

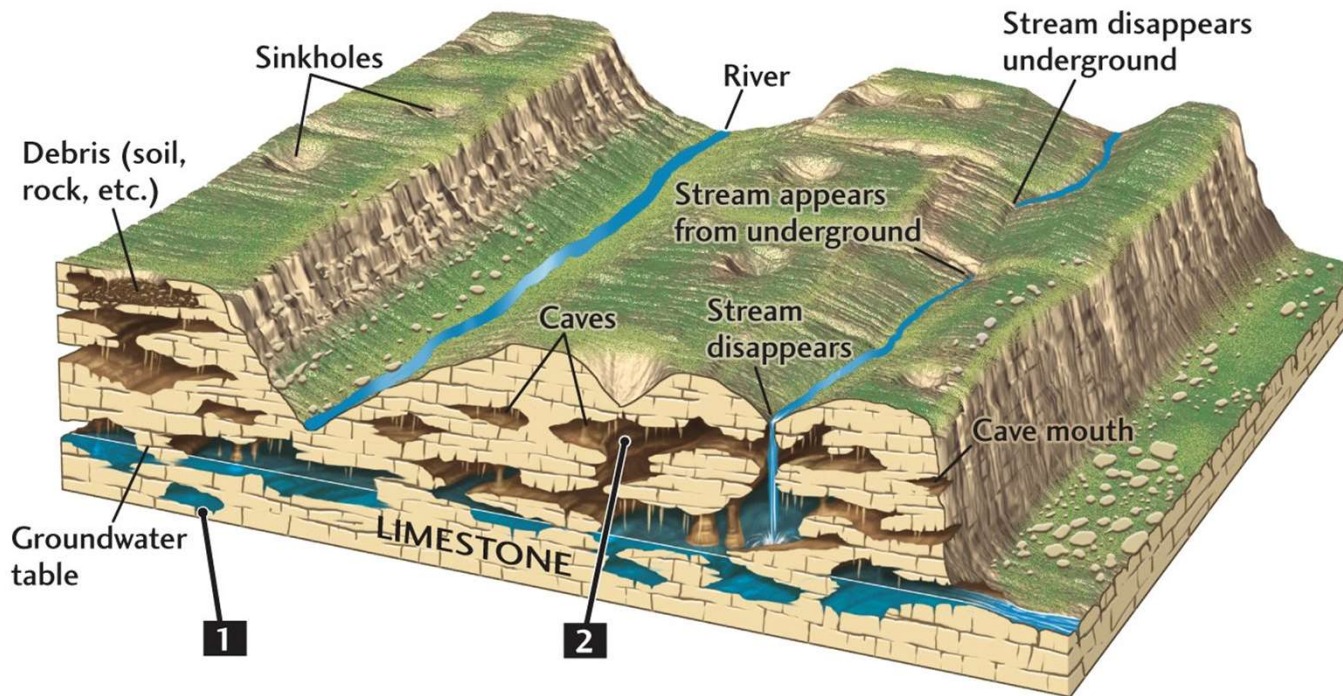
Exploring Karst with Robots

Exploration Robotics for Confined, Unstructured Subaquatic Environment

FARO, 26-27 November 2024,
LIX, Polytechnique, Palaiseau

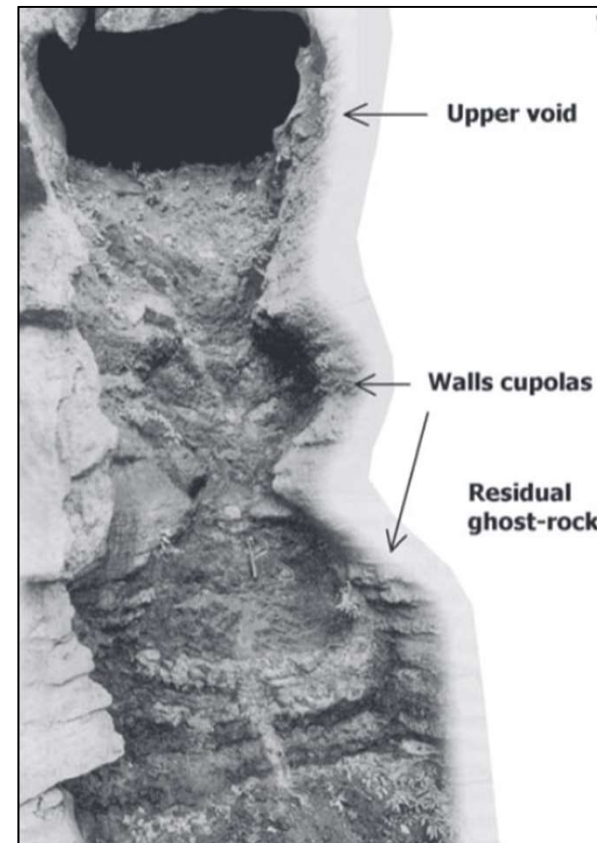
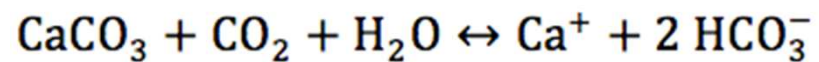
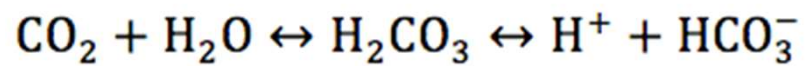
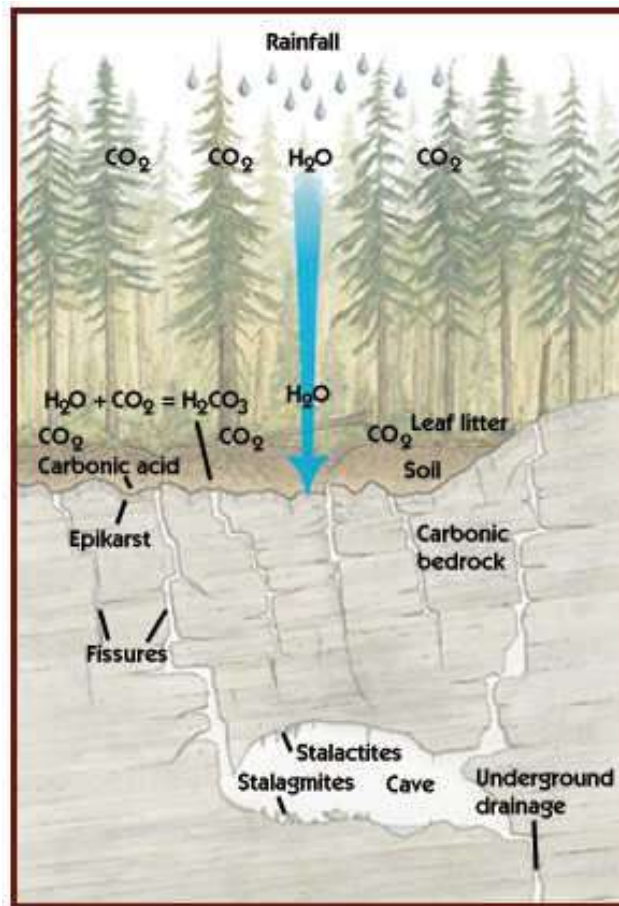
KARST : DEFINITION

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



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

KARSTOGENESIS



Speleogenesis by
phantomization
(ghost-rock models)

KARST : REMARKABLE HIDDEN ENVIRONMENT

- The Largest (known) cave : Son Doong, Vietnam (2010)



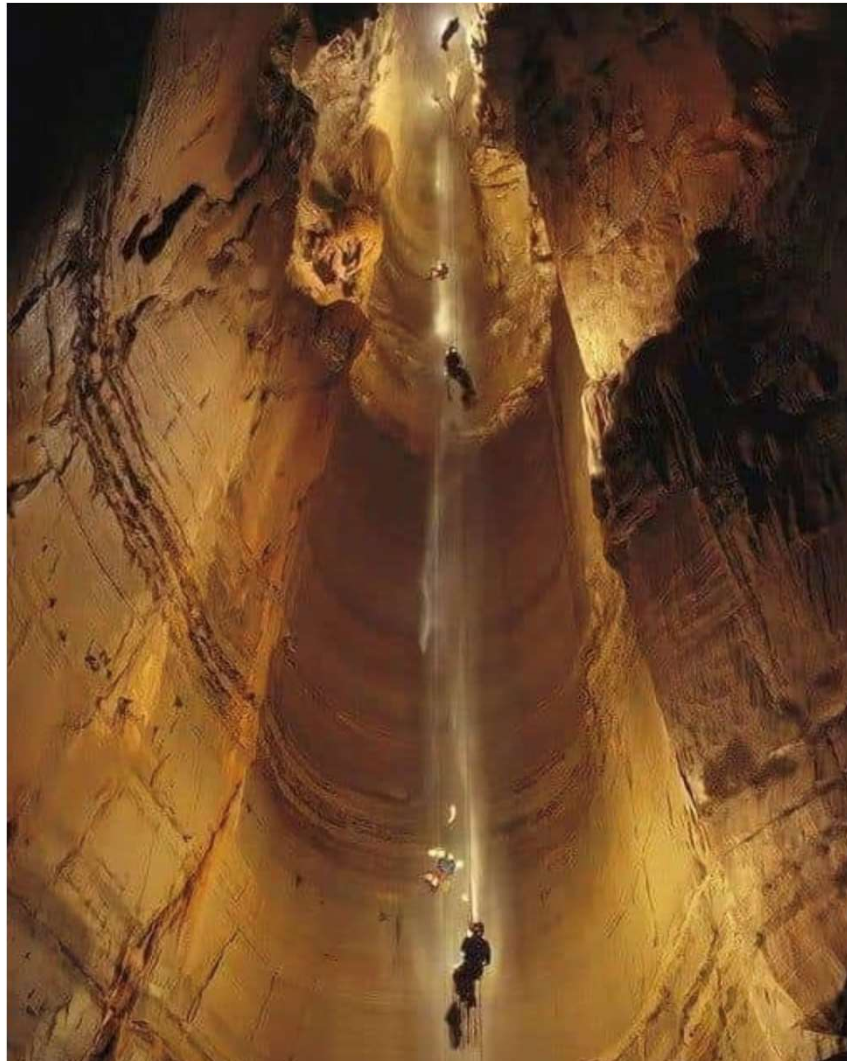


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KARST : REMARKABLE HIDDEN ENVIRONMENT

- The Deepest (known) cave : Veryovkina Cave, Abkhazia



© Julia Ferra



© P Jakopin

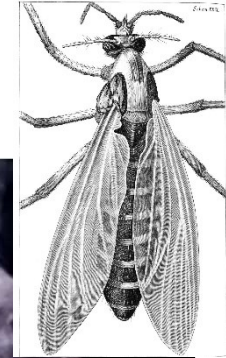
KARST : REMARKABLE HIDDEN ENVIRONMENT

- The Strangest cave (1) : Cueva de los cristales, Mexico (2000)



KARST : REMARKABLE HIDDEN ENVIRONMENT

- The Strangest cave (2) : Waimoto cave, New Zealand



Arachnocampa luminosa (Skuse, 1891)



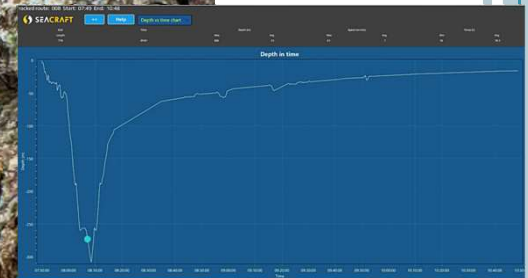
KARST : REMARKABLE HIDDEN ENVIRONMENT

- The Longest Underwater cave (1) : Sistema Sac Actun, Mexico



KARST : REMARKABLE HIDDEN ENVIRONMENT

- The Deepest cave diving: F. Swierczynski, Font Estramar, France



-308m, 3rd November, 2023, 11h

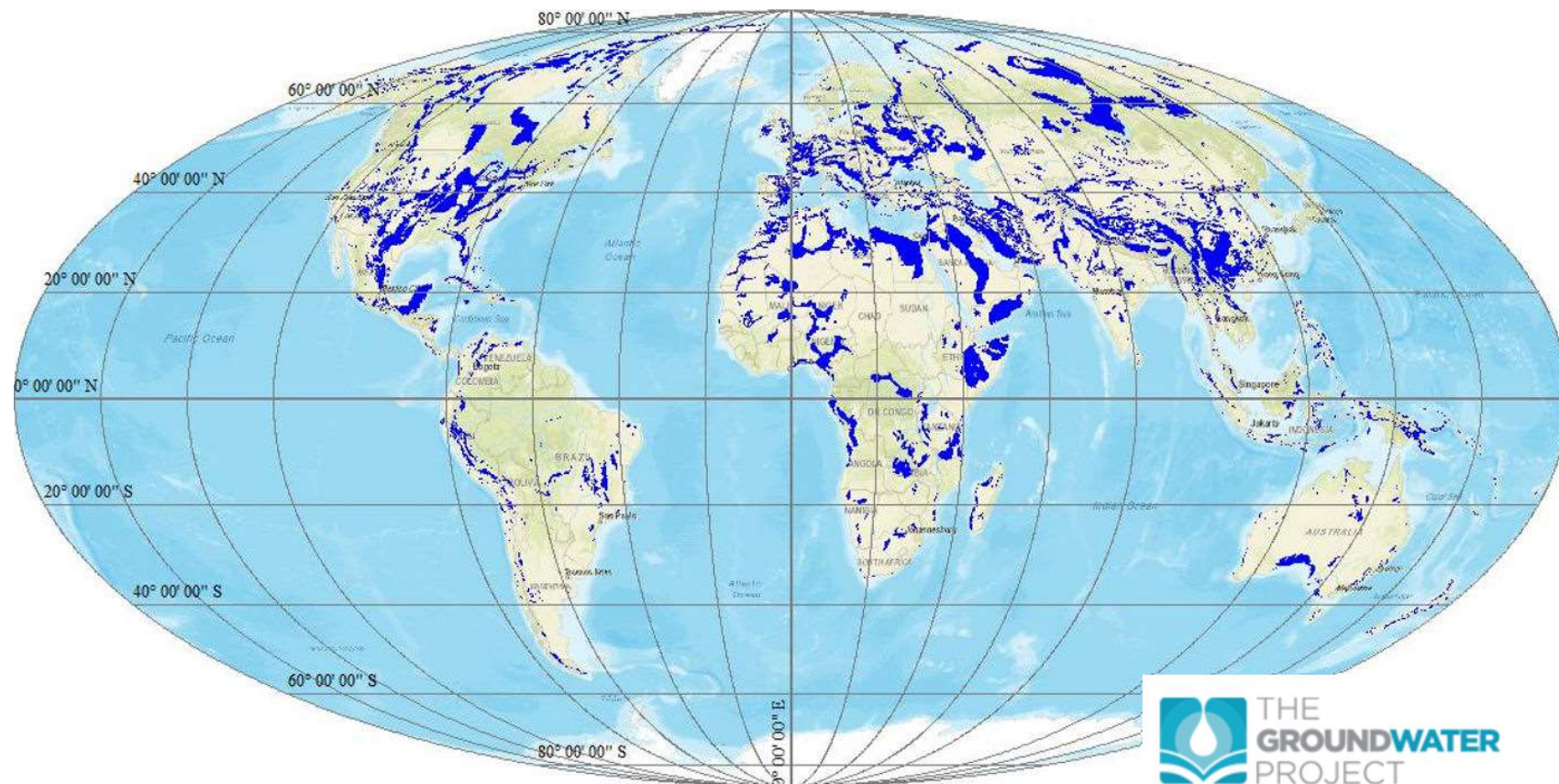
KARST : GROUNDWATER RESERVOIR



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

GROUNDWATER IN KARST SETTINGS

- With carbonate bedrock forming about 15% of Earth's ice-free surface, more than 25% of the world's population either lives on, or obtains its water from, karst aquifers



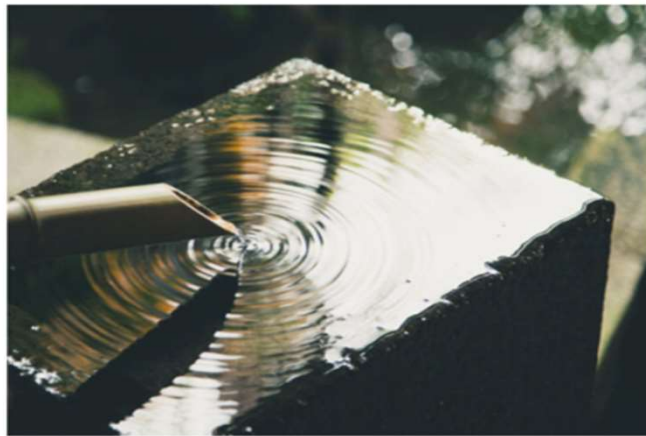
GLOBAL WATER CRISIS

○ Key facts



unicef

- Four billion people — almost two thirds of the world's population — experience severe water scarcity for at least one month each year.
- Over two billion people live in countries where water supply is inadequate.
- Half of the world's population could be living in areas facing water scarcity by as early as 2025.
- Some 700 million people could be displaced by intense water scarcity by 2030.
- By 2040, roughly 1 in 4 children worldwide will be living in areas of extremely high water stress.



Why is Groundwater Critical to Solving the Global Water Crisis?

The global water crisis is in fact a groundwater crisis because **groundwater makes up 99% of all liquid fresh water** and **in times of drought, groundwater is the only freshwater available in many regions**. Yet much of the educational material needed to solve the crisis exists behind expensive paywalls and global university programs are at present inadequate to address the issue.

GLOBAL WATER CRISIS

PLANETA FUTURO

ENTRADA LINEA - HOY DE EXPERTOS - QUE MEJOR A - DESARROLLO EN LA PRACTICA - PLUS - CINCUENTA SEPTIEMBRE

EL PAÍS

EMERGENCIA CLIMÁTICA • PRIMA • E
La crisis del agua: no solo falta inversión, también necesitamos nuevas políticas

Dos próximas cumbres mundiales pueden ayudar a empezar a responder a los desafíos hídricos: la COP27 en Egipto en noviembre de este año y la cumbre del Agua de ONU en Nueva York en marzo de 2023



Resaca en la orilla del lago Powell, en el río Colorado (Arizona, EE.UU.), afectado por la sequía, con la nieve derretida. BOBMY DECKE (AFP)

UNESCO Report : Global water crisis is threatening world peace and prompting calls for change

About 2.2 billion people live without access to safely managed drinking water

Emergenza idrica: 1,4 milioni di persone muoiono ogni anno nel mondo

di Vito de Ceglia

I rischi legati all'acqua aumenteranno a ogni incremento di grado del riscaldamento globale. Secondo Bcg e Wwf settore pubblico e privato, istituzioni finanziarie e Ong devono agire con un piano condiviso e dare priorità a soluzioni nature-based

la Repubblica



FOTOGRAFIA

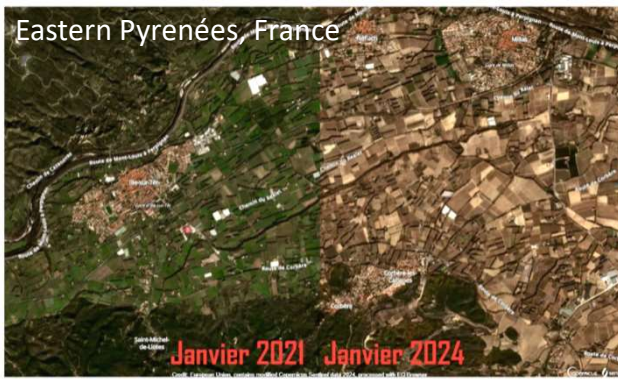
Uma visita a Acredo, a aldeia que a seca devolveu à paisagem da Galiza

P3 . 22 de Fevereiro de 2022, 7:55



P

Eastern Pyrenées, France



Janvier 2021 Janvier 2024

PHOTOS : ©FRANCH DUBRAY (OUEST-FRANCE)

LE13H TFI



AVANT/APRÈS, LA MÉTAMORPHOSE DE LA LOIRE



Oroville Lake, California, USA. 2011 vs 2014

Le Monde

UNE SÉCHERESSE CRITIQUE S'INSTALLE DANS LE BASSIN MÉDITERRANÉEN

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



Drought Touches a Quarter of Humanity, U.N. Says, Disrupting Lives Globally

The New York Times

The crisis, worsened partly by climate change, has been accompanied by soaring food prices and could have consequences for hunger, elections and migration worldwide.

WATER AS A WAR WEAPON

The Guardian

Eur ▾

As water becomes a weapon of war, we must focus on cooperation and peace

Peter Gleick

Record increase in water-related violence shows how urgently we need to reduce these tensions between countries



Climate & Development
Knowledge Network

Water for peace, or water for war? Notes on weaponisation of water for World Water Day 2024

Le Monde

David Blanchon, géographe : « A l'échelle internationale, les "guerres de l'eau" ne sont pas une fatalité »

Propos recueillis par Claire Legros

Publié le 27 juillet 2024 à 05h00

NEWSECURITYBEAT

the blog of the Environmental Change and Security Program

WHO WE ARE TOPICS COLUMNS MULTIMEDIA FILMS PUBLICATIONS

ON THE BEAT

The Global Challenge of Water's Weaponization in War: Lessons from Yemen, Ukraine, and Libya

March 22, 2024 | By Lauren Herzer Risi & Eleanor Greenbaum

Revue Défense Nationale 2020/3 N° 828

Article de revue

L'eau, cause et instrument de guerre ?

Par [Alain Lamballe](#)

Pages 75 à 80

APPLICATIONS OF HYDROLOGY
IN MILITARY PLANNING
AND OPERATIONS



MILITARY HYDROLOGY BULLETIN 1
JUNE 1957

A
CORPS OF ENGINEERS
RESEARCH AND DEVELOPMENT REPORT
PREPARED UNDER DIRECTION OF
CHIEF OF ENGINEERS
BY
MILITARY HYDROLOGY PAO BRANCH
U. S. ARMY ENGINEER DISTRICT, WASHINGTON



Ministère de la Transition
Écologique et du Climat
Ministère de l'Énergie
Ministère de l'Intérieur
Ministère de la Santé
Ministère de la Justice
Ministère de l'Éducation
Ministère de l'Enseignement
Supérieur et de la Recherche
Ministère de l'Égalité
Territoriale et de la
Régionalisation
Ministère de la Culture
Ministère de la Mer
Ministère de l'Outre-mer
Ministère de la Pêche
Ministère de l'Agriculture
Ministère de l'Alimentation
Ministère de la Santé
Ministère de la Justice
Ministère de l'Éducation
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Régionalisation
Ministère de la Culture
Ministère de la Mer
Ministère de l'Outre-mer
Ministère de la Pêche
Ministère de l'Agriculture
Ministère de l'Alimentation

Protection des points d'eau

Évaluation de la mise en œuvre de l'arrêté du 4 mai 2017



Courrier international

GÉOPOLITIQUE • GUERRE EN UKRAÏNE

Récit. Des Romains à l'Ukraine, la longue histoire de l'eau comme arme de guerre

Le 6 juin, le barrage de Kakhovka sur le fleuve Dniepr, dans le sud de l'Ukraine, a été détruit. Ce qui semble être un acte de sabotage n'est pas un cas isolé dans l'histoire, pointe le quotidien italien "La Repubblica". Depuis deux millénaires, en effet, l'eau est utilisée pour bloquer ou détruire des armées ennemies.

Franck Galland
Préface de Grégoire Lewandowski

Guerre et eau

L'eau, enjeu stratégique
des conflits modernes



Le monde comme il est
Robert Laffont

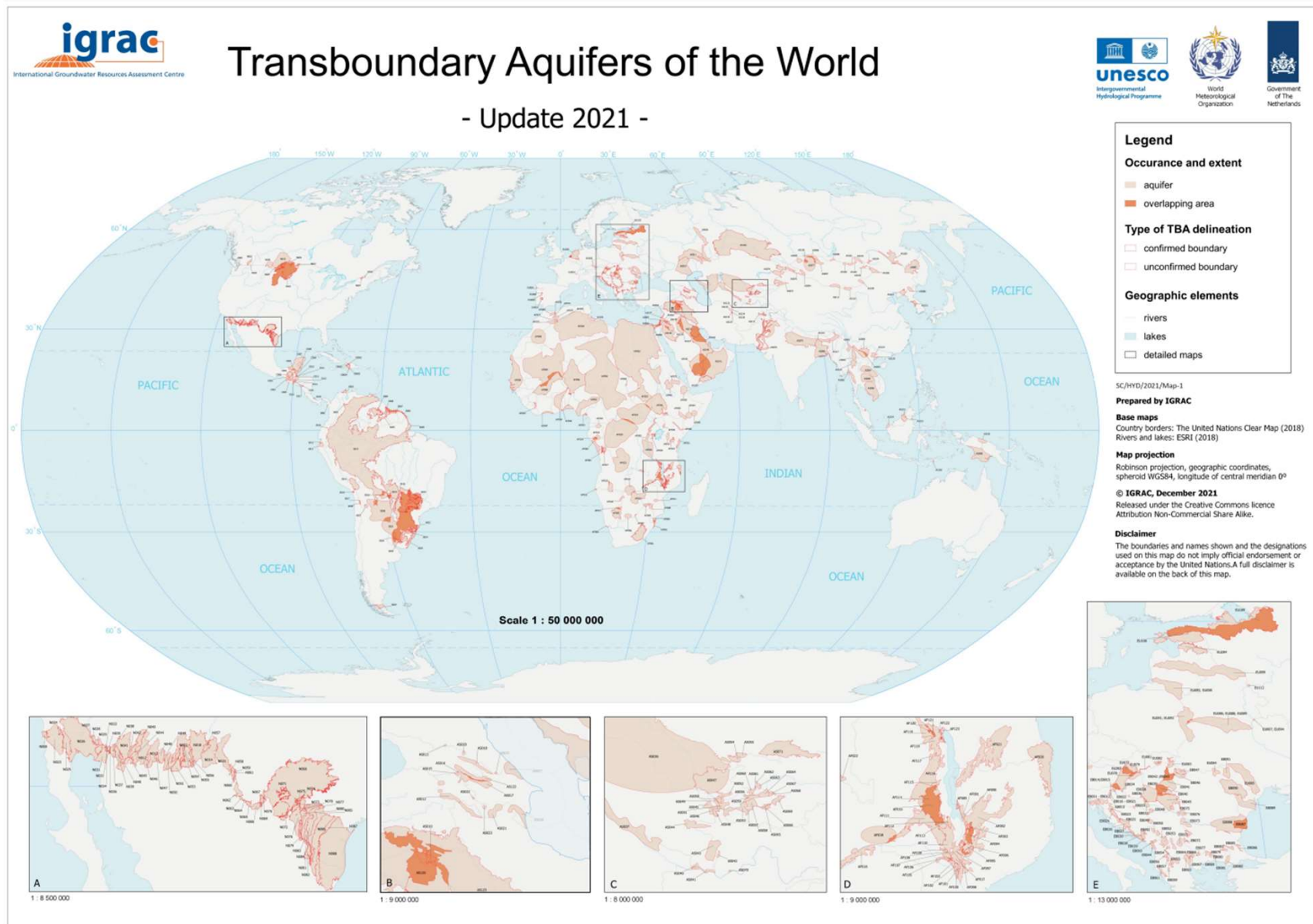
DefenseNews

Opinion! Hydraulic warfare is here to stay.
NATO should plan for it.

By Lionel Beehner, Liam Collins and John Spencer

Jun 14, 2023

TRANSBOUNDARY AQUIFERS AND CONFLICTS



WATER CONFLICTS



**PACIFIC
INSTITUTE**

THE WORLD'S WATER
Information on the World's Freshwater Resources

- **"Trigger:"** Water as a trigger or root cause of conflict, or underlying cause of ongoing tension that is contributing to conflict, where there is a dispute over the control of water or water systems, or where economic or physical access to water, or scarcity of water, triggers violence.
- **"Weapon:"** Water as a weapon of conflict, where water resources, or water systems themselves, are used as a tool or weapon in a violent conflict.
- **"Casualty:"** Water resources or water systems as a casualty of conflict, where water resources, or water systems, are intentional or incidental casualties or targets of violence.

The water war between the US and Mexico

By Devika Rao, Published on 06/27/2024 • THE WEEK

The U.S. and Mexico are experiencing another border dispute, and this one is about water. The conflict stems from an 80-year-old treaty where the countries agreed to share water from the Colorado River and the Rio Grande. However, because water is in more demand but scarcer than ever, sharing has not been going to plan.

Sharing the Rio Grande

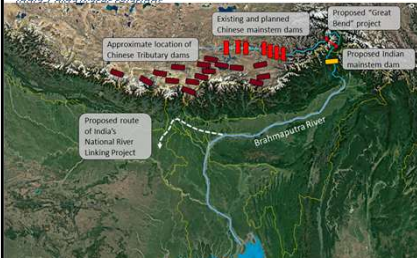
The Rio Conchos is the most important tributary of the Rio Grande. Under a 1944 treaty, Mexico provides water to the U.S. from the Conchos and other tributaries. In recent years Mexico has fallen behind on its obligations, sparking controversy.



The Water Wars : India, China and the Brahmaputra

By Anya Wahal, Published on December 8, 2022

What the hydrology and geopolitics of the Brahmaputra River mean for India-China water relations



Water disputes in the Mekong basin

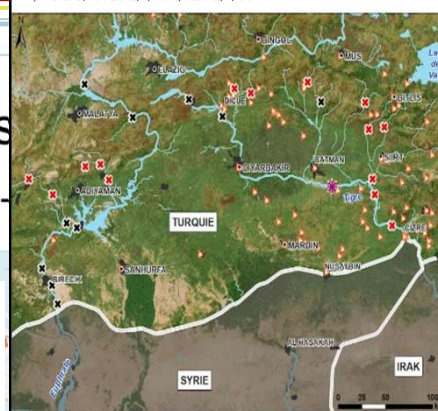
By Hervé Amiot, Published on 11/28/2013 • Updated on 05/11/2020

The Mekong is south-east Asia's longest river (around 4 900 km). From its source in Tibet, it flows southwards through the Chinese province of Yunnan before passing through five south-east Asian countries (Myanmar, Thailand, Laos, Cambodia and Vietnam). Nearly half of the river is in China, where it is known as the Lancang. For the 70 million people who live in the Mekong basin, the river is a vital source of food and water, as well as an important transport route. Increasingly, it is being used to generate hydroelectricity. Human activity threatens the river's fauna and flora, and competition for natural resources is intensifying.



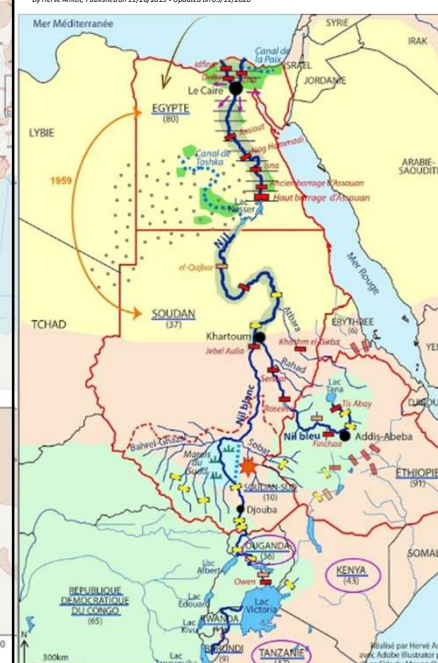
The Southeastern Anatolia Project (GAP): Between Colossal Economic Undertaking and Unprecedented Counter-insurgency Tool

By Emile Bouwler, Published on 05/11/2020 • Updated on 05/11/2020 •



The Nile: A Driver of Economic Development and Geopolitical Tensions

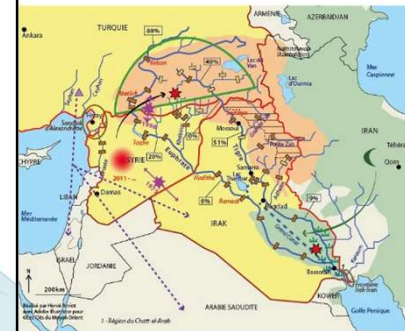
By Hervé Amiot. Published on 11/28/2013 • Updated on 05/11/2020



Water: Cause or Pretext for Conflicts? The Example of the Tigris and Euphrates

By Hervé Amiot, Published on 11/28/2013 • Updated on 05/11/2020

The Tigris and Euphrates form the fertile crescent of Mesopotamia, where Neolithic civilization emerged in the 9th millennium BCE. Today, however, the waters of these rivers are less associated with prosperity and more with conflicts. Population growth requires ever-increasing withdrawals from the two rivers to support the agricultural and hydroelectric sectors.



Geographic elements

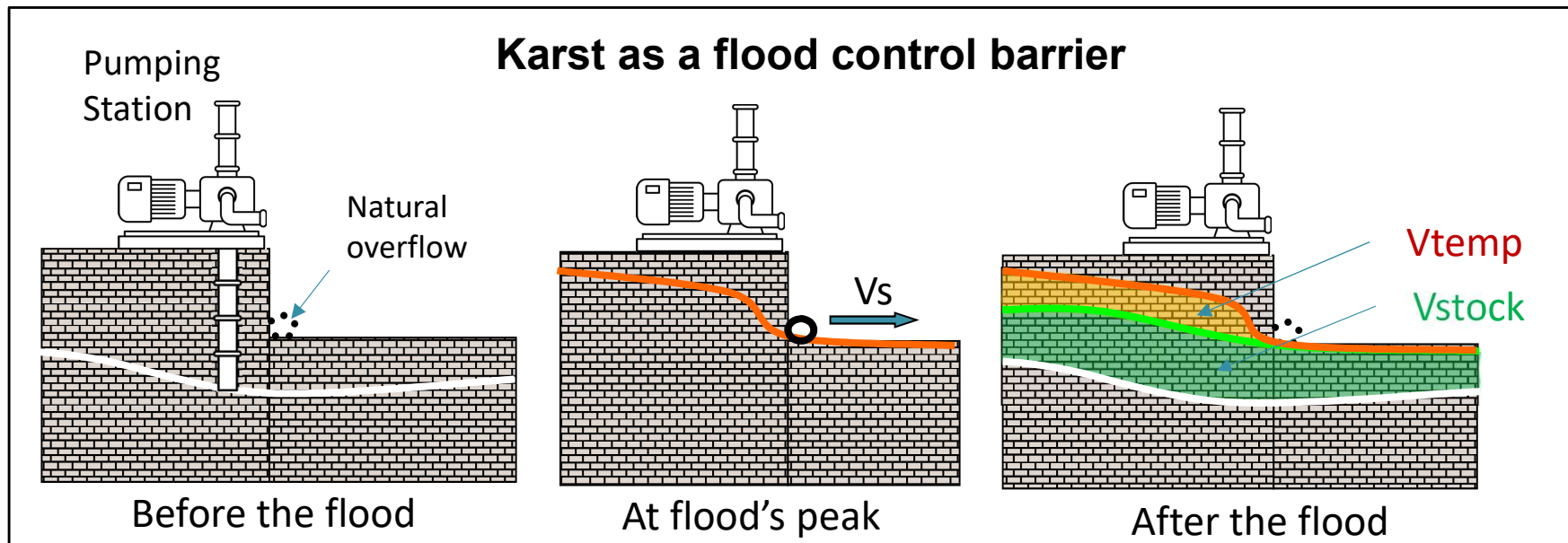
Water and Conflicts in the Jordan Basin

By Hervé Amiot Published on 12/12/2013 • Updated on 03/11/2018 •

While the Jordan Basin is not as large as those of the Tigris-Euphrates or the Nile, it is nevertheless the site of perhaps more frequent and intense conflicts. Originating in Lebanon, the Jordan River separates Israel from neighboring Arab states, Syria and Jordan.



ROLE OF KARST IN FLASH FLOODS



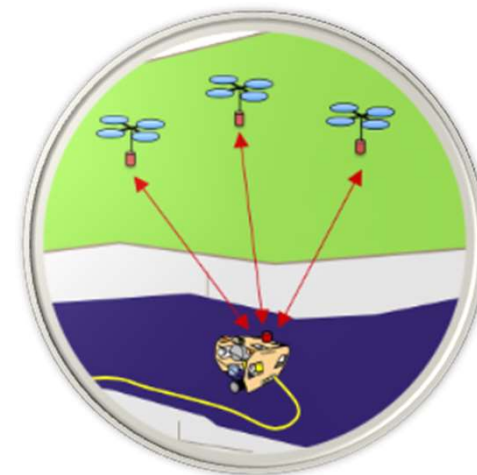
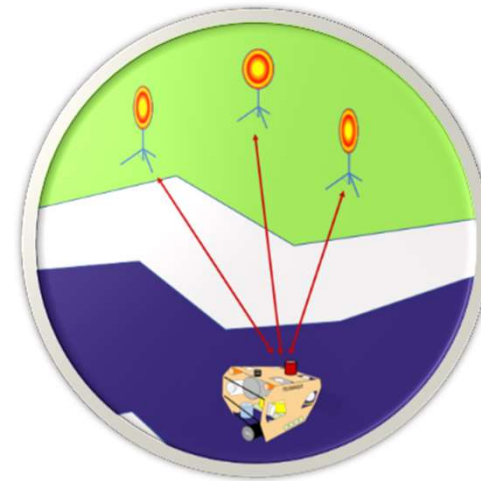
KARST : GROUNDWATER RESERVOIR



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

KARST EXPLORATION : CONSTRAINTS

- Exploration of Confined, Unstructured, Subaquatic Environment
 - GPS denied -> Underground GPS : **Dirac System** © Syera



KARST EXPLORATION : CONSTRAINTS

- Exploration of Confined, Unstructured, Subaquatic Environment
 - No GPS -> Underground GPS : **Dirac System** © Syera
 - Cable / No cable ?



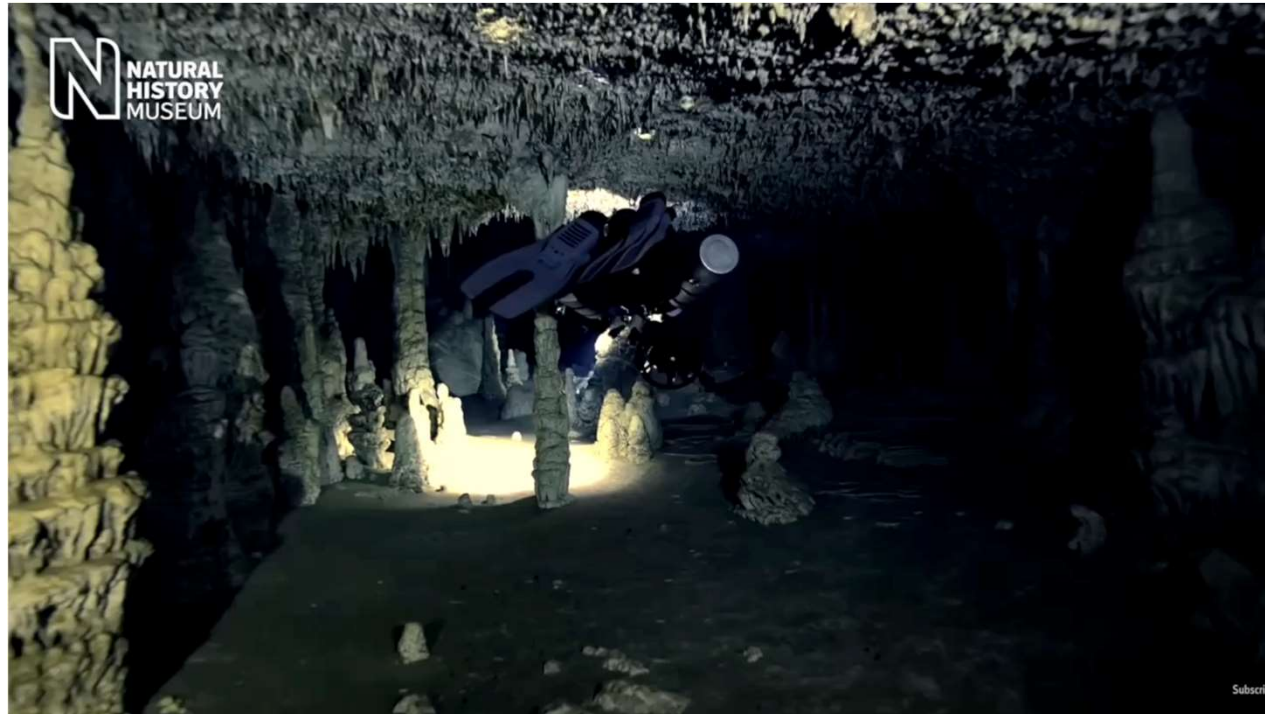
KARST EXPLORATION : TRADITIONAL / UNCONVENTIONAL TOOLS

- Exploration of Confined, Unstructured, Subaquatic Environment
 - No GPS -> Underground GPS : **Dirac System** © Syera
 - Cable / No cable ?
 - Vision or Acoustic ?



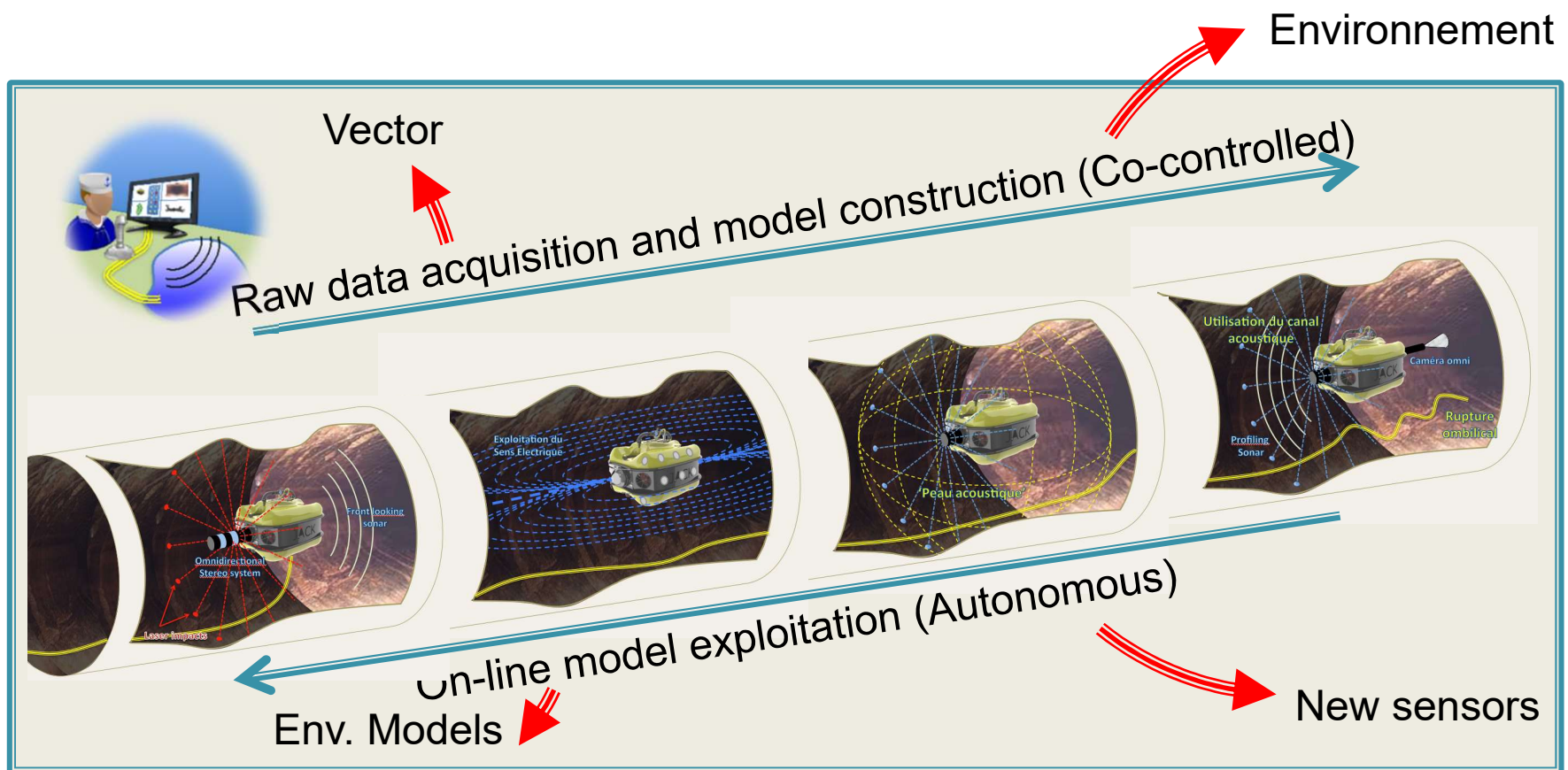
KARST EXPLORATION : TRADITIONAL / UNCONVENTIONAL TOOLS

- Exploration of Confined, Unstructured, Subaquatic Environment
 - No GPS -> Underground GPS : **Dirac System** © Syera
 - Cable / No cable ?
 - Vision or Acoustic ?
 - Environmental disturbances and complexity



KARST EXPLORATION : GLOBAL STRATEGY

- Exploration of Confined, Unstructured, Subaquatic Environment



KARST EXPLORATION : THE ROBOTIC CHALLENGES

○ Unconventional Sensors

- Acoustic Skin
- Active Umbilical
- Electric Sense
- Acc. Interf. patterns as inv. landmarks

○ Navigation

- Global Navigation System / Mag. Pos.
- No distinction btw nav. sensors / payload
- Acoustic / visual SLAM
- Vacancy Evidence Grids
- Clustering and Saliency Data Analysis

○ Guidance

- Autonomous Centring
- Autonomous Targeting
- Env. Models on-line building / exploit°

○ Models

- Multi-modality & Scalability
- Uncertainty Consideration

○ Control

- Robustness
- Co-control,
- Open-loop stability

○ Actuation

- Reactive redundant A.S.
- Variable Geometry A.S.
- Anguilliform Locomotion

○ Mission Management

- Management of sensors (acc. jamming)
- Adaptive Autonomy
- GoP & Interval approach

○ Technology

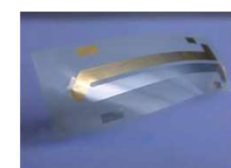
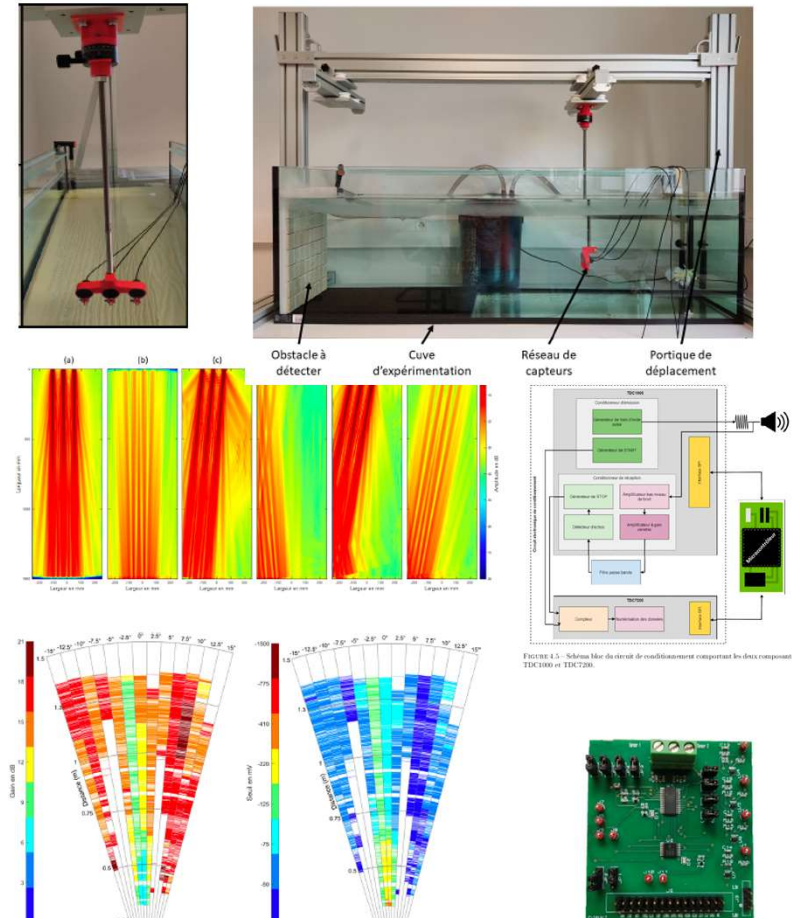
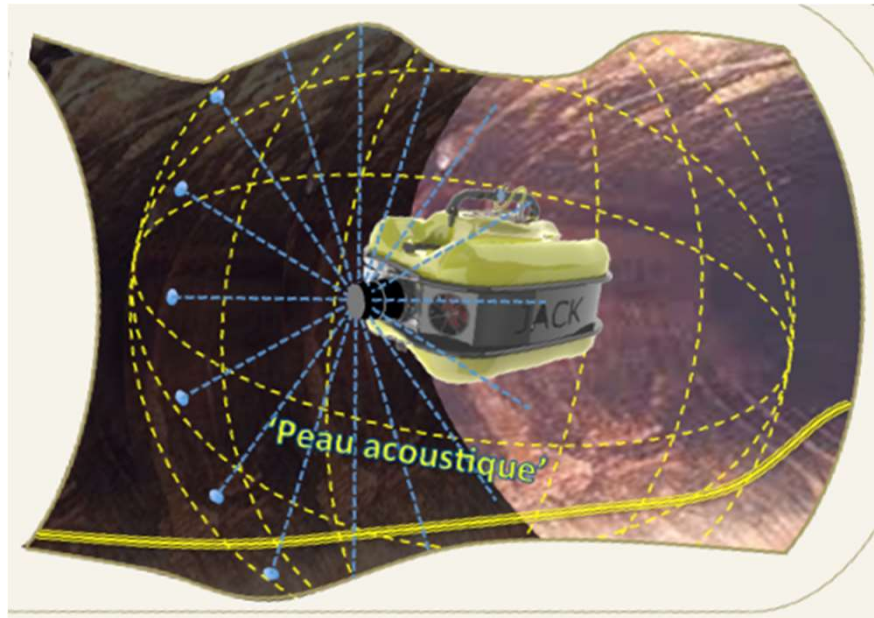
- Active Truncanner, NRJ opt.
- Magnetic Positioning

○ Economic

- Evangelization of a Blue Ocean

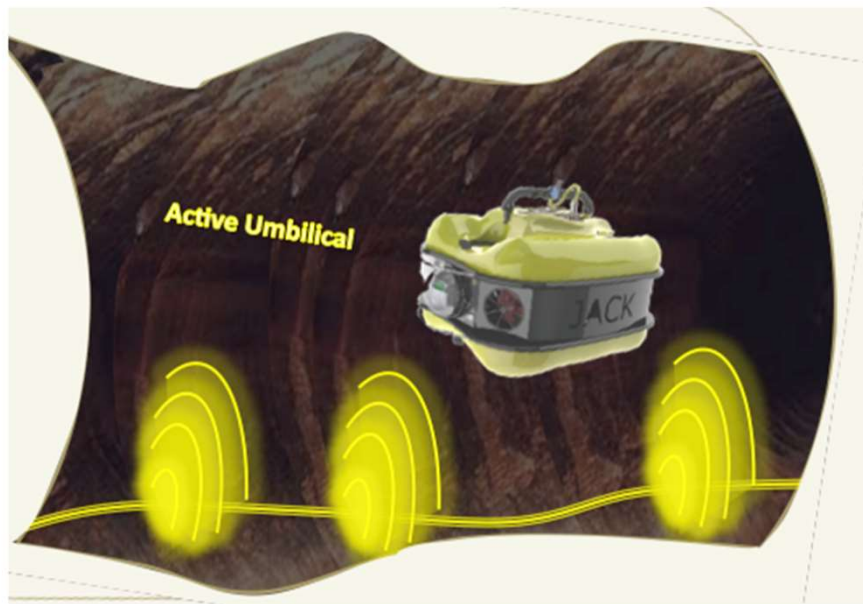
KARST EXPLORATION : UNCONVENTIONAL SENSORS

Acoustic Skin

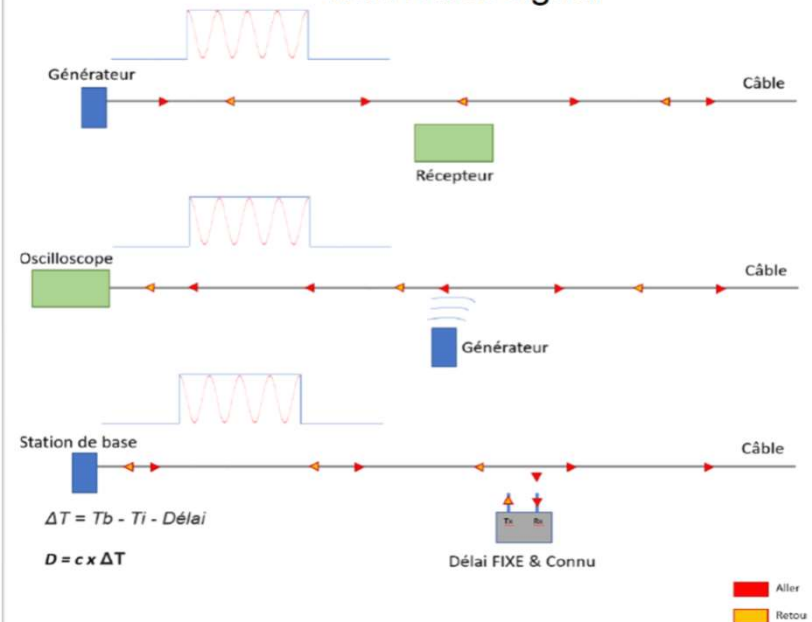


KARST EXPLORATION : UNCONVENTIONAL SENSORS

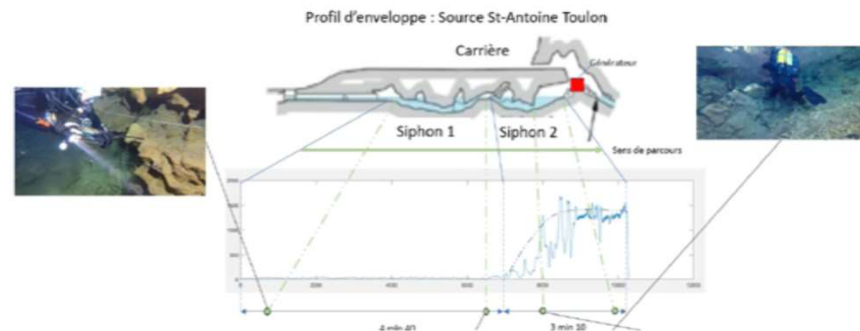
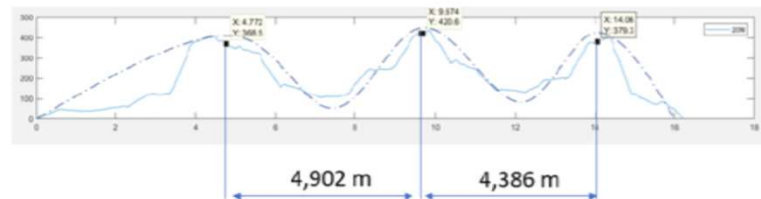
○ Active Umbilical



Wireless Communication/localisation with Burst signal



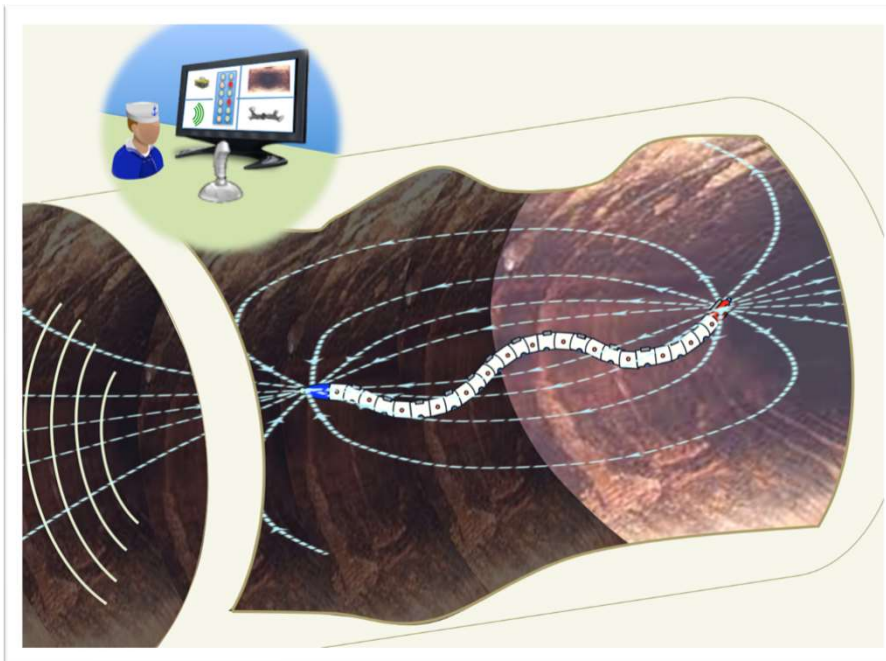
Détection of Stationnary waves in single wire



KARST EXPLORATION : UNCONVENTIONAL SENSORS



Electric Sense



JOURNAL OF IEEE TRANSACTIONS ON ROBOTICS

Underwater reflex navigation in confined environment based on electric sense

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

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

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

1. INTRODUCTION

In spite of its high potential interest for applications such as deep seas exploration or rescue missions in catastrophic conditions, underwater navigation in confined unstructured environments and turbid waters where vision is useless remains a challenge in robotics. In the same conditions, echolocation by sonar is problematic because the multiple small particles as well as the numerous obstacles cause diffraction and interfering reflections of the signal. In fact, nature has already discovered an original sense well adapted to this situation: the electric sense. Developed by several hundreds of fish species which have evolved independently on both the African and South-American continents, the electric sense was discovered by Lissman in the 50s [8]. The African fish *Gnathopetistus petersii* pictured in figure 1 is a typical electric fish. By polarizing its body with respect to an electric organ of discharge (EOD) located at the base of its tail. This polarization which is of short duration, generates a dipolar shaped electric field around the fish which is distorted by the objects present in its surroundings. Then, thanks to the many electroreceptors distributed along its body, the fish "senses" the distortions of the electric field and processes with its brain an image of its surroundings [2]. Named "electrolocation", this sensorial ability has been extensively studied by neuro-ethologists who showed 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 repulsive character that enables it a sense naturally suited to the obstacle avoidance. Thus,

understanding and imitating this sense with technology would offer the opportunity to enhance the navigation abilities of our current under-water robots. In this perspective, McIver et al. have recently used a sensor based on the measurement of the electric voltage through electrodes in order to address the problem of electrolocation of small objects through particle filtering [12]. Their sensor - two point electrodes between which the difference of potentials is measured - was sufficiently small so that it did not perturb the electric field produced by another pair of point (sensing) electrodes between which the voltage was imposed. In Angeli [10], another technological solution is proposed for the electric sense. This sensor is embedded in a realistic 3D body. Each electrode can be polarized with respect to the others through a given vector of voltage U . The electric field distortions are then measured through the vector I of the currents flowing across the electrodes. We term this measurement mode $U-I$, the first letter standing for the unknown (here, a vector of voltage U), the second, for the measured (here a vector of currents I), to distinguish it from the $U-U$ mode of [13], [14]. In this article we address the problem of the underwater electro-navigation in confined environments using this sensor. The proposed approach is inspired by the observation of electric fish in nature. It exploits the interactions of the sensor body with the electric field deformations produced by the objects in its surrounding. It amounts to a set of reactive control loops whose parametrization allows one to achieve relevant behaviors for underwater-robotics in a robust manner with respect to the scene complexity.

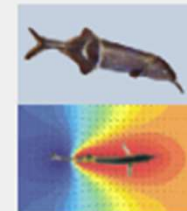


Fig. 1. From Van der Horst [20] (top) The African electric fish *Gnathopetistus petersii*, bottom) Top view of the fish head electric field.

The article is structured as follows. First we will briefly

KARST EXPLORATION : UNCONVENTIONAL SENSORS

- Acoustic Interference Patterns as Invariant Landmarks

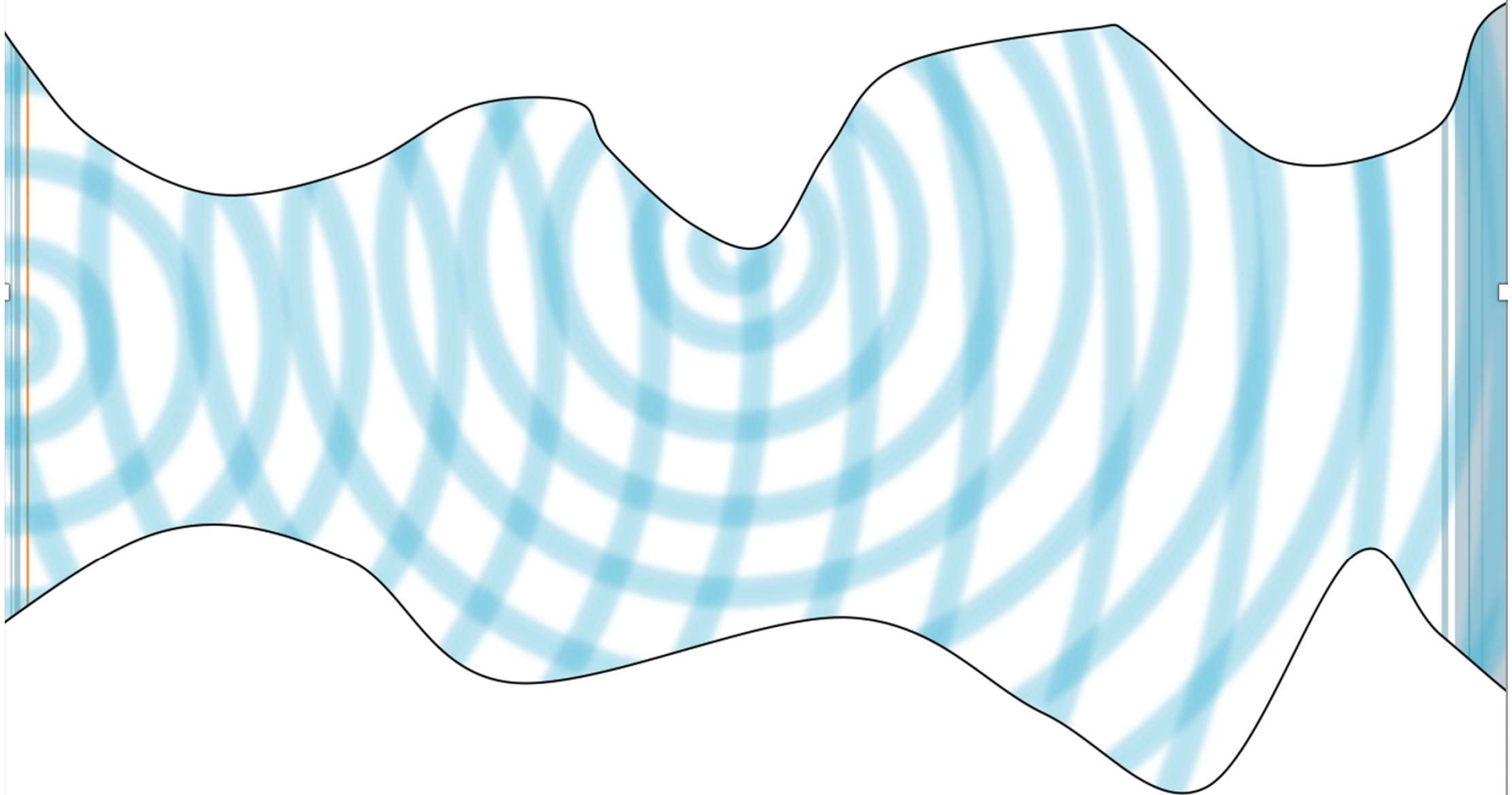
Sinusoidal acoustic source



The diagram illustrates the concept of acoustic interference patterns as invariant landmarks in a karst system. It features a cross-section of a karst environment with irregular black lines representing the boundaries of the underground space. On the left, a 'Sinusoidal acoustic source' is indicated by a series of concentric blue circles, representing the propagation of sound waves. These waves travel through the karst system, creating a series of vertical blue bands that represent the resulting interference patterns. The text 'Sinusoidal acoustic source' is underlined in red.

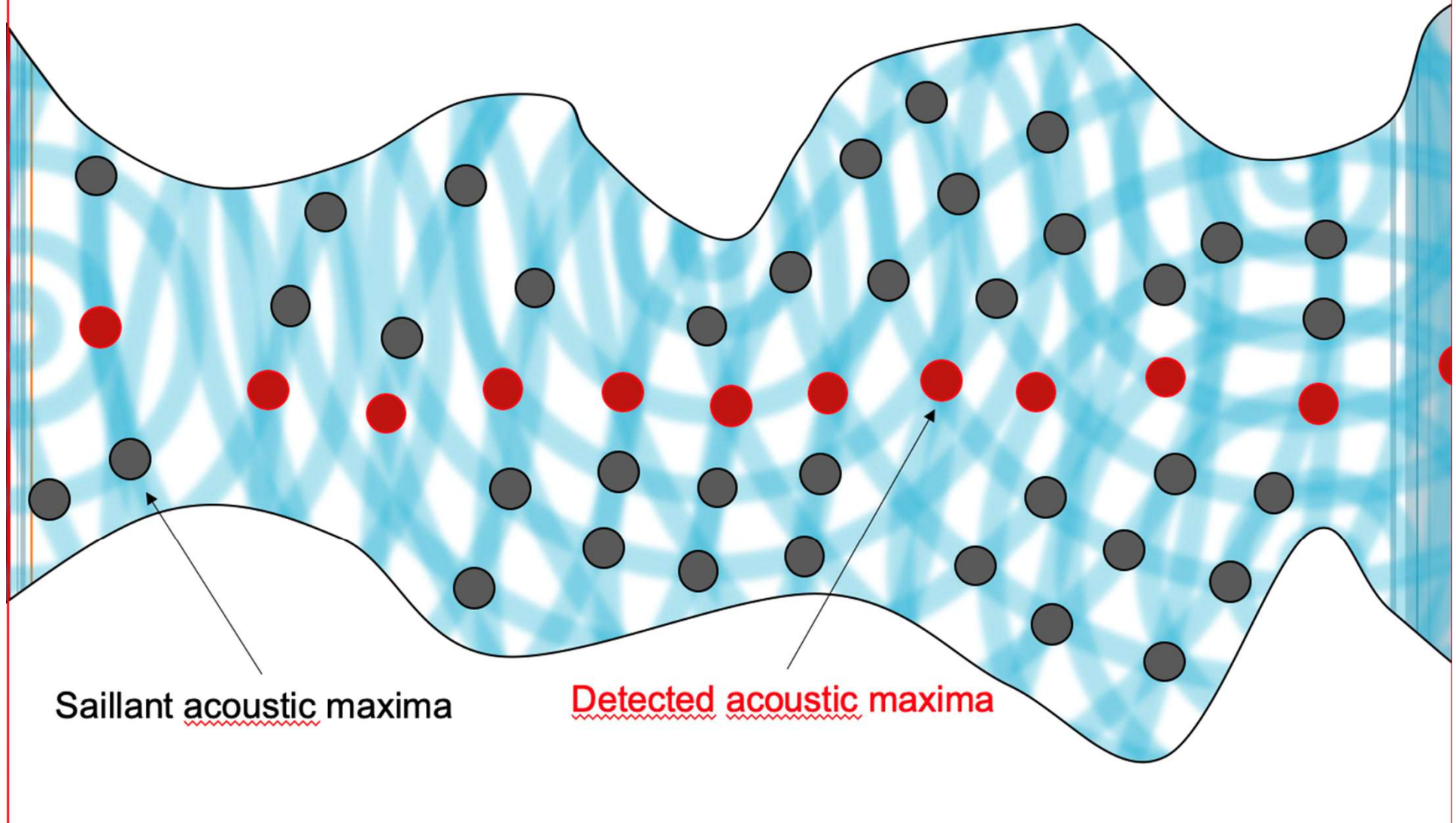
KARST EXPLORATION : UNCONVENTIONAL SENSORS

- Acoustic Interference Patterns as Invariant Landmarks



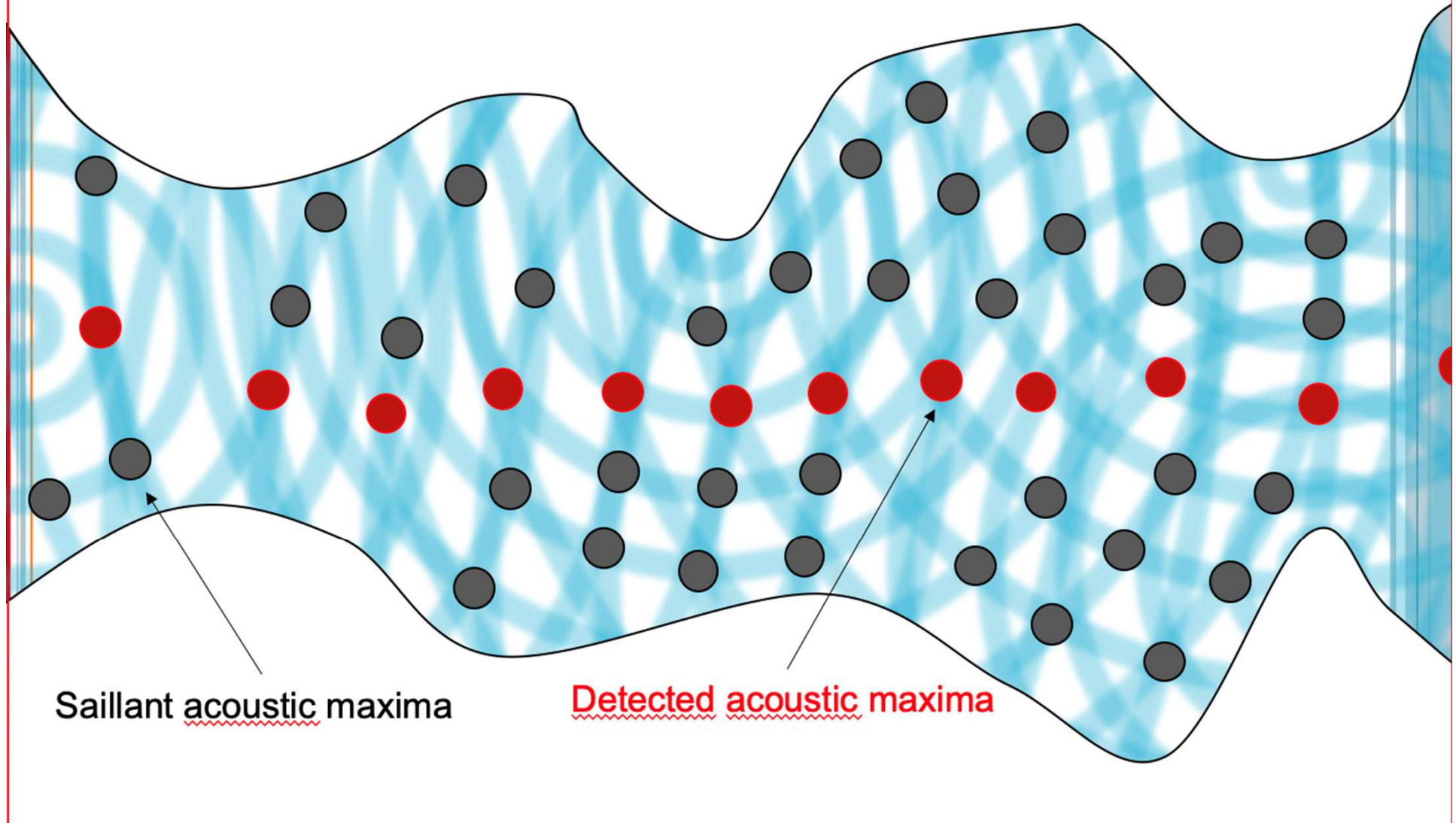
KARST EXPLORATION : UNCONVENTIONAL SENSORS

- Acoustic Interference Patterns as Invariant Landmarks -> SLAM



KARST EXPLORATION : UNCONVENTIONAL SENSORS

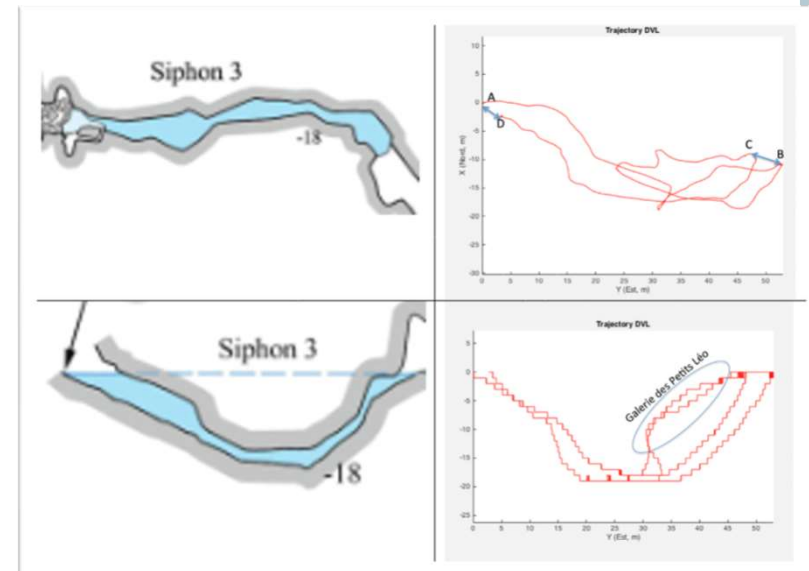
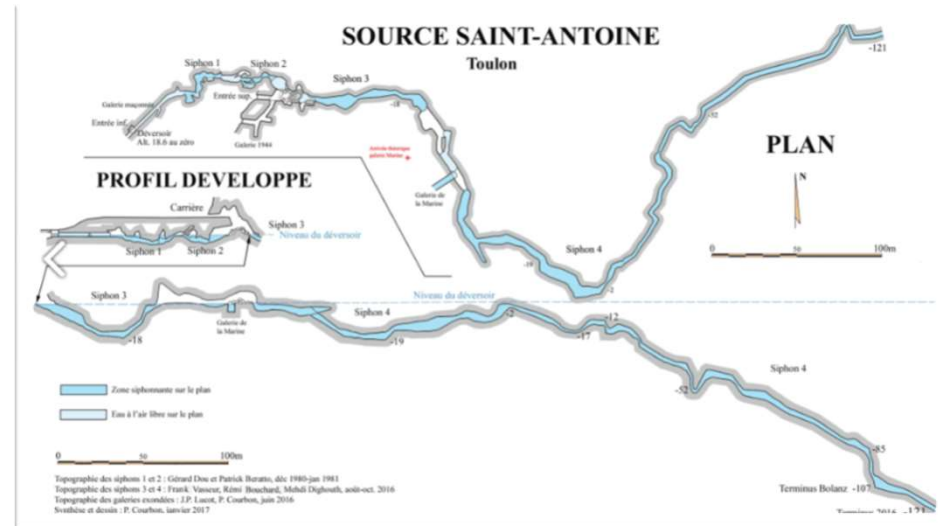
- Acoustic Interference Patterns as Invariant Landmarks -> SLAM



KARST EXPLORATION : NAVIGATION

Global Navigation System

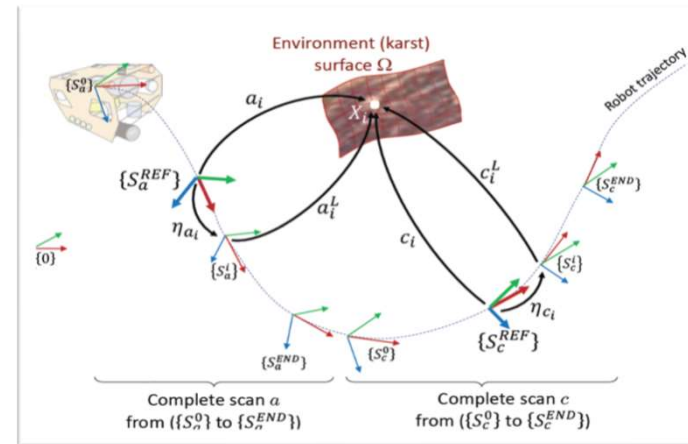
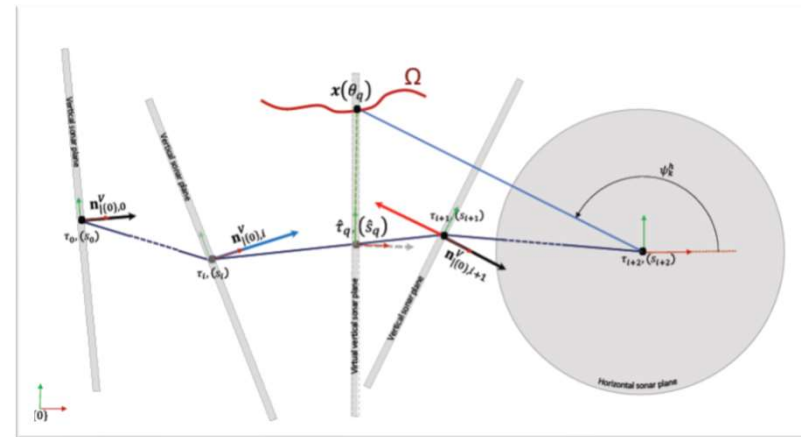
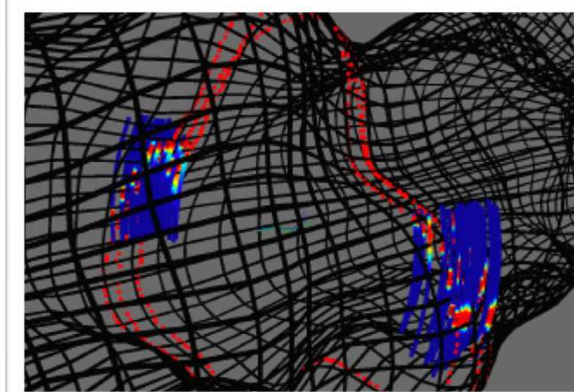
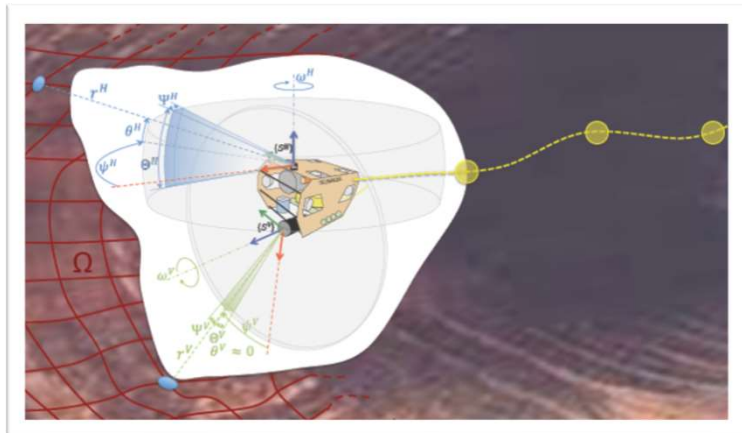
- IMU (SBG Ellipse D)
- DVL (Nortek 1000)
- Pressure Sensor (Blue Robotics)



KARST EXPLORATION : NAVIGATION

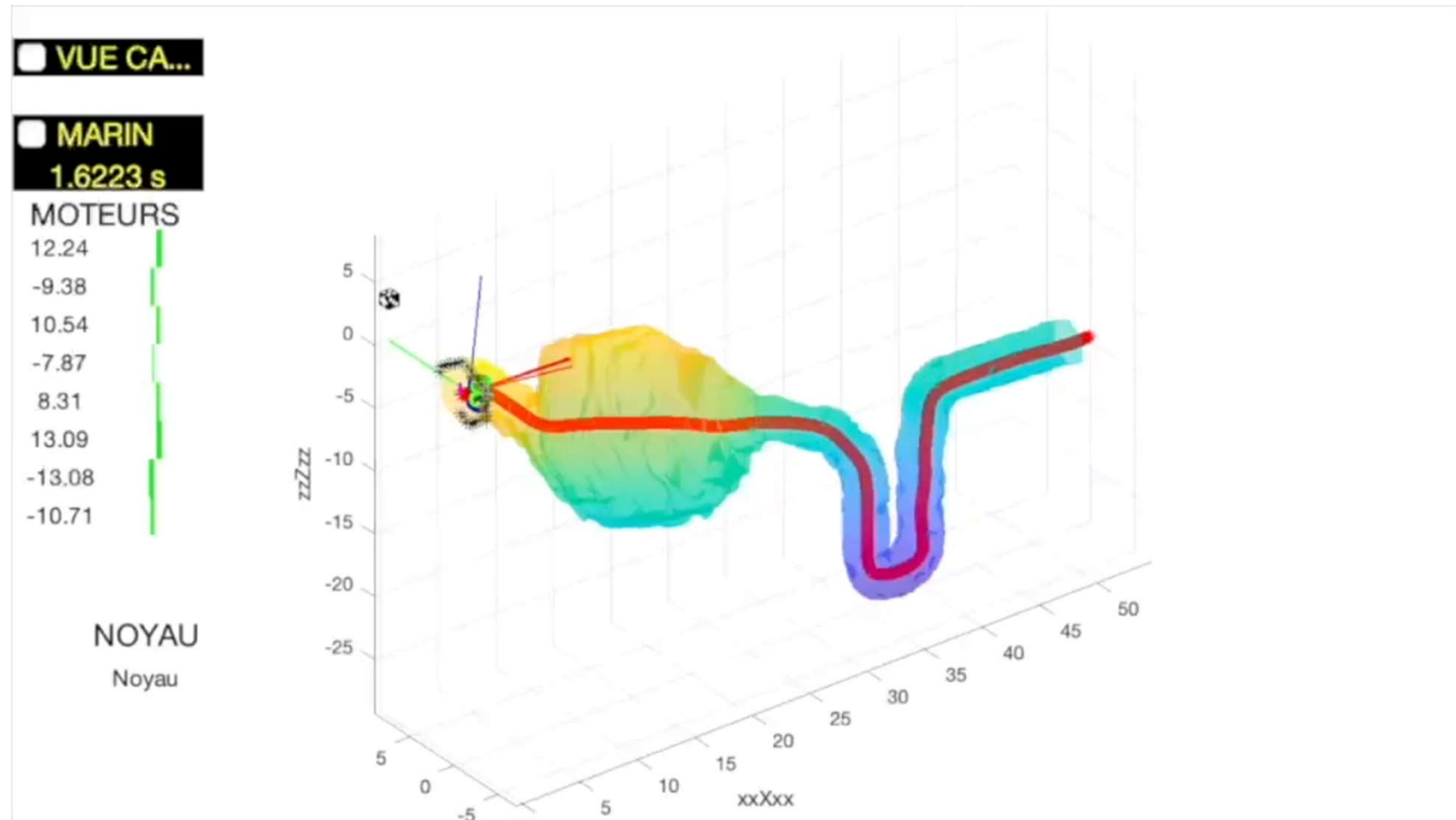
Acoustic SLAM

- Vertical / Horizontal Scans Fusion
- Scan Matching (point to point and point to plane)
- Graph SLAM and loop closure detection



KARST EXPLORATION : NAVIGATION

- Acoustic SLAM, with helicoidal constraints

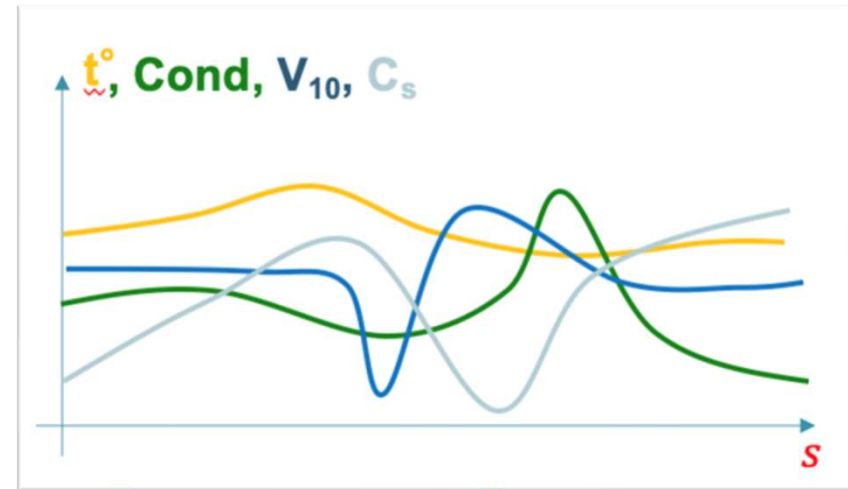


KARST EXPLORATION : NAVIGATION

- Clustering and Saliency Data Analysis

$$f(t^\circ, \text{Cond}, V_{10}, C_s, d(\alpha))?$$

which maximizes
 $SALS(f(s))$ over S ,
 $s \in S$

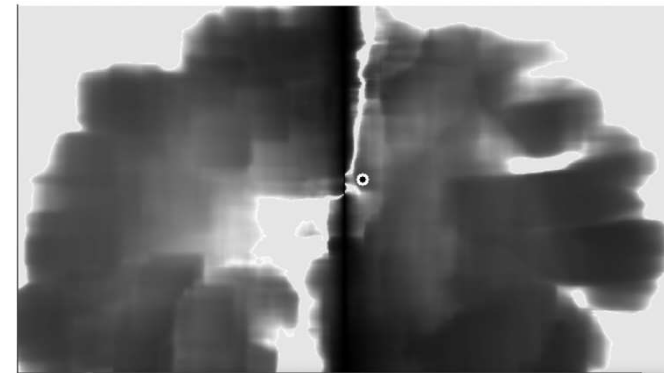


Helicoidal acoustic sampling : $d(\alpha(s))$

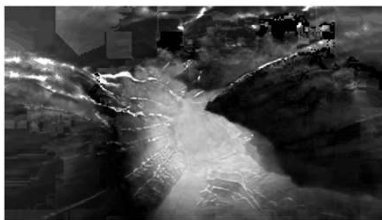
Robot trajectory : $X(s)$

KARST EXPLORATION : GUIDANCE

- Visual Analysis : Centering, Advancement Vector, SLAM, 3D reconstruction



Depth map



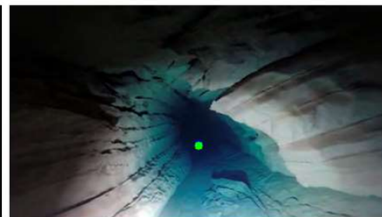
(a) Saturation



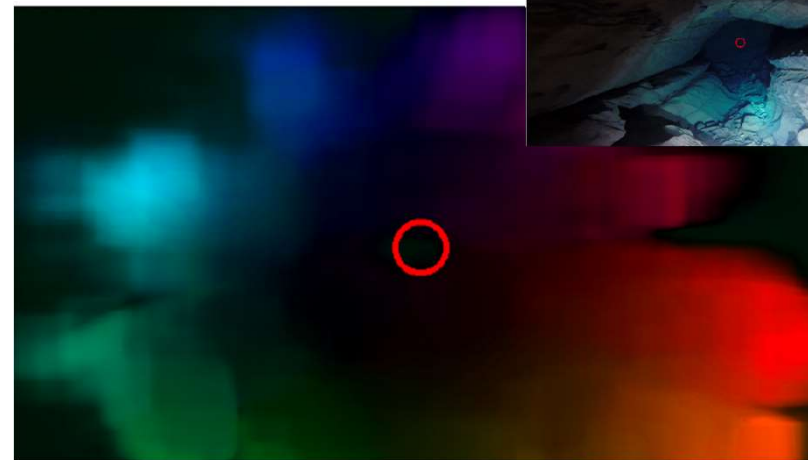
(b) Segmented



(c) Largest blob



(d) Result

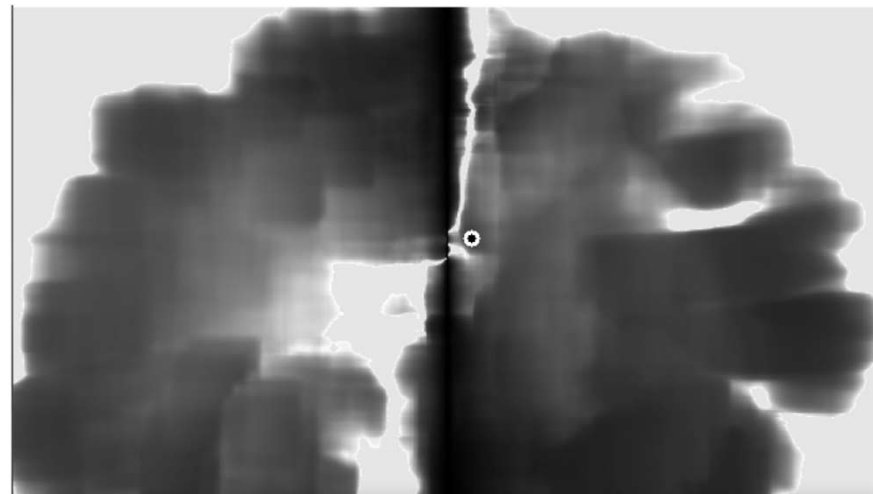


Dense Optical Flow



KARST EXPLORATION : GUIDANCE

- Vacancy Evidence Grid



KARST EXPLORATION : GUIDANCE

Environmental Model Consideration

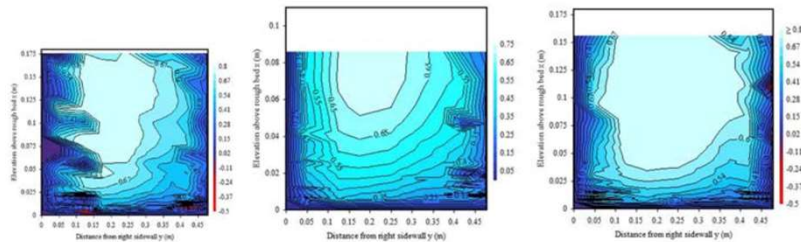
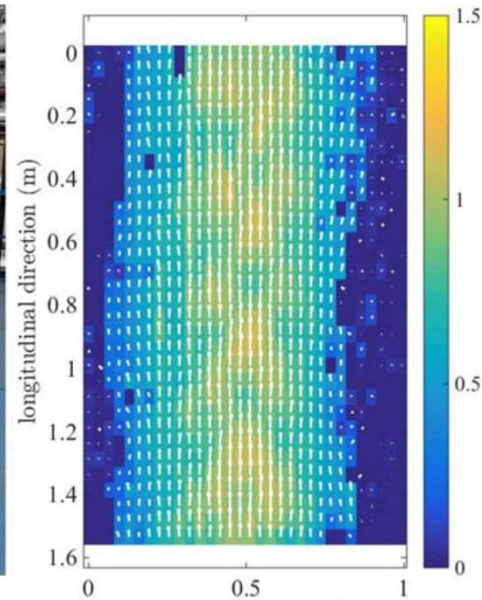
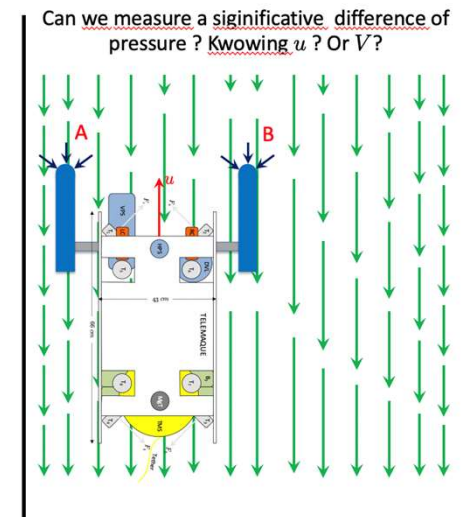
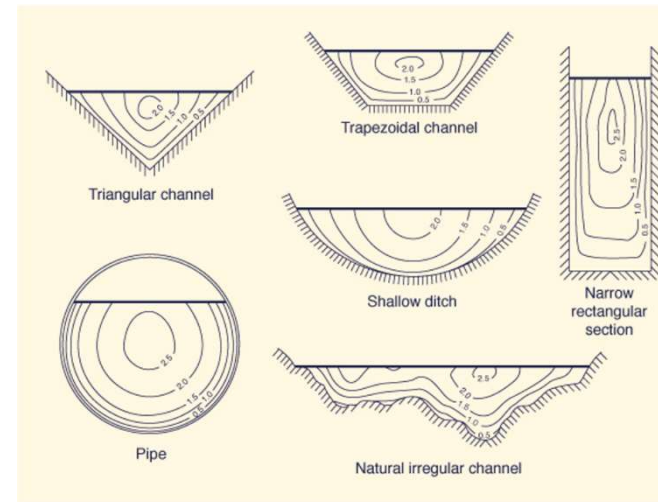
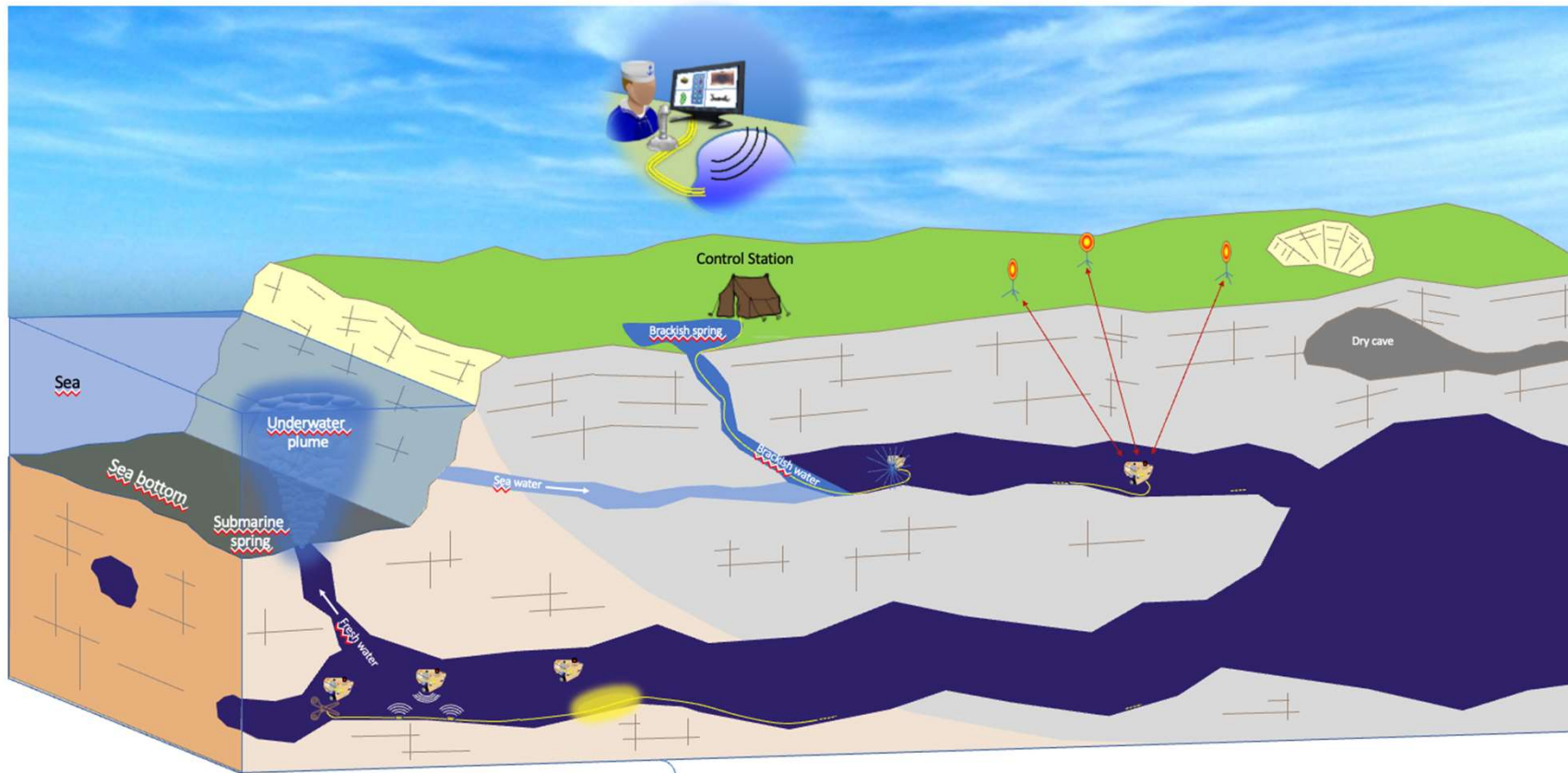


Fig.12 Experimental velocity fields from Wang et al. [34] for $h = 0.175$ m and $Q = 0.0556$ l/s (left), $h = 0.085$ m. and $Q = 0.0261$ l/s (center) and $h = 0.155$ m and $Q = 0.0556$ l/s (right)



KARST EXPLORATION : CONTROL

Co-control



[C-39] Lasbouygues A., Louis S., Ropars B., Rossi L., Jourde H., Delas H., Balordi P., Bouchard R., Dighouth M., Dugrenot M., Jacquemin E., Vasseur F., Lapierre L. and Andreu D., 'Robotic mapping of a karst aquifer', IFAC World Congress 2017, demonstration paper.

KARST EXPLORATION : CONTROL

Open-Loop Stability

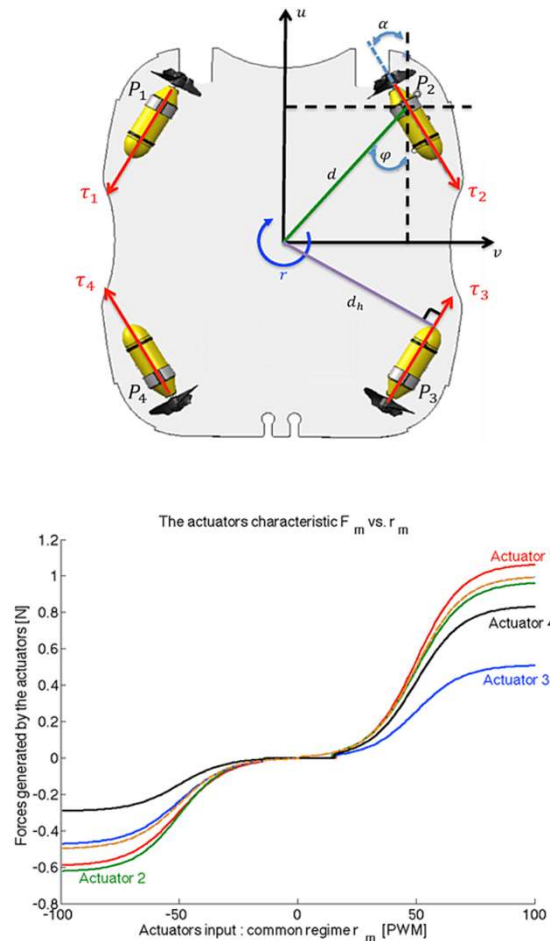


Fig. 6. Illustration of the actuators' characteristics disparity (simulation).

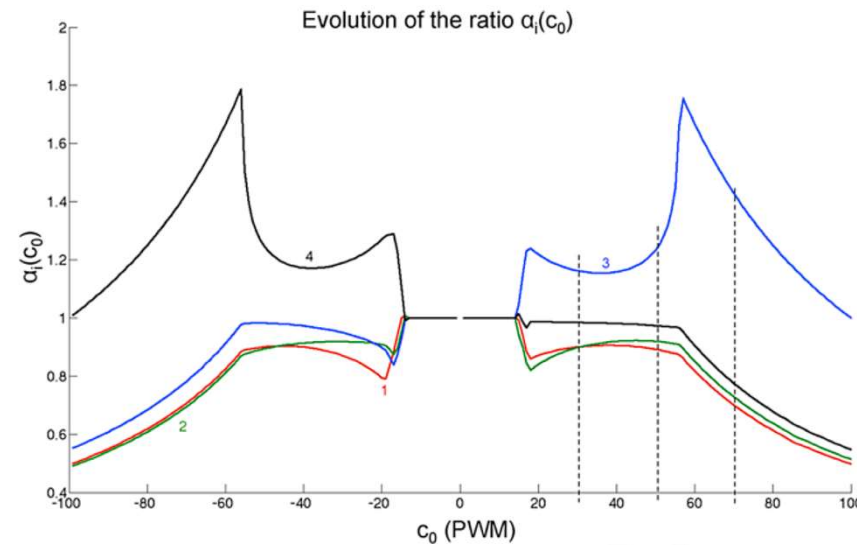


Fig. 10. Evolution of the corrective coefficient versus the common motor regime (simulation).

$$\mathbf{c}_m = \mathcal{Q} \left(\widehat{\mathcal{M}}^{-1} (\mathbf{A}^+ \cdot \mathbf{F}_B^d) + c_0 \cdot \mathbf{1}_4 \right)$$

KARST EXPLORATION : CONTROL

○ Autonomous Centering & Targeting

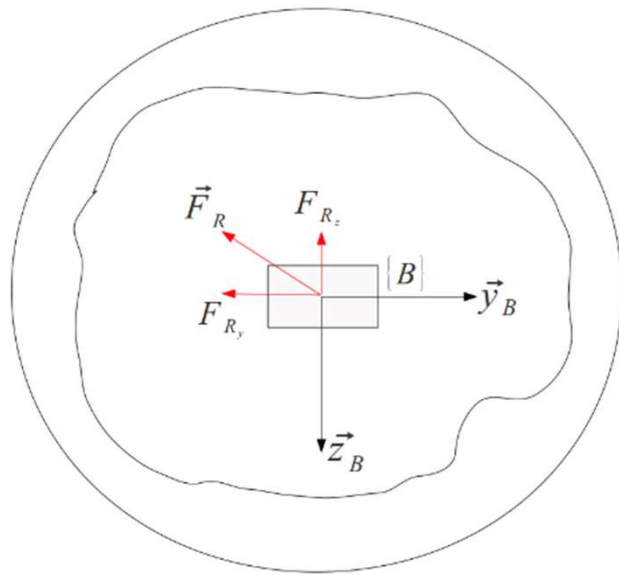
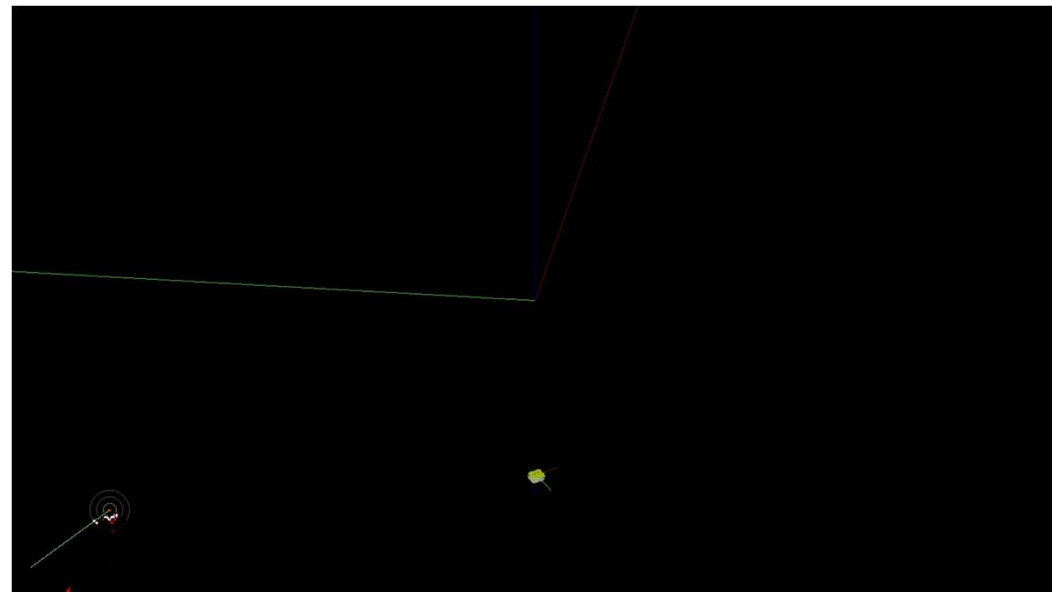
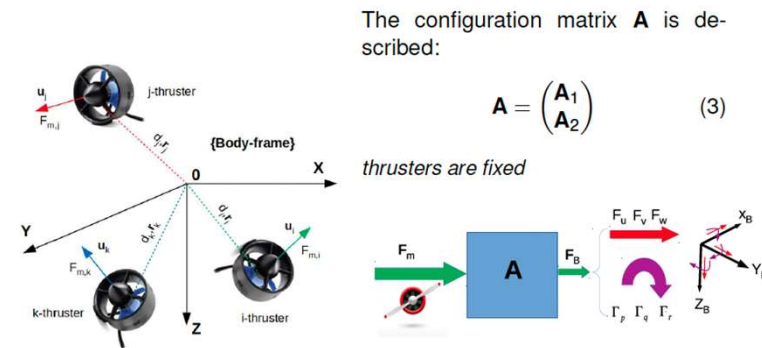
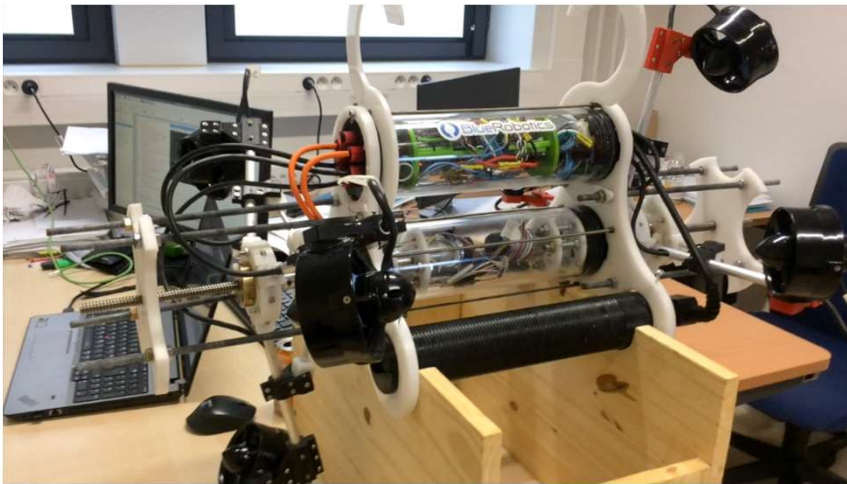
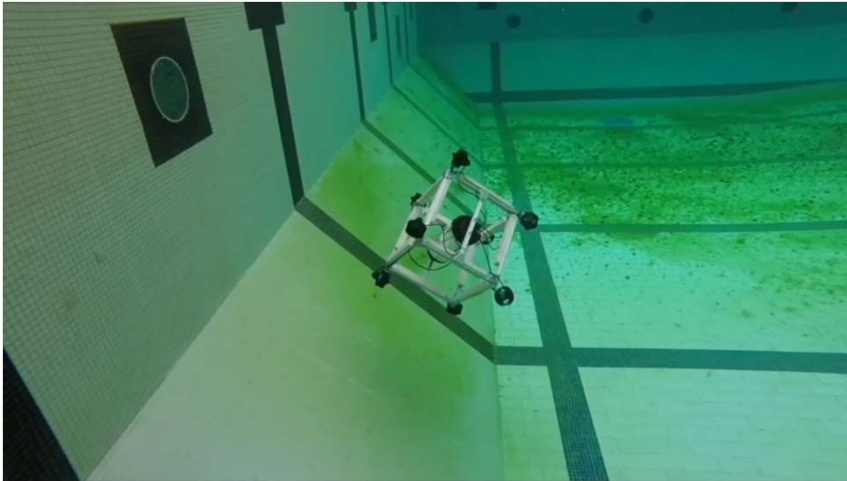


Fig. 6. Resulting force



KARST EXPLORATION : ACTUATION

Reactive redundant Allocation System and Variable Actuation Geometry



$$\mathbf{F}_B = \mathbf{A} \cdot \mathbf{F}_m$$

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

$$\mathbf{F}_m = [\mathbf{A}^+ \quad \mathbf{M}_m] \cdot \begin{bmatrix} \mathbf{F}_B^d \\ \mathbf{r}_m \end{bmatrix}$$

A k -dimensional space to explore redundant solutions

KARST EXPLORATION : ACTUATION

○ Anguilliform Locomotion & Underwater Swimming Manipulator



ANR ElectroKarst



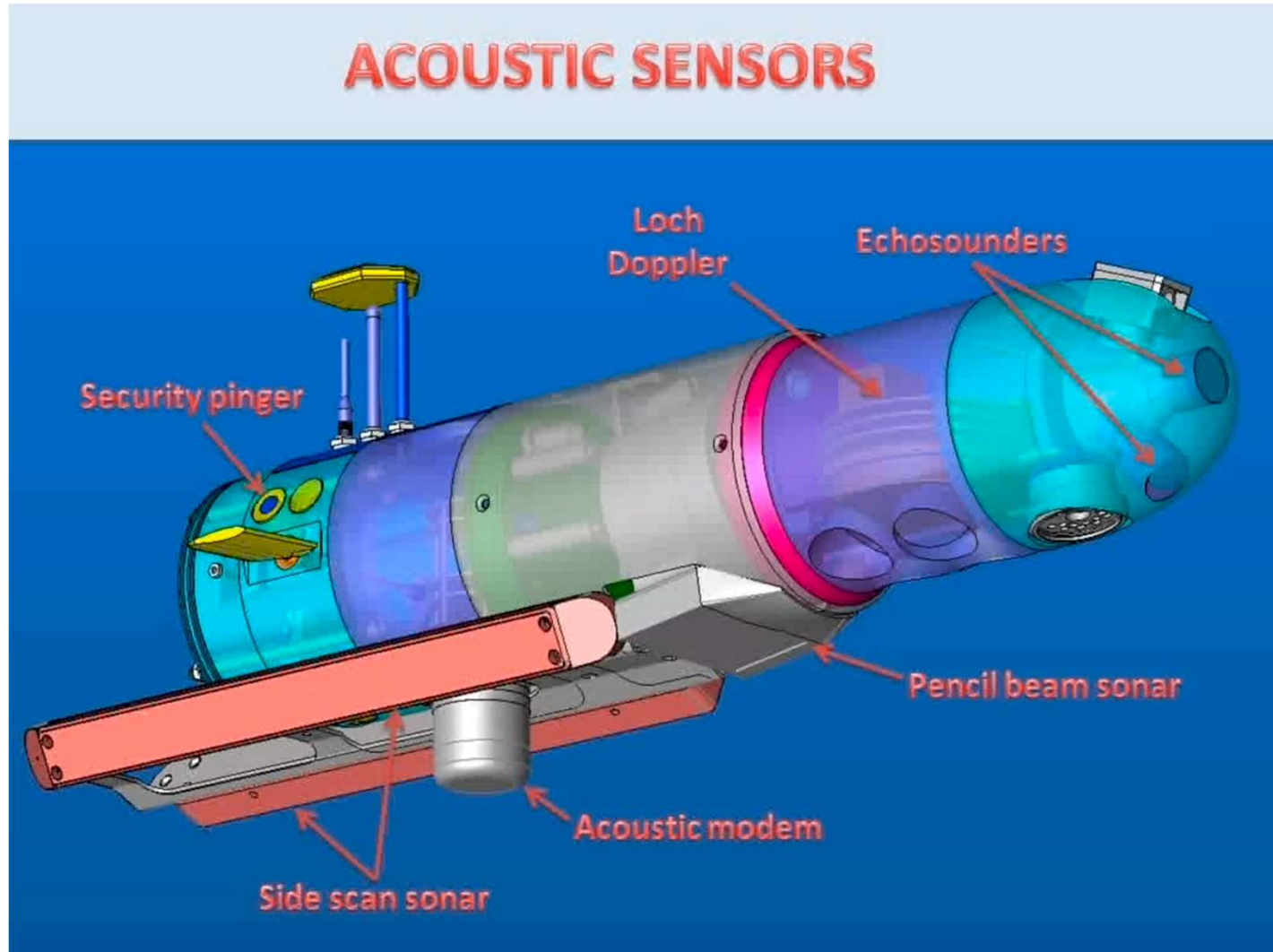
+



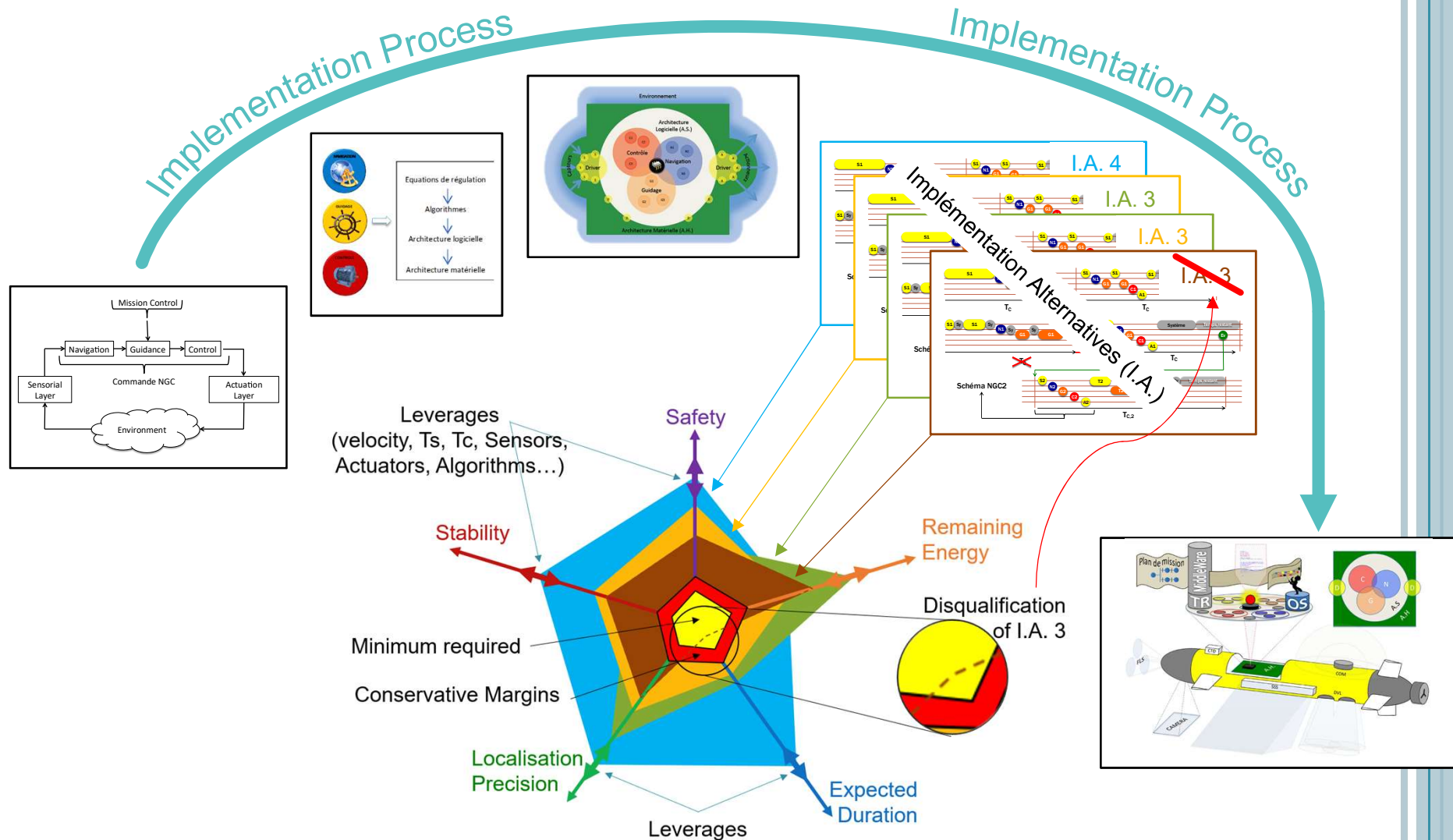
SLAM ?

KARST EXPLORATION : MISSION MANAGEMENT

- Management of interfering sensors (Acoustic sensors jamming)



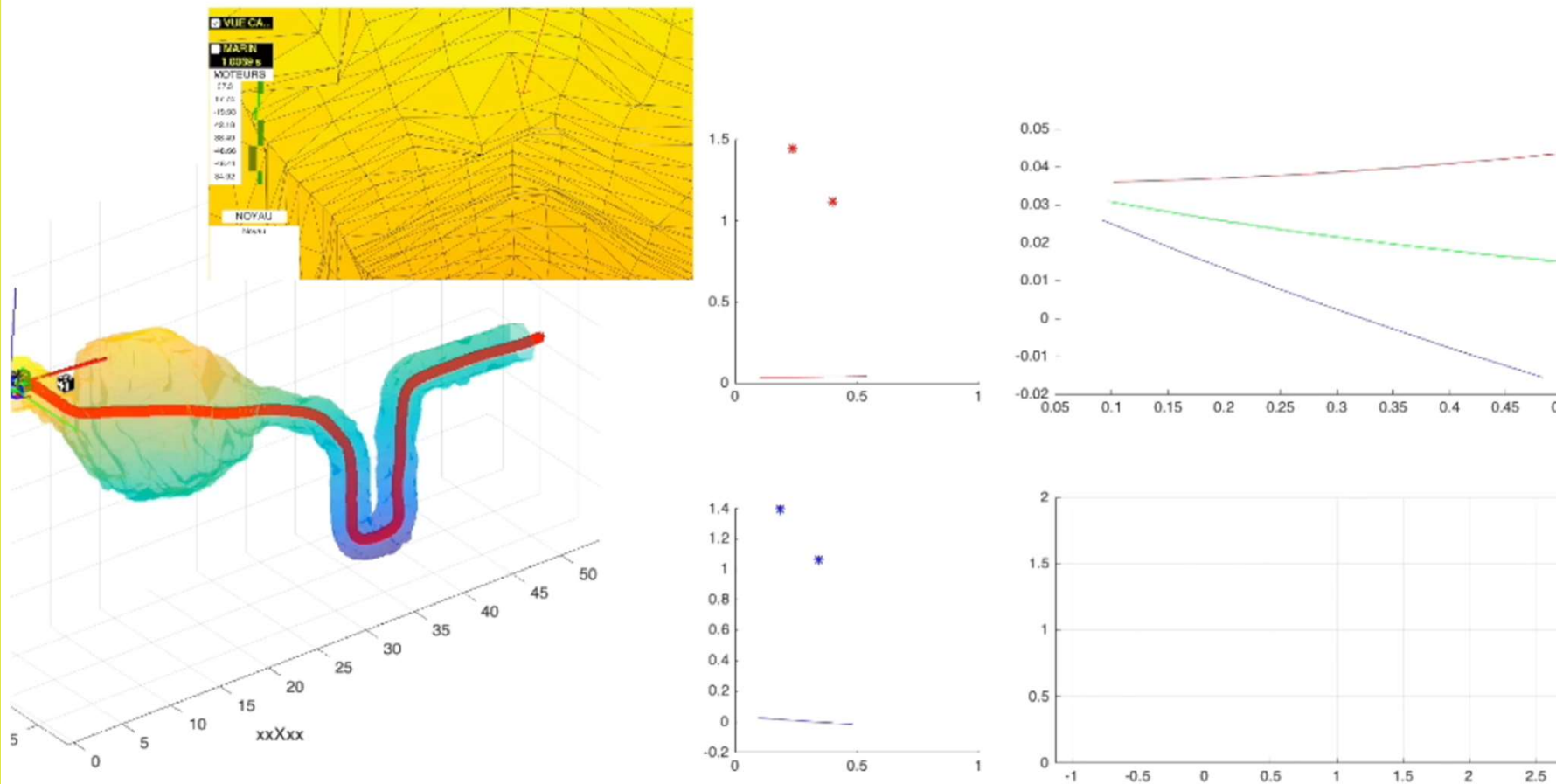
Adaptive Autonomy / Guarantees of Performance



KARST EXPLORATION : MISSION MANAGEMENT

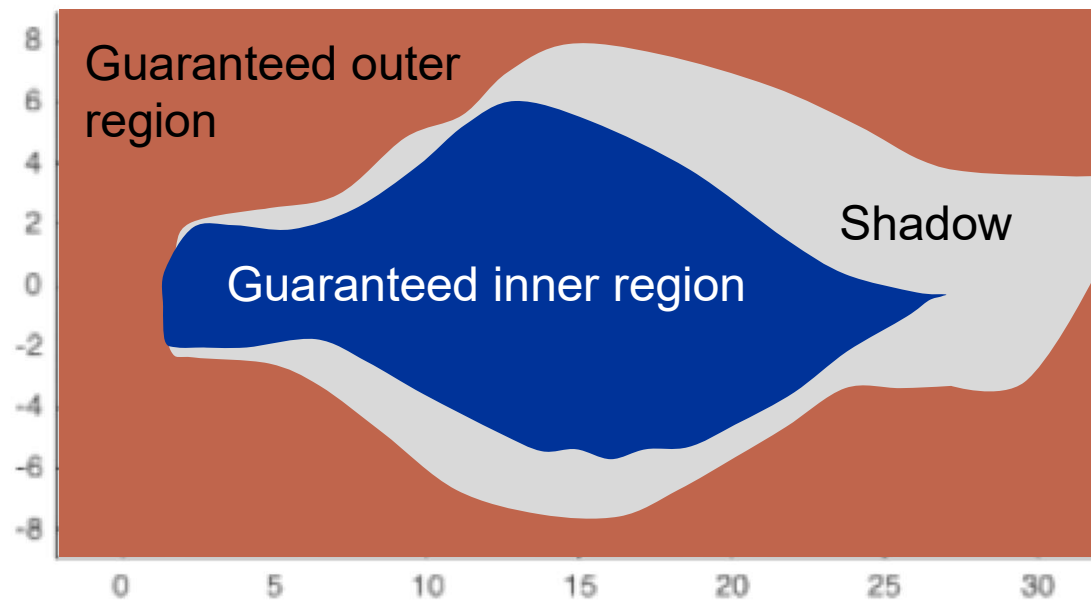
- (Seeking) for Guarantees of Performance & Interval approach

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



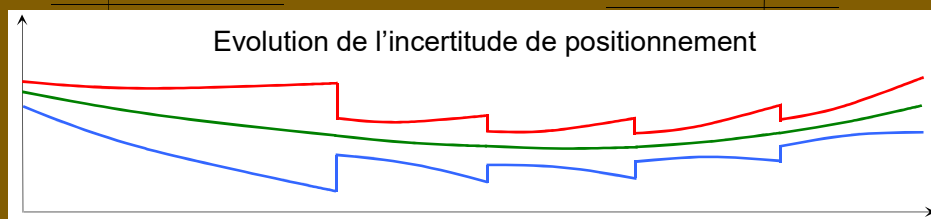
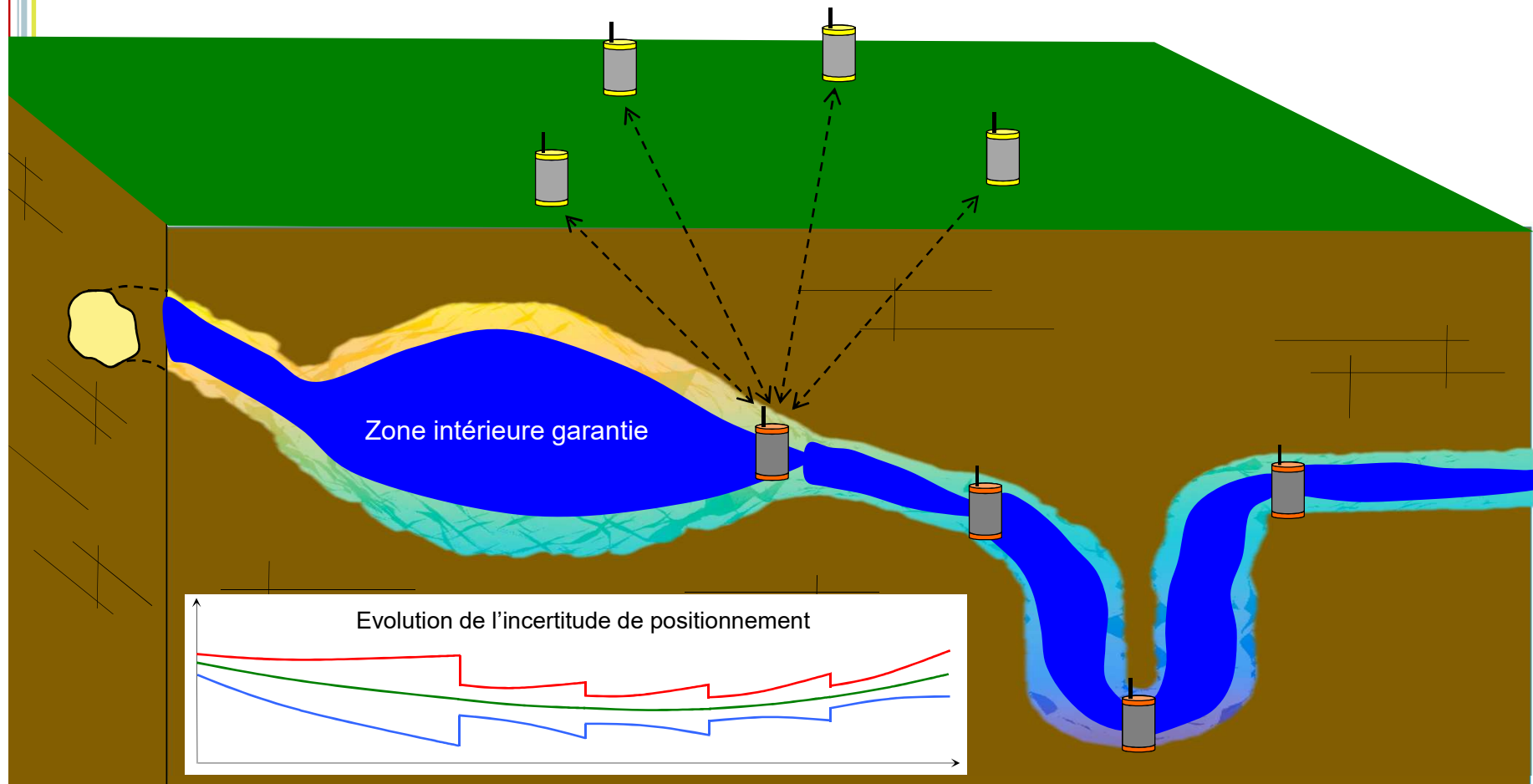
KARST EXPLORATION : MISSION MANAGEMENT

- (Seeking) for Guarantees of Performance & Interval approach



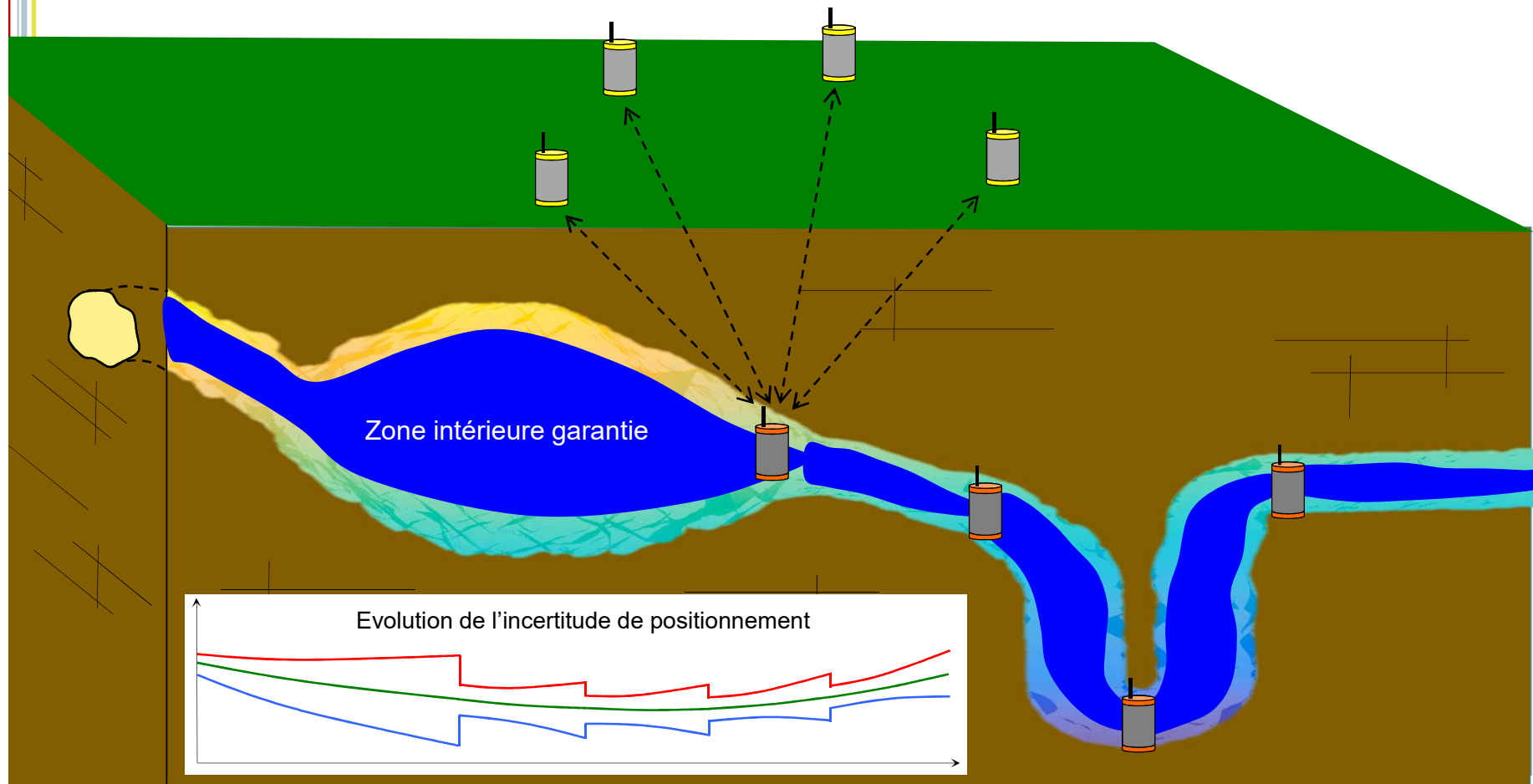
KARST EXPLORATION : MISSION MANAGEMENT

- (Seeking) for Guarantees of Performance & Interval approach
- Global positioning using UGPS



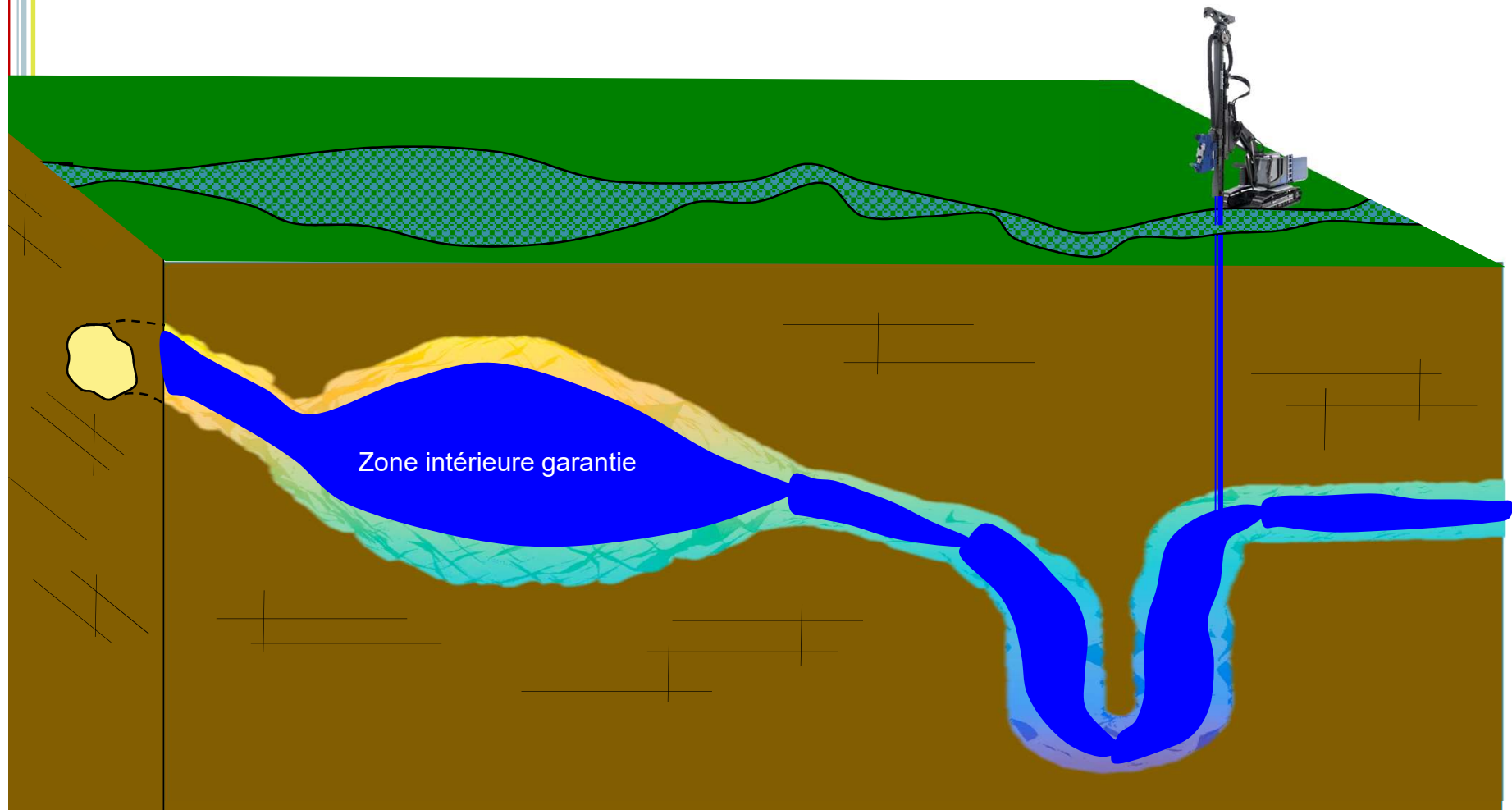
KARST EXPLORATION : MISSION MANAGEMENT

- (Seeking) for Guarantees of Performance & Interval approach
- Global positioning using UGPS
- Application to hydraulic drilling



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

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



KARST EXPLORATION : TERRAIN RESULTS

- Ulysse



Co-contrôle Réactif

Exploitation de la Redondance d'actionnement

Commande Orientée Modèles d'Environnement

Commande S-NGC-A

Décomposition Atomique de la Commande

Polyvalence et Robotique

Autonomie Adaptative

Garanties de Service

Garanties de Performance

Gestion des Commutations de Modes

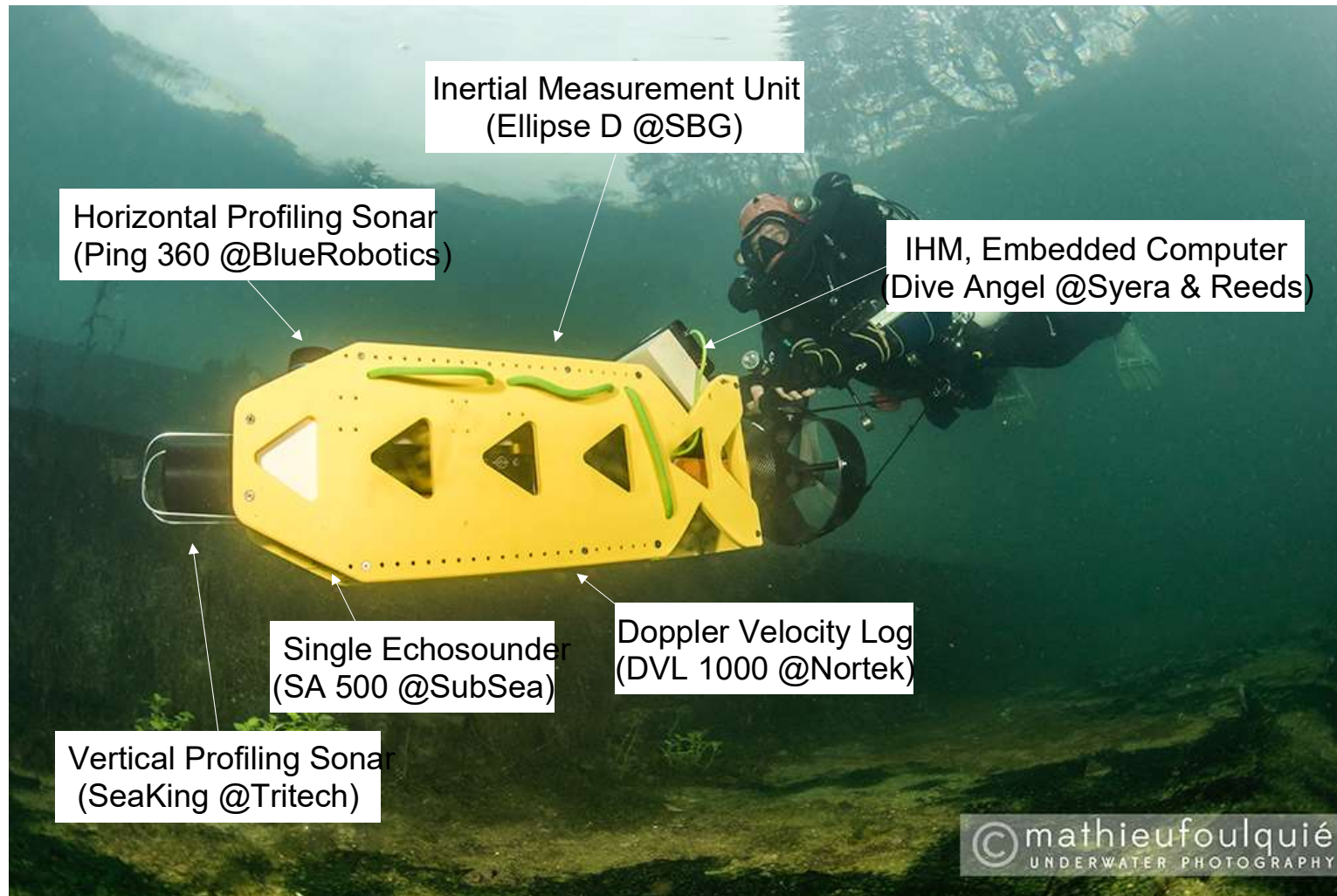
KARST EXPLORATION : TERRAIN RESULTS

- Ulysse, Gourneyras, France



KARST EXPLORATION : TERRAIN RESULTS

- NavScoot 2



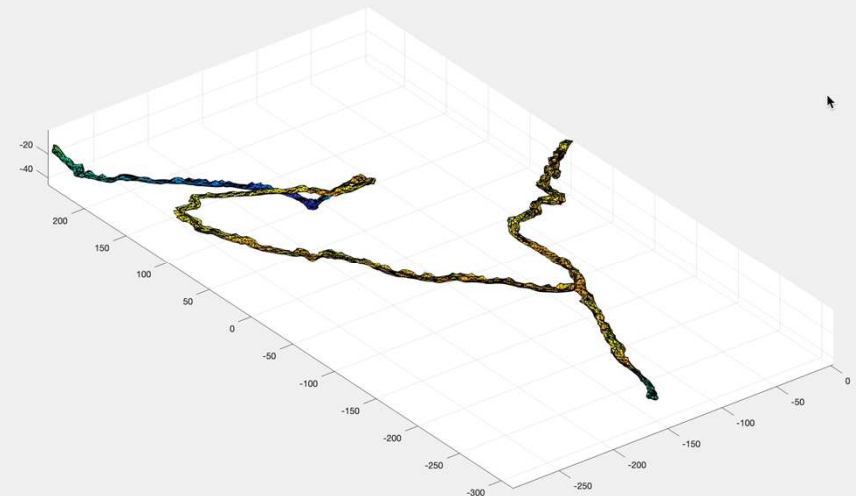
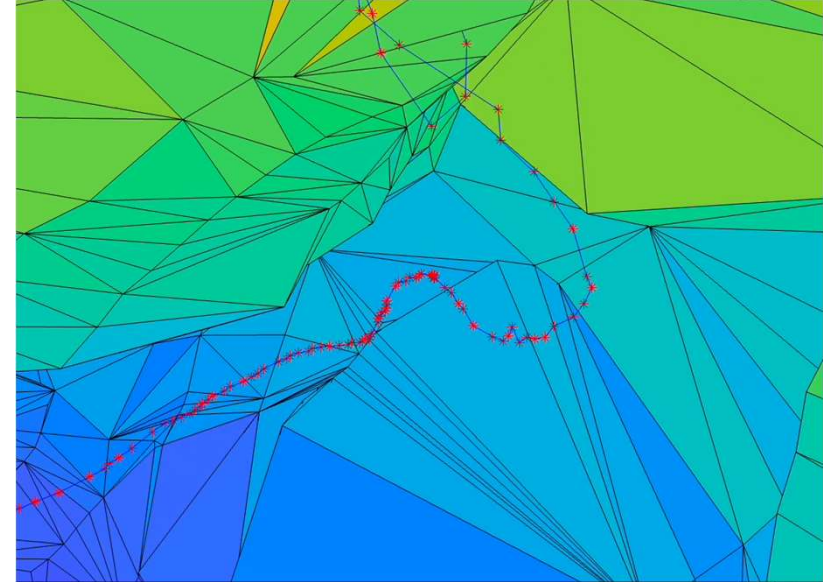
TERRAIN RESULTS: FONTAINE DE NÎMES, 8/03/2023



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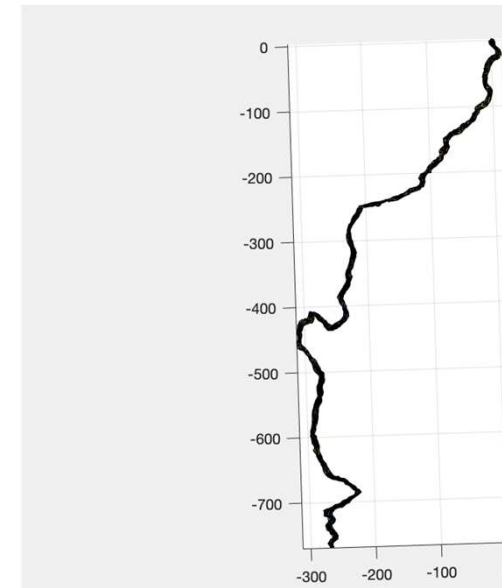
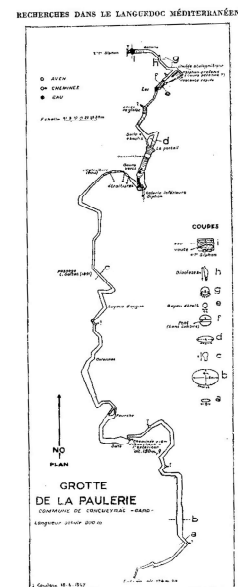
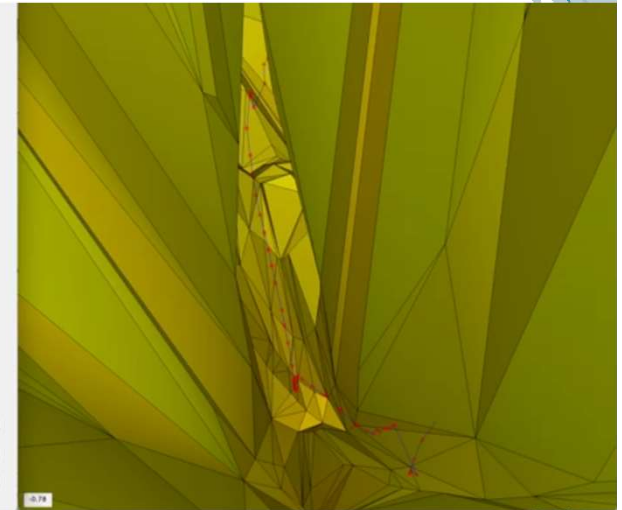
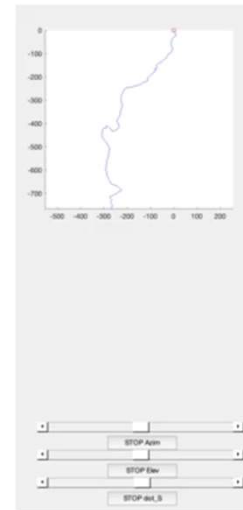


TERRAIN RESULTS: FONTAINE DE SAUVE, 24/05/2023



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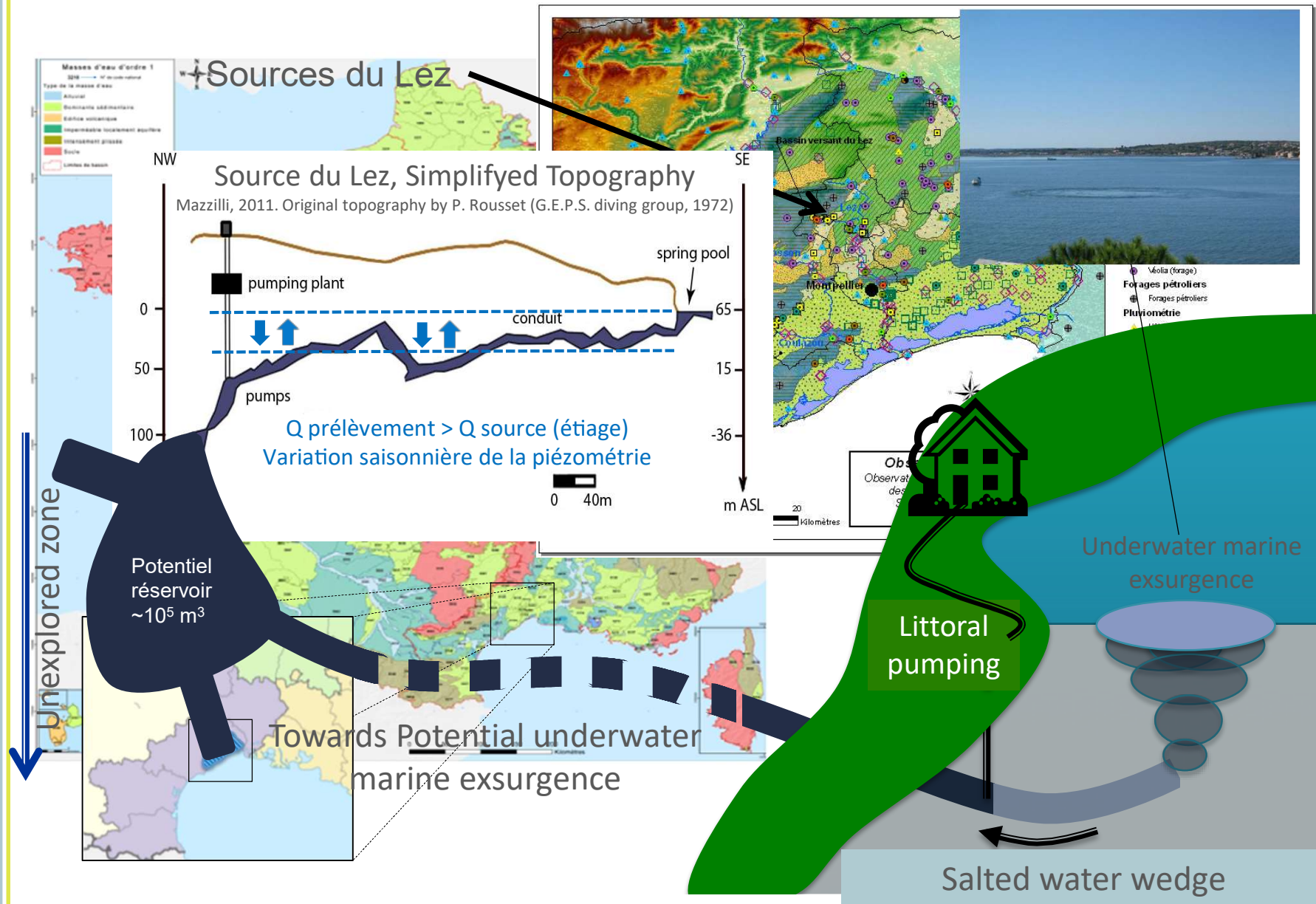
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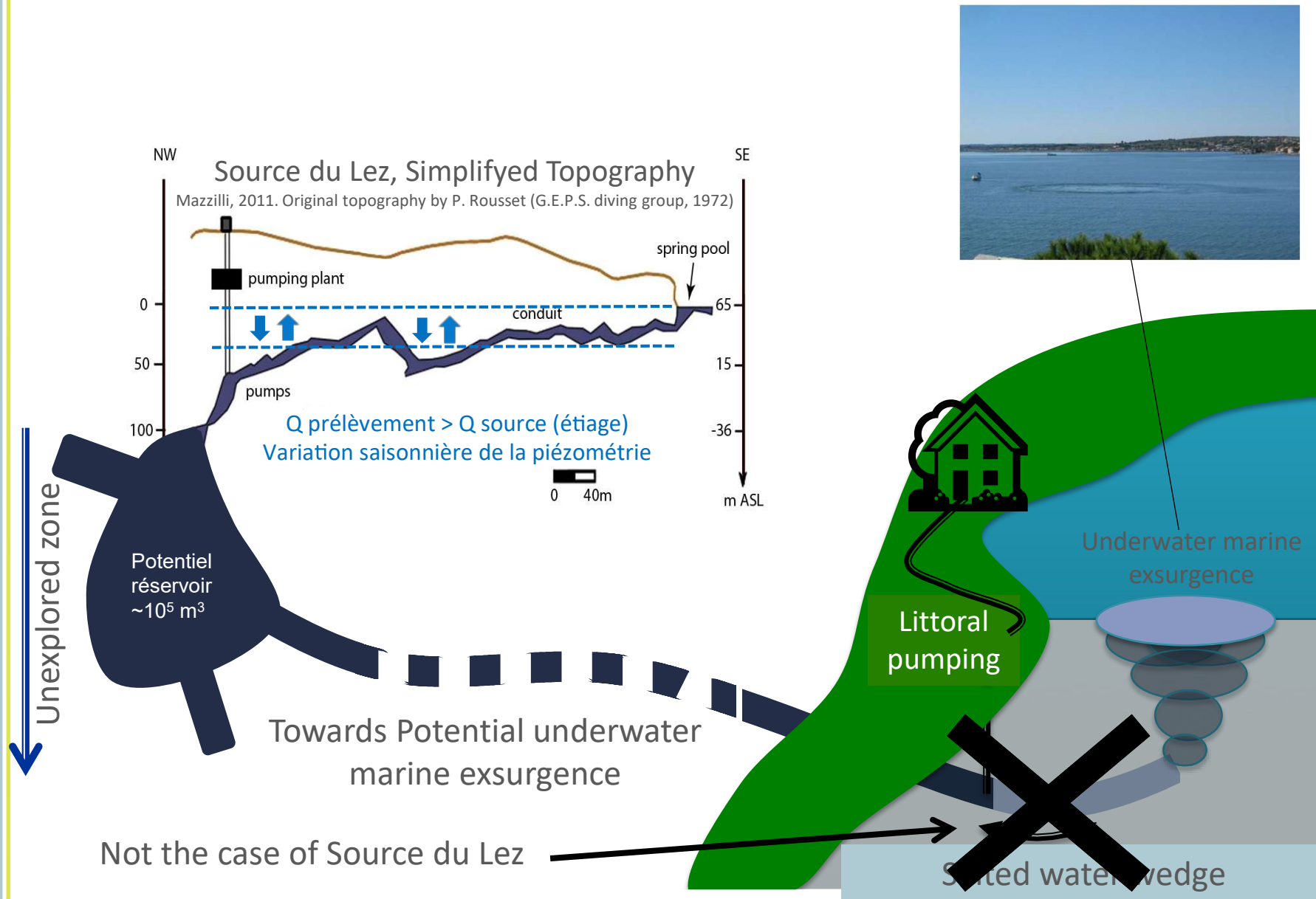
TERRAIN RESULTS: SOURCE DU LEZ, 15/03/2023



SOURCES DU LEZ : A SEMINAL CASE STUDY



SOURCES DU LEZ : ACTIVE MANAGEMENT OF GW RESOURCE

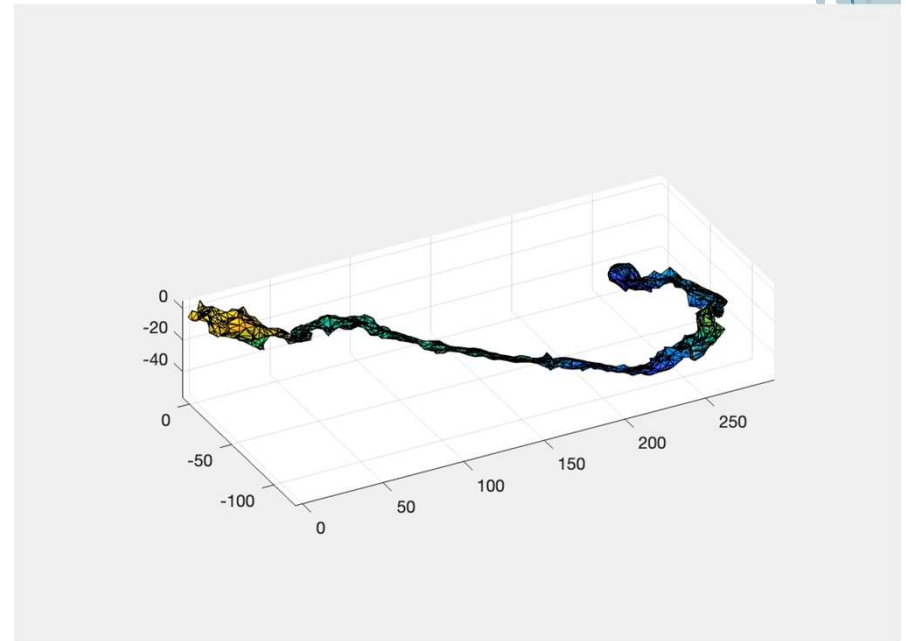
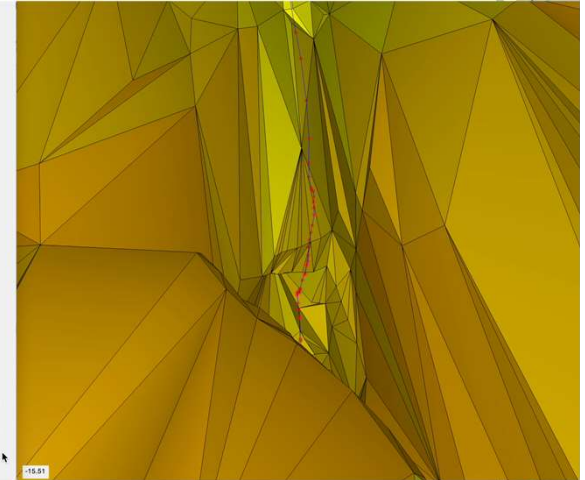
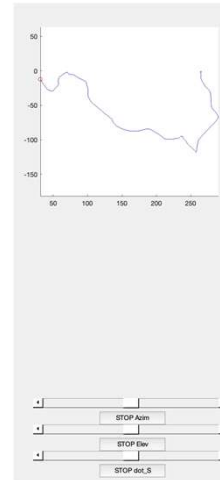


TERRAIN RESULTS: SOURCE DU LEZ, 15/03/2023



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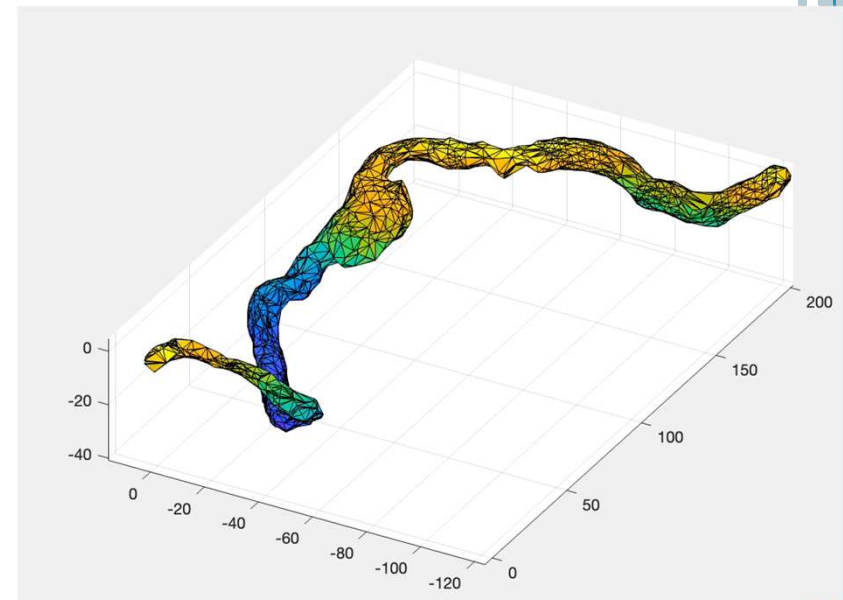
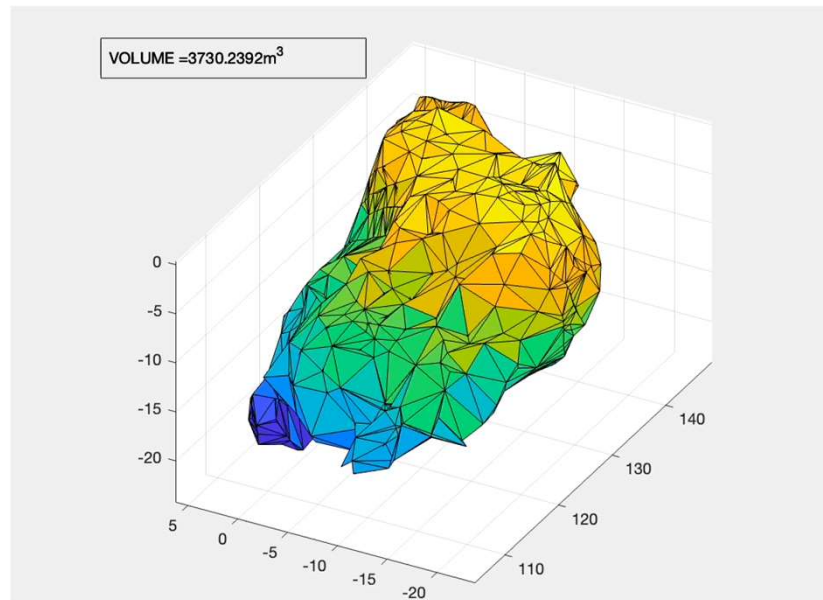
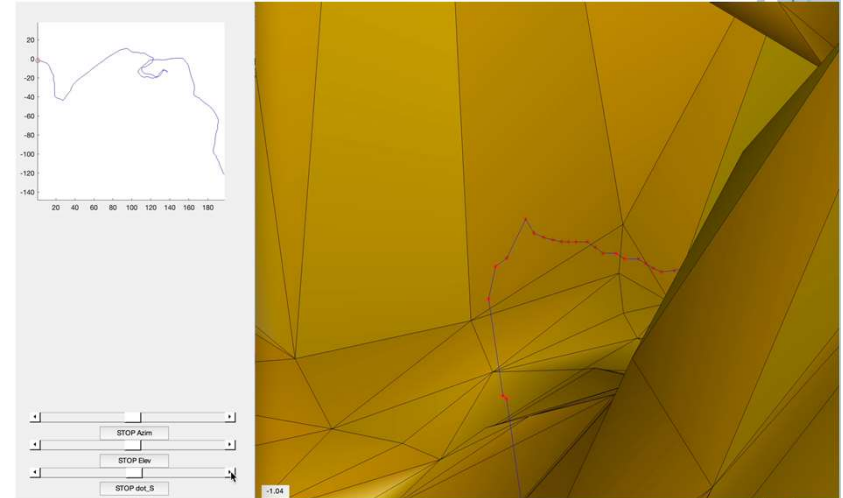


TERRAIN RESULTS: FONTANILLES, 15/03/2023

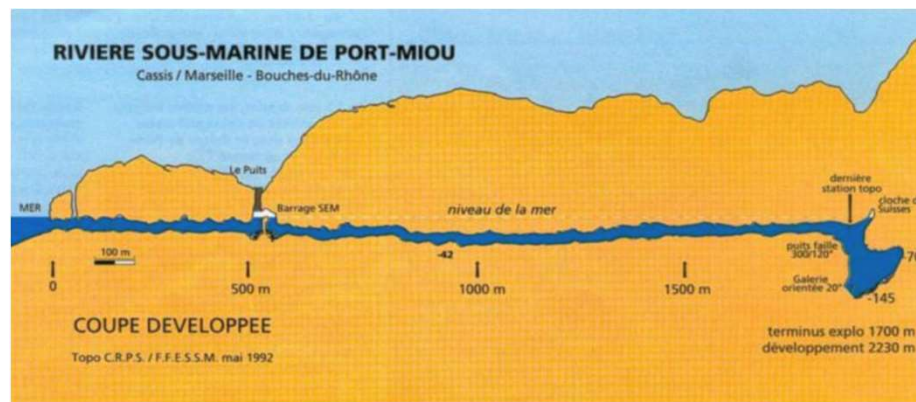


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A VENIR : PORT MIOU, UN SITE PILOTE



BILL STONE AND THE SUNFISH


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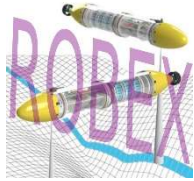
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Exploring Karst with Robots

Exploration Robotics for Confined, Unstructured Subaquatic Environment

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