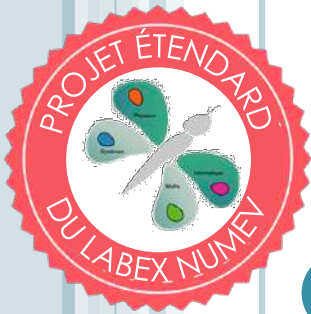




Aleyin, A journey to the underside

Robotique d'Exploration Karstique: bilan et perspectives



Journées scientifiques de Numev, 4/10/2019

PEOPLE INVOLVED

○ LIRMM

- Lionel Lapierre
- Didier Crestani
- René Zapata
- Jean Triboulet
- Sébastien Druon
- Karen Godary-D
- Dang Huu Tho
- Quentin Massone
- Rodolfo Villalobos

○ HSM

- Hervé Jourde

○ BRGM

- J.C. Maréchal

○ IES

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

○ IMAG

- Bijan Mohammadi
- André Mas
- Yohan Breux

○ LEM/MRM

- Saïd Yami
- Gérald Naro

○ 3M

- Arnaud Vestier
- Adélaïde Kasolter

○ PlongéeSout

- Frank Vasseur
- Rémi Bouchard
- Mehdi Dighouth

○ Companies

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

○ Interns

- Polytech (12)
- Epita (2)

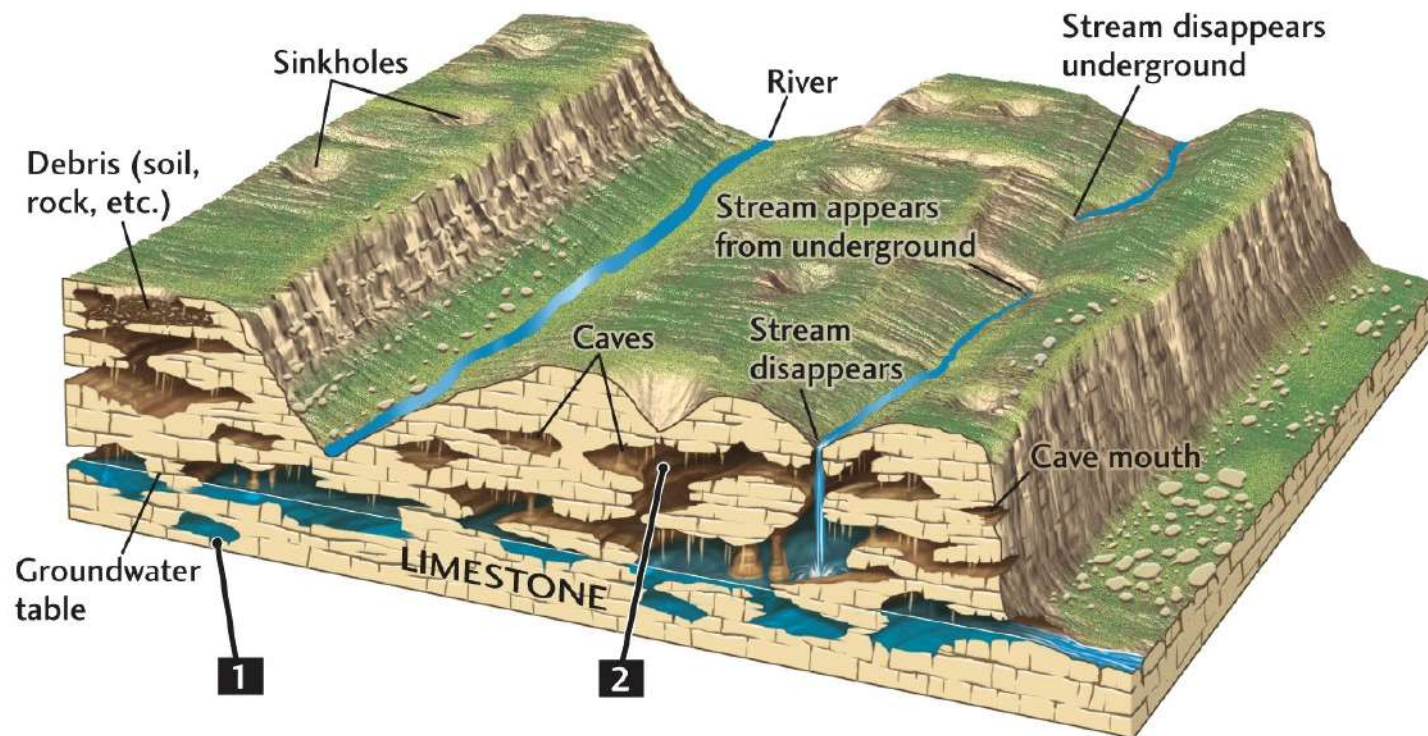


ROBOTIQUE D'EXPLORATION KARSTIQUE : OBJECTIFS



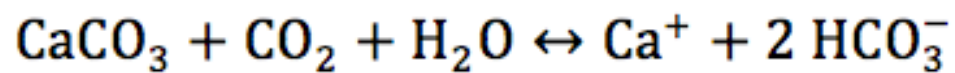
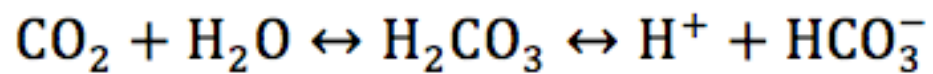
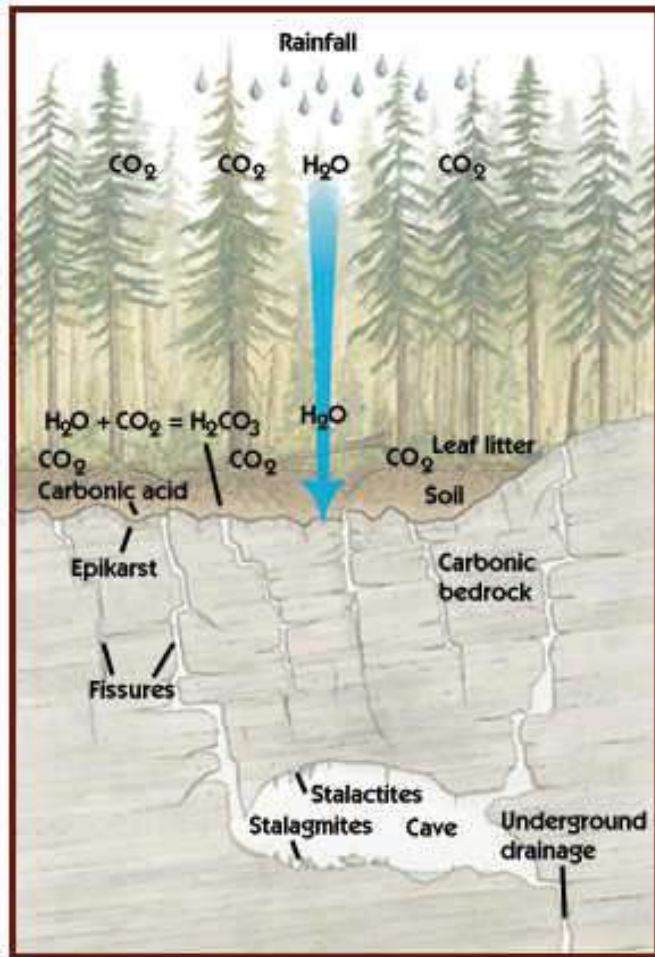
KARST : DEFINITION

- 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 : UNDERGROUND CONTINUATION



Ruby Falls ,Chattanooga, Tennessee, USA



Cueva de los Cristales, Naica,, Mexico



Furong Cave, Wulong District, Chongqing, China

KARST : GROUNDWATER RESERVOIR



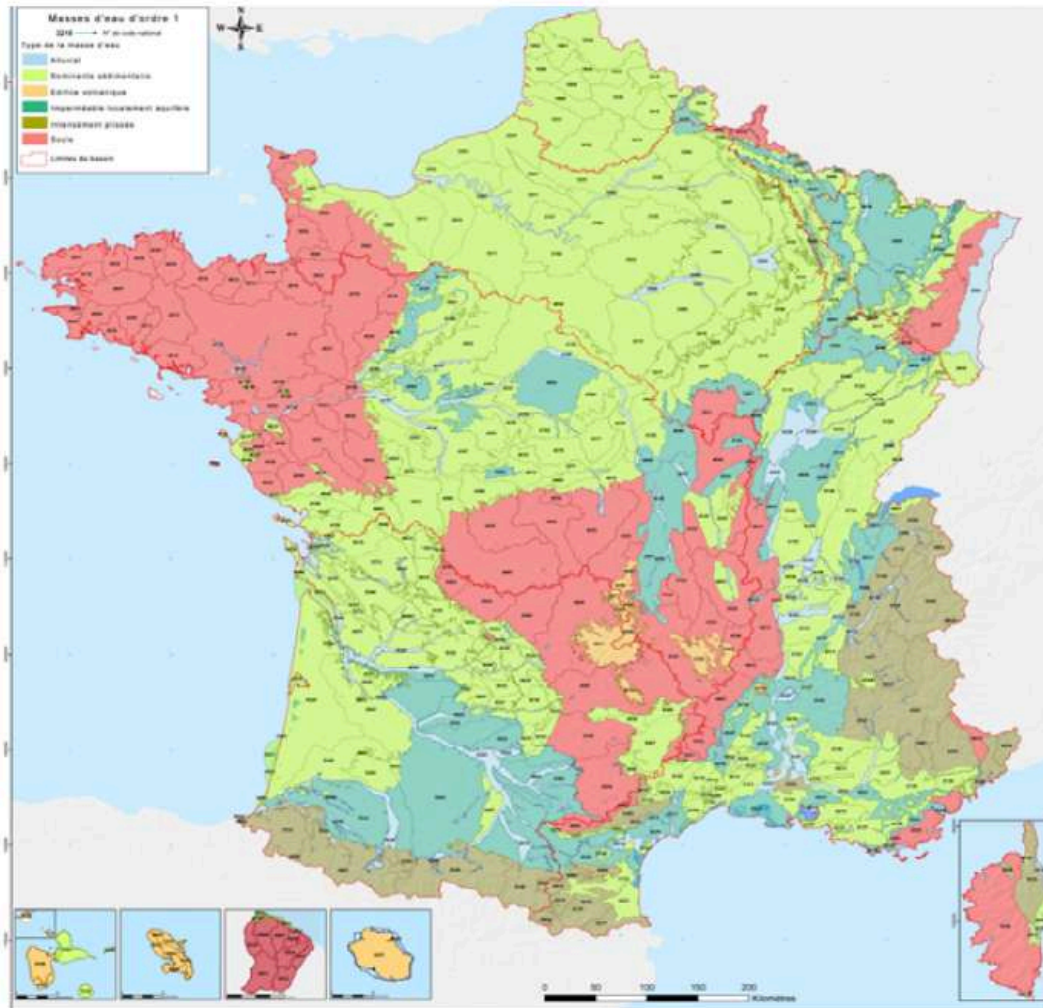
*Eclairage : Cédrik Bancarel
Dominique François
Photo.: Frank Vasseur*

KARST : GROUNDWATER RESERVOIR



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

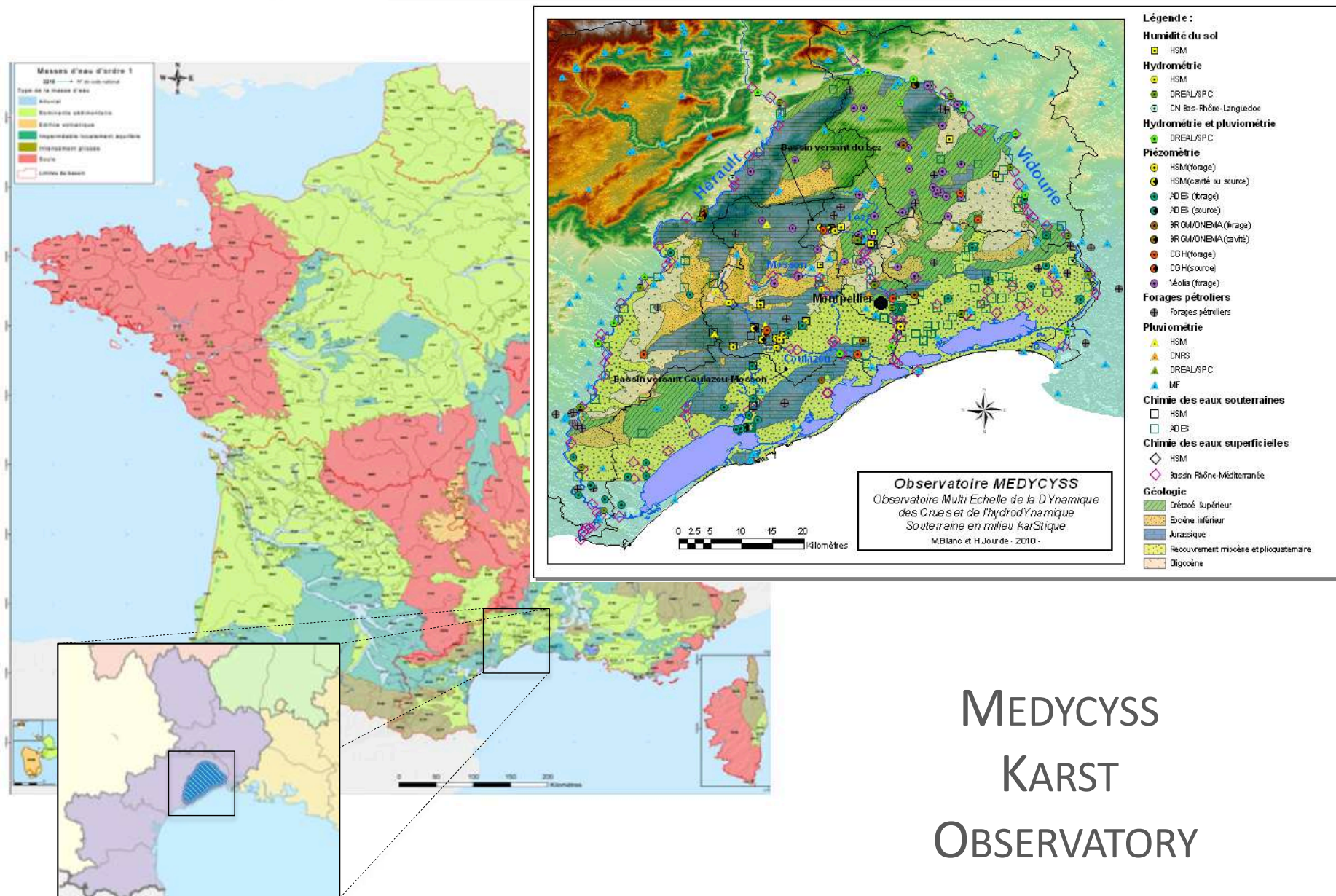
KARST : GROUNDWATER MANAGEMENT, A NATIONAL ISSUE



+ 50% of Drinking Water Supply

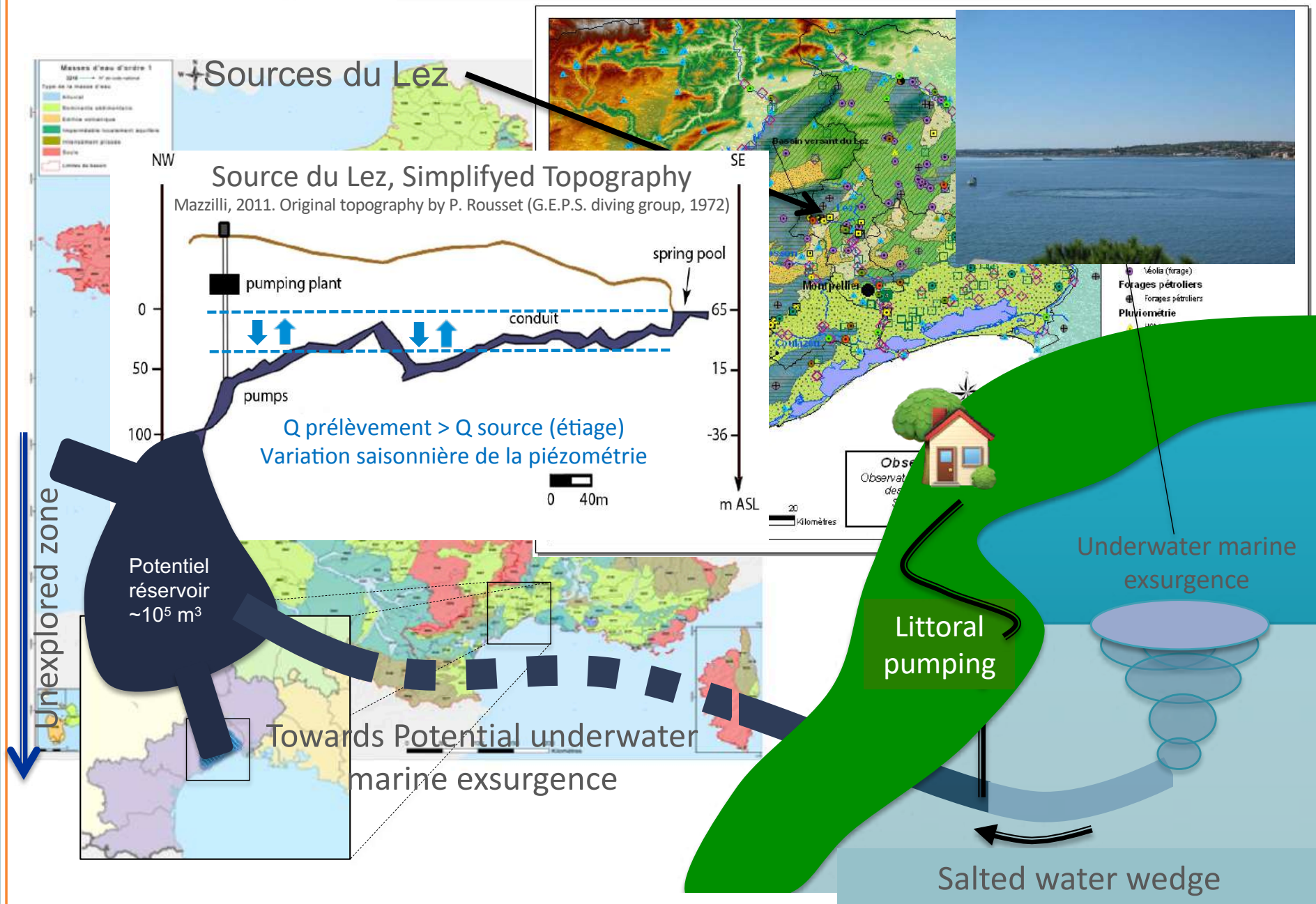
Service National d'Observation
du KARST,
SNO INSU/CNRS
OSU OREME (UM)
Coordinator H. Jourde

MONTPELLIER'S CATCHMENT BASIN : A SEMINAL CASE STUDY

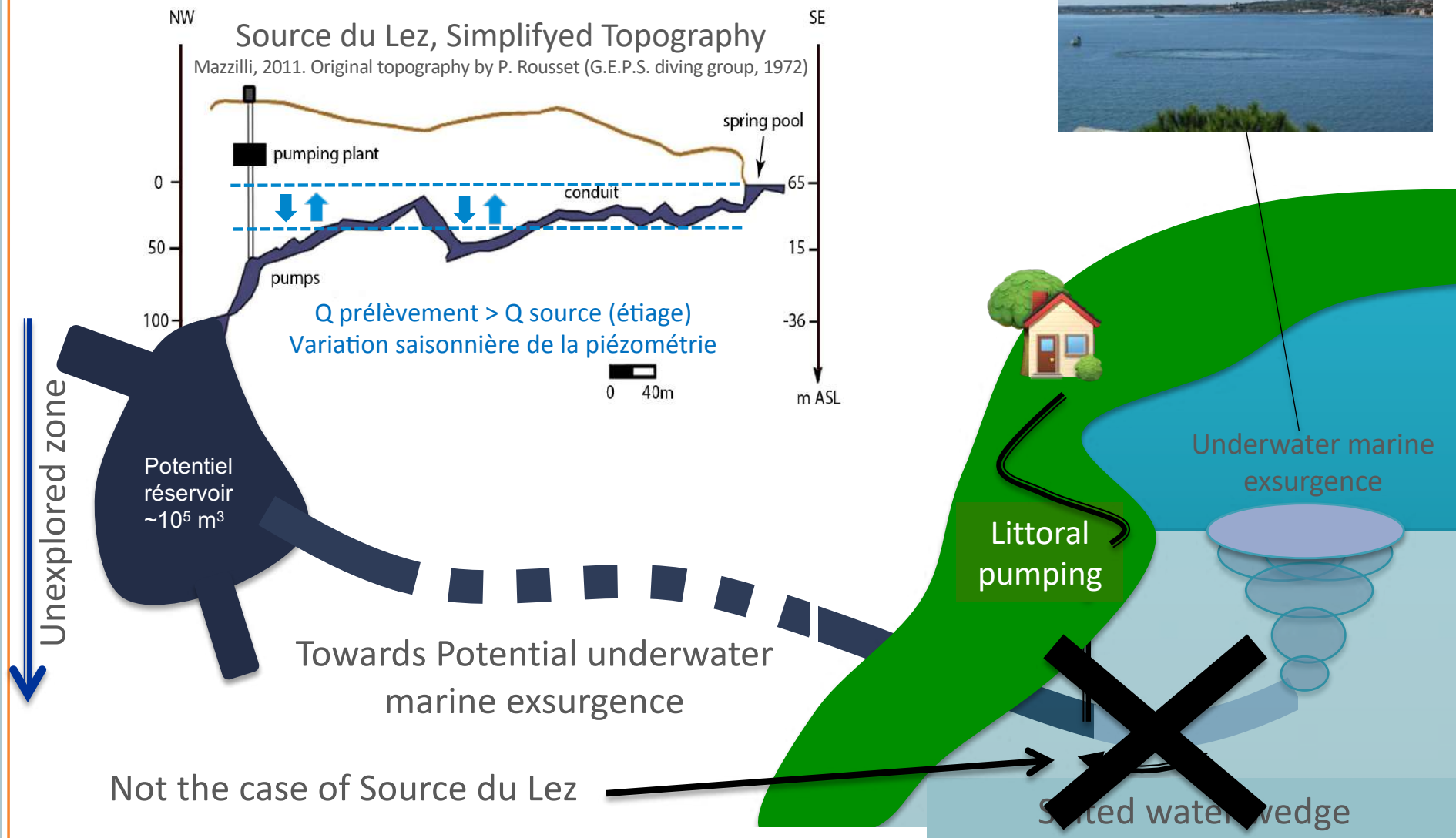


MEDCYSS
KARST
OBSERVATORY

SOURCES DU LEZ : A SEMINAL CASE STUDY

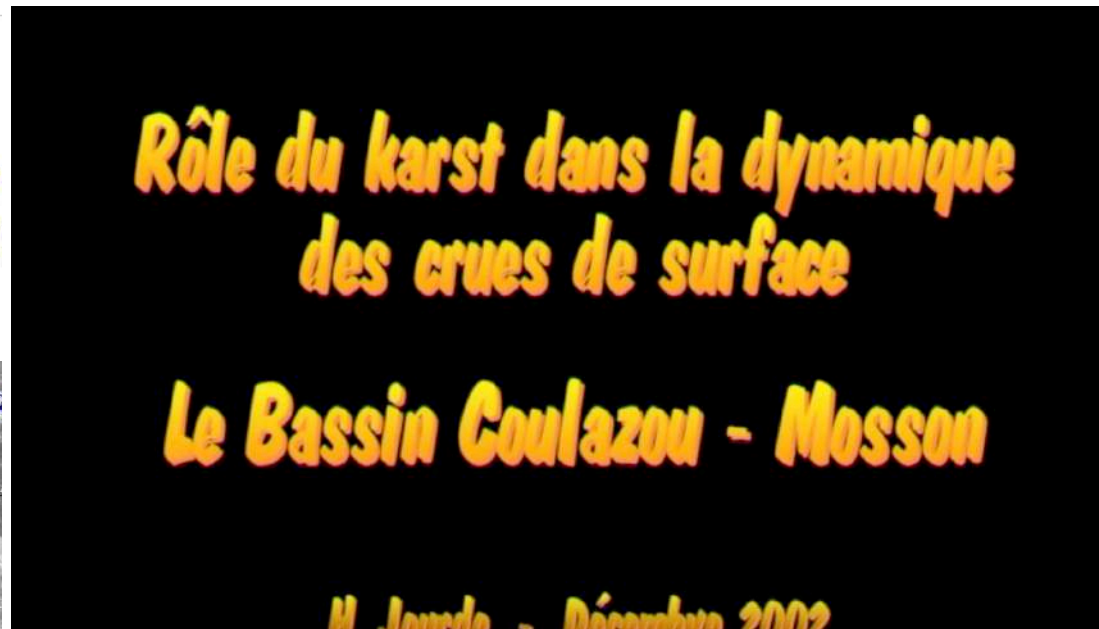
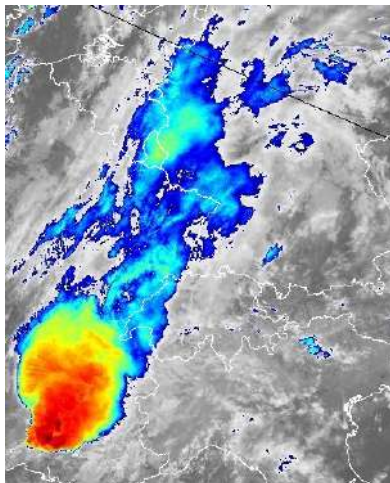
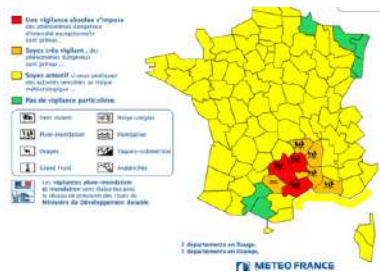


SOURCES DU LEZ : ACTIVE MANAGEMENT OF GW RESOURCE



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 : SKINHOLES



Harbin, Heilongjiang province, China.



Guatemala City, Guatemala



Orlando, Florida, USA



Dead-Sea shore, Israel

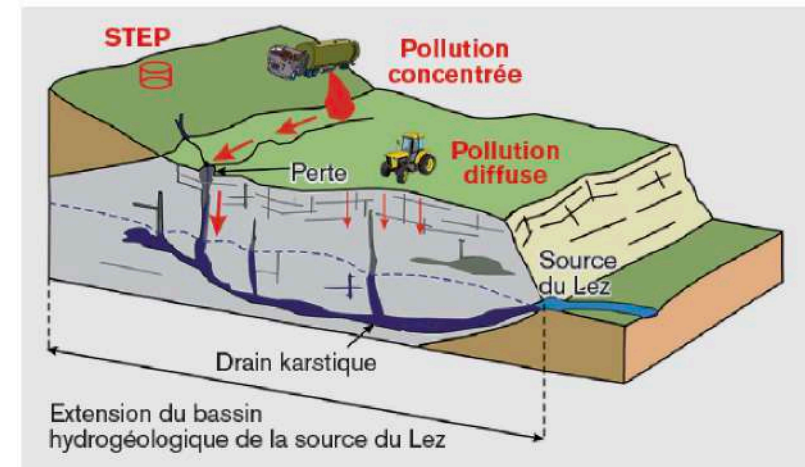
THE STAKES

○ Prospection / Preservation/ Management of Water Resource

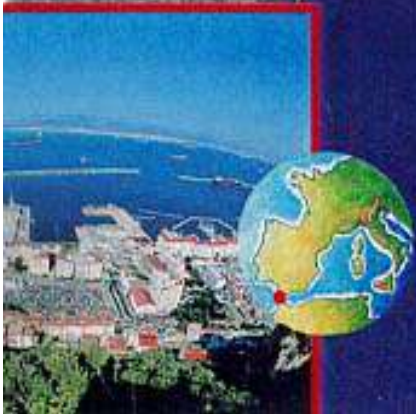
- Pumping and drilling regulation and guidance
- Management of supply redundancy in case of massive contamination

○ 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

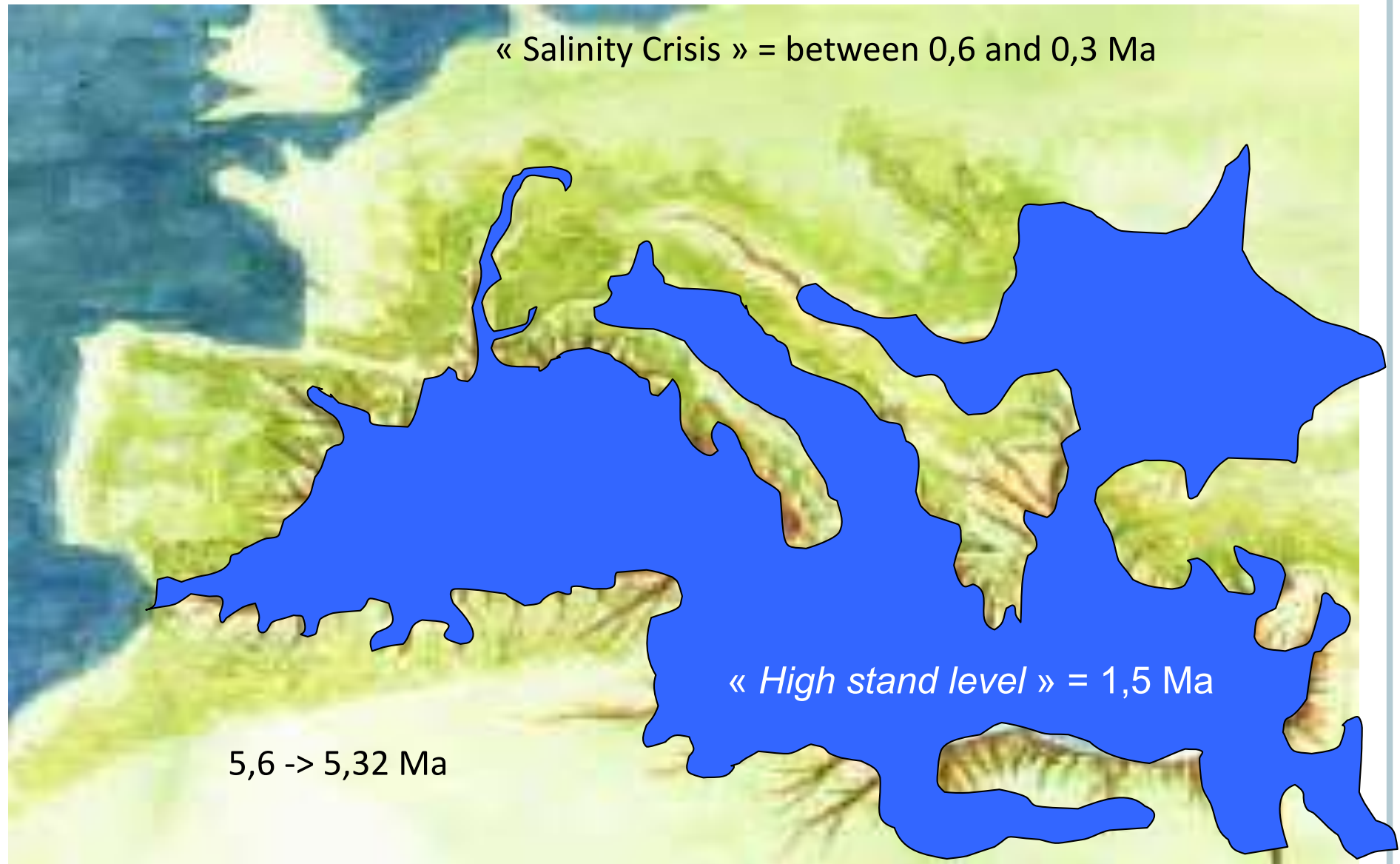


Messinian events : 2 salinity crisis

1/ 5.95 - 5.6 Ma 100 m

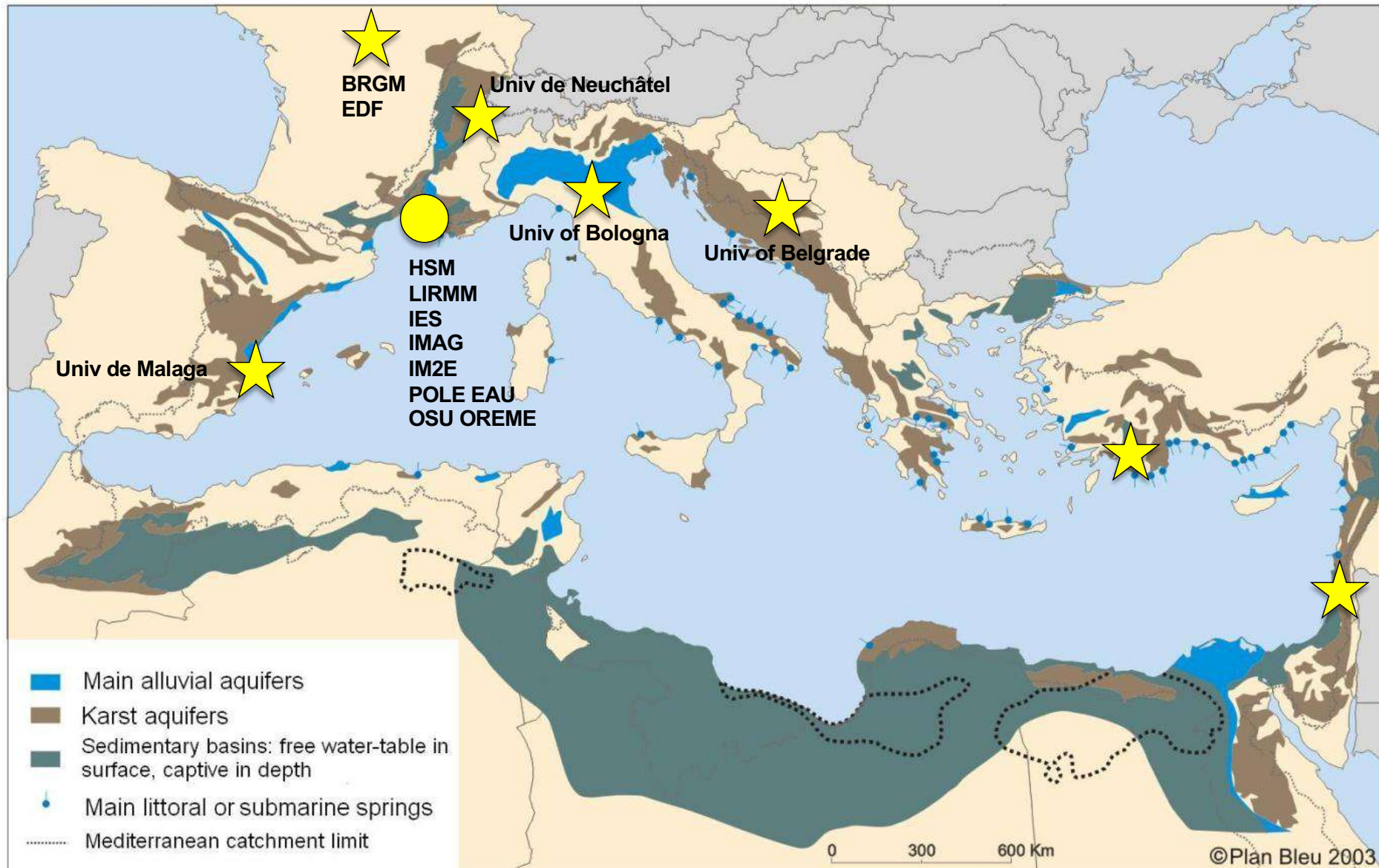
2/ 5.6 - 5.32 Ma 1500 m

MEDITERRANEAN KARSTS DURING MESSINIAN SALINITY CRISIS

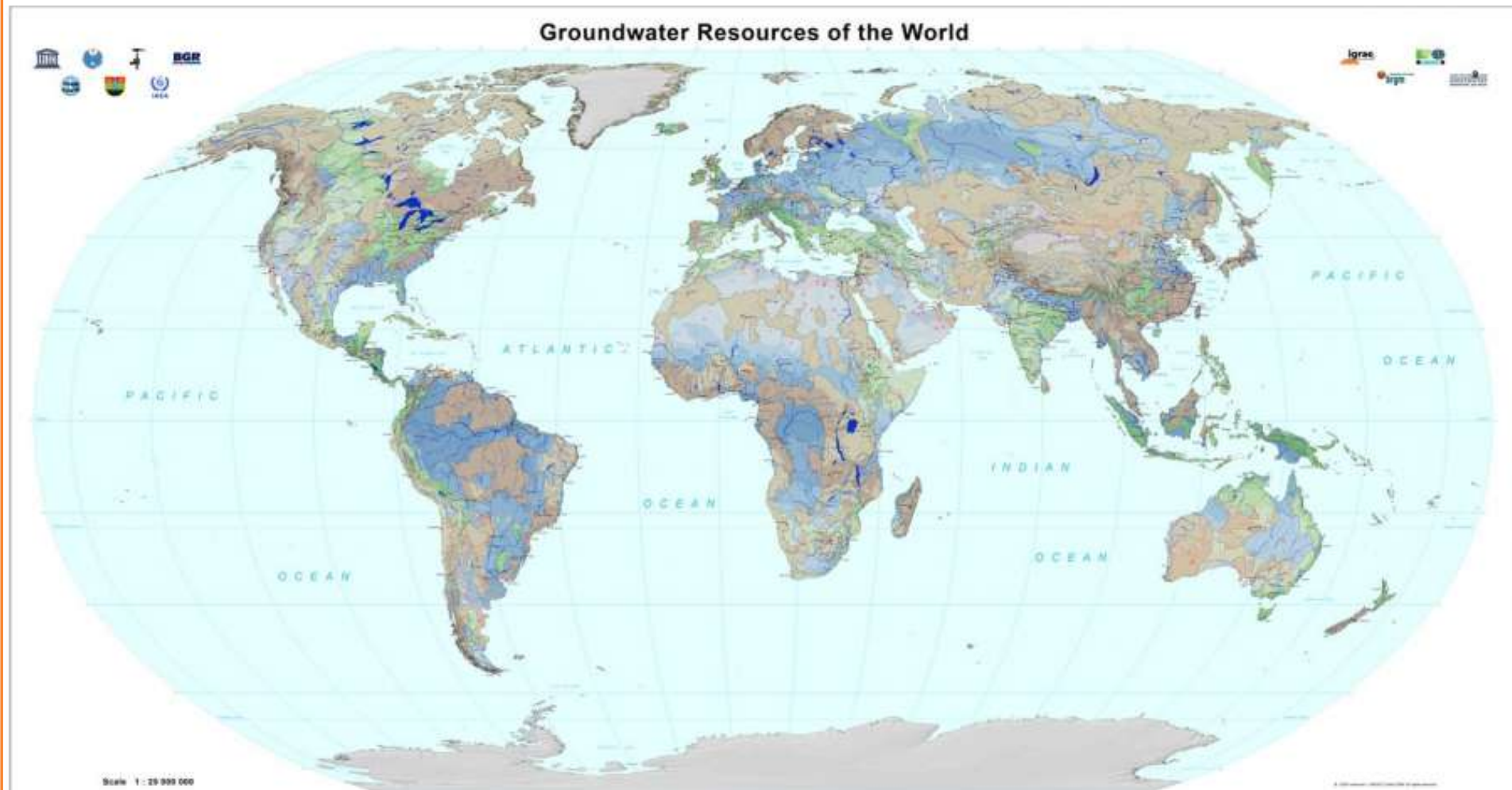


Deep Karstification

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.

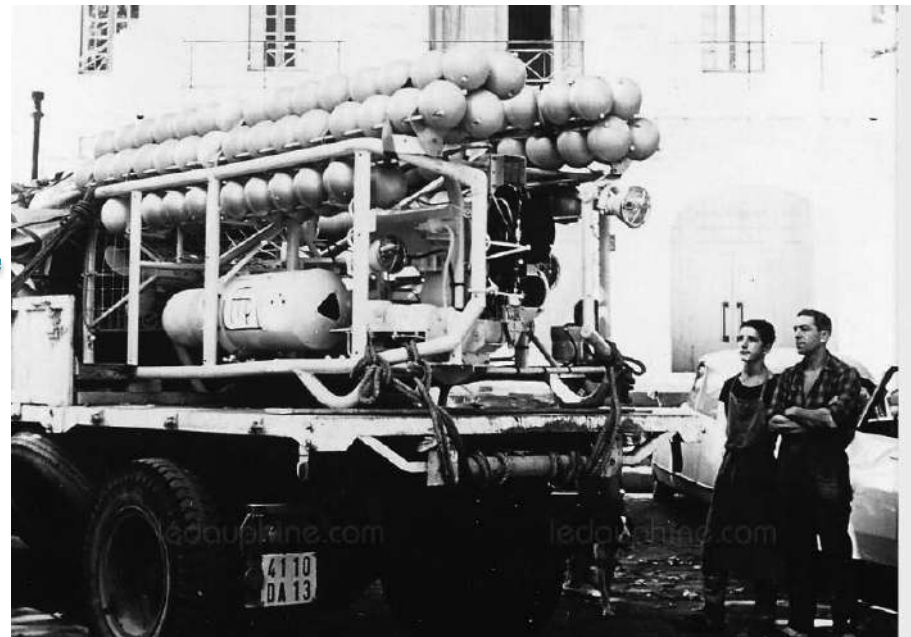
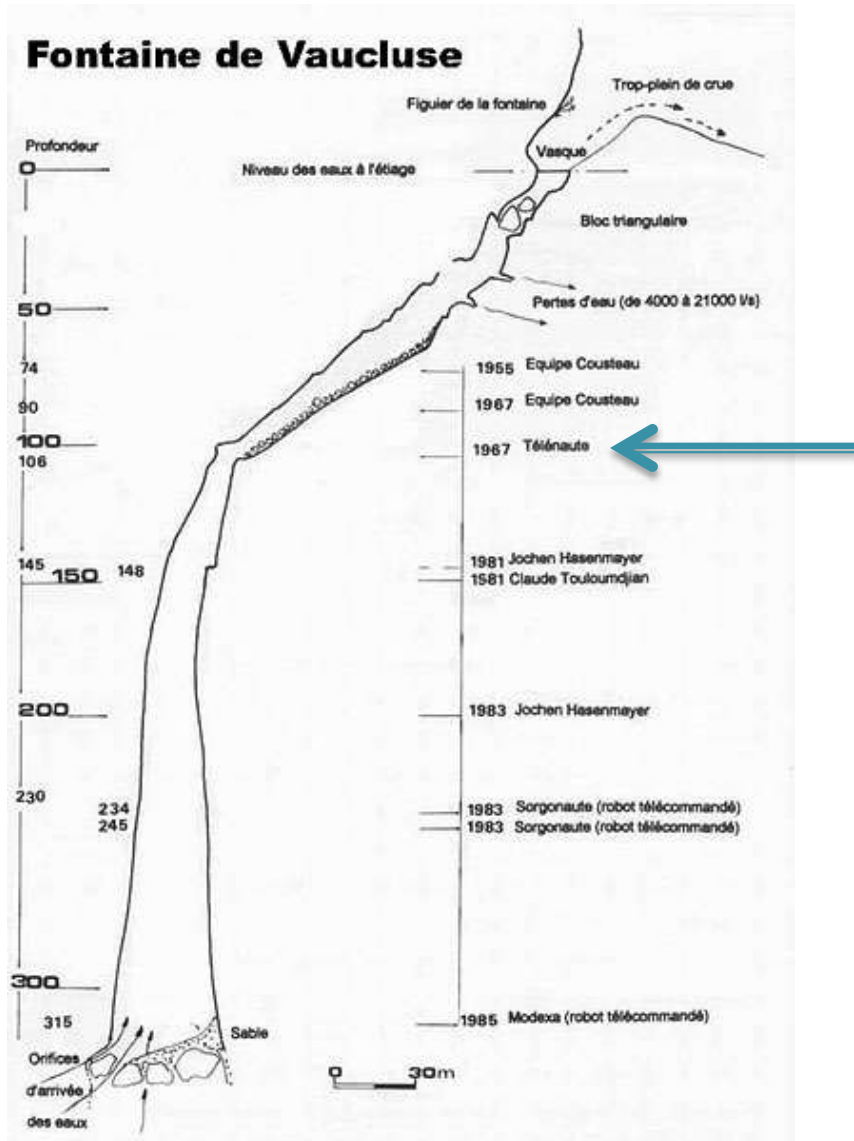
N-D geomorphological models

Karst Dynamics



A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

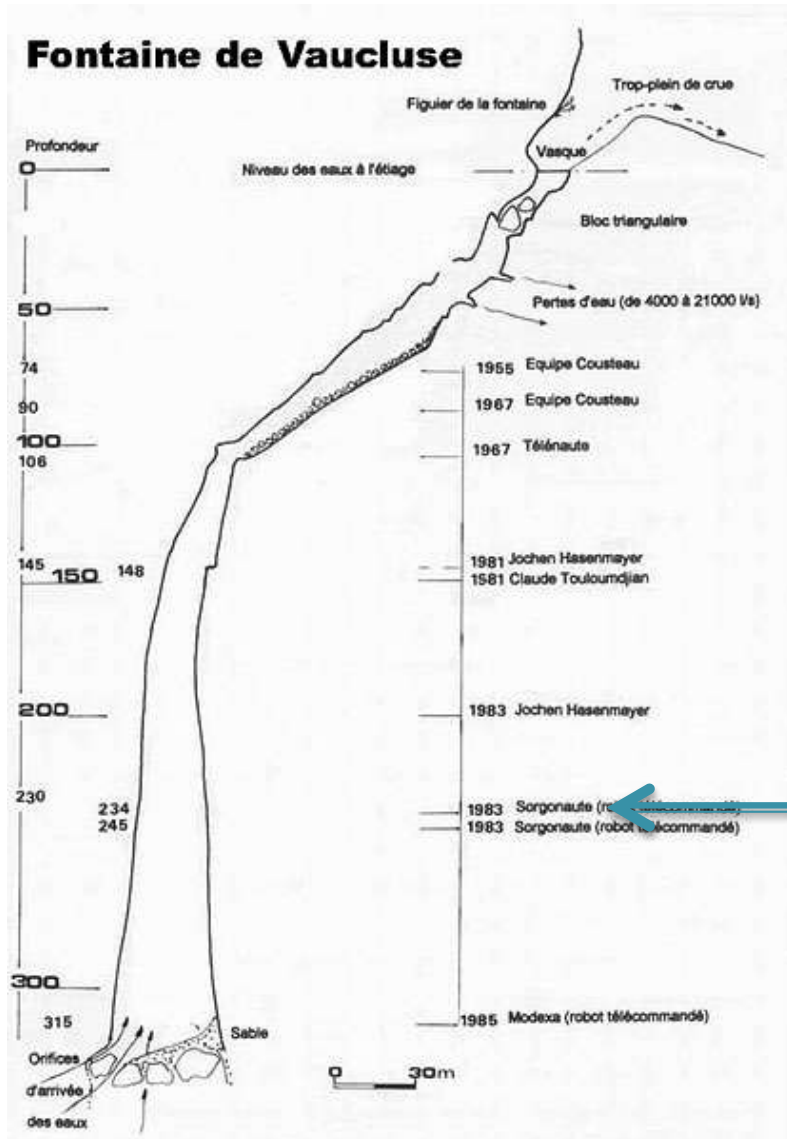
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1967, Télénaut (Cdt Cousteau)
106m

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

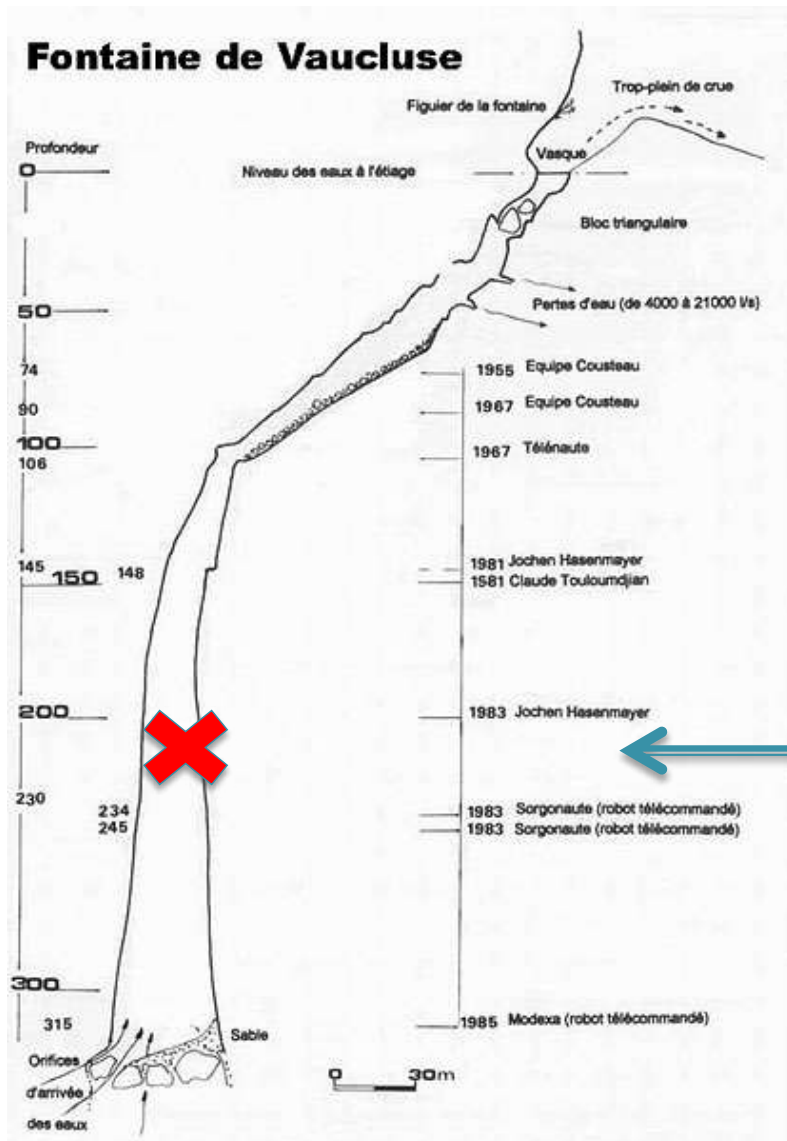
○ Fontaine de Vaucluse : A magnificent Robotic Failure



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

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

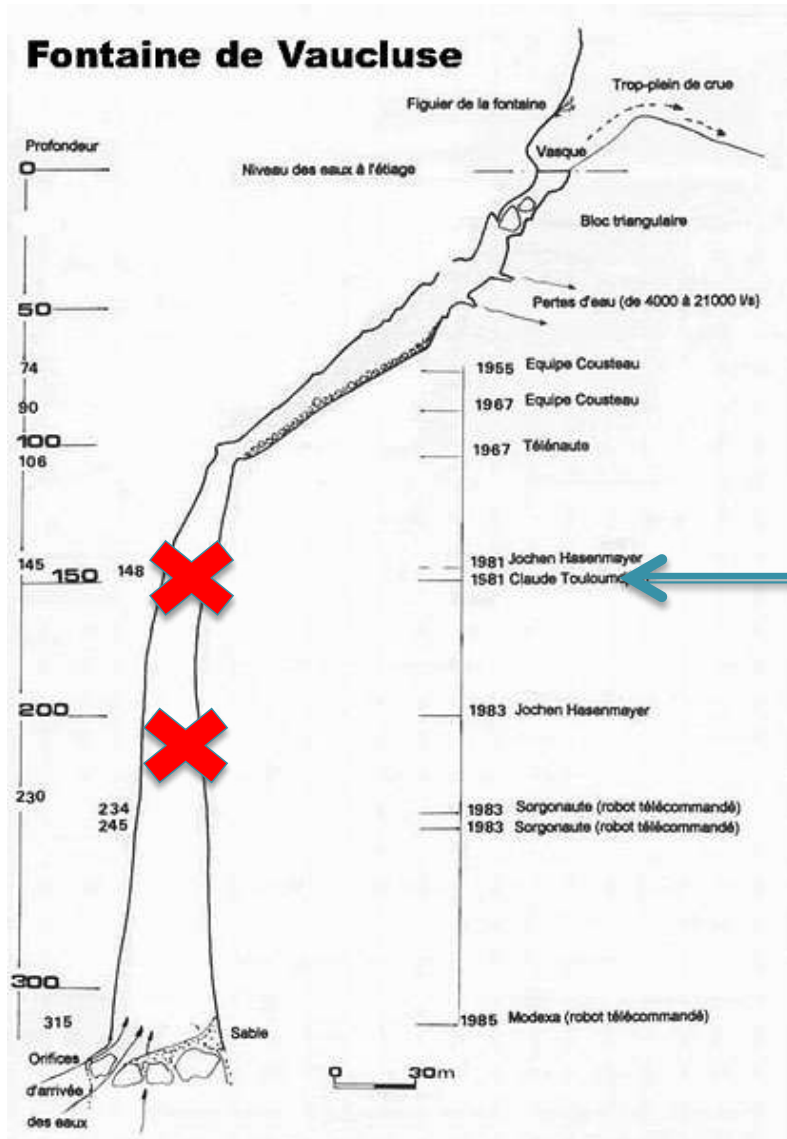
○ Fontaine de Vaucluse : A magnificent Robotic Failure



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

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

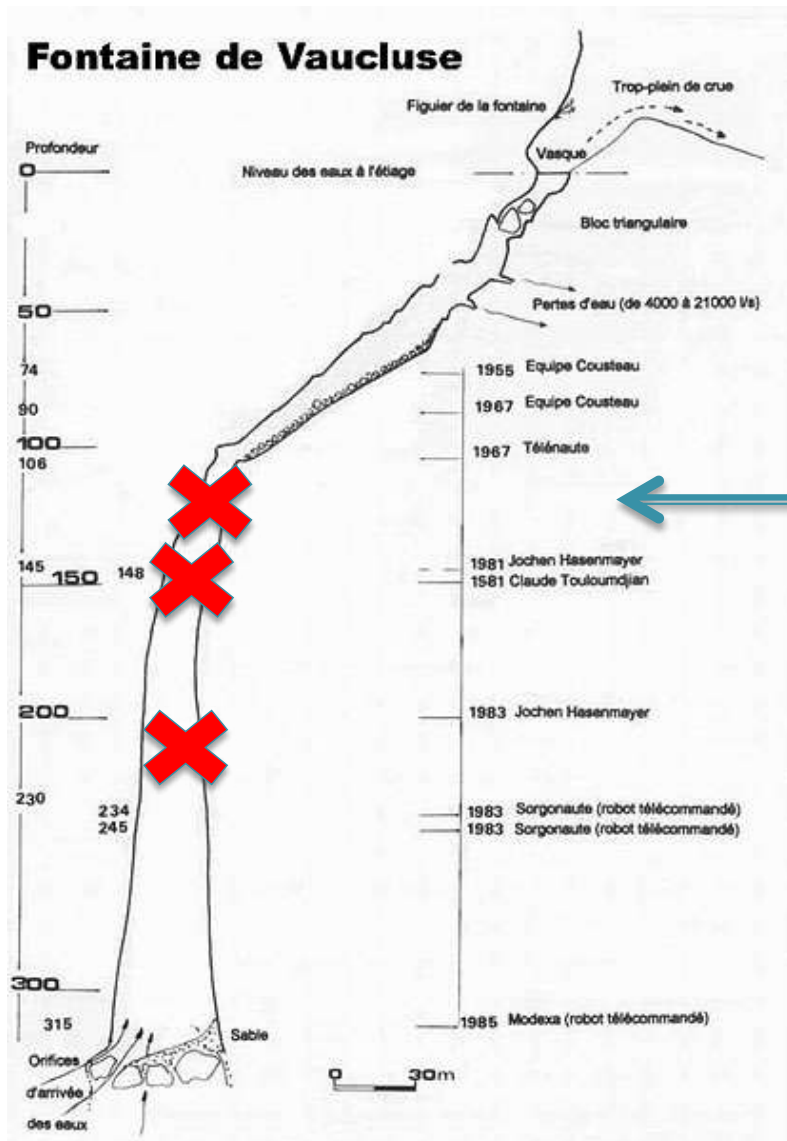
Fontaine de Vaucluse : A magnificent Robotic Failure



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

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

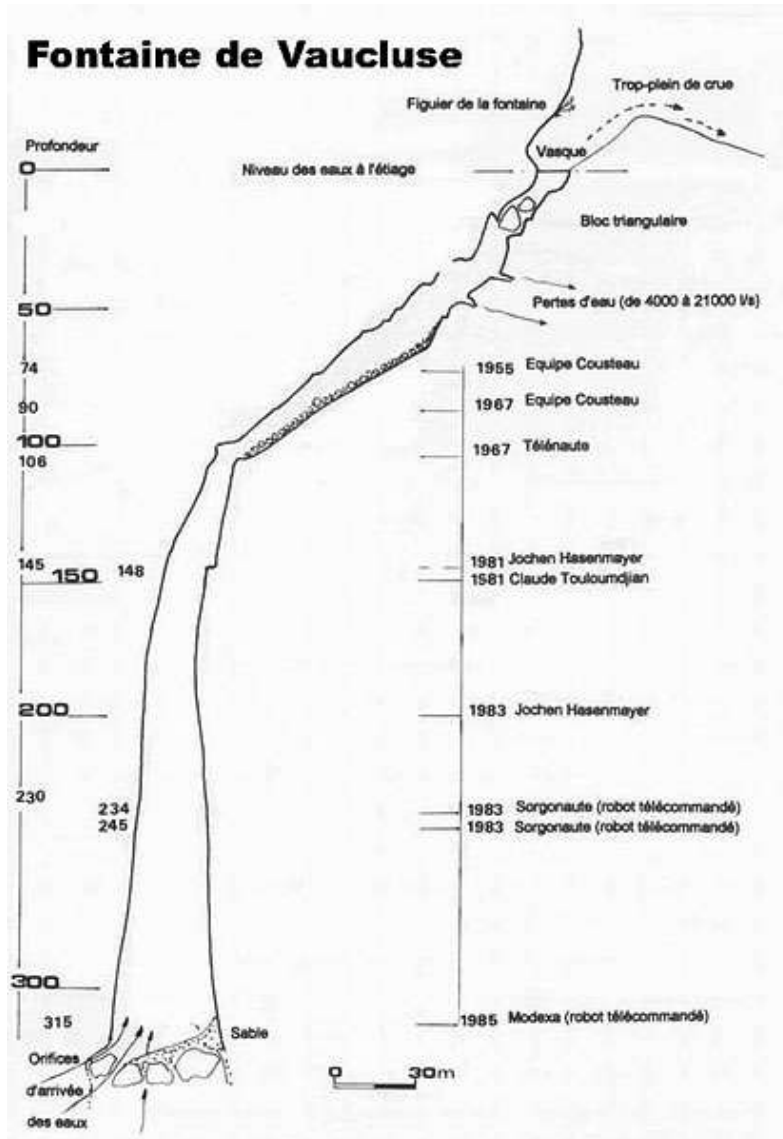
○ Fontaine de Vaucluse : A magnificent Robotic Failure



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

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

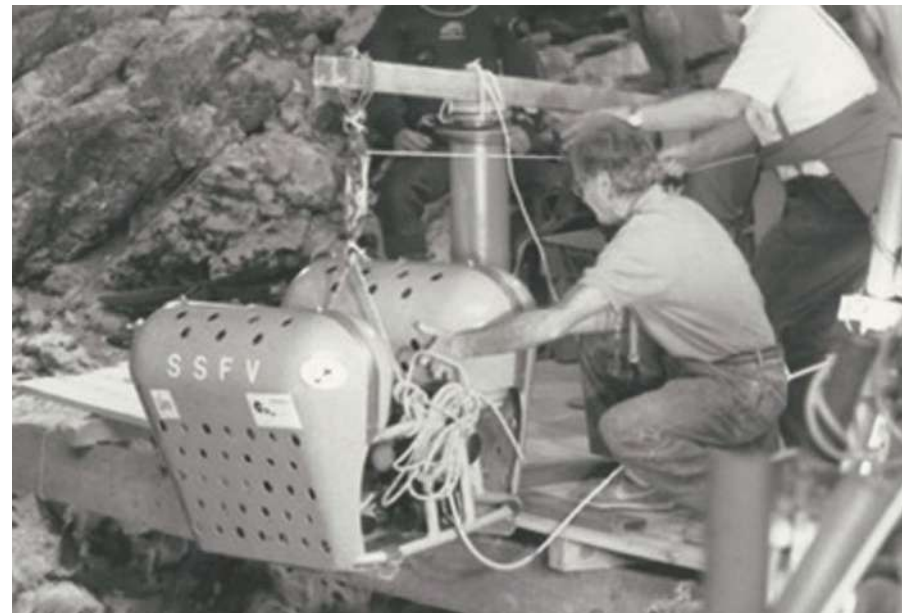
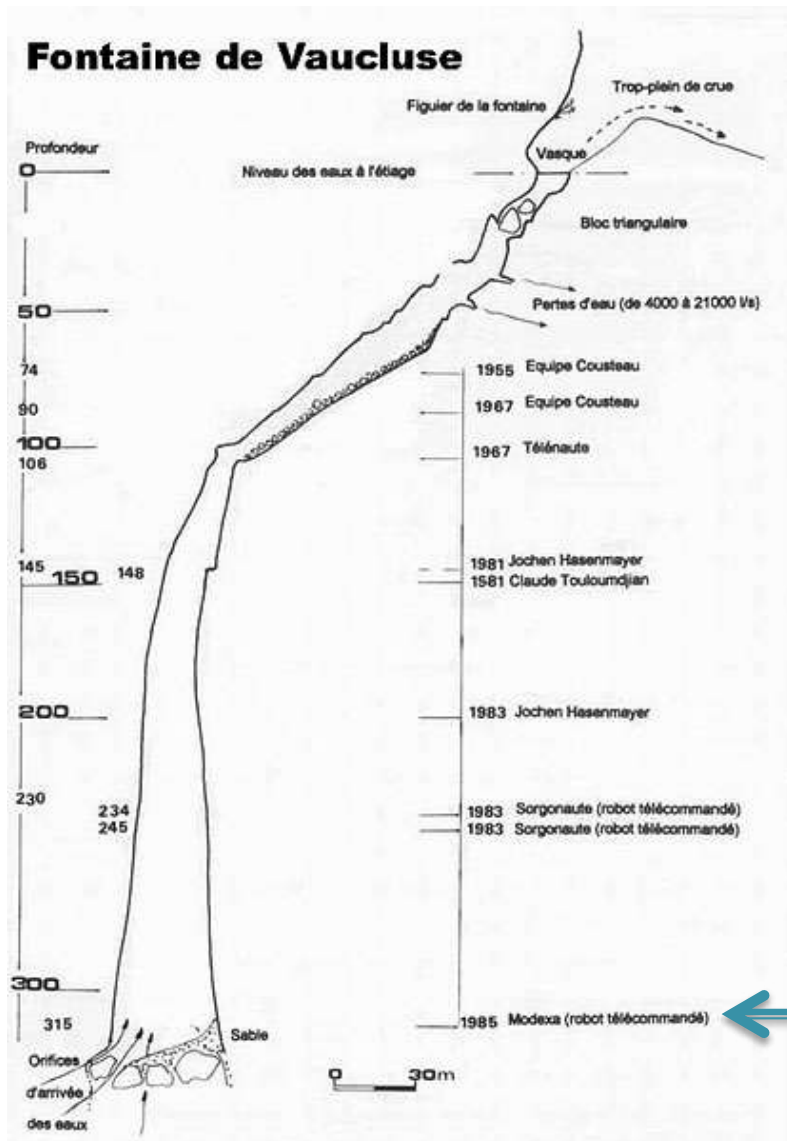
○ Fontaine de Vaucluse : A magnificent Robotic Failure



1984, The chasm was cleared by divers

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

○ Fontaine de Vaucluse : A magnificent Robotic Failure

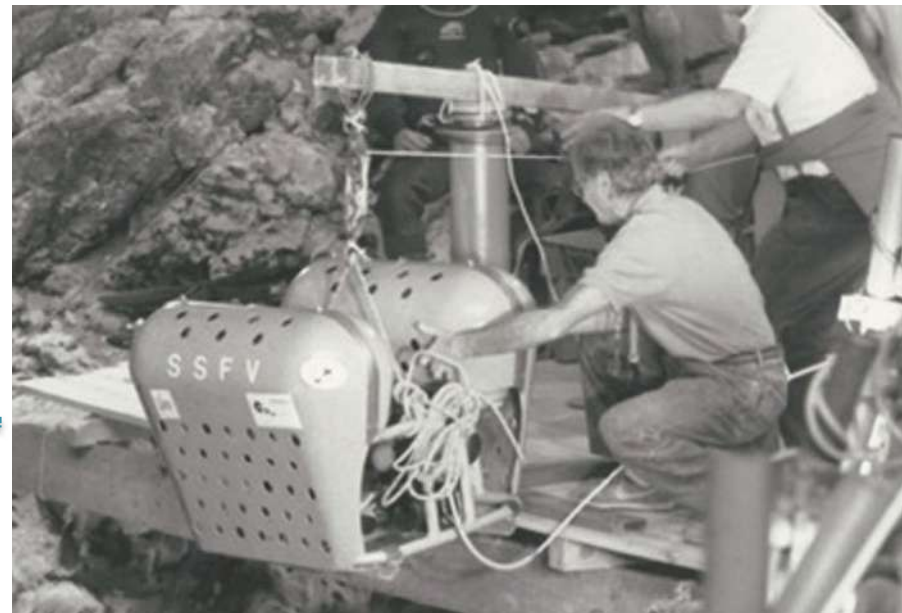
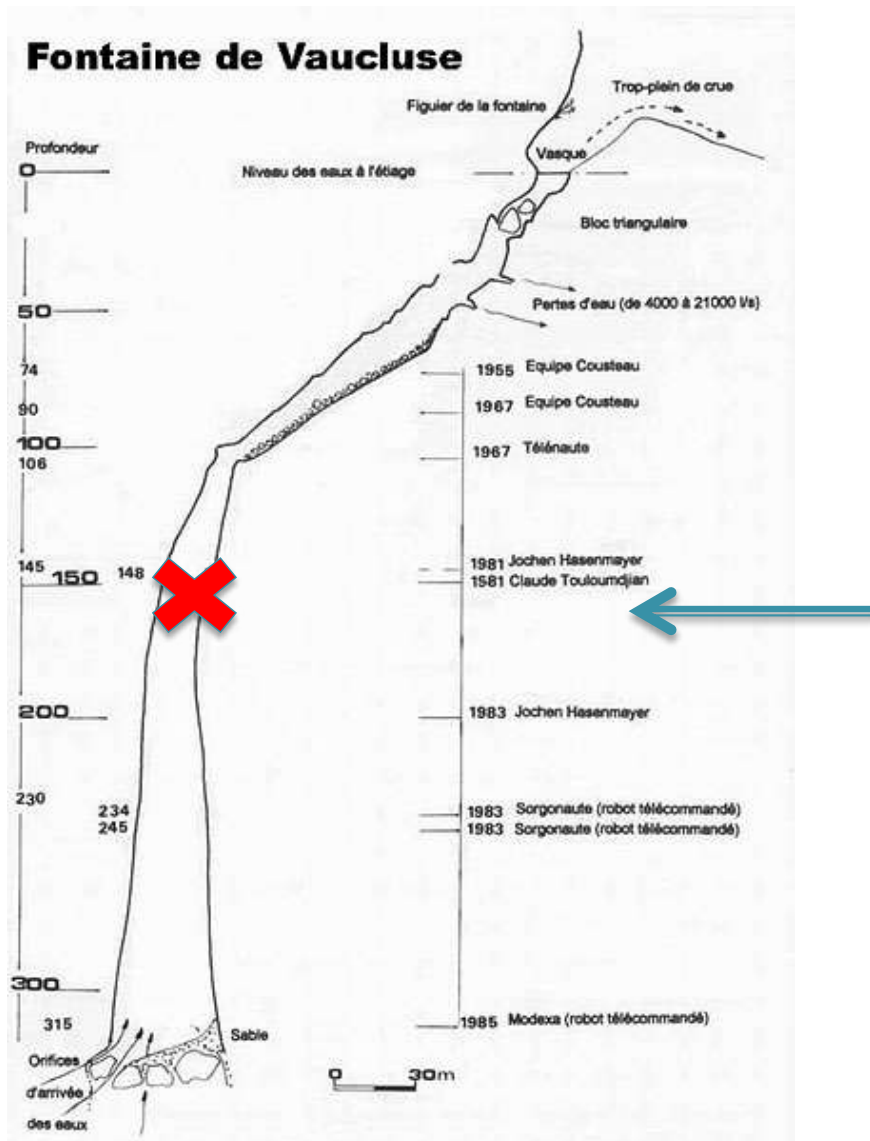


1989, Spélénaute (S.S.F.V.)
Touch-down : 315m

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

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

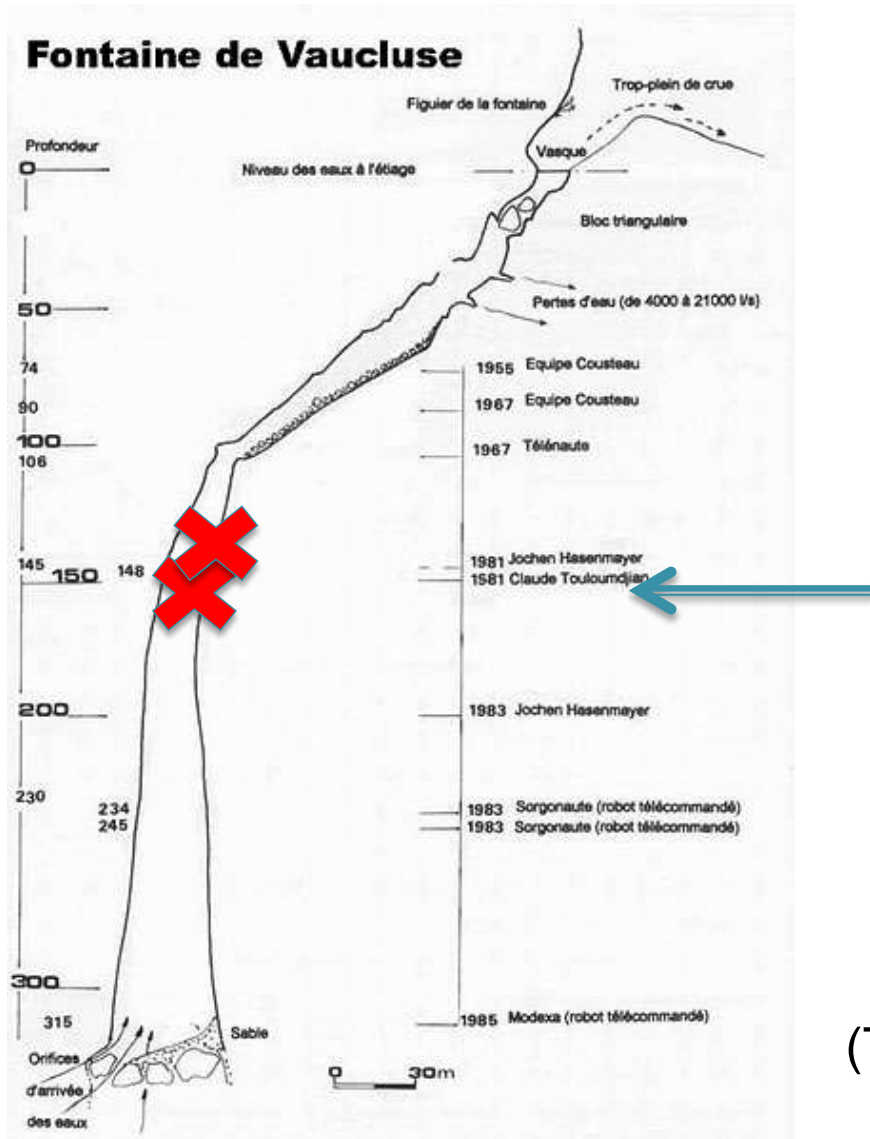
○ Fontaine de Vaucluse : A magnificent Robotic Failure



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

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

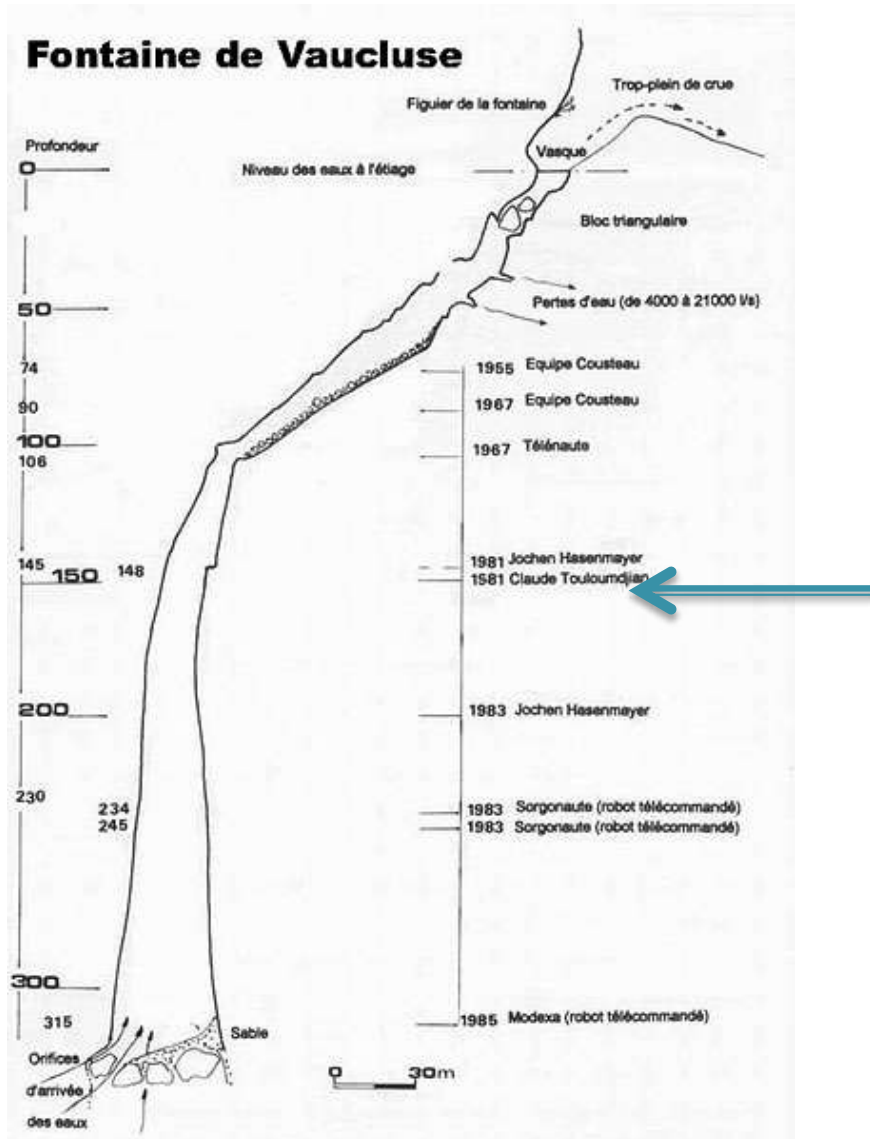
○ Fontaine de Vaucluse : A magnificent Robotic Failure



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

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

○ Fontaine de Vaucluse : A magnificent Robotic Failure



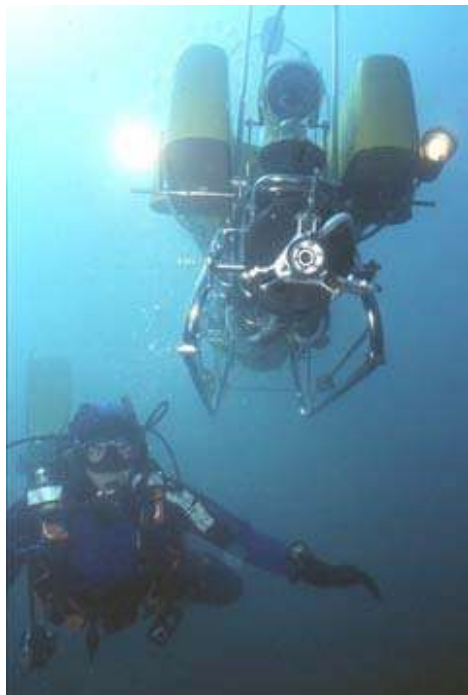
1996, Chasm cleared by divers

A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

○ Exploration of the Pozzo Del Merro (Italy)



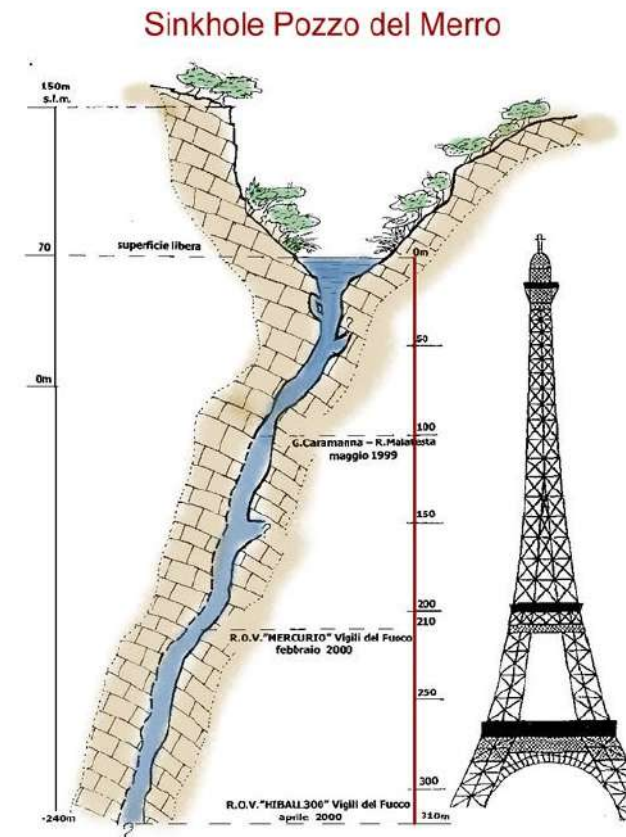
2001, Hyball, 310m



2000, Mercury, 210m

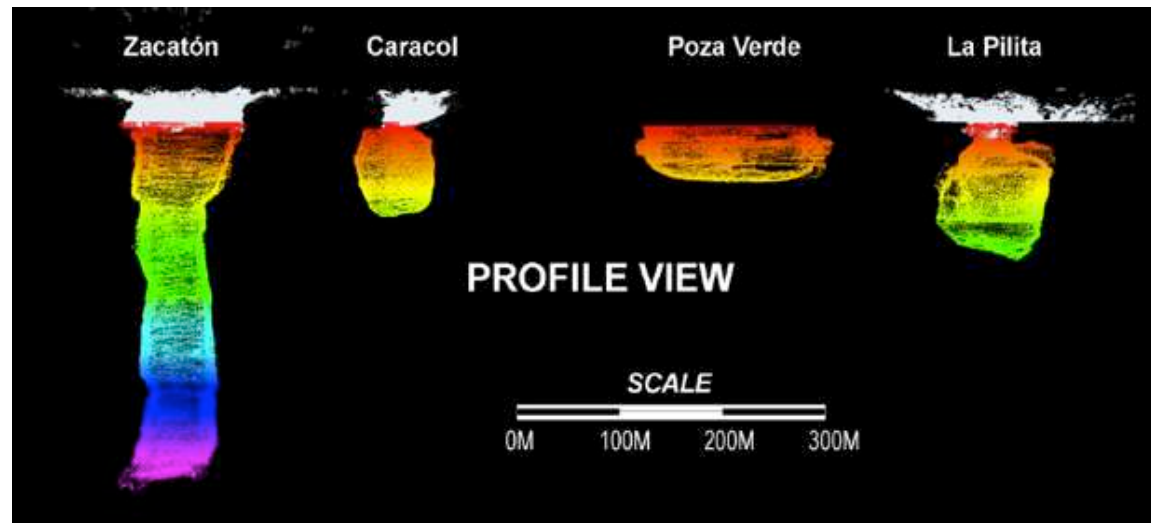
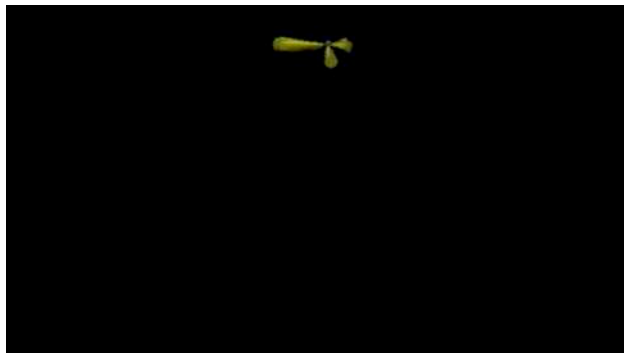
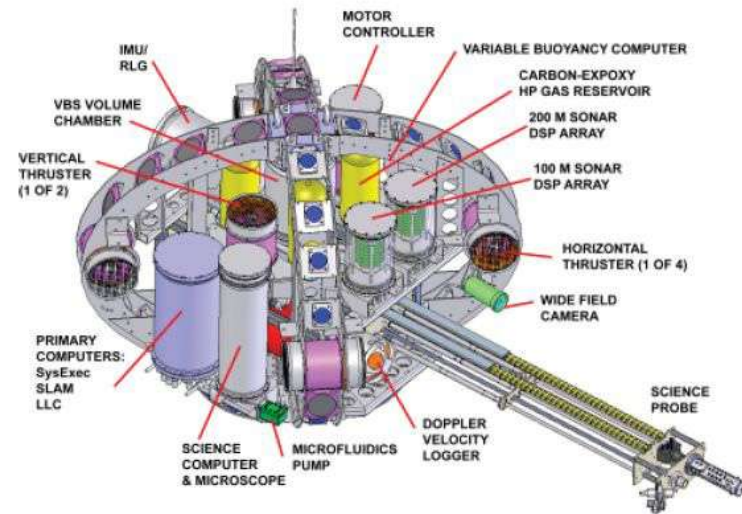


2002, Prometheus, 392m



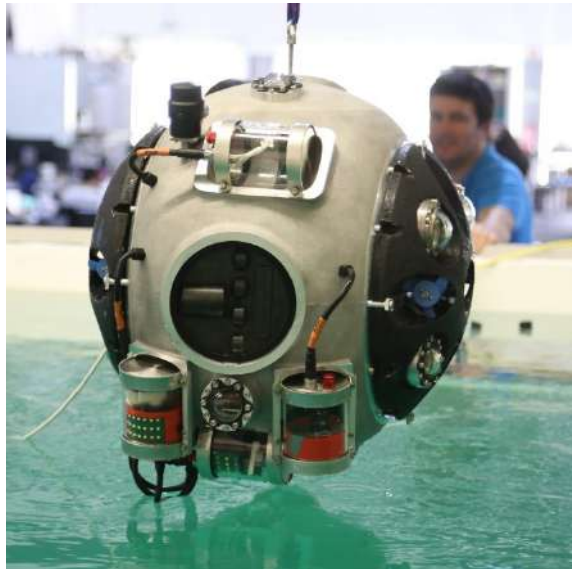
A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

DepthX (DEep Phreatic THERmal eXplorer)



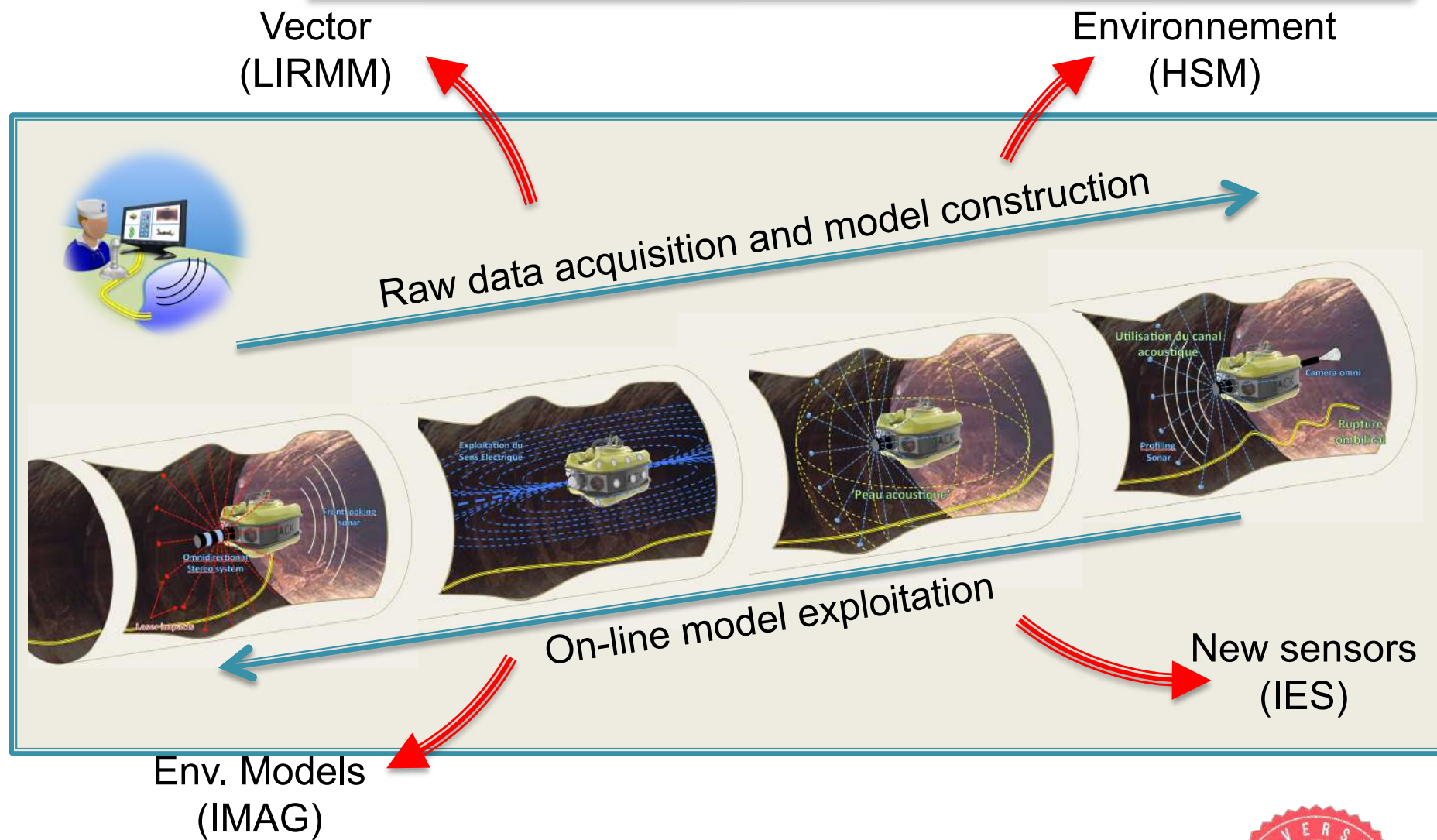
A RAPID HISTORY OF KARST EXPLORATION WITH ROBOT

○ 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



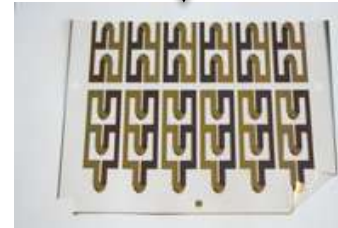
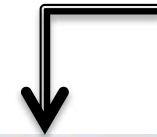
THE RKE INITIATIVE : FORCES AT WORK

○ New Sensors Development

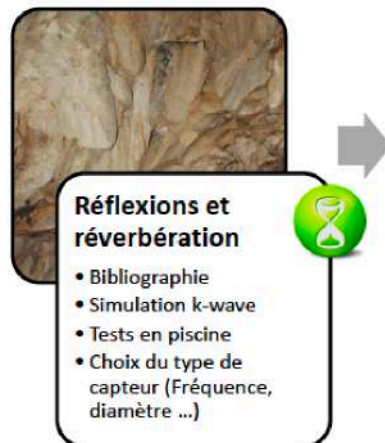
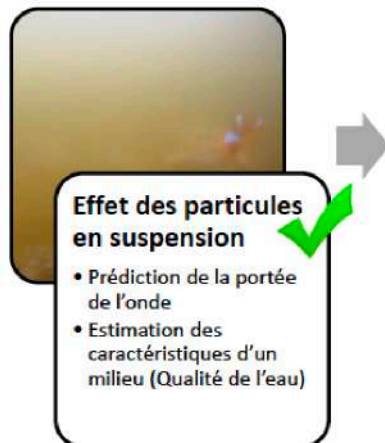
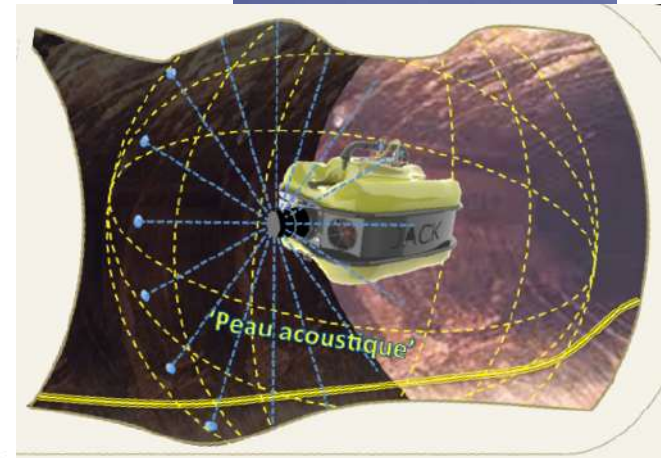
- Acoustic Skin
- Active Umbilical

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

Protocole de stimulation



Time of Arrival Sensor
(piezotech)



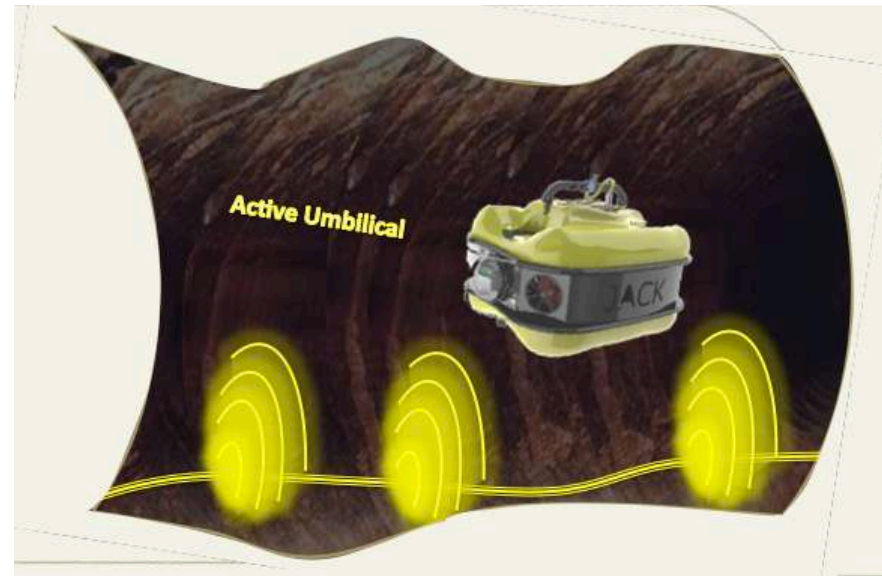
THE RKE INITIATIVE : FORCES AT WORK

○ New Sensors Development

- Acoustic Skin
- Active Umbilical

A. Vena (IES)
PIFEs EPUM

-> Rech. financements



N° 10

ECOLE POLYTECHNIQUE
UNIVERSITAIRE
DE MONTPELLIER

Projet industriel de fin d'études
Département Electronique, Robotique,
Informatique Industrielle
ANNEE 2016-2017

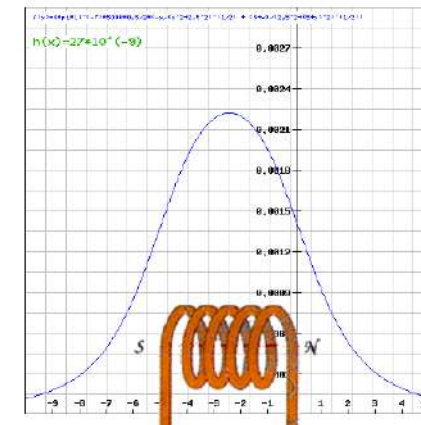
PROJET

Youri BASTIAENSSEN

Développement d'un système électronique
permettant la recherche et l'identification
de sources électromagnétiques
dans un contexte sous-marin

ECOLE POLYTECHNIQUE UNIVERSITAIRE DE MONTPELLIER
UNIVERSITAT MONTPELLIER SCIENCES ET TECHNOLOGIES DU LANGUEDOC
Place Eugène Bataillon 34095 MONTPELLIER CEDEX 5
Tél. 04 67 14 33 00 - Fax. 04 67 14 45 14
E-mail : contact@univ-montp2.fr

POLYTECH
MONTPELLIER



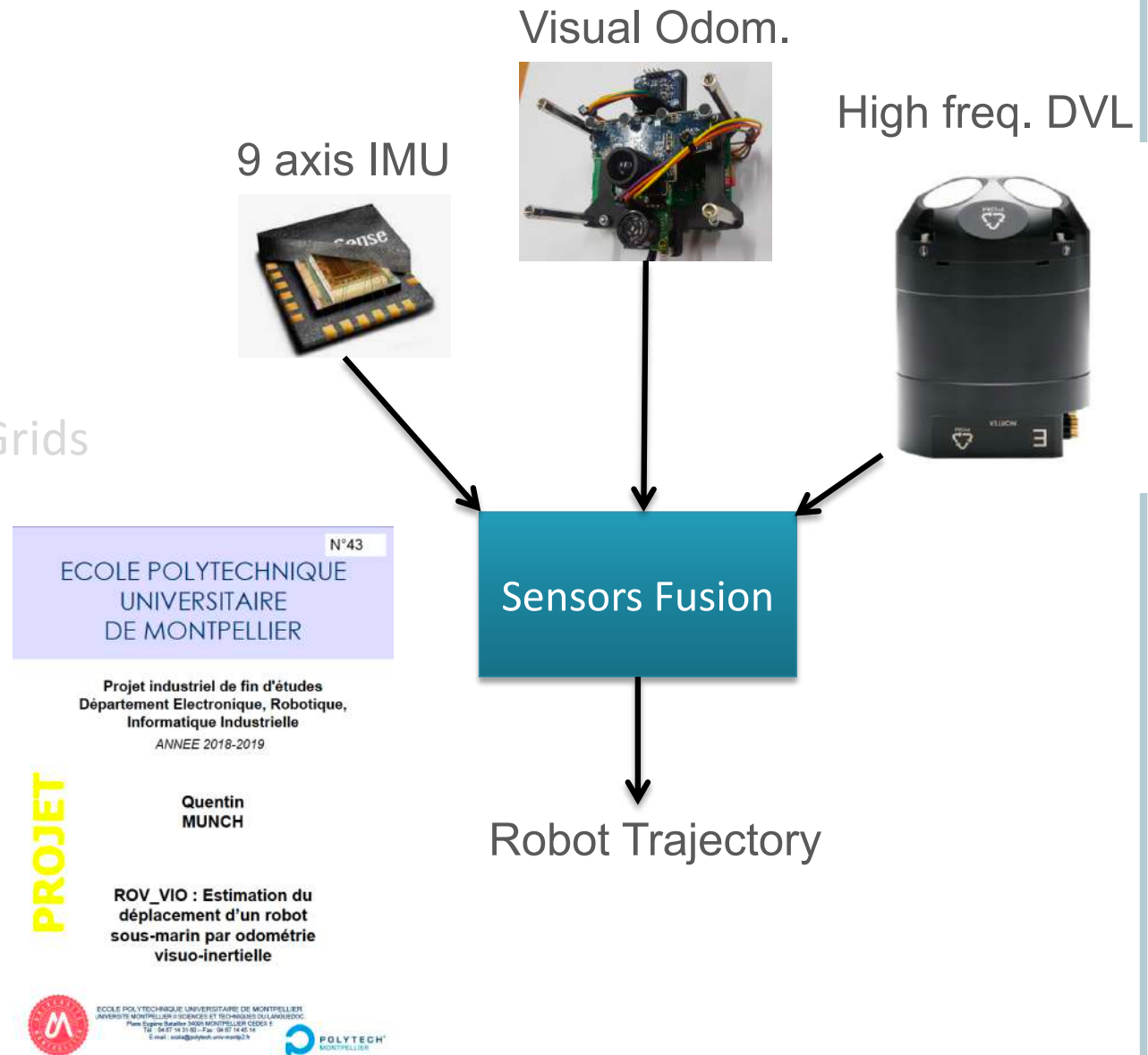
PIFE Y. Bastiaenssen

THE RKE INITIATIVE : FORCES AT WORK

Navigation

- Glob. Nav. System
- n-D SLAM
- Vacancy Evidence Grids

A. Gademer (IES)
B. Ropars (Reeds)
L. Rossi (Syera)
L. Lapierre (LIRMM)

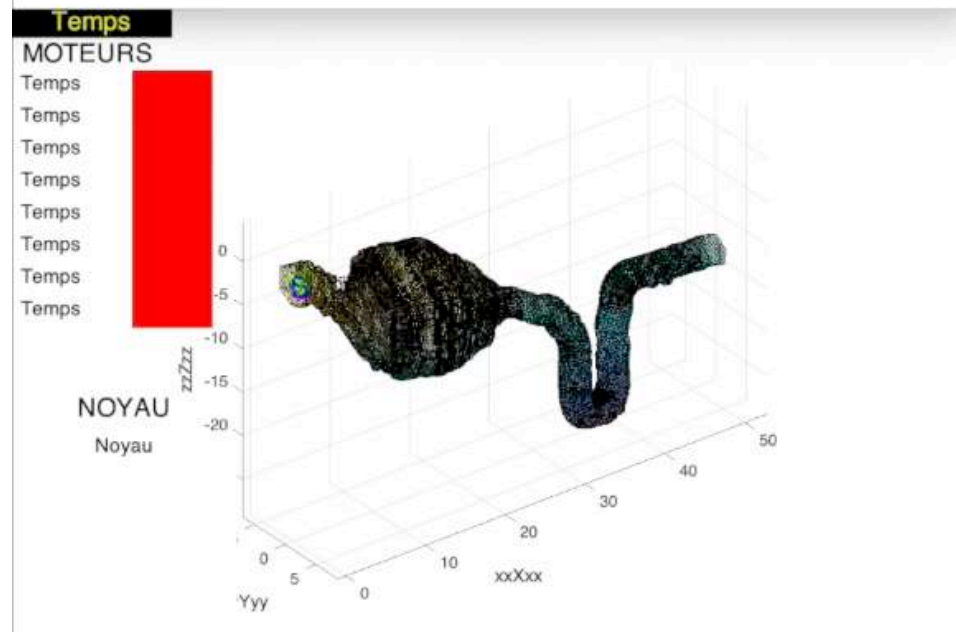
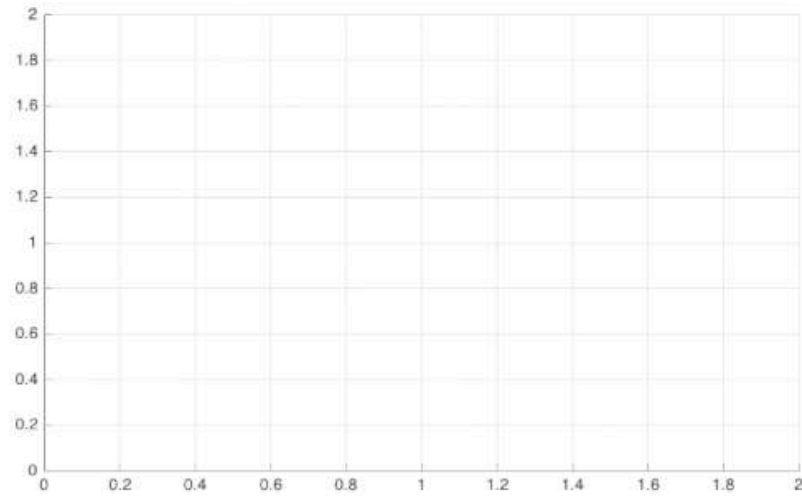


THE RKE INITIATIVE : FORCES AT WORK

Navigation

- Glob. Nav. System
- n-D acoustic SLAM
- Vacancy Evidence Grids

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

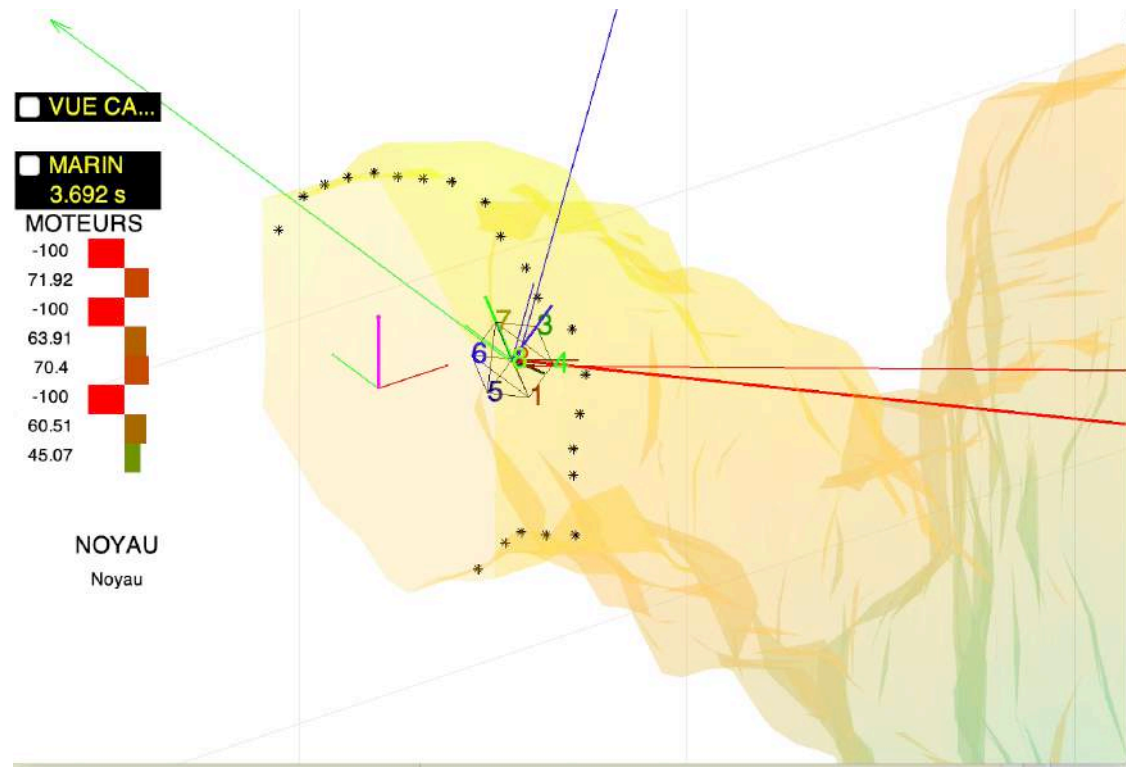


THE RKE INITIATIVE : FORCES AT WORK

Navigation

- Glob. Nav. System
- n-D acoustic SLAM
- Vacancy Evidence Grids

Y. Breux (LIRMM)
B. Mohammadi (IMAG)
A. MAS (IMAG)



Guidance

- Control

-
- VUE CA...**
- MARIN**
4.1955 s
- MOTEURS**
- | | |
|--------|--|
| 69.11 | |
| -100 | |
| 66.85 | |
| -100 | |
| 61.98 | |
| -100 | |
| -79.79 | |
- NOYAU**
Noyau

THE RKE INITIATIVE : FORCES AT WORK



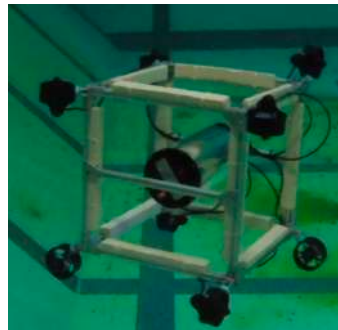
Ulysse



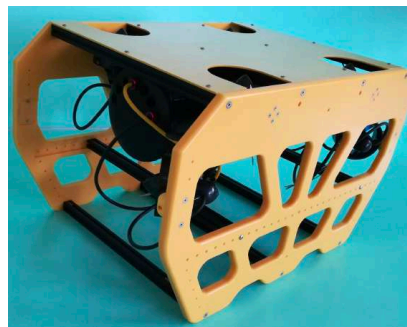
Sentinel



Anguilla



Cube



Télémaque

Actuation

- Reactive redundant A.S.
- 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)

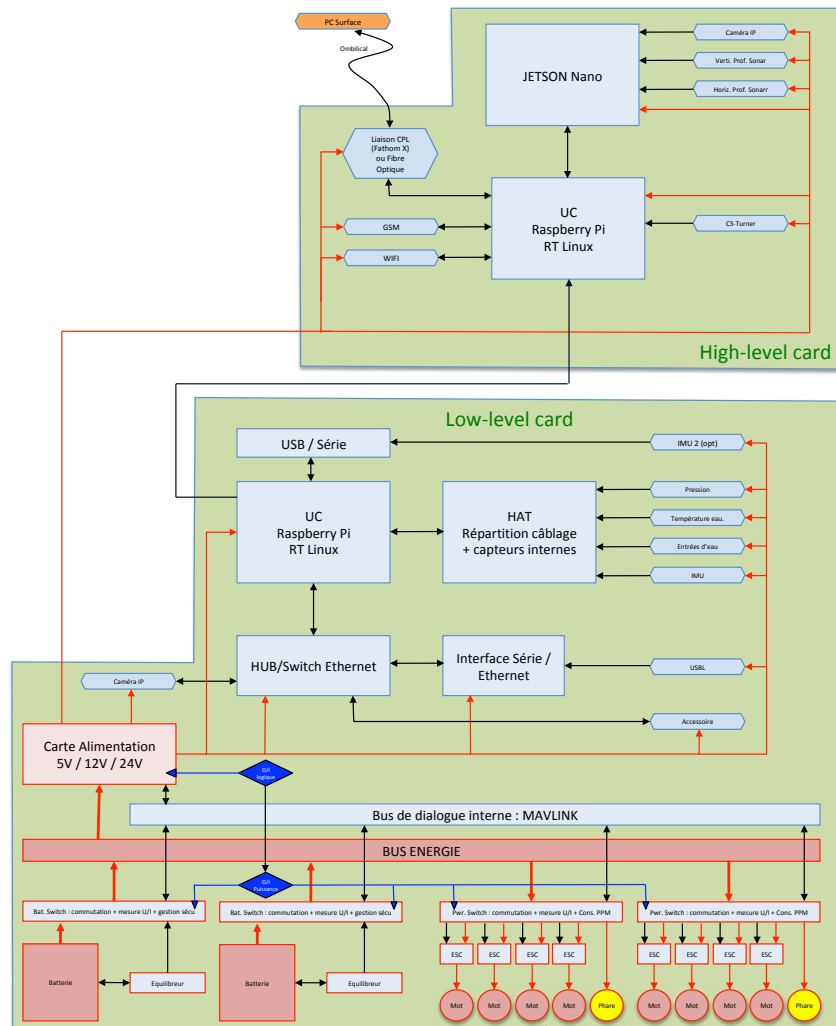


NavScoot

HammerHead



THE RKE INITIATIVE : FORCES AT WORK



Hardware Architecture

- Observable
- hybrid
- Adaptive Autonomy
- 2 layers

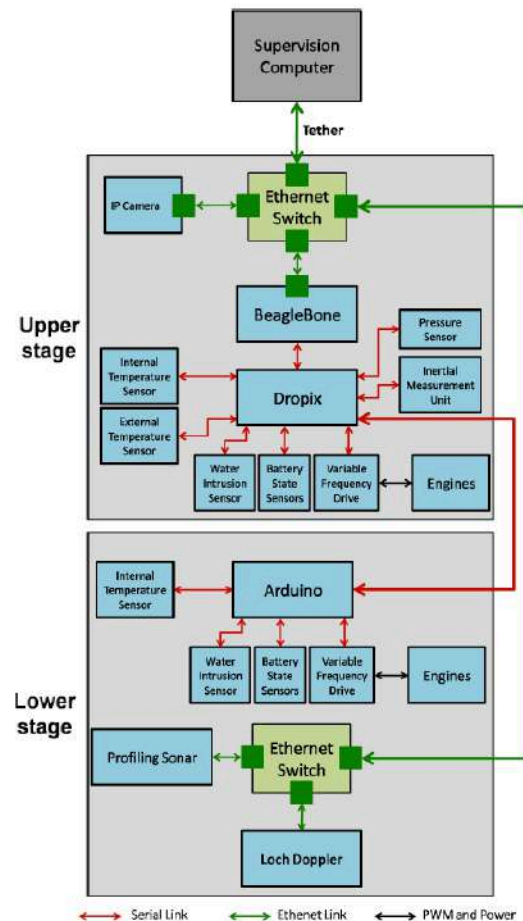
B. Ropars (Reeds)

L. Rossi (Syera)

K. Godary-Dejean (LIRMM)

PD Bubot (LIRMM)

THE RKE INITIATIVE : FORCES AT WORK

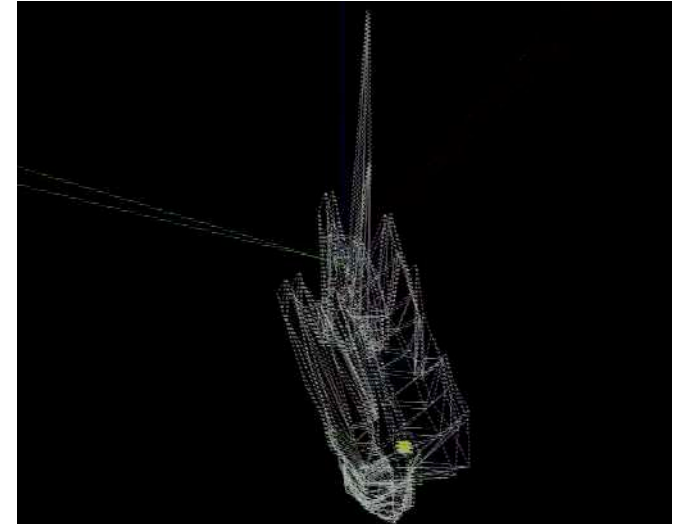
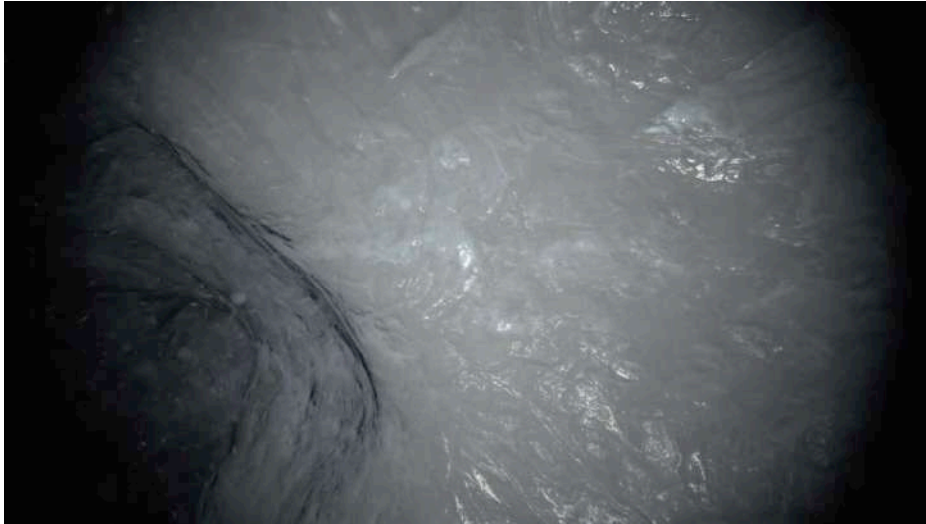


Software Architecture

- Management of sensors recruitment (acc. jamming)
- Adaptive Autonomy
- Dependability & GoP

D. Crestani (LIRMM)
L. Lapierre (LIRMM)
R. Villalobos (LIRMM)

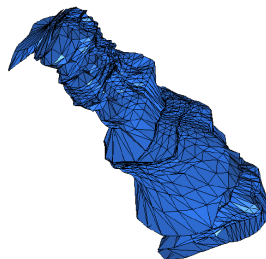
THE RKE INITIATIVE : FORCES AT WORK



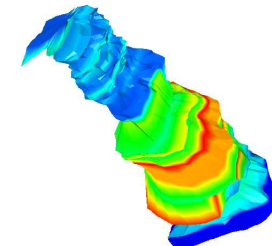
J. Triboulet (LIRMM)
S. Druon (LIRMM)
Q. Massone (LIRMM)
B. Mohammadi (IMAG)
Y. Breux (IMAG)
A. Mas (IMAG)

Models

- Multi-modality & Scalability
- Uncertainty Consideration



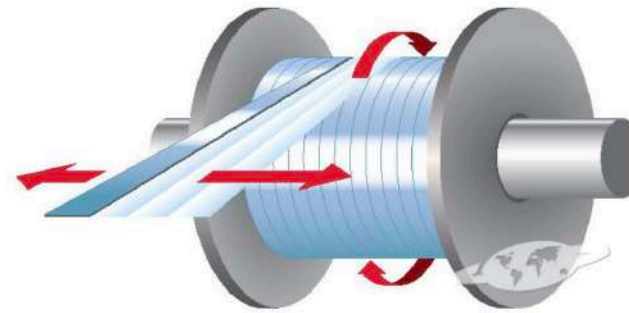
Extractions de données
fonctionnelles :
Volume (1187 m³),
Surfaces,
Vitesses
d'écoulements...



Carte des incertitudes

THE RKE INITIATIVE : FORCES AT WORK

B. Ropars (Reeds)
L. Rossi (Syera)



S. Yami (LEM)
G. Naro (MRM)
B. Ropars (Reeds)
L. Rossi (Syera)
L. Lapierre (LIRMM)
R. Bouchard (PlongeeSout)
F. Vasseur (PlongeeSout)



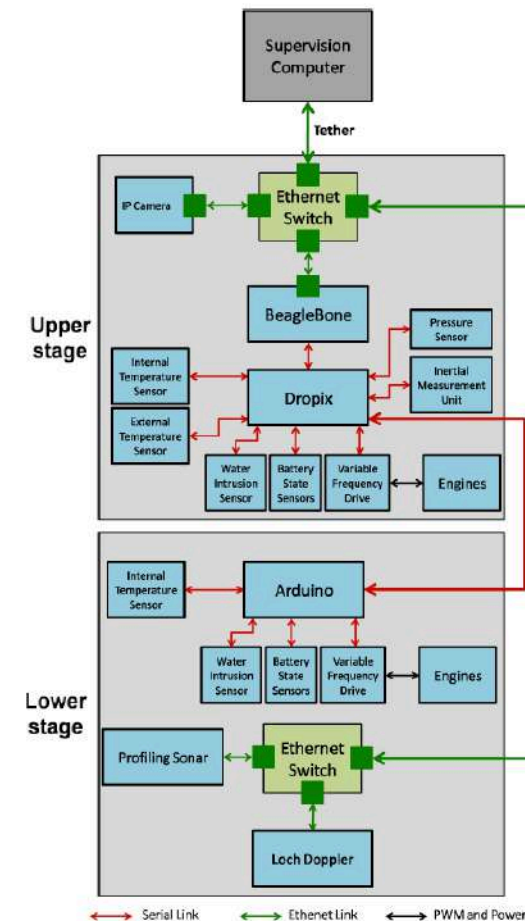
- Technology
 - Active Truncanner, NRJ opt.
- Economic
 - Evangelization of a Blue Ocean



TERRAIN RESULTS



-
- A yellow and white robotic platform named JACK. It has a white frame with a yellow top deck. The name "JACK" is printed in blue on the yellow top. A large, clear, circular camera lens is mounted on the front. Below the camera, a black motor with "BlueView" branding is visible. The robot is equipped with several small black fans and yellow-and-black striped wheels. A label on the side indicates a "LINE" sensor.



SYSTEMS



Ulysse

*Eclairages : Mehdi Dighouth
Maxu Dagrenot
Photo : Frank Vassear*

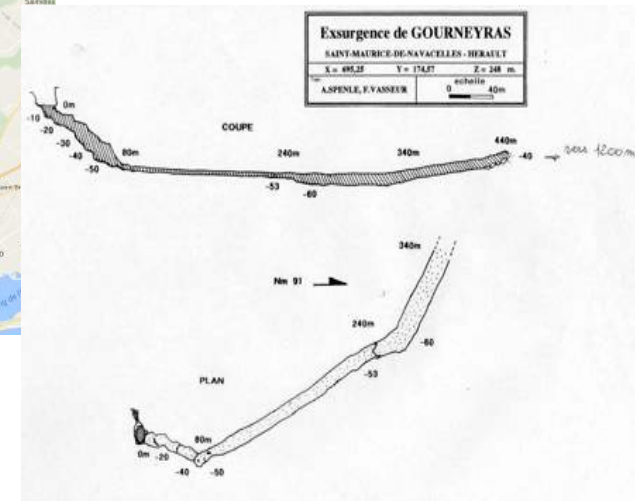
NavScoot



*Eclairages : Mehdi Dighouth
Photo : Frank Vassear*

FISRT TERRAIN RESULTS

○ Gourneyras, 11-14/07/2016



○ Gourneyras, 23/01/2017.



Exploration and cartography of the entry chasm (robot)

Extended network cartography (NavScout)

Validations : co-control, new electronic and software architectures.

FISRT TERRAIN RESULTS

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

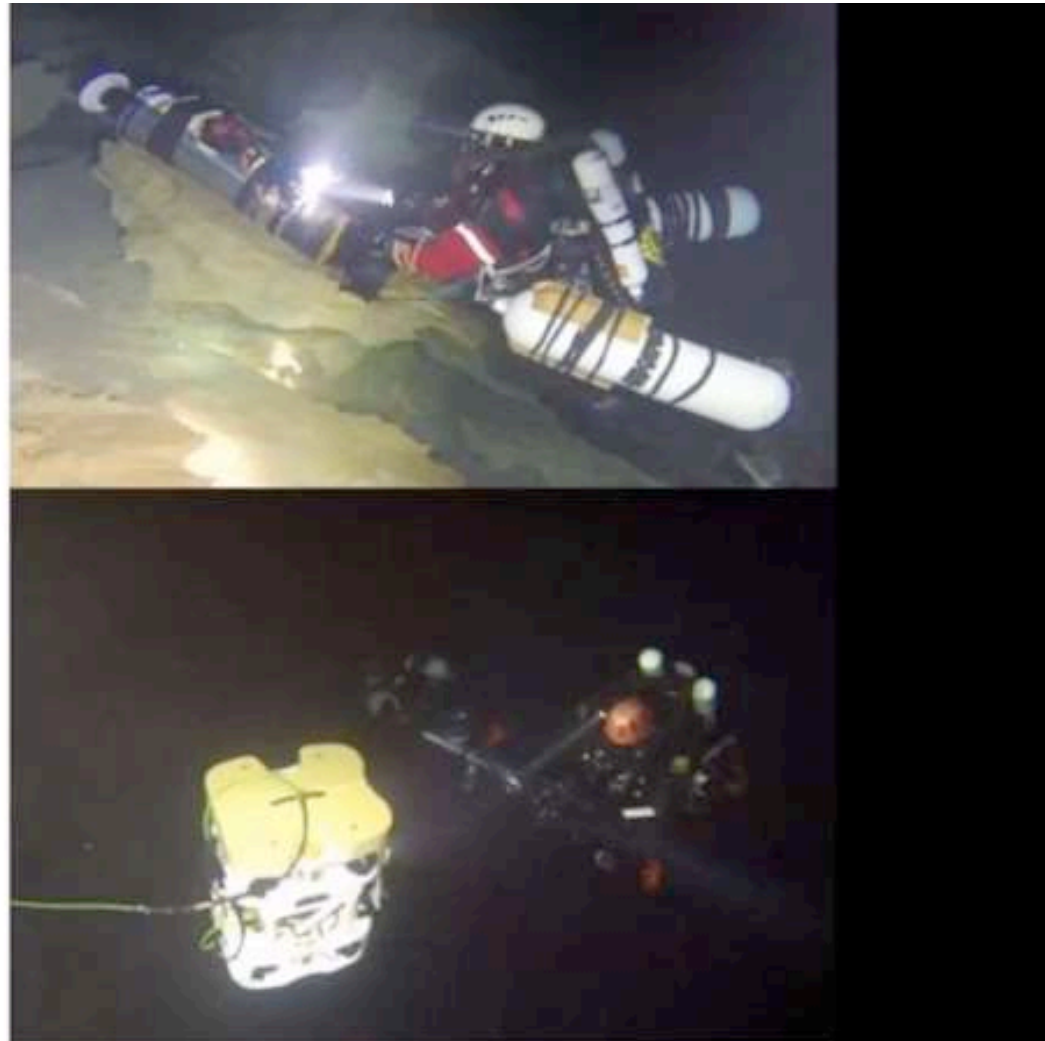


**ROBOTS, SONARS
&
CAVE DIVING**

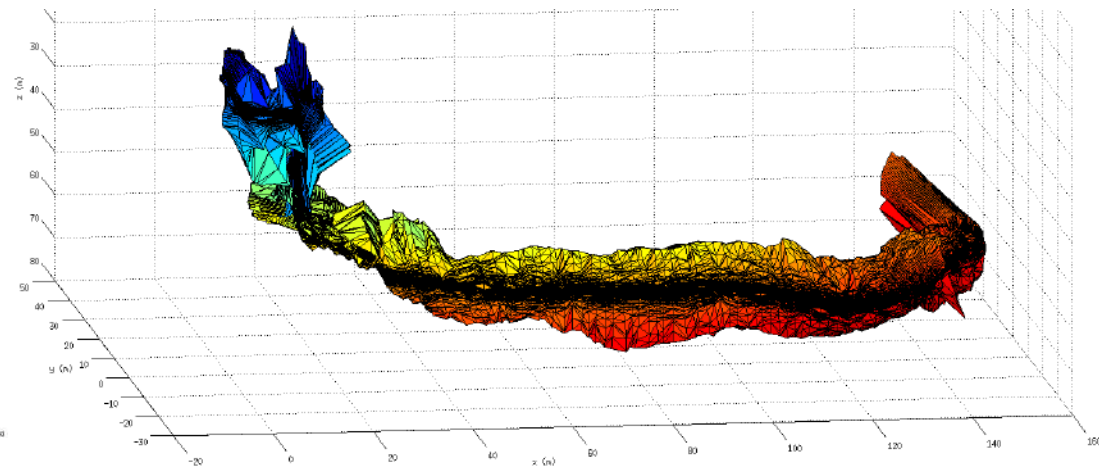
GOURNEYRAS 2016



LIRMM

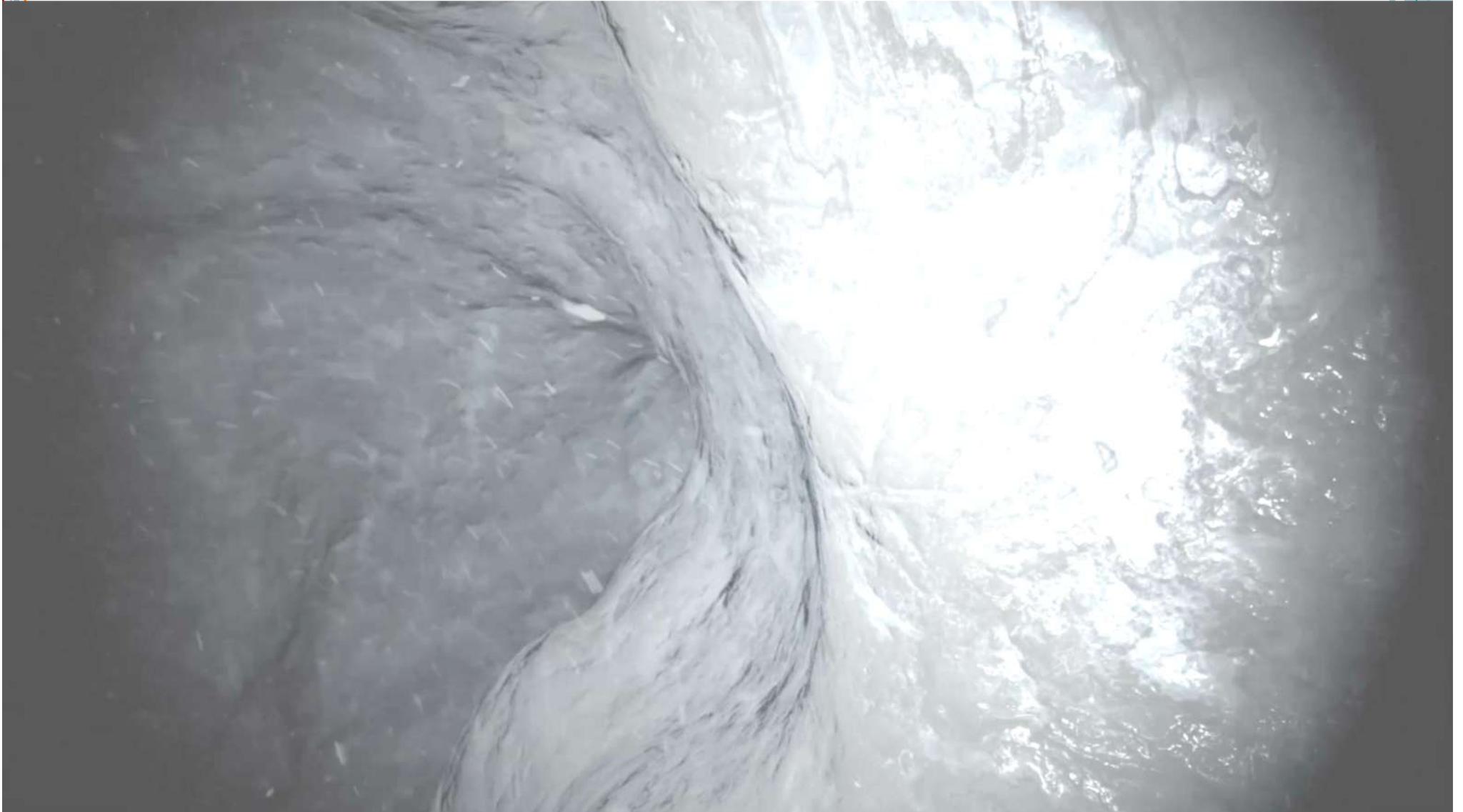


- Gourneyras, 11-14/07/2016 and 23/01/2017



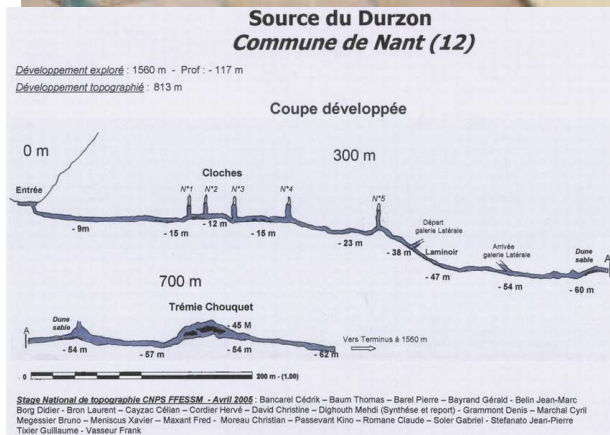
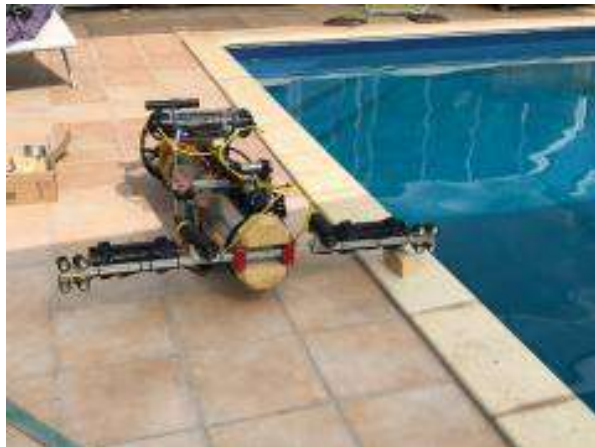
FISRT TERRAIN RESULTS

- Gourneyras, virtual visit



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.



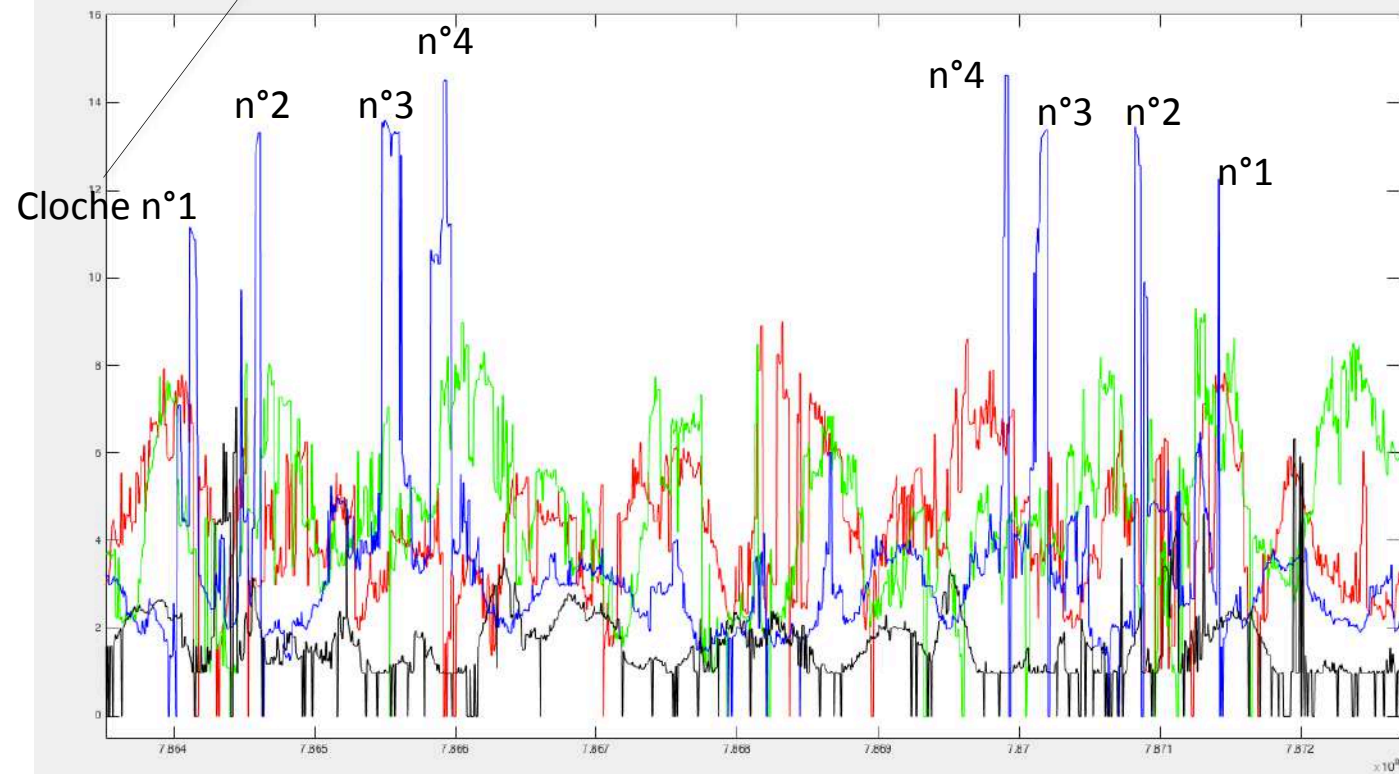
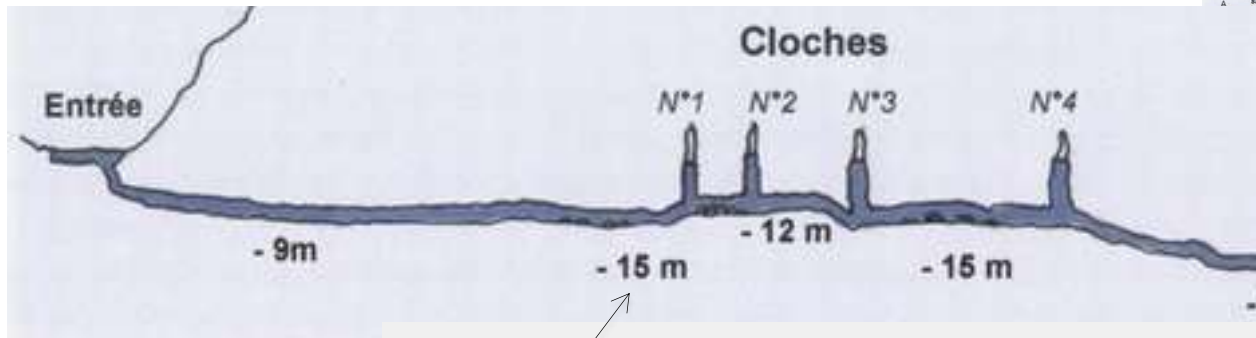
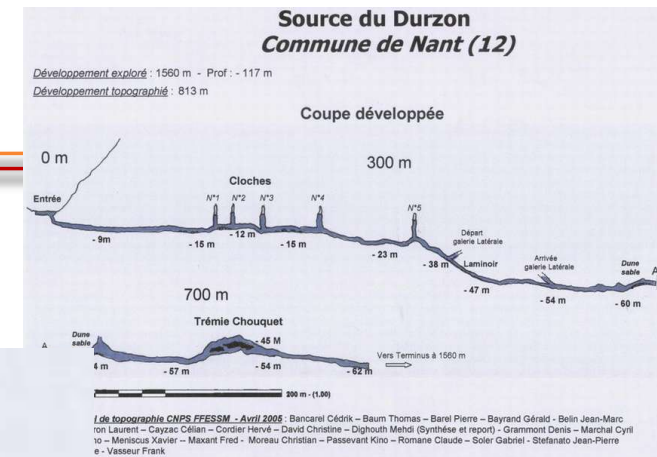
FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

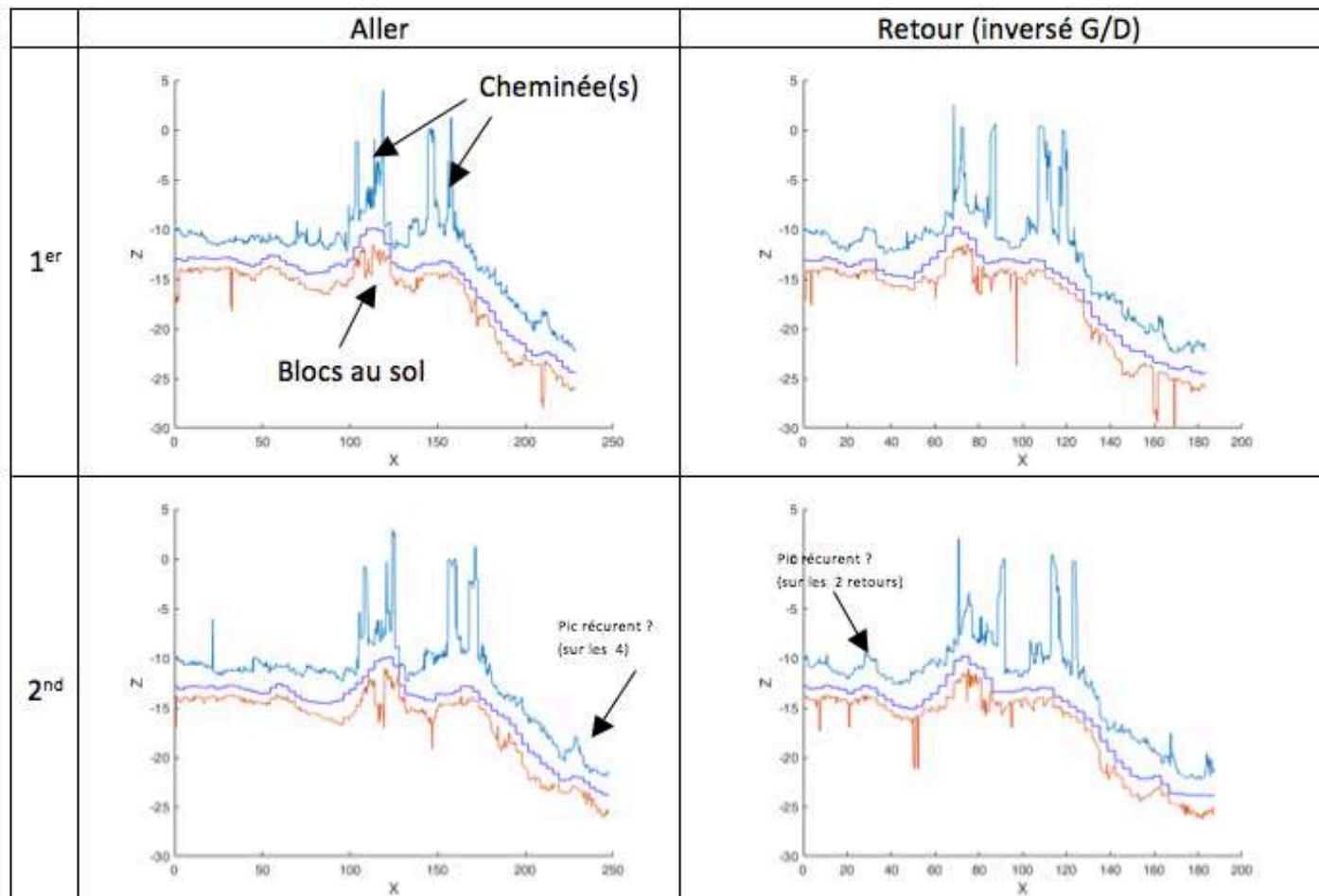


FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

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

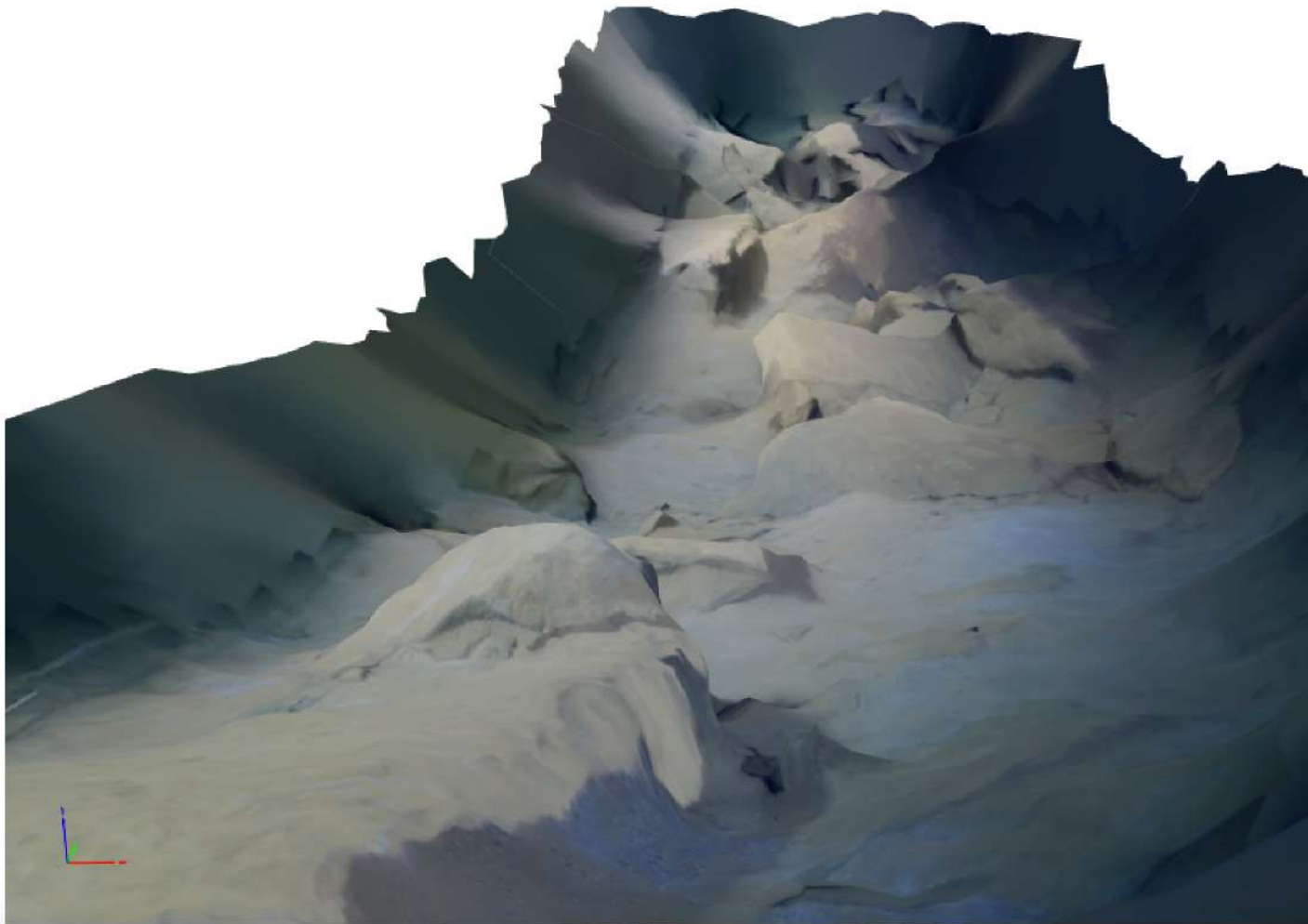
Données :



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

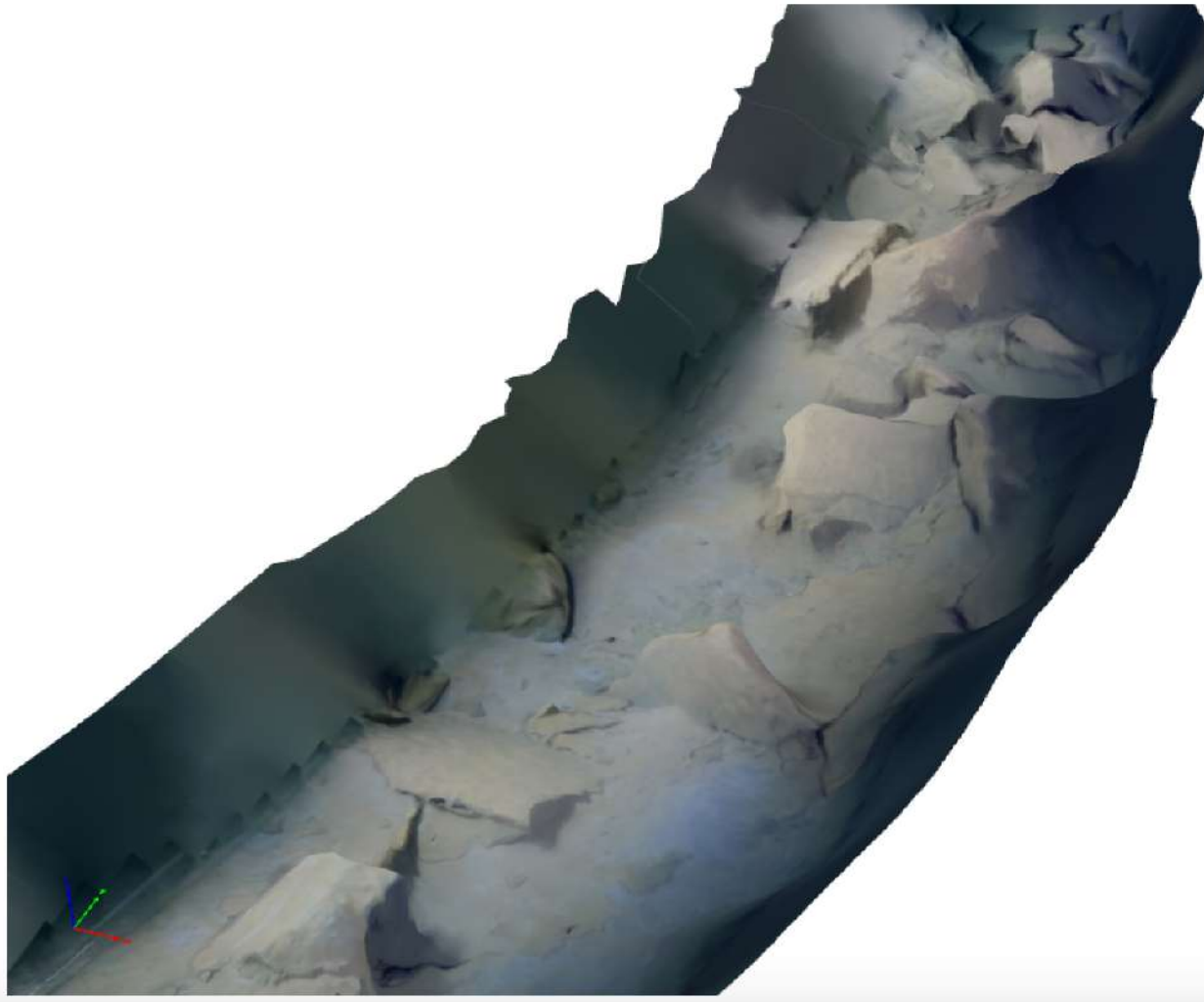
Photogrammetric reconstruction



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

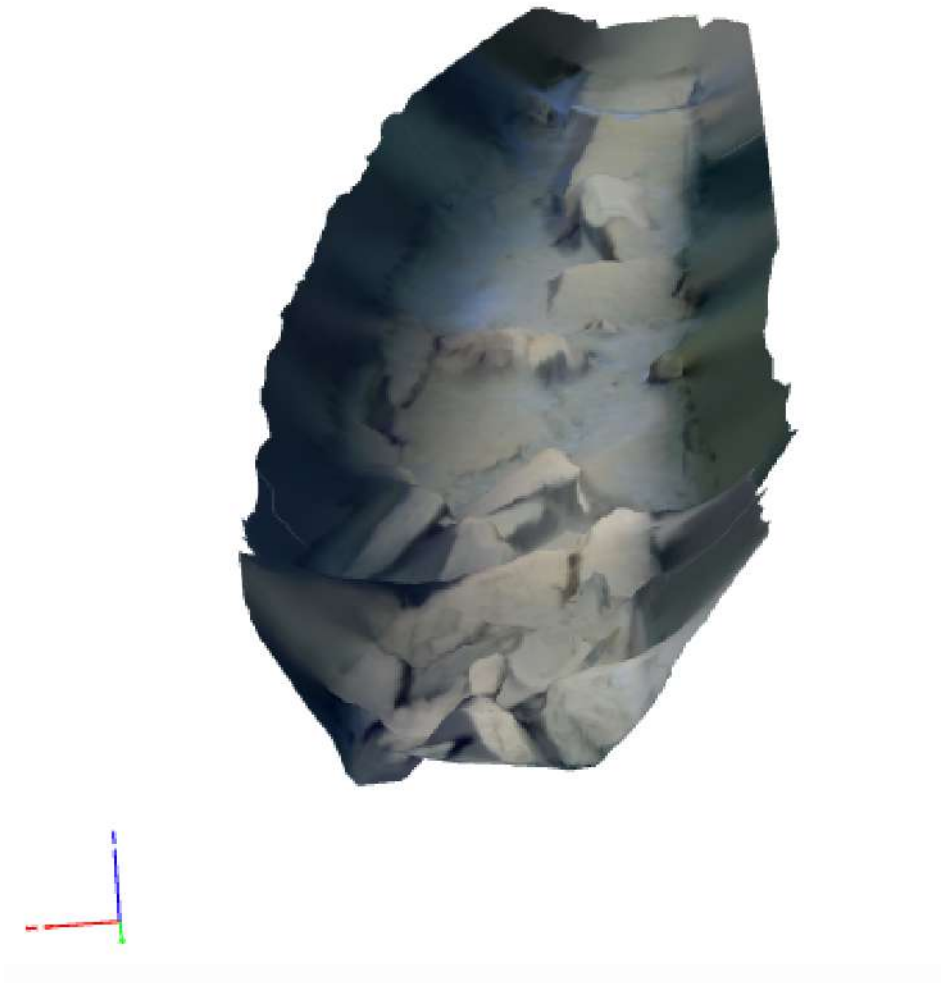
Photogrammetric reconstruction



FISRT TERRAIN RESULTS

○ Durzon, Nant, 24/06/2018.

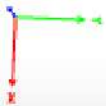
Photogrammetric reconstruction



FISRT TERRAIN RESULTS

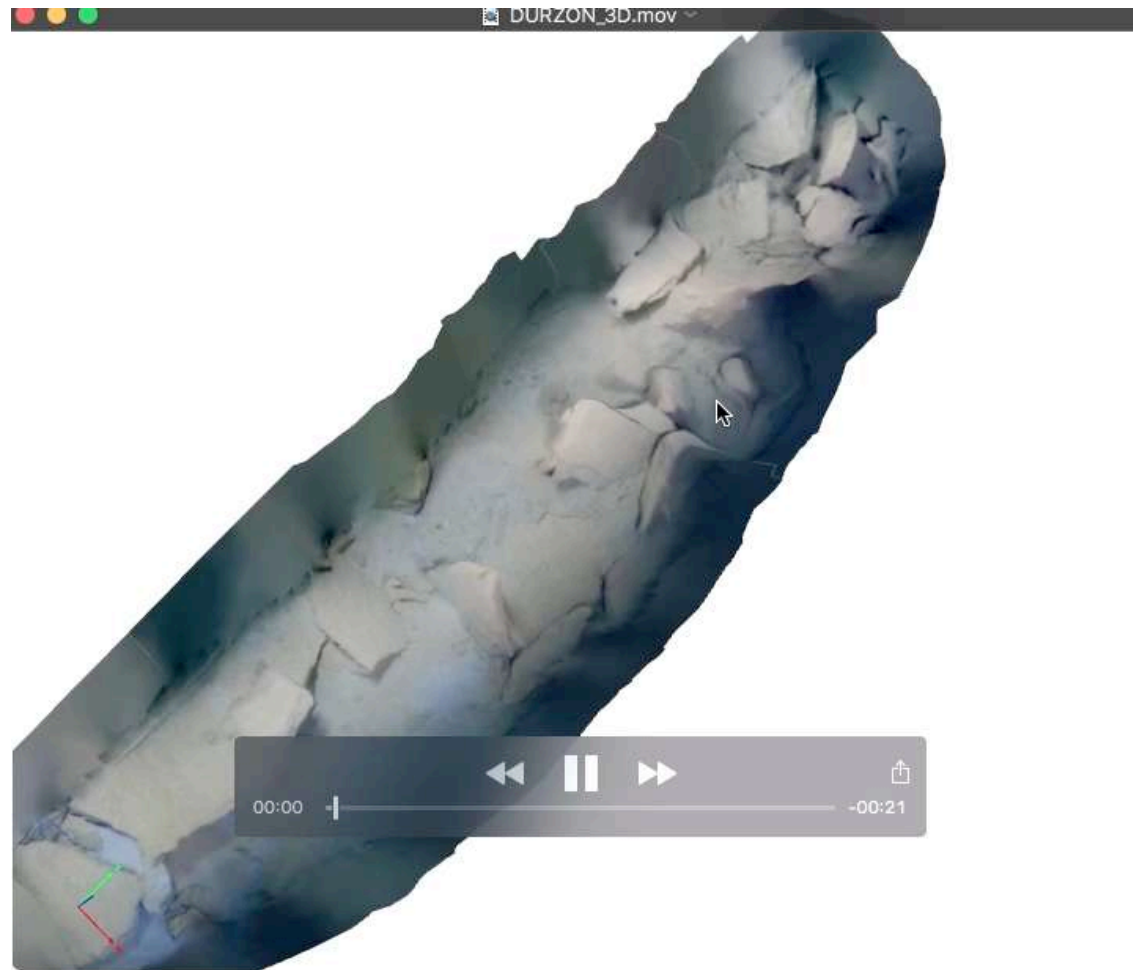
○ Durzon, Nant, 24/06/2018.

Photogrammetric reconstruction



FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.

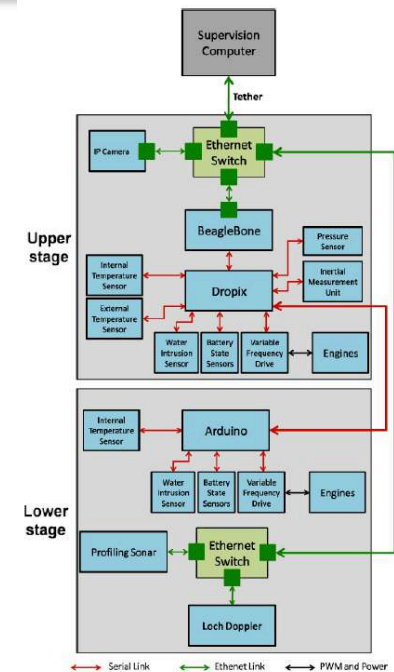
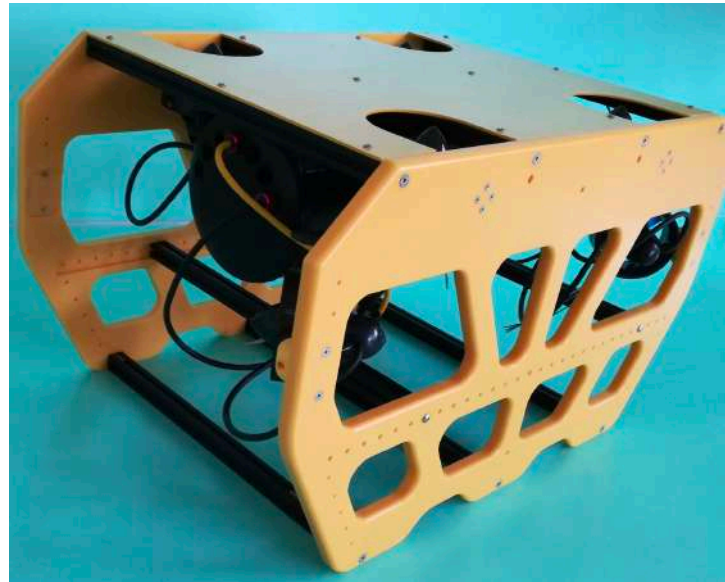
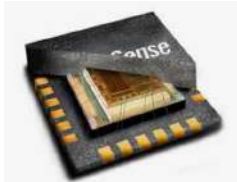


Partial photogrammetric reconstruction



RÉSULTATS À VENIR (2019)

NOUVEAU PORTEUR : TÉLÉMAQUE



Fin 2019, Source de Saint-Antoine (Toulon), galerie de la Marine

- Validation centrage
- Validation système de Nav.

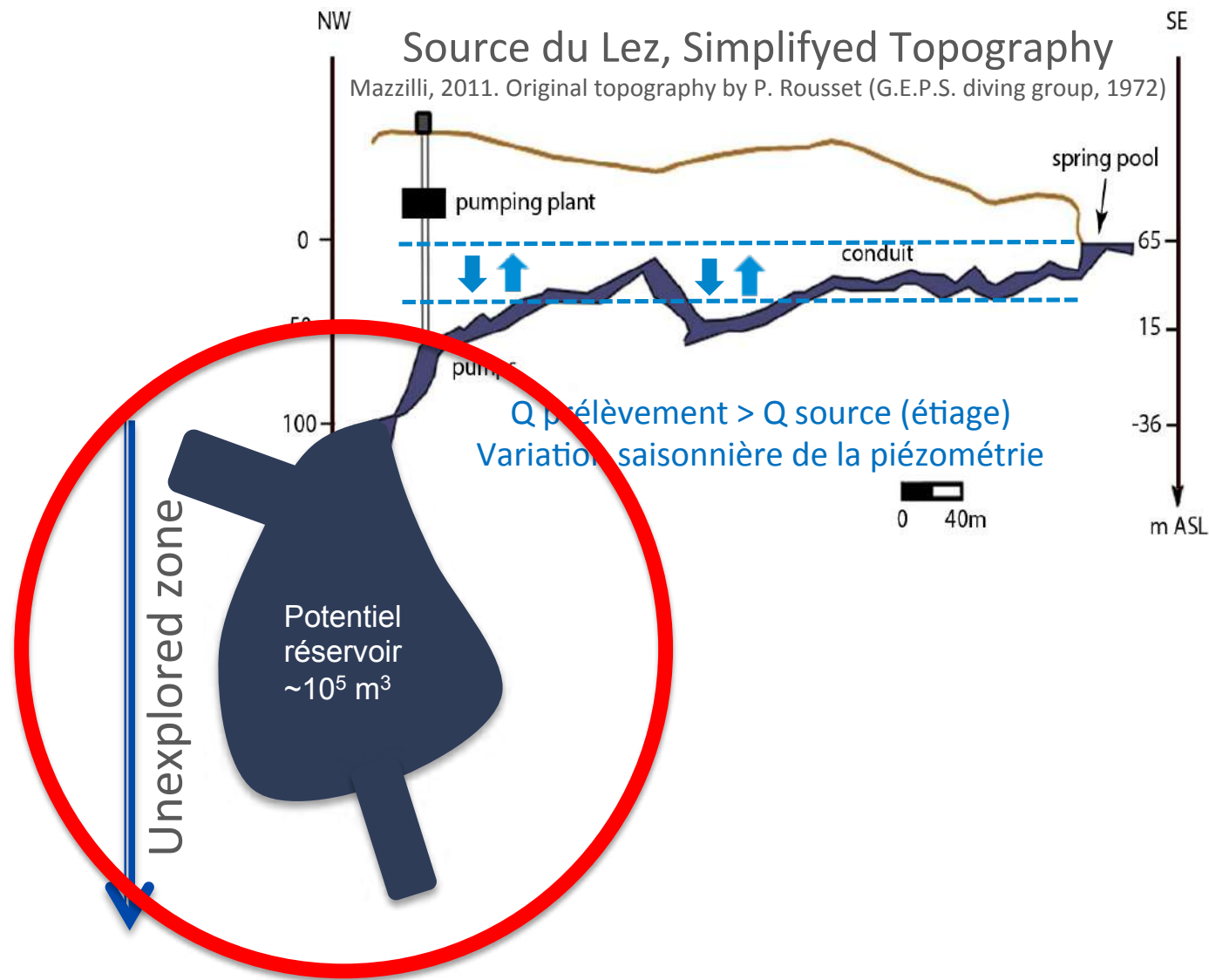




LE PROJET LEZ 2020



PROJET RÉGION OCCITANIE R&S : LEZ-2020



LEZ-2020

- Objectif
 - Cartographie des zones en amonts de la station AVIAS
- Durée : 3 ans
- Partenaires académiques
 - LIRMM, HSM, IES, IMAG, MRM, LEM
- Partenaire institutionnel : 3M, Régie des eaux
- Partenaires industriels : SYERA et REEDS
- Associés : BRGM, Hydrokarst, F. Vasseur, PlongéeSout
- Budget : 706 K€ (dont 460K€ demandés FEDER)

LEZ-2020

- Dépenses

- Ressources humaines

- 36 PM Ingénieur de Recherche Robotique

- 18 PM Post-Doc Hydrogéologie

- 36 PM Stagiaires Ingénieur/Master 2

- 12 PM Robotique

- 12 PM Electronique

- 12 PM Business

- Capteurs

- Profilo Balayage électronique SubTop DT 360

- Prestations

- Réalisation mécanique et électronique

- Opérations de plongée

- Pressentis : F. Vasseur et Hydrokarst

LEZ-2020

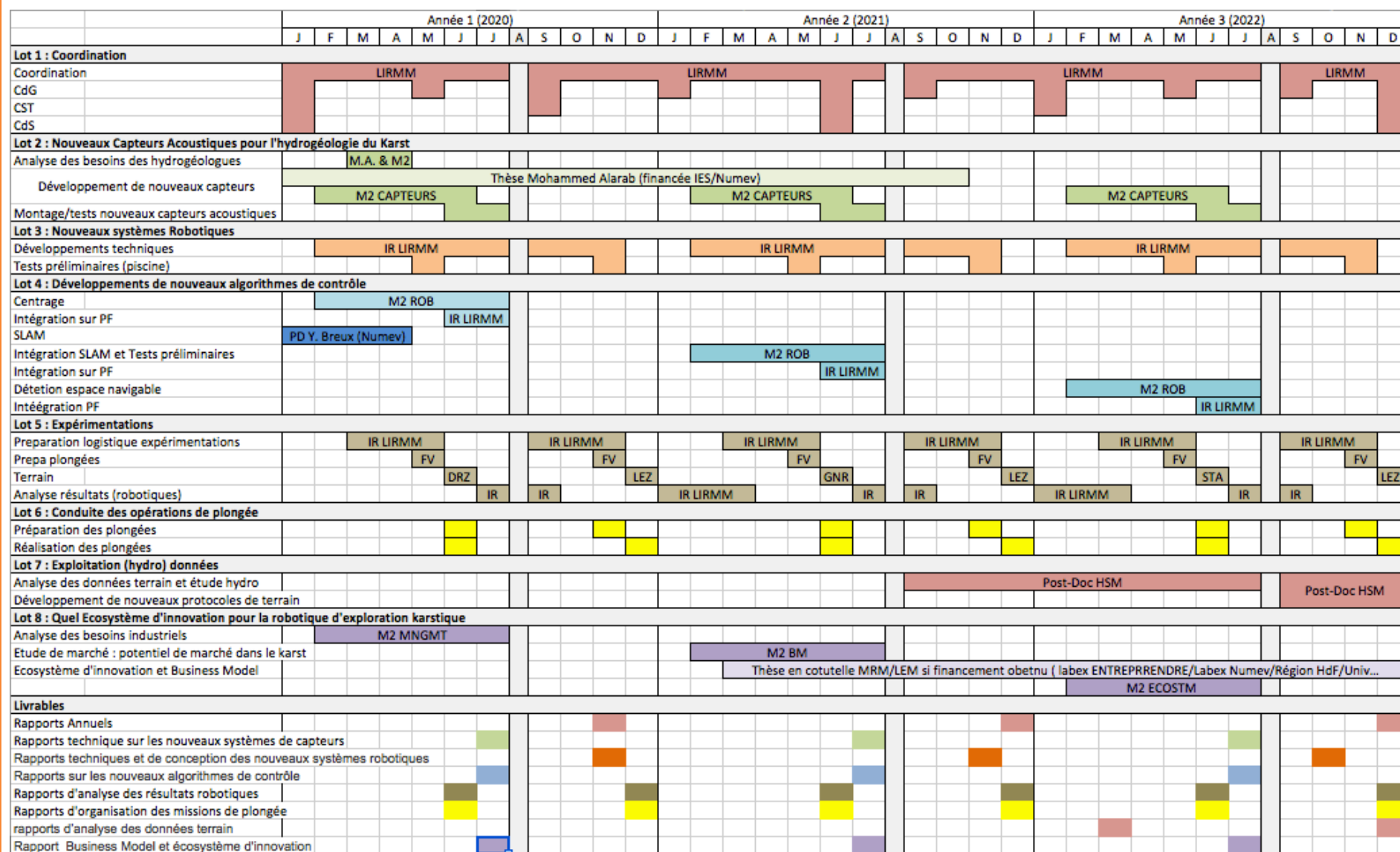
- Apports en nature
 - UM : frais de personnels
 - REEDS et Syera
 - Adaptation et mise à disposition Trancanner
 - Appuis terrain
 - Appuis logistiques 3M
 - Autorisations d'accès à la source
 - Communications sur les opérations Lez

LEZ-2020

- Lot 1 : Coordination
- Lot 2 : Nouveaux capteurs acoustiques pour la navigation robotique et l'hydrogéologie du karst
- Lot 3 : Nouveaux systèmes robotiques
- Lot 4 : Développement de nouveaux algorithmes de contrôle
- Lot 5 : Expérimentations
- Lot 6 : Conduite des missions de plongée
- Lot 7 : Exploitation des résultats et développement de nouveaux protocoles de terrain
- Lot 8 : Quel Ecosystème d'innovation pour la robotique d'exploration karstique

LEZ-2020

○ GANTT





Vector

Business

Environnement

Raw data acquisition and model construction

On-line model exploitation

Env. Models, SLAM

End-Users

New sensors

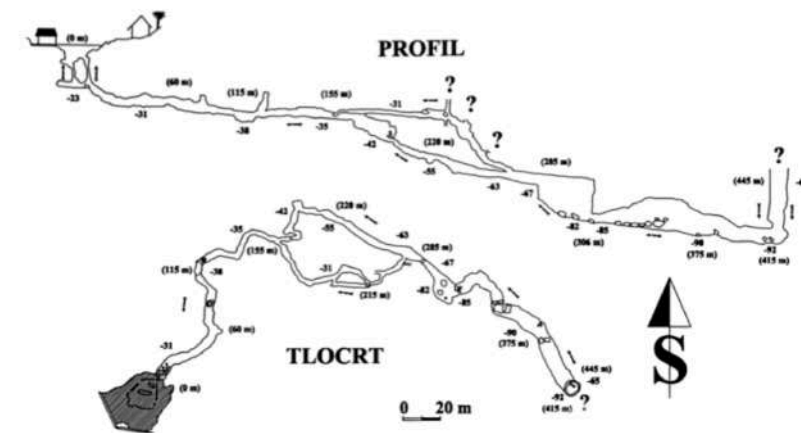
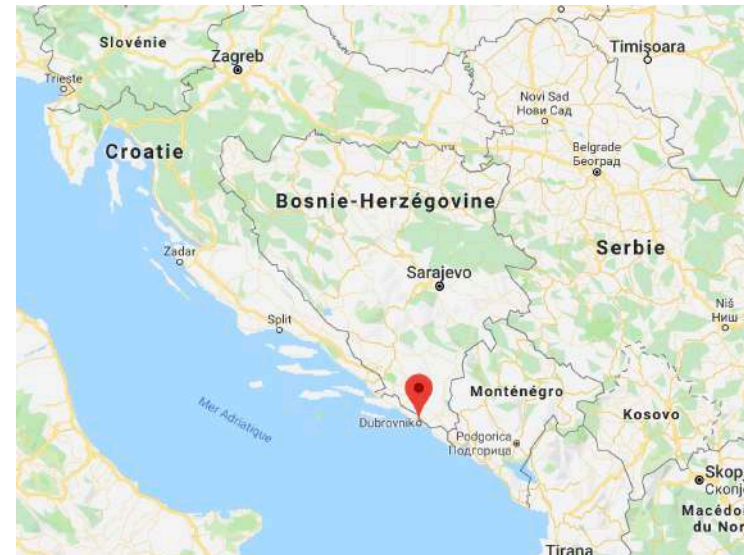
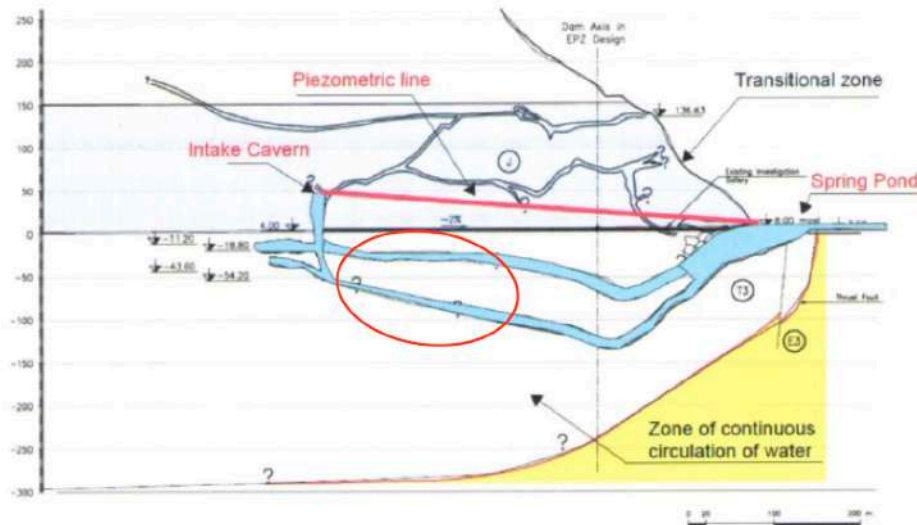


NEAR FUTURE : THE ANZAR EUROPEAN EXTENSION



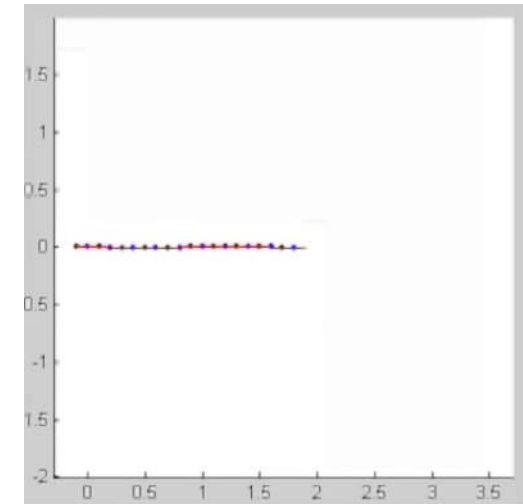
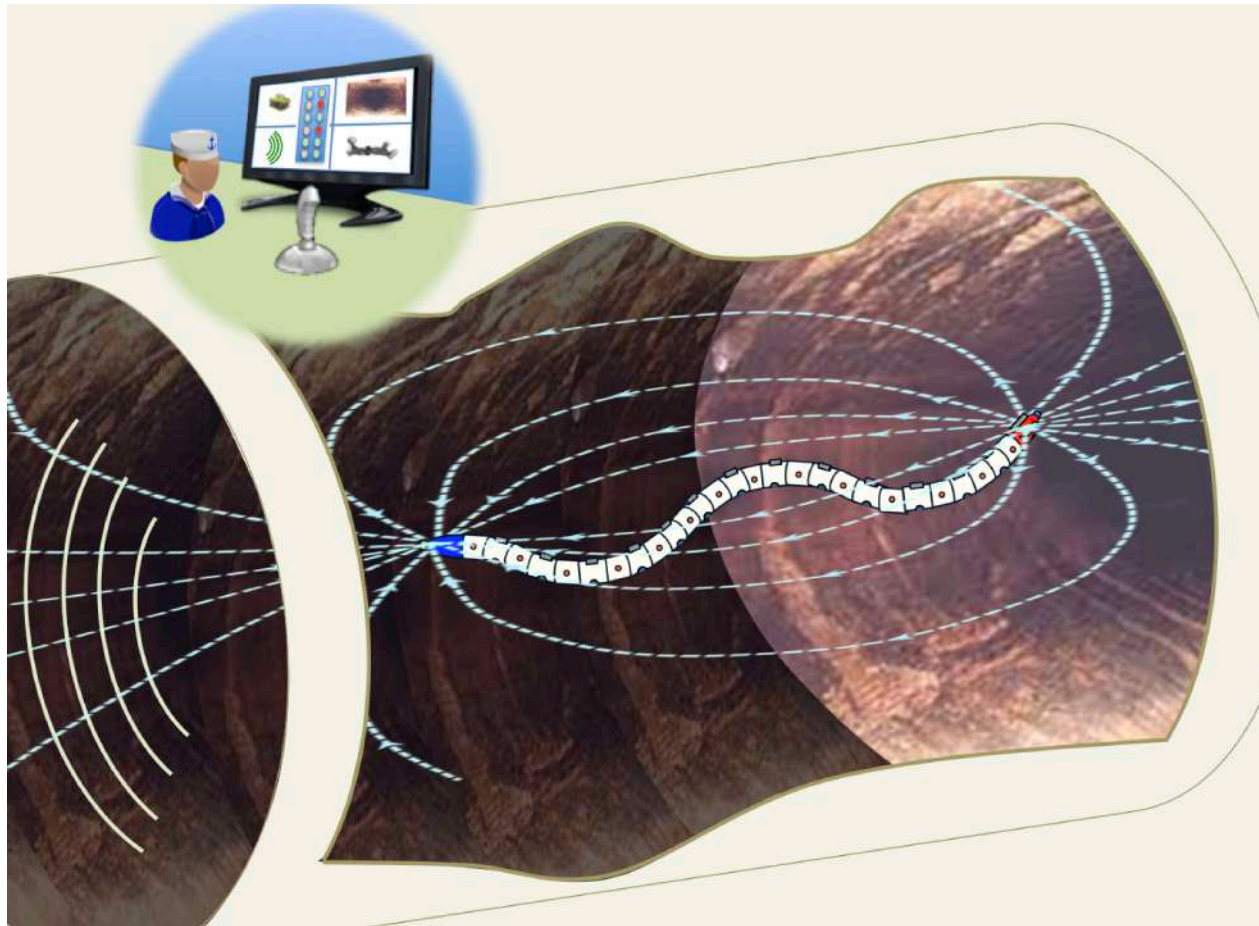
NEAR FUTURE : THE ANZAR EUROPEAN EXTENSION

○ Ombla Spring, Dubrovnik, Croatia



NEAR FUTURE : ANR LS2N, ENSTA, ISSKA

Locomotion anguilliforme et Sens électrique



Underwater reflex navigation in confined environment based on electric sense

Fabrice Boyer, Vincent Leboucq, Christine Chevalier, and Noël Servagne

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 could allow a robot to detect simple behaviors such as avoiding any electrically contrasted object, or seeking a set of objects while avoiding others according to their electric properties. In proposed. Their reflex behavior as observed on simulation and experimentally 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, electrolocation, 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 artificial waters where vision is useless remains a challenge in robotics. In the same conditions, electrolocation 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 Laumier in the 1930s [1]. The African fish *Gnathopetris* (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 electric field around the fish which is distorted by the objects present in its surroundings. Then, thanks to the many electroreceptors 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 survival 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,

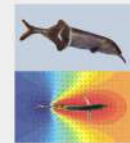


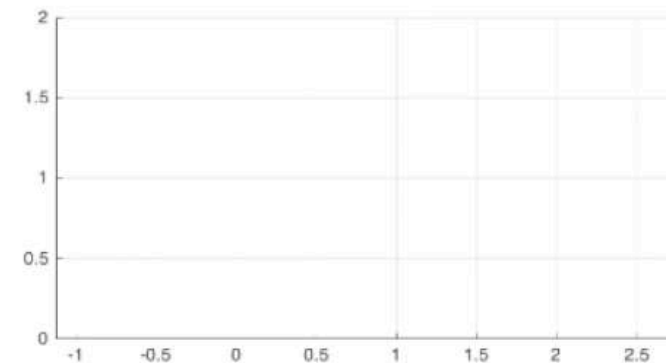
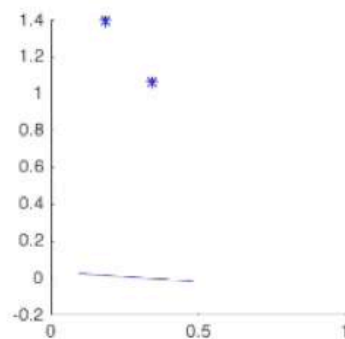
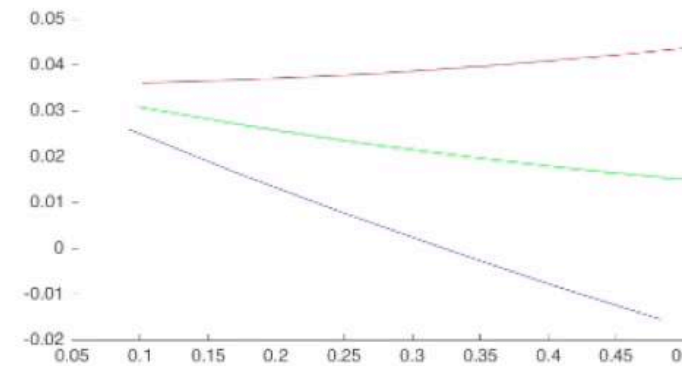
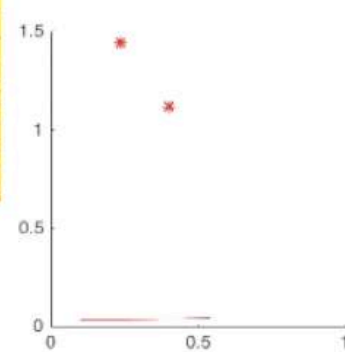
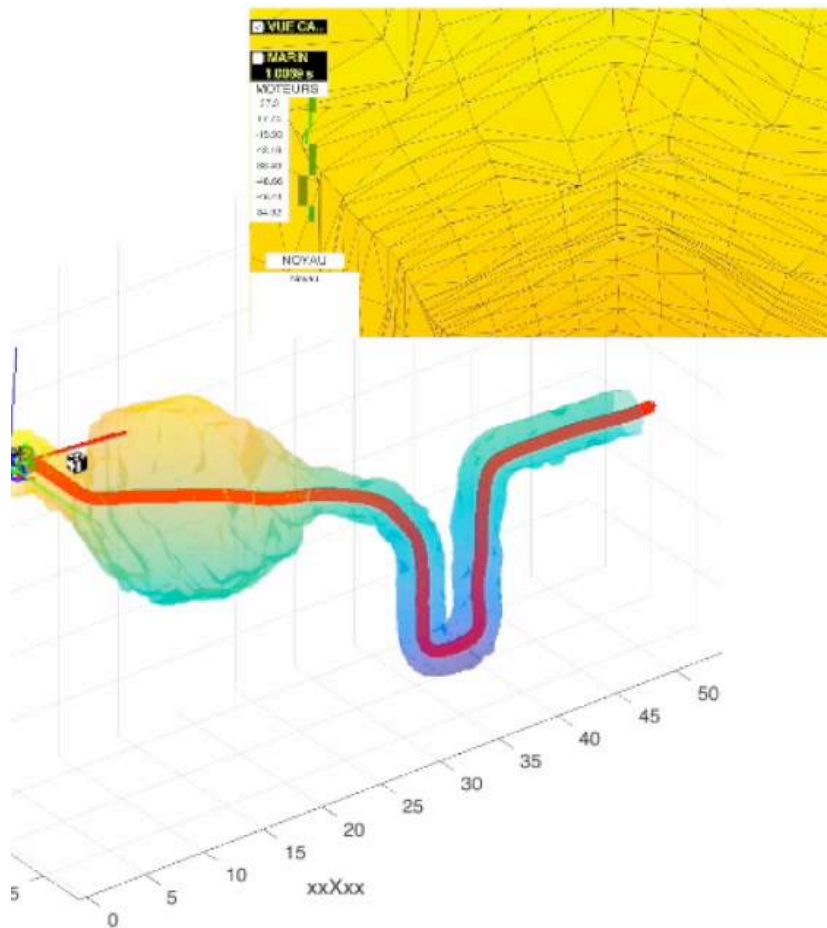
Fig. 1. From Van der Zand [16] (top): The African Molefish *Gnathopetris* (bottom): top view of the fish head electric field.

The article is structured as follows. First we will briefly

NEAR FUTURE : ANR LS2N, ENSTA, ISSKA

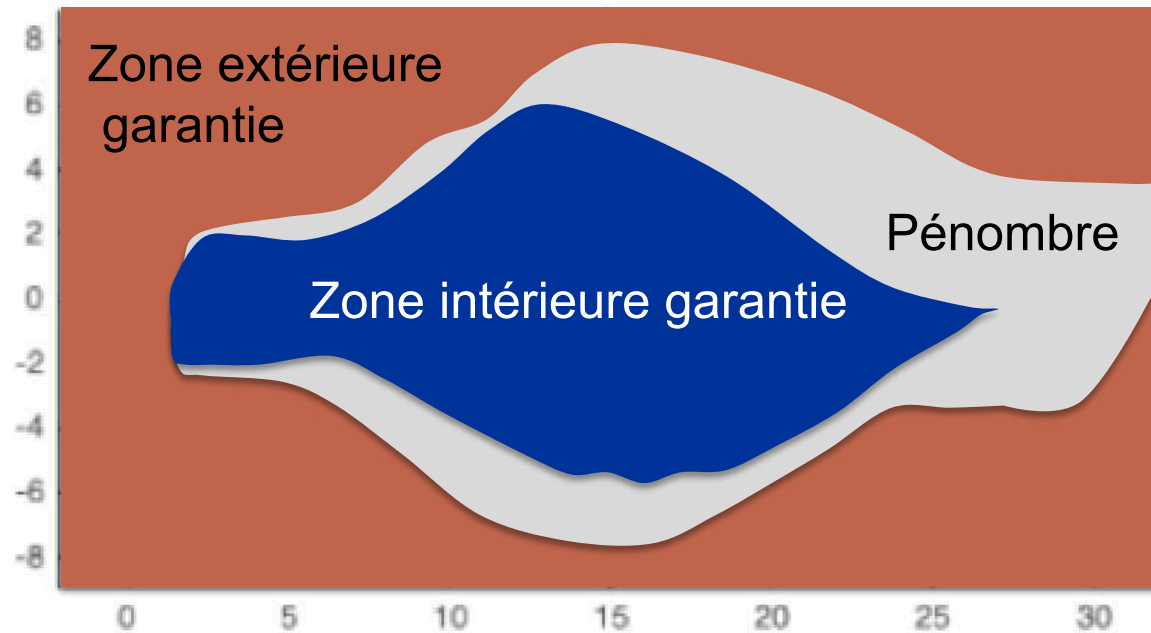
- Locomotion anguilliforme et Sens électrique
- Cartographie garantie, analyse par intervalles

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



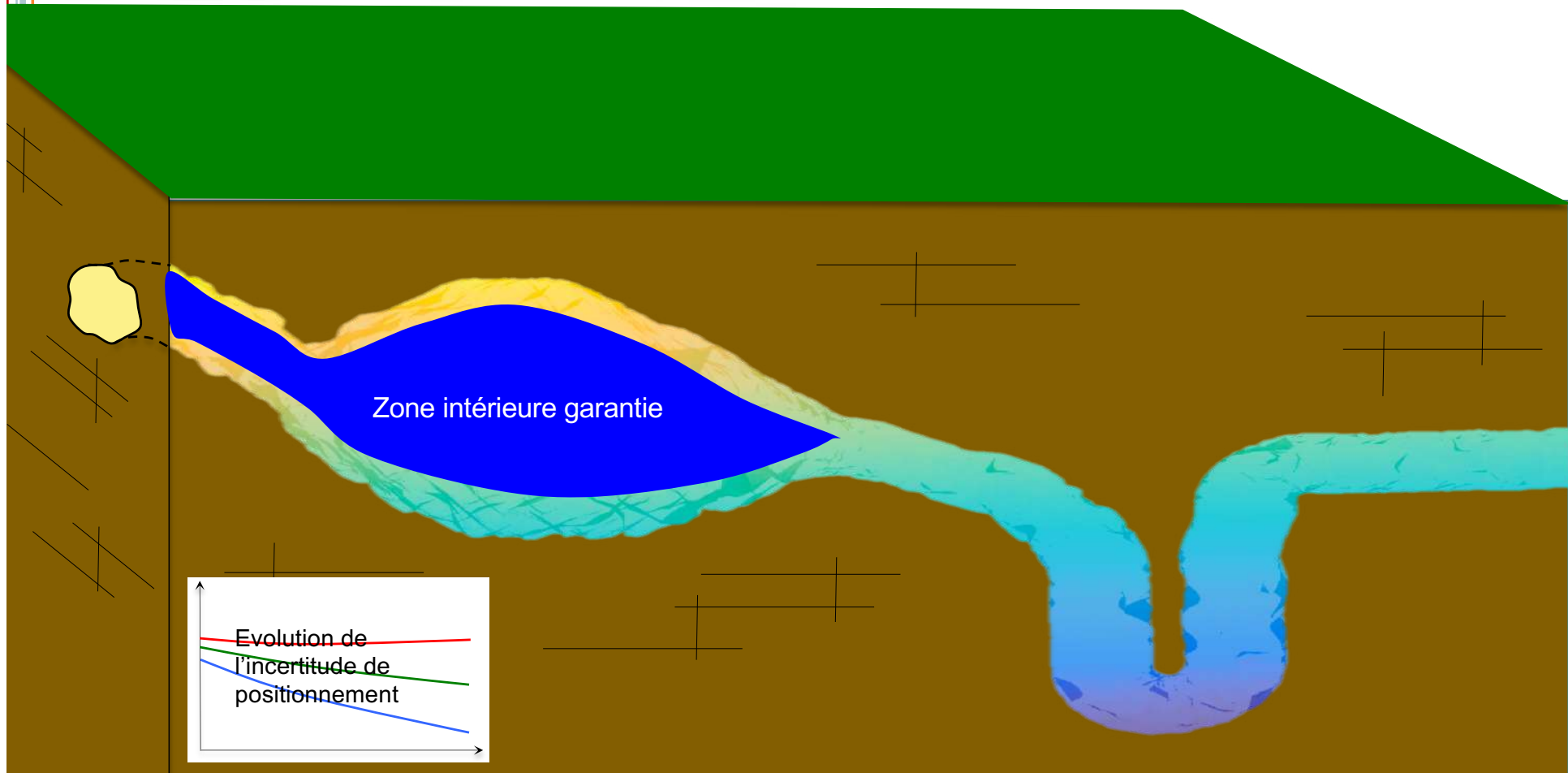
NEAR FUTURE : ANR LS2N, ENSTA, ISSKA

- Locomotion anguilliforme et Sens électrique
- Cartographie garantie, analyse par intervalles



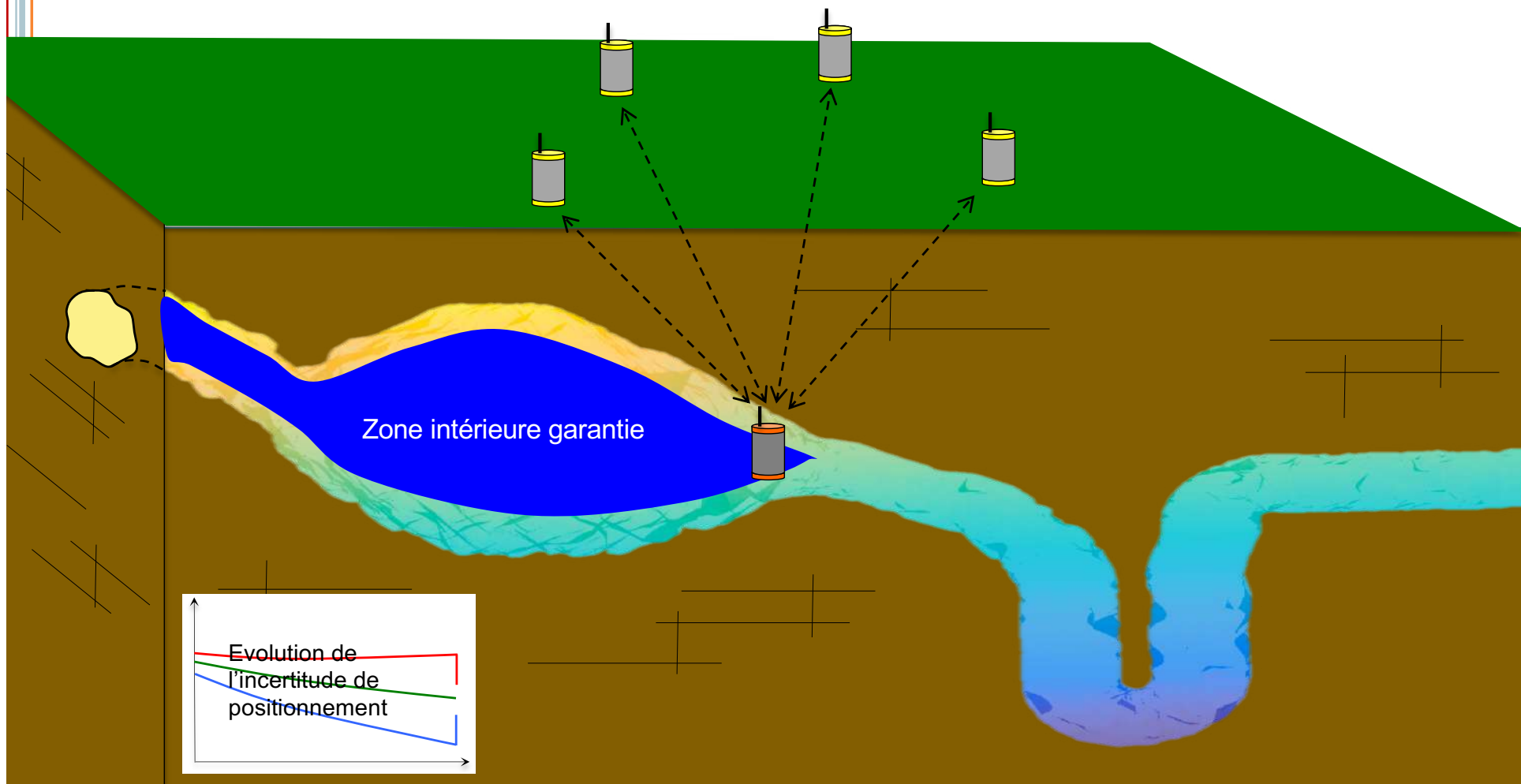
NEAR FUTURE : ANR LS2N, ENSTA, ISSKA

- Locomotion anguilliforme et Sens électrique
- Cartographie garantie, analyse par intervalles
- Recalage par UG-GPS (ISSKA, localisation magnétique)



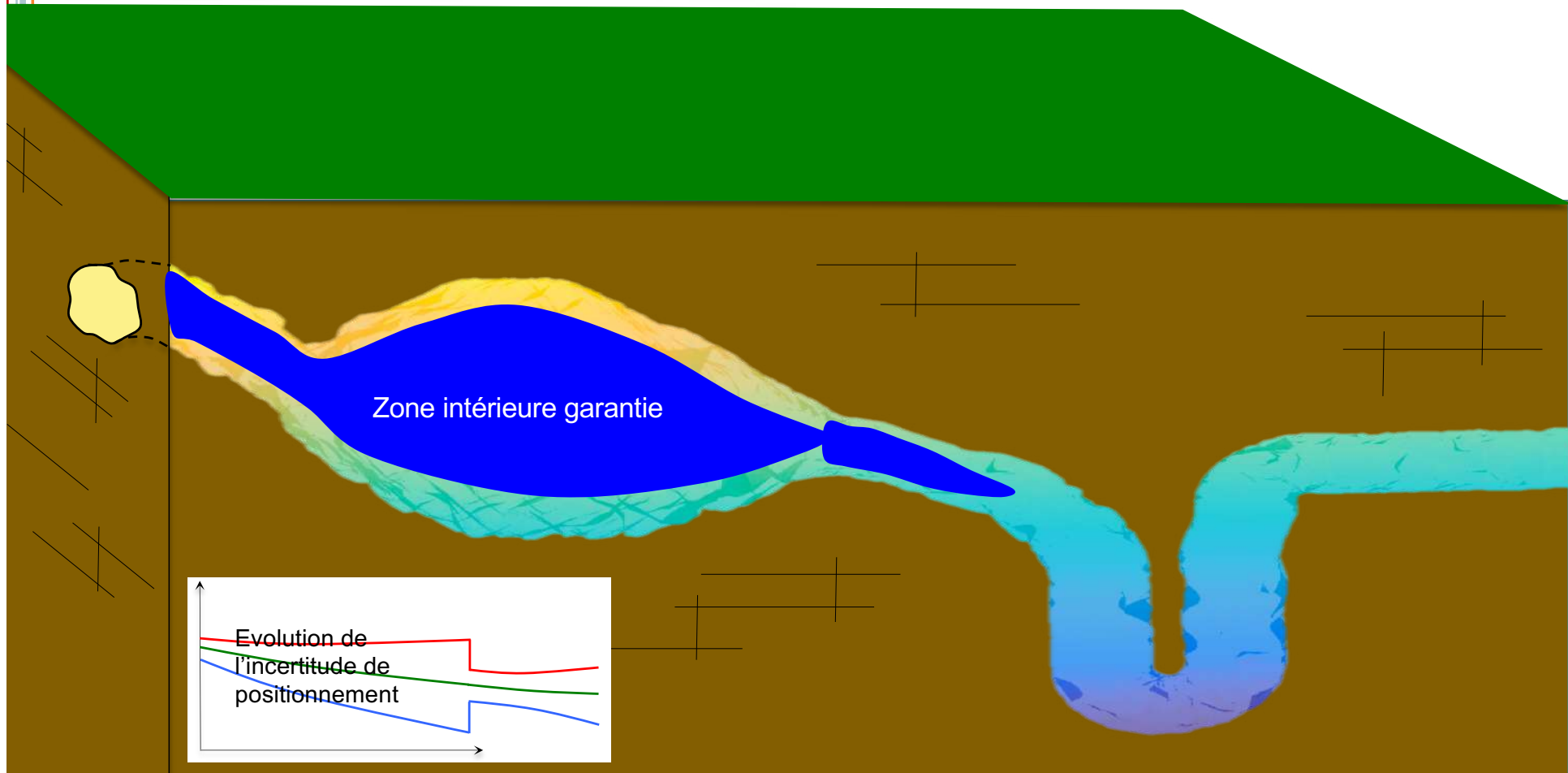
NEAR FUTURE : ANR LS2N, ENSTA, ISSKA

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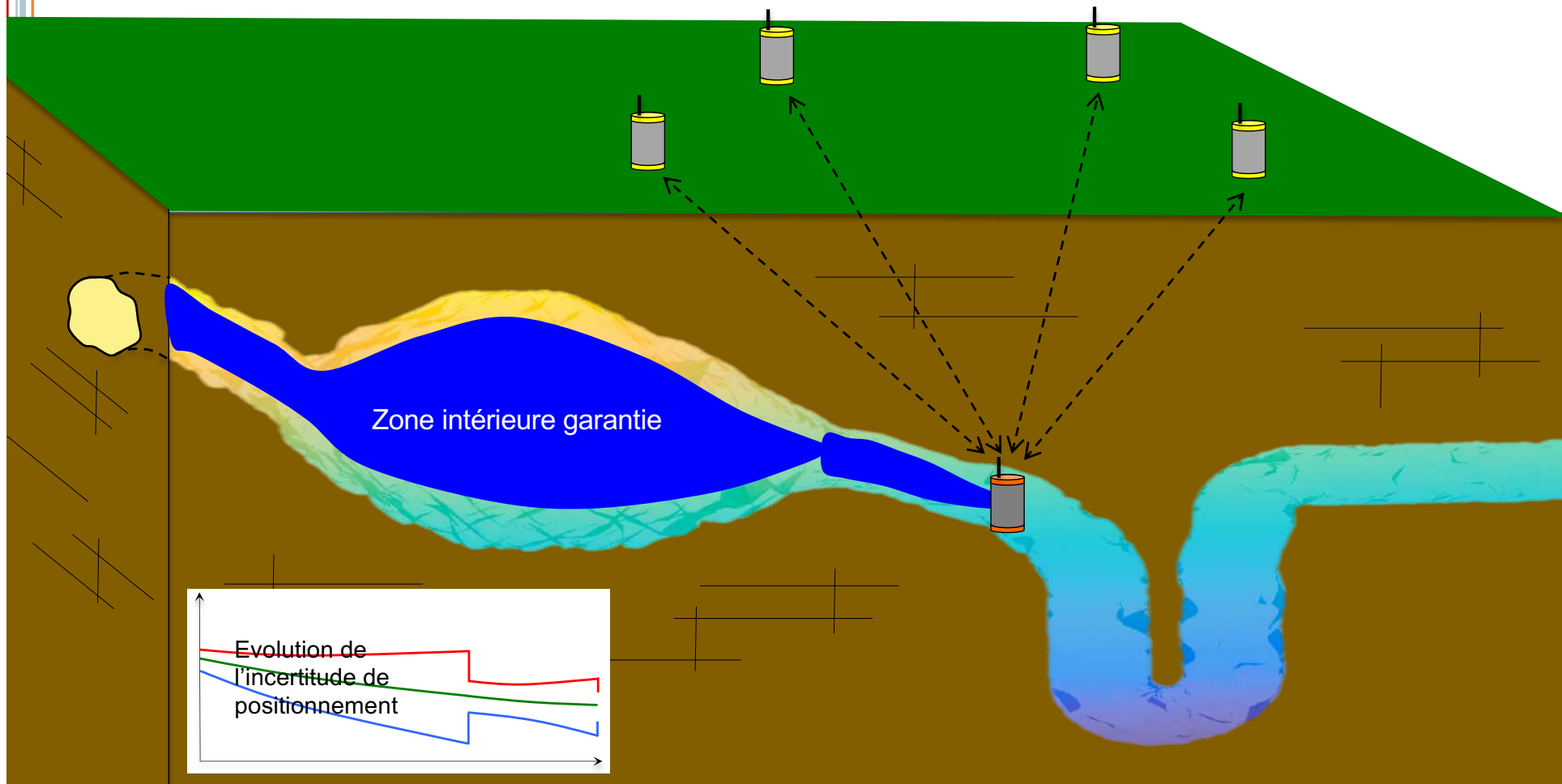
NEAR FUTURE : ANR LS2N, ENSTA, ISSKA

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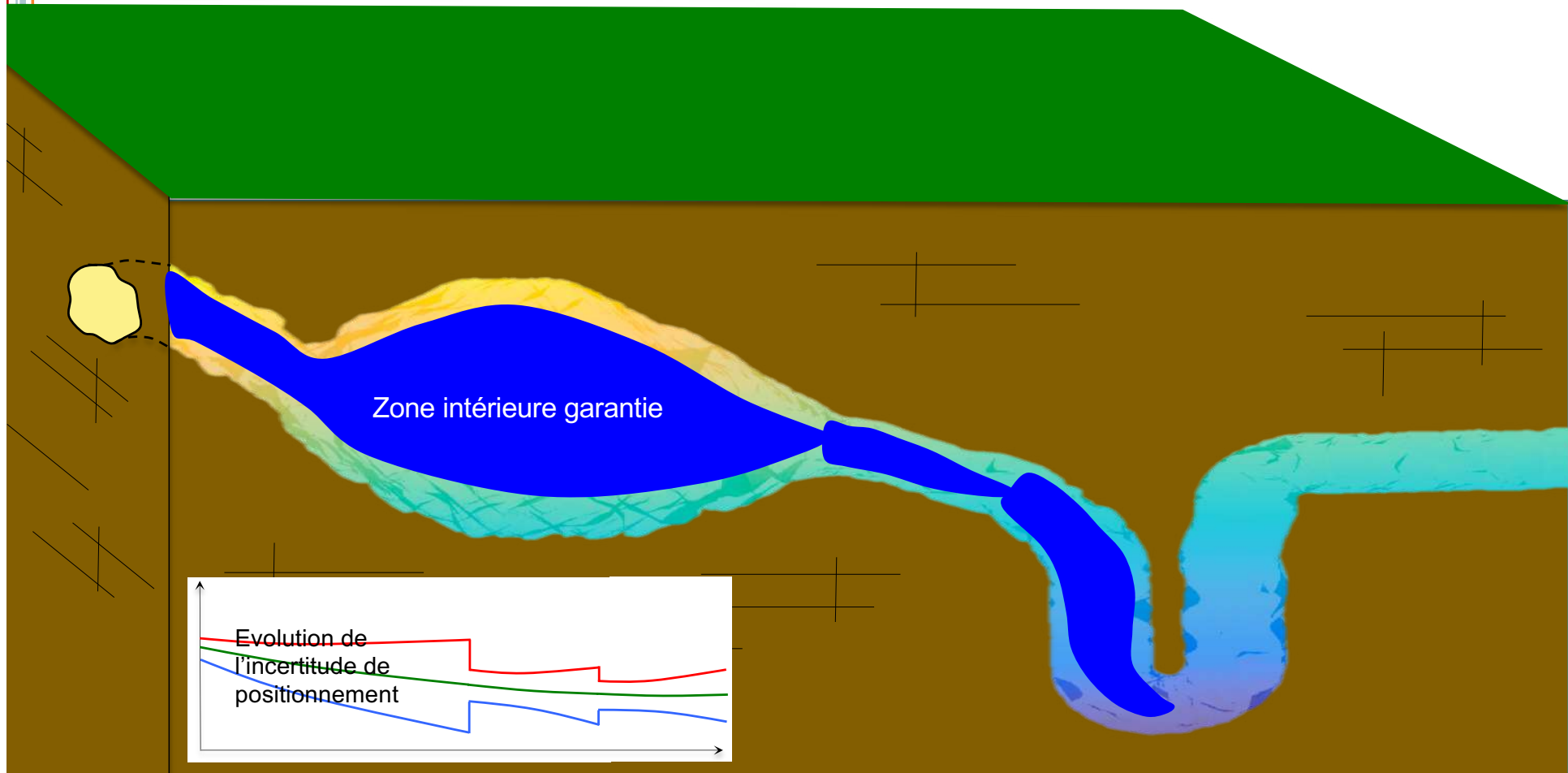
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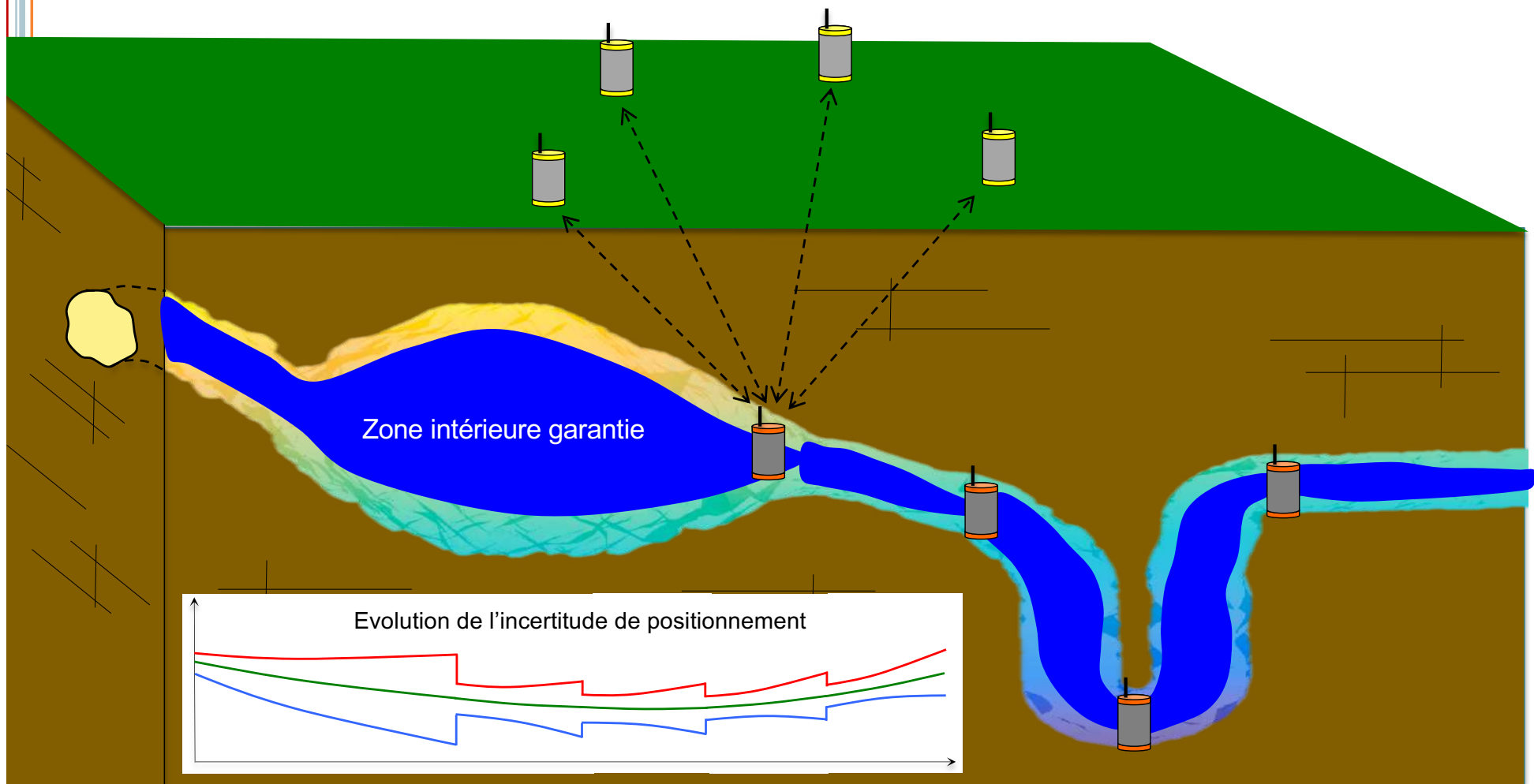
NEAR FUTURE : ANR LS2N, ENSTA, ISSKA

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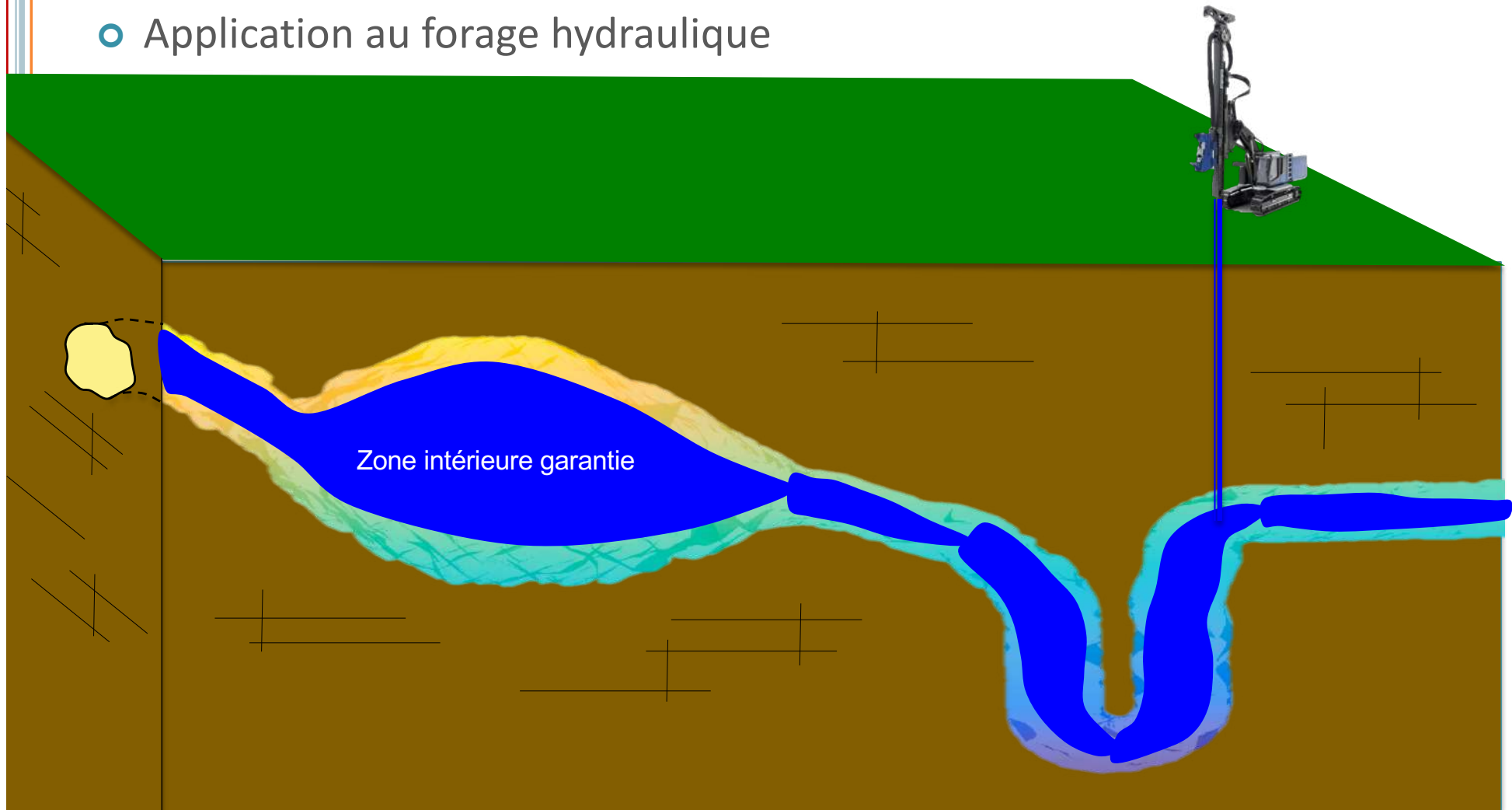
NEAR FUTURE : ANR LS2N, ENSTA, ISSKA

- Locomotion anguilliforme et Sens électrique
- Cartographie garantie, analyse par intervalles
- Recalage par UG-GPS (ISSKA, localisation magnétique)



NEAR FUTURE : ANR LS2N, ENSTA, ISSKA

- Locomotion anguilliforme et Sens électrique
- Cartographie garantie, analyse par intervalles
- Recalage par UG-GPS (ISSKA, localisation magnétique)
- Application au forage hydraulique





LE PROJET DE FONDATION

LE PROJET DE FONDATION

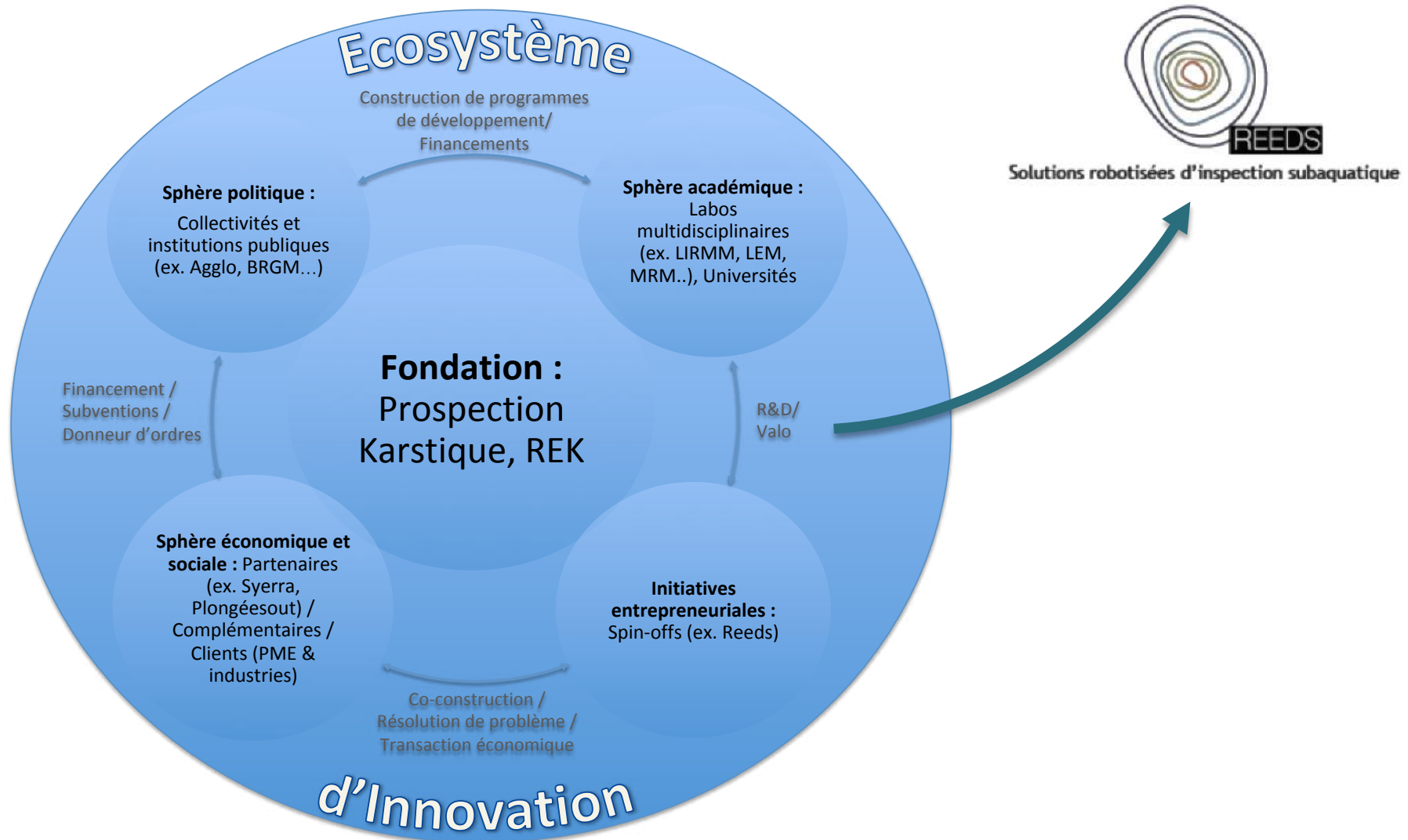
La Fondation



Connaître l'eau cachée pour mieux la protéger

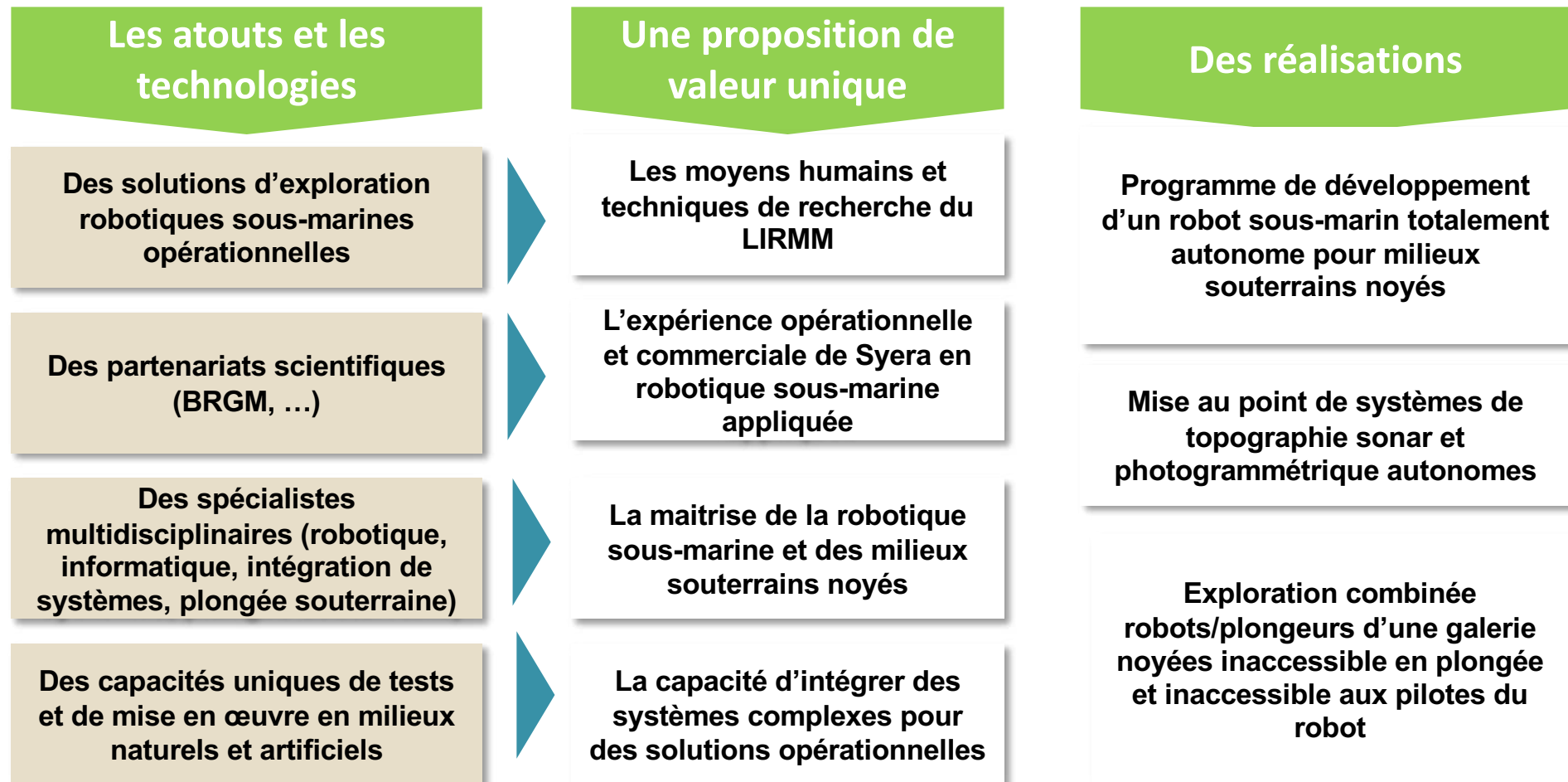
LE PROJET DE FONDATION

- Abriter l'écosystème d'innovation qui verra l'avènement du marché de l'exploration karstique.

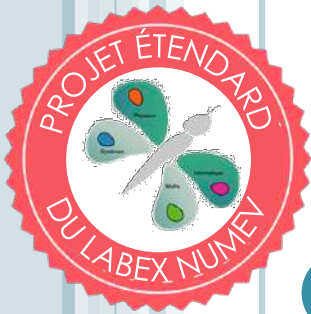


LE PROJET DE FONDATION

- Abriter l'écosystème d'innovation qui verra l'avènement du marché de l'exploration karstique.







Robotique d'Exploration Karstique: Bilan et perspectives

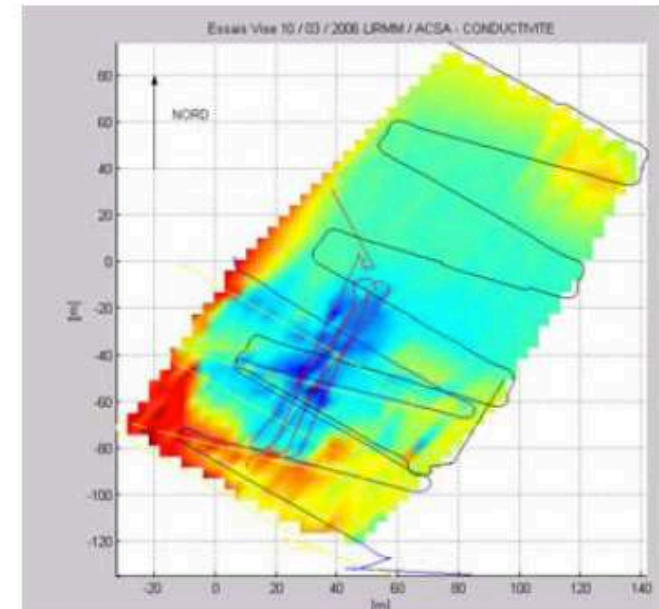
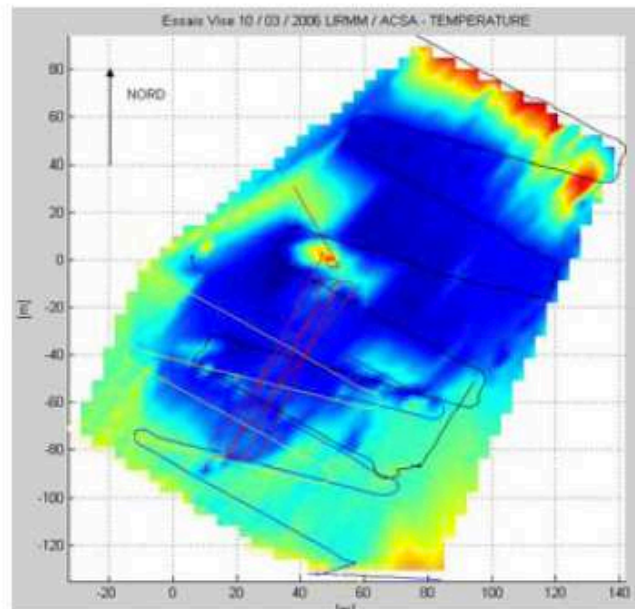
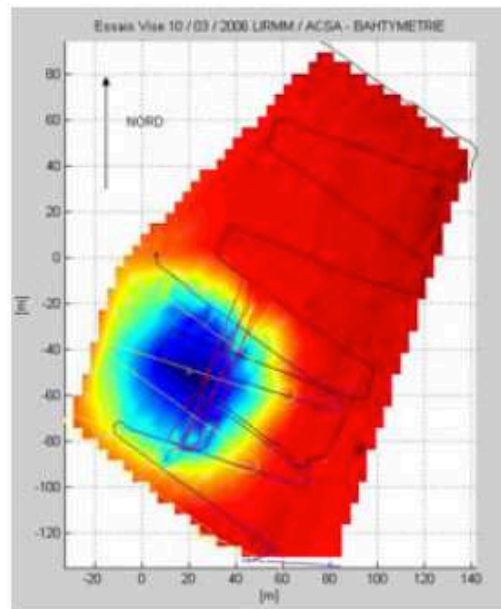


SOURCES DU LEZ : A SEMINAL CASE STUDY

- Fresh water plume detection : MEDITATE EC Project



Taipan II



SOME RESULTS : ACTUATION LAYER ROBUSTNESS

Consider the redundant system

$$\mathbf{F}_B = \mathbf{A} \cdot \mathbf{F}_m \quad (\text{Concentrator}) \quad \mathbf{A} = \begin{bmatrix} -.866 & -.866 & .866 & .866 \\ -.5 & .5 & .5 & -.5 \\ .226 & -.226 & .226 & -.226 \end{bmatrix}$$

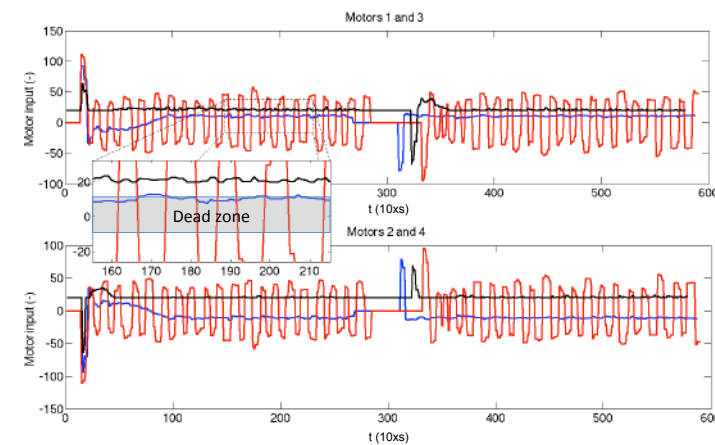
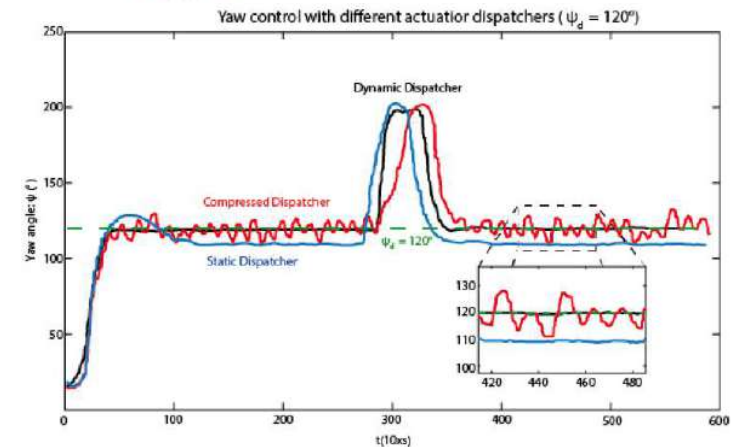
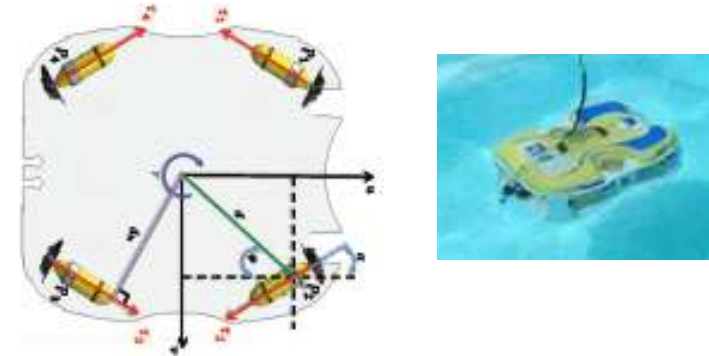
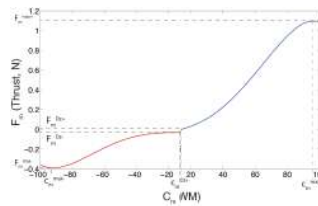
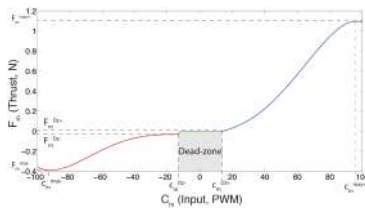
Consider the yaw control (simple PD)

$$\mathbf{F}_B^d = \begin{bmatrix} F_u \\ F_v \\ \Gamma_r \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ k_1 \cdot (\psi_d - \psi) - k_2 \cdot r \end{bmatrix}$$

Compute Actuator Forces (classic Moore-Pensose Pseudo-inverse)

$$\mathbf{F}_m = \mathbf{A}^+ \cdot \mathbf{F}_B^d \quad (\text{Classic Dispatcher})$$

Classic reflex : Compress dead-zone



SOME RESULTS : ACTUATION LAYER ROBUSTNESS

Consider the redundant system

$$\mathbf{F}_B = \mathbf{A} \cdot \mathbf{F}_m \quad (\text{Concentrator}) \quad \mathbf{A} = \begin{bmatrix} -.866 & -.866 & .866 & .866 \\ -.5 & .5 & .5 & -.5 \\ .226 & -.226 & .226 & -.226 \end{bmatrix}$$

Consider the yaw control (simple PD)

$$\mathbf{F}_B^d = \begin{bmatrix} F_u \\ F_v \\ \Gamma_r \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ k_1 \cdot (\psi_d - \psi) - k_2 \cdot r \end{bmatrix}$$

Exploit redundancy

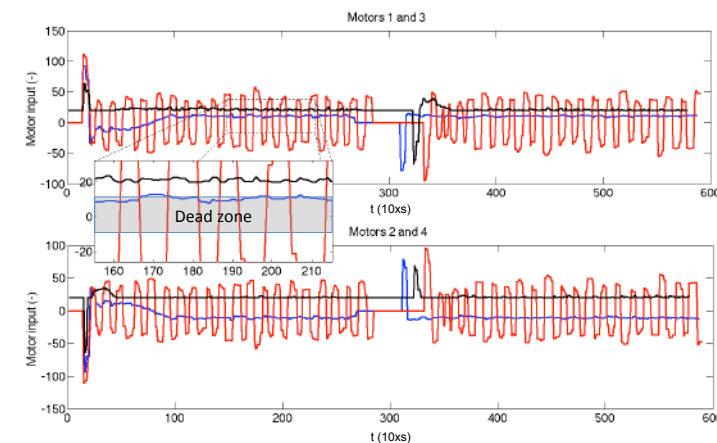
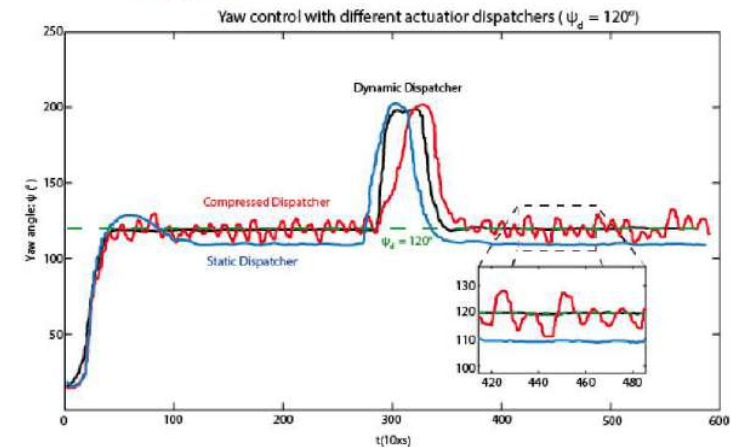
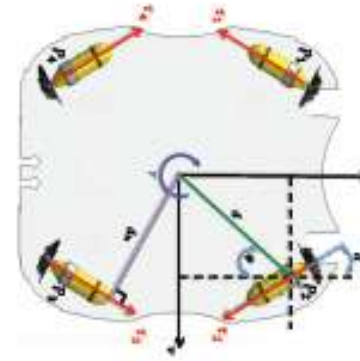
$$\mathbf{F}_m = \begin{bmatrix} \mathbf{A}^+ & \mathbf{M}_m \\ (\text{Dispatcher}) \end{bmatrix} \cdot \begin{bmatrix} \mathbf{F}_B^d \\ r_m \end{bmatrix}$$

$$\mathbf{M}_m \in \ker(\mathbf{A}) \Rightarrow \mathbf{A} \cdot \mathbf{M}_m = \mathbf{0}$$

$$\mathbf{F}_B = \mathbf{A} \cdot \mathbf{A}^+ \cdot \mathbf{F}_B^d + \mathbf{A} \cdot \mathbf{M}_m \cdot r_m$$

$$\mathbf{F}_B = \mathbf{A} \cdot \mathbf{A}^+ \cdot \mathbf{F}_B^d = \mathbf{F}_B^d, \quad \forall r_m$$

(for some nice properties of A)



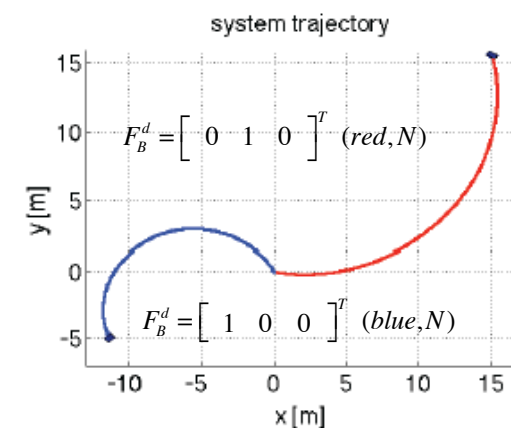
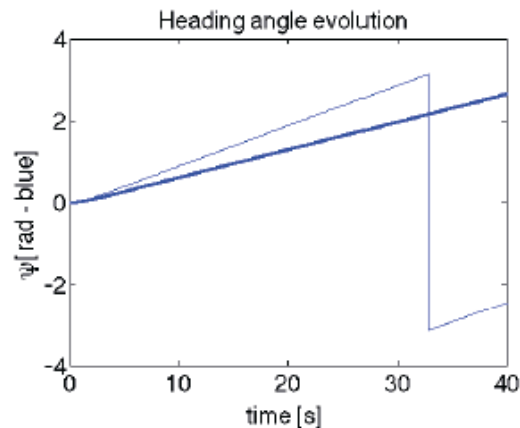
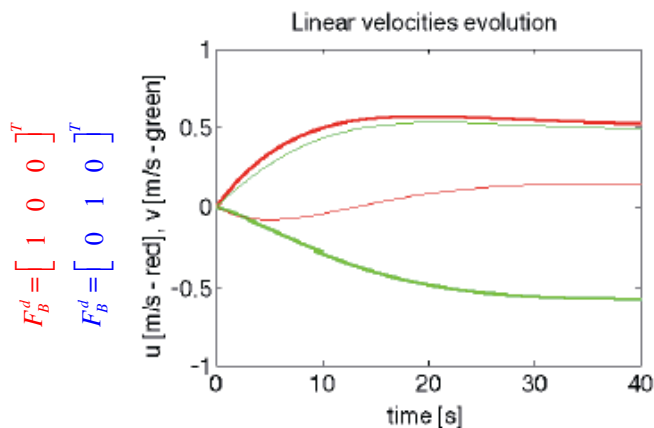
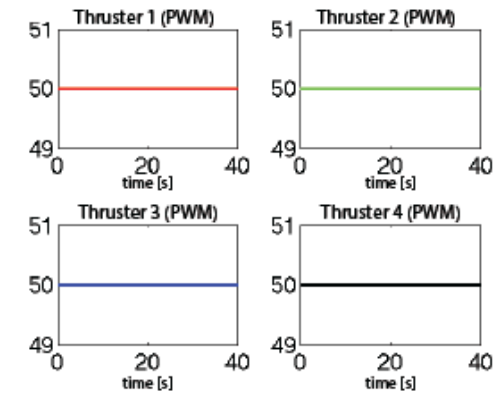
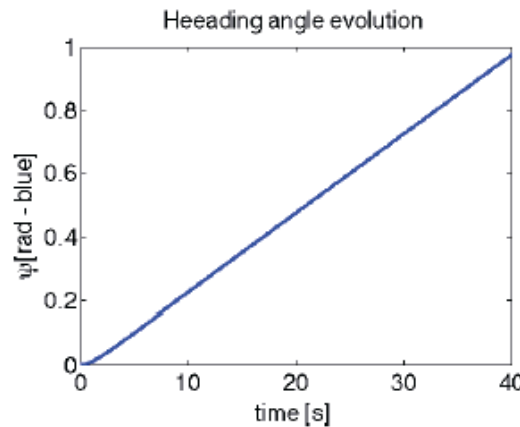
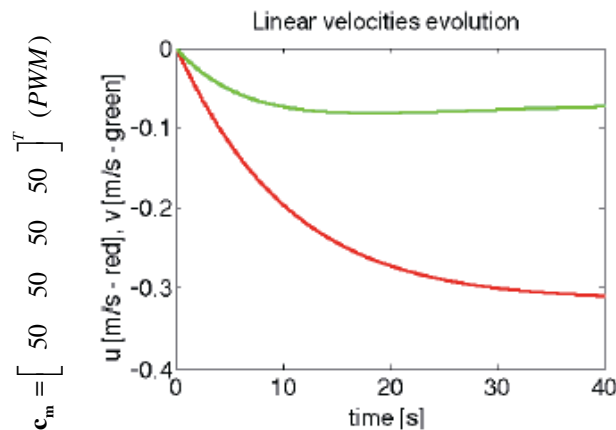
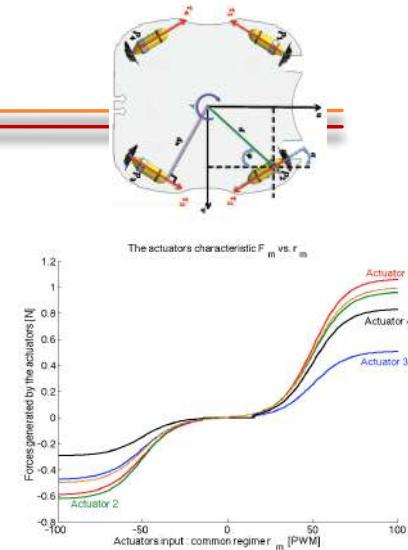
SOME RESULTS : ACTUATION LAYER ROBUSTNESS

Consider the motors' characteristic uncertainty and disparity

$$\mathbf{F}_m = \Omega(\mathbf{c}_m) \quad \mathbf{c}_m = \hat{\Omega}^{-1}(\mathbf{F}_m)$$

$$\mathbf{F}_B = \mathbf{A} \cdot \Omega\left(\hat{\Omega}^{-1}\left(\mathbf{A}^+ \cdot \mathbf{F}_B^d + \mathbf{M}_m \cdot r_m\right)\right) \equiv \mathbf{A} \cdot \Omega \cdot \hat{\Omega}^{-1} \cdot \left(\mathbf{A}^+ \cdot \mathbf{F}_B^d + \mathbf{M}_m \cdot r_m\right) \neq \mathbf{F}_B^d$$

→ DOF Coupling effect



SOME RESULTS : ACTUATION LAYER ROBUSTNESS

Consider the motors' characteristic uncertainty and disparity

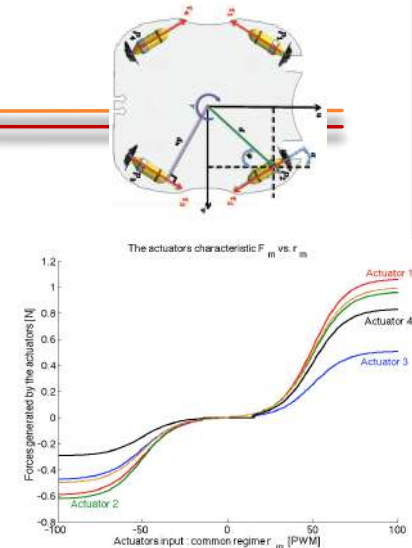
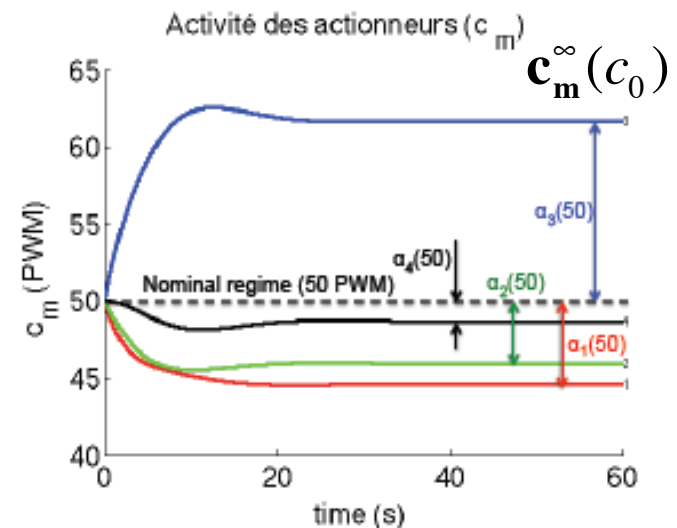
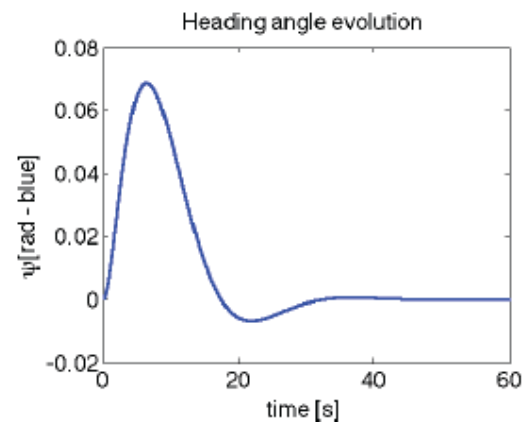
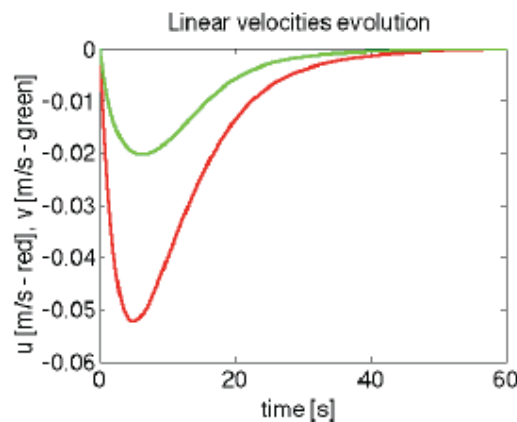
$$\mathbf{F}_m = \Omega(\mathbf{c}_m) \quad \mathbf{c}_m = \hat{\Omega}^{-1}(\mathbf{F}_m)$$

$$\mathbf{F}_B = \mathbf{A} \cdot \Omega\left(\hat{\Omega}^{-1}\left(\mathbf{A}^+ \cdot \mathbf{F}_B^d + \mathbf{M}_m \cdot r_m\right)\right) \equiv \mathbf{A} \cdot \Omega \cdot \hat{\Omega}^{-1} \cdot \left(\mathbf{A}^+ \cdot \mathbf{F}_B^d + \mathbf{M}_m \cdot r_m\right) \neq \mathbf{F}_B^d$$

→ DOF Coupling effect

Consider the following closed loop control

$$\mathbf{F}_B^d = \begin{bmatrix} -u - \int_0^t u \cdot dt \\ -v - \int_0^t v \cdot dt \\ -\psi - r - 0.1 \cdot \int_0^t \psi \cdot dt \end{bmatrix}, \left\{ \begin{array}{l} \mathbf{c}_m = \hat{\Omega}^{-1} \cdot \mathbf{A}^+ \cdot (\mathbf{F}_B^d + \mathbf{M}_m \cdot r_m) \\ r_m = \Omega \cdot c_0 \end{array} \right.$$



SOME RESULTS : ACTUATION LAYER ROBUSTNESS

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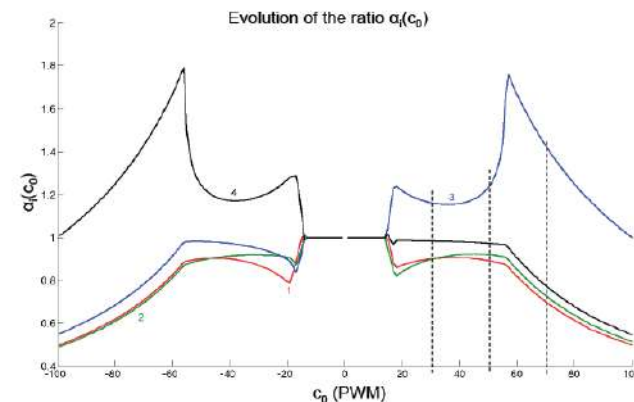
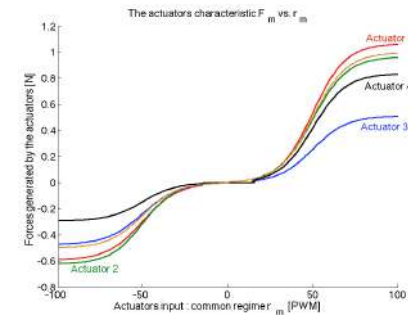
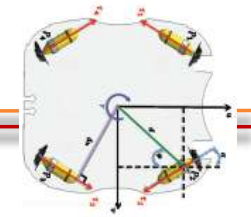
Iterate for $c_{m,\min} < c_m < c_{m,\max}$

$$\mathbf{F}_B = \mathbf{A} \cdot \Omega \cdot \mathbf{c}_m^\infty(c_0) = \mathbf{0}$$

$$\Rightarrow \mathbf{c}_m^\infty(c_0) \in \ker(\mathbf{A} \cdot \Omega)$$

$$\Rightarrow \alpha_i(c_0) = \frac{c_{m,i}^\infty}{c_0}$$

$$\Rightarrow \mathbf{Q}(\mathbf{c}_m) = \text{diag}(\alpha_1, \alpha_2, \alpha_3, \alpha_4)$$



SOME RESULTS : ACTUATION LAYER ROBUSTNESS

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$$\mathbf{F}_m = \Omega(\mathbf{c}_m) \quad \mathbf{c}_m = \hat{\Omega}^{-1}(\mathbf{F}_m)$$

$$\mathbf{F}_B = \mathbf{A} \cdot \Omega\left(\hat{\Omega}^{-1}\left(\mathbf{A}^+ \cdot \mathbf{F}_B^d + \mathbf{M}_m \cdot r_m\right)\right) \equiv \mathbf{A} \cdot \Omega \cdot \hat{\Omega}^{-1} \cdot \left(\mathbf{A}^+ \cdot \mathbf{F}_B^d + \mathbf{M}_m \cdot r_m\right) \neq \mathbf{F}_B^d$$

→ DOF Coupling effect

Consider the following closed loop control

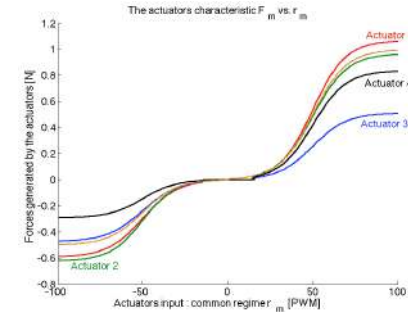
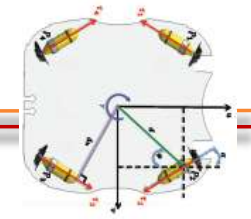
$$\mathbf{F}_B^d = \begin{bmatrix} -u - \int_0^t u \cdot dt \\ -v - \int_0^t v \cdot dt \\ -\psi - r - 0.1 \cdot \int_0^t \psi \cdot dt \end{bmatrix}, \begin{cases} \mathbf{c}_m = \hat{\Omega}^{-1} \cdot \mathbf{A}^+ \cdot (\mathbf{F}_B^d + \mathbf{M}_m \cdot r_m) \\ r_m = \Omega \cdot c_0 \end{cases}$$

Iterate for $c_{m,\min} \leq c_m \leq c_{m,\max}$

Implement the following open loop control

$$\mathbf{c}_m = \mathbf{Q}\left(\hat{\Omega}^{-1} \cdot \mathbf{A}^+ \cdot (\mathbf{F}_B^d + \mathbf{M}_m \cdot r_m)\right)$$

$$\mathbf{F}_B \equiv \mathbf{A} \cdot \Omega \cdot \mathbf{Q} \cdot \hat{\Omega}^{-1} \cdot \begin{bmatrix} \mathbf{A}^+ & \mathbf{M}_m \end{bmatrix} \cdot \begin{bmatrix} \mathbf{F}_B^d \\ r_m \end{bmatrix} = k_Q \cdot \mathbf{F}_B^d$$

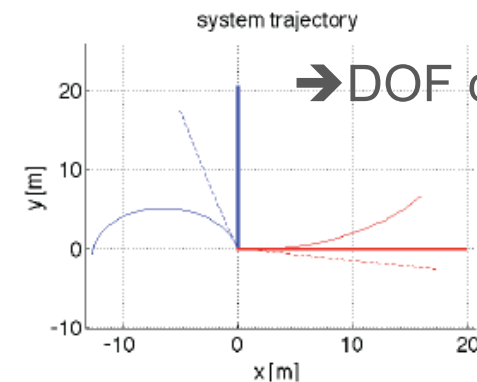


$$\mathbf{F}_B = \mathbf{A} \cdot \Omega \cdot \mathbf{c}_m^\infty(c_0) = \mathbf{0}$$

$$\Rightarrow \mathbf{c}_m^\infty(c_0) \in \ker(\mathbf{A} \cdot \Omega)$$

$$\Rightarrow \alpha_i(c_0) = \frac{c_{m,i}^\infty}{c_0}$$

$$\Rightarrow \mathbf{Q}(\mathbf{c}_m) = \text{diag}(\alpha_1, \alpha_2, \alpha_3, \alpha_4)$$

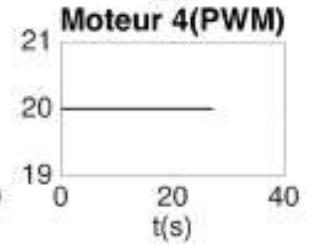
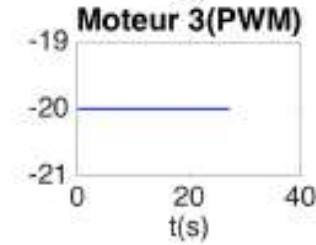
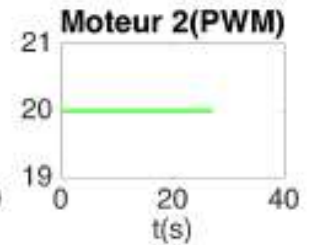
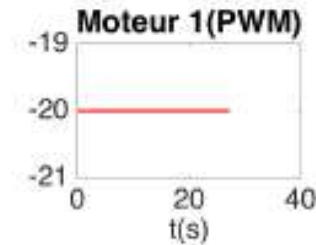
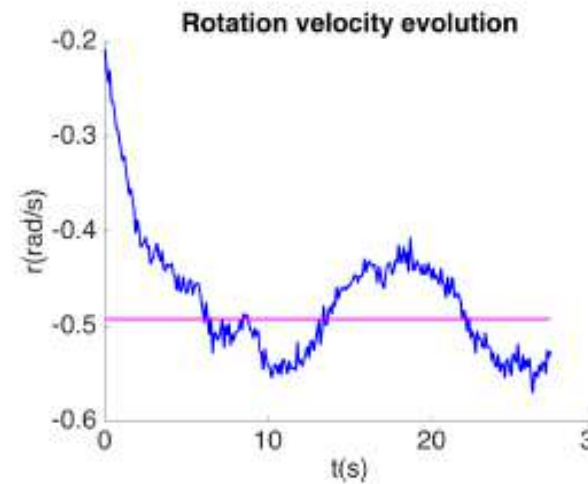
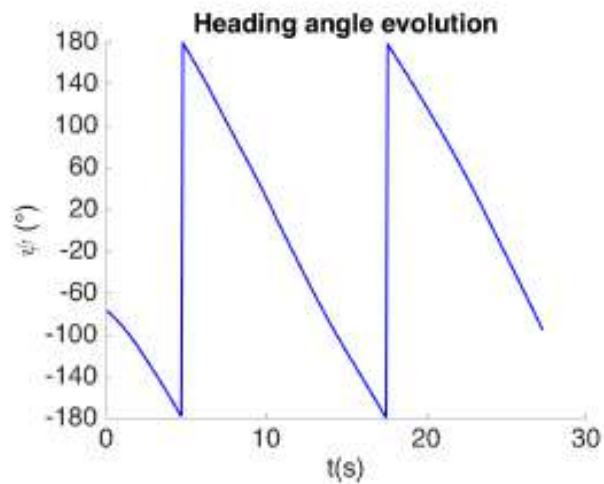


→ DOF decoupled

SOME RESULTS : ACTUATION LAYER ROBUSTNESS

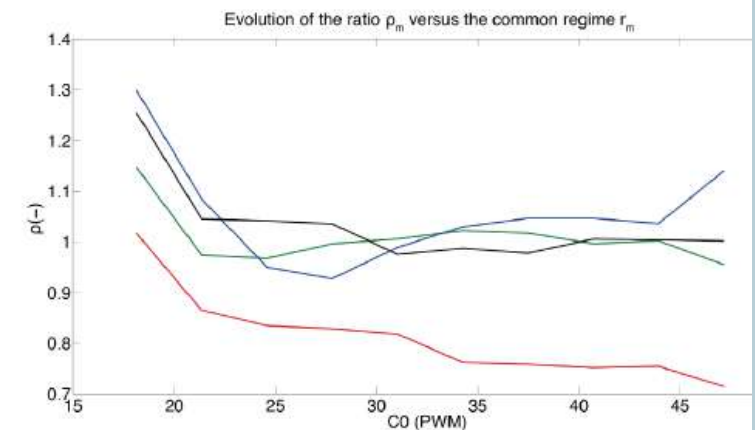
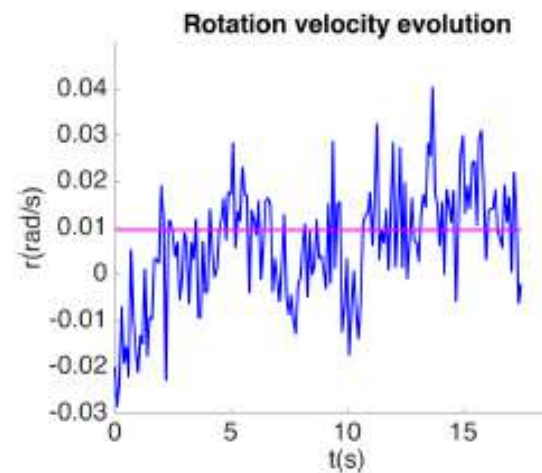
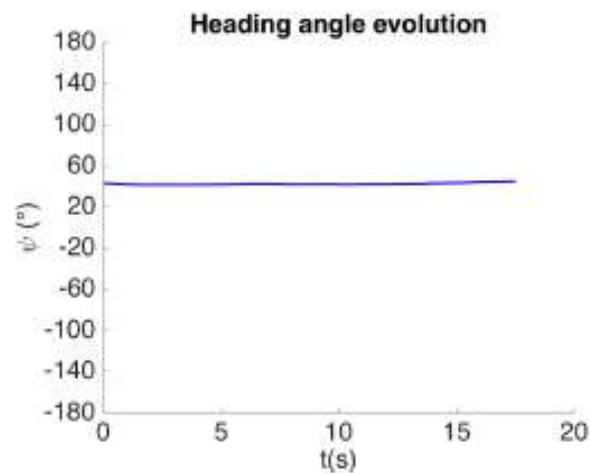


$$\mathbf{c}_m = \hat{\mathbf{\Omega}}^{-1} \cdot \mathbf{A}^+ \cdot (\mathbf{0} + \mathbf{M}_m \cdot \mathbf{r}_m)$$



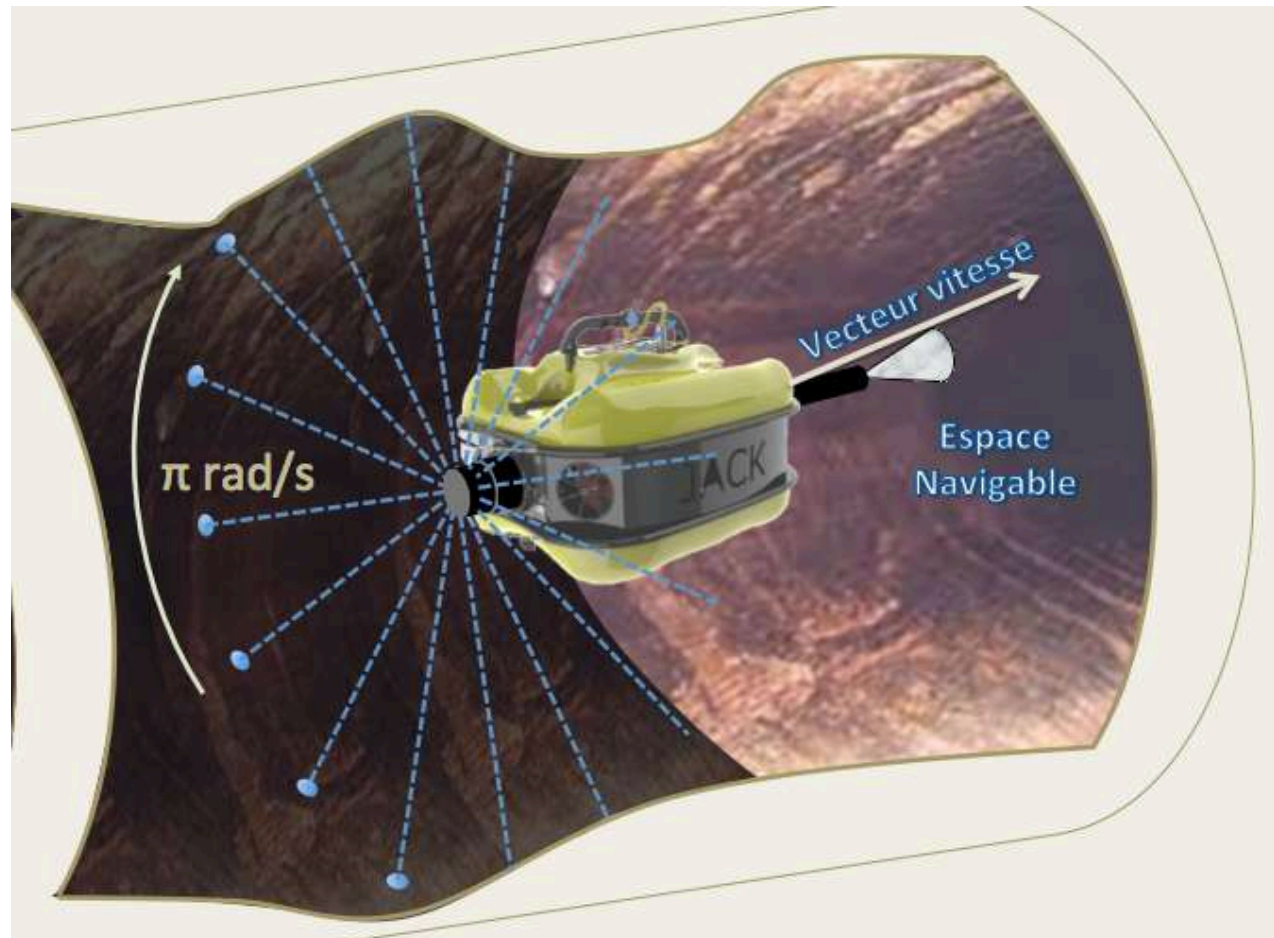
$$\mathbf{c}_m = \mathbf{Q}(\hat{\mathbf{\Omega}}^{-1} \cdot \mathbf{A}^+ \cdot (\mathbf{0} + \mathbf{M}_m \cdot \mathbf{r}_m))$$

$$\mathbf{Q}(\mathbf{c}_m)$$



CHANTIERS SCIENTIFIQUES EN COURS

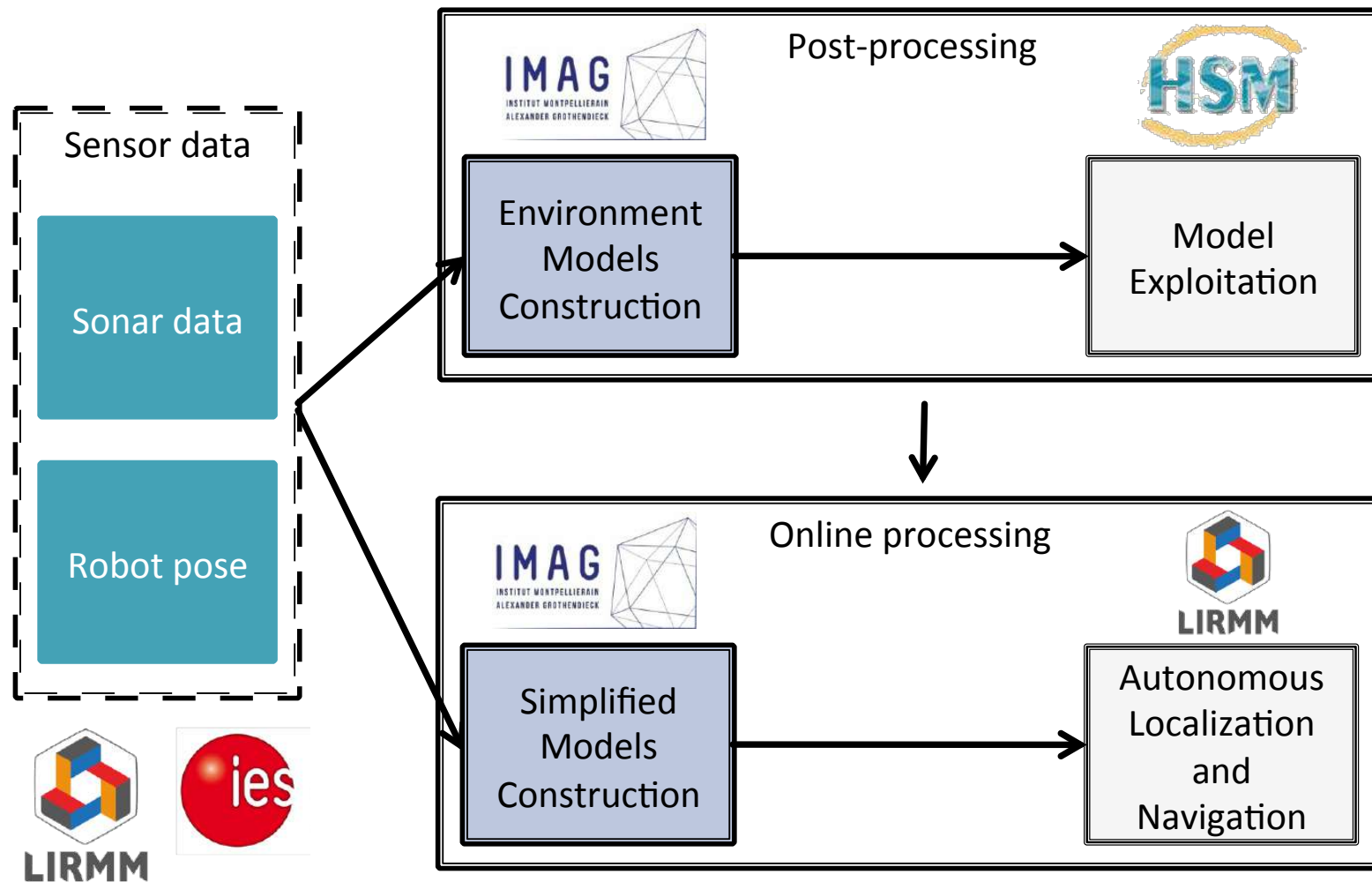
- Commande réactive orientée modèle de terrain



CHANTIERS SCIENTIFIQUES EN COURS

○ Modèles et Navigation (Post-Doc LIRMM-IMAG)

- From Sensors to Environmental models



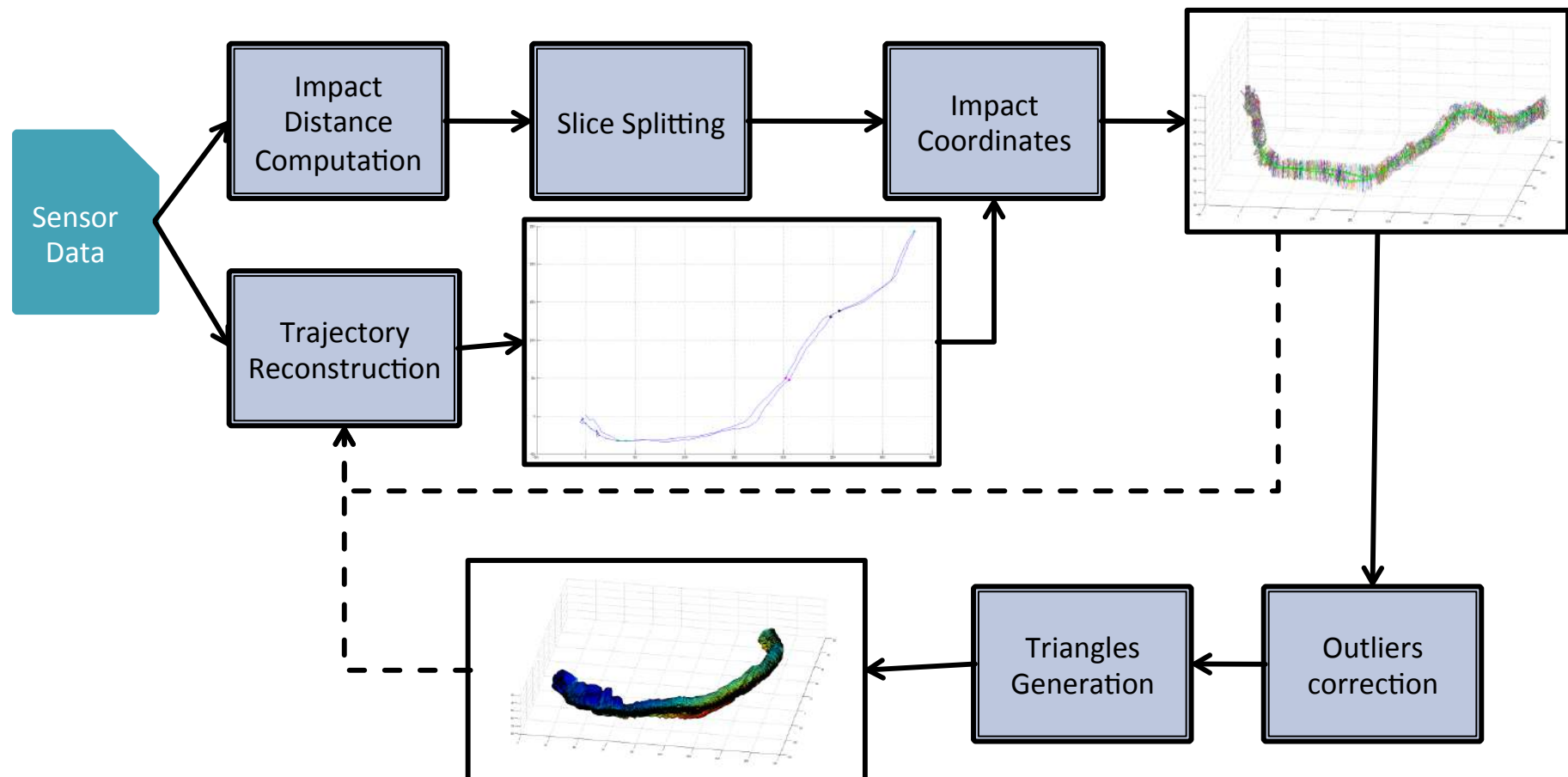
CHANTIERS SCIENTIFIQUES EN COURS

- Modèles et Navigation (Post-Doc LIRMM-IMAG)
 - Online Processing challenges
 - Producing a **simplified model** that can be used online for **autonomous navigation and localization**
 - Simplified model must contain **environment outline**, notable features (**AMERs***) while considering **uncertainty**
 - Should be used on the robot : **low computational power** requirements

CHANTIERS SCIENTIFIQUES EN COURS

Modèles et Navigation (Post-Doc LIRMM-IMAG)

- Online Processing Pipeline



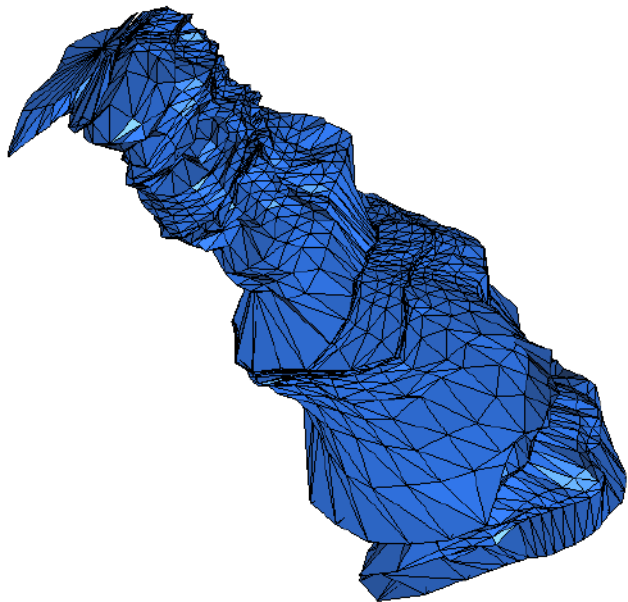
CHANTIERS SCIENTIFIQUES EN COURS

- Modèles et Navigation (Post-Doc LIRMM-IMAG)
 - Post-Processing Challenges
 - Dealing with **imprecision and uncertainties**
 - Use **prior knowledge or expert information** to remove uncertainties and/or check data consistency
 - **Automating** Triangles generation, Consistency check, uncertainties analysis, learning algorithms.

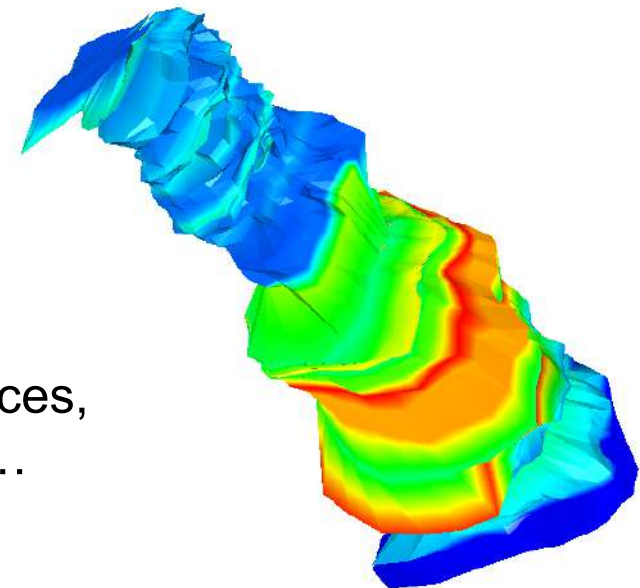
CHANTIERS SCIENTIFIQUES EN COURS

○ Modèles et Navigation (Post-Doc LIRMM-IMAG)

- Post-Processing : uncertainty management
- Example of 3D triangular mesh generated from slices with confidence index. Index can also discriminate between :
 - Missing information (filled using local neighbours)
 - Outliers (inconsistent data corrected using local neighbours)



Extractions de données
fonctionnelles :
Volume (1187 m³), Surfaces,
Vitesses d'écoulements...



Carte des incertitudes

CONCEPTS ET OUTILS MATHÉMATIQUES POUR ALEYIN (IMAG)

Formalisation

Il s'agit d'identifier la distribution de probabilité de x incertain dans R^n à partir d'observations incomplètes et incertaines y_t (commande+capteurs) dans R^m , par extraction d'information et apprentissage:

$x=(\text{localisation+amer\&cartographie\&environnement physique})$

$$u_t = G(x(t,s))$$

u états: solutions de modèles $G=(\text{hydro, salinité, turbidité, turbulence,...})$

avec $x=F^{-1}(y(t,s))$

$y(t,s)$ sorties spatiaux-temporelles de capteurs embarqués.

on supposera la nature de l'aléa sur x , y et u connue.

FSLAM : 'Functional' version of Simultaneous Localization & Mapping

Introduction de la modélisation physique (multi-physique hydro, à complexité réduite pour la phase online) lors de l'apprentissage et l'inversion (Bayésien fonctionnelle)

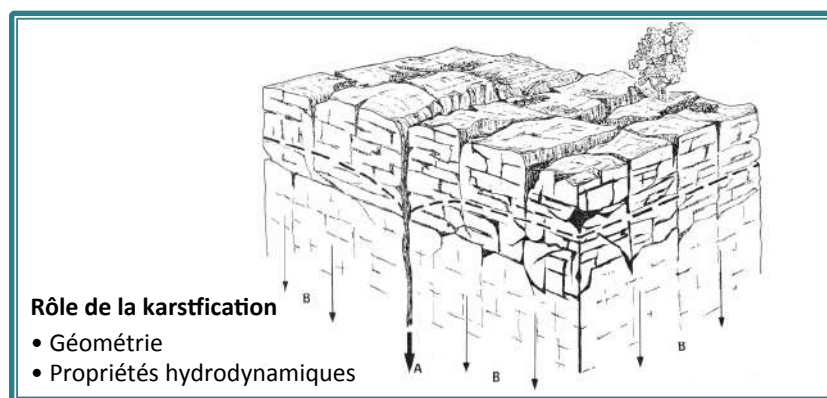
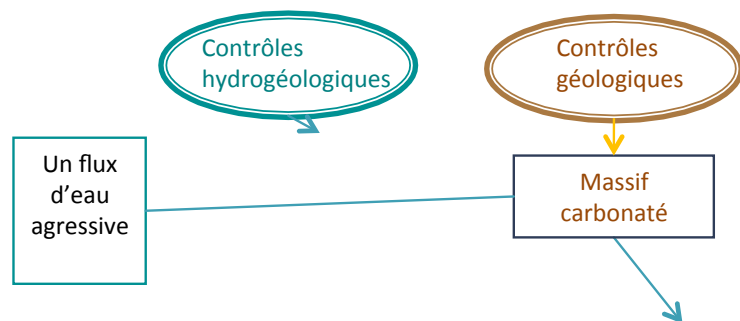
Contraintes de la phase online (pour navigation robot)

- Quasi temps réel pour la reconstruction en cohérence avec les capacités d'acquisition (utilisation de modèle à complexité réduite: Venturi-Bernoulli-Poiseuille)
 - Information cachée, apparaît lors du retour du robot
- Acquisition hélicoïdale de l'information spatiale (2.5m/s)
- Nécessité de modèle géométrique à complexité réduite

Phase offline:

- Grande quantité d'information, mais temps de traitement non contraint (HPC)
- Modélisation plus complexe possible (traitement du signal) en lien avec les hydrologues

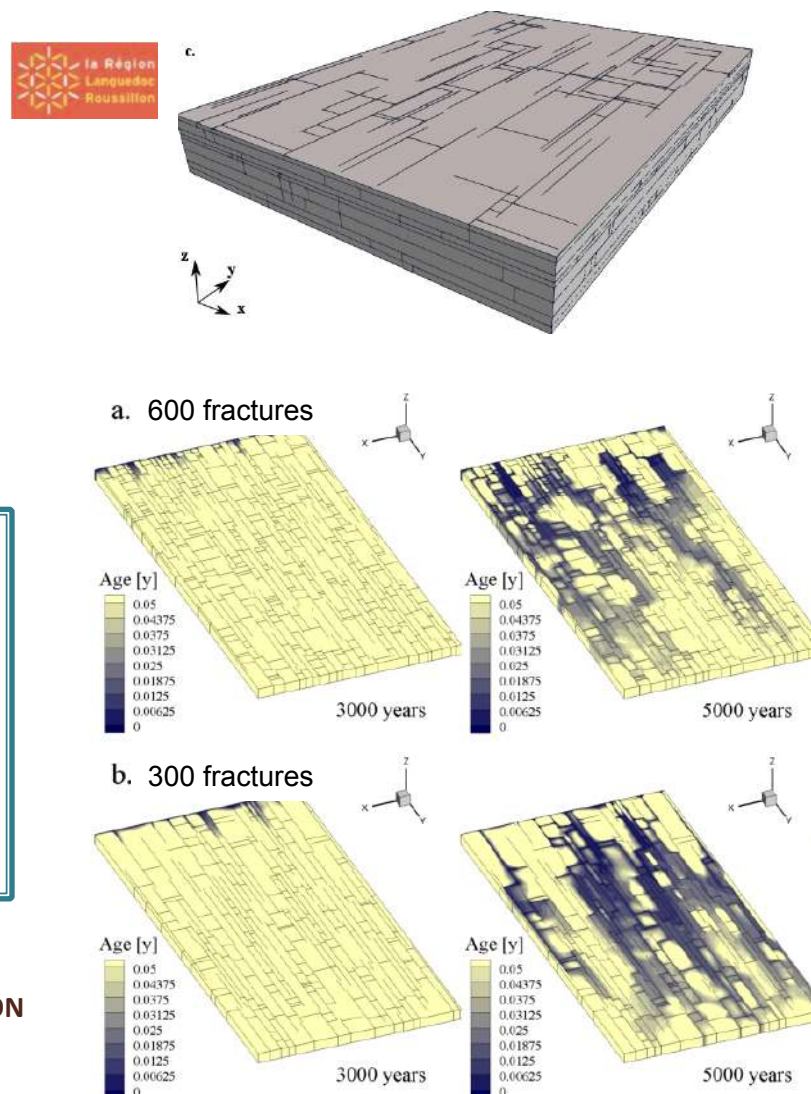
MODÉLISATION DE LA KARSTOGÉNÈSE



PRINCIPAUX CONTRÔLES DES PROCESSUS DE KARSTIFICATION

Thèse: A Lafare (2011)

Structure et hydrodynamique

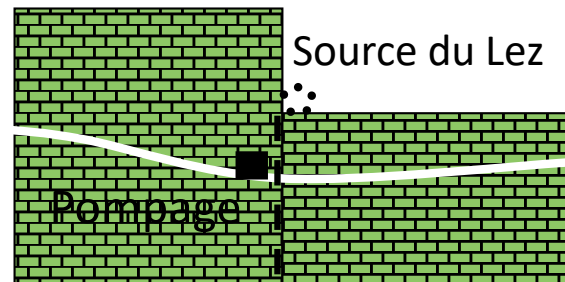


LES ENJEUX

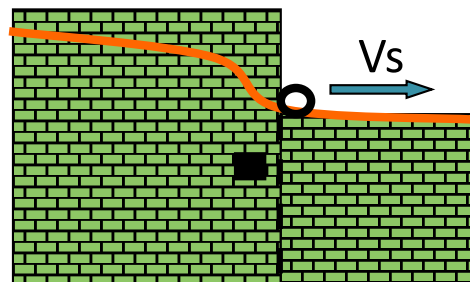
- Incidence des pompages pour l'alimentation en eau des populations (Montpellier Métropole)

Pompage à la source du Lez : Dépression piézométrique
Augmentation de l'espace disponible pour les eaux météoriques infiltrées

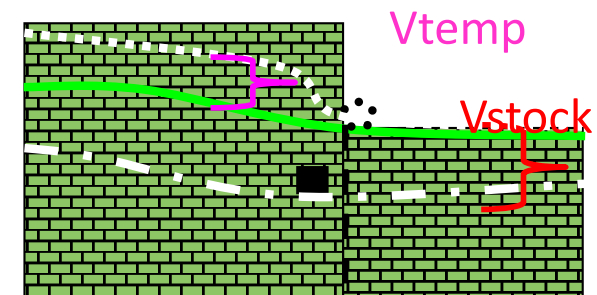
Avant la crue



Au pic de crue



Après la crue



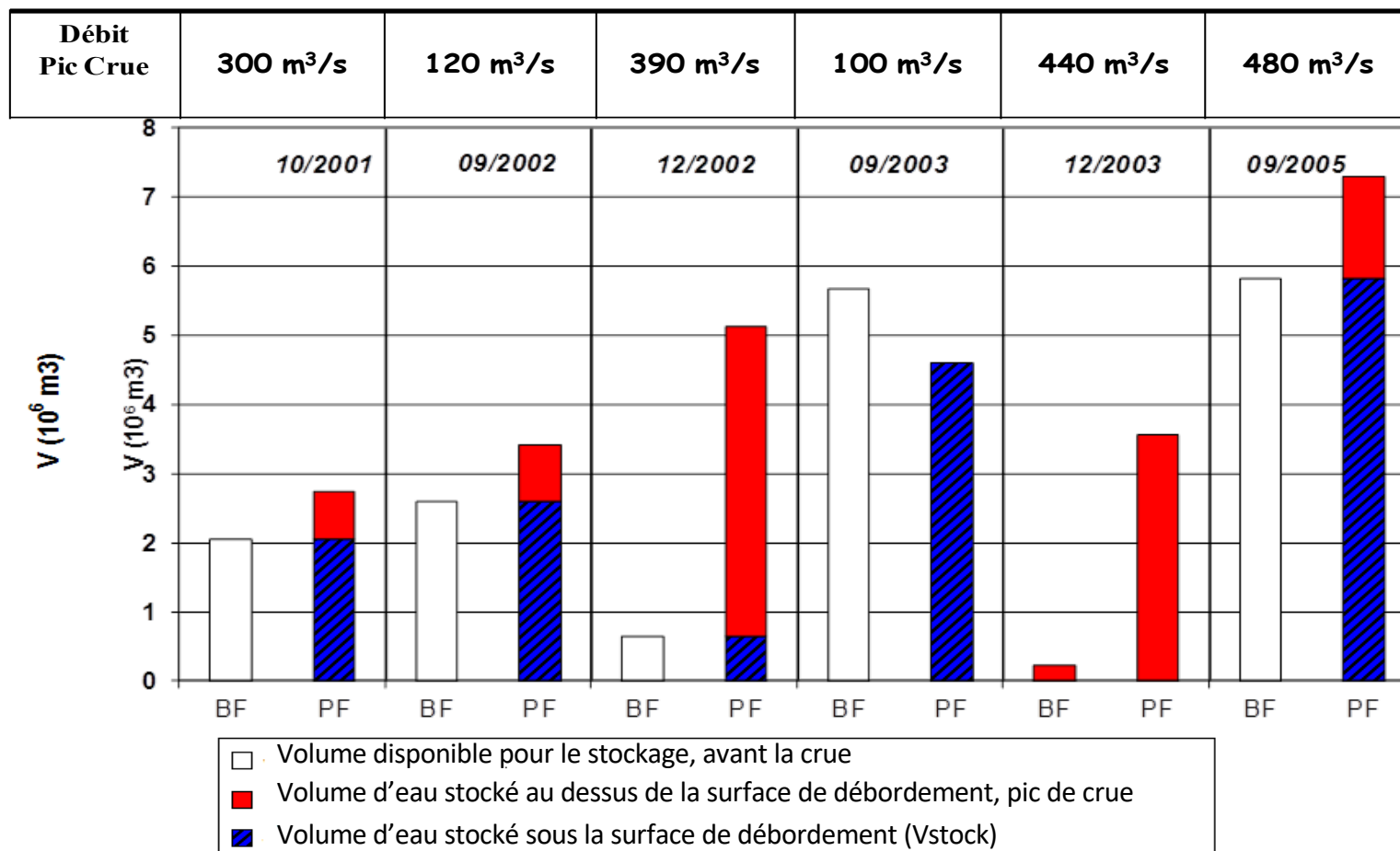
V_{temp} volume d'eau emmagasiné temporairement au dessus de la *surface de débordement*

V_{stock} volume d'eau emmagasiné sous la *surface de débordement*

Porosité effective du karst : $\sim 0.2 \%$

LES ENJEUX

○ Stockage des précipitations dans le karst



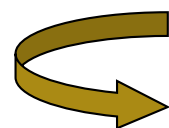
Estimation du volume d'eau emmagasiné dans l'aquifère karstique (▨)

Évènements de Septembre : Fort emmagasinement

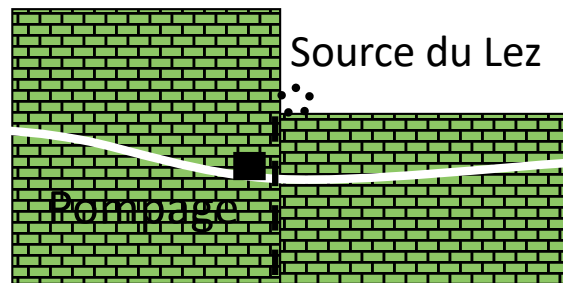
Évènements de Décembre : Faible emmagasinement

LES ENJEUX

○ "Gestion active" de la ressource en eau

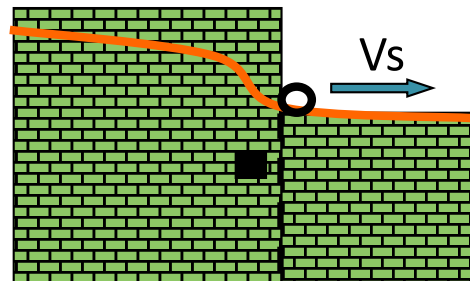
 Pompage à la source du Lez : Sollicitation des réserves renouvelables
Augmentation de l'espace disponible pour les eaux météoriques infiltrées

Avant la crue



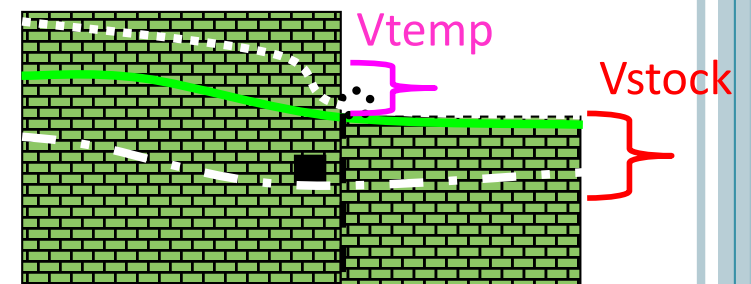
Sollicitation de la
ressource

Au pic de crue



Renouvellement de la
ressource

Après la crue

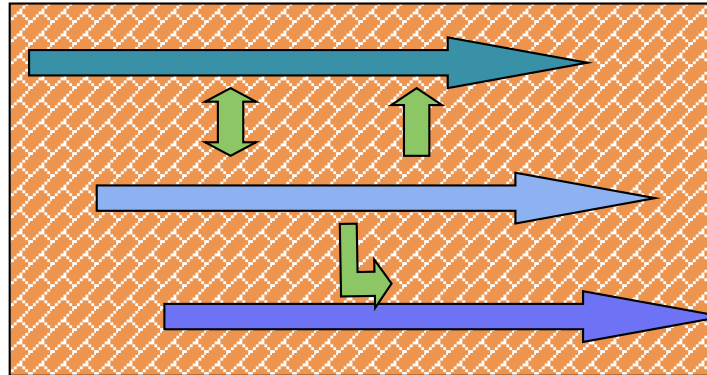


Stockage d'eau par le karst jusqu'à $\sim 7 \text{ M m}^3$
Rôle de "barrage écrêteur de crues"

CONSÉQUENCE DES PROCESSUS DE KARTIFICATION

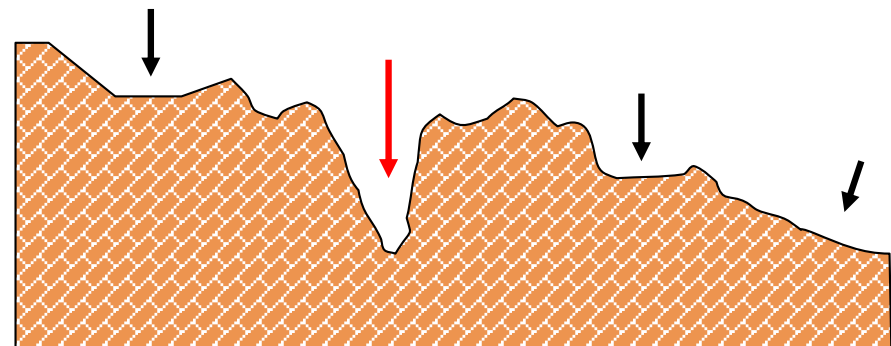
Les réseaux spéléologiques

- La structuration horizontale
- La structuration verticale



Les surfaces karstiques

- Paléo-surfaces aplanies
- Incisions en canyons reculés et vallées périphériques



NIVEAU DE BASE (contrôle le potentiel de karstification)
Point topographique le + bas de l'affleurement karstique



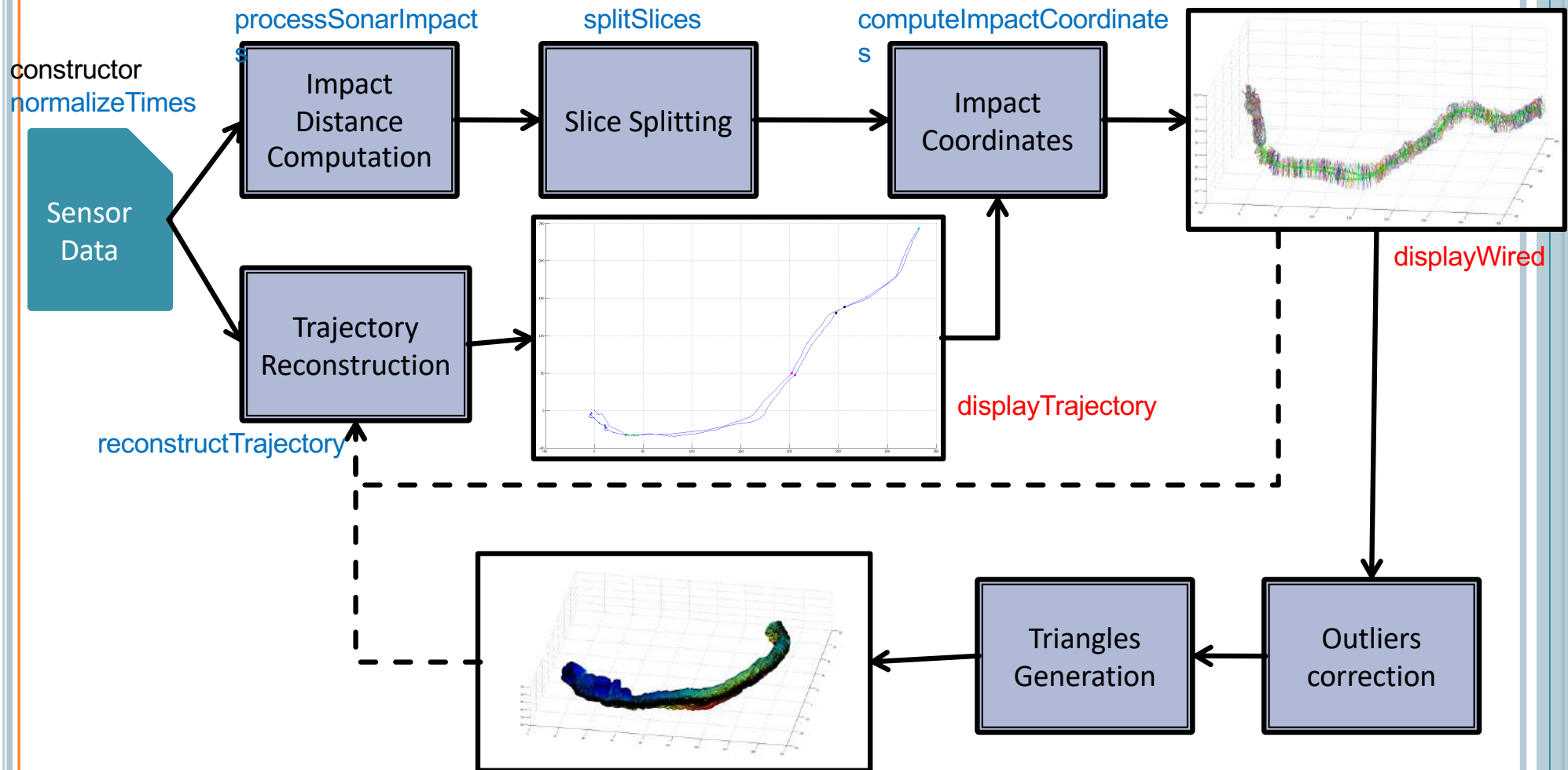
3"E, 11-14/07/2016

RMM



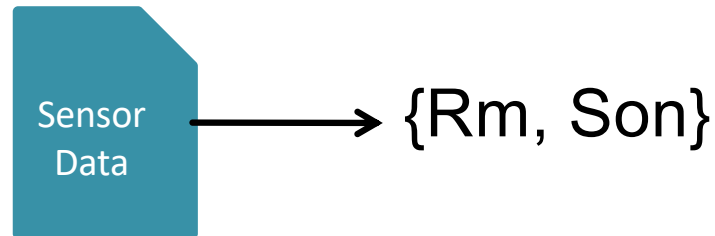
SyERA





All mentioned methods are part of the **ExperimentGourneyras** object.
Except constructor all other methods are called in **process** or **displayResults**

SENSOR DATA



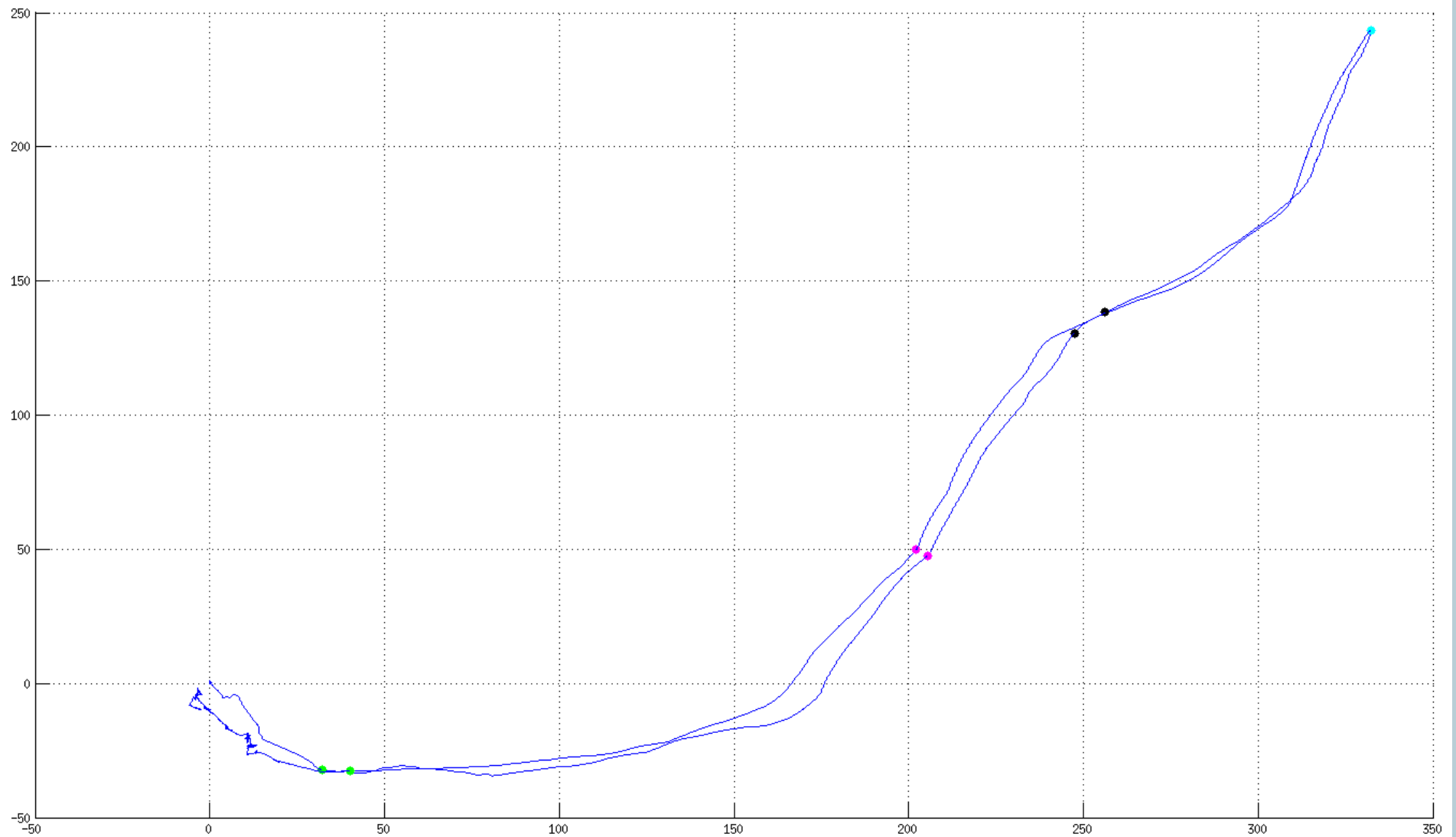
- Robot Motion : $R_m = \{t_{rm}, u, v, w, \phi, \theta, \psi, z, t_{wp}, ID_{wp}\}$
 - Time (t_{rm})
 - Speeds in sensor frame (u, v, w)
 - Orientation in world frame (ϕ, θ, ψ)
 - Depth in world frame (z)
 - Waypoints (t_{wp}, ID_{wp})
- Sonar measurements : $S_{on} = \{t_{son}, \alpha, range, scanline\}$
 - Time (t_{son})
 - Ray Angle (α)
 - Sensor Range ($range$)
 - Scanline (Echo array : $echo_amplitude = f(distance)$)

TRAJECTORY RECONSTRUCTION



- Trajectory : $Tr = R_m \cup \{dx, dy, dz, x, y, z, x_{wp}, y_{wp}, z_{wp}\}$
 - Speeds in world frame (dx, dy, dz)
 - Coordinates in world frame (x, y, z)
 - Waypoint coordinates (x_wp, y_wp, z_wp)
- Waypoints are used to improve trajectory

TRAJECTORY RECONSTRUCTION



IMPACT DISTANCE COMPUTATION



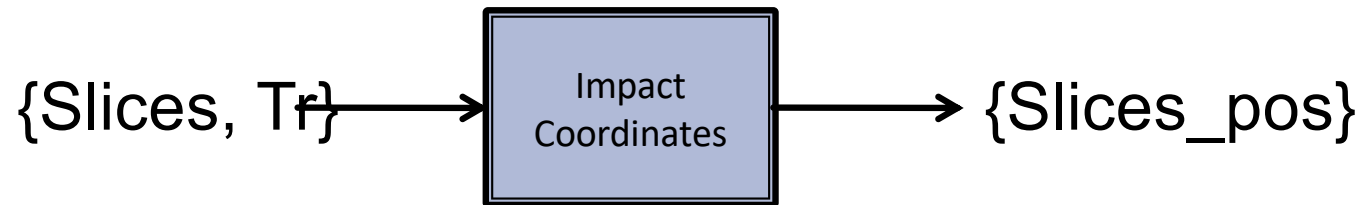
- Sonar measurements : $Son_d = \{t_son, \alpha, range, dist\}$
 - Time (t_son)
 - Ray Angle (α)
 - Sensor Range ($range$)
 - Distance ($dist$)
- Scanline is converted to distance

SLICE SPLITTING



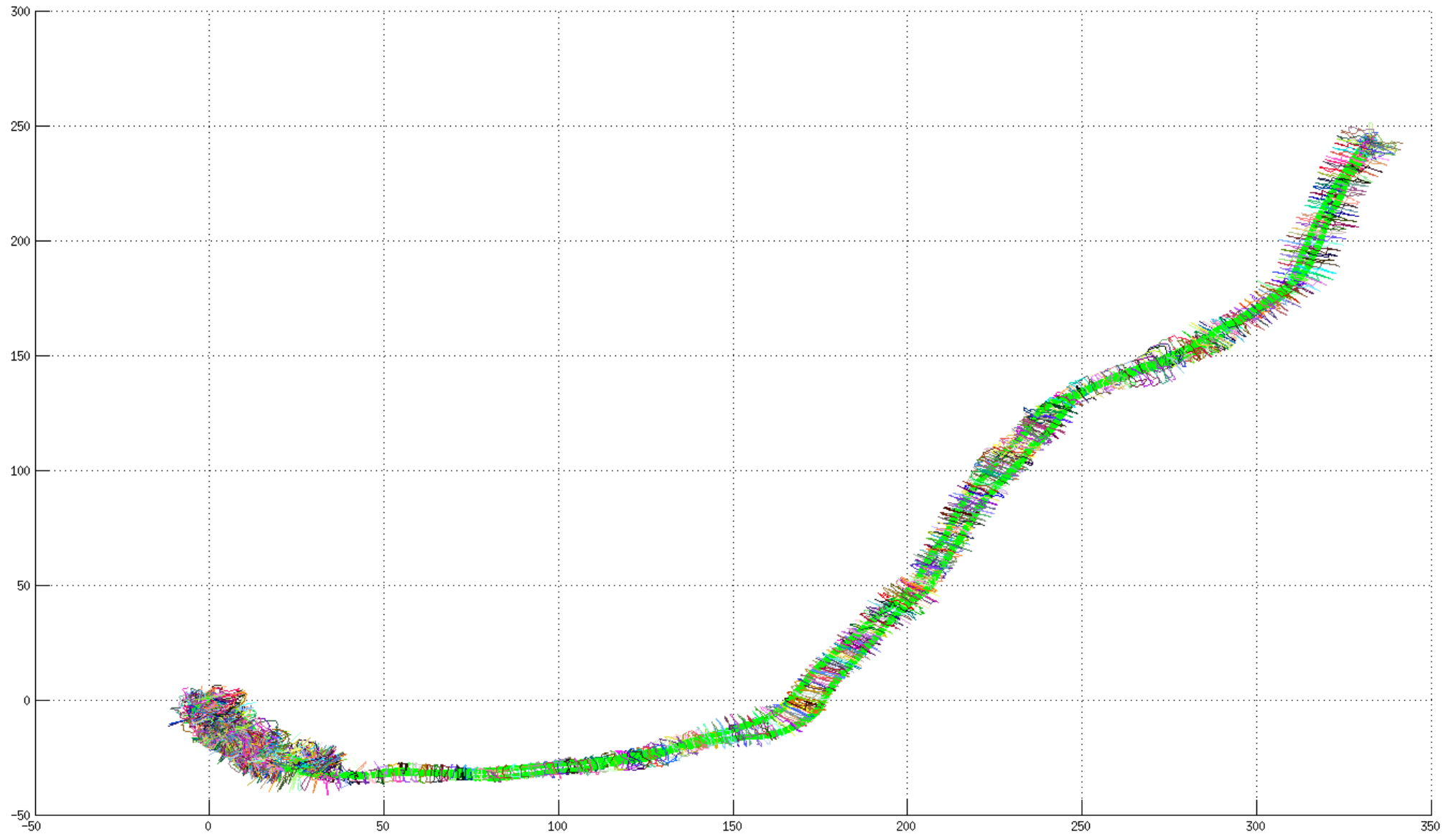
- Slices : N slices $\times$ M impacts (avec $N * M \approx \text{dim}(\text{Son_d})$)
- Division based on ray angles
- Each slices' impact has the same structure as Son_d

IMPACT COORDINATES



- Slices_pos : N slices x M impacts defined as $\{t_{\text{son}}, \alpha, \text{range}, \text{dist}, x_{\text{rob}}, y_{\text{rob}}, z_{\text{rob}}, \phi_{\text{rob}}, \theta_{\text{rob}}, \psi_{\text{rob}}, x_{\text{imp}}, y_{\text{imp}}, z_{\text{imp}}\}$
 - Robot pose ($x_{\text{rob}}, y_{\text{rob}}, z_{\text{rob}}, \phi_{\text{rob}}, \theta_{\text{rob}}, \psi_{\text{rob}}$)
 - Impact coordinates ($x_{\text{imp}}, y_{\text{imp}}, z_{\text{imp}}$)
- Compute 3D coordinates of each impact based on robot trajectory
- 3D Point cloud or « Wire » representation
- Can it be used (automatically) to improve trajectory ?

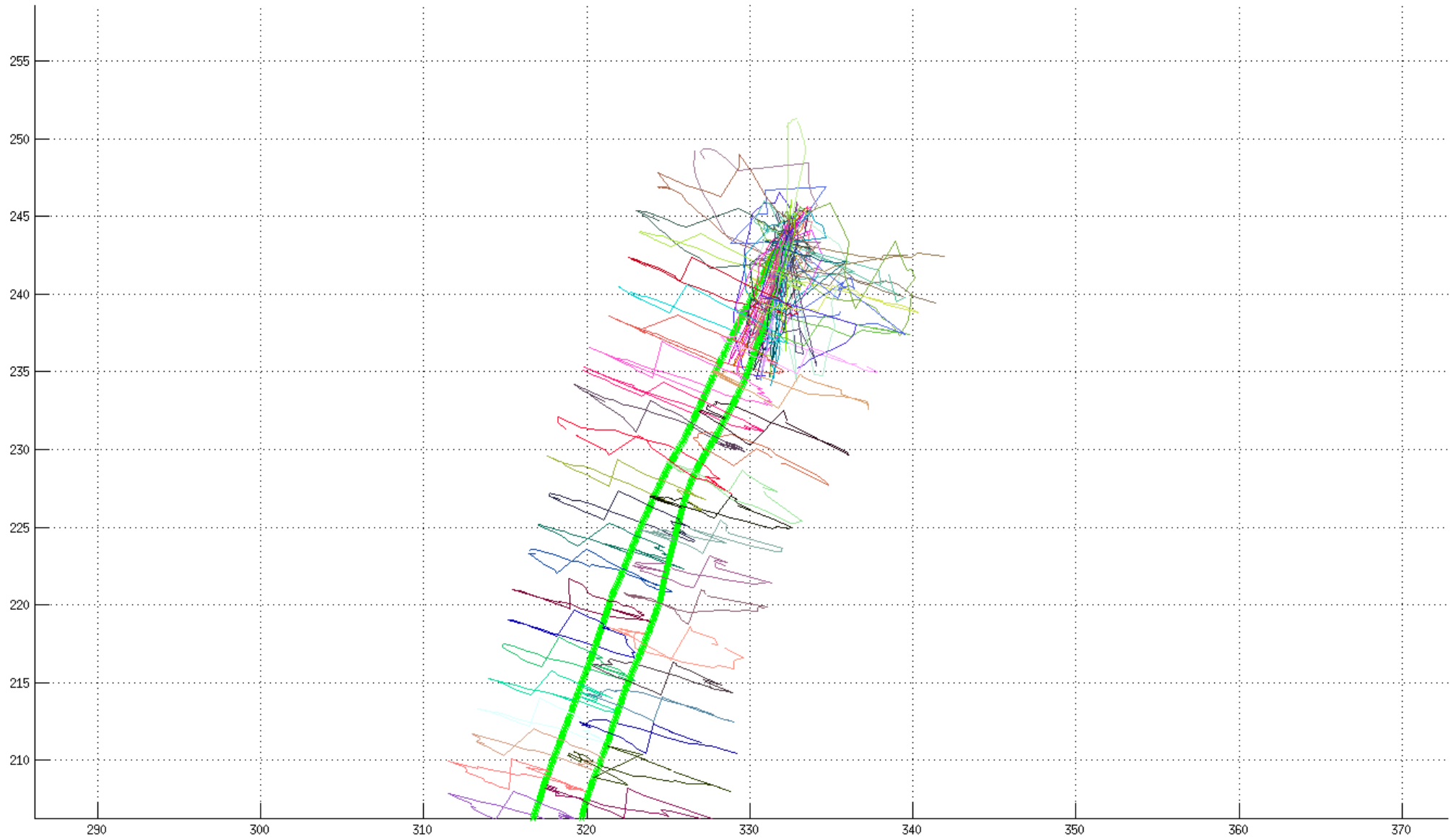
IMPACT COORDINATES



OUTLIERS CORRECTION

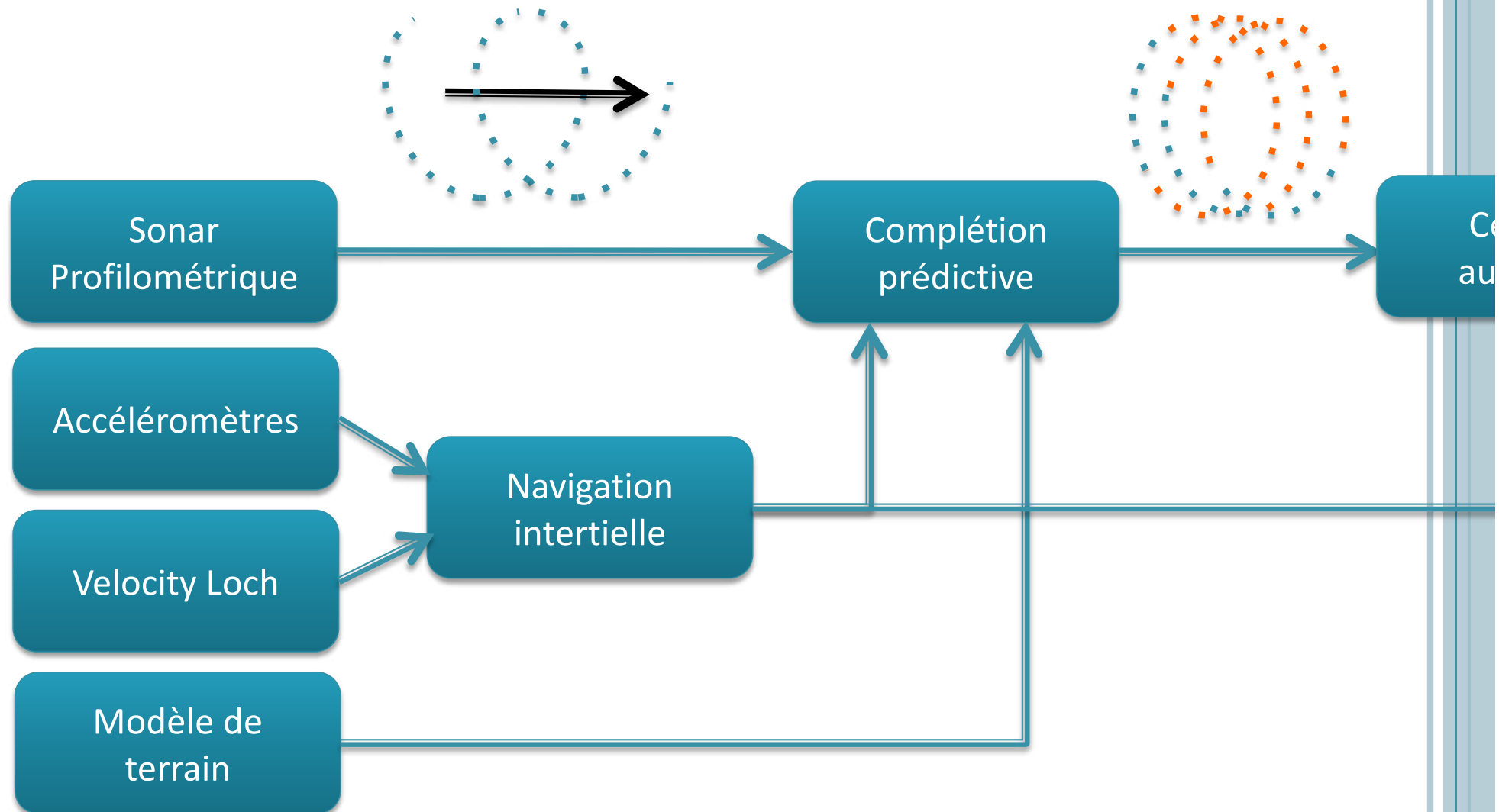
- 18% of undetected points + outliers
- « Fill the Gaps » or ignore these points in reconstruction ?

TRIANGLES GENERATION

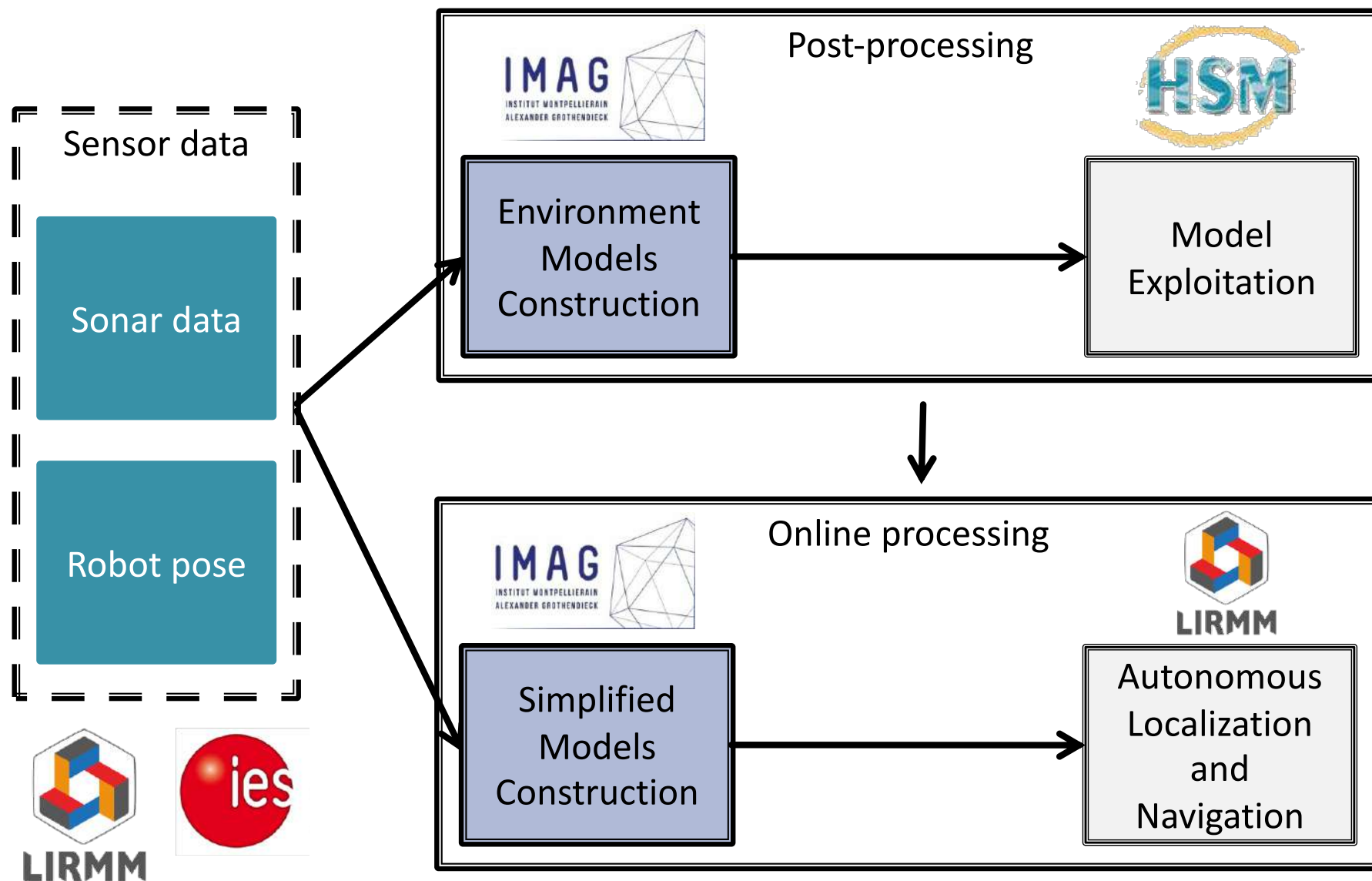


CHANTIERS SCIENTIFIQUES EN COURS

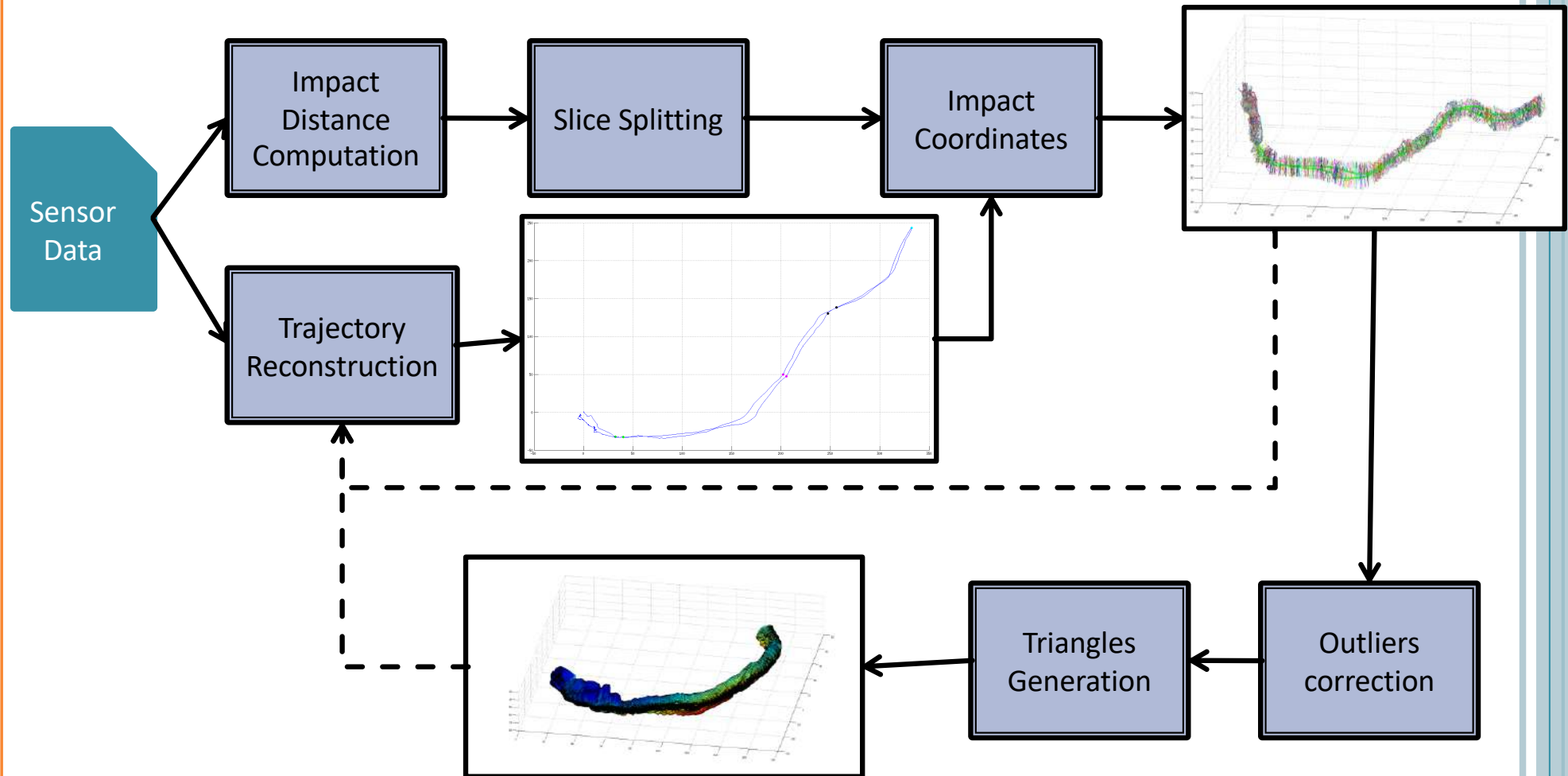
○ Commande réactive orientée modèle de terrain



FROM SENSOR DATA TO ENVIRONMENTAL MODELS

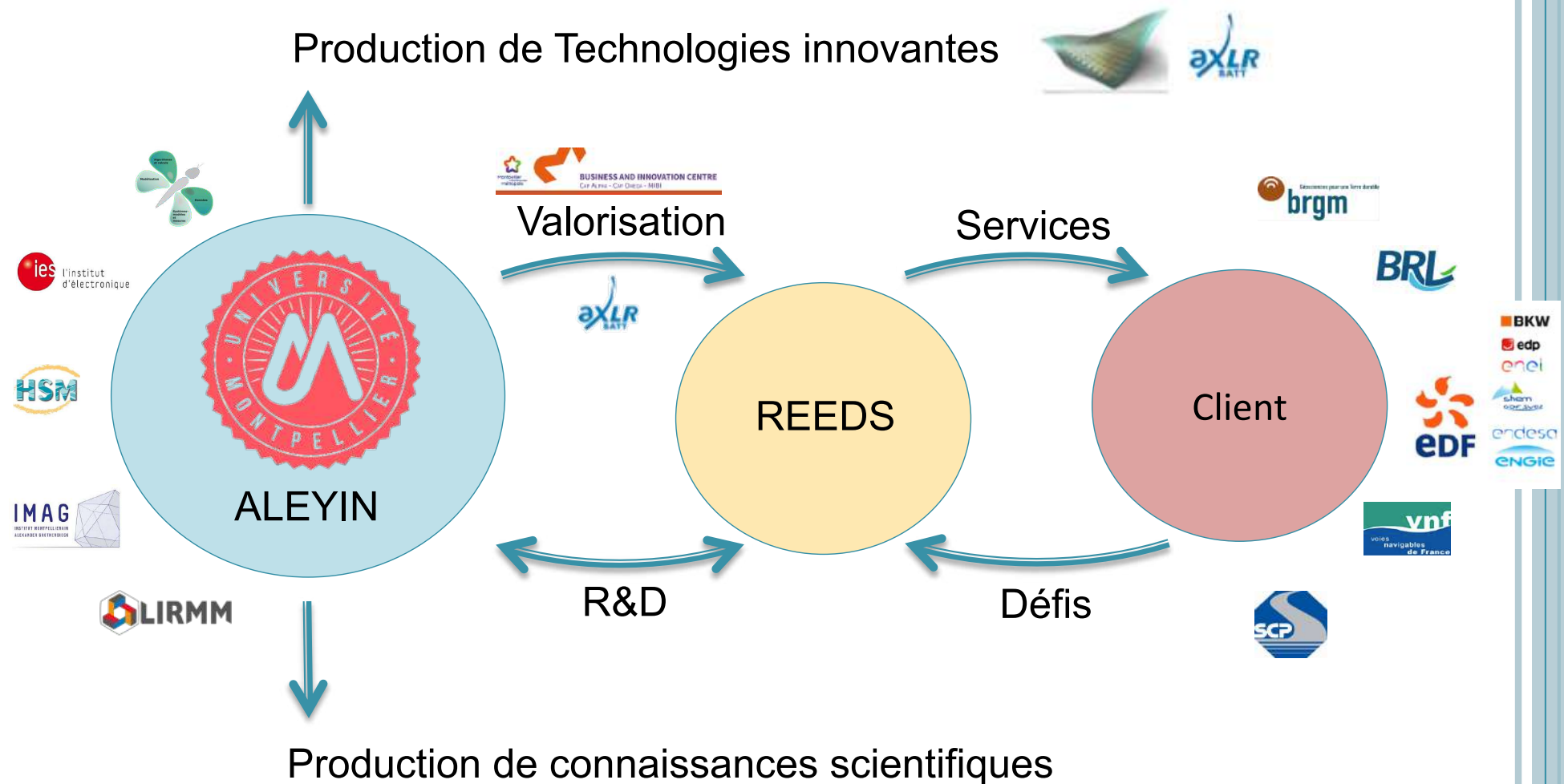


POST-PROCESSING : PIPELINE



LA TRANSDISCIPLINARITÉ COMME TERRAIN DE L'INNOVATION

les objets-frontières (*boundary objects*)

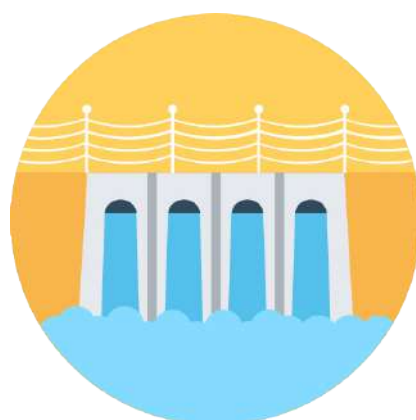


VALORISATION : STARTUP REEDS

- REEDS : Transférer les savoirs et savoir-faire académiques vers de nouveaux services d'inspection subaquatique en environnement confinés.



Canaux et voies
navigables



Barrages et infrastructures
hydrauliques



Galeries
immergées



Karst et conduites
naturelles

- Services à forte Valeur Ajoutée
 - Acquisition de données en env. difficiles
 - Modélisation fiable et pertinente
 - Diminution du risque & coût de la donnée

VALORISATION : L'OFFRE DE REEDS

Grâce à sa maîtrise de l'ensemble des maillons de la chaîne de valeur et sa conception modulaire, REEDS propose une prestation sur mesure.



REEDS travaille également auprès des exploitants de structures comme SCP (Société du Canal de Provence) qui ouvre ces ouvrages pour valider ces solutions

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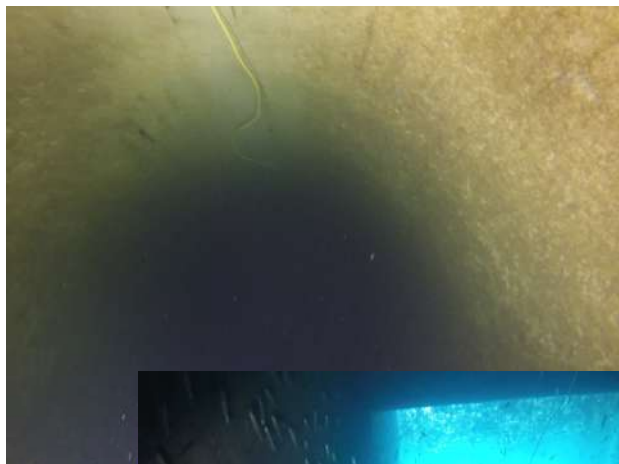


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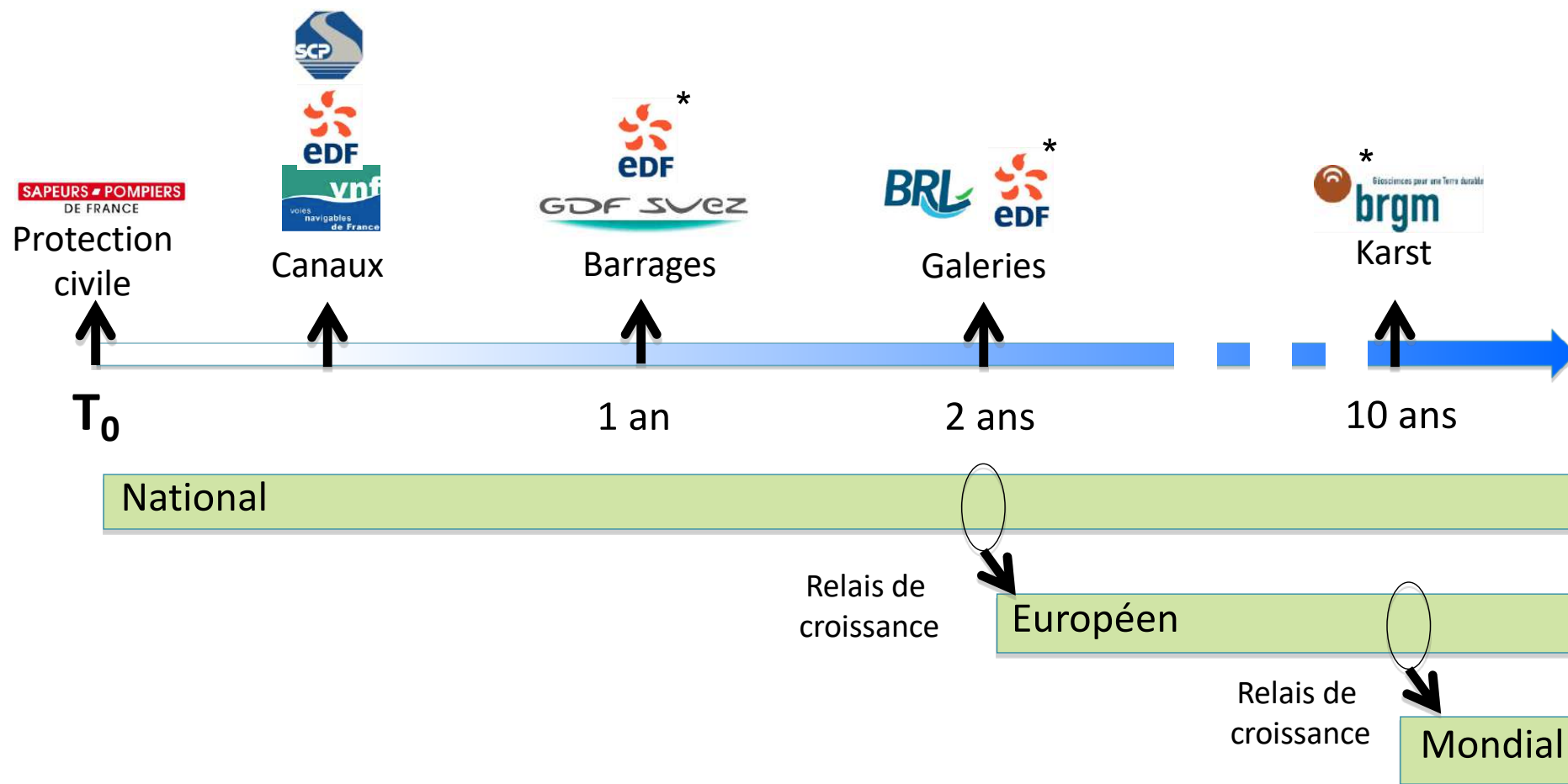
VALORISATION : LA R&D AU CŒUR DE REEDS

- Un site d'expérimentation mis à disposition par la société du canal de Provence
 - 3 km de canaux ouverts
 - 11 km de galeries fermées

SOCIÉTÉ DU CANAL DE PROVENCE
ET D'AMÉNAGEMENT DE LA RÉGION PROVENÇALE

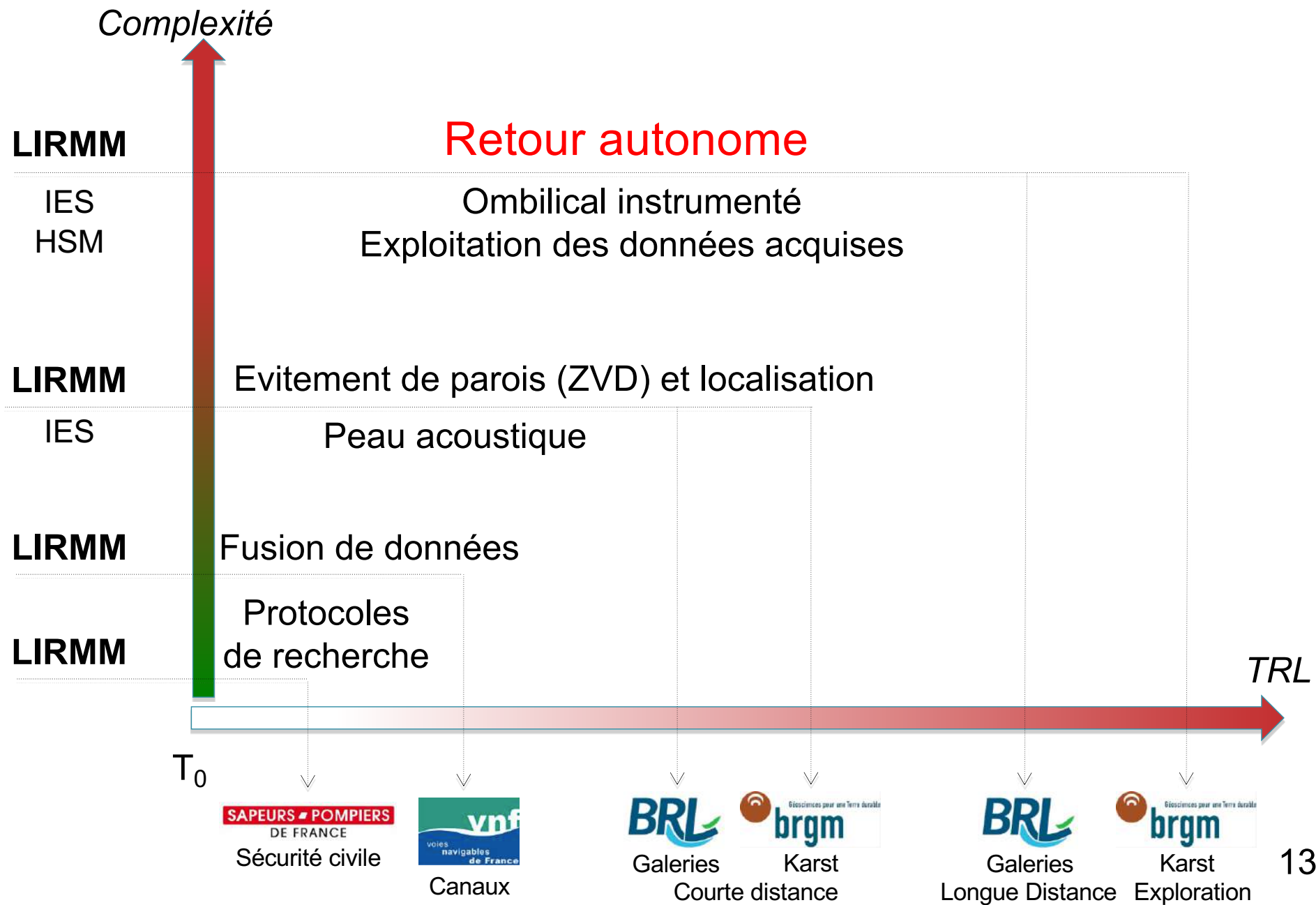


REEDS : DES MARCHÉS DE NICHE ATTAQUÉS PROGRESSIVEMENT

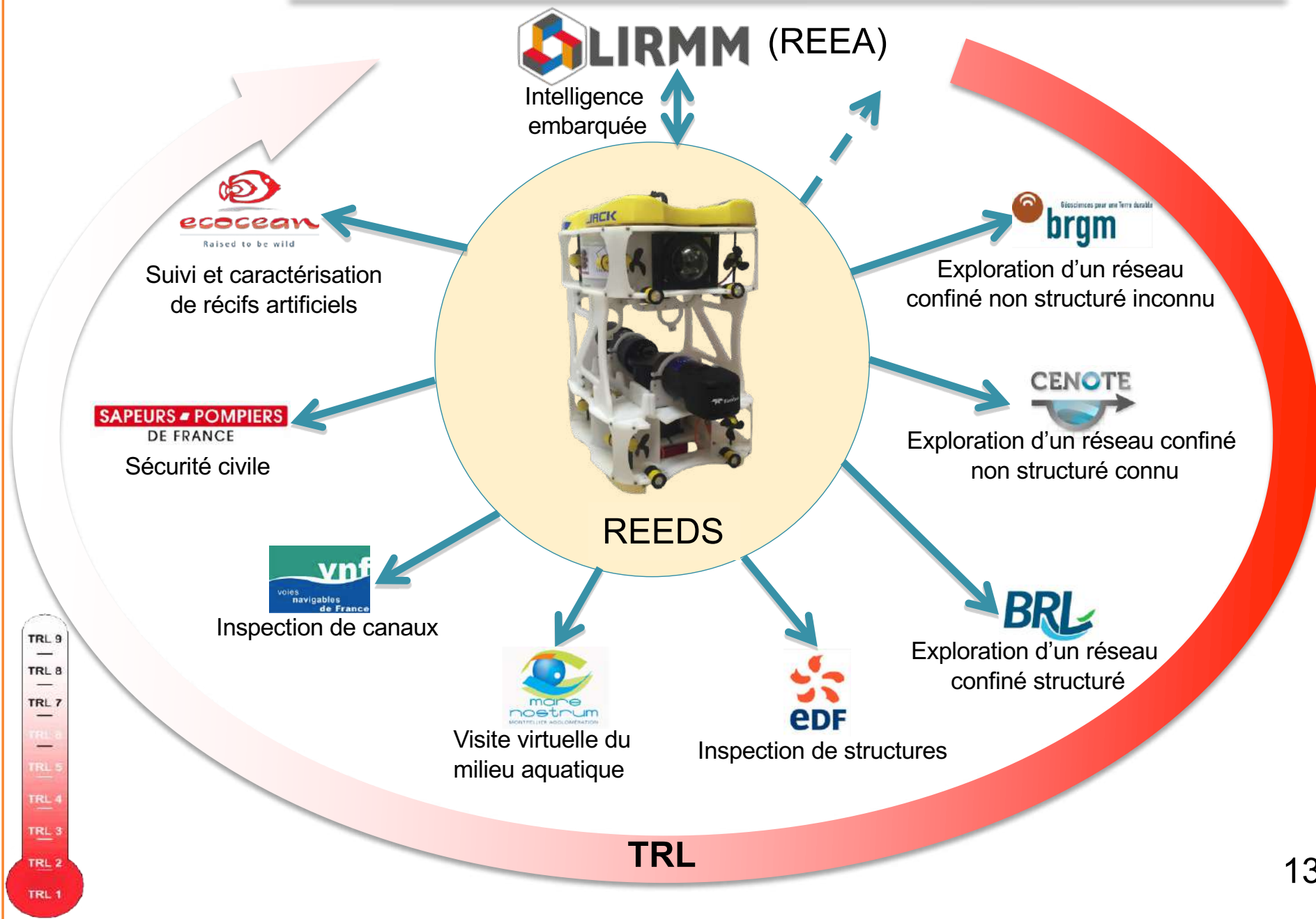


* Partenaires Aleyin (Projet Étendard Numev)

REEDS : VEROUS TECHNOLOGIQUES IDENTIFIÉS



REEDS : SEGMENTATION DU MARCHÉ



VALORISATION : L'ÉQUIPE REEDS

Une équipe complémentaire :

Lionel LAPIERRE
Référant Scientifique
Sénior

Benoît ROPARS
Scientifique (Ph.d)
Technologie

Luc ROSSI
Expert technique
Technologie

Bruno PIGNARD
Business developer
Entreprise

Saïd YAMI
Référant Scientifique
Sénior

Collaborateurs académiques:

David ANDREU
Enseignant Chercheur
Conseiller

Hervé JOURDE
Enseignant Chercheur
Intervenant

PERPSECTIVES

○ Extension du réseau de partenaires

- Académiques
 - Appel de coopération PRIMA (2018 ->)
 - France, Italie, Espagne, Portugal
 - Actions bilatérales
 - Vietnam, Europe de l'est.
- Implication des industriels partenaires
 - EDF, BRGM, CNP, VNF...
 - Repérage et ouverture de sites industriels
 - Contractualisation des collaborations (LabCom...)

○ Validation centrage autonome

- Mission de terrain 01/2018
 - Gourneyras, Durzon...

BUILDING PROJECT : 4 INGREDIENTS OF SUCCESS

- Pave new research avenues
 - Transdisciplinarity : a very strange alchemy
- Impact territory
 - Local coherency : regional application of global interest
- Network people of goodwill
 - Technological-scientific-Industrial-Financial Consortium coherency : towards creation of new services.
- Raise funds
 - Financial aspect : when bottom – up tracks top – down.

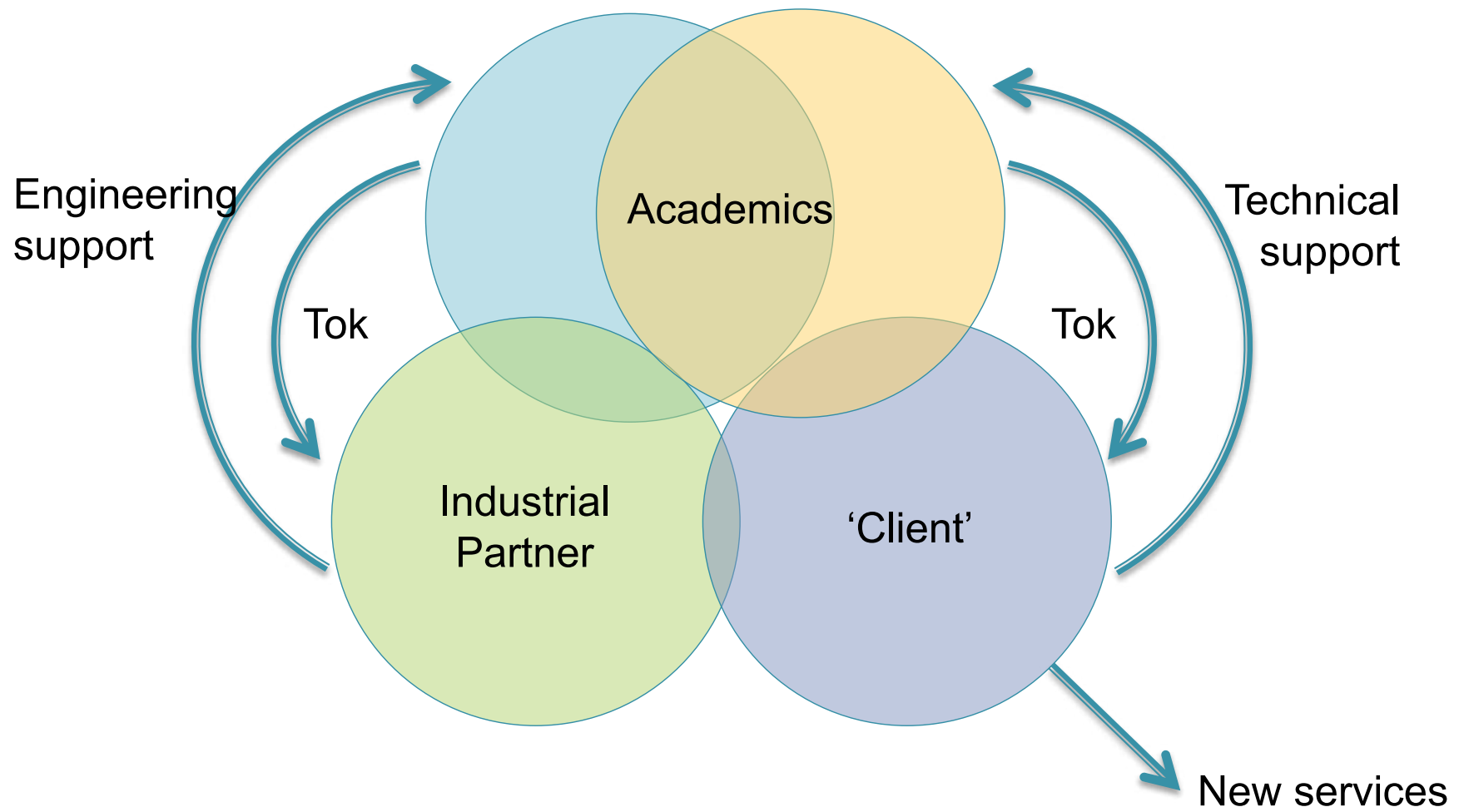
TRANSDISCIPLINARITY

- Breaking the disciplinary barriers
 - 1. Learn different scientific languages, tools and objectives
 - 2. Circumvent overlapping regions of interest
 - 3. Assimilate partner(s) objective(s)
 - 4. Revisit your science with a brilliant co-advised PhD student
- Co-design
- Opportunity is at interface

IMPACT TERRITORY

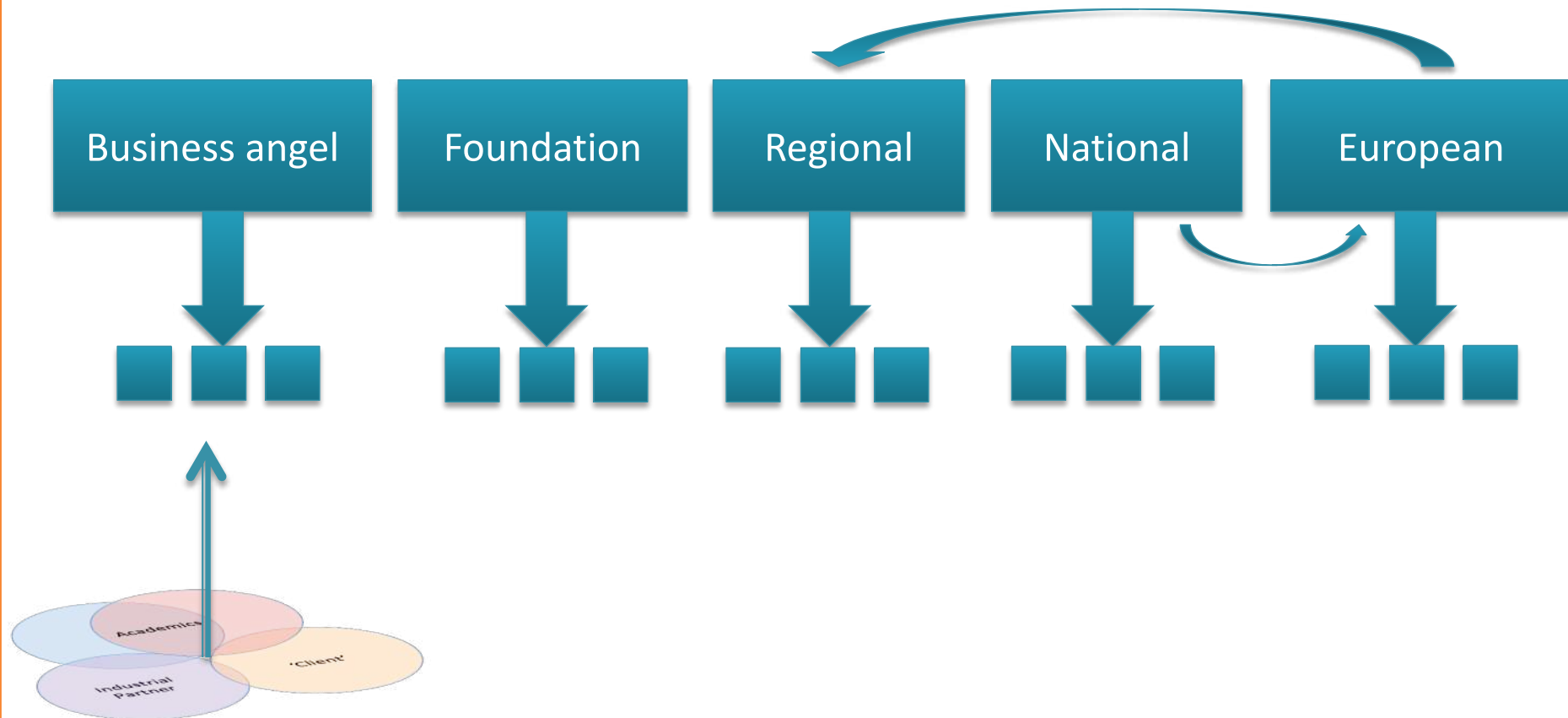
- Local coherency
 - 1. Integrate territory strategy
 - 2. Map local needs and actors
 - 3. Identify unseen and unquestionable applications
 - 4. Intersect with actors needs (new services)
- Route for innovation is known, and crowded, within specific discipline
 - Cross disciplines
 - Services requiring transdisciplinary TOK.

NETWORK PEOPLE OF GOODWILL



RAISE FUNDS

- When Bottom – up tracks Top – down



DEEP KARSTS IN THE MIDI DE LA FRANCE

