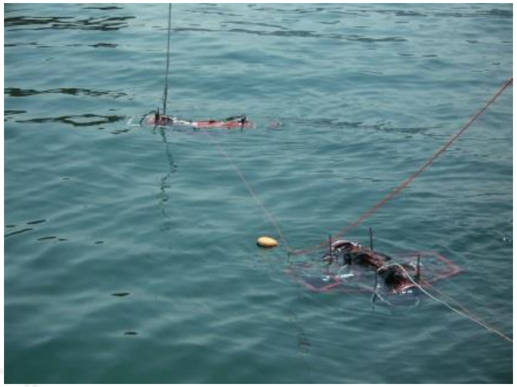
ENSTA Bretagne

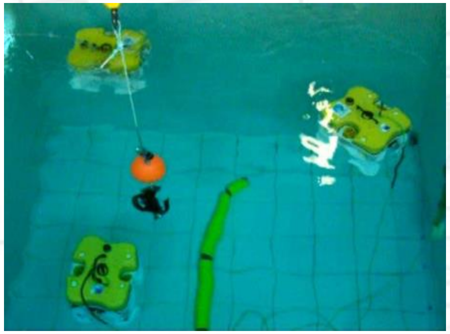

# [ Localization problems in mobile robotics ]

# Introduction

# Localization problems in mobile robotics

- To be able to know what to do, an **autonomous mobile robot** first needs to **know its current state**, especially its position, as well as the state of other potential mobile elements such as other **collaborating robots** around it

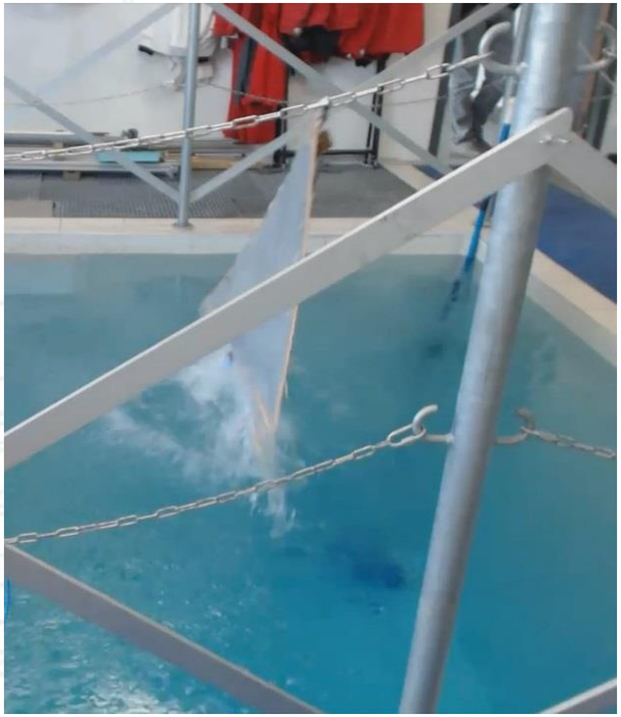




# Localization problems in mobile robotics

- Facts
  - Autonomous robotics rise new and difficult problems
  - There are few demonstrations of cheap autonomous robots able to do survey, cartography, detection and localization tasks, especially in marine and submarine environments

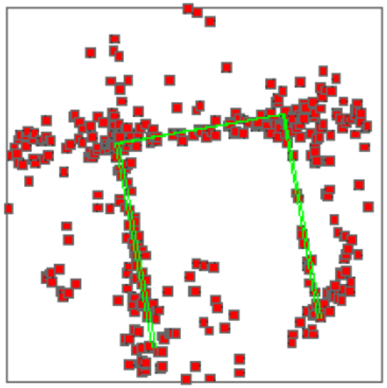
# Localization problems in mobile robotics

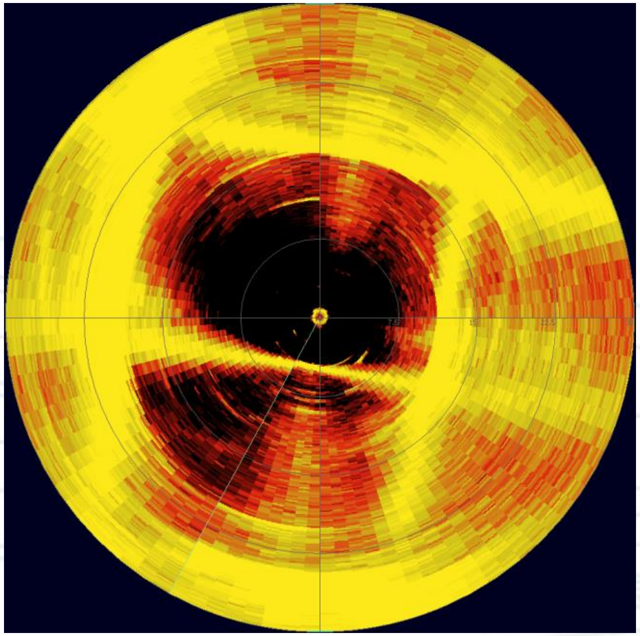
- Technological problems
  - Lack of cheap and lightweight sensors such as acoustic sensors in the submarine field for communication and localization
  - AHRS (Attitude and Heading Reference System) to get an accurate orientation even in case of magnetic disturbances or for long-running missions
  - GPS not available underwater or indoor, multi-domain specificities

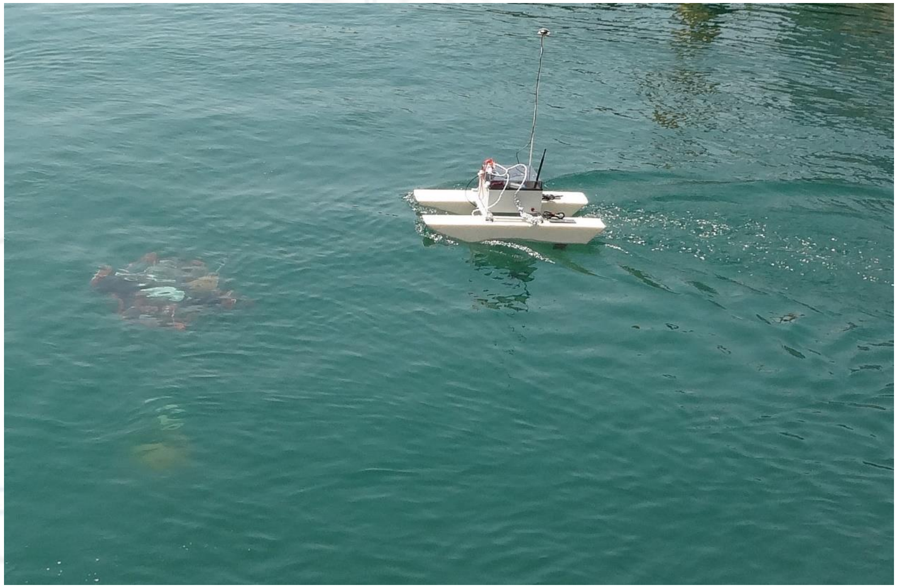


# Localization problems in mobile robotics

- Theoretical problems
  - Non-linear dynamic model of the robots
  - Deal with outliers in measurements
  - Heterogeneous group of robots collaboration to help as known marks for localization
  - Fusing different types of data
  - Representation of uncertainties







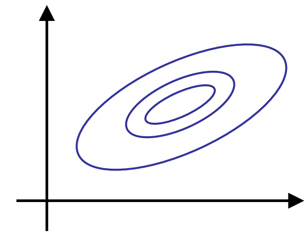
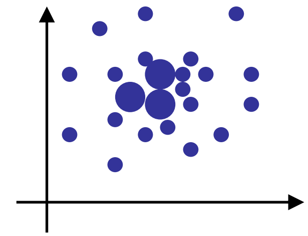
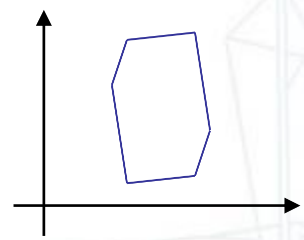
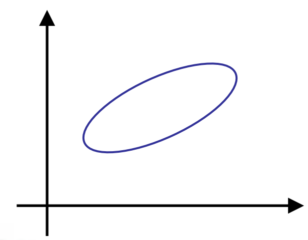
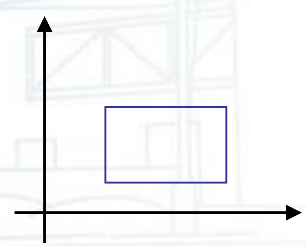
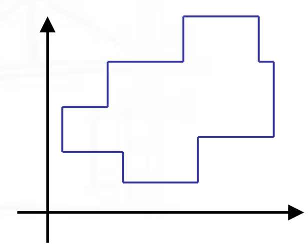
# Interval analysis

# Uncertainties

- Representations of uncertainties
  - Probabilistic methods
    - Gaussian
    - Particles

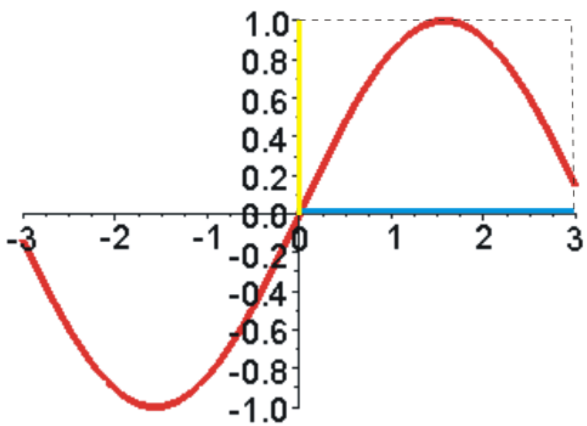
    => Try to get most probable solutions
  - Set-membership methods
    - Zonotopes
    - Ellipsoids
    - Intervals

    => Try to enclose all possible solutions

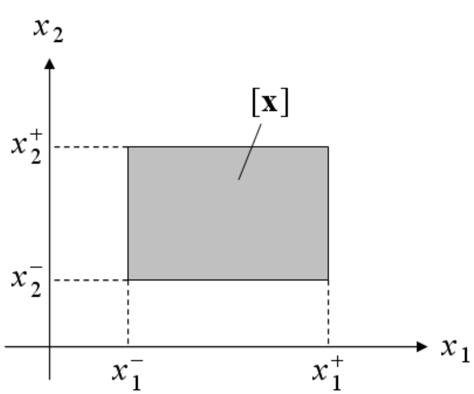
# Interval arithmetic

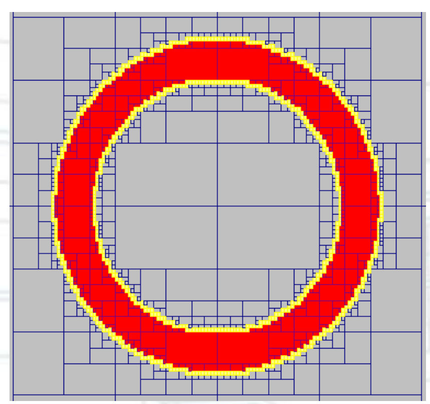
- $[-\infty, 2]$, $[-1, 4]$, $[-\infty, \infty]$ are examples of intervals
- Operations $\diamond \in \{+, -, *, /\}$
  - $[x^-, x^+] \diamond [y^-, y^+] =$ smallest interval containing the set of all possible values for $x \diamond y$
  - $[-1, 4] + [2, 3] = [1, 7]$
  - $[-1, 4] * [2, 3] = [-3, 12]$
  - $[-1, 4]/[2, 3] = [-1/2, 2]$
- Multiplication by a number, intersection, union
  - $2[-1, 4] = [-2, 8]$
  - $[-1, 3] \cap [2, 4] = [2, 3]$
  - $[-1, 2] \sqcup [3, 4] = [-1, 4]$
- Image by a function
  - $\sin([0, \pi]) = [0, 1]$

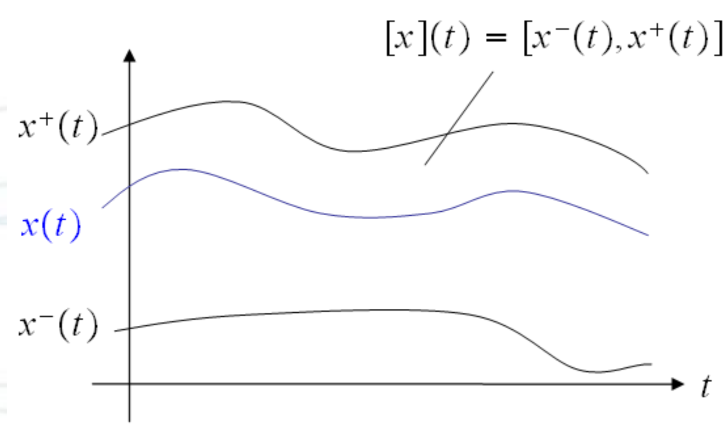


# Interval analysis

- Real intervals can be generalized
  - Vectors intervals (boxes)
  - Sets intervals
  - Functions intervals (tubes)
  - Any set with a lattice structure



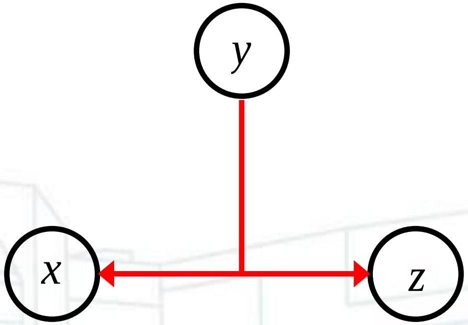


# Interval analysis

- CSP (Constraint Satisfaction Problem)
  - A CSP is made of
    - A set of variables
    - A set of domains enclosing the variables
    - A set of constraints between the variables

# Interval analysis

- Contraction
  - If $z^2 = \exp(x) + y$ and $x \in [1,4]$, $y \in [3.1, 3.2]$, $z \in [4,7]$, then
    - $x = \ln(z^2 - y) \Rightarrow x \in [x] \cap \ln\left([z]^2 - [y]\right) = [2.5, 3.9]$

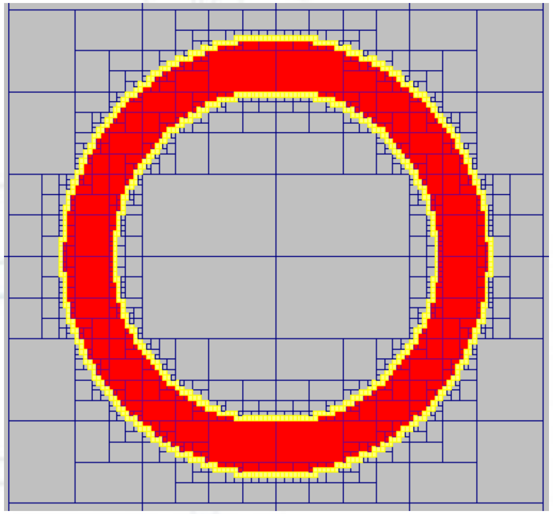


# Interval analysis

- Contraction and propagation
  - We call *contractor* an operator that reduce the domain of variables
  - A *propagation* is a repeated call to contractors
  - We can repeat contractions until a fix point

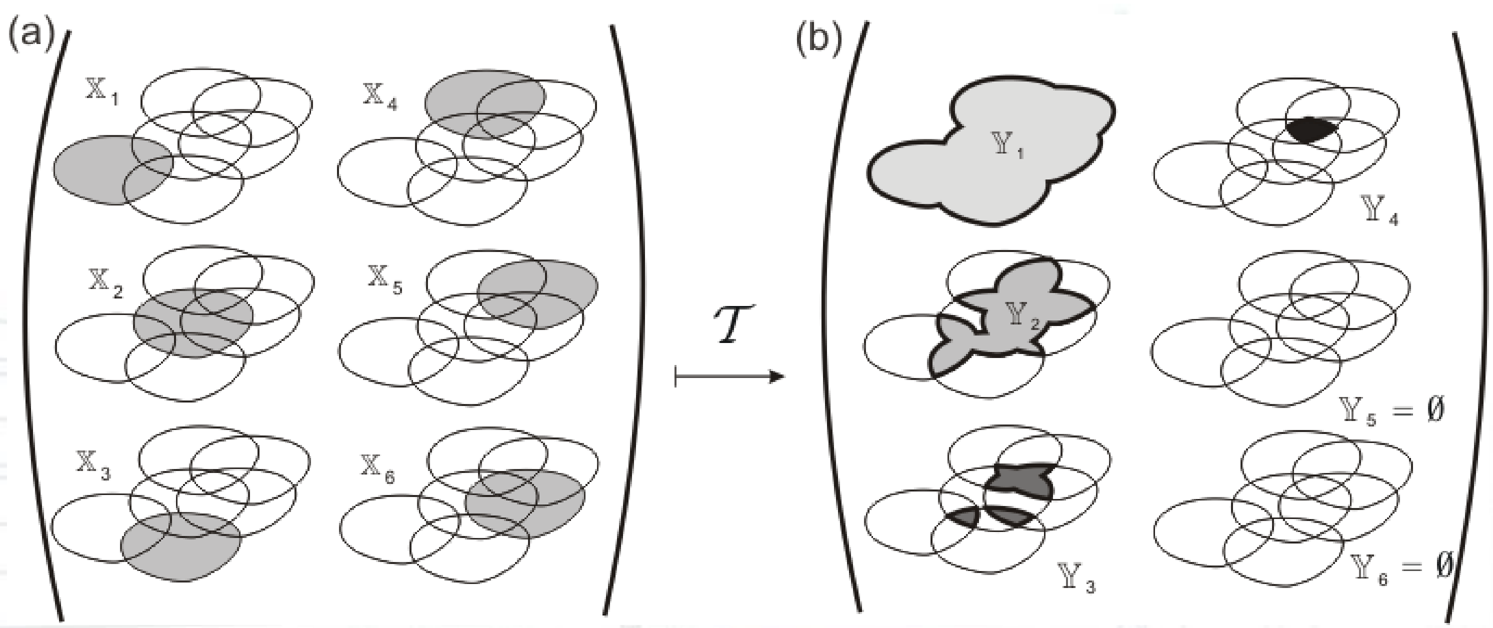
# Interval analysis

- Other techniques such as bisections can also be done



# Interval analysis

- Handling outliers : relaxed intersection (q-intersection)
  - Example of a CSP with 6 constraints : $C_1,C_2,C_3,C_4,C_5,C_6$ where 2 constraints are **inconsistent**




Sets that satisfy only one constraint

Sets that satisfy only a defined number of constraints

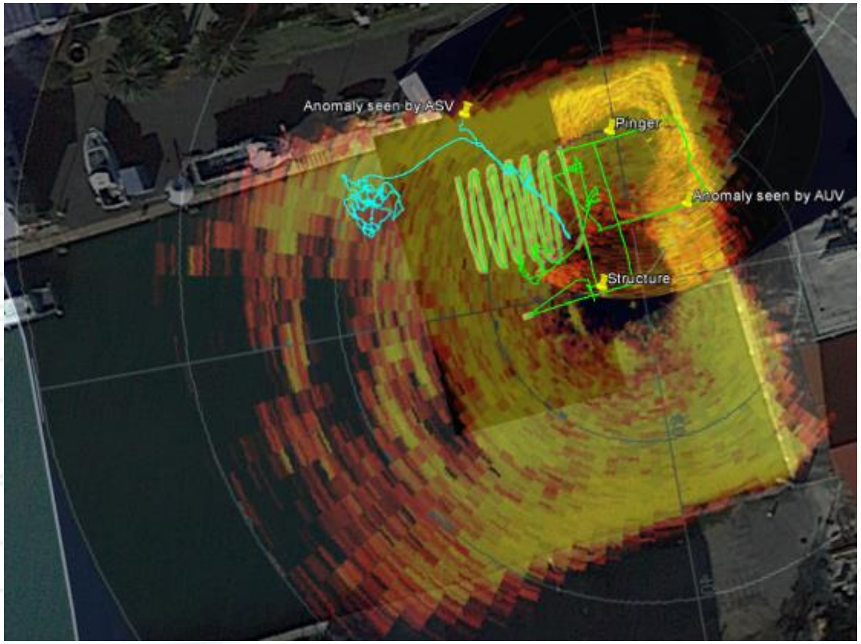
# Interval analysis

- To learn
  - IAMOOC : https://www.ensta-bretagne.fr/jaulin/iamooc.html
  - pyIbex : http://www.ensta-bretagne.fr/desrochers/pyibex
  - EASIBEX-MATLAB : https://github.com/ENSTABretagneRobotics/EASIBEX-MATLAB

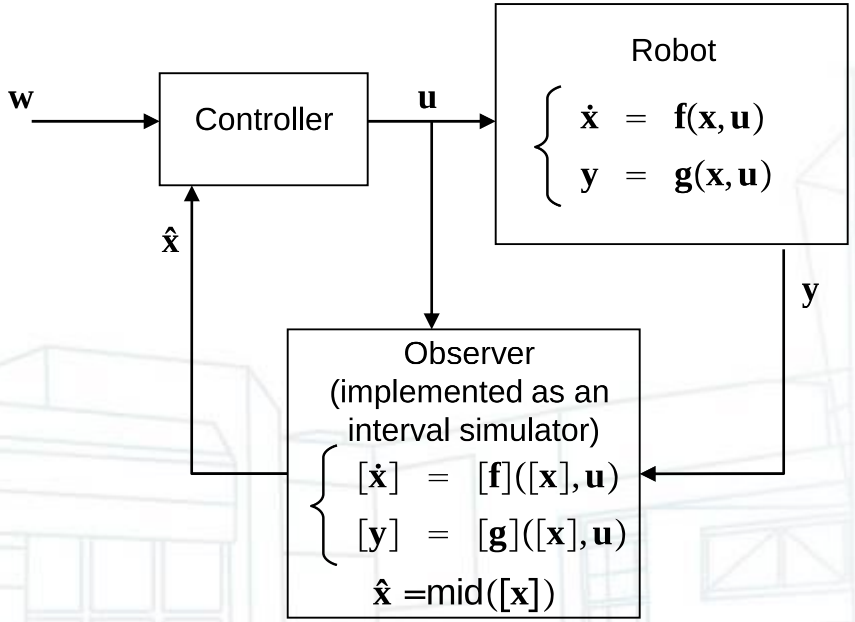
# Examples of different localization scenarios for an AUV

# Localization problems in mobile robotics

- Examples of different localization scenarios for an AUV
  - Dead-reckoning using compass and thrusters inputs or using DVL
  - Position of an ASV and distance using acoustic modems
  - Static sonar localization when inside a basin



# Dead-reckoning



# Dead-reckoning

- Simplified state equations of the AUV using compass and thrusters inputs
  - Need some known position, e.g. using GPS when on surface
  - Need to set coefficients related to the speed of the robot depending on inputs, damping, etc.
  - Possible forward and backward propagation in time using interval analysis

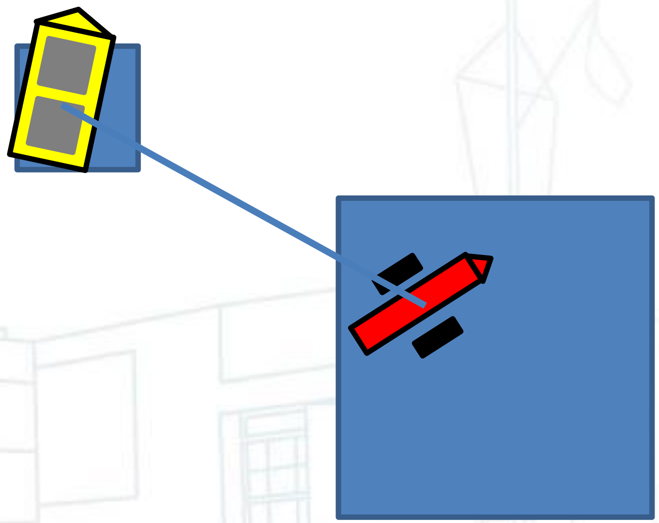
$$\begin{aligned} \dot{x} &= v \cos\theta \\ \dot{y} &= v \sin\theta \\ \dot{\theta} &= u_2 - u_1 \\ \dot{v} &= u_1 + u_2 - v \end{aligned}$$

# Dead-reckoning

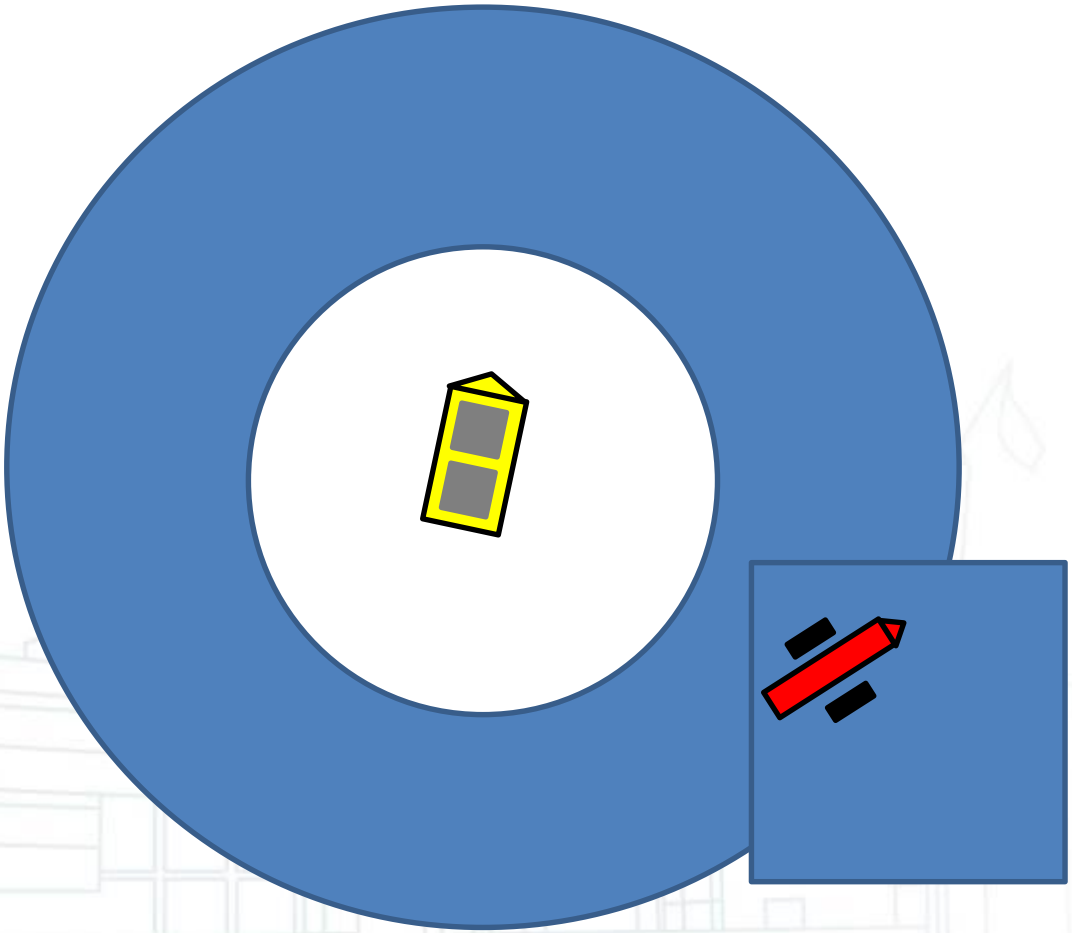
- More general equations if using a DVL

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{pmatrix} = R(\phi, \theta, \psi) \begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix}$$

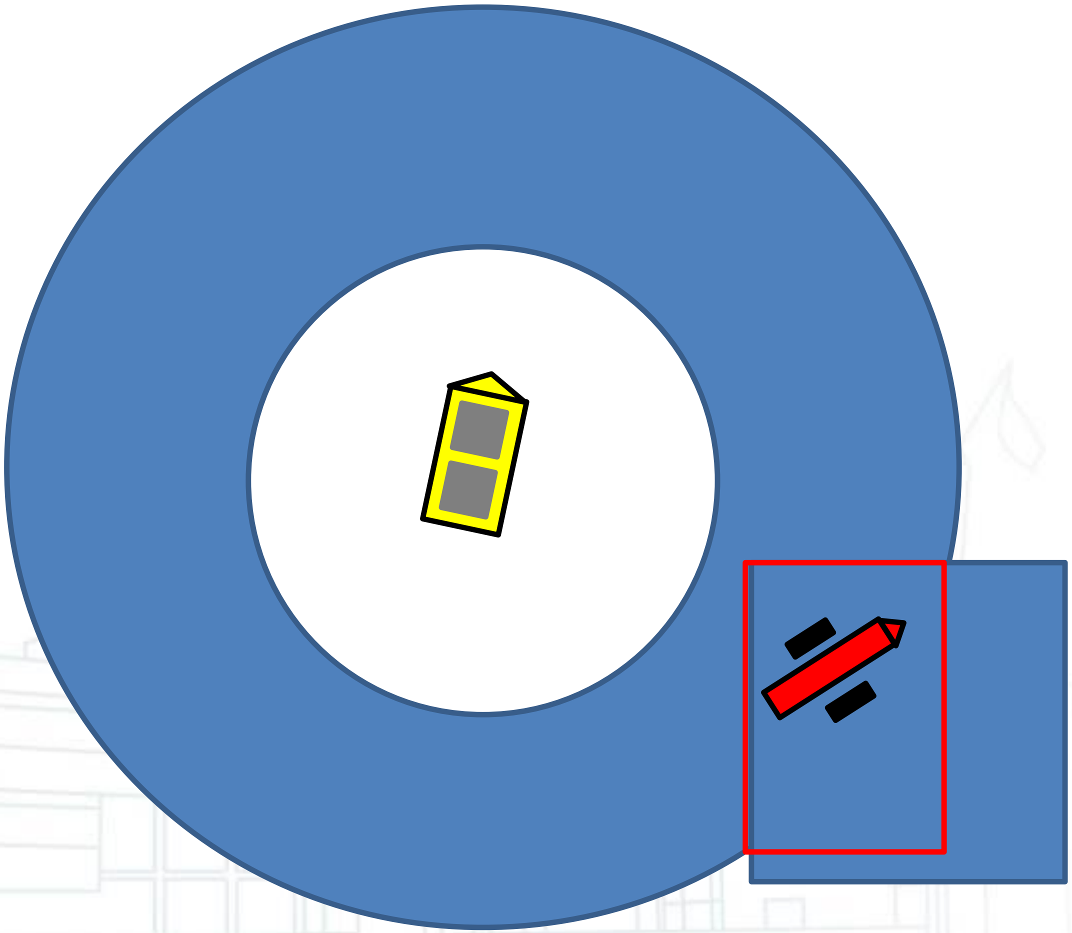
# Collaboration with an ASV



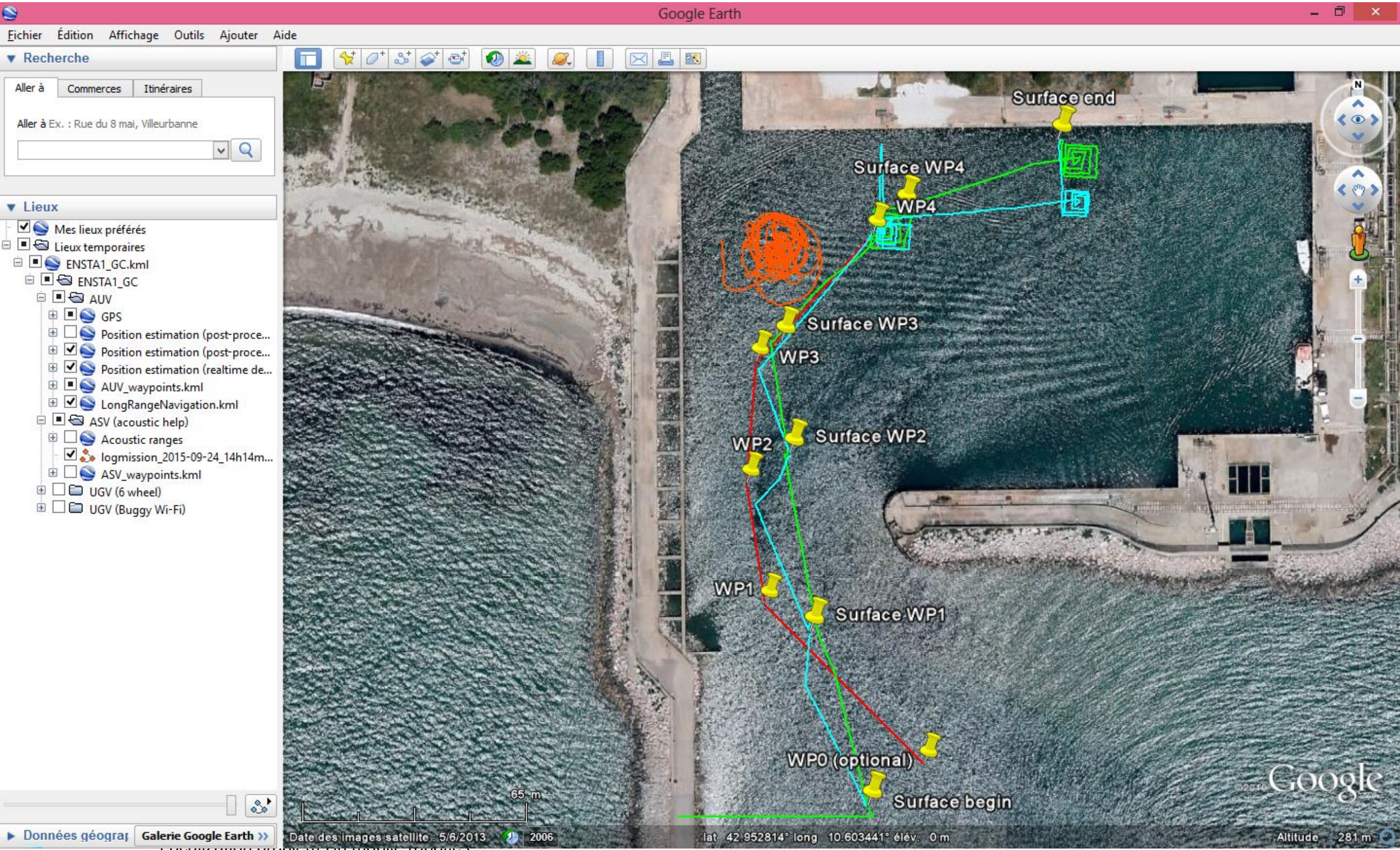
# Collaboration with an ASV



# Collaboration with an ASV

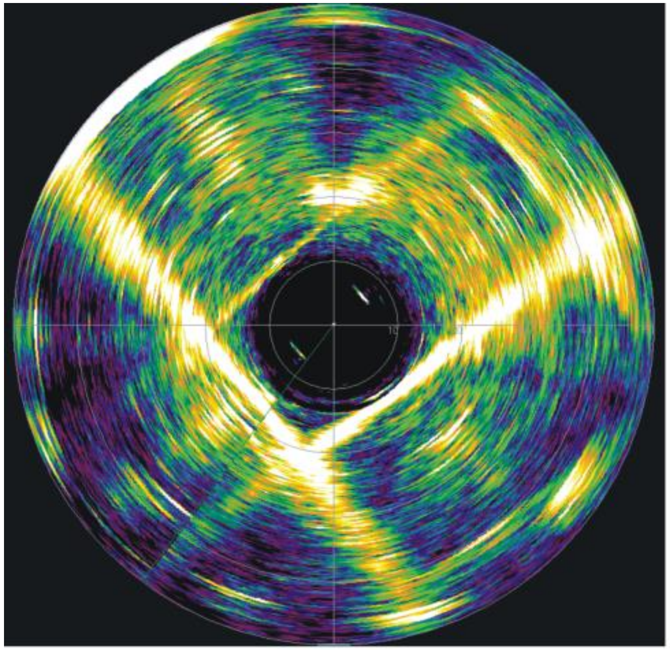


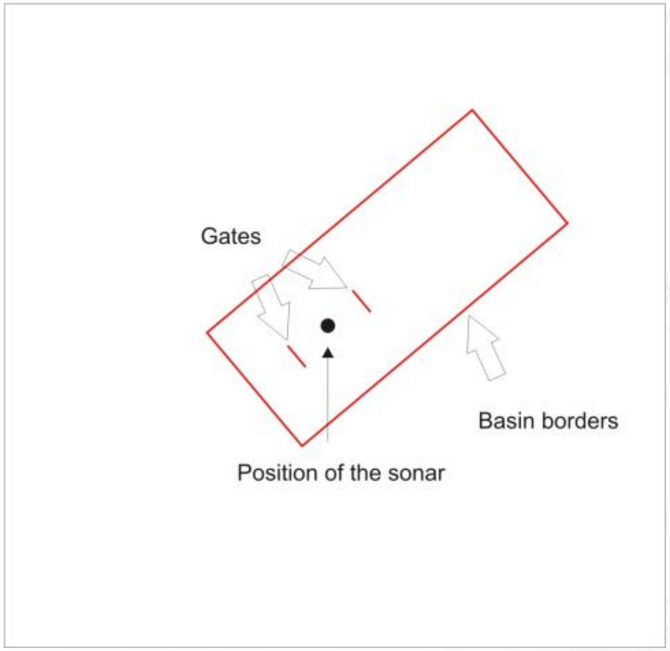
# Collaboration with an ASV

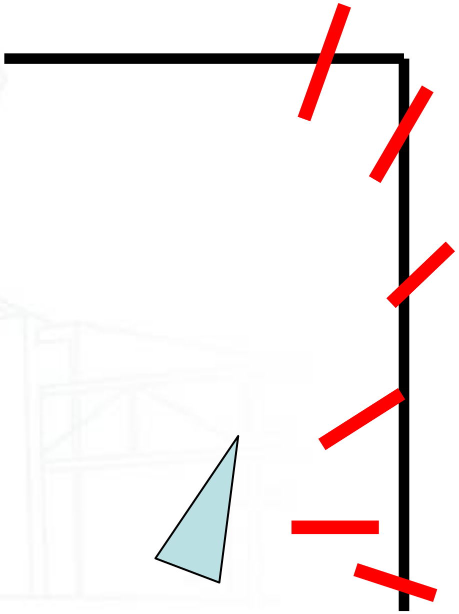


# Static sonar localization

- Sonar data

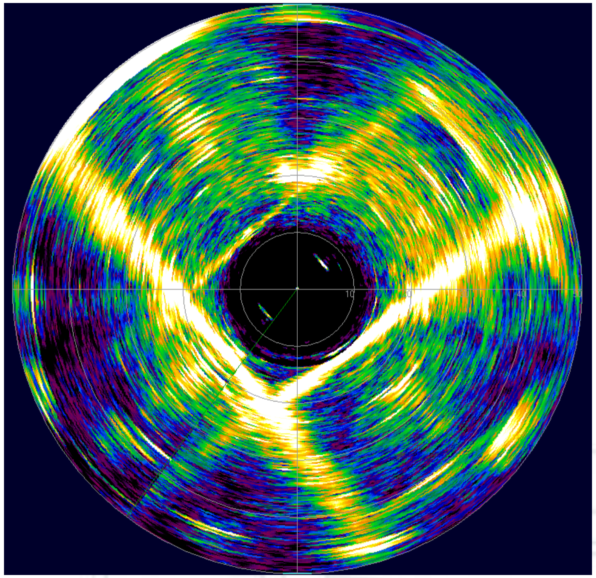
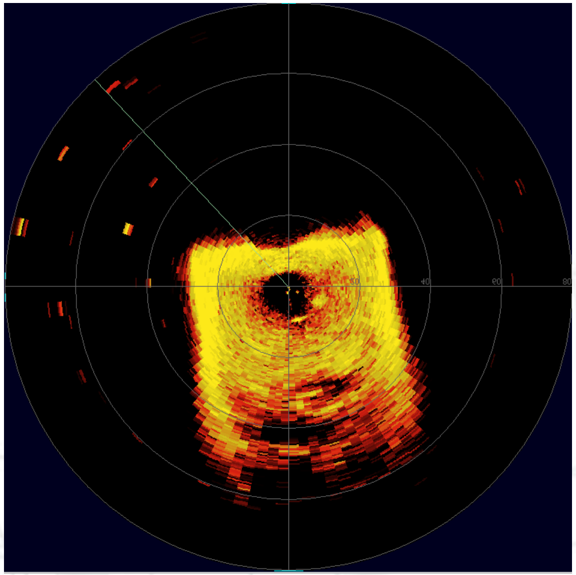
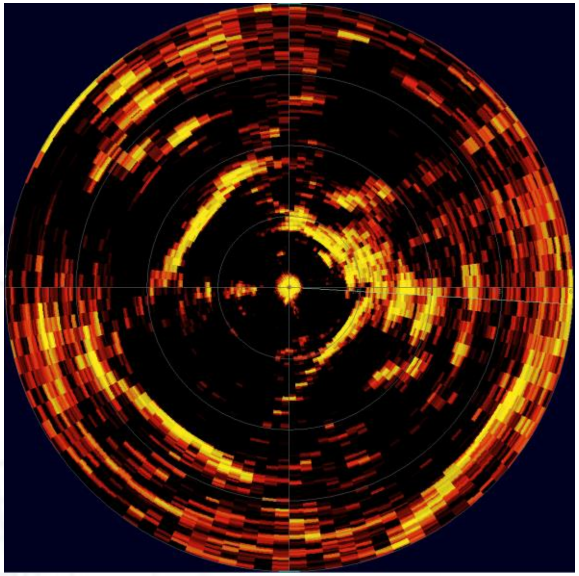




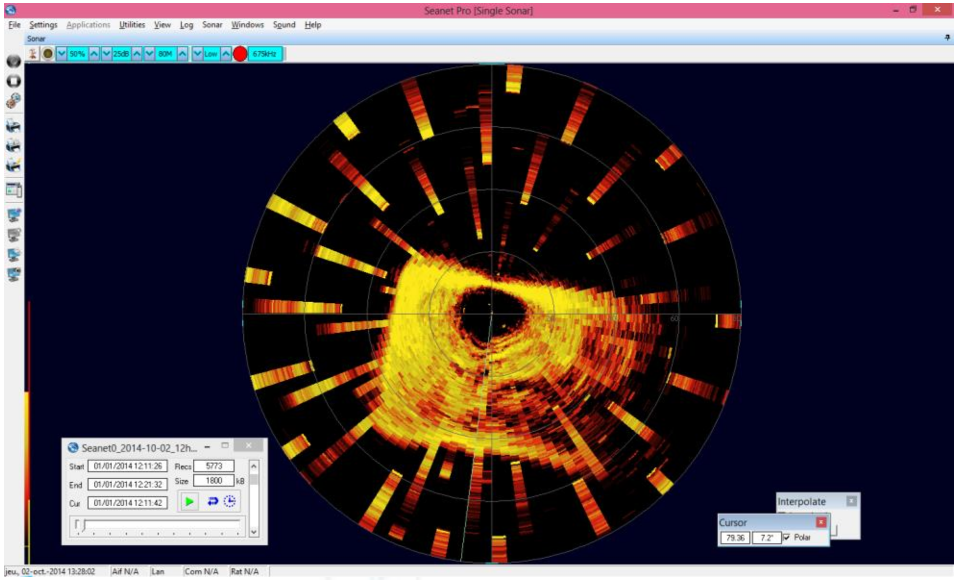
# Static sonar localization

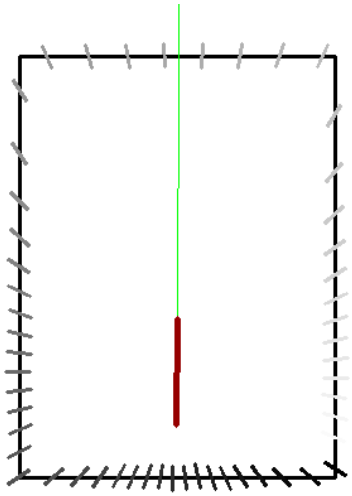
- Sonar data

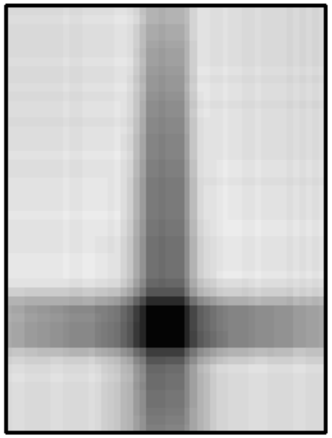




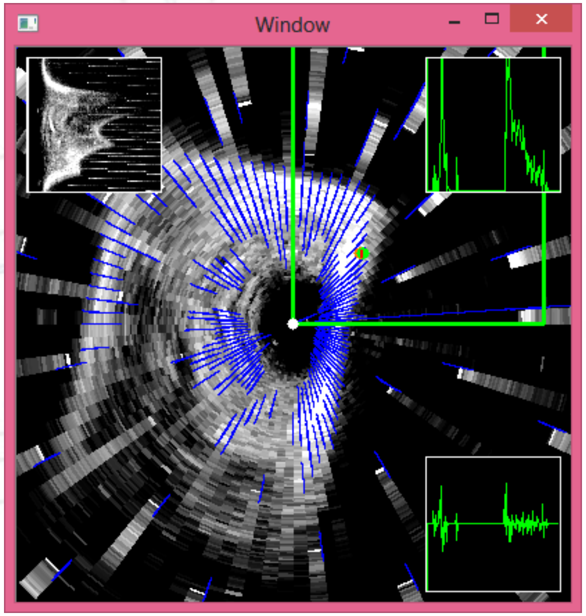
# Static sonar localization

- Context : map of the environment known but outliers expected, good compass and a sonar available
- First problem : where are the walls on the sonar image?
- Second problem : where is the robot w.r.t the walls?

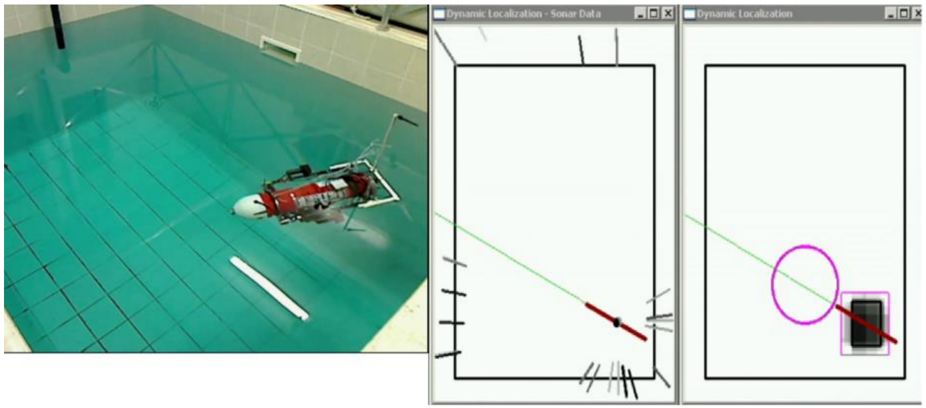


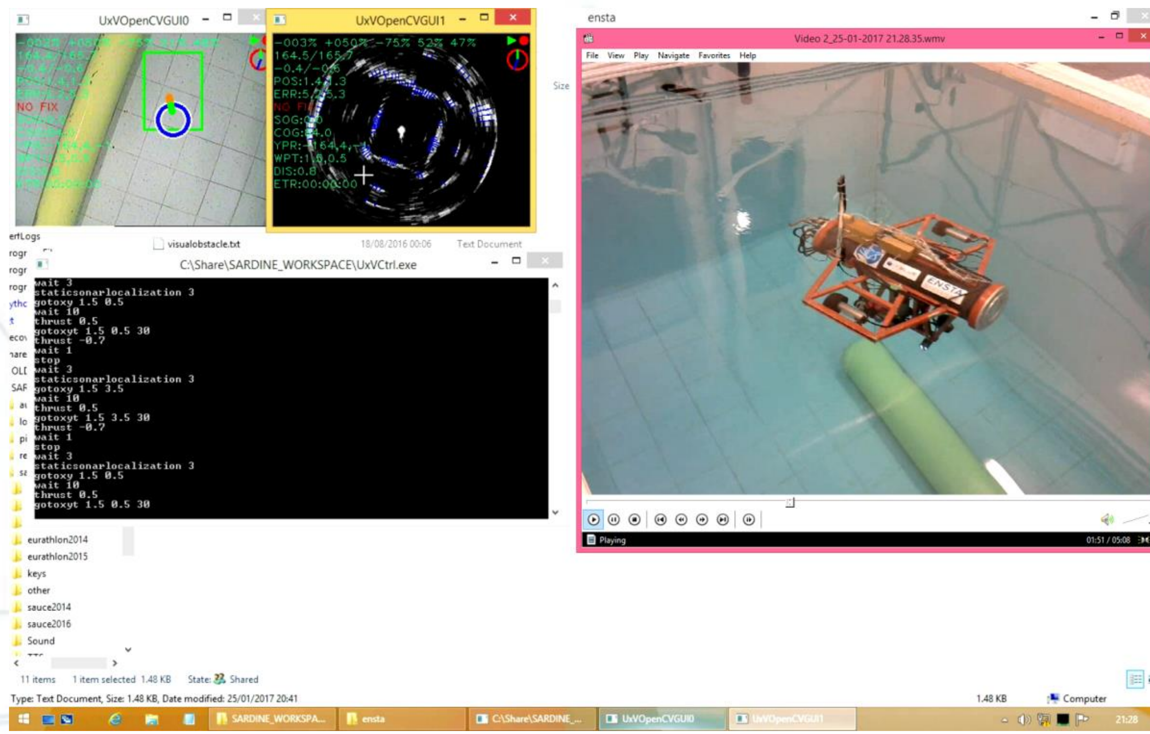





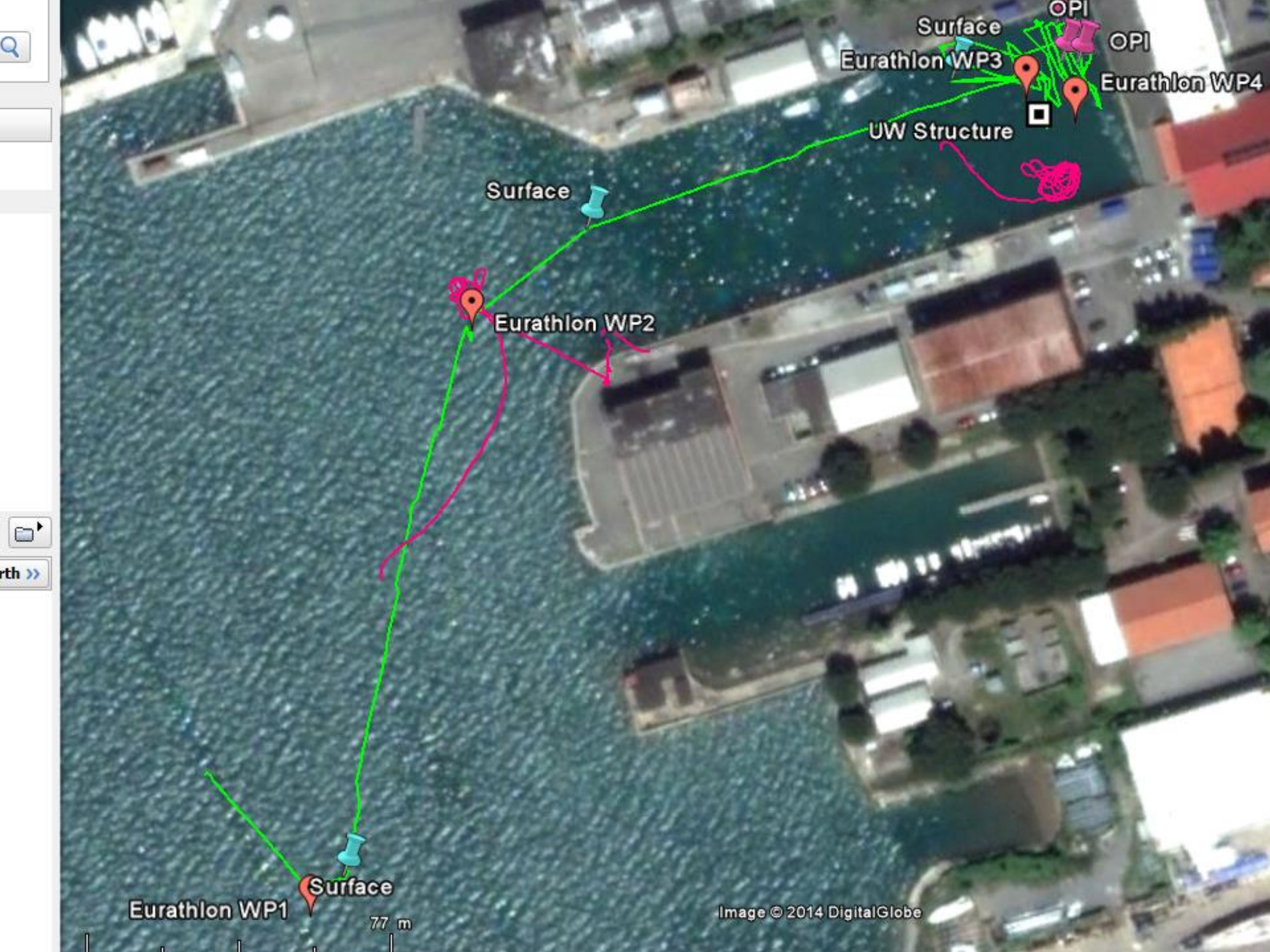


# Static sonar localization



# Combination between dead-reckoning, collaboration with an ASV and static sonar localization


OPI
Surface
OPI
Eurathlon WP3
Eurathlon WP4
UW Structure
Surface
Eurathlon WP2
Surface
Eurathlon WP1
77 m
Image © 2014 DigitalGlobe

# Future work

# Future work

- Dead-reckoning
  - Loops detection
  - Process and fuse with raw IMU data using interval analysis
- Collaboration with ASV
  - Time uncertainties
- Static sonar localization
  - Estimate the heading using sonar data
  - Better classify the different types of outliers
  - Use the 3D of the sonar data