Subaquatic robotics, Robots for Karstic Exploration:

REEA
ALEYIN
LEZ 2020

BTS meeting, 27/09/2021

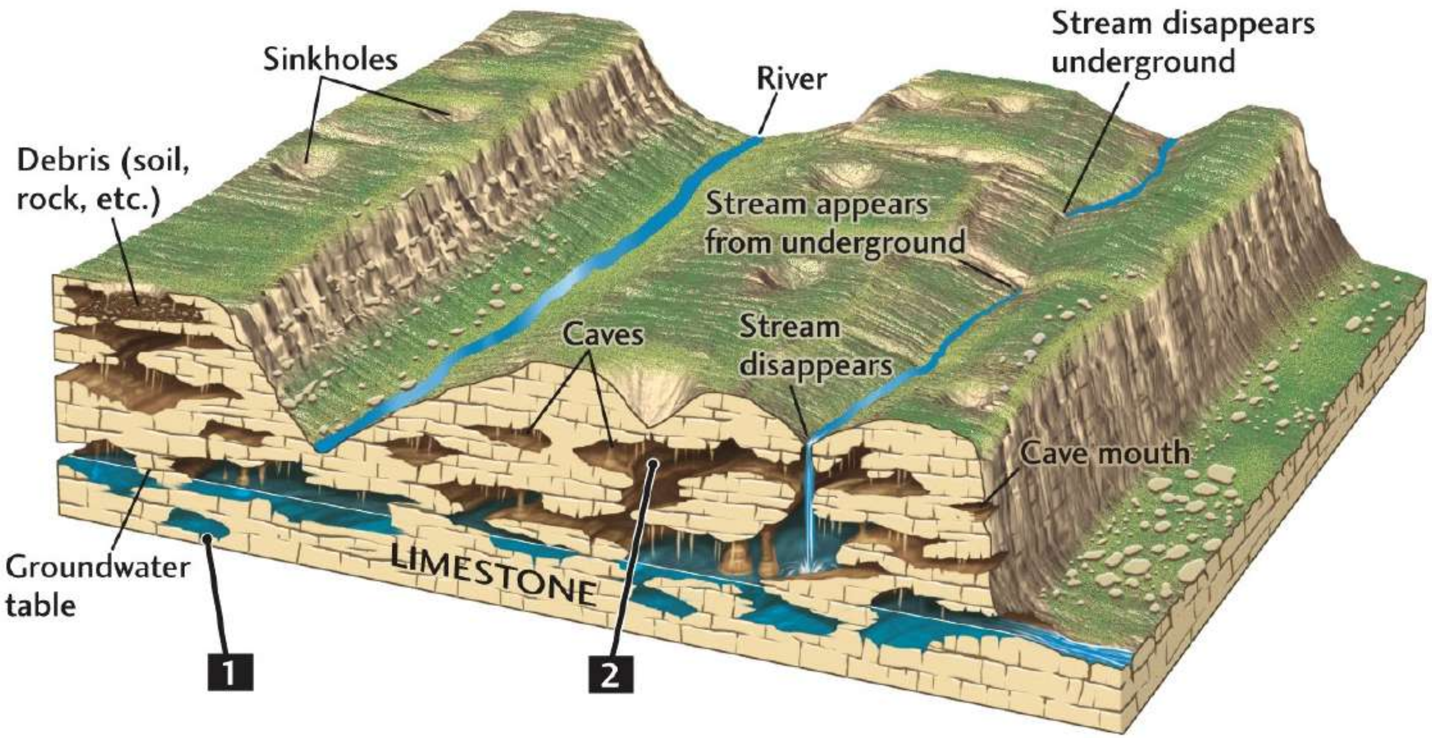
People Involved

- 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

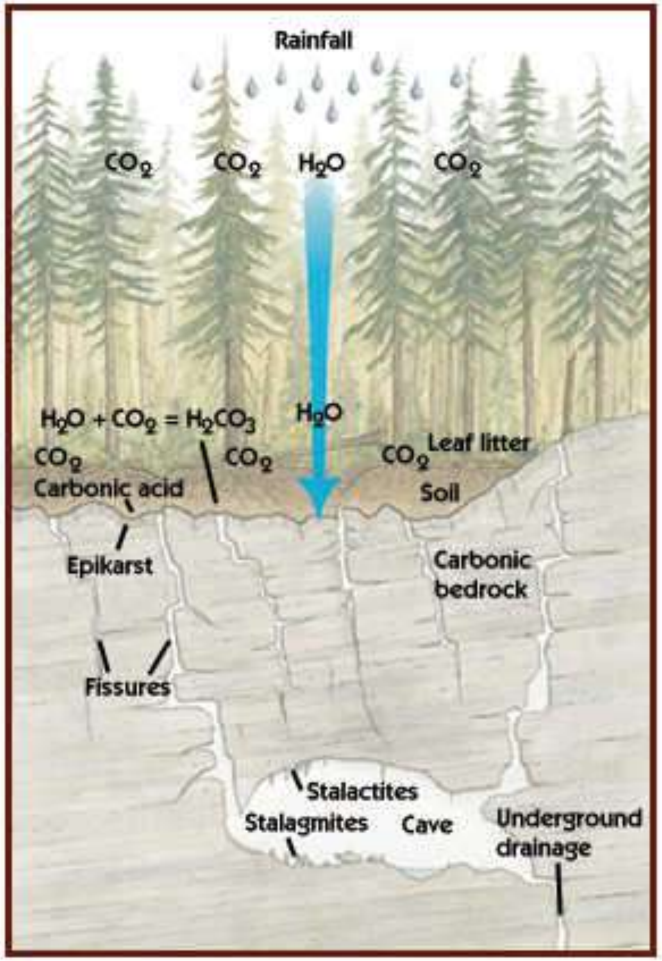
Karst : Definition

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



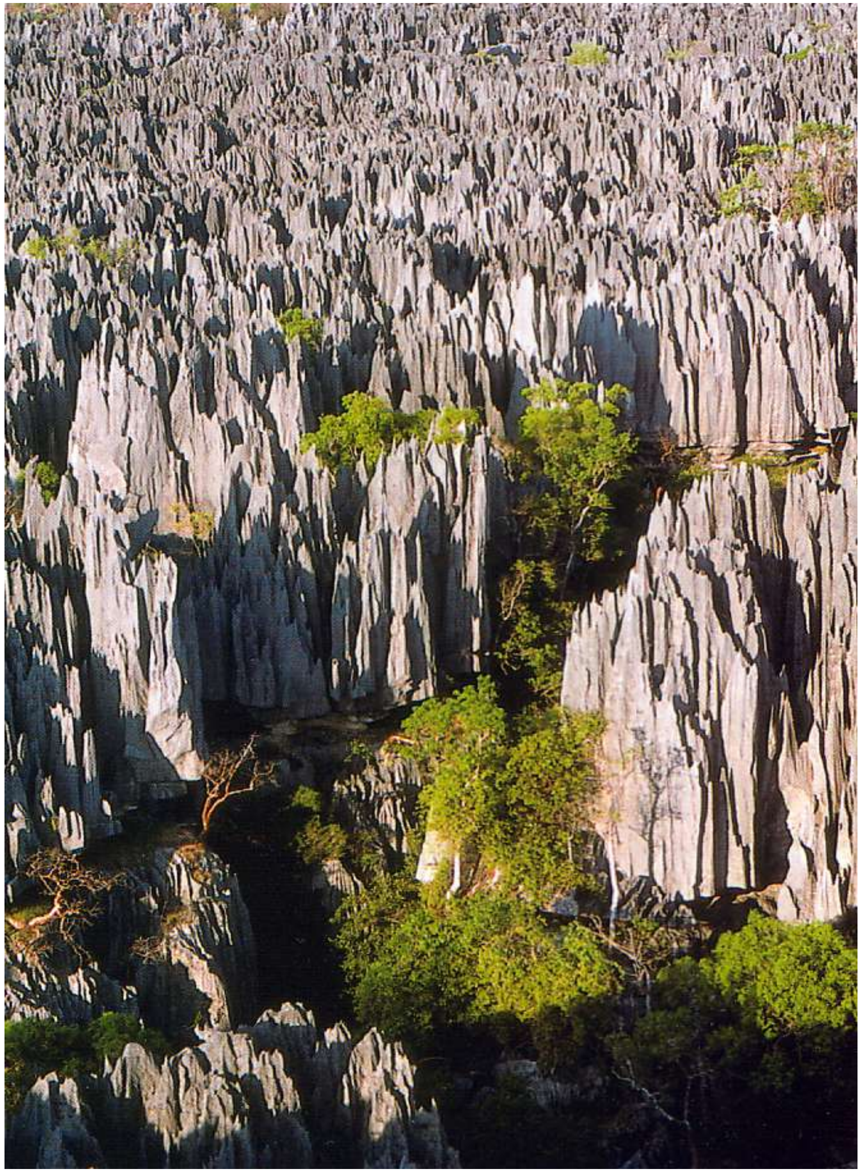
- Characterized by **underground drainage hydrosystems** with sinkholes and caves.

KARST : DEFINITION



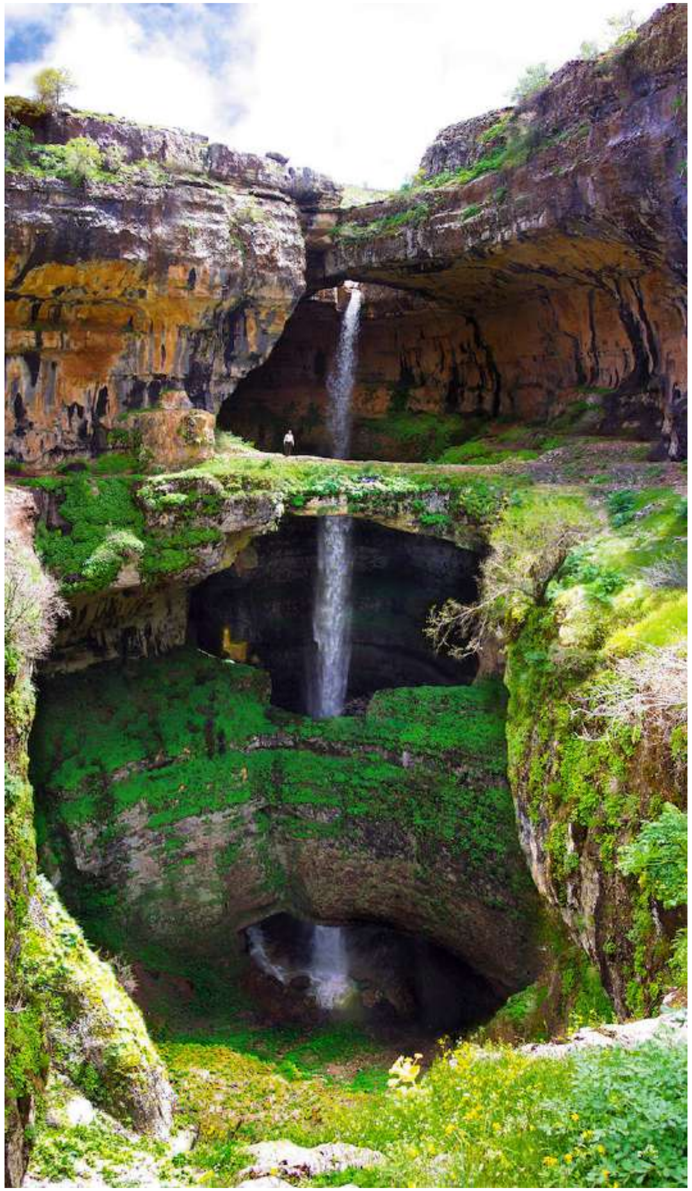
$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^+ + 2\ HCO_3^-$$



Tsingy de Bemaraha, Madagascar

KARST : SURFACE STIGMATA



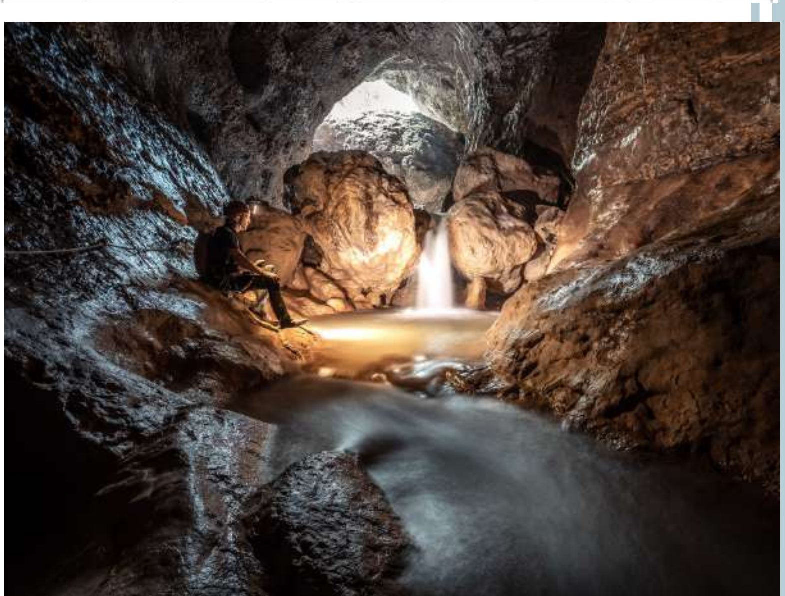
Balaa, Tannourine, Lebanon

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

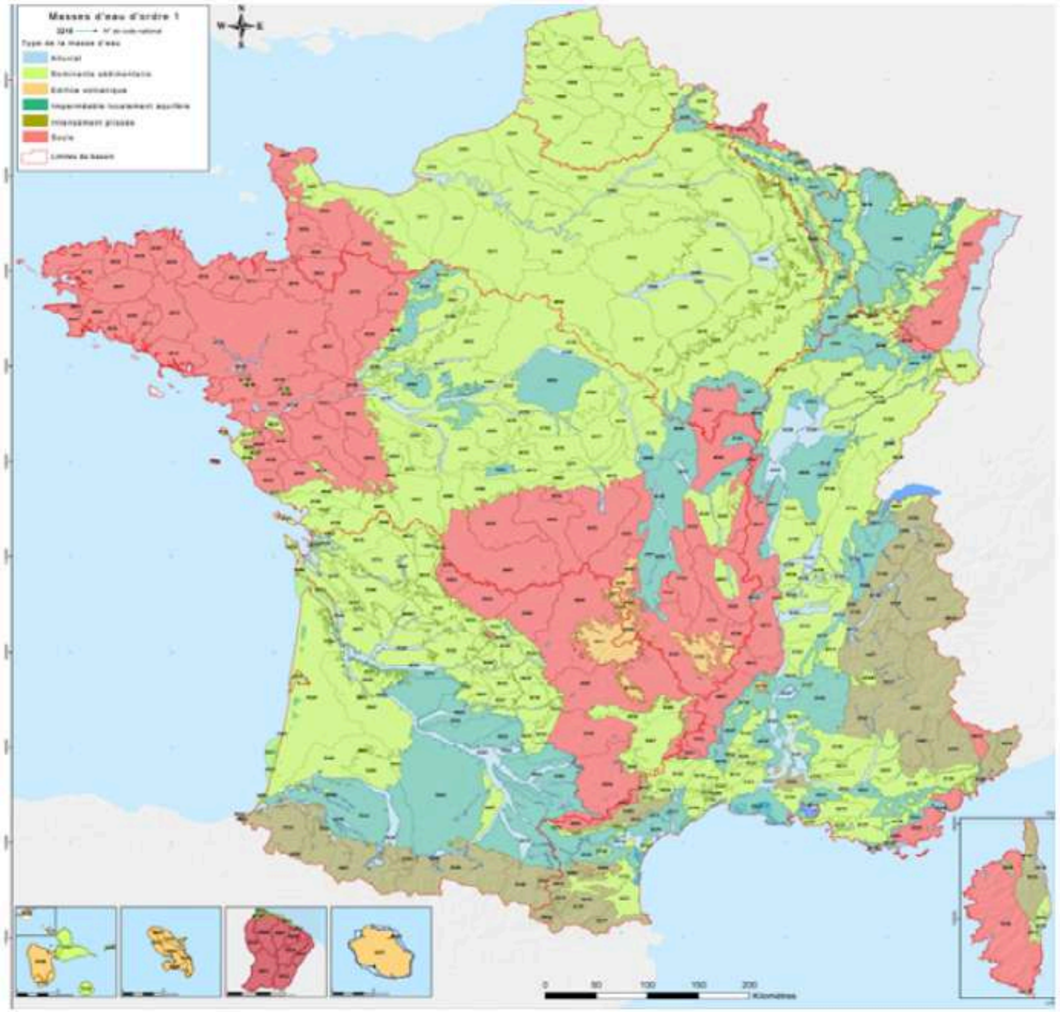
Furong Cave, Wulong District, Chongqing, China

KARST : GROUNDWATER RESERVOIR

KARST : GROUNDWATER RESERVOIR

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

KARST : GROUNDWATER MANAGEMENT, A NATIONAL ISSUE

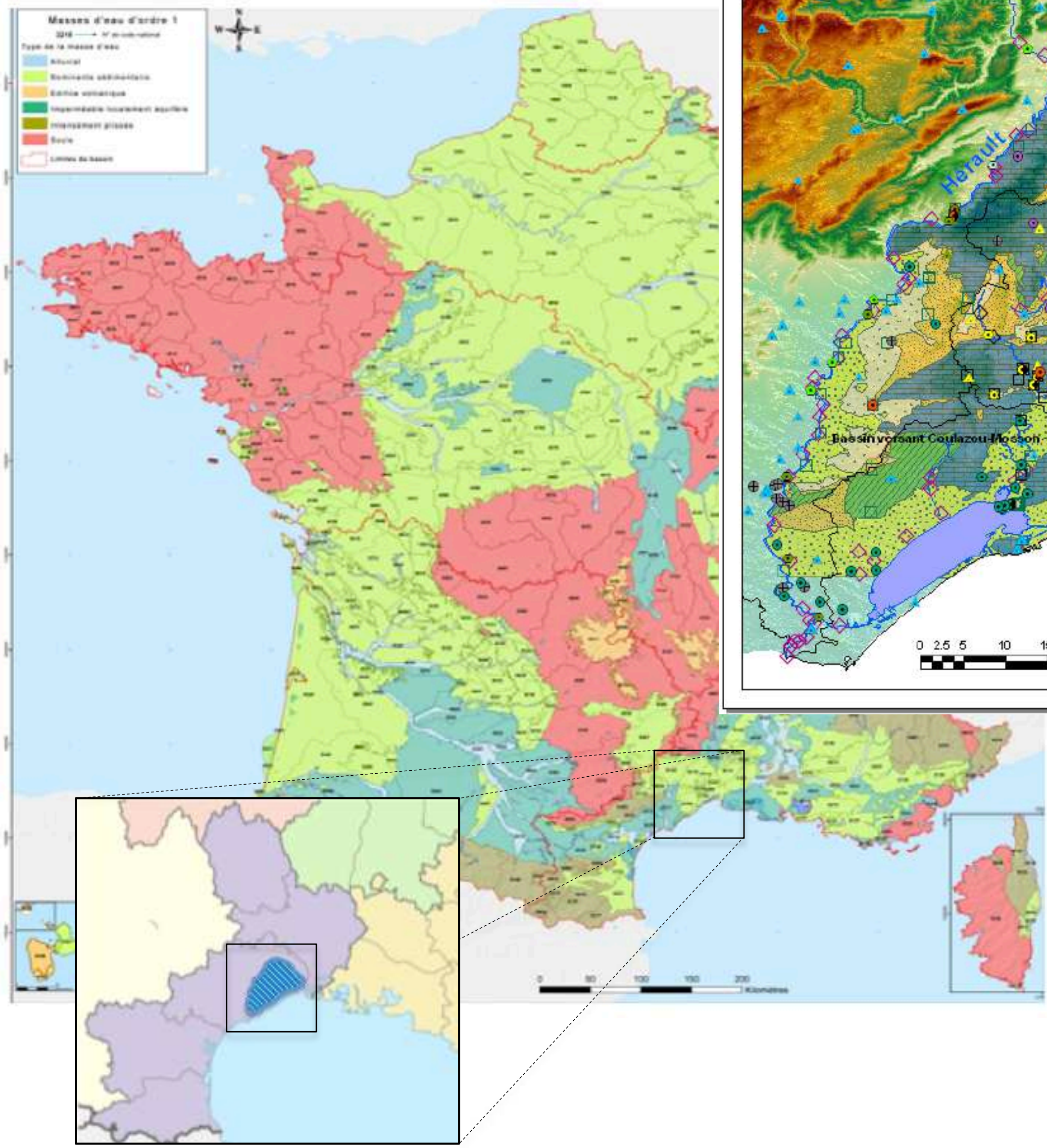


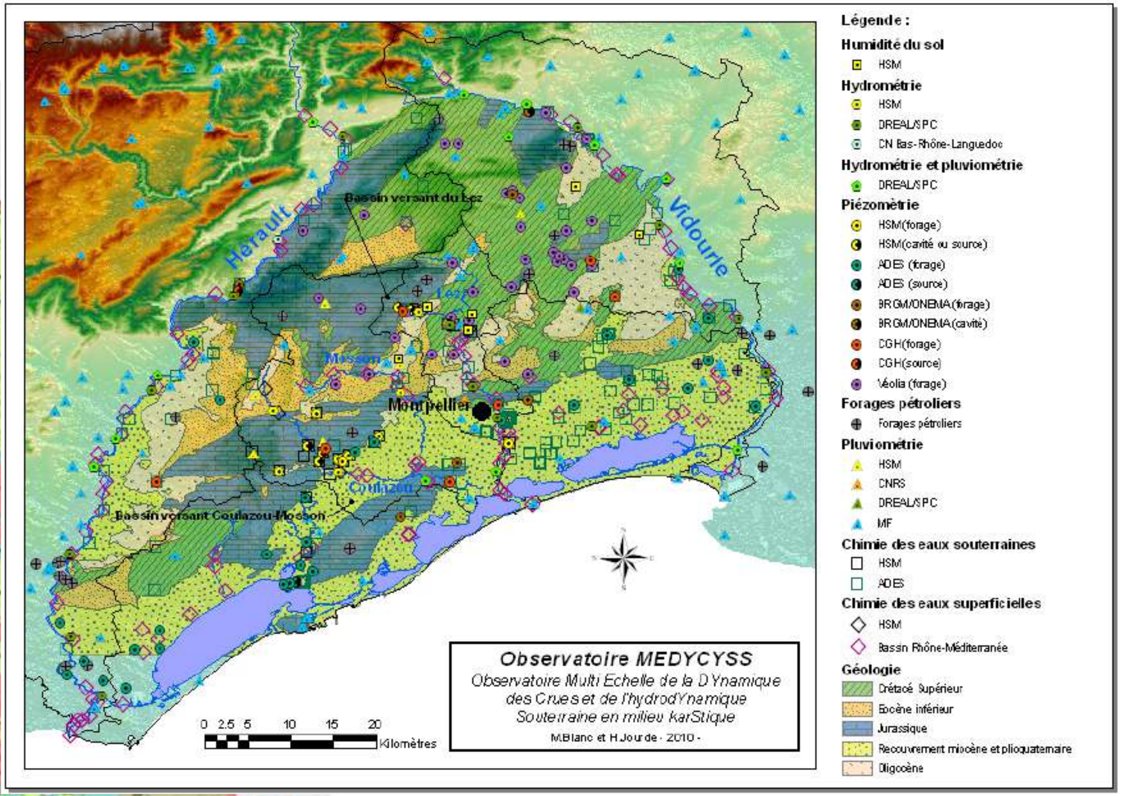
+ 50% of Drinking Water Supply

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

Carte hydrogéologique des formations carbonatées karstifiables (EASAC report)

MONTPELLIER'S CATCHMENT BASIN : A SEMINAL CASE STUDY



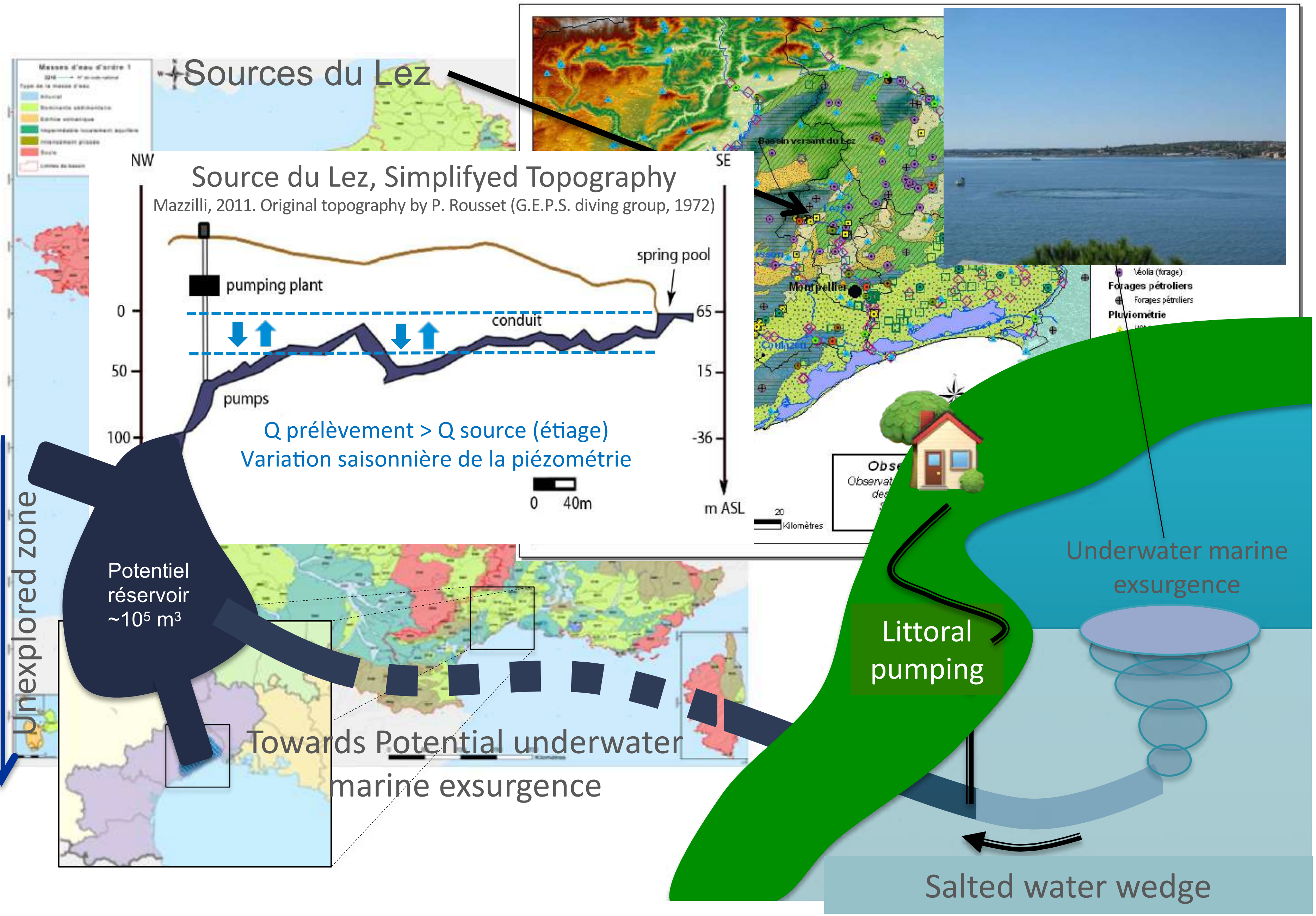


MEDYCYSS

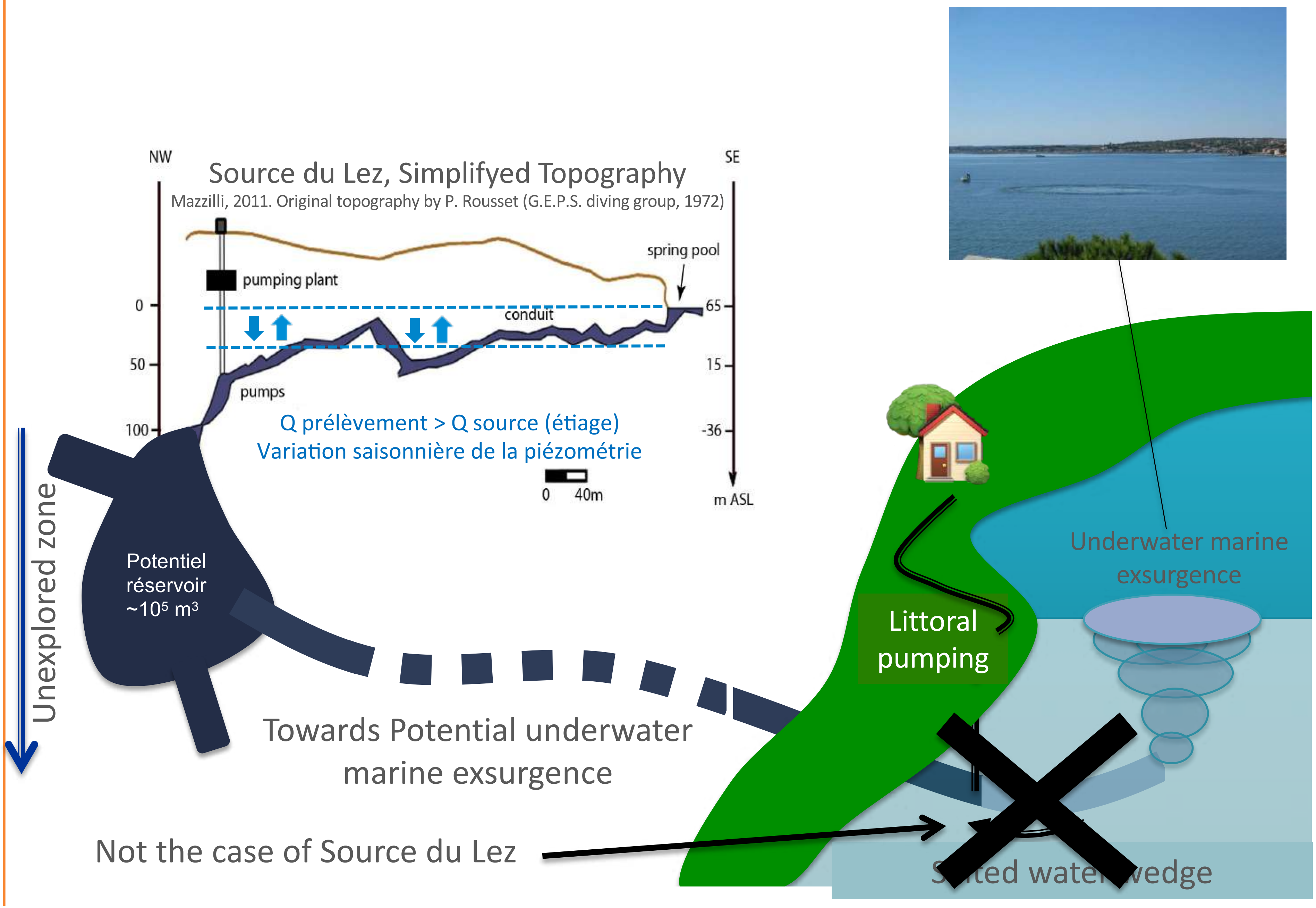
KARST

OBSERVATORY

Sources du Lez : a Seminal Case Study

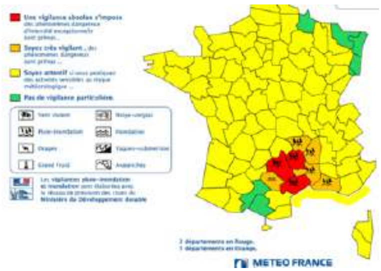


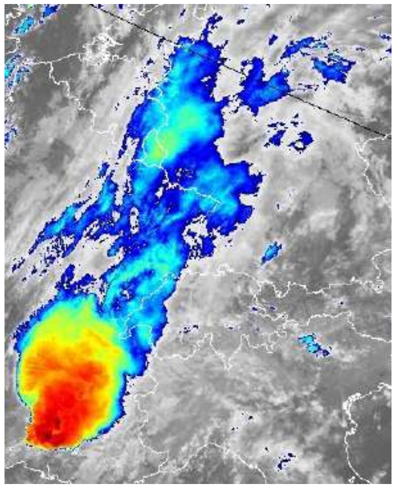
Sources du Lez : Active Management of GW Resource

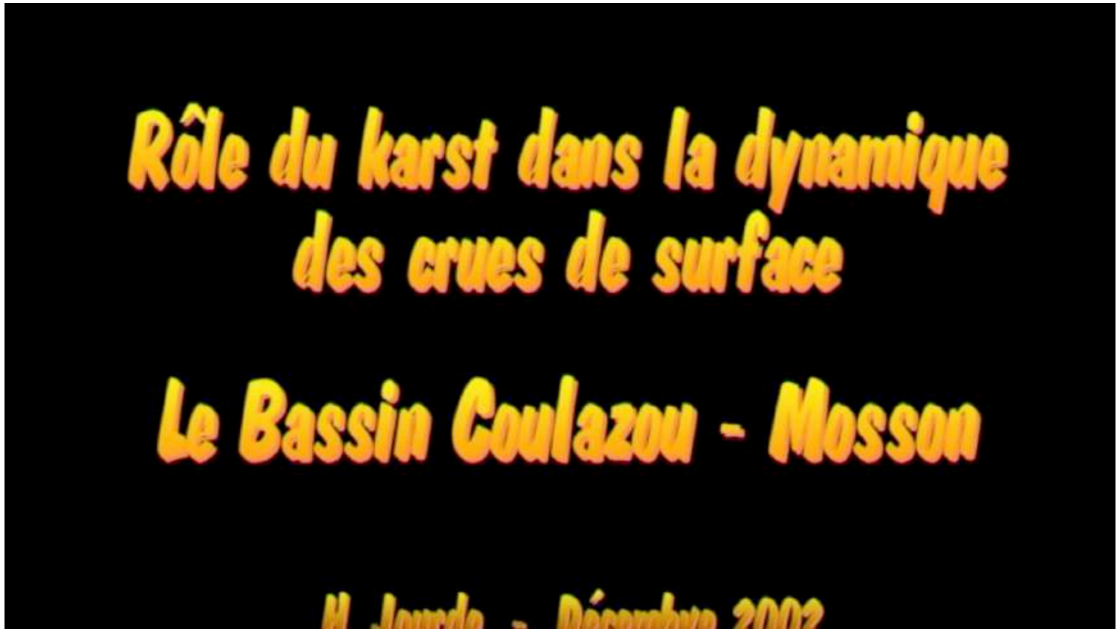


MONTPELLIER'S CATCHMENT BASIN : A SEMINAL CASE STUDY

- 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.

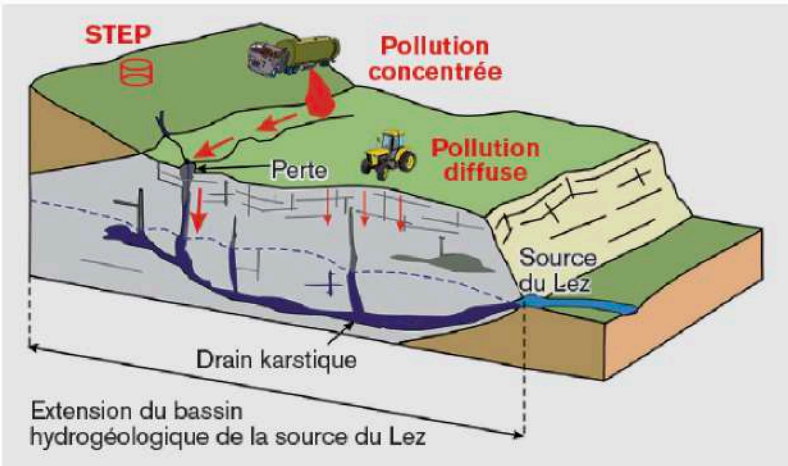
Guatemala City, Guatemala

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

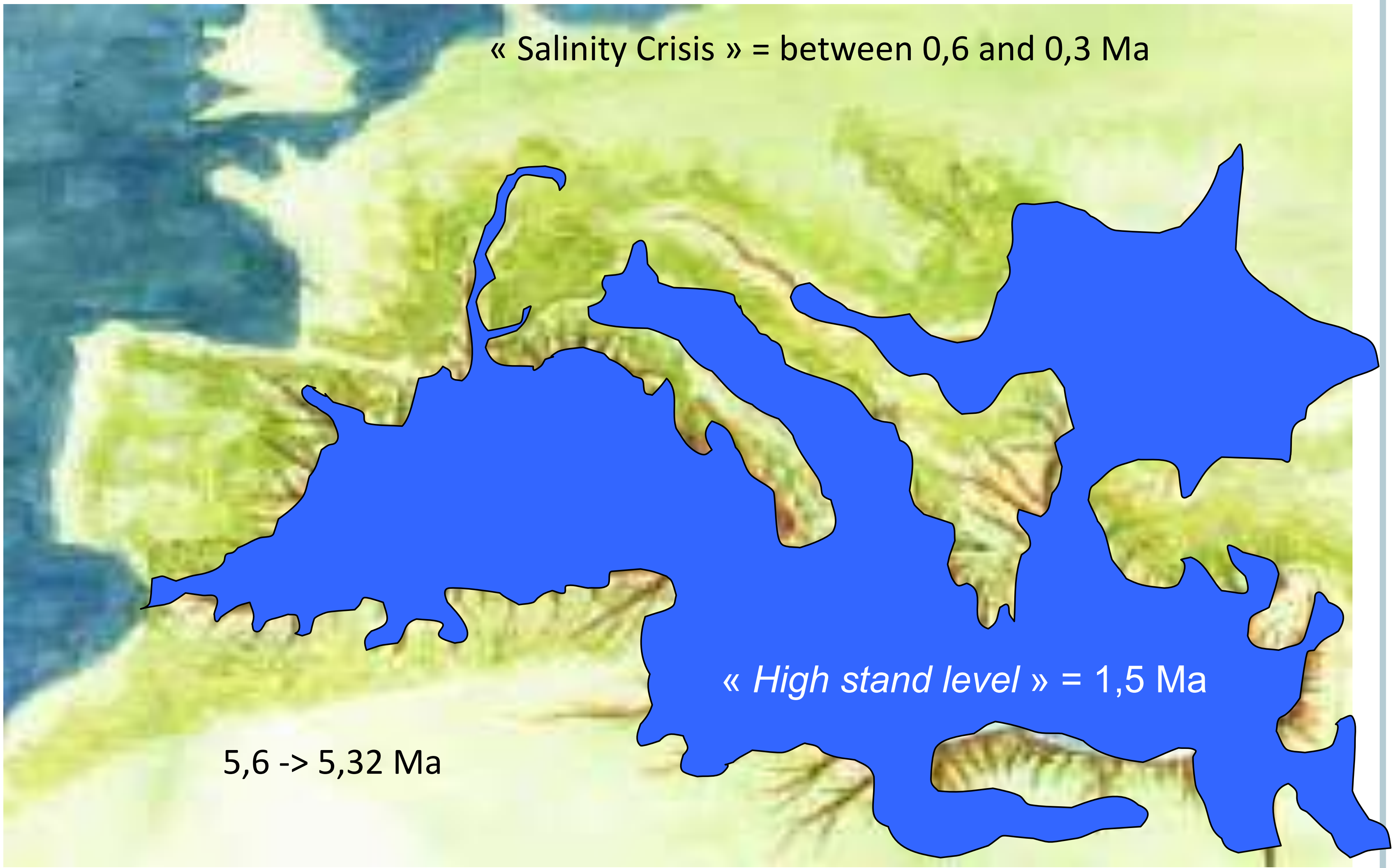
Closure of the Gilbraltar Strait

Messinian events : 2 salinity crisis

1/ 5.95 – 5.6 Ma 100 m

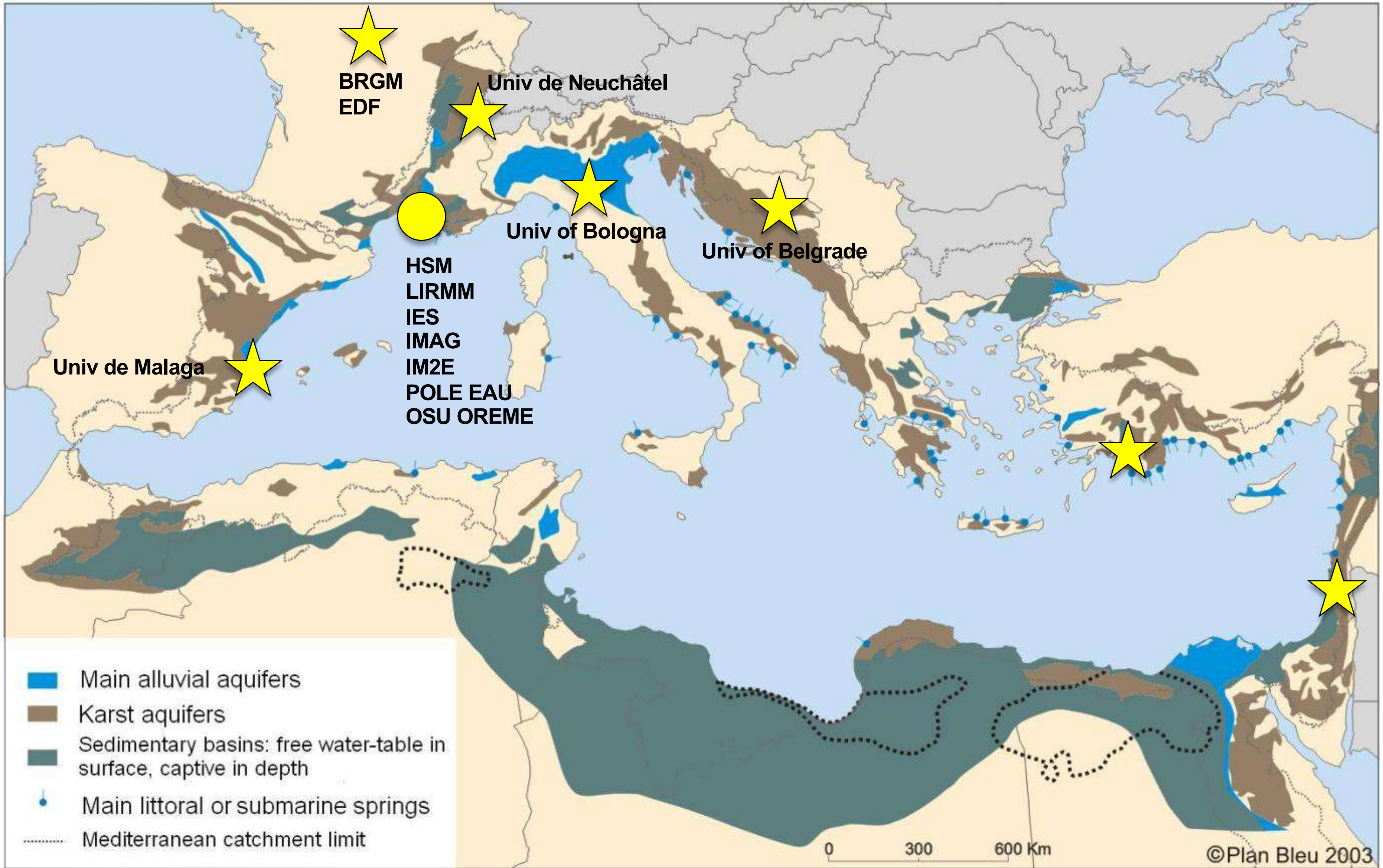
2/ 5.6 – 5.32 Ma 1500 m

Mediterranean Karsts During Messinian Salinity Crisis

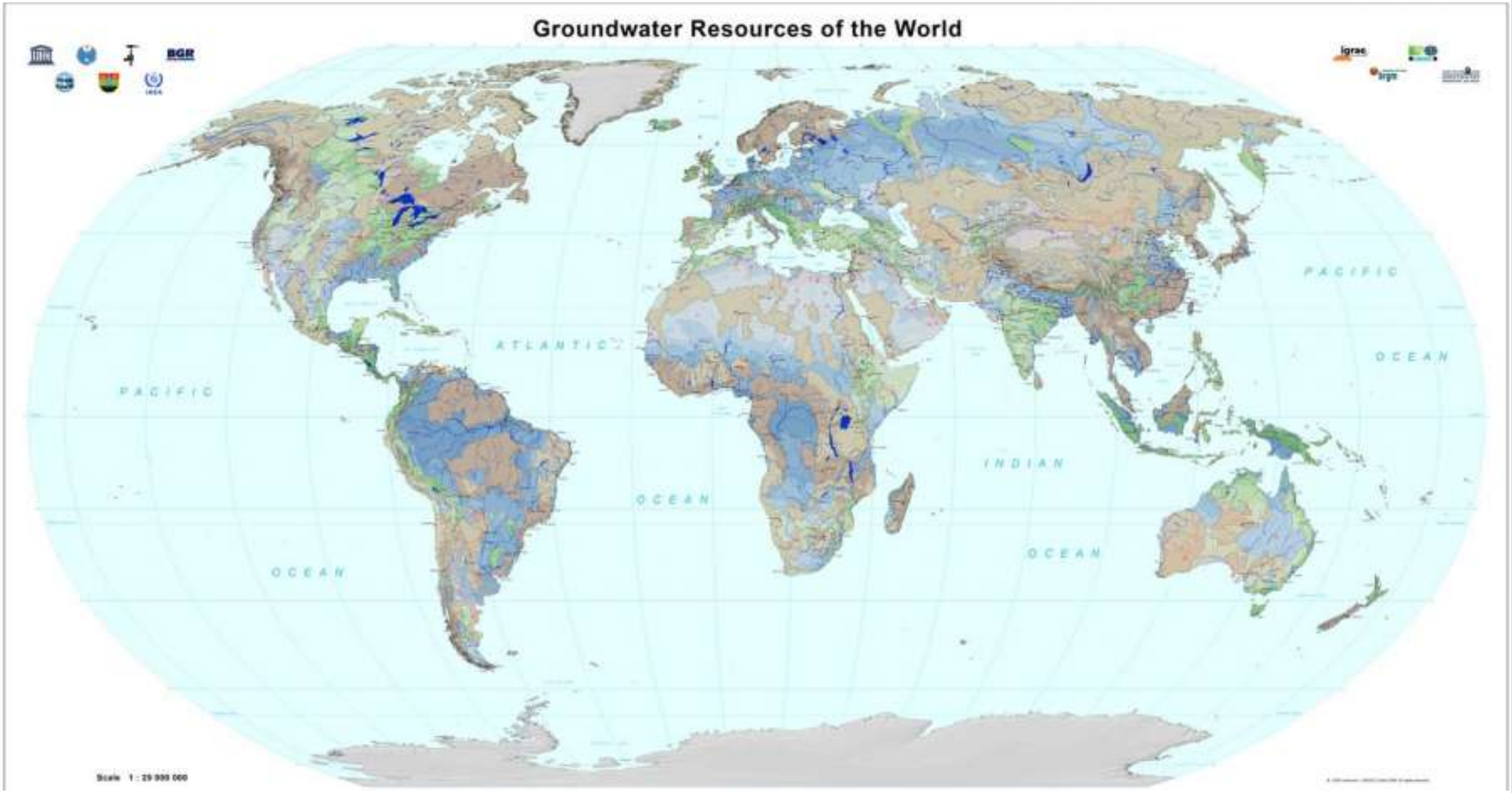


Deep Karstification

MEDITERRANEAN KARSTS



WOLRD 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.

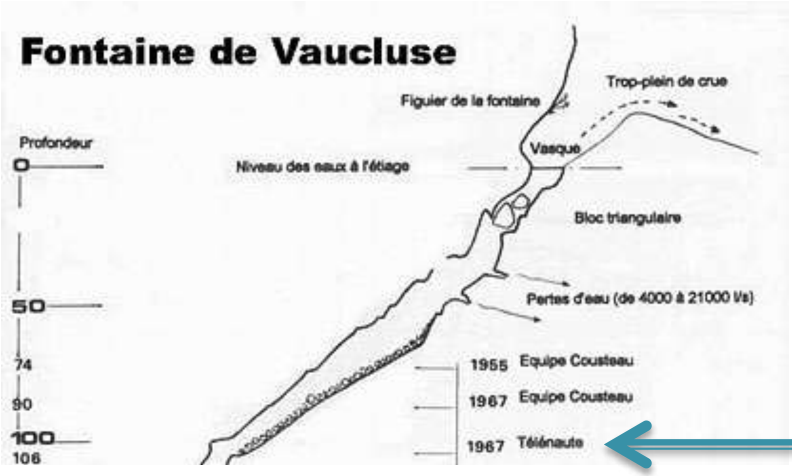
Geomorphology of the flooded zone (volumes) : new sensors, new models.

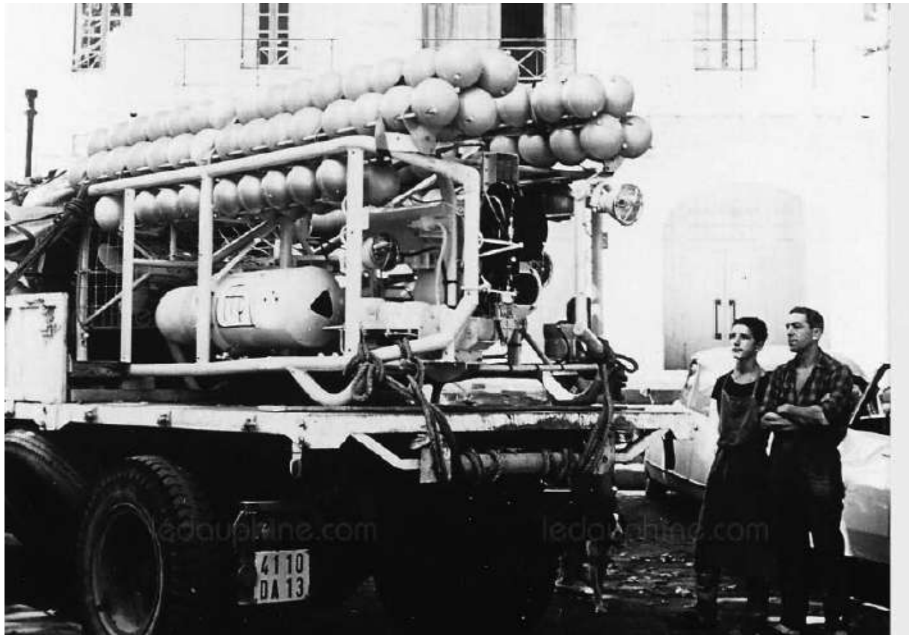
N-D geomorphological models

Karst Dynamics

A Rapid History of Karst Exploration With Robot

- Fontaine de Vaucluse : A magnificent Robotic Failure





1967, Télénaute (Cdt Cousteau)
106m

A Rapid History of Karst Exploration With Robot

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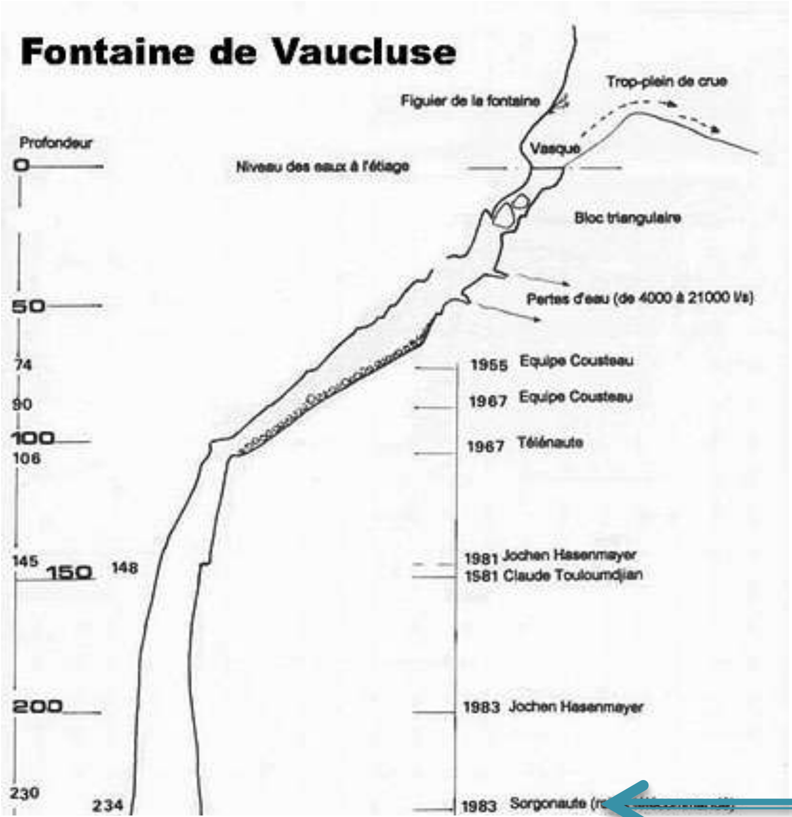
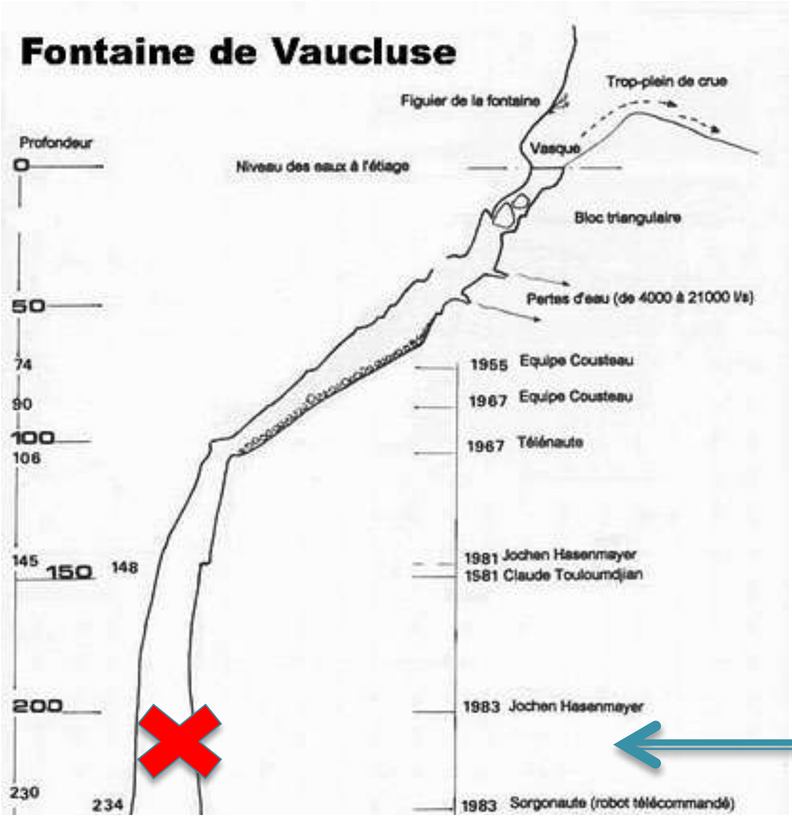


1983, Sorgaunote (Renault)
243m
(stopped by cable length)

A Rapid History of Karst Exploration With Robot

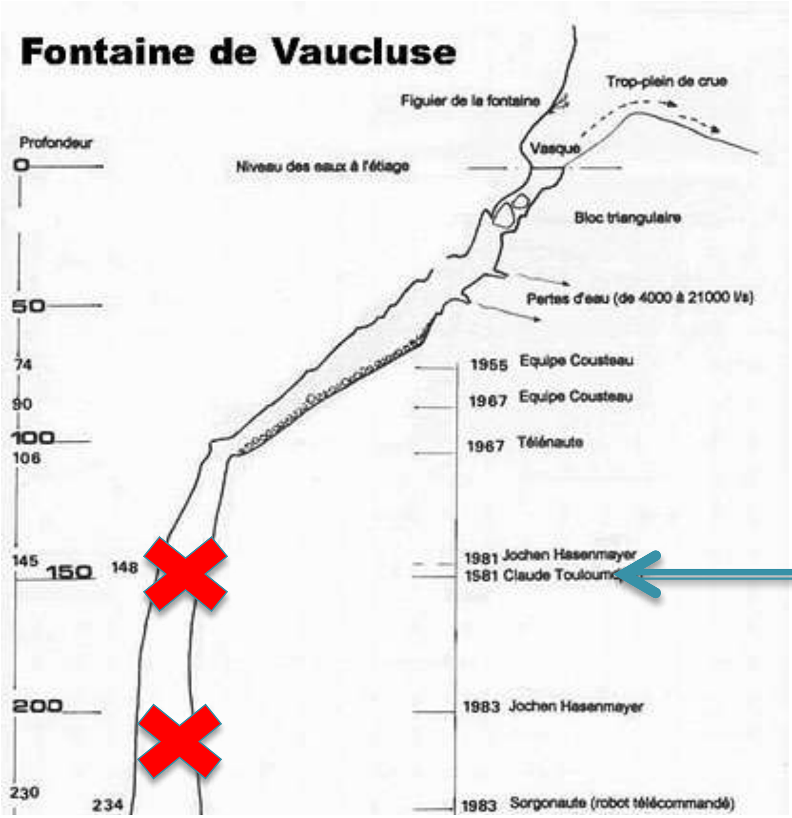
- Fontaine de Vaucluse : A magnificent Robotic Failure



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

A Rapid History of Karst Exploration With Robot

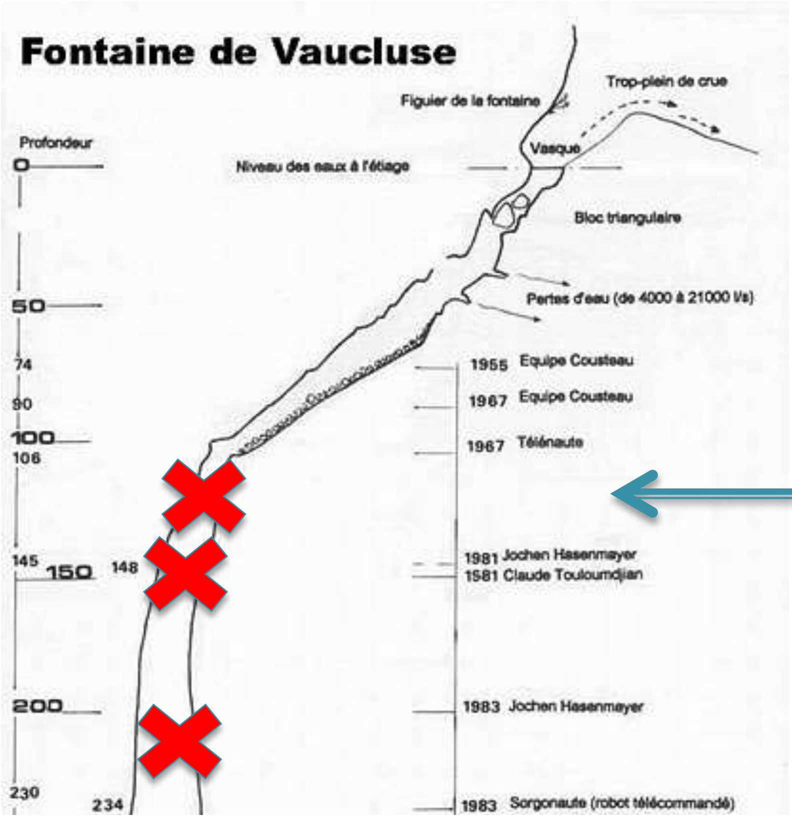
- Fontaine de Vaucluse : A magnificent Robotic Failure



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

A Rapid History of Karst Exploration With Robot

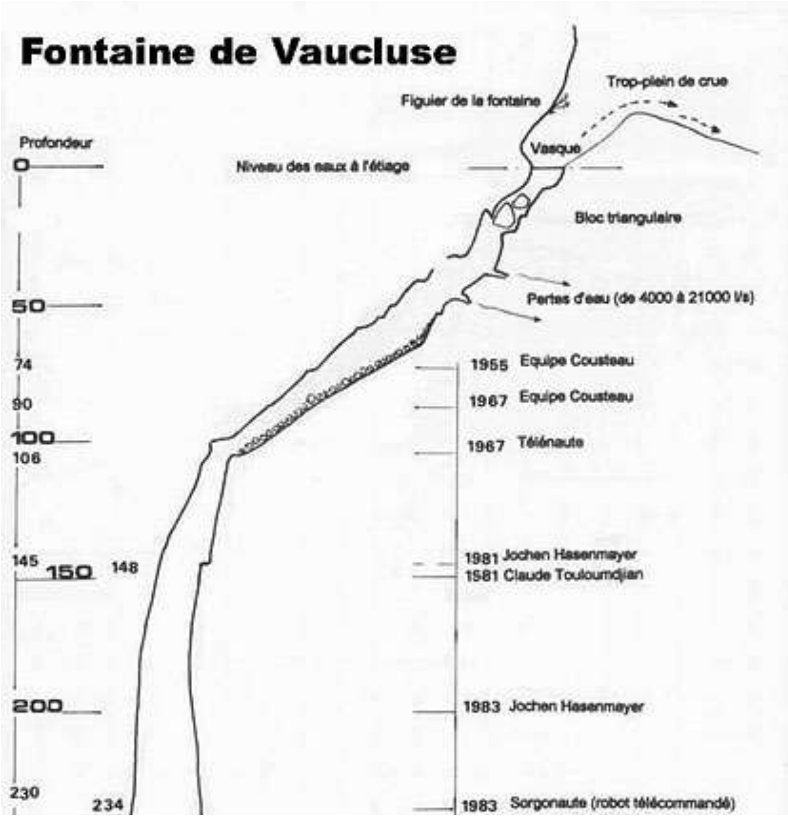
- Fontaine de Vaucluse : A magnificent Robotic Failure



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

A Rapid History of Karst Exploration With Robot

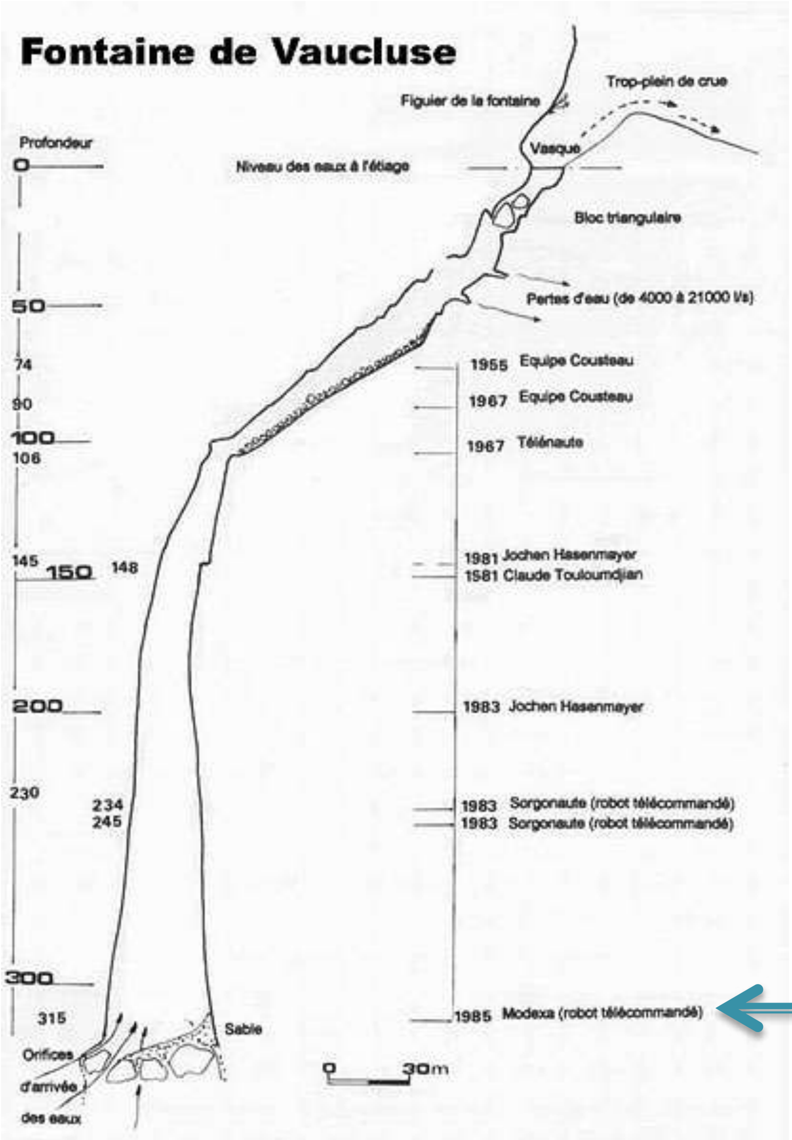
- Fontaine de Vaucluse : A magnificent Robotic Failure

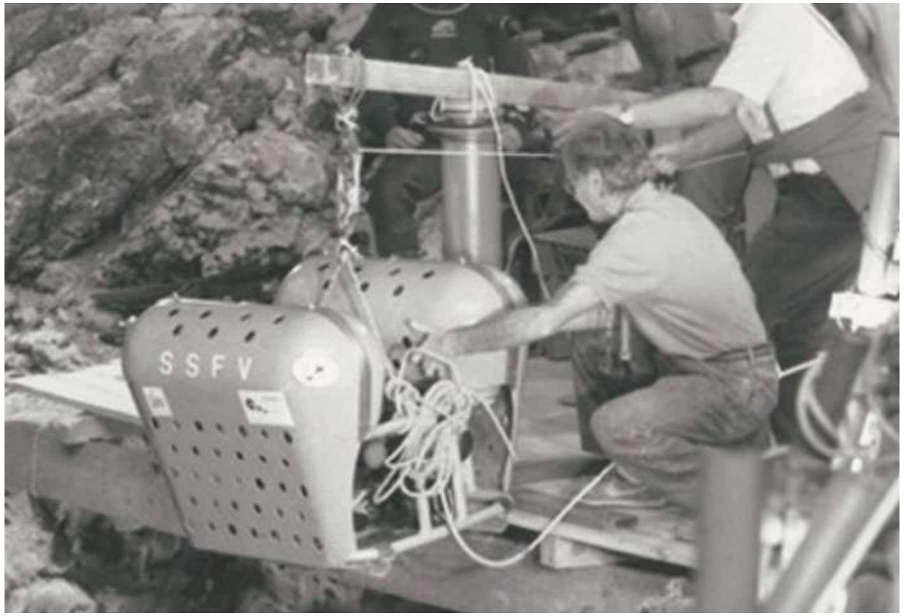


1984, The chasm was cleared by divers

A Rapid History of Karst Exploration With Robot

- Fontaine de Vaucluse : A magnificent Robotic Failure



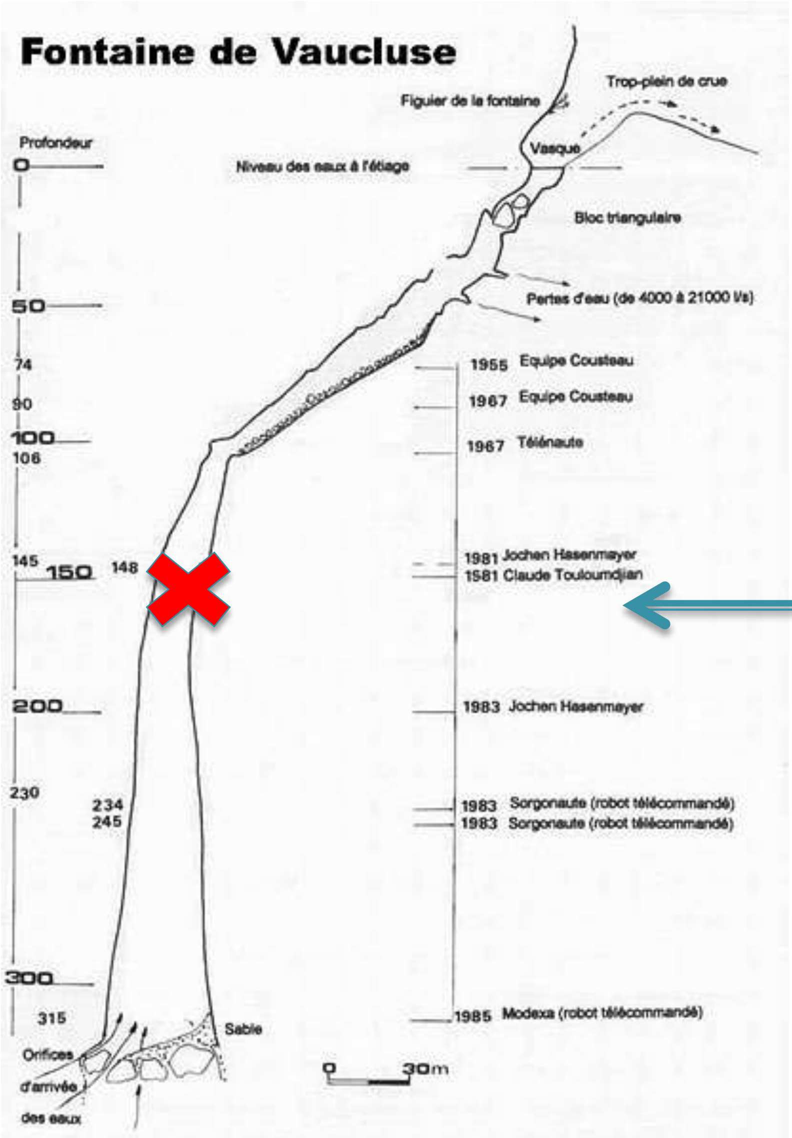


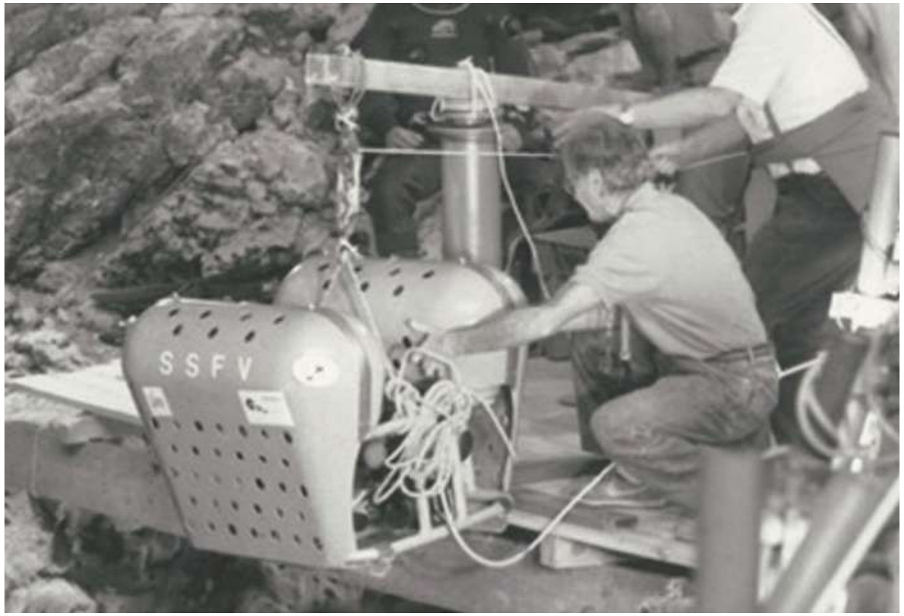
1989, Spélénaute (S.S.F.V.)
Touch-down : 315m

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

A Rapid History of Karst Exploration With Robot

- Fontaine de Vaucluse : A magnificent Robotic Failure

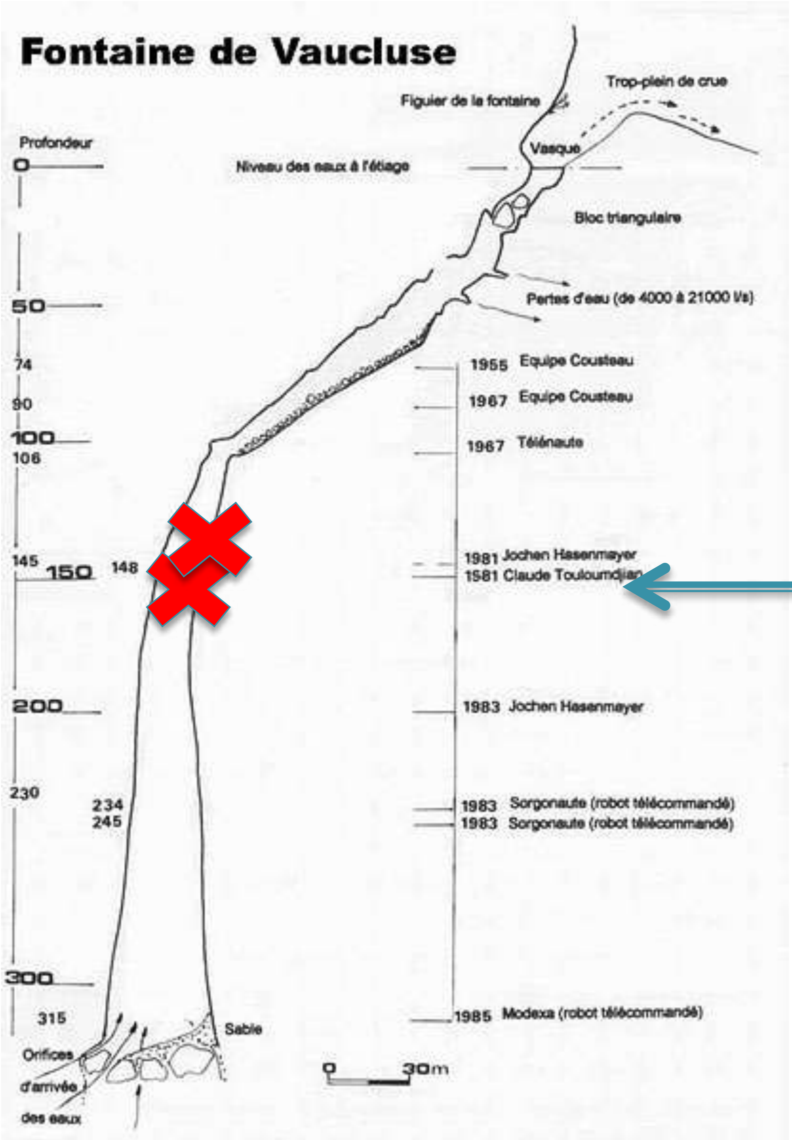




1996, Spélénaute III (S.S.F.V.)
Lost at 164m
(Trapped in a remaining lifeline)

A Rapid History of Karst Exploration With Robot

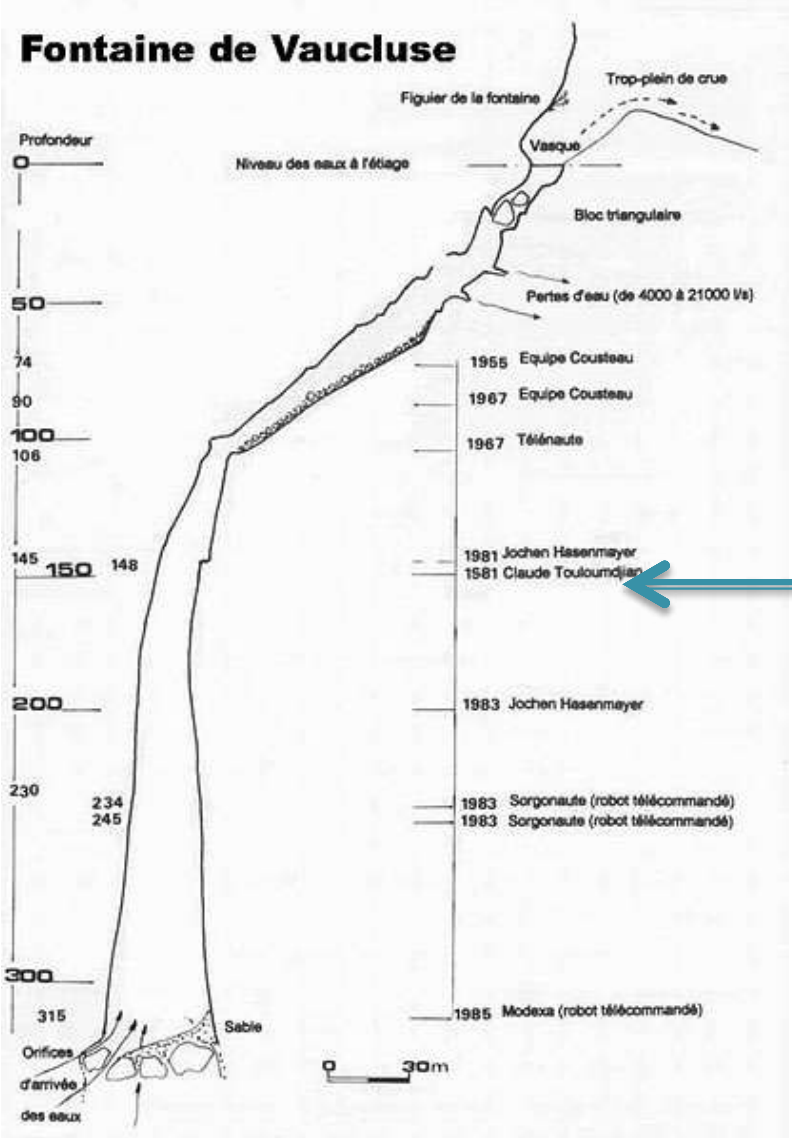
- Fontaine de Vaucluse : A magnificent Robotic Failure



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

A Rapid History of Karst Exploration With Robot

- Fontaine de Vaucluse : A magnificent Robotic Failure

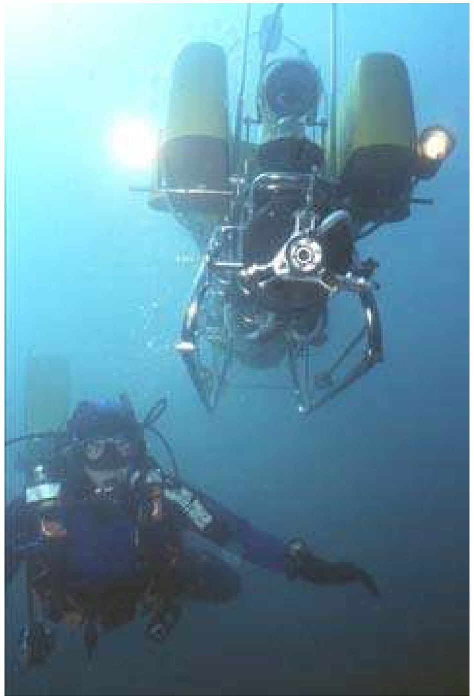


1996, Chasm cleared by divers

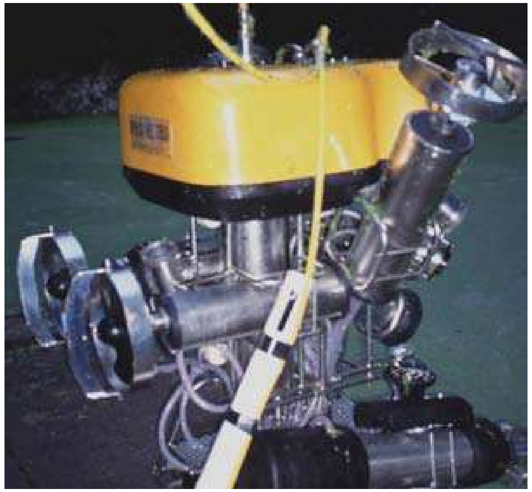
A Rapid History of Karst Exploration With Robot

- Exploration of the Pozzo Del Merro (Italy)

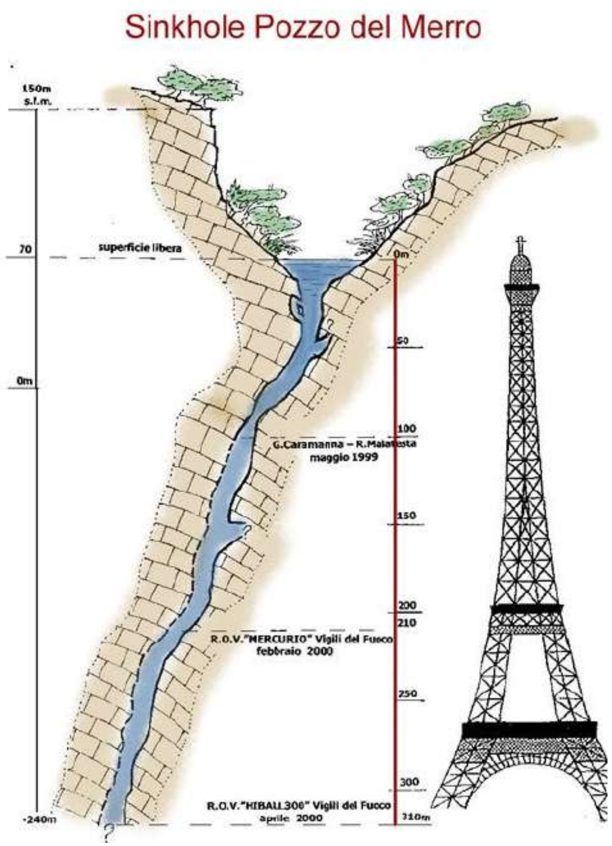
2001, Hyball, 310m



2000, Mercury, 210m

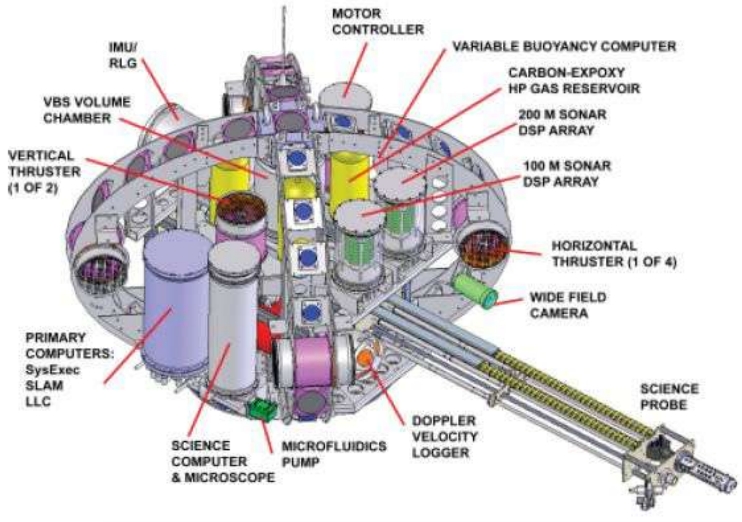


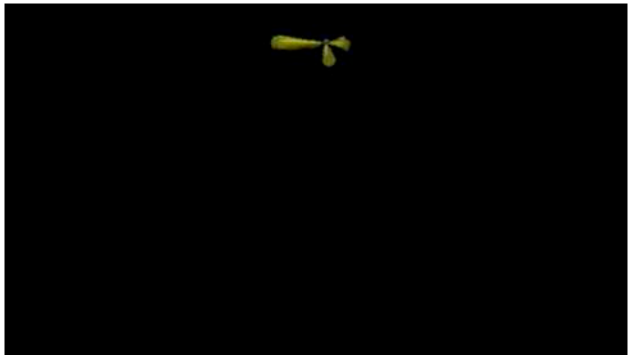
2002, Prometheus, 392m

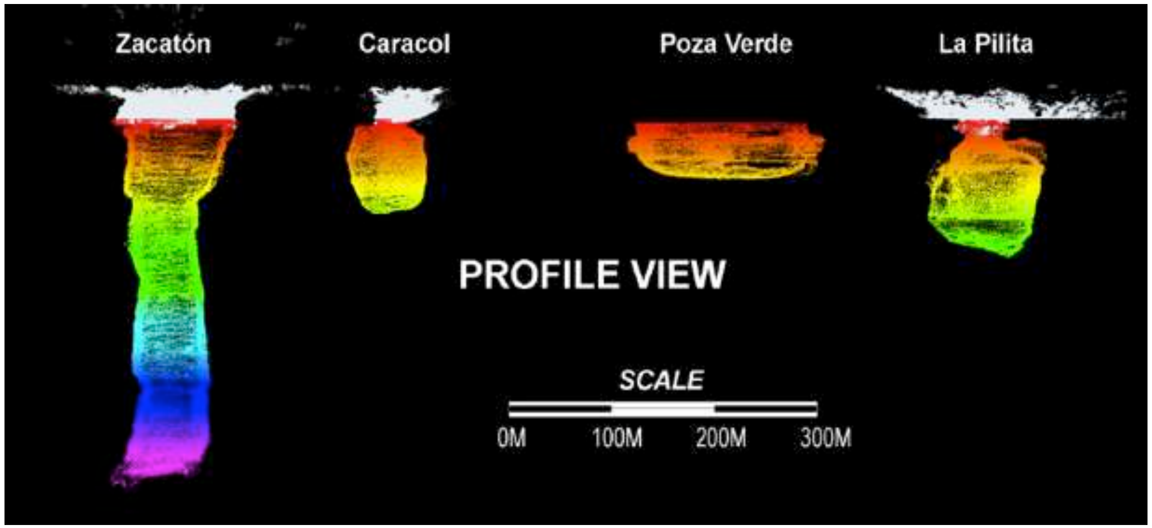


A Rapid History of Karst Exploration With Robot

- DepthX (DEep Phreatic THermal eXplorer)

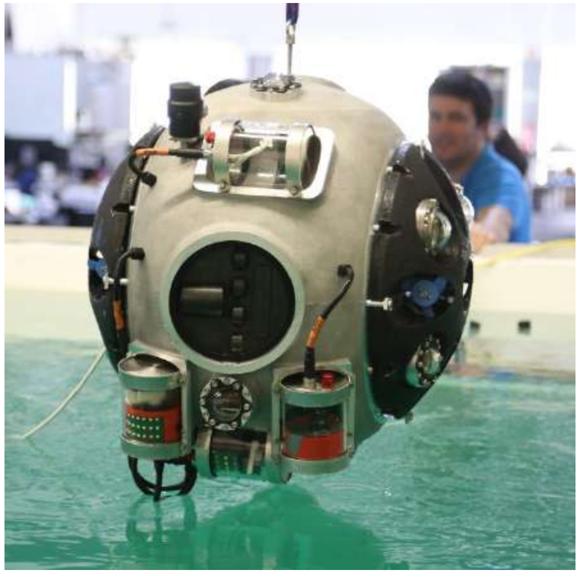






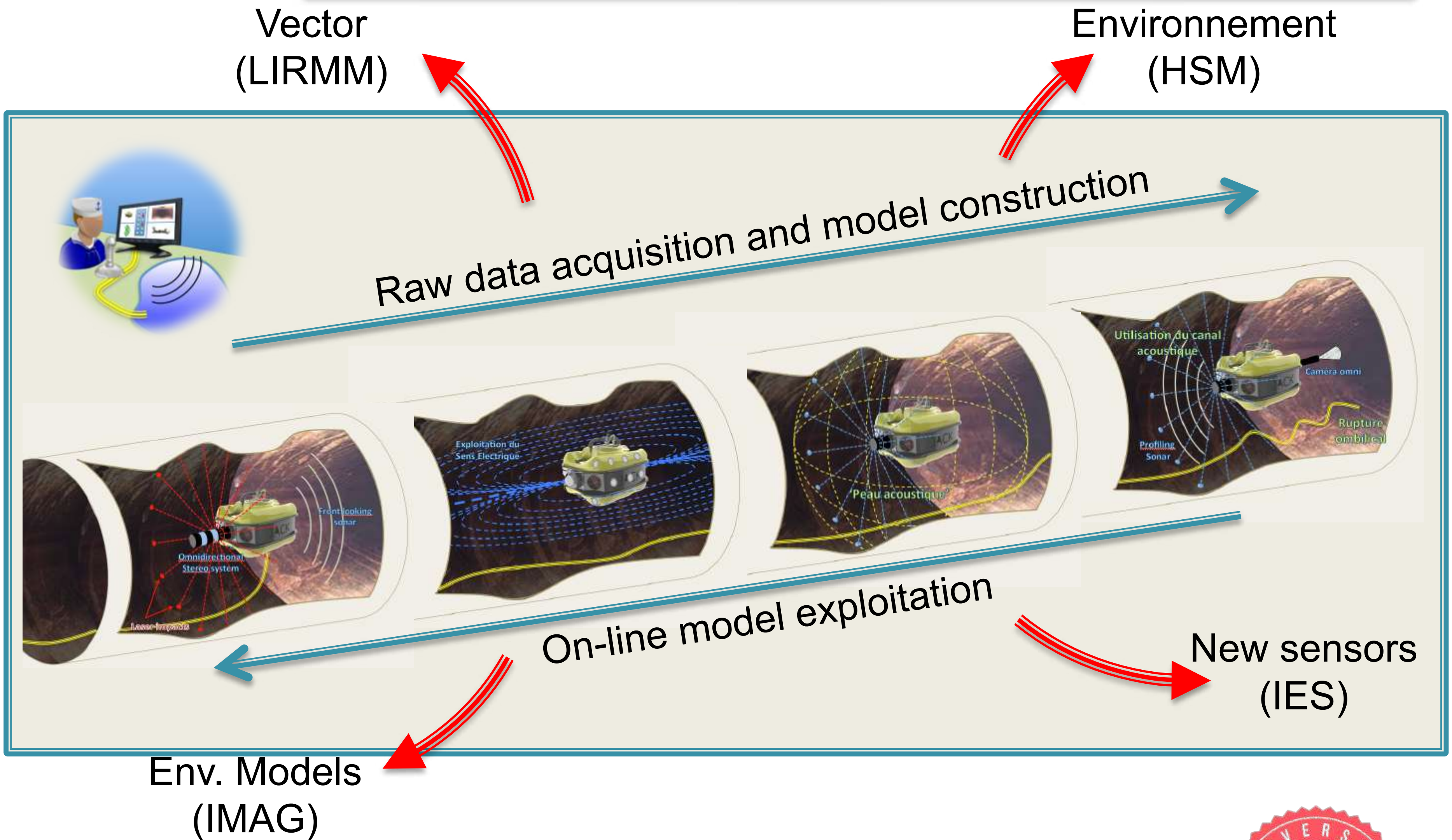
A Rapid History of Karst Exploration With Robot

- 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



LIRMM HSM ies l'institut d'électronique IMAG INSTITUT MONTPELLIERAIN ALEXANDER GROTHENDIECK UNIVERSITÉ MONTPELLIER

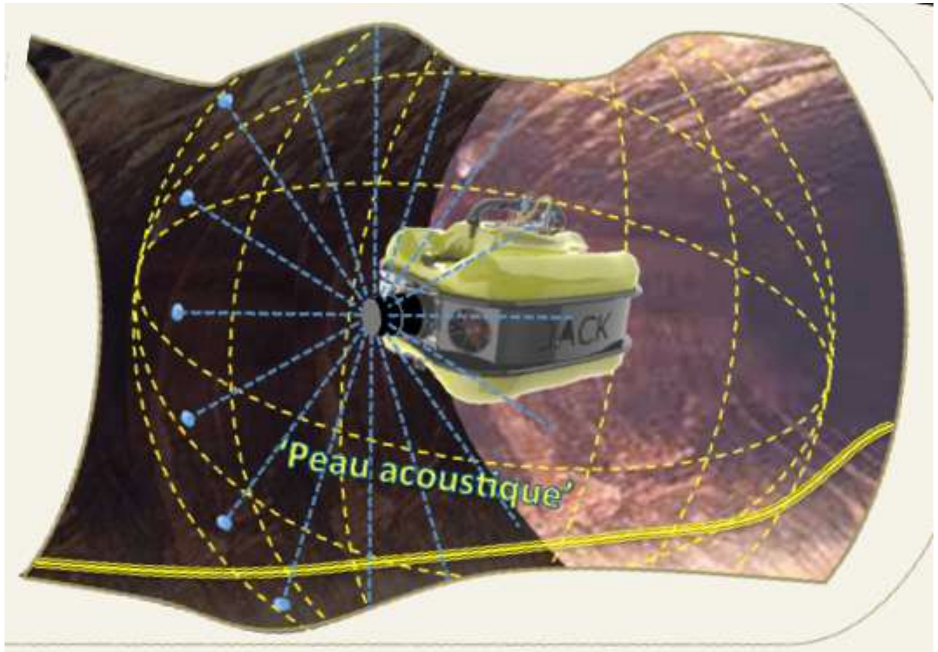
The RKE Initiative : The Challenges

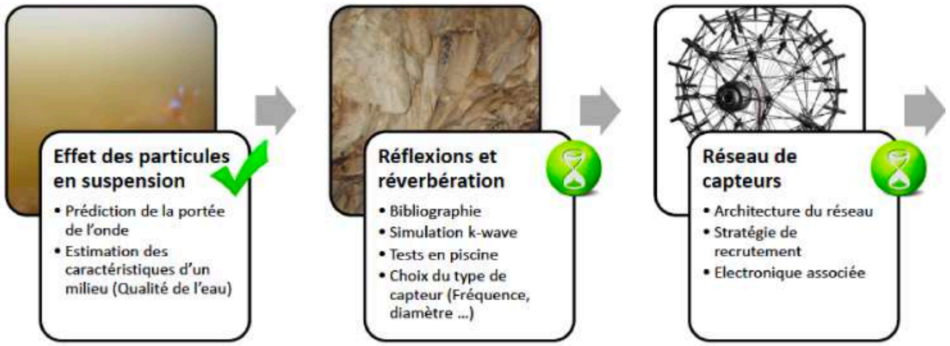
- New Sensors Development
  - Acoustic Skin
  - Active Umbilical
- Navigation
  - Glob. Nav. System
  - n-D Acoustic SLAM
  - Vacancy Evidence Grids
- Guidance
  - Autonomous Centring
  - Autonomous Targeting
  - Env. Models inclusion
- Control
  - Robustness
  - Co-control
  - Open-loop stability
- 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

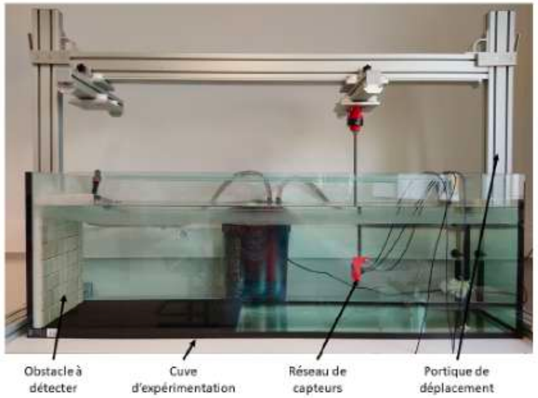
Forces at Work

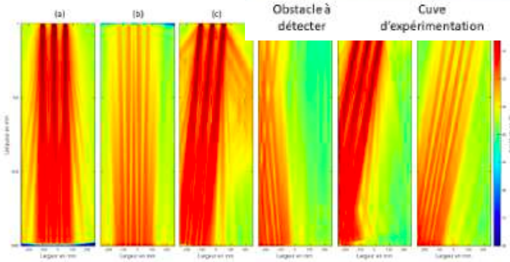
F. Augereau (IES)
D. Laux (IES)
M. Alarab (Thèse)

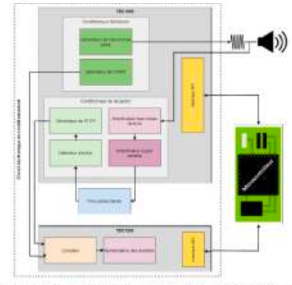
- New Sensors Development
  - Acoustic Skin

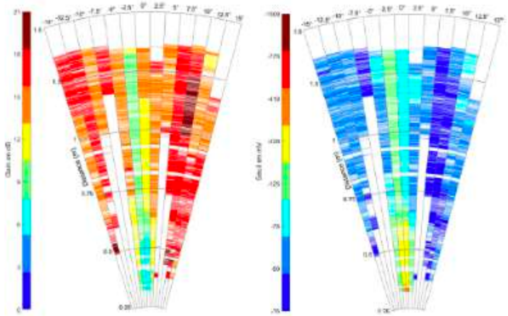






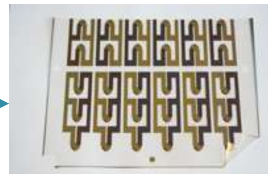


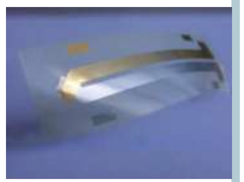




IGURE 5.12 – Variation du gain (à gauche) et du seuil (à droite) de détection de rcuit de conditionnement en fonction de la distance de détection et l'angle d'incidence. onfiguration : 3 transducteurs émetteurs espacés de 5 cm, réflexion contre le paroi de quarium en verre. Représentation des variations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

Stimulation Protocol →

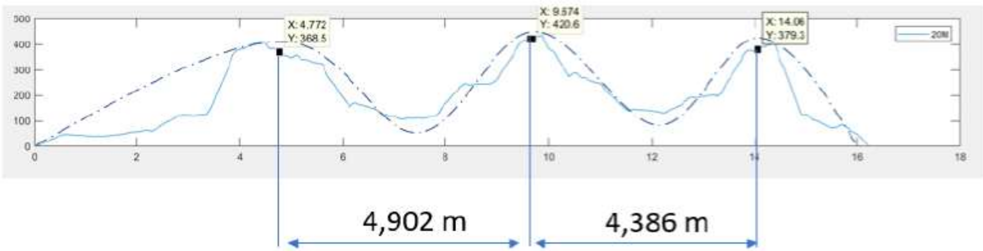


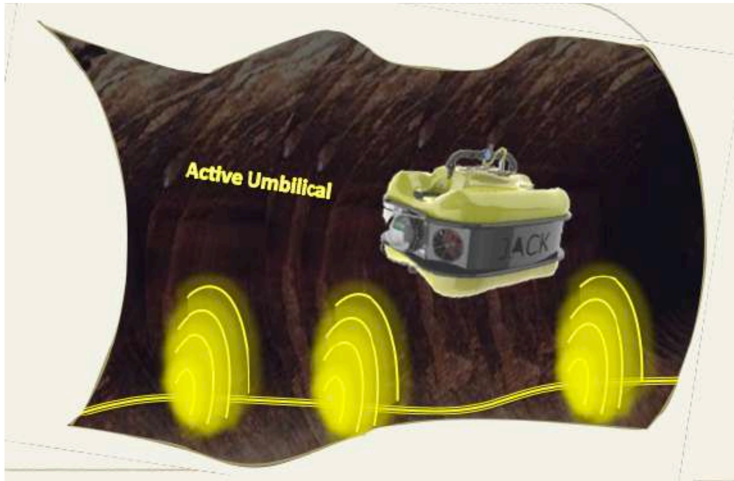


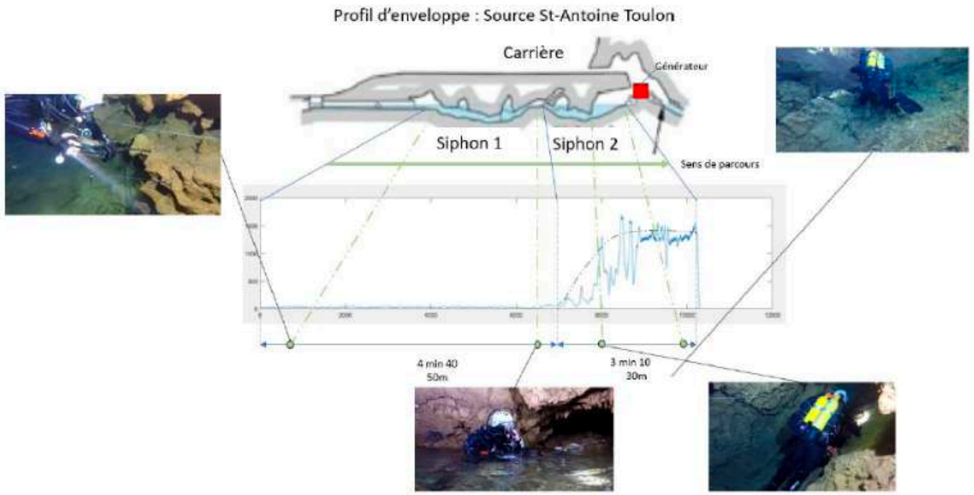
Time of Arrival Sensor (piezotech)

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

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



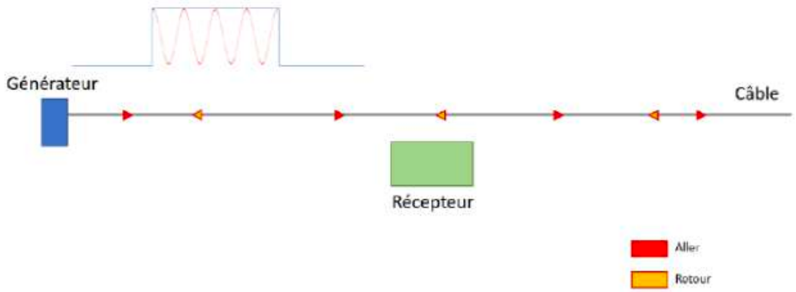


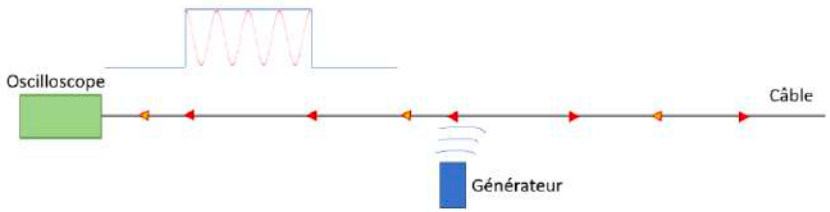


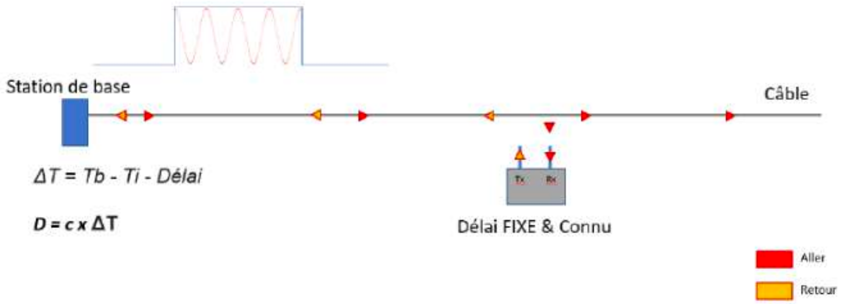
Experimentation in the St Antoine spring (Toulon)

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

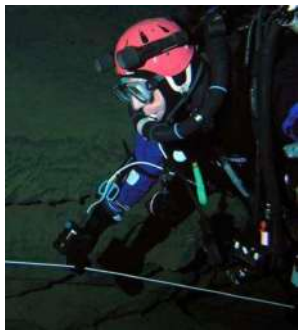
- New Sensors Development
  - <u>Active Umbilical (localisation and communication)</u>
    - Détection of Stationnary waves in single wire (fil d'ariane)
    - Communication/localisation with Burst / Ping





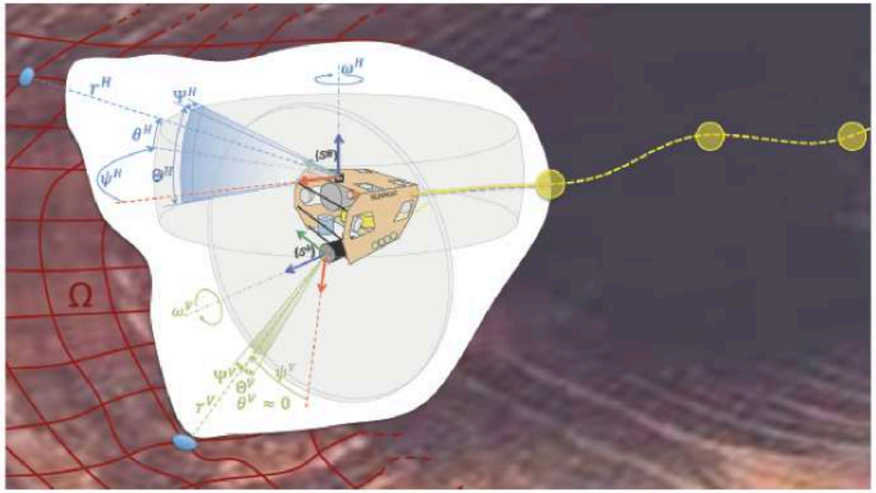


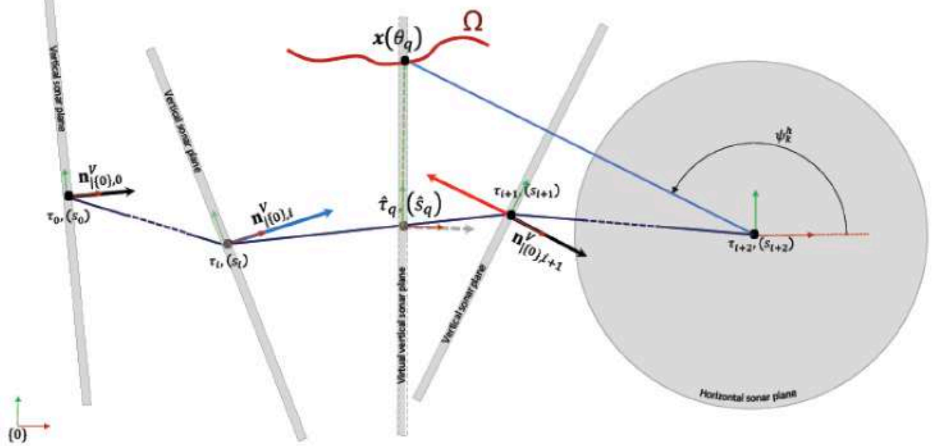
amperometric clamp
(pince ampèremétrique)

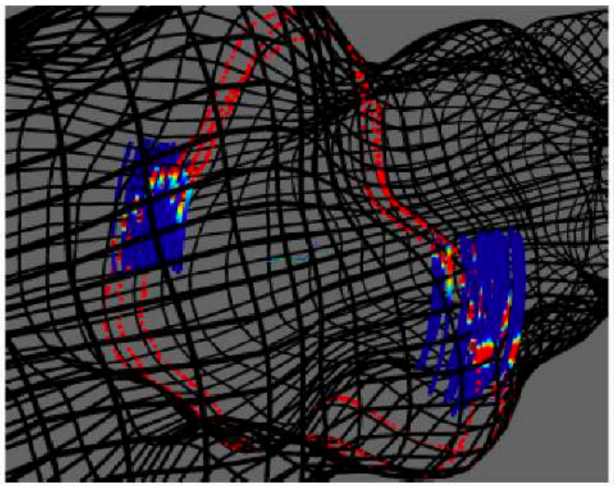


Y. Breux (LIRMM/IMAG)
B. Mohammadi (IMAG)
A. Mas (IMAG)
L. Lapierre (LIRMM)

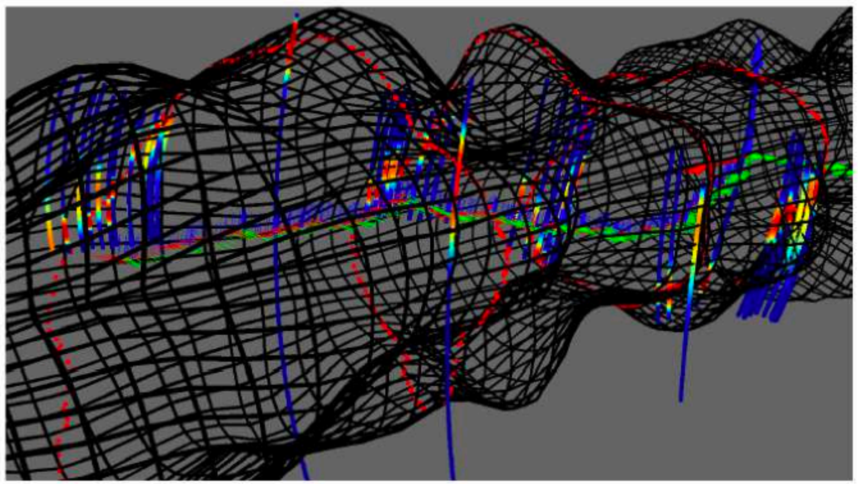
- Navigation
  - 3D Acoustic SLAM (1) : Estimation of the elevation angle of the large angle vertical profiling sonar.







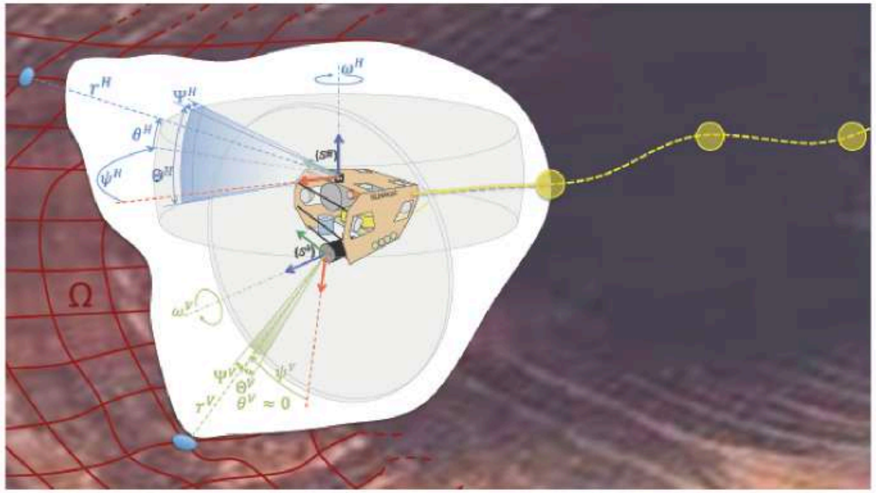
(a) Dense case.

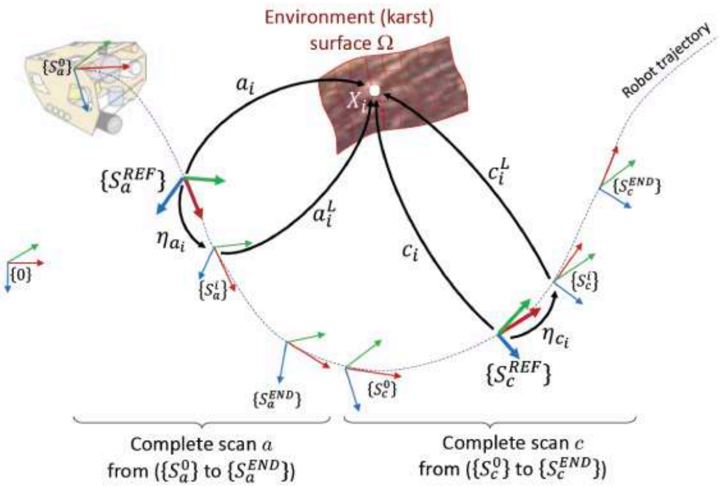


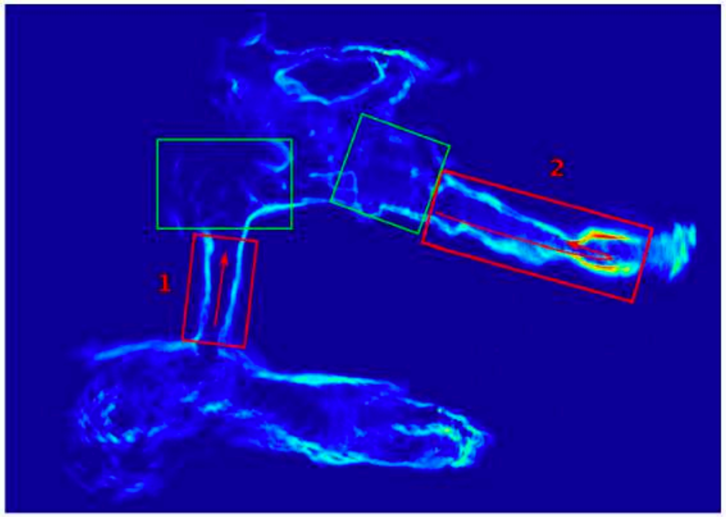
(c) Sparse case.

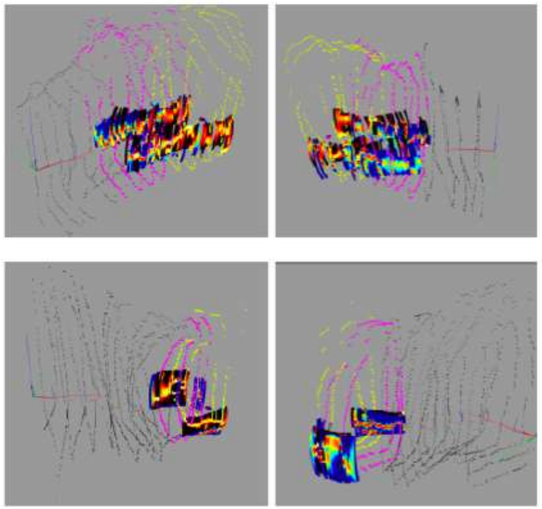
Y. Breux (LIRMM/IMAG)
B. Mohammadi (IMAG)
A. Mas (IMAG)
L. Lapierre (LIRMM)

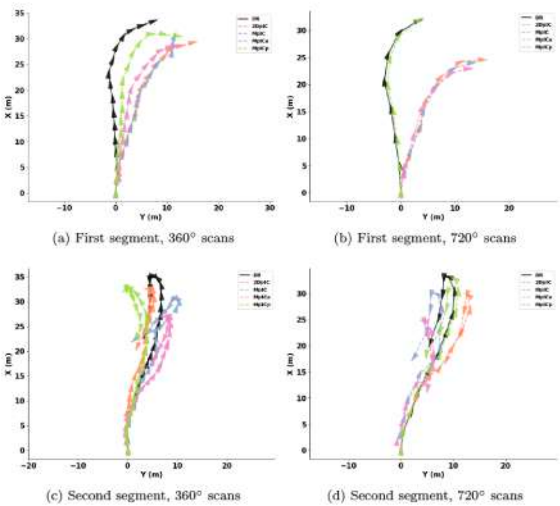
- Navigation
  - 3D Acoustic SLAM (2) : Scan Matching (point to point and point to plane).









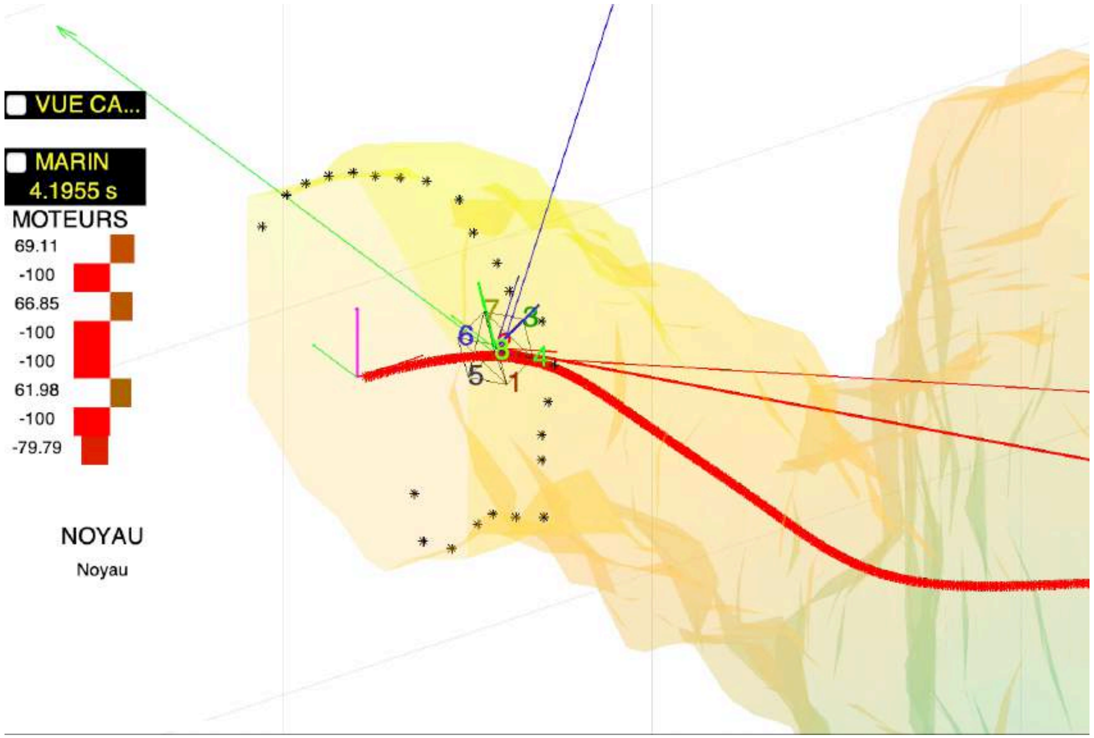


  - Acoustic SLAM (3) : Graph SLAM and loop closure detection...

The RKE Initiative : Forces at Work

L. Lapierre (LIRMM)
R. Zapata (LIRMM)
B. Ropars (Reeds)

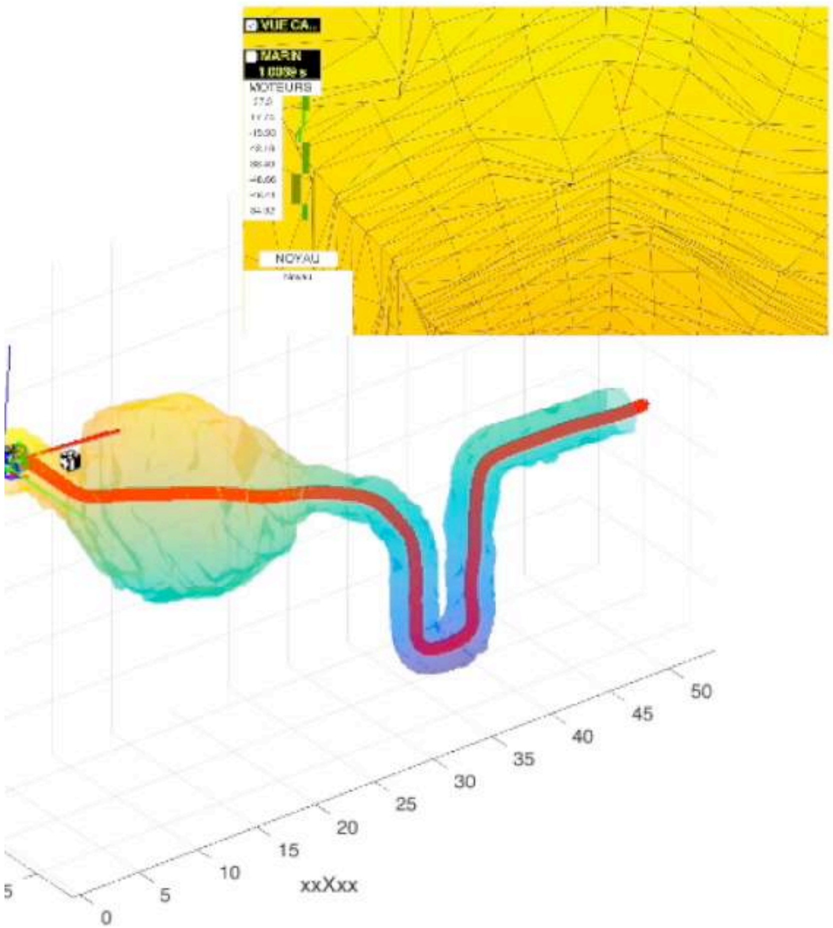
- Navigation
  - Vacancy Evidence Grids
  - Advance vector
- Local Path-planning
- Guidance
  - Autonomous Centring
  - Path Following
  - Obstacle Avoidance
- Control
  - Robustness
  - Co-control
  - Open-loop stability

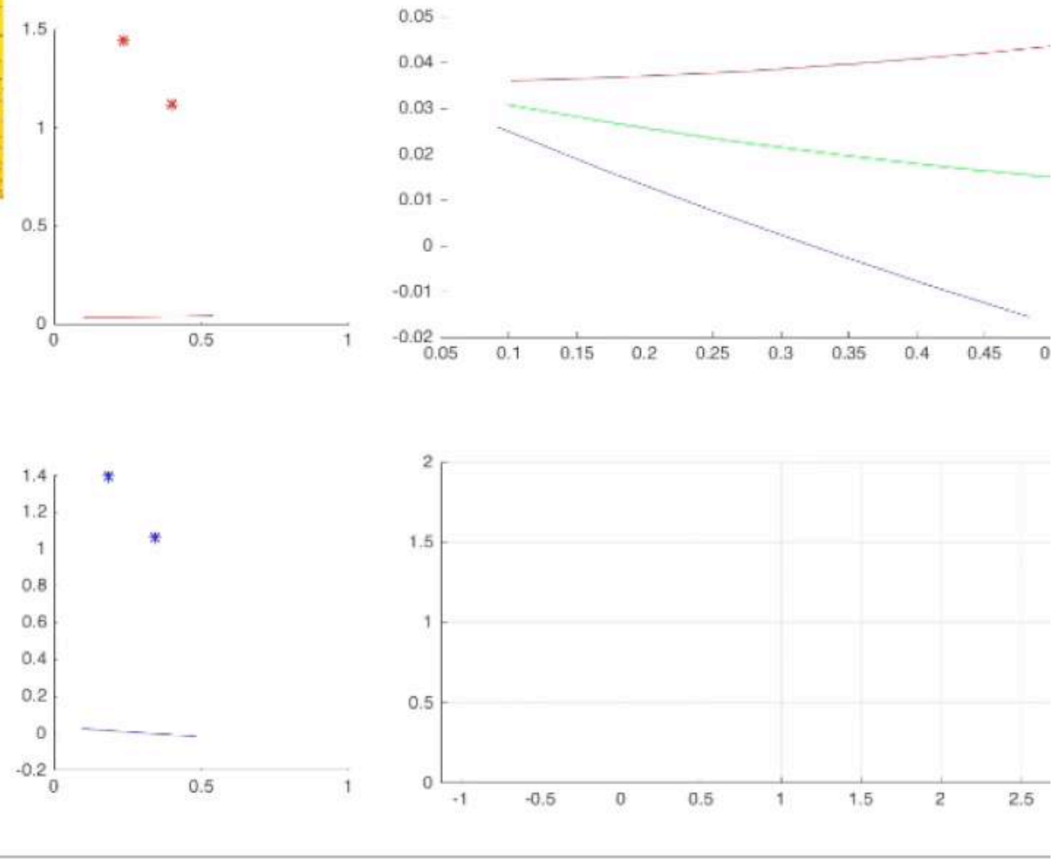


THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

- Cartographie garantie, analyse par intervalles

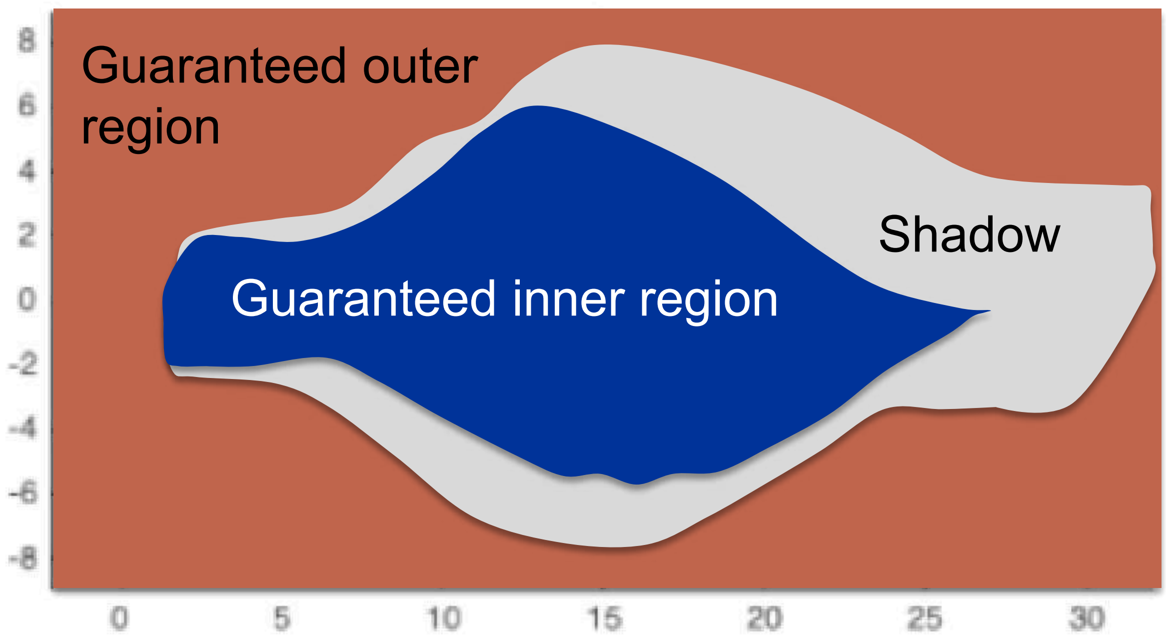
$$X, \tilde{X} \rightarrow [X]$$





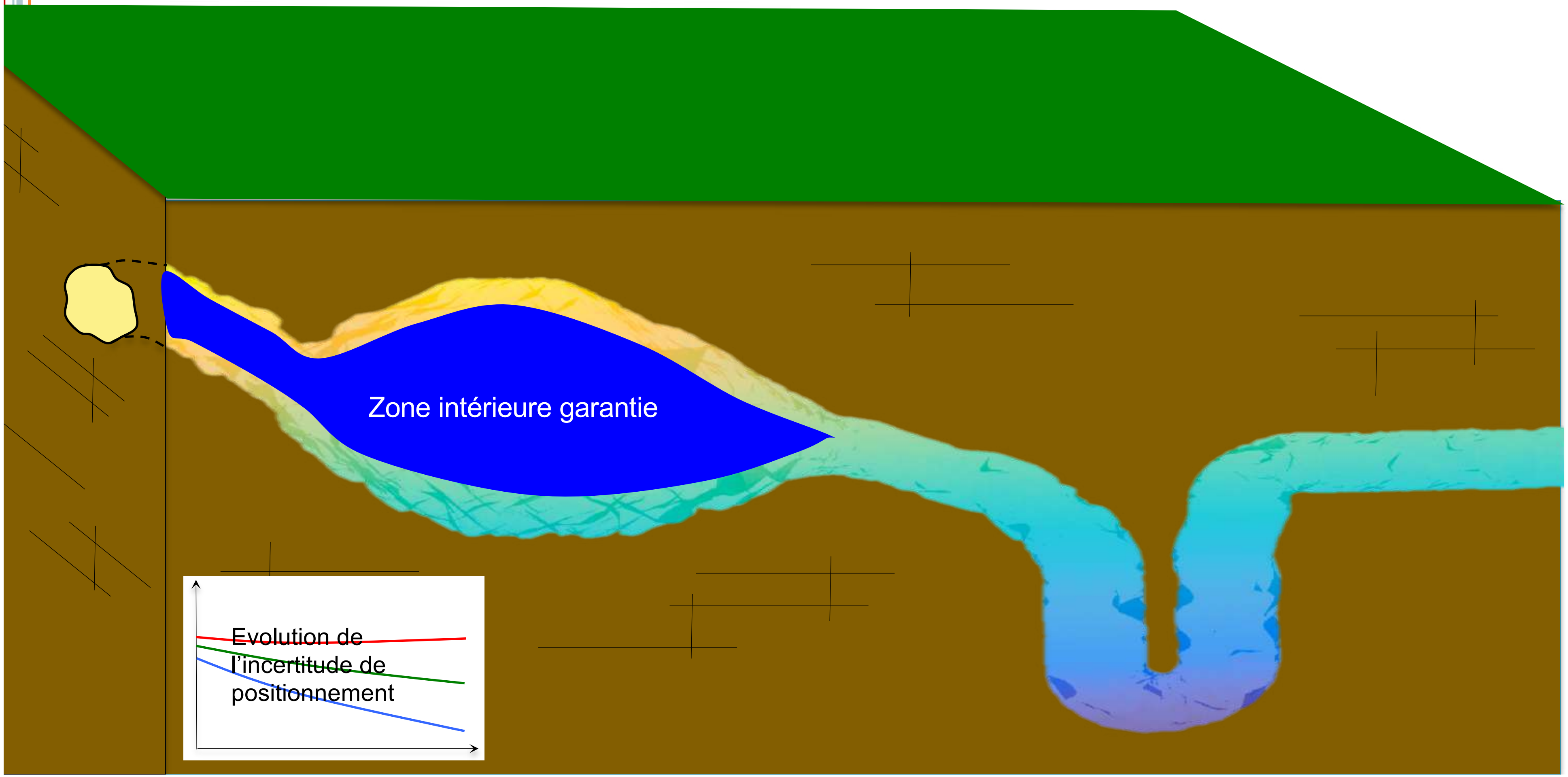
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

- Cartographie garantie, analyse par intervalles



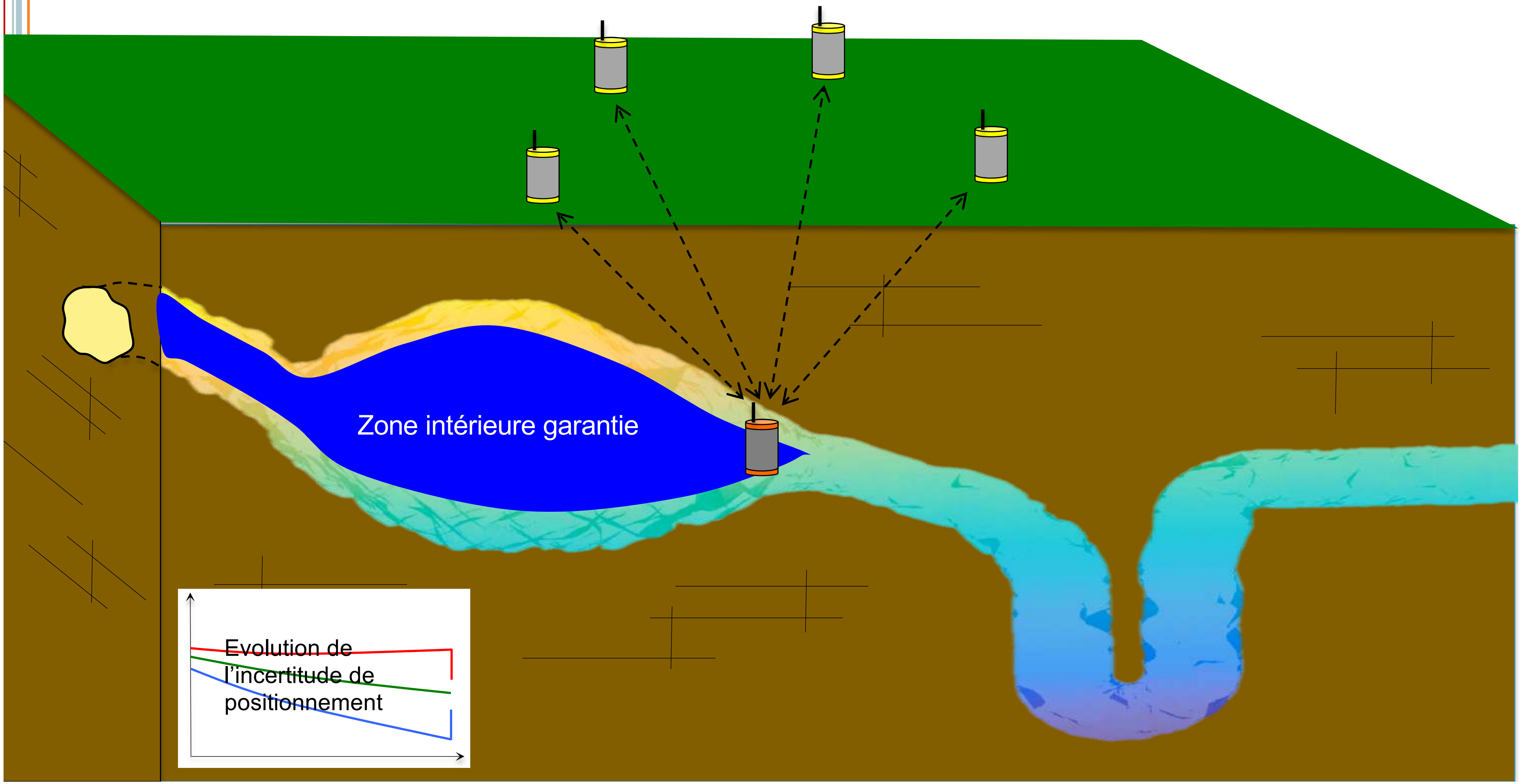
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

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



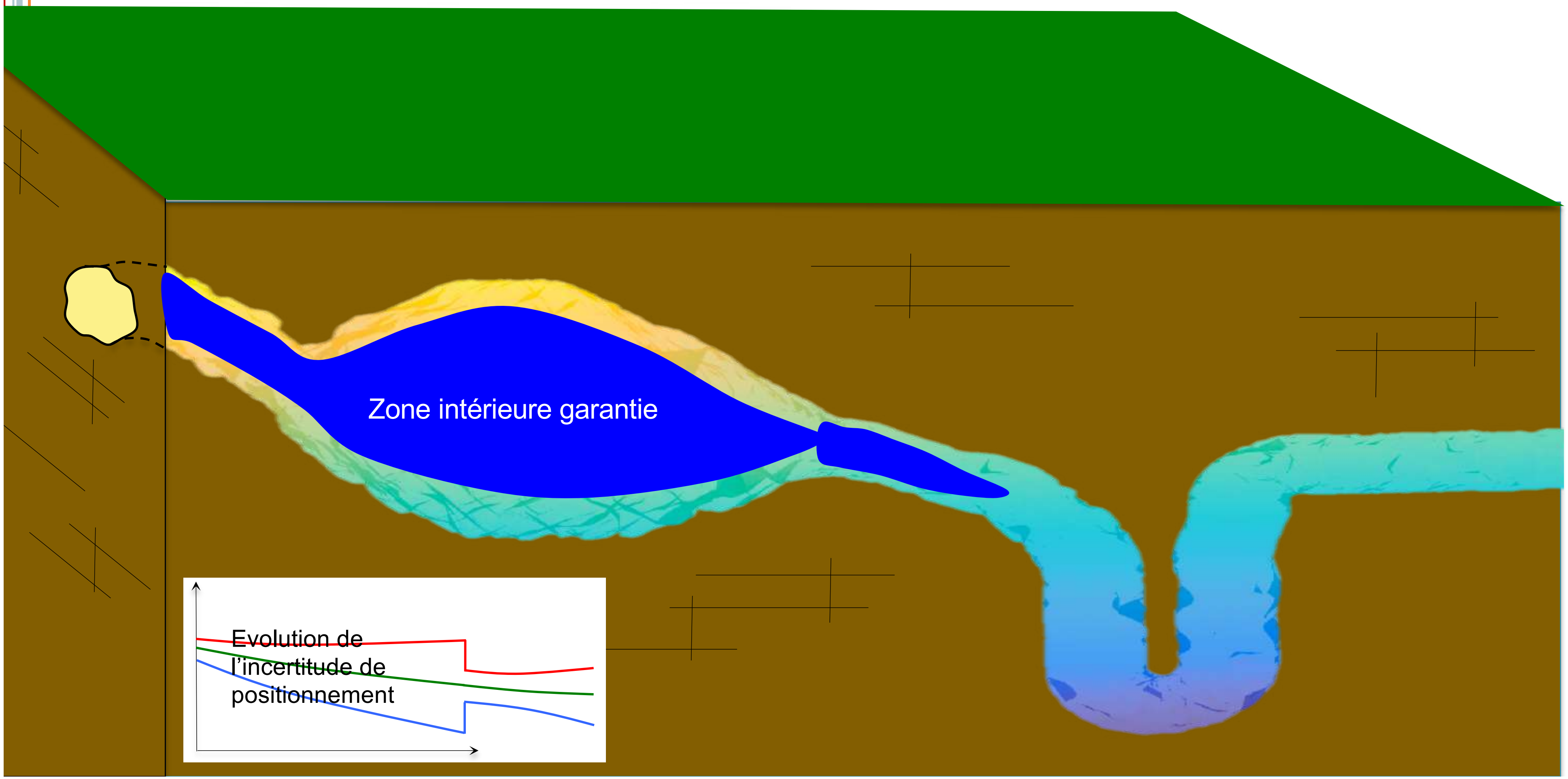
The RKE Initiative : Forces at Work (LIRMM, ENSTA)

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



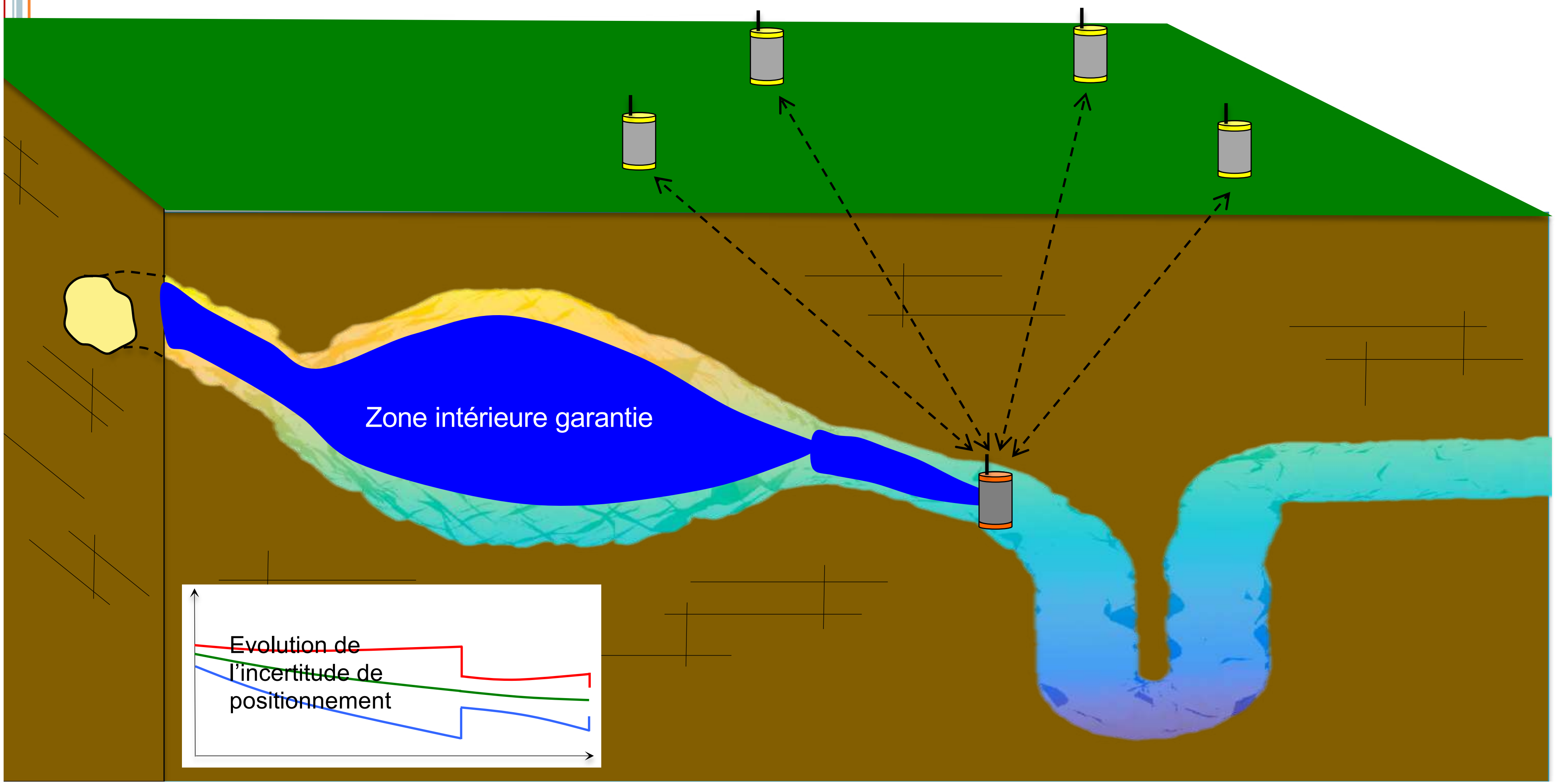
The RKE Initiative : Forces at Work (LIRMM, ENSTA)

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



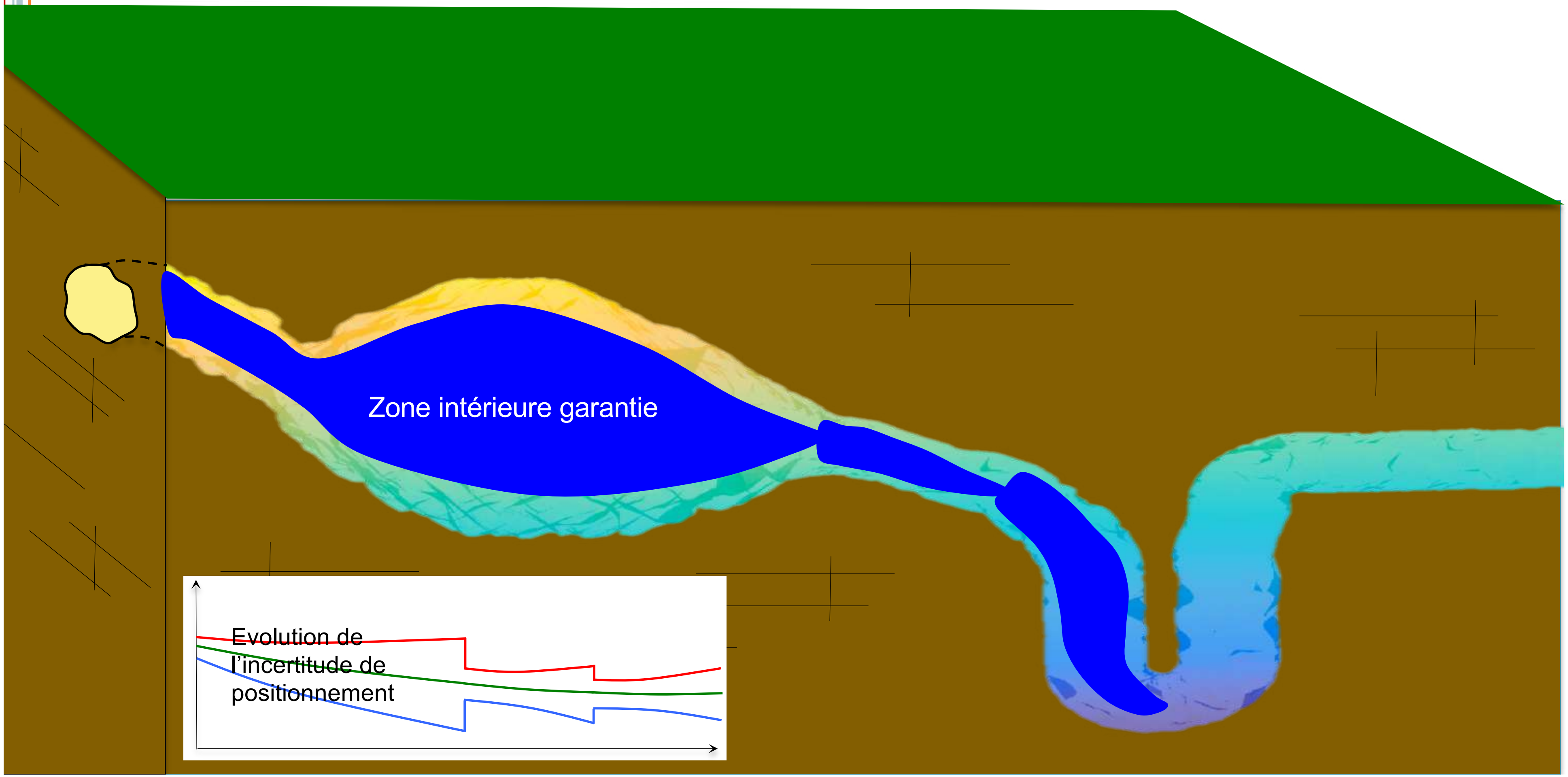
The RKE Initiative : Forces at Work (LIRMM, ENSTA)

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



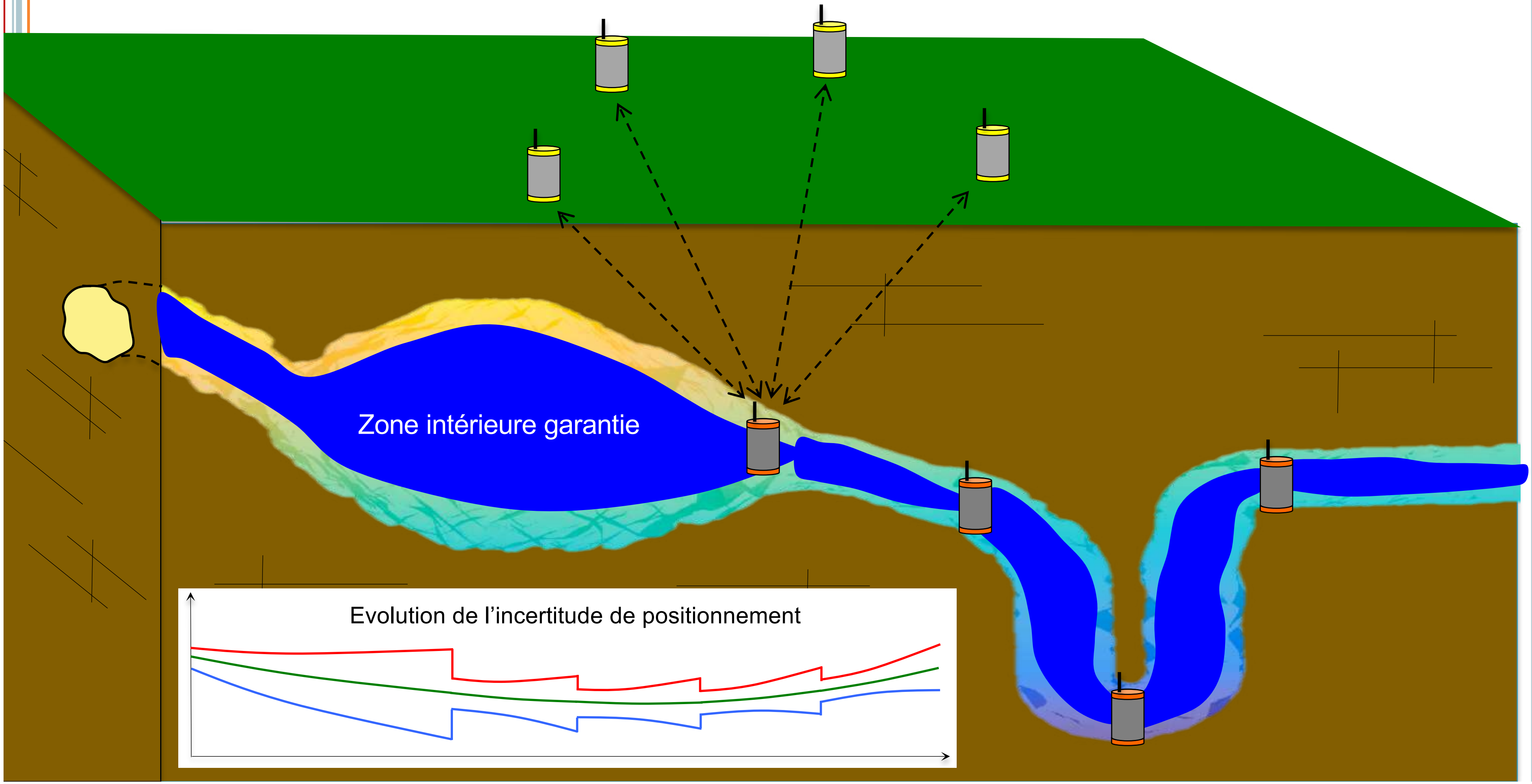
The RKE Initiative : Forces at Work (LIRMM, ENSTA)

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



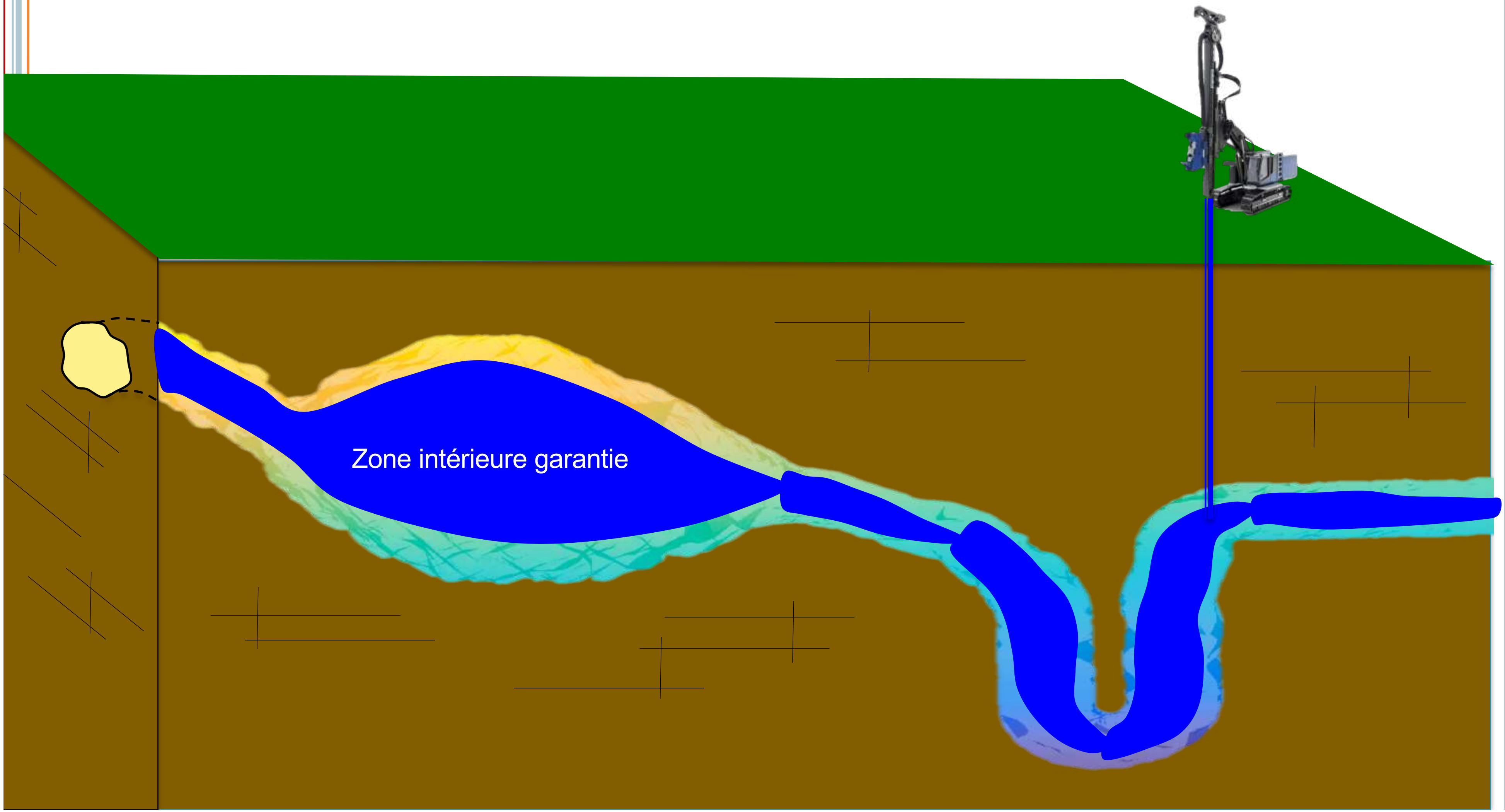
THE RKE INITIATIVE : FORCES AT WORK (LIRMM, ENSTA)

- 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

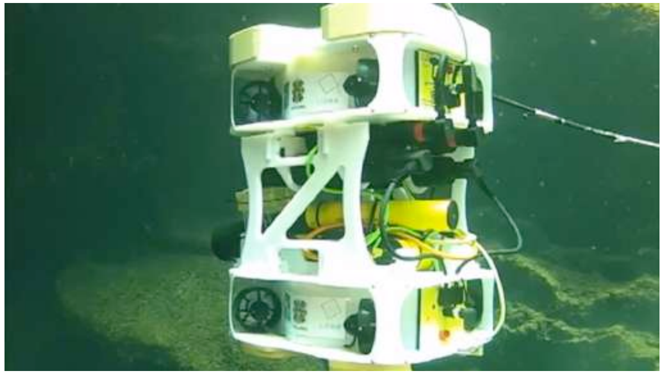


The RKE Initiative : Forces at Work

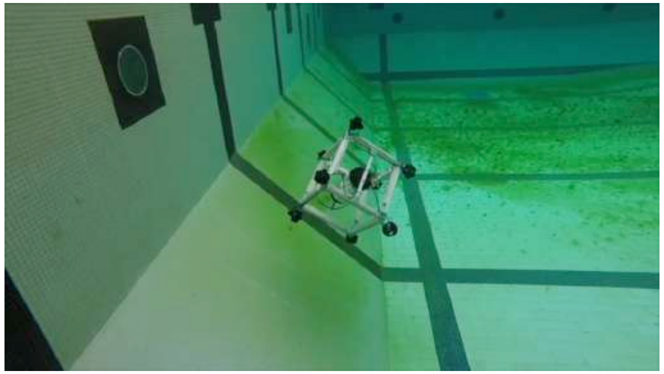
R. Zapata (LIRMM)
L. Lapierre (LIRMM)
B. Ropars (Reeds)
D. Huu Tho (Thèse)
Luc Rossi (Syera)
R. Bouchard (PlongeeSout)
F. Vasseur (PlongeeSout

Actuation

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

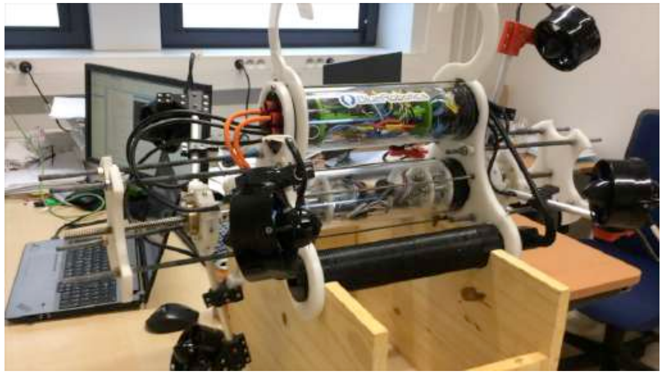


Ulysse



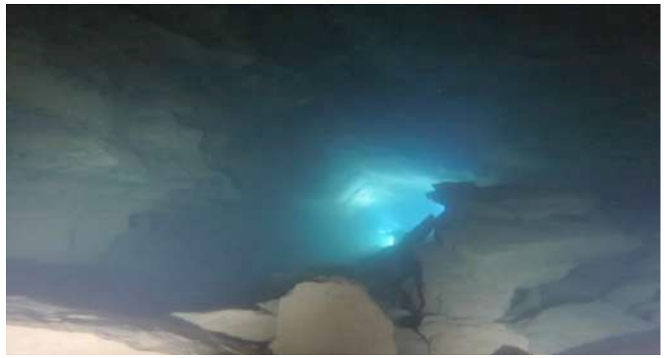
Cube

Anguille



Umbrella

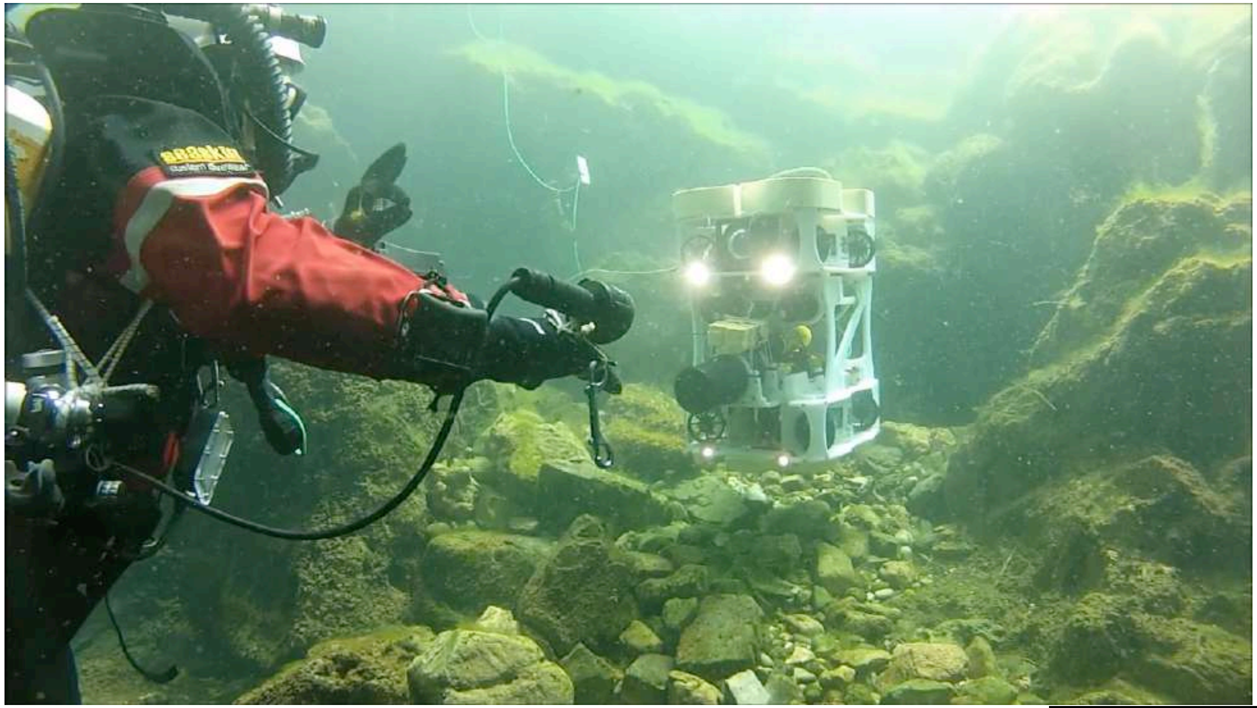
NavScoot

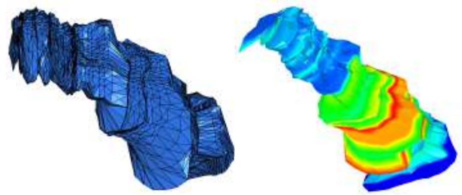


HammerHead

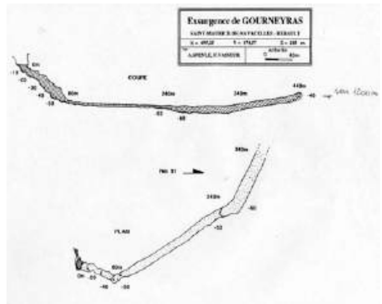
Fisrt Terrain Results

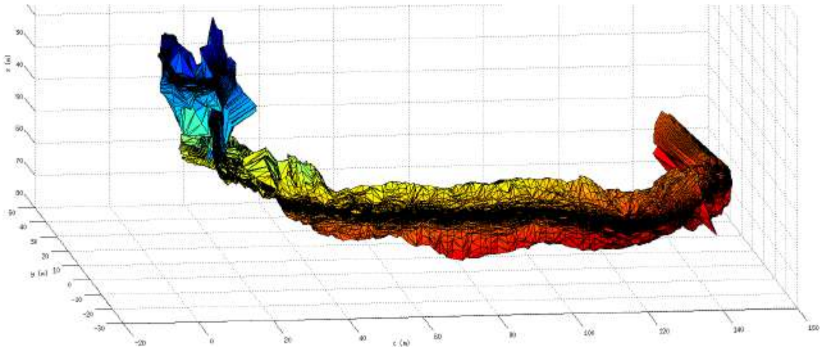
- Gourneyras, 11-14/07/2016 and 23/01/2017.





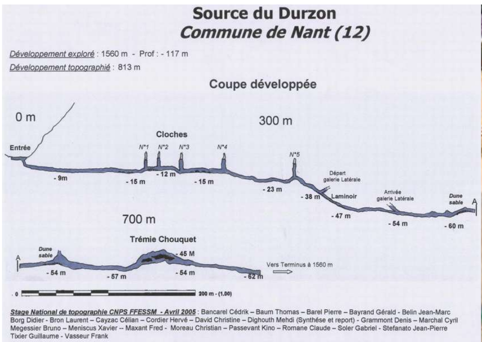
Volume (1187 m^3)

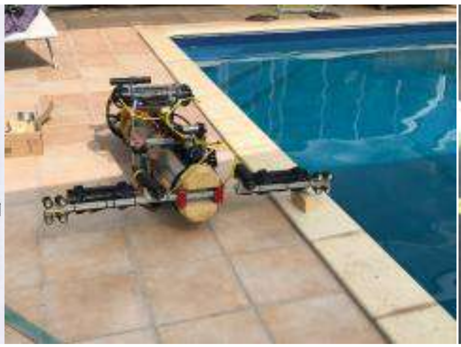




Fisrt Terrain Results

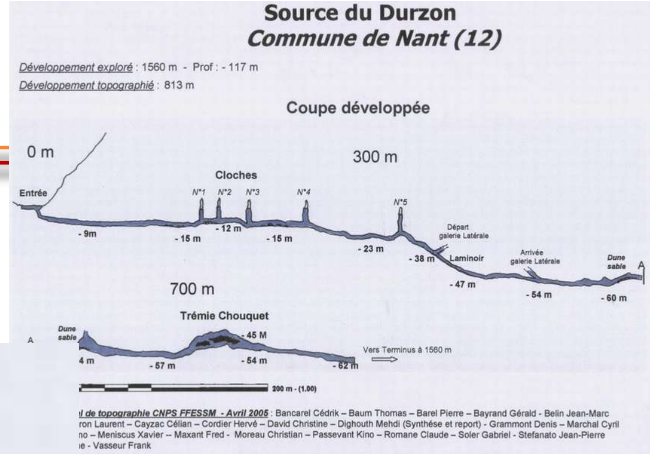
- Durzon, Nant, 24/06/2018.

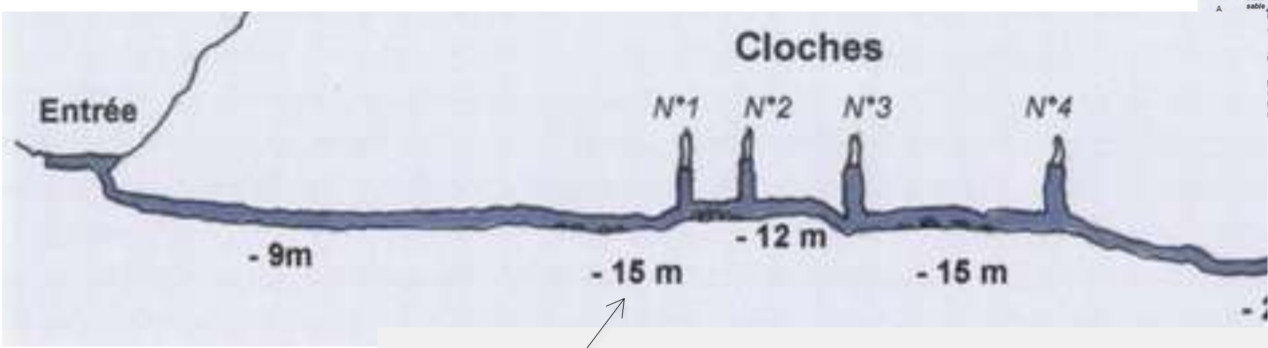


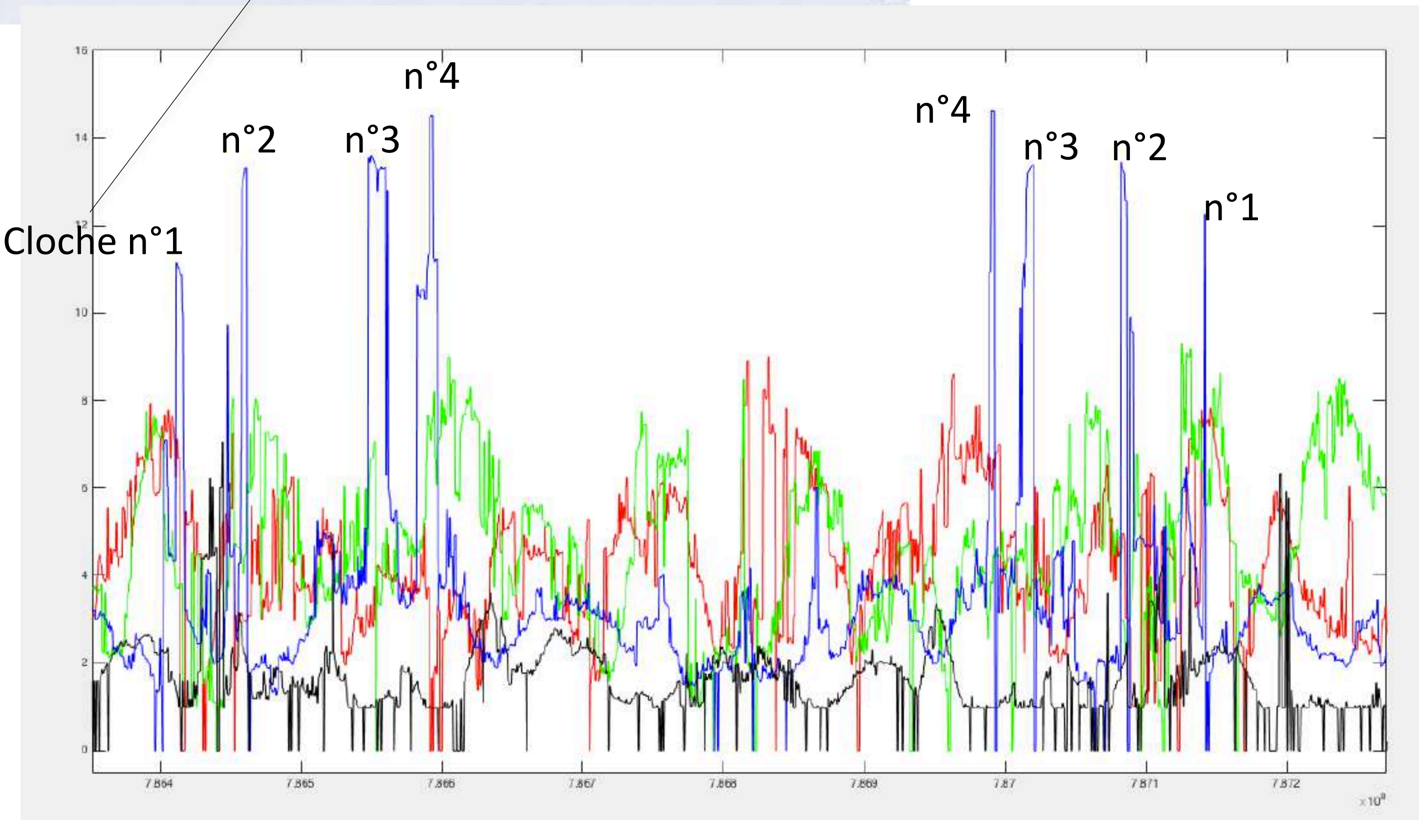


FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.





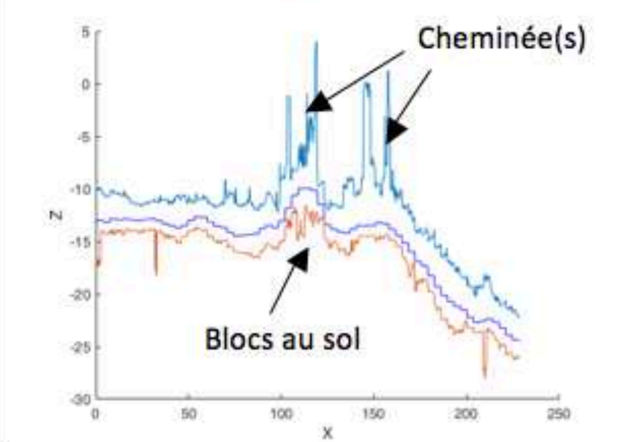
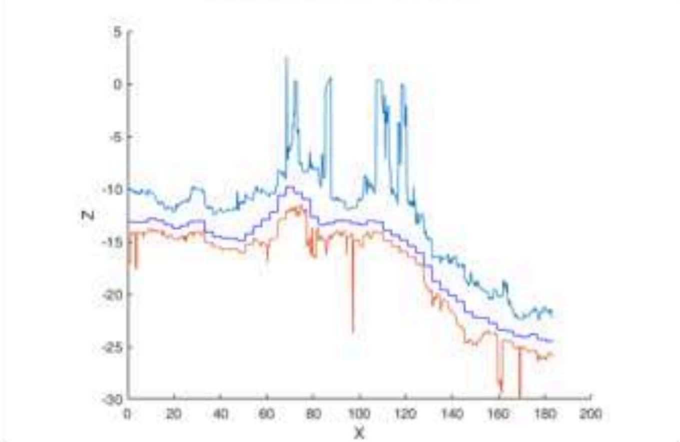
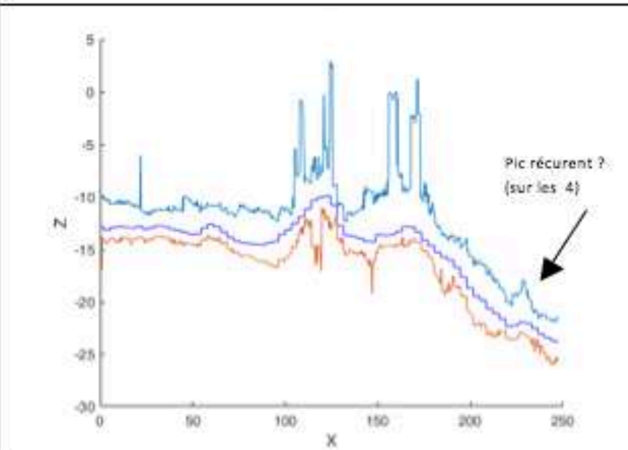
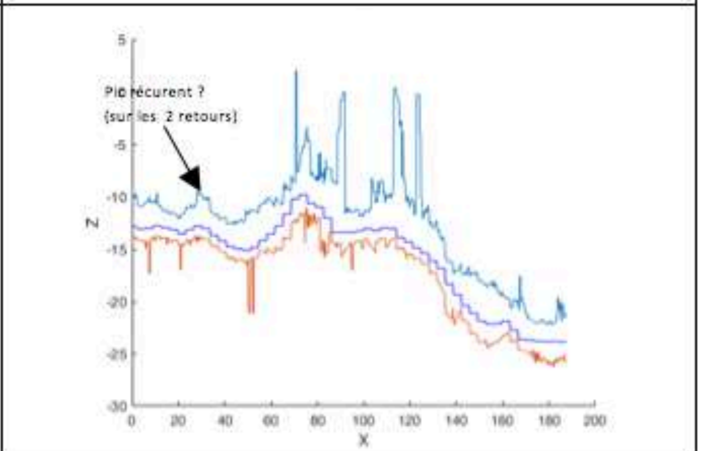


FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.

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

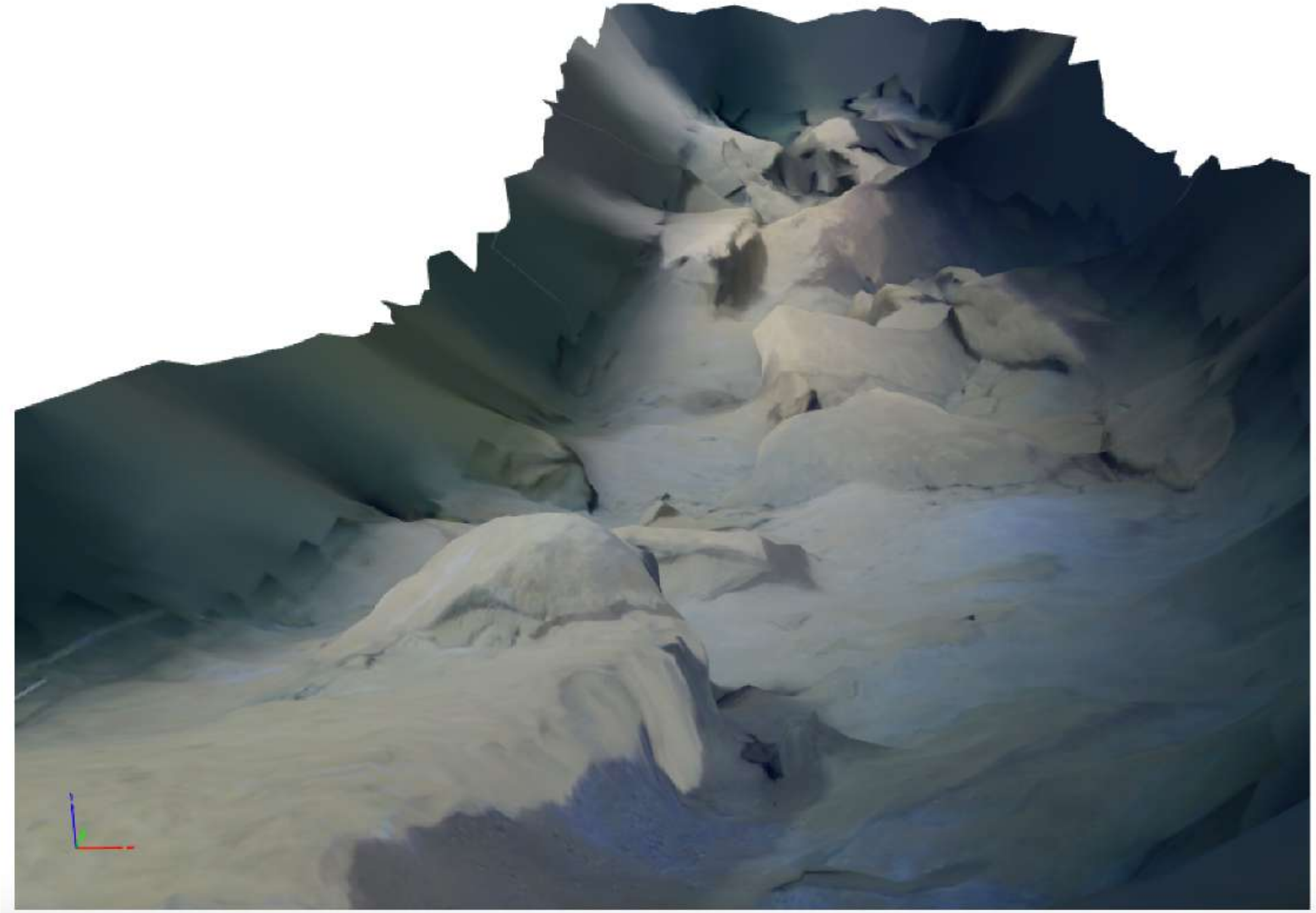
Données :

	Aller	Retour (inversé G/D)
1er		
2nd		

FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.

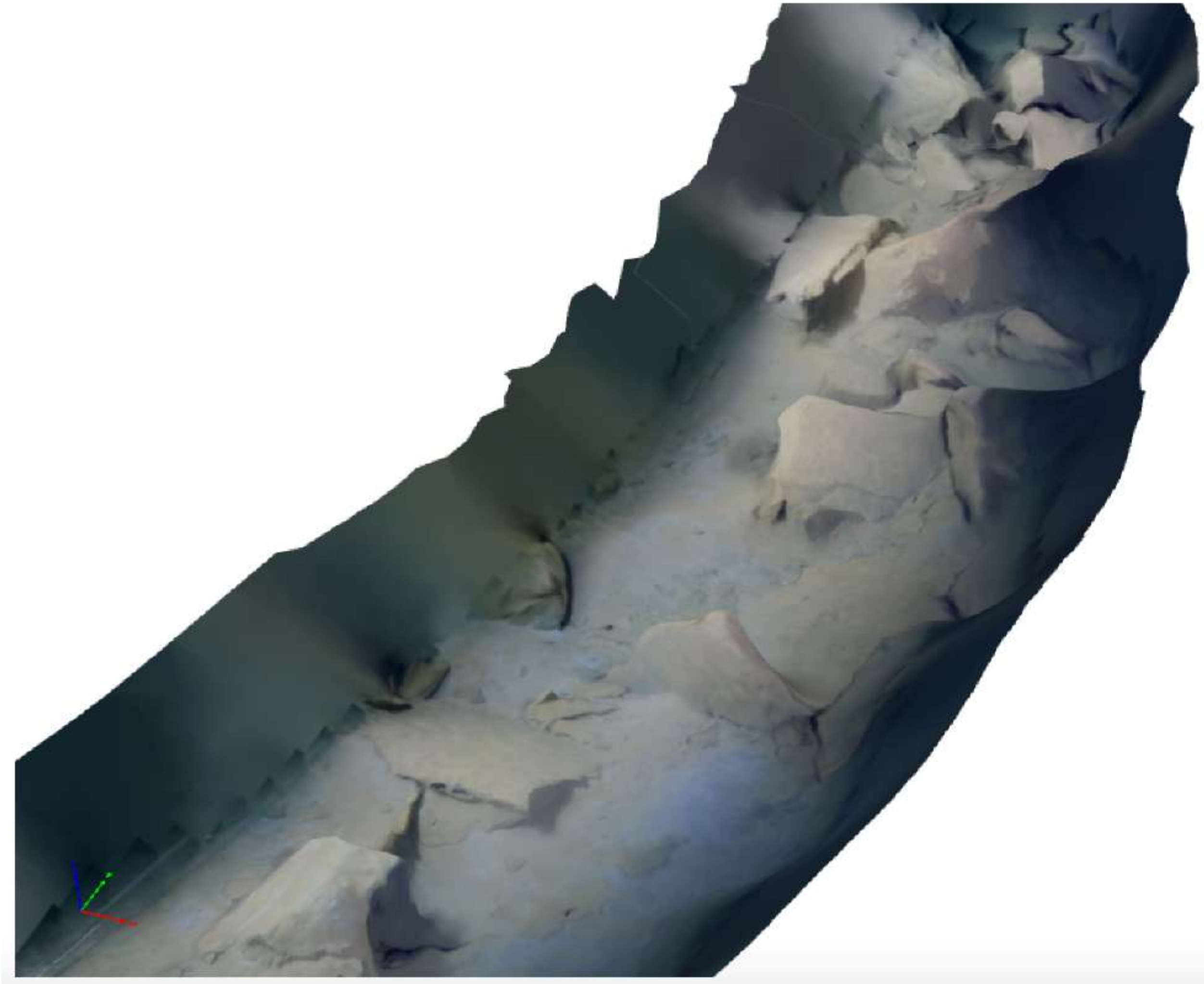
Photogrammetric reconstruction



Fisrt Terrain Results

- Durzon, Nant, 24/06/2018.

Photogrammetric reconstruction



Fisrt Terrain Results

- Durzon, Nant, 24/06/2018.

Photogrammetric reconstruction

FISRT TERRAIN RESULTS

- Durzon, Nant, 24/06/2018.

Photogrammetric reconstruction

Fisrt Terrain Results

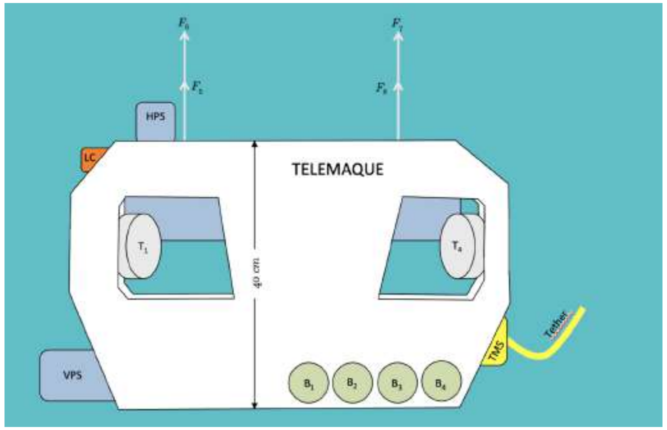
- Durzon, Nant, 24/06/2018.

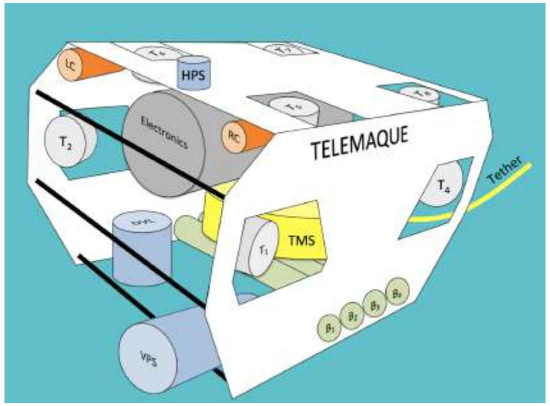
Partial photogrammetric reconstruction

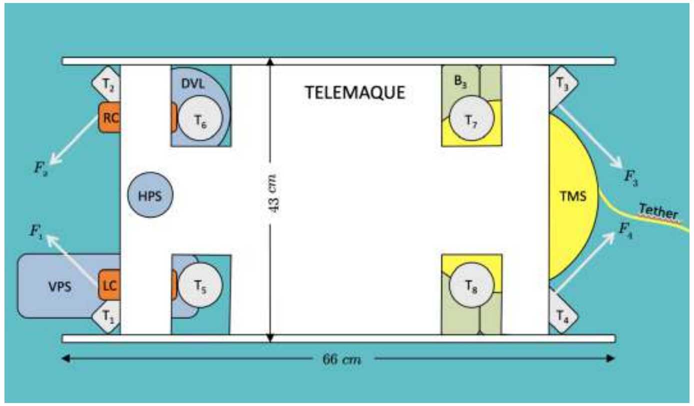
What's next ?

New Systems

- Télémaque





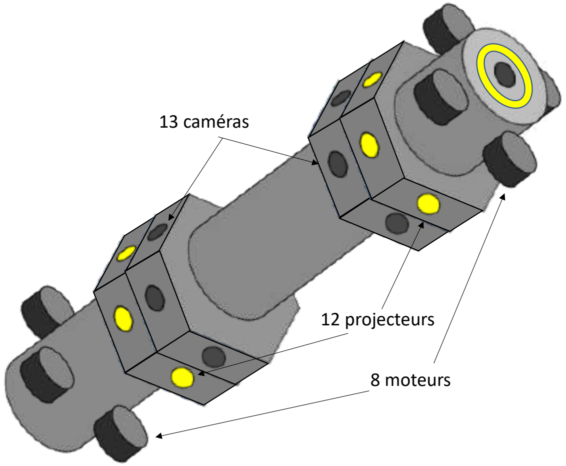


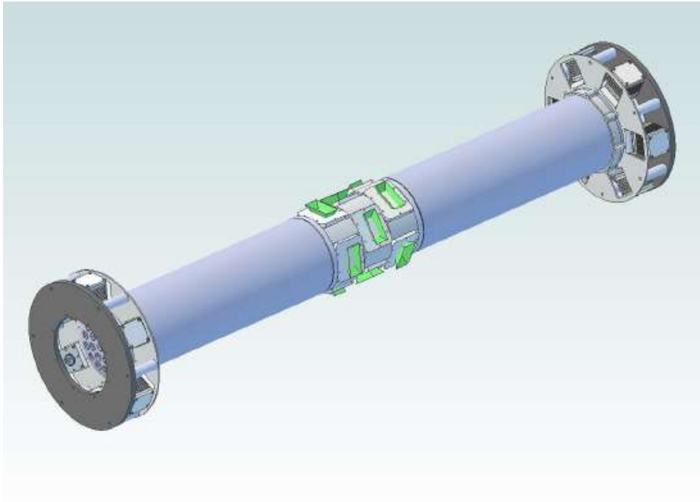
8 thrusters (T_1 to T_8) : T200 from BlueRobotics
4 batteries (B_1 to B_4) : 4x9Ah
IMU : cheap mems
Vertical Profiling Sonar (VPS) : Superseaking Tritech (or Subtop "DT360", Multibeam 360 Profiling Sonar)
Horizontal Profiling Sonar (VPS) : ping360, from BR

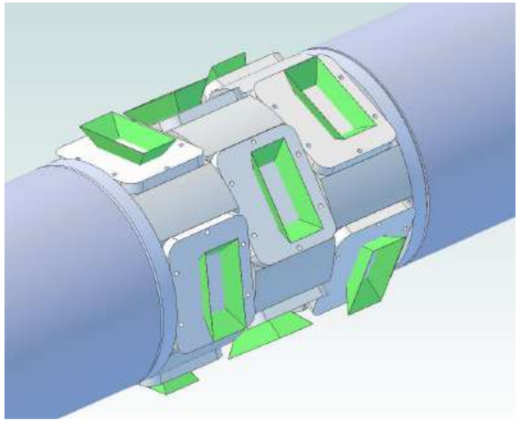
Doppler Velocity Log (DVL) : Nortek 1Mhz
2 cameras (Left and Right, LC and RC) :
Tether Management System (TMS) : from Syera and Reeds
Water leaks detectors
Batteries' consumption

New Systems

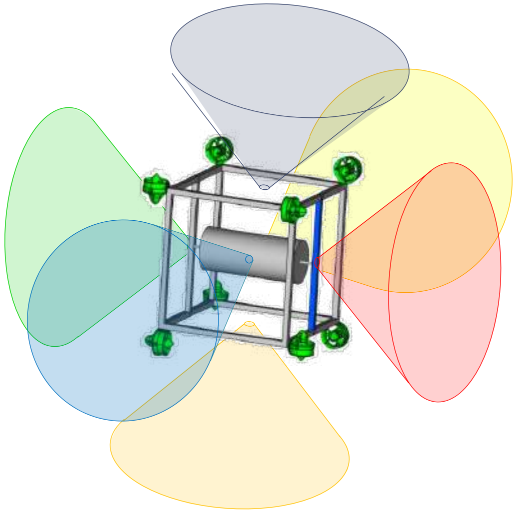
- Dodécam : système photogrammétrique 12 caméras

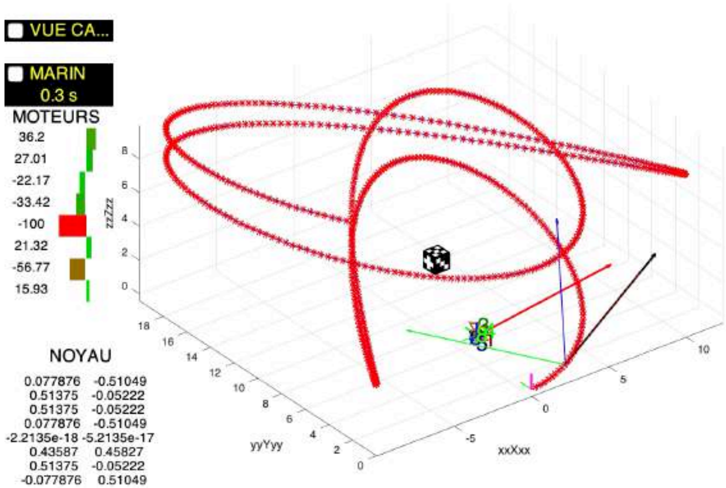






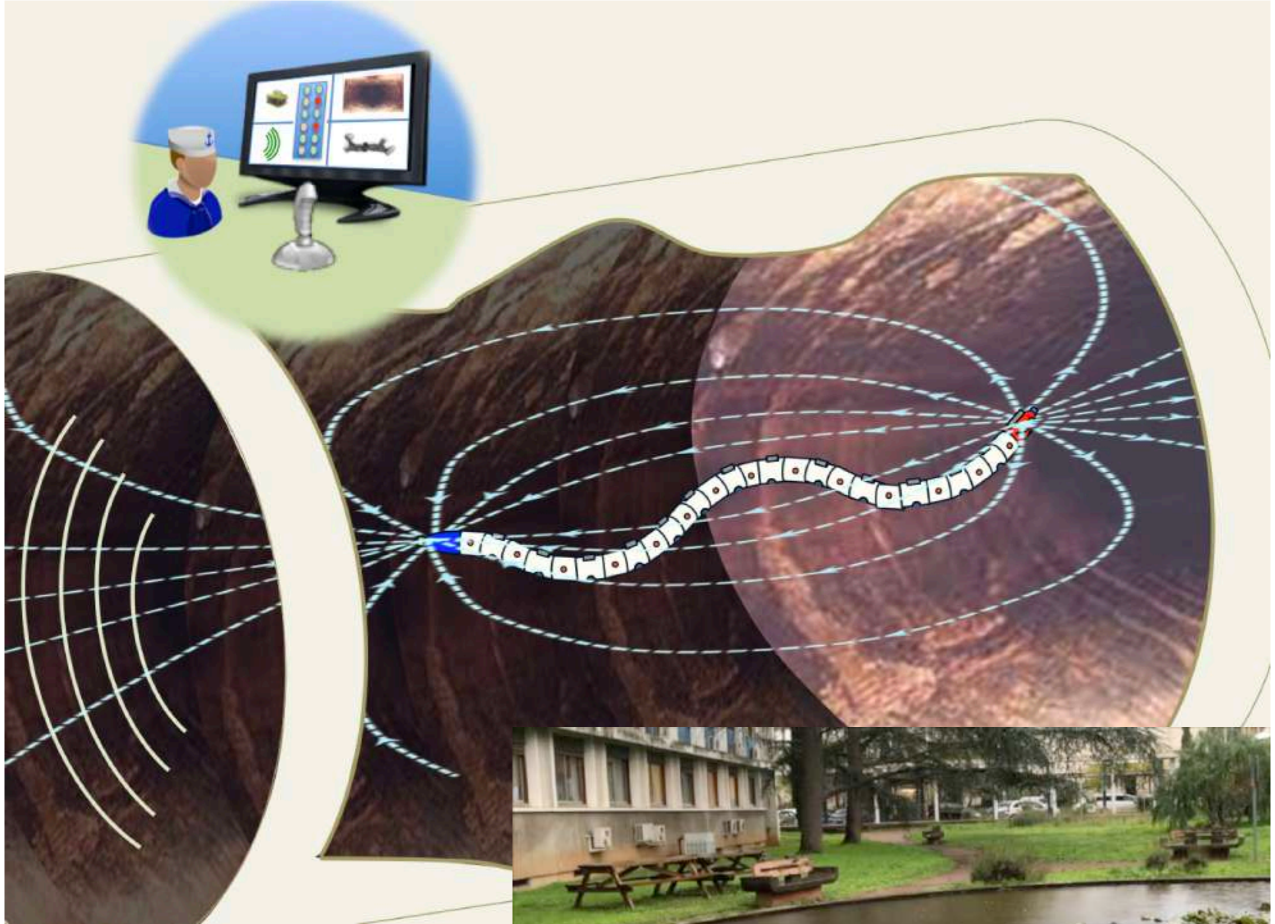
- Cube

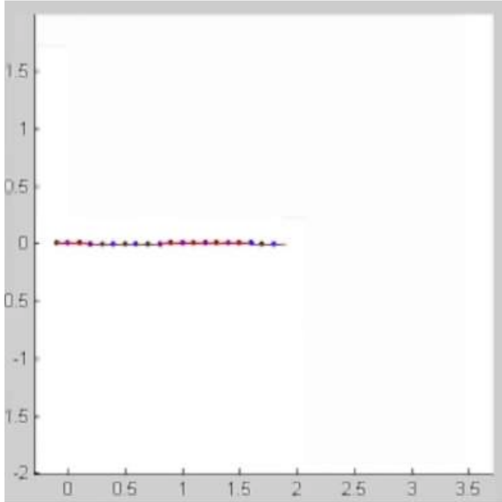


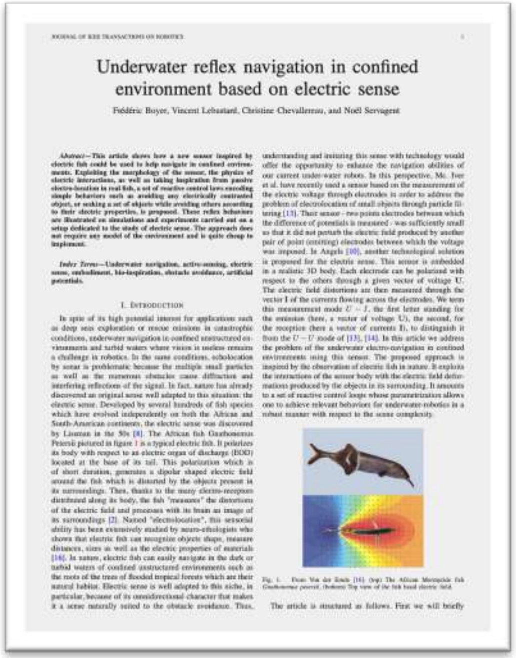


Near Future : ANR LIRMM, LS2N, ENSTA, Syera, Reeds

- Locomotion anguilliforme et Sens électrique





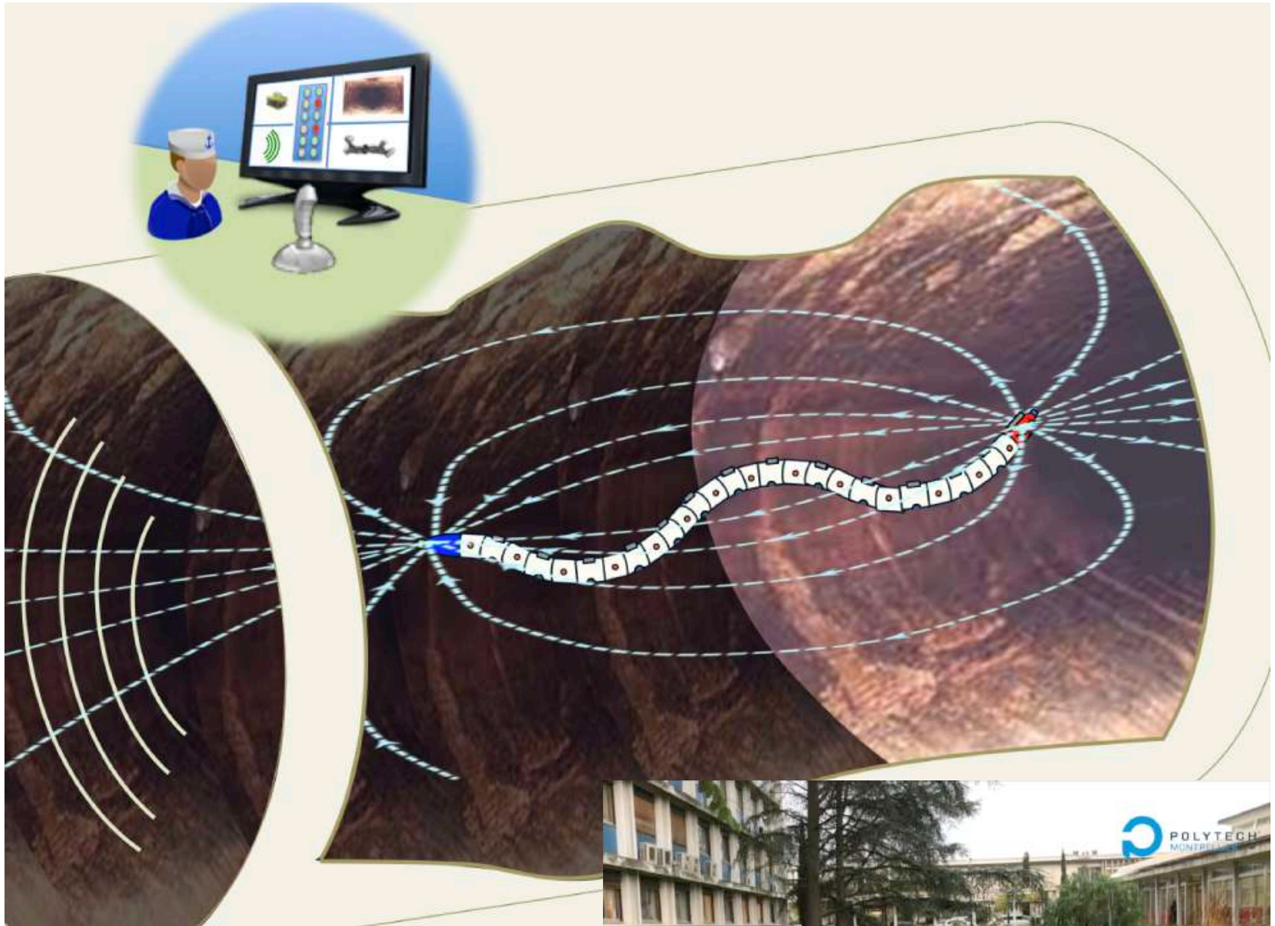


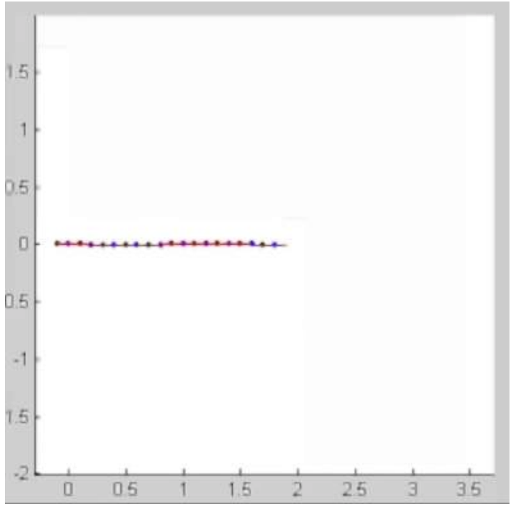
Underwater reflex navigation in confined environment based on electric sense

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

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

- Locomotion anguilliforme et Sens électrique



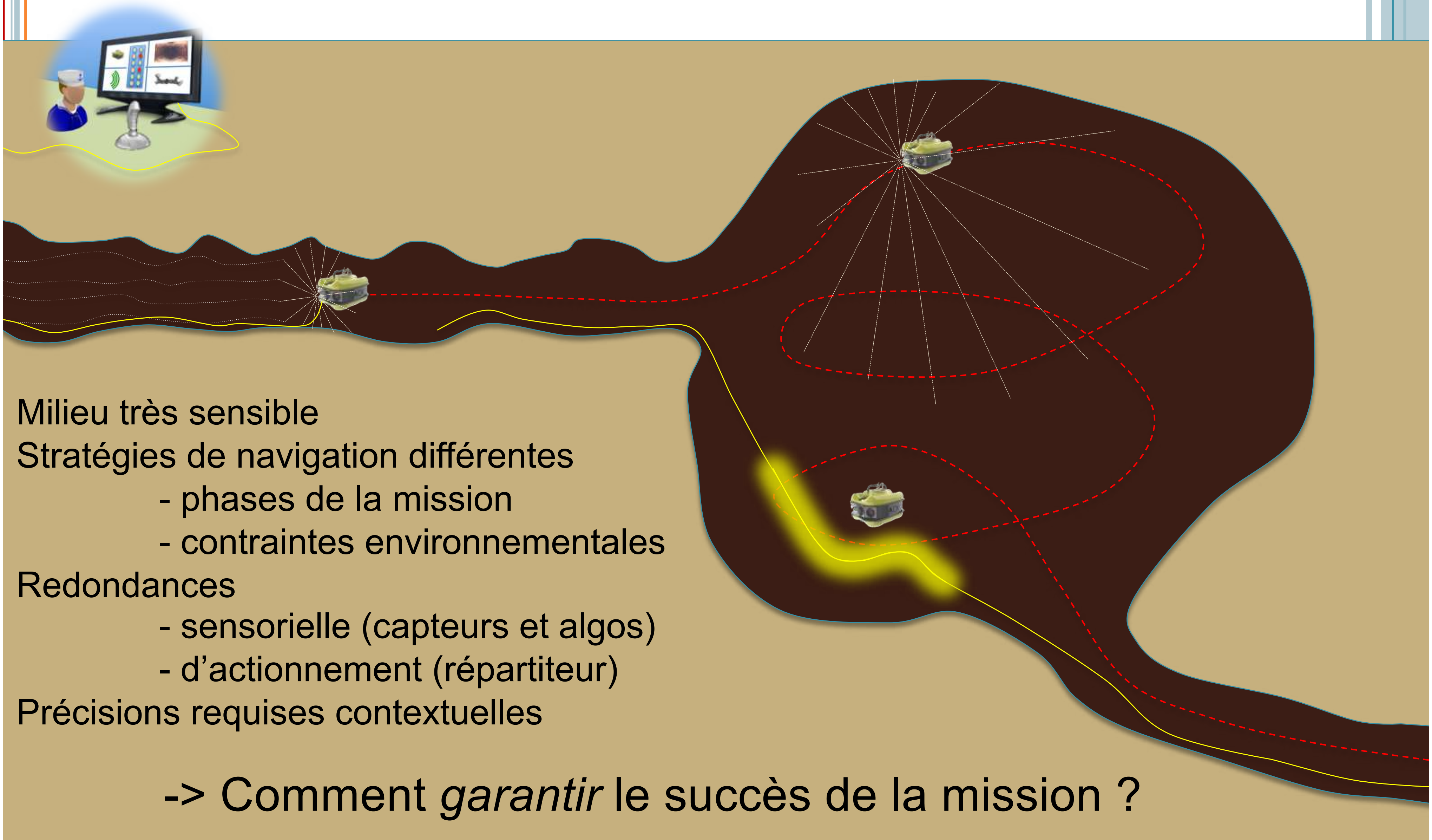


Underwater reflex navigation in confined environment based on electric sense

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

Near Future : LIRMM, ENSTA

- Autonomie et *garanties* de performances



Milieu très sensible

Stratégies de navigation différentes
- phases de la mission
- contraintes environnementales

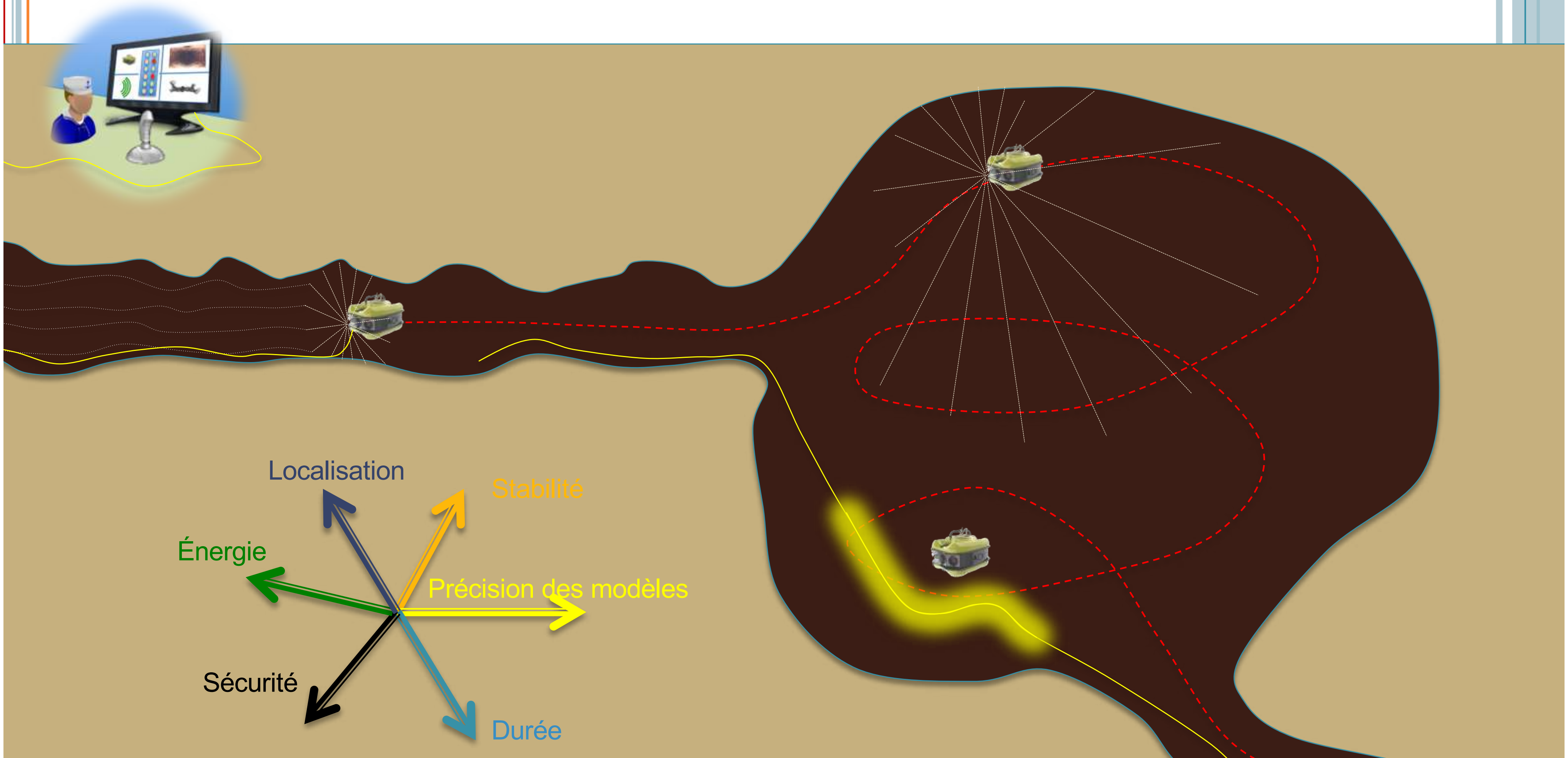
Redondances
- sensorielle (capteurs et algos)
- d'actionnement (répartiteur)

Précisions requises contextuelles

-> Comment *garantir* le succès de la mission ?

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

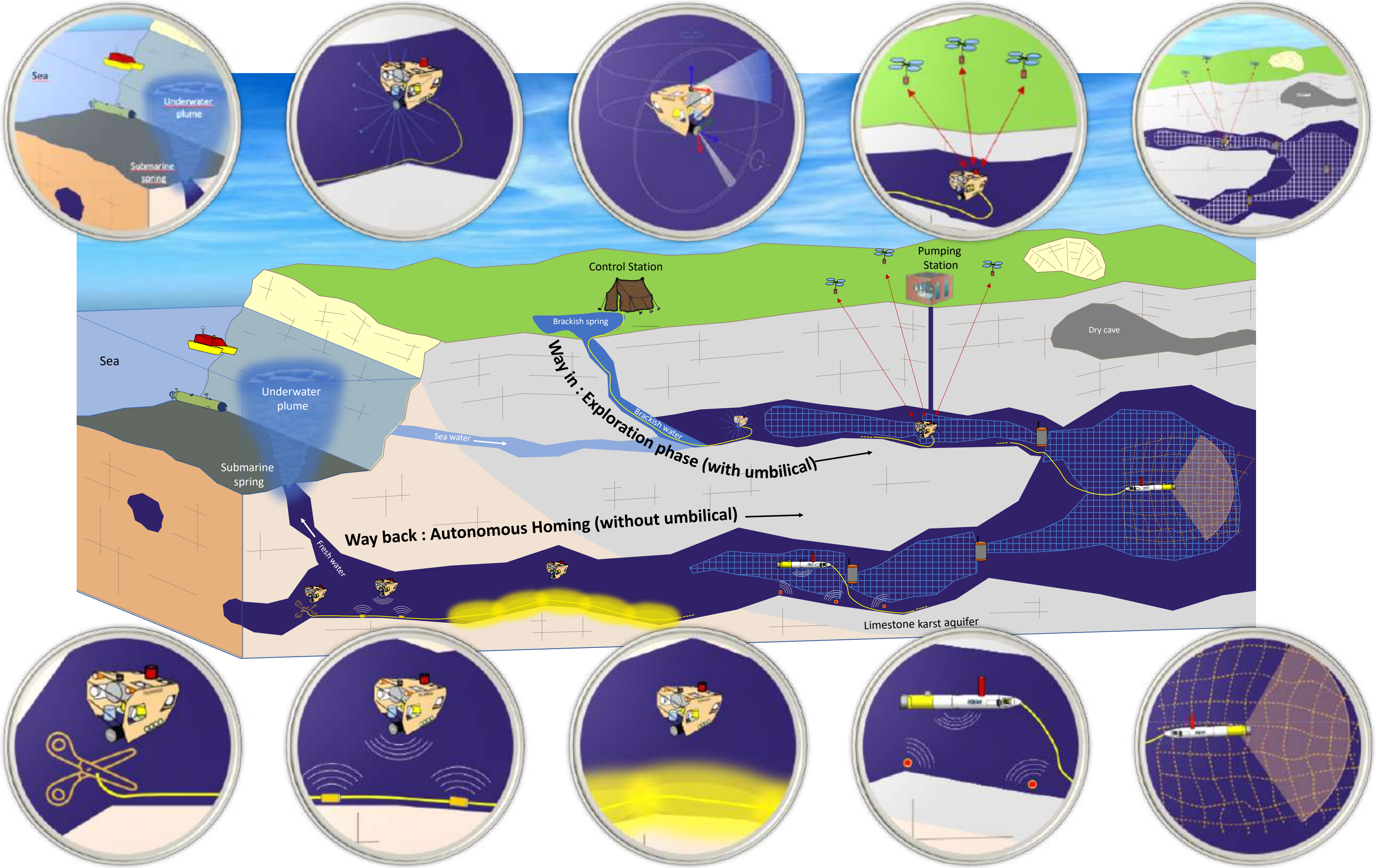
Underwater Fresh Water Spring Localisation

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

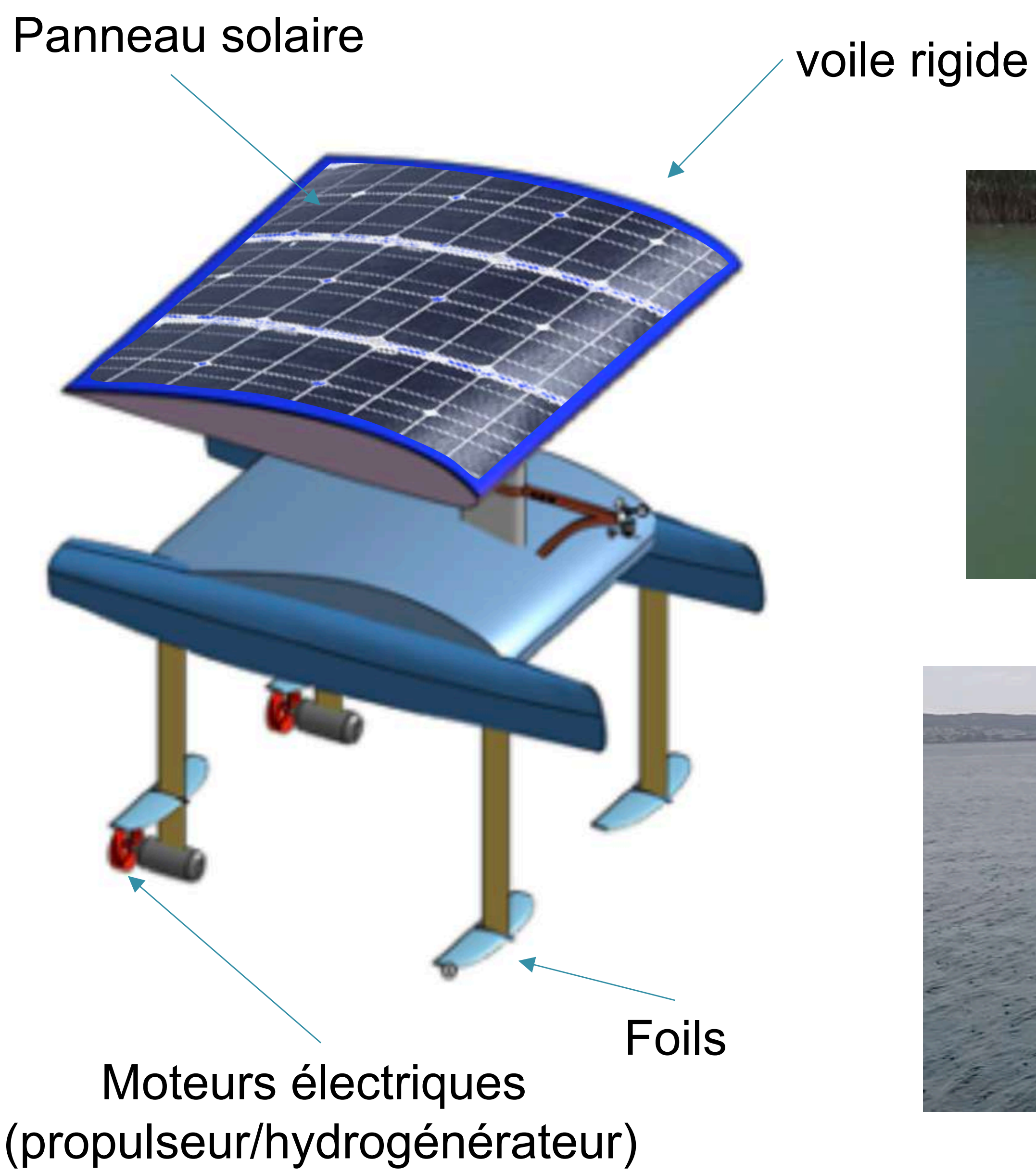
Rotative Multibeam sonar for mapping and Occupancy Grid

Subaquatic robotics, Robots for Karstic Exploration:

REEA
ALEYIN
LEZ 2020

BTS meeting, 27/09/2021

AUTRES SUJETS : ASV MOBULA



AUTRES SUJETS : ASV MOBULA