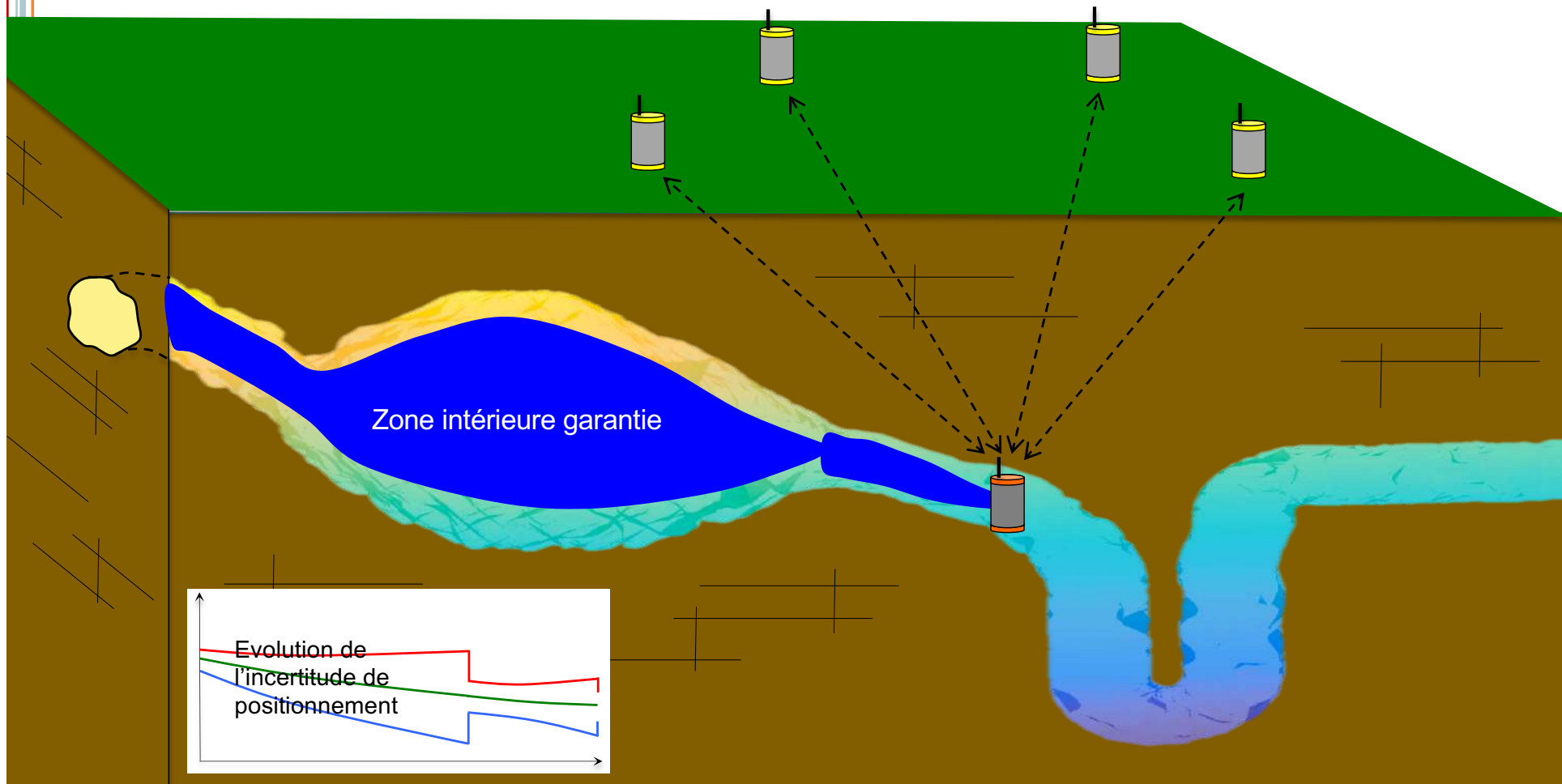
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

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



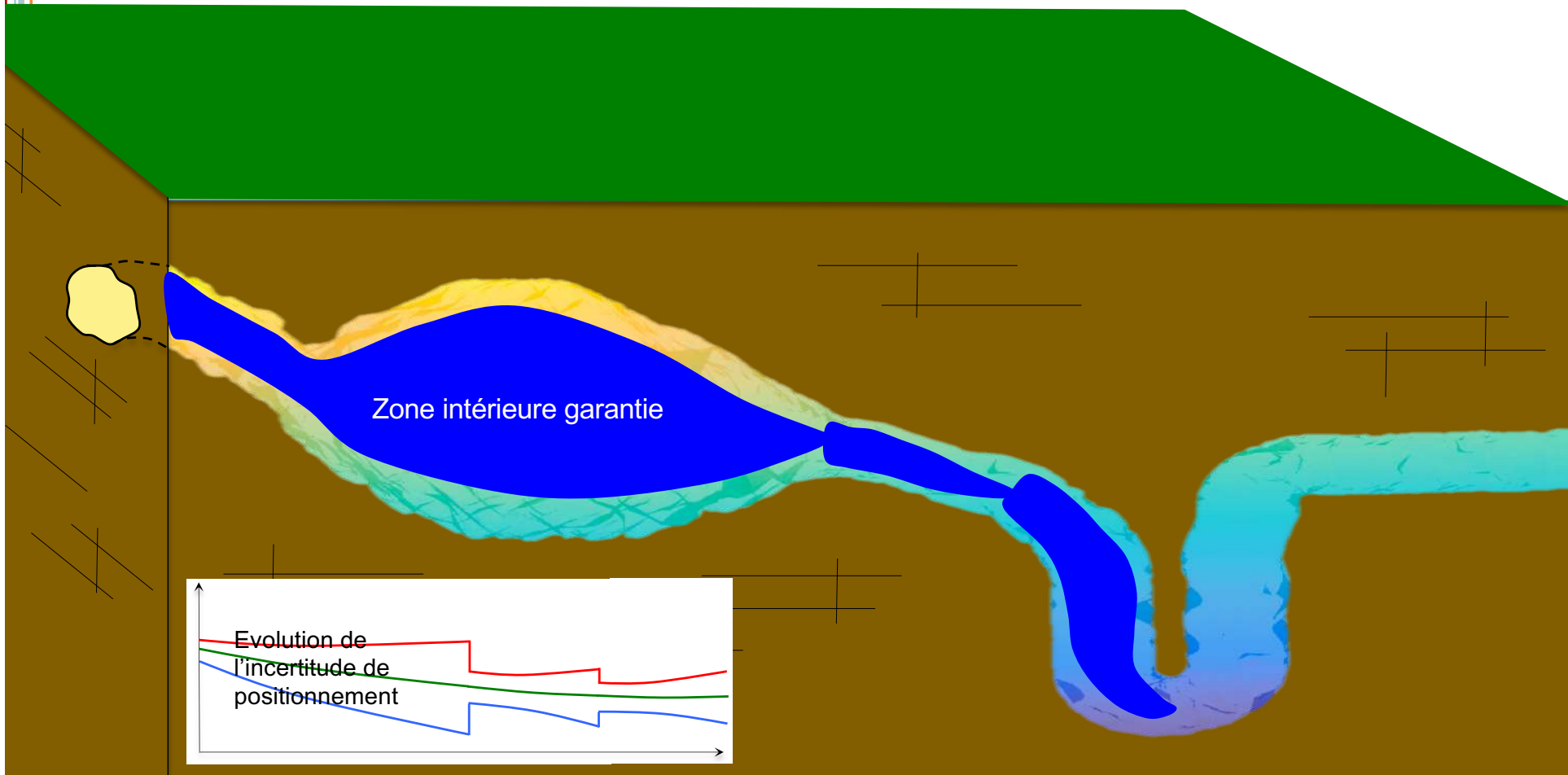
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

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



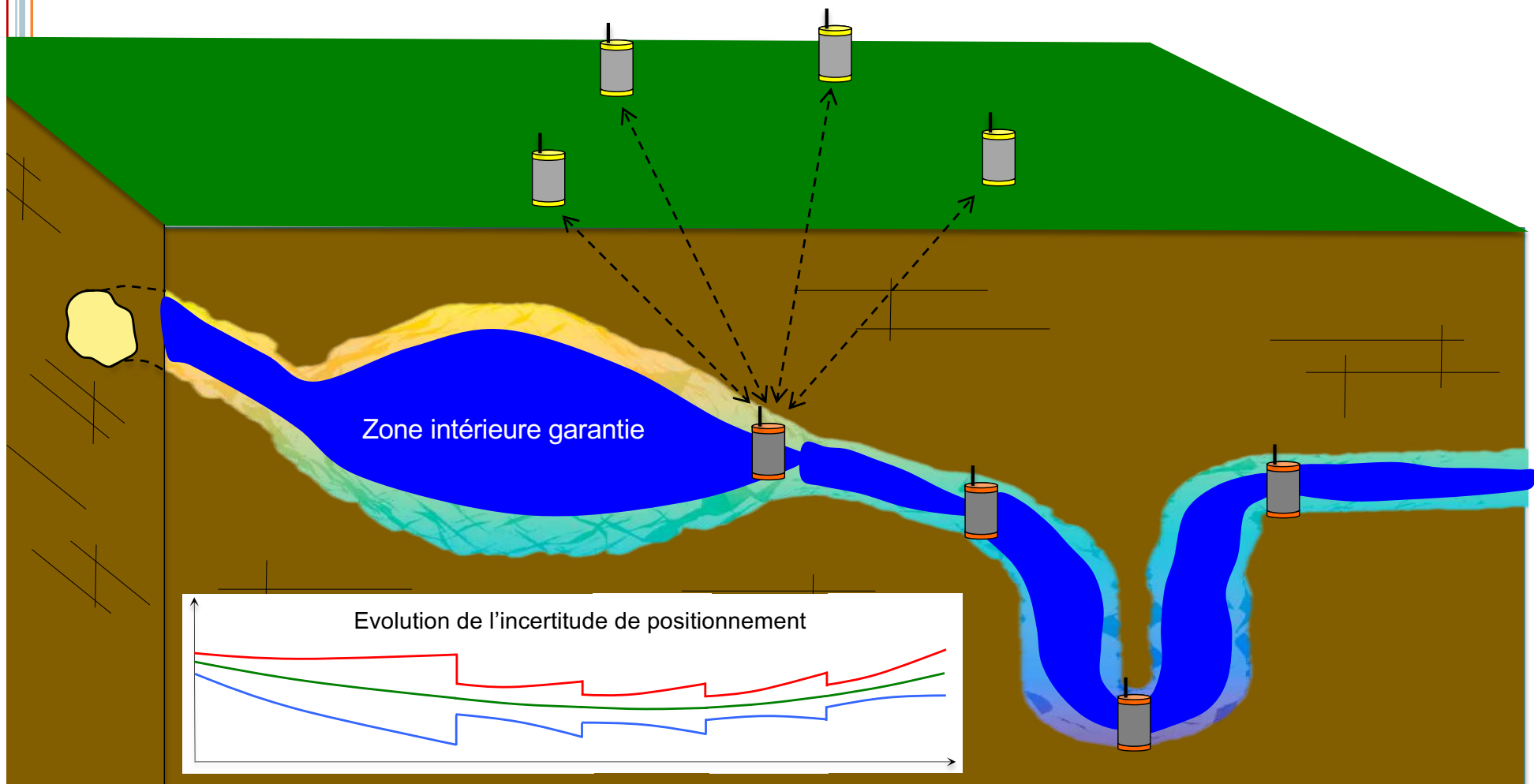
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

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



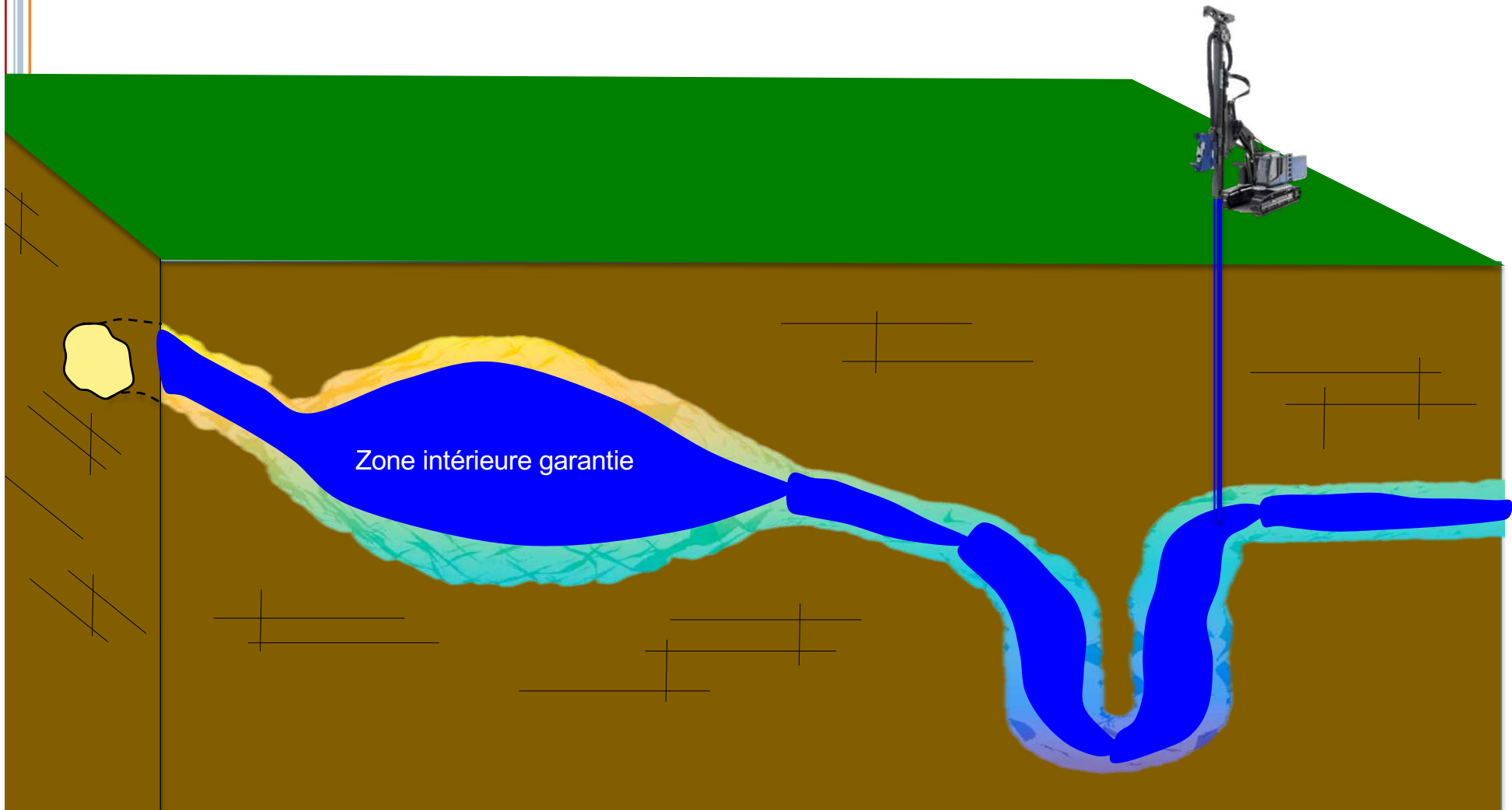
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

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



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

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

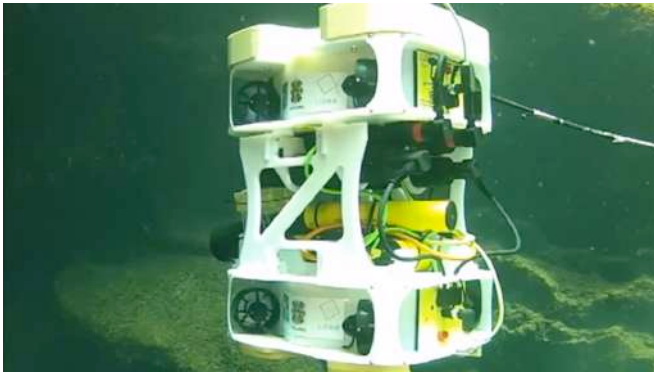


THE RKE INITIATIVE : FORCES AT WORK

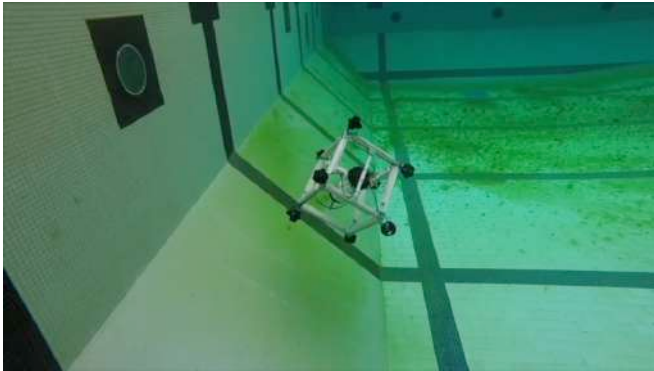
Actuation

- 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



Anguille



Umbrella



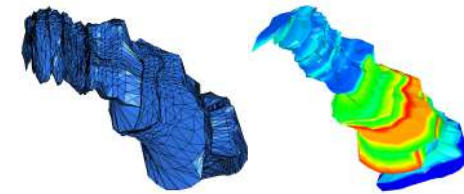
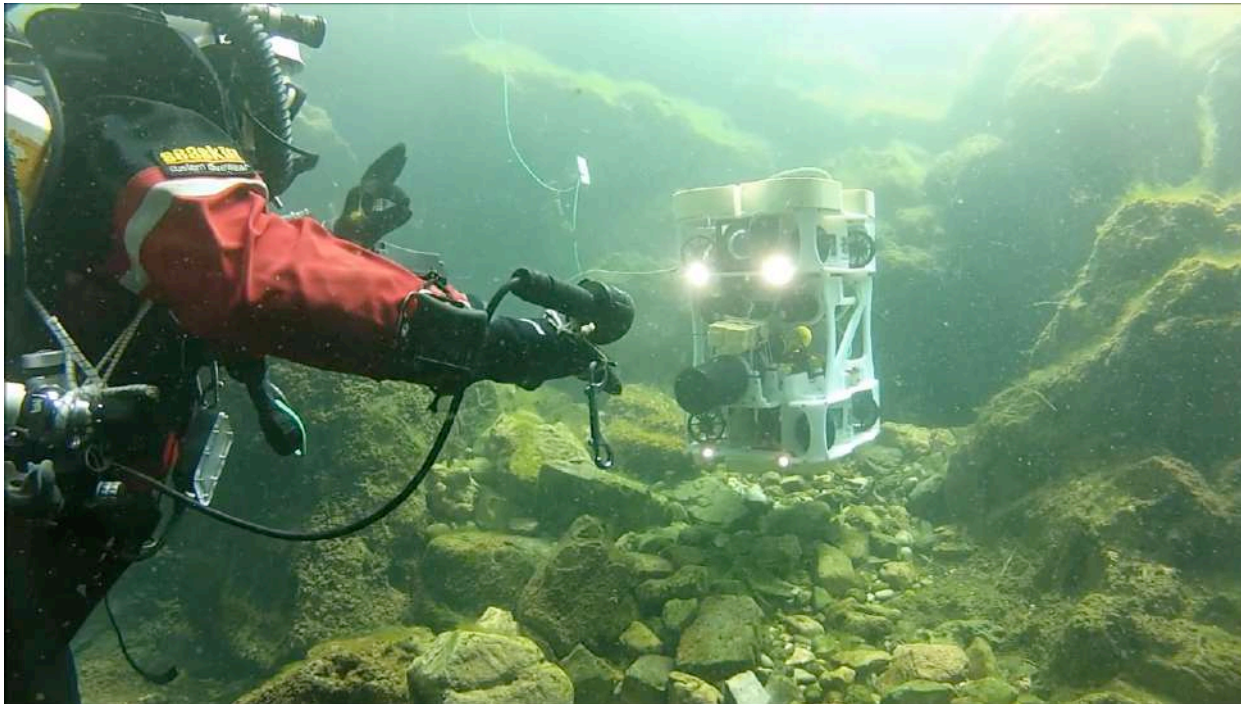
NavScoot



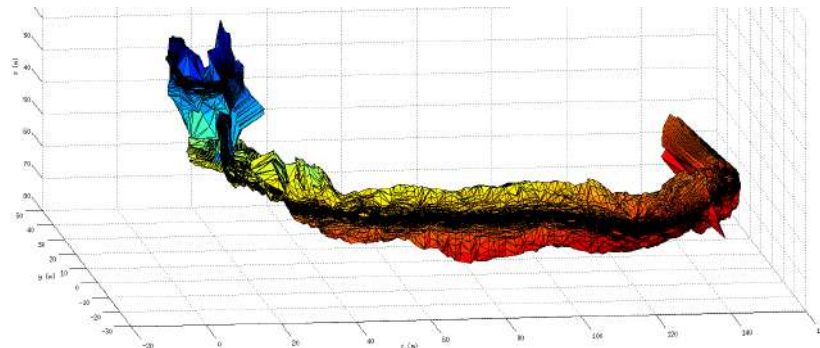
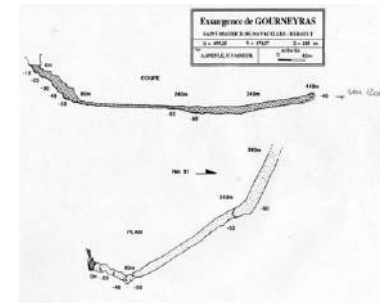
HammerHead

FISRT TERRAIN RESULTS

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

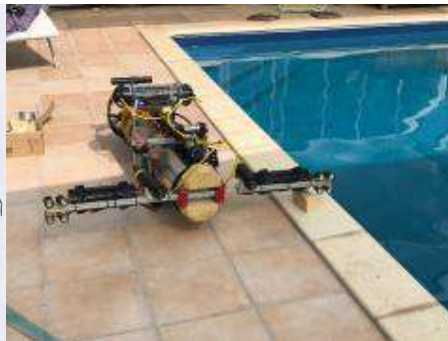
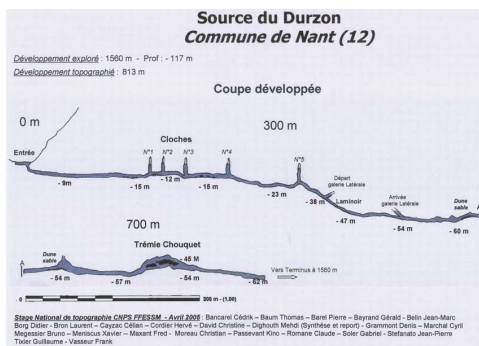


Volume (1187 m³)



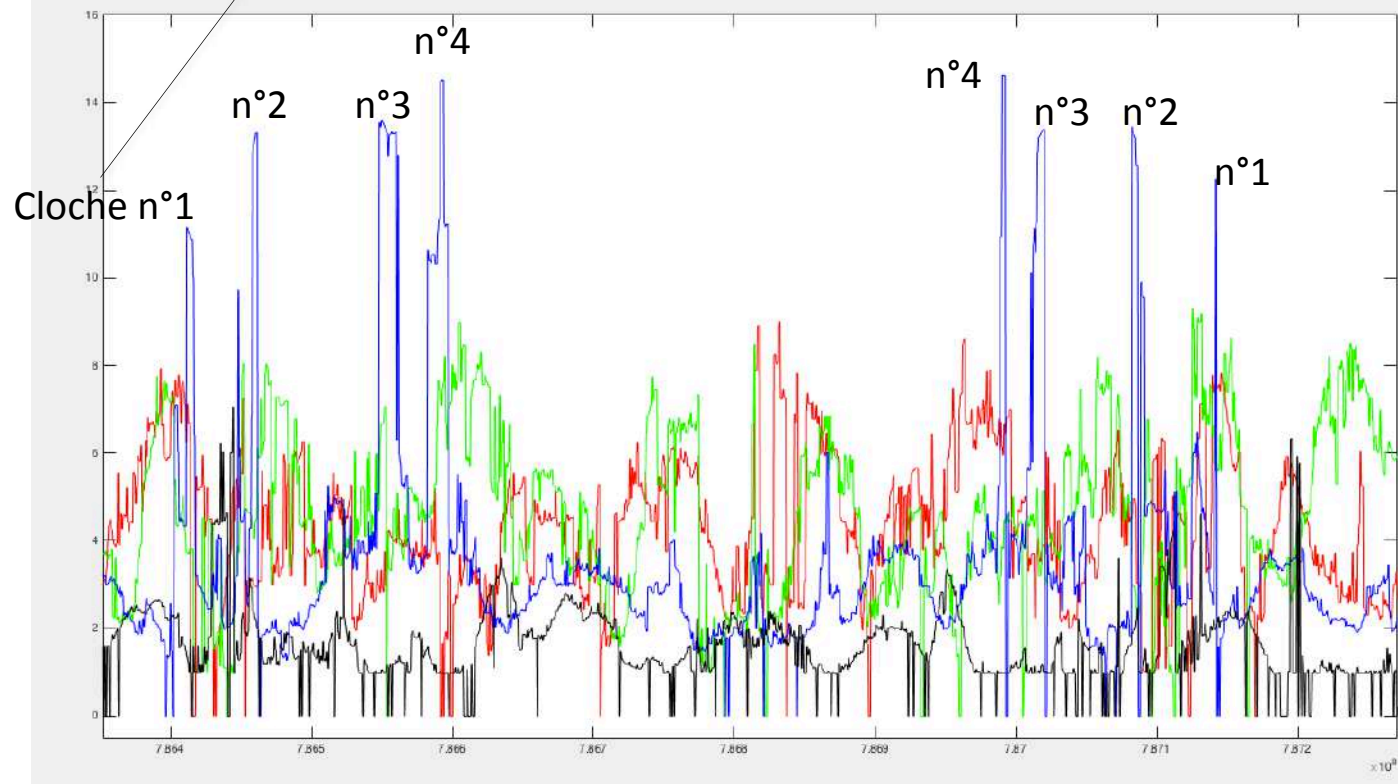
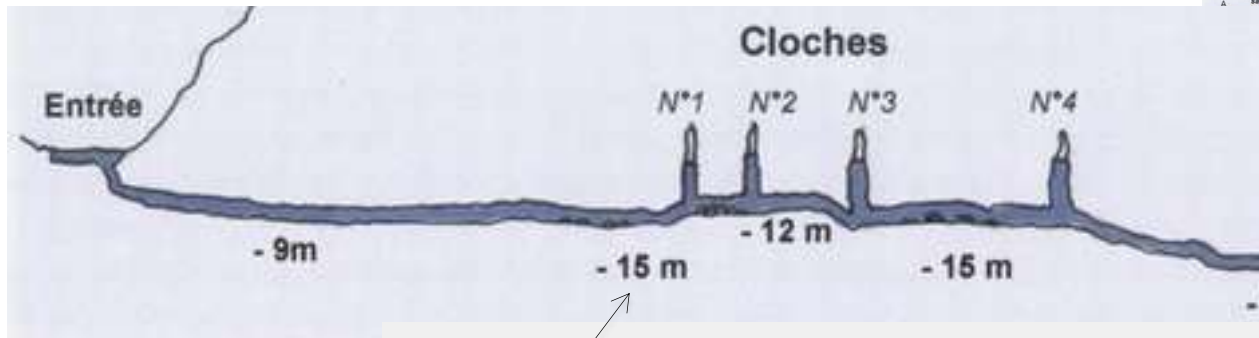
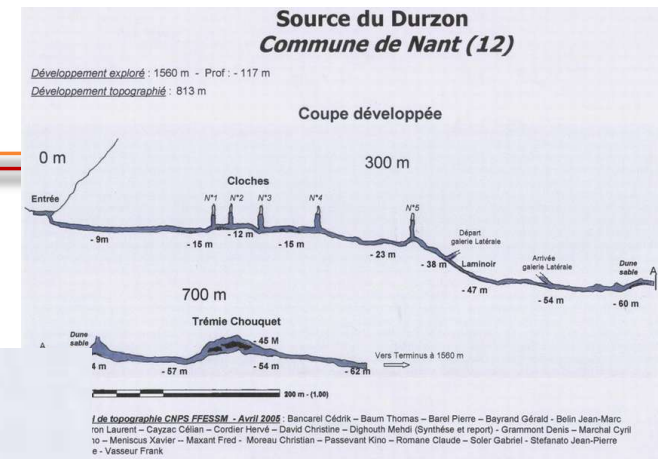
FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

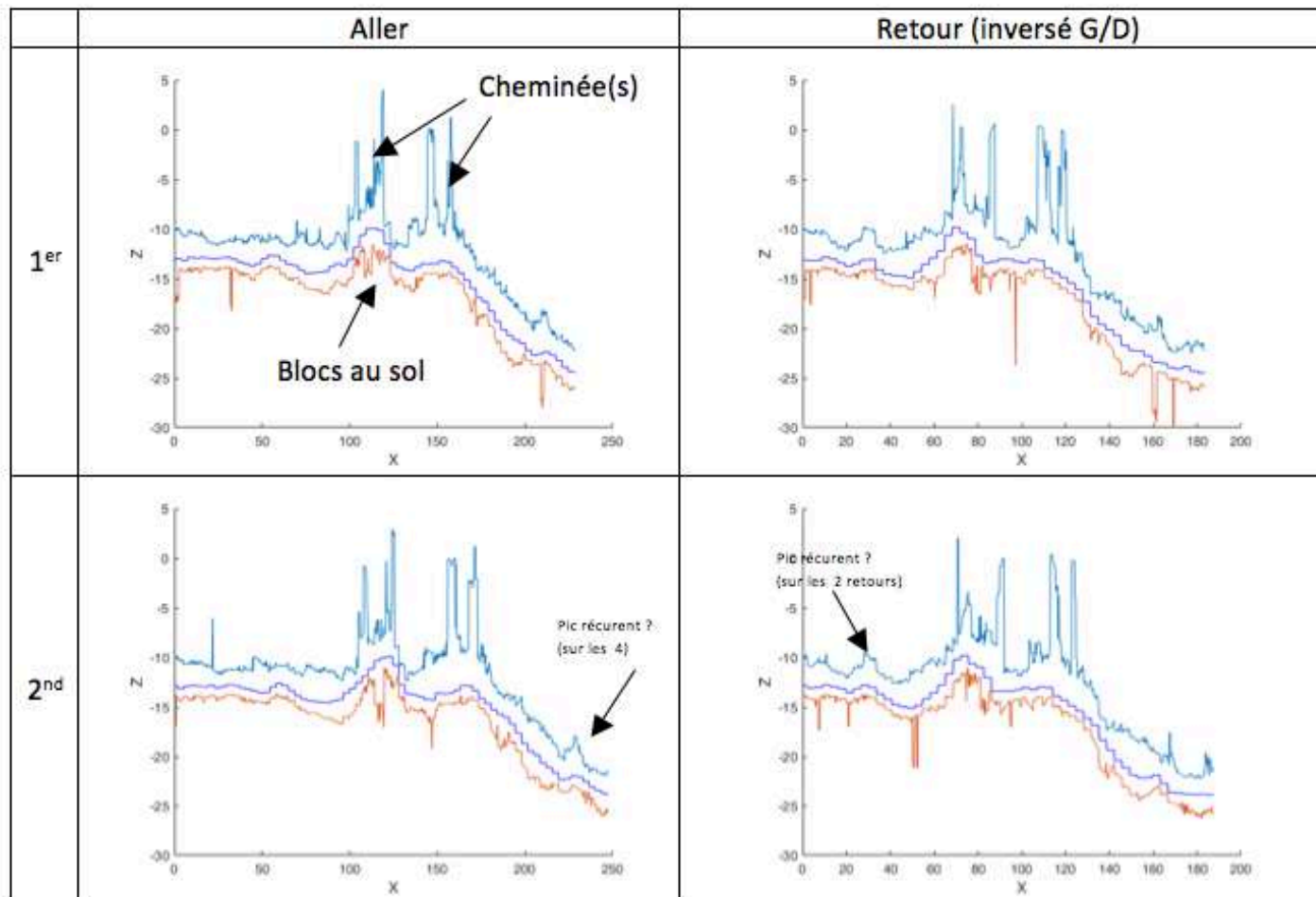


FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

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

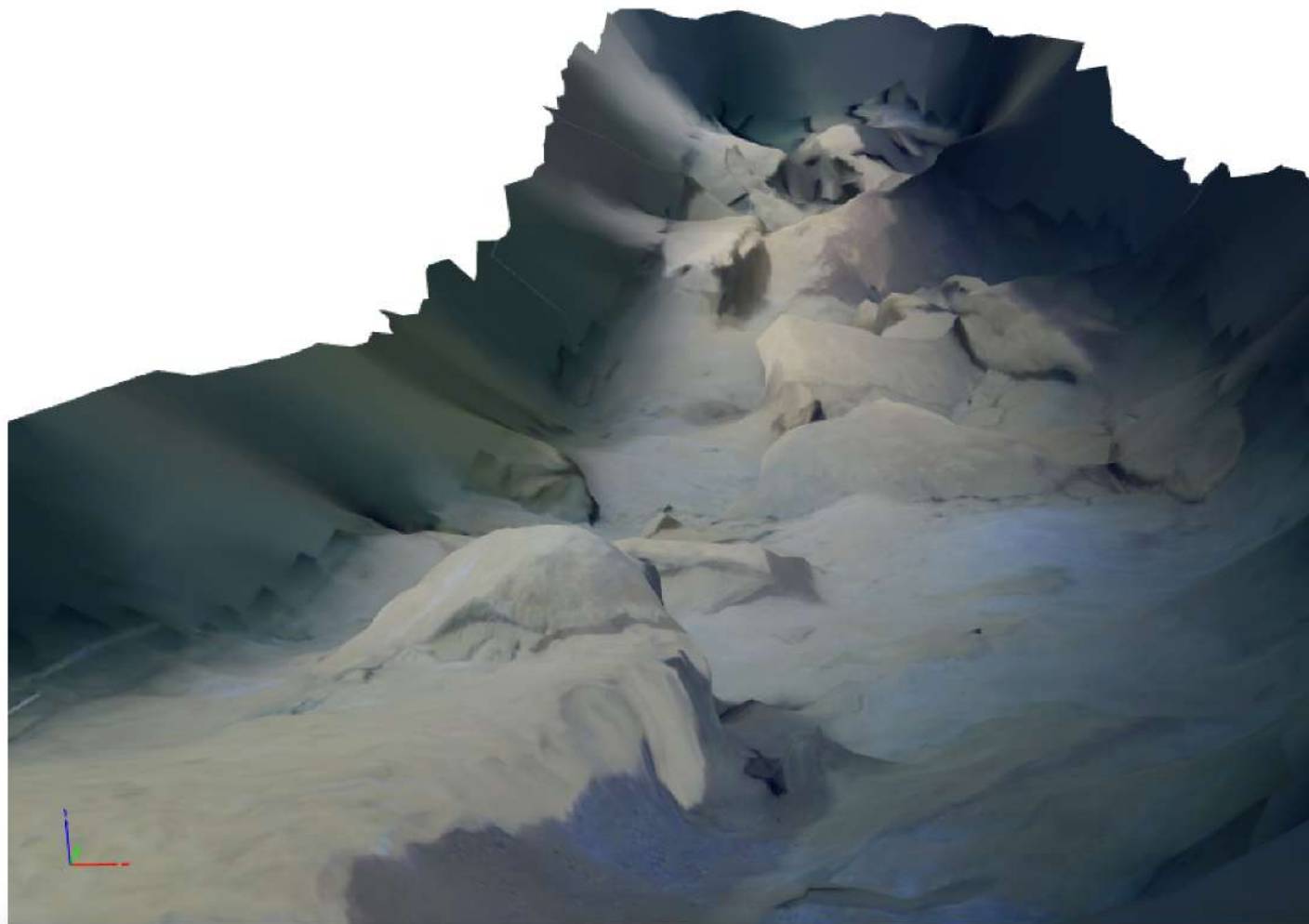
Données :



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

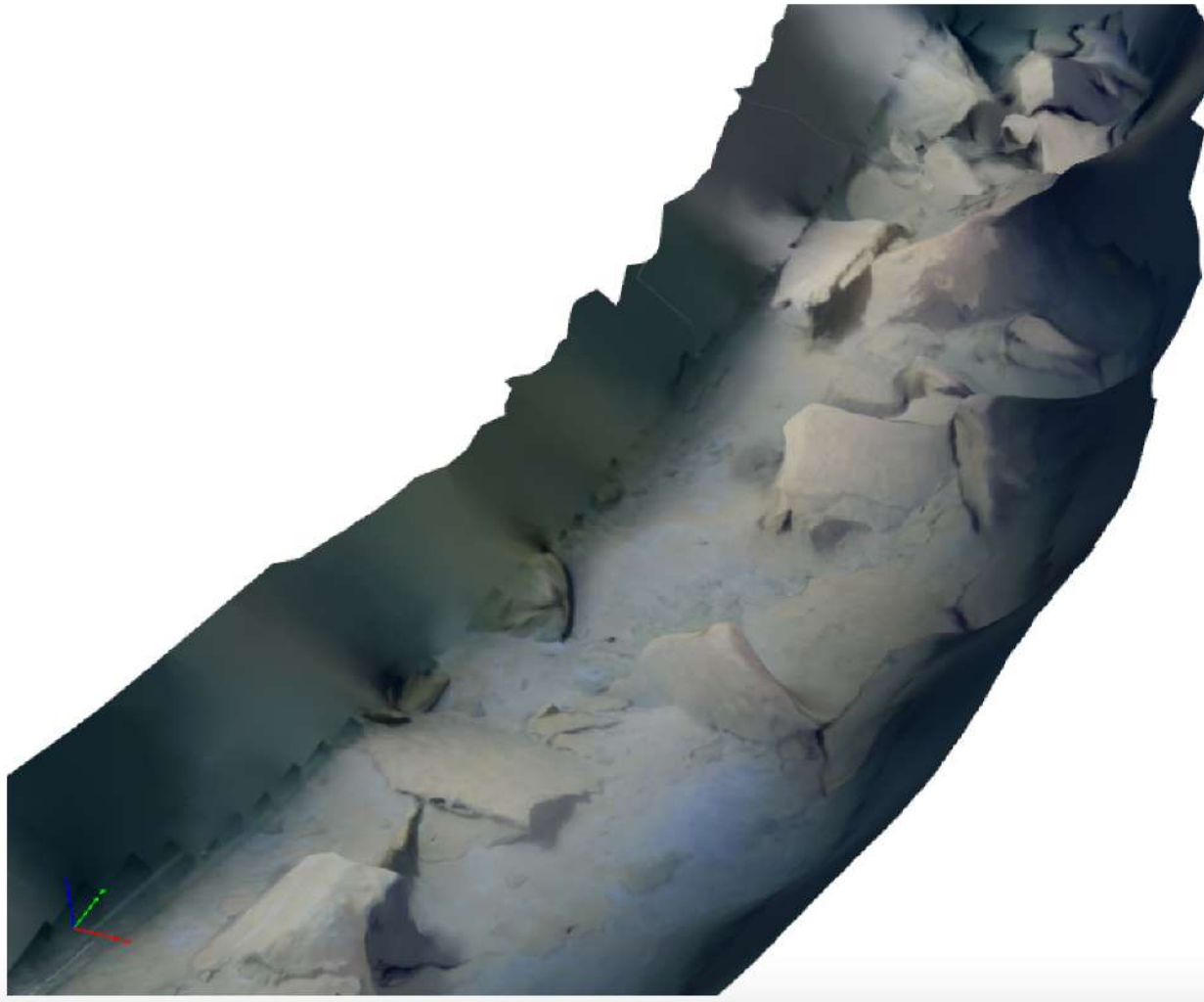
Photogrammetric reconstruction



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

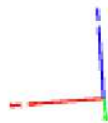
Photogrammetric reconstruction



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

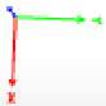
Photogrammetric reconstruction



FISRT TERRAIN RESULTS

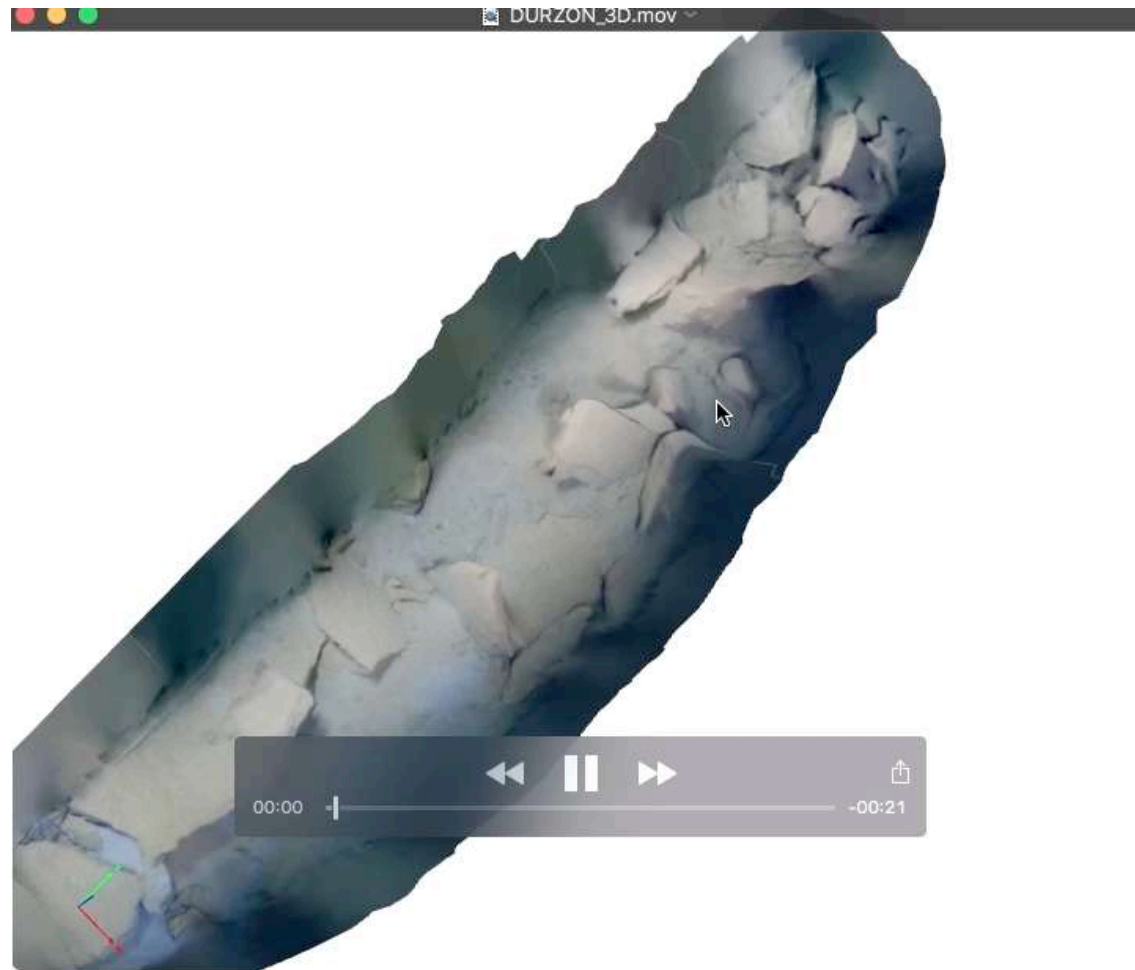
○ Durzon, Nant, 24/06/2018.

Photogrammetric reconstruction



FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.



Partial photogrammetric reconstruction

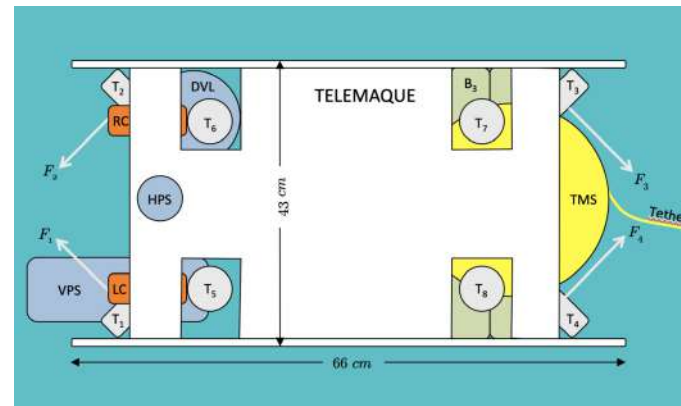
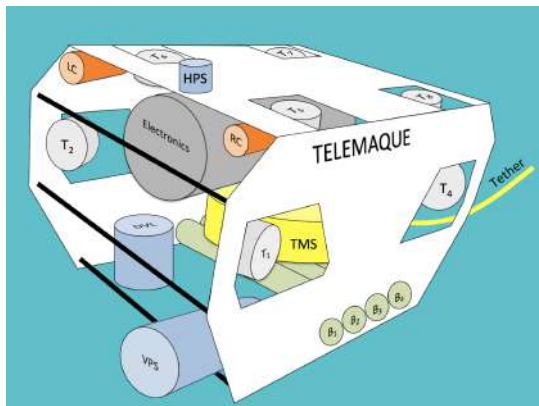
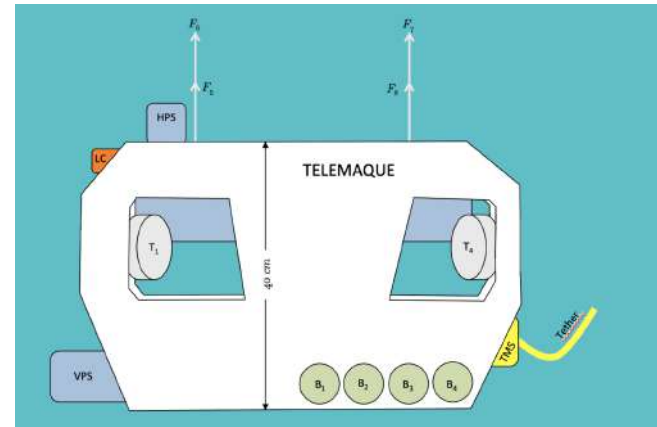


WHAT'S NEXT ?



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 Trittech (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) :

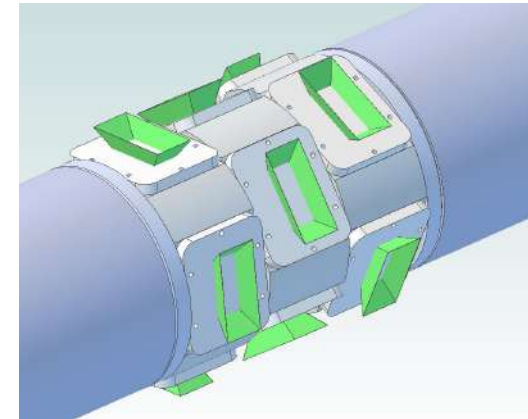
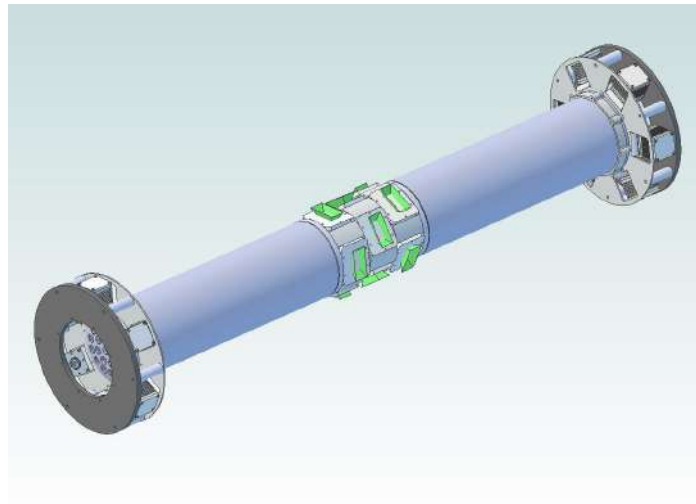
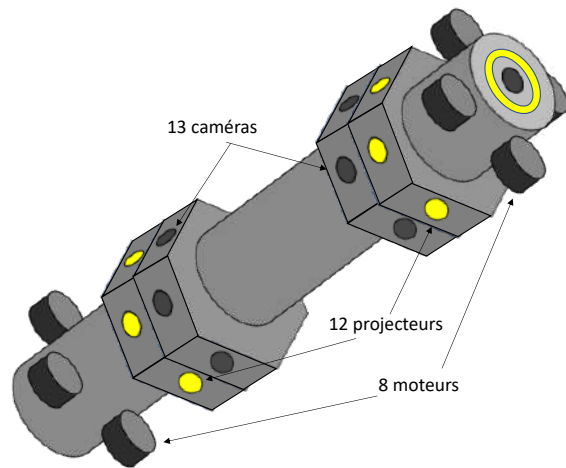
Tether Management System (TMS) : from Syera and Reeds

Water leaks detectors

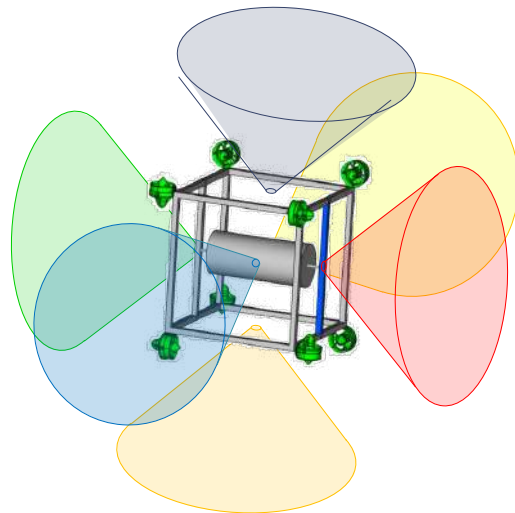
Batteries' consumption

NEW SYSTEMS

- Dodécam : système photogrammétrique 12 caméras



- Cube



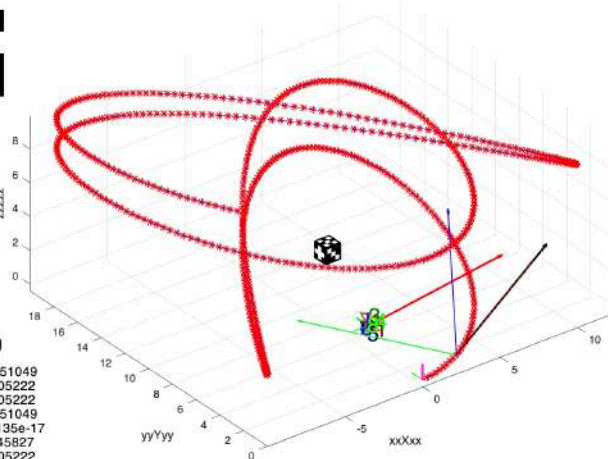
■ VUE CA...

■ MARIN
0.3 s

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

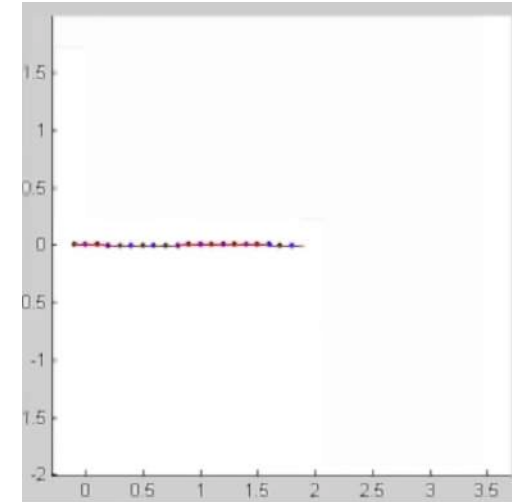
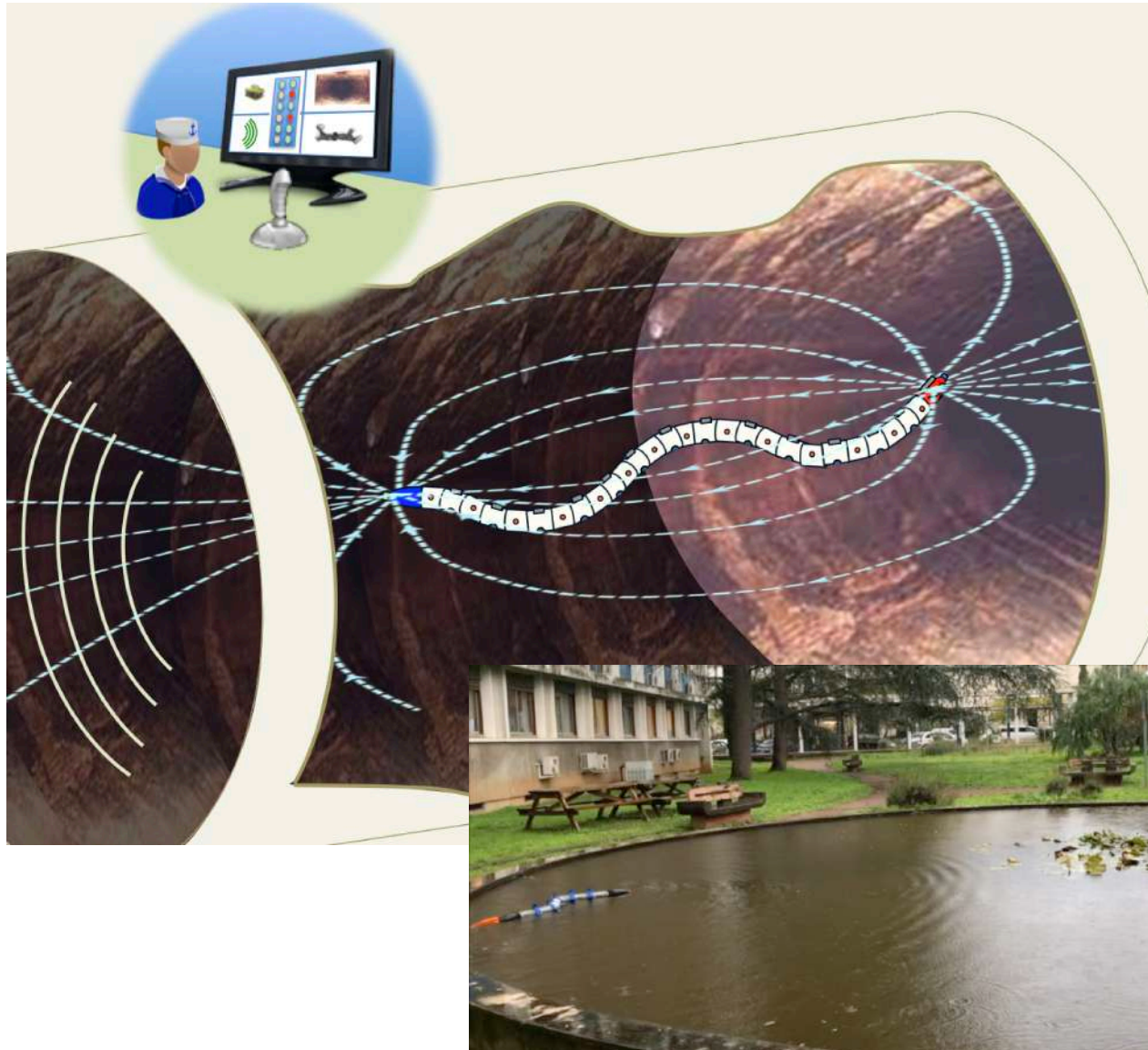
NOYAU

0.077876 -0.51049
0.51375 -0.05222
0.51375 -0.05222
0.077876 -0.51049
-2.2135e-18 -5.2135e-17
0.43587 0.45827
0.51375 -0.05222
-0.077876 0.51049



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 Leboucq, Christine Chevalereau, and Noël Servigne

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 electrolocation in real fish, a set of sensors control lines controlled simple behaviors such as avoiding any electrically contrasted object, or making a set of objects with varying others according to their electric properties, is proposed. Their reflex behaviors are illustrated in simulation 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, underwater, bio-inspired, obstacle avoidance, artificial potentials.

1. INTRODUCTION

In spite of its high potential interest for applications such as deep sea exploration or mine clearance 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, subterranean navigation 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 elegant 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 Laumax in the 50s [1]. The African fish *Gnathopoma Faintsi* (pictured in figure 1) is a typical electric fish. It polarizes its body with respect to its 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. Thus, 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]. “Natural” electrolocation: this natural ability has been extensively studied by neuro-ethologists who shows the electric fish can recognize objects shape, measure distance, size 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 unidirectional character that makes it a sense naturally suited to the obstacle avoidance. Thus,

understanding and mimicking this sense with technology would offer the opportunity to enhance the navigation abilities of our current underwater robots. In this perspective, Mr. Invernizzi 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-point 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 (sensing) electrodes between which the voltage was measured. 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 V_i . The electric field distortions are then measured through the vector I of the currents flowing across the electrodes. We term this measurement made $V_i \cdot I$. The first laser standing for the sensor has three, a vector of voltage V_1 , the second, for the reception there a vector of current I_1 , to distinguish it from the $V_i - I_i$ mode of [13], [14]. In this article we address the problem of the underwater electro-location in confined environments using this sensor. The proposed approach is inspired by the observation of electric fish in nature. It explains the interactions of the sensor body with the electric field distortions produced by the objects in its surrounding. It presents the use of electric control loops whose parameters allows one to achieve robust behavior for obstacle avoidance in a robust manner with respect to the sense complexity.

The article is structured as follows. First we will briefly

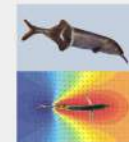
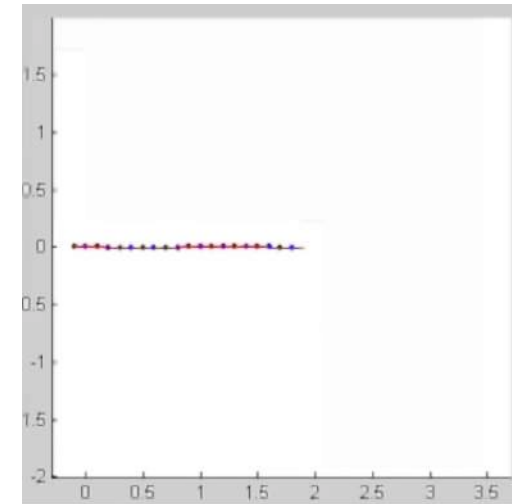
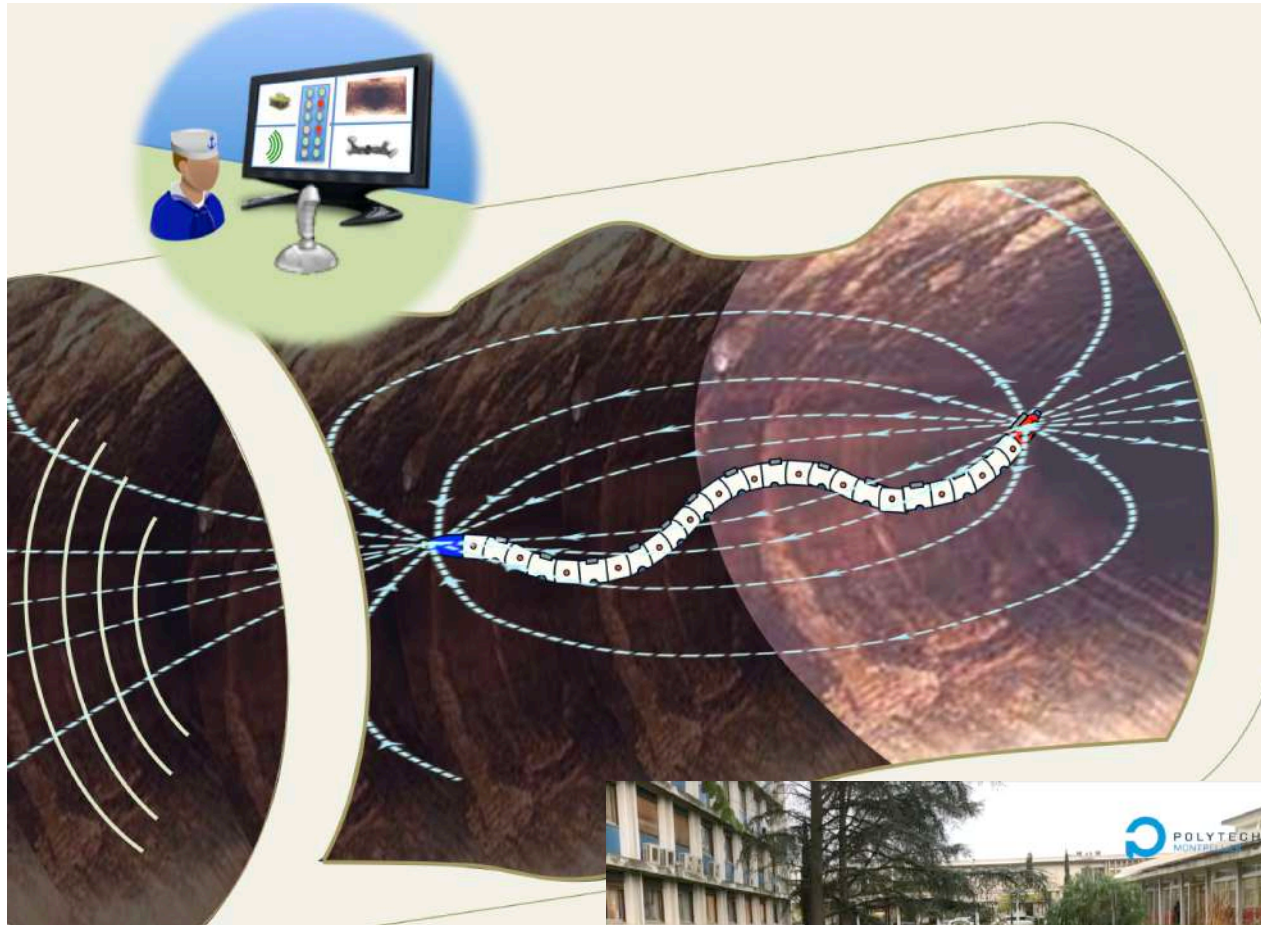


Fig. 1. From Van der Sluis [16] (1961) The African teleost fish *Gnathopoma faintsi*. (Source by view of the best stock photo)

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

Locomotion anguilliforme et Sens électrique



JOURNAL OF ROBOTICS AND MECHANICAL SYSTEMS

Underwater reflex navigation in confined environment based on electric sense

Fabrice Boyer, Vincent Leboucq, Christine Chevalereau, and Noël Servajean

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 electrolocation in real fish, a set of sensors control lines controlled simple behaviors such as avoiding any electrically contrasted object, or making a set of objects with varying sizes according to their electric properties, is proposed. Their reflex behaviors are illustrated in simulation 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, underwater, bio-inspired, obstacle avoidance, artificial potentials.

1. INTRODUCTION

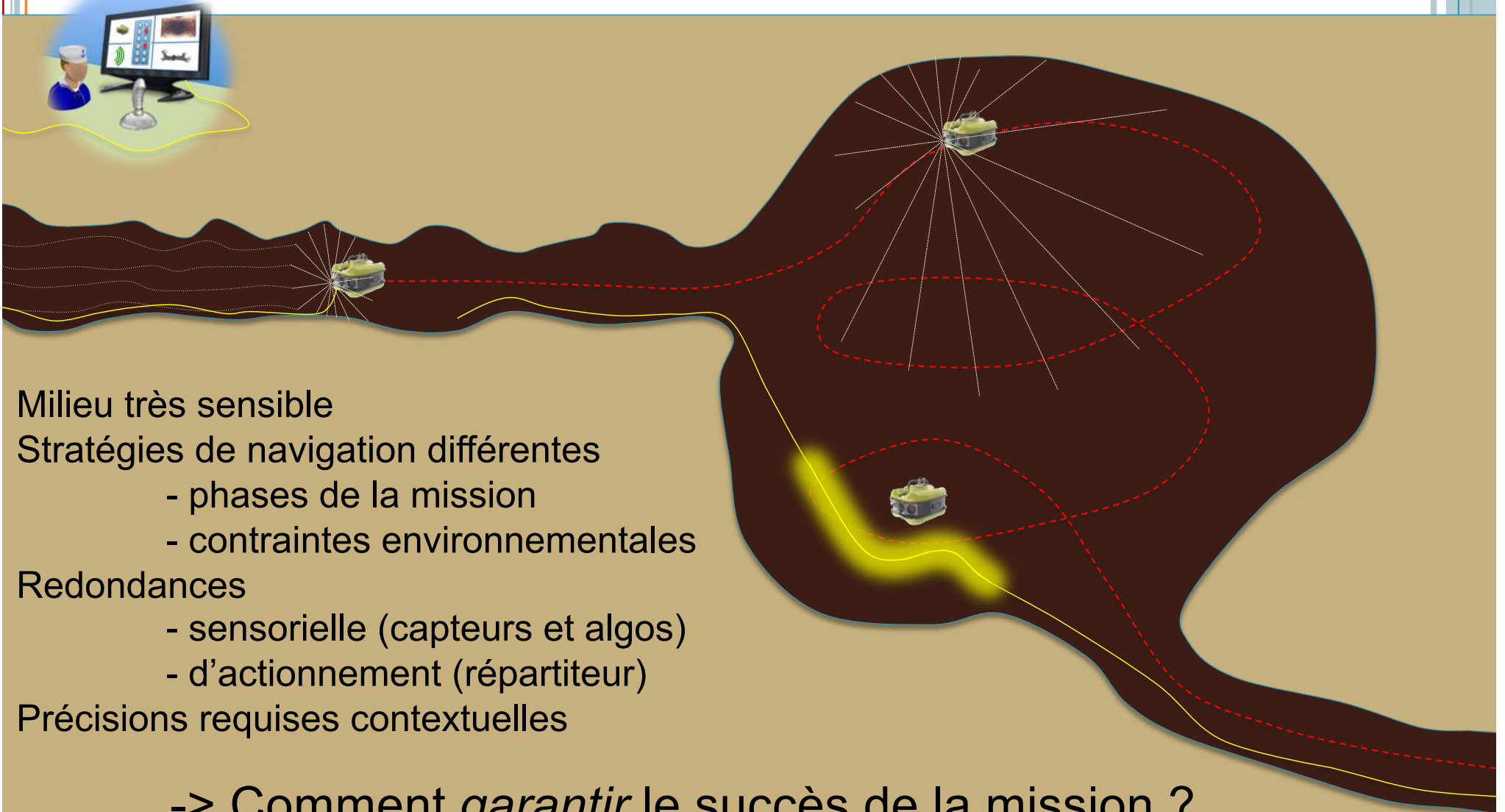
In spite of its high potential interest for applications such as deep sea exploration or mine clearance in catastrophic conditions, underwater navigation in confined unstructured environments and turbid waters where vision is useless remains a challenge in robotics. In the same conditions, subterranean navigation 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 Laumans in the 50s [1]. The African fish *Gnathostomus Pinnati* pictured in figure 1 is a typical electric fish. It polarizes its body with respect to its 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. Thus, 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]. Natural "electrobiology": this natural ability has been extensively studied by neuro-ethologists who show the electric fish can recognize objects shape, measure distances, sense 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 unidirectional character that makes it a sense naturally suited to the obstacle avoidance. Thus,

understanding and mimicking this sense with technology would offer the opportunity to enhance the navigation abilities of our current underwater robots. In this perspective, Mr. Invernizzi 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-point 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 (sensing) 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 V_i . The electric field distortions are then measured through the vector I of the currents flowing across the electrodes. We term this measurement made $V_i \cdot I$. The first letter standing for the excitation there, a vector of voltage V_i , the second, for the reception there a vector of currents I , to distinguish it from the $V - I$ mode of [13], [14]. In this article we address the problem of the underwater electro-navigation in confined environments using this sense. The proposed approach is inspired by the observation of electric fish in nature. It exploits the characteristics of the sensor body with the electric field distortions produced by the objects in its surrounding. It assumes the use of electric control loops whose parameters allow a robot to achieve reflexive behavior for underwater robot in a robust manner with respect to the sense complexity.

Fig. 1. From Van der Sluis [16] (left) The African Molepompilid fish *Gnathostomus pinnati*, shown by view of the head electric field. The article is structured as follows. First we will briefly

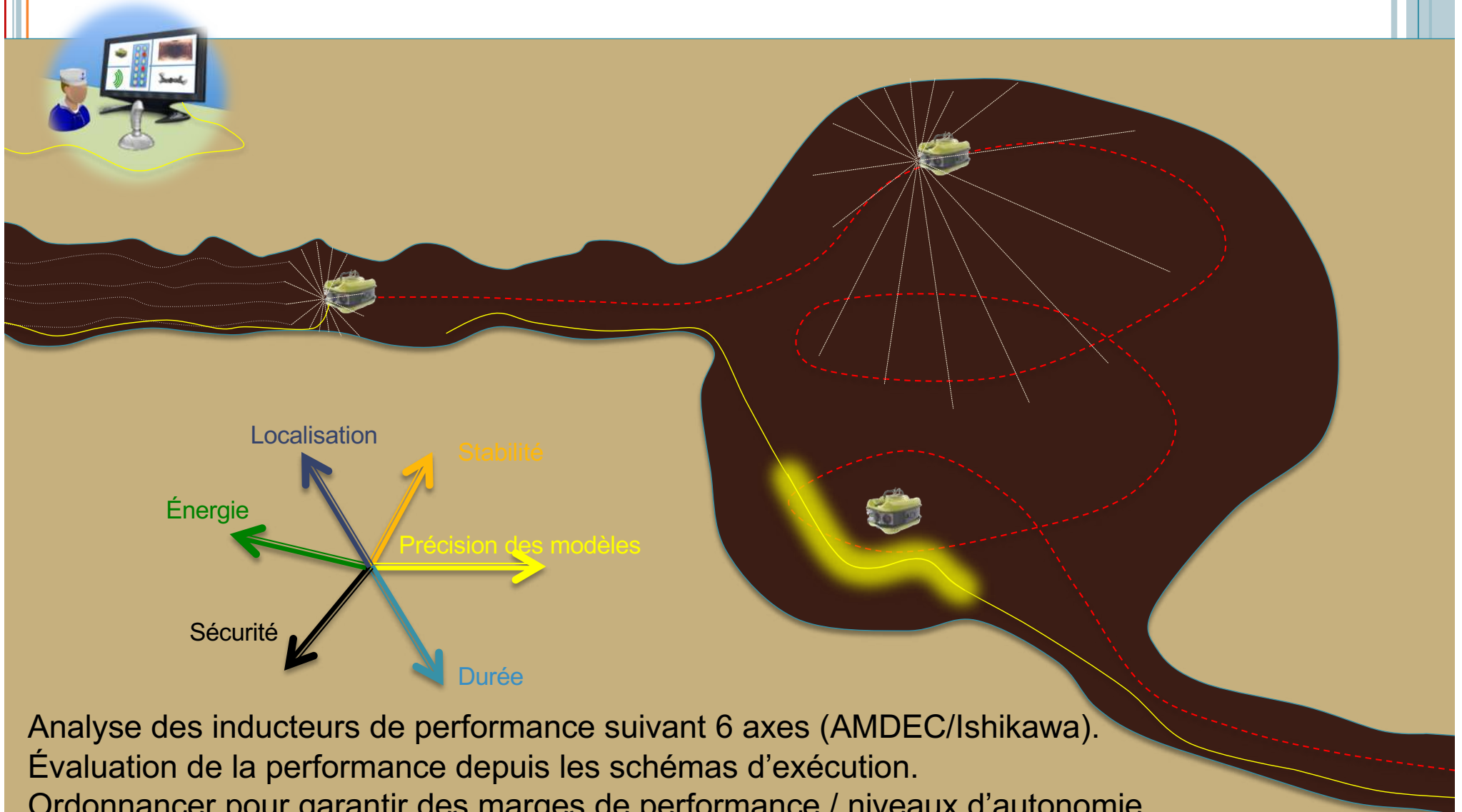
NEAR FUTURE : LIRMM, ENSTA

- Autonomie et *garanties* de performances



NEAR FUTURE : LIRMM, ENSTA

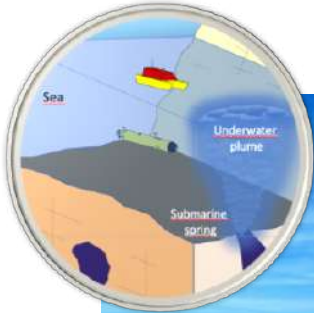
- Autonomie et *garanties* de performances



Analyse des inducteurs de performance suivant 6 axes (AMDEC/Ishikawa).
Évaluation de la performance depuis les schémas d'exécution.
Ordonnancer pour garantir des marges de performance / niveaux d'autonomie

EUROPEAN PROJECT : ANZAR

Underwater Fresh Water Spring Localisation



Reactive Control and Real-Time Motion Planning



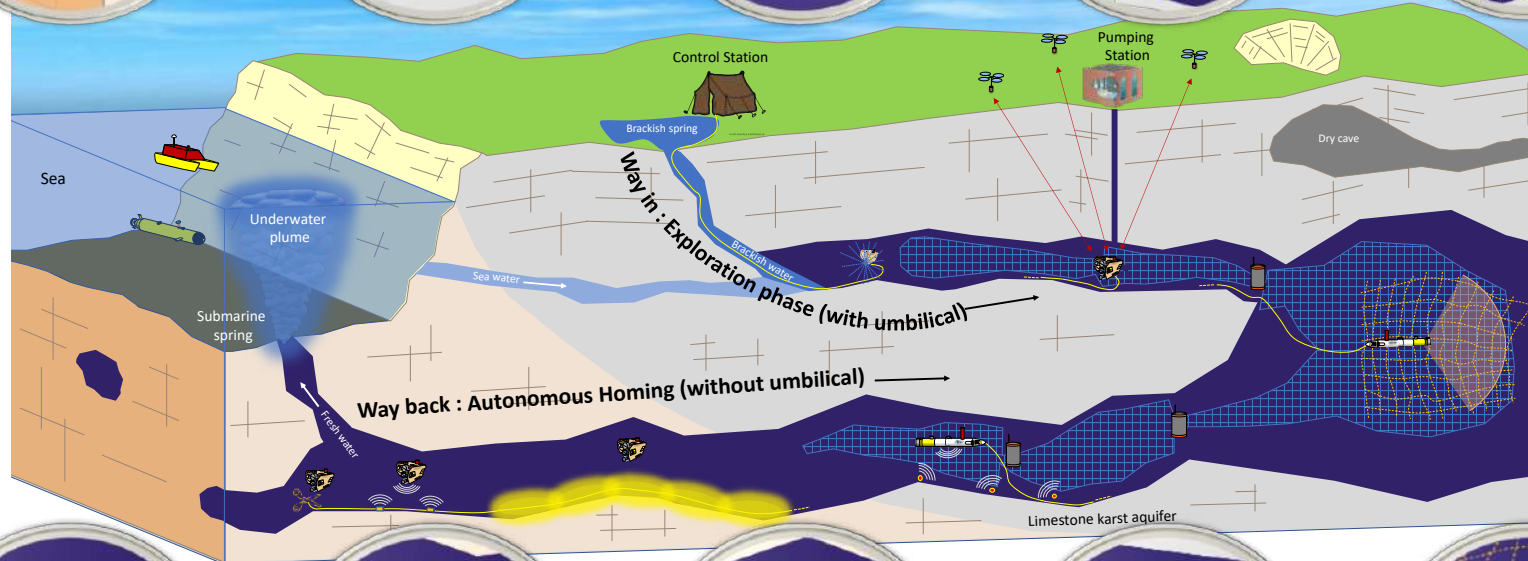
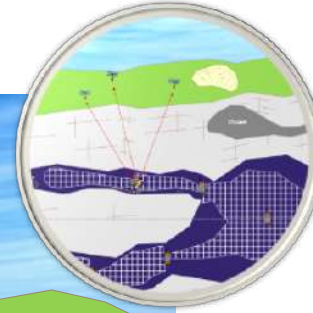
Dual Profiling Sonars Acoustic Graph-SLAM



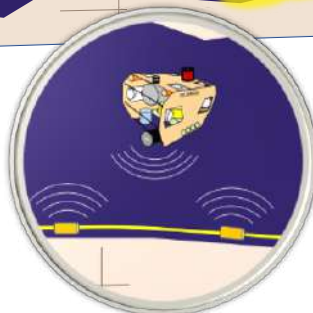
Magnetic Positioning System using Aerial Drones



Guaranteed Cartography (intervalist approach)



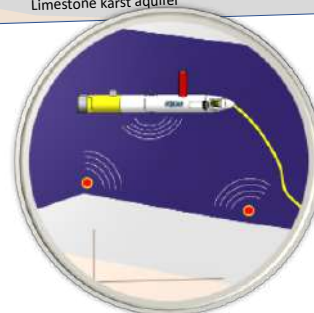
Way in : Co-controlled
Way out : Autonomous



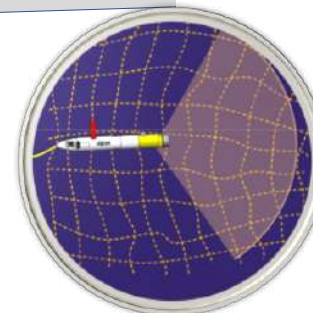
Active Cable for Communication



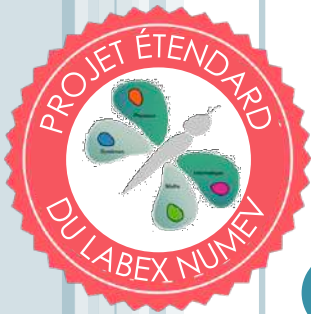
Electro-magnetic Active Cable for Localisation



Acoustic Transponder based SLAM



Rotative Multibeam sonar for mapping and Occupancy Grid



Subaquatic robotics, Robots for Karstic Exploration:

REEA
ALEYIN
LEZ 2020



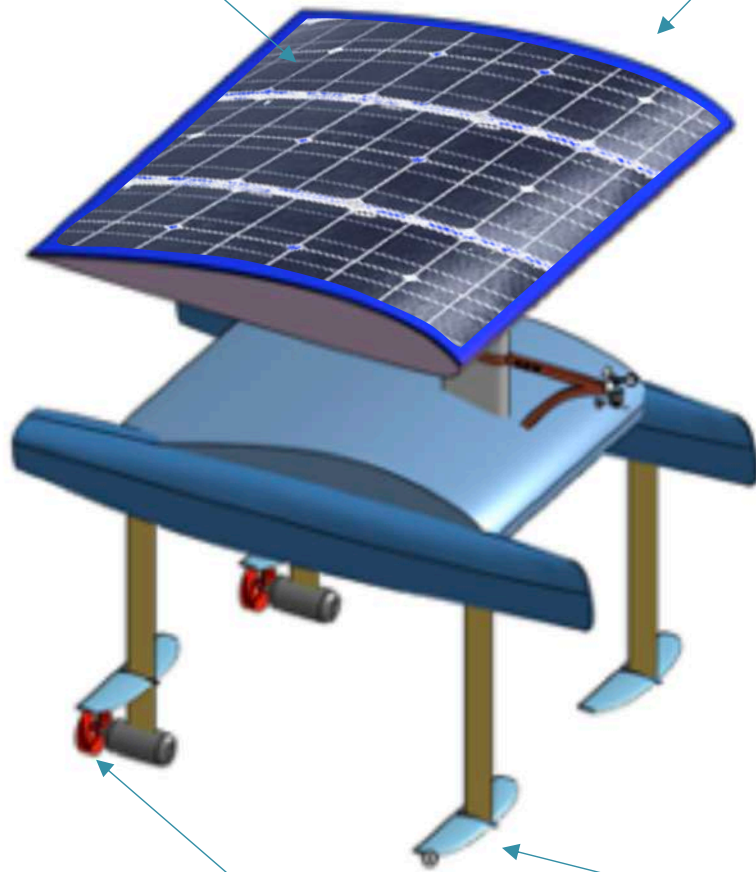
BTS meeting, 27/09/2021



AUTRES SUJETS : ASV MOBULA

Panneau solaire

voile rigide



Moteurs électriques
(propulseur/hydrogénérateur)

Foils



AUTRES SUJETS : ASV MOBULA

