experiences in multiple underwater vehicle coordination based on acoustic communication (constraints)

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Background & Motivation

- Practical swarm scenario
- Reduce cost , reducing ship time mainly
- Offer new ways and new missions with existing fleets
- Design of the squadron is complex and mission dependent
- Evaluation of communications constraints in real world!

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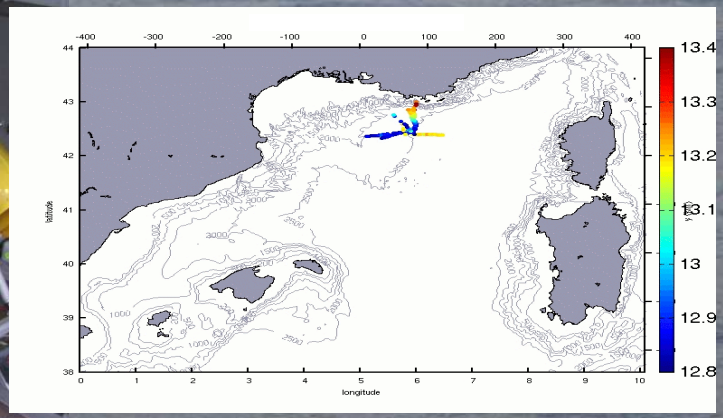

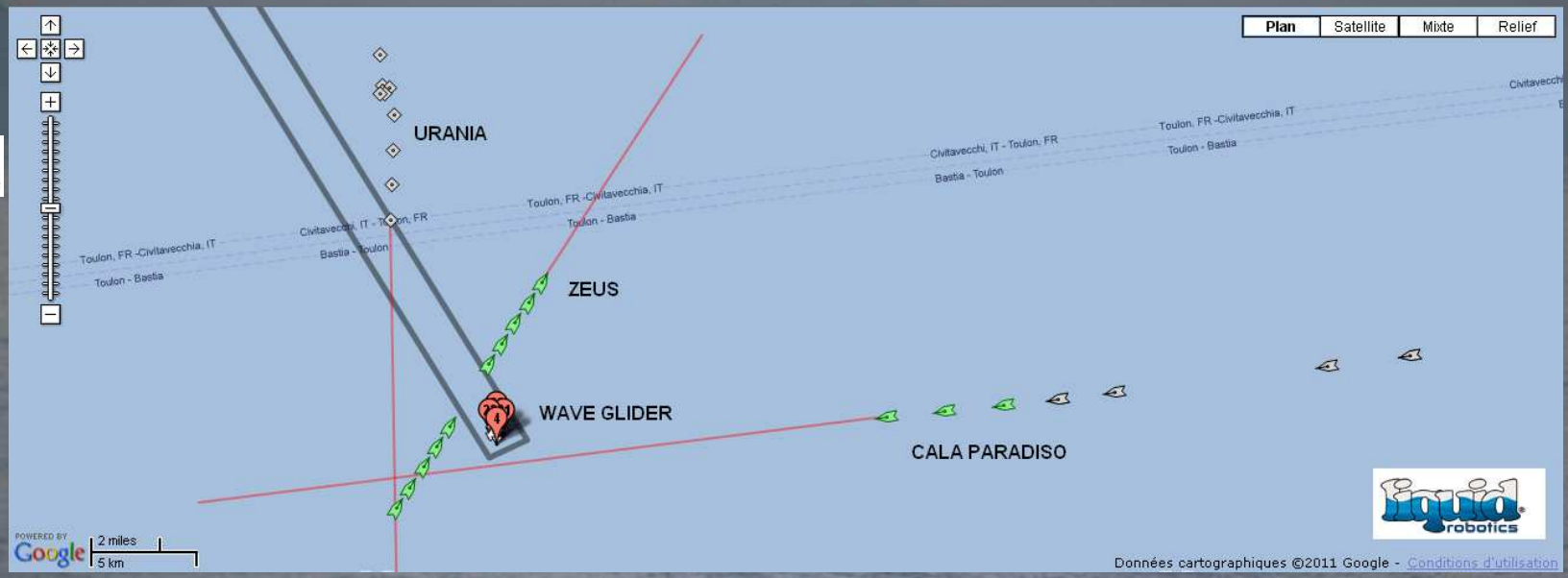

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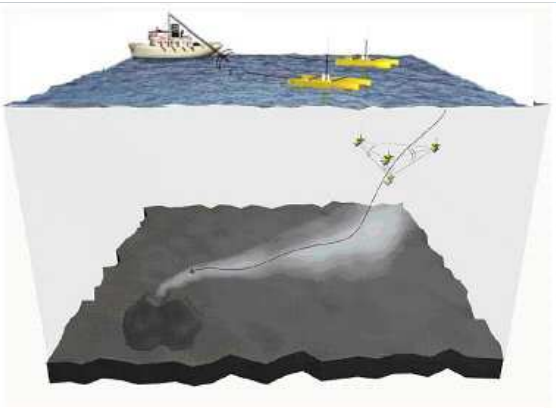
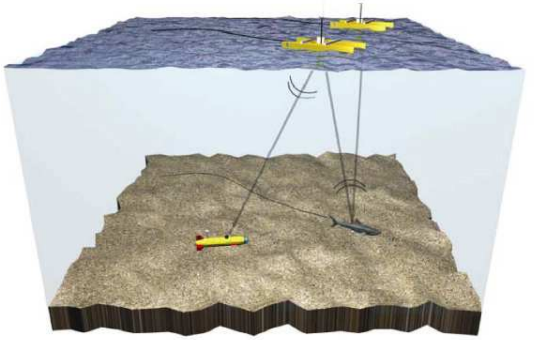
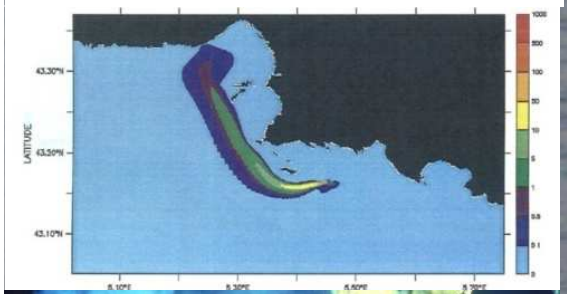
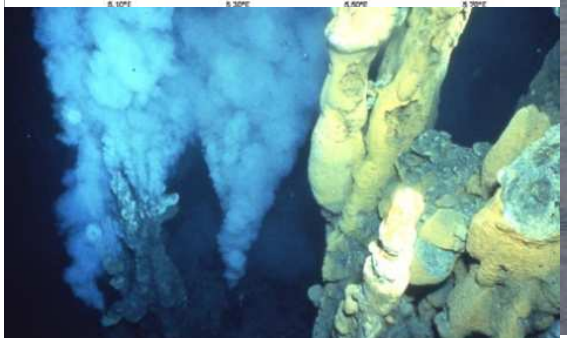
Cooperative and non cooperative Swarms

Comm autonomy FT and reliability : Swarm corner stones





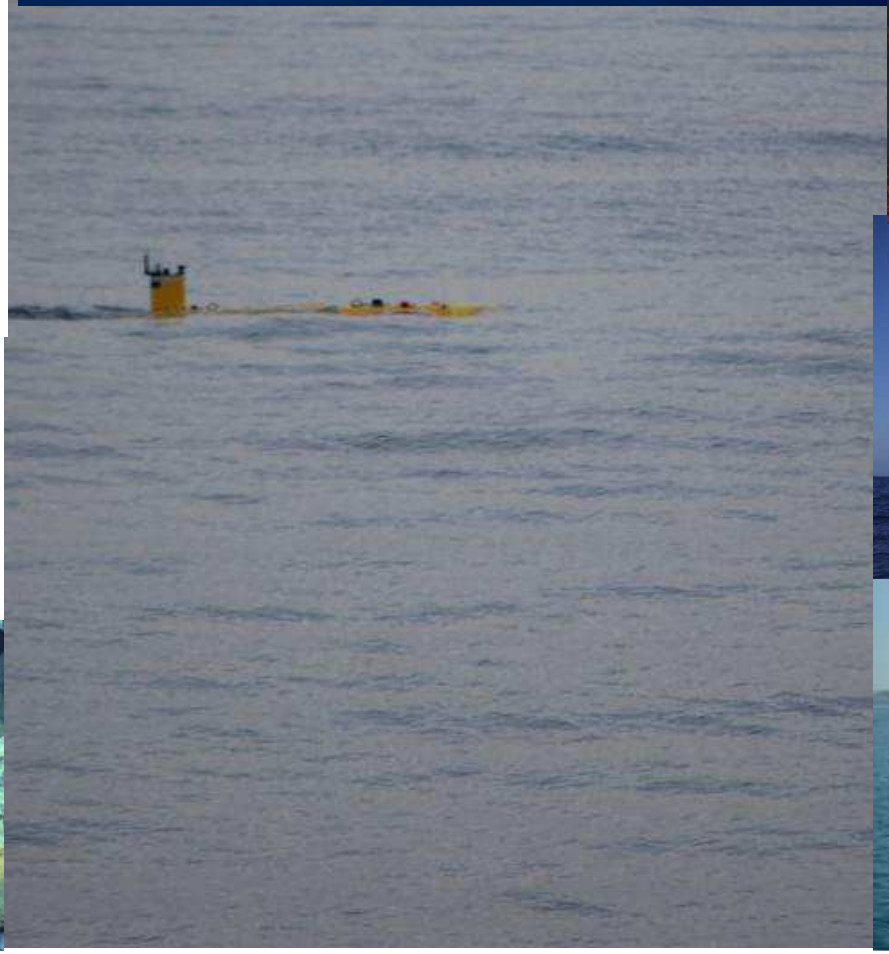




Scenario

AUV-USV Swarms needs ?

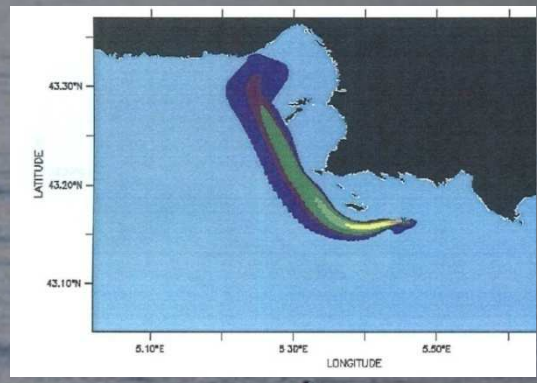
2D,3D,4D survey!

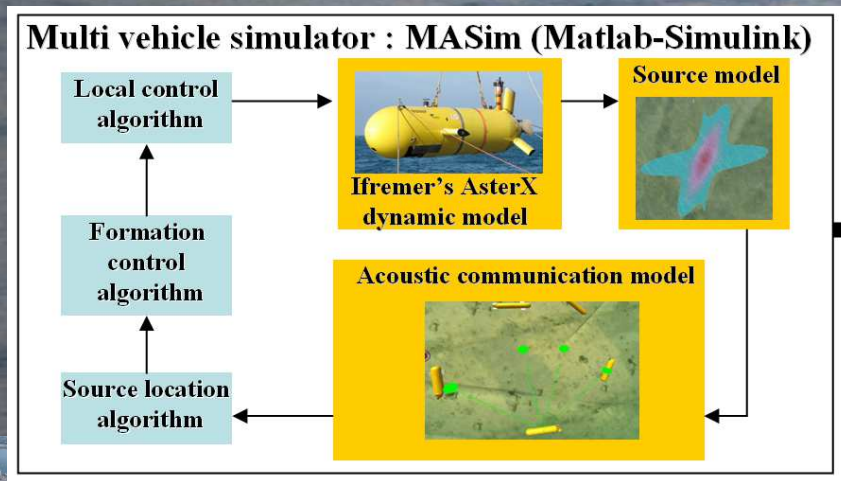


Case Study

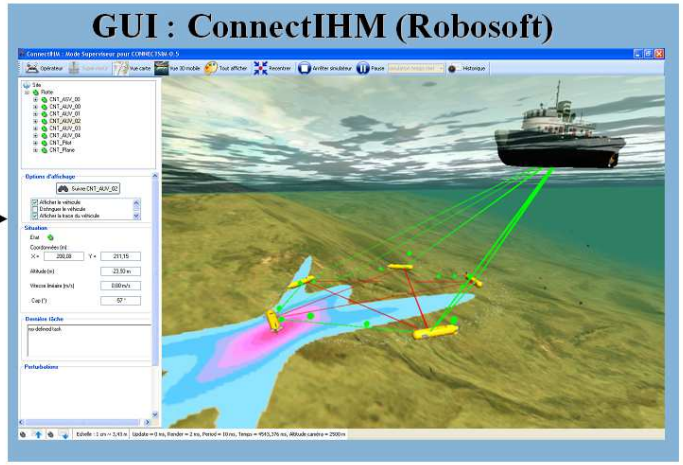
"Source seeking with swarms (SSS)"
Design the swarm with simulator

- **Simulator architecture covers all aspects**
  - Environment model
  - Dynamic vehicle model
  - Vehicle control
  - Formation control
  - Acoustic communication model
  - Search algorithm

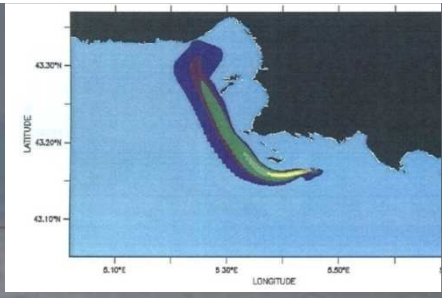




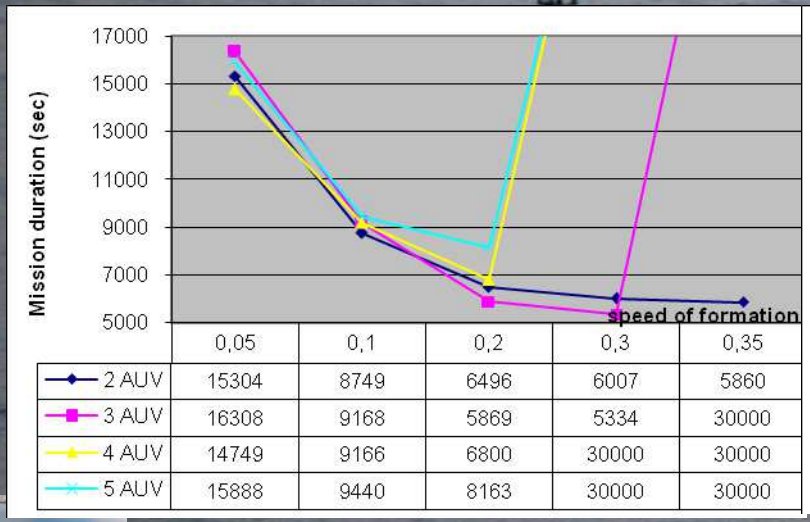
off-line viewing



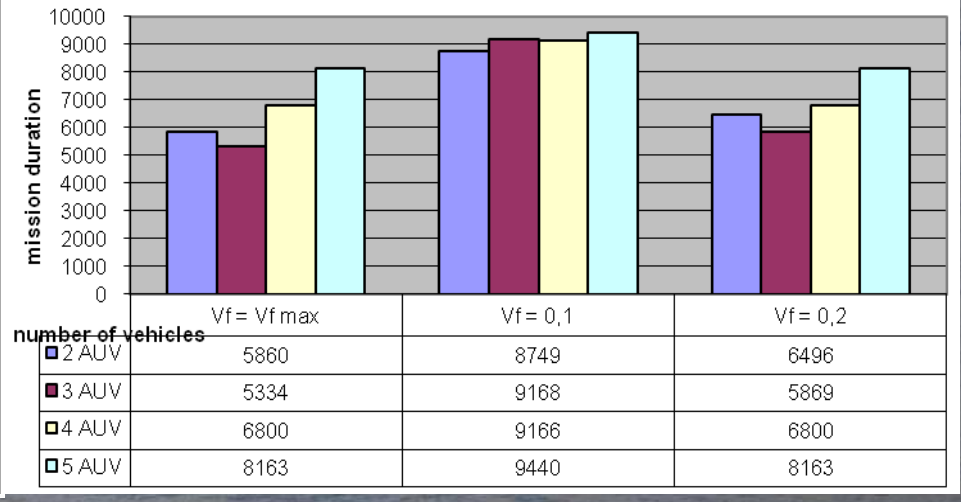
Swarm design: build the team from simulation SSS



- Formation Control : Swarm design vs mission duration
- Formation holds up to 50% of communication packet loss
- Large fleet –> Long communication cycle, because of spectral occupation real limitations
- ->Large fleet –> Low formation velocity
- Circle formation allows move to any direction

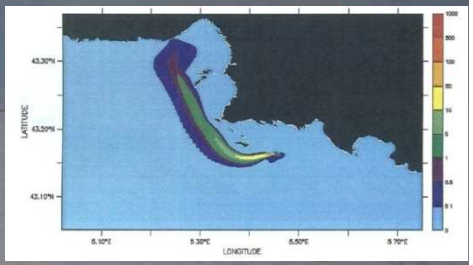


	0,05	0,1	0,2	0,3	0,35
2 AUV	15304	8749	6496	6007	5860
3 AUV	16308	9168	5869	5334	30000
4 AUV	14749	9166	6800	30000	30000
5 AUV	15888	9440	8163	30000	30000



	Vf = Vf max	Vf = 0,1	Vf = 0,2
2 AUV	5860	8749	6496
3 AUV	5334	9168	5869
4 AUV	6800	9166	6800
5 AUV	8163	9440	8163

Some results
SSS



- Gradient Search

- Circle radius : gradient estimate vs. formation velocity
- Gradient estimate : spatial distribution vs. exchanged information

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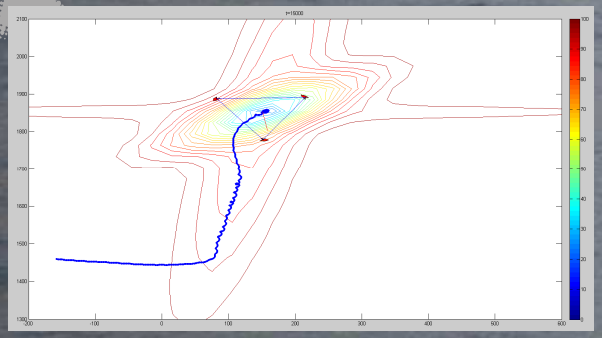
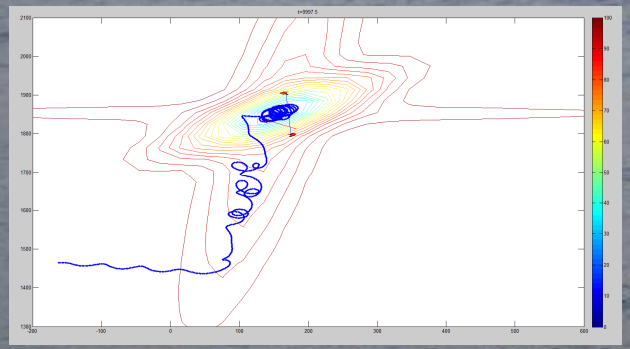
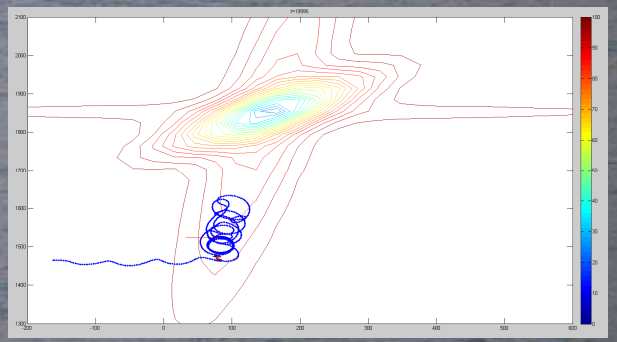
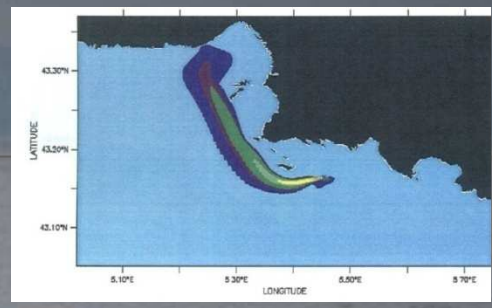






From simulation to @ sea validation



- Vehicle and communication model
- Models verified by sea trials
- Severe conditions as test case

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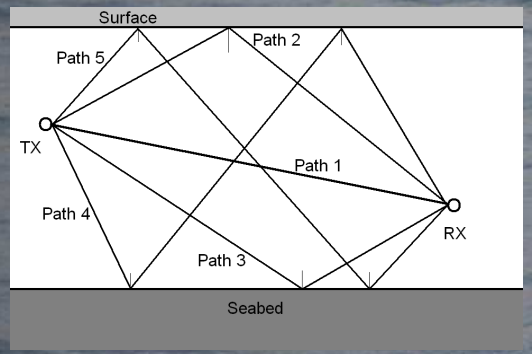
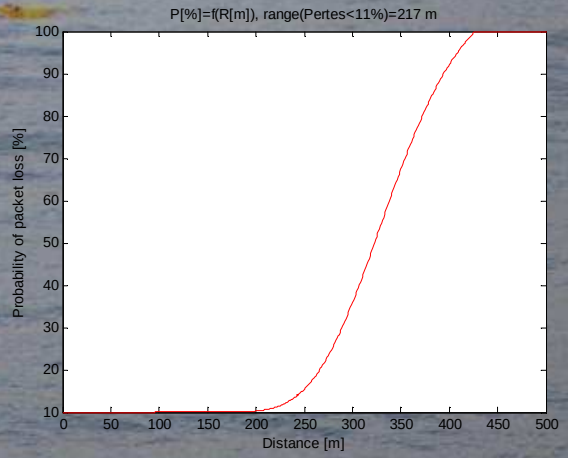




Probability of packet loss for DI=2, SL=173 db ref 1µPa at 1m, Nis=90 dbV/sqrt(Hz) at f, BW=239.8Hz, f=10kHz, gamma1=0.246, Kb=60 bits,k=2

Communication : Sea trials Objectives

« qualitative Tests with two-way acoustic communication between two moving AUVs »

- **Practical outcomes for the realised tests**

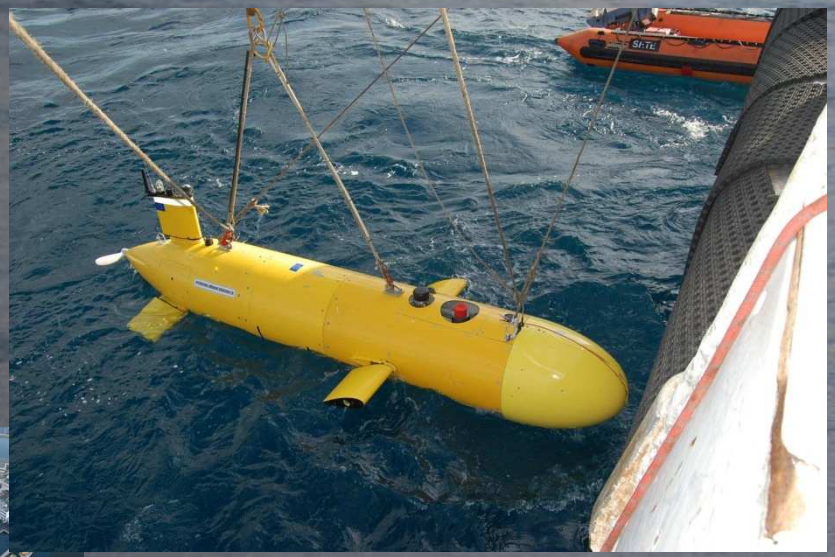
A better understanding of:

1. Integration of DSPCOMM modem on AUVs
2. Acoustic bandwith in realistic conditions
3. Data compression and bandwith optimisation
4. Range measurement
5. Medium Access Control
6. Acoustic networking

Requirements: the AUVs

VORTEX AUV

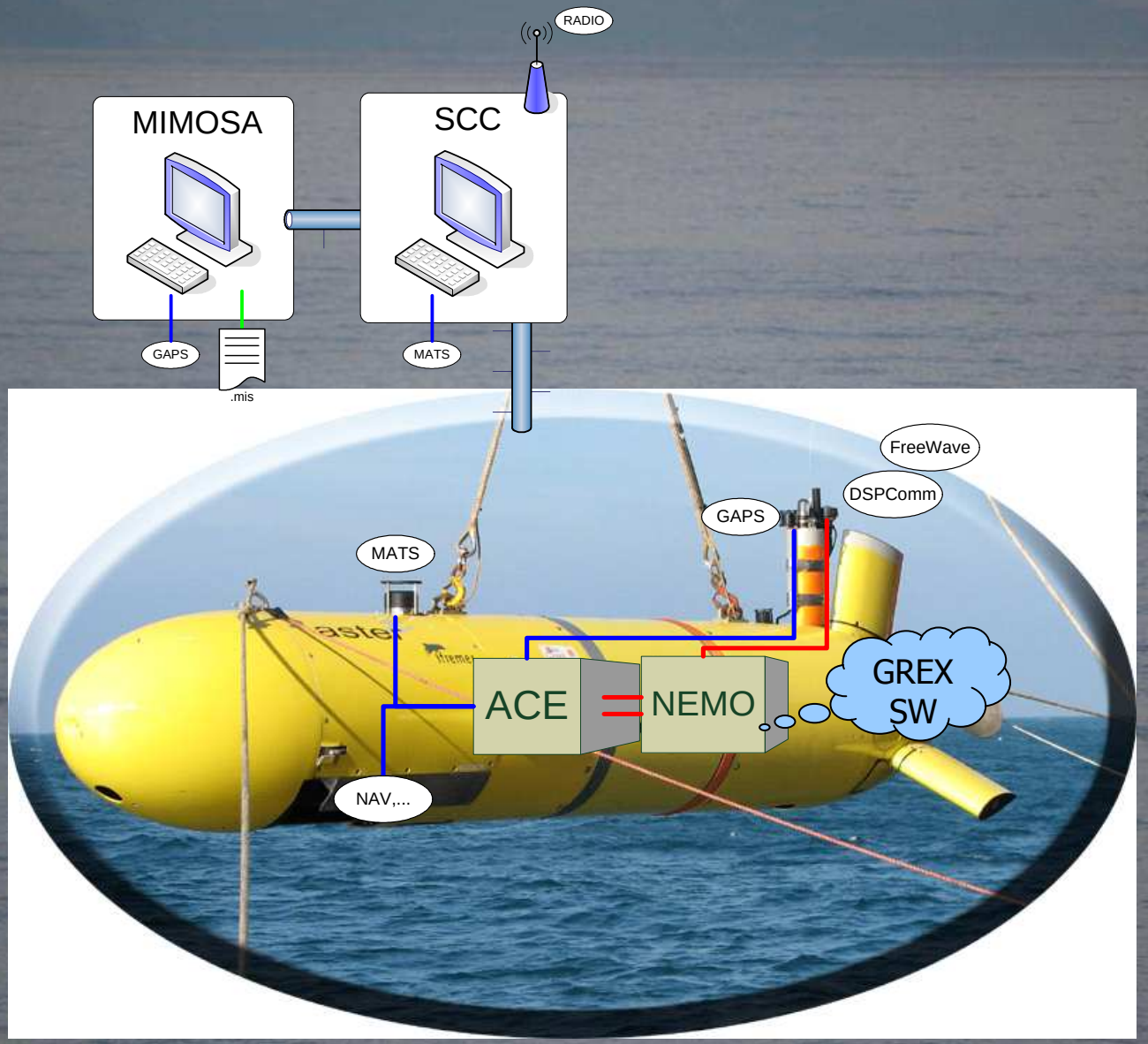
- Hover capable AUV
- 50m max depth,
- 0.7 m/s max speed
- 4 degrees of freedom
- Radio, WiLan and acoustic communication
- Simple dead reckoning NAV (DVL, compass, depth, altitude)
- MIMOSA mission compatible



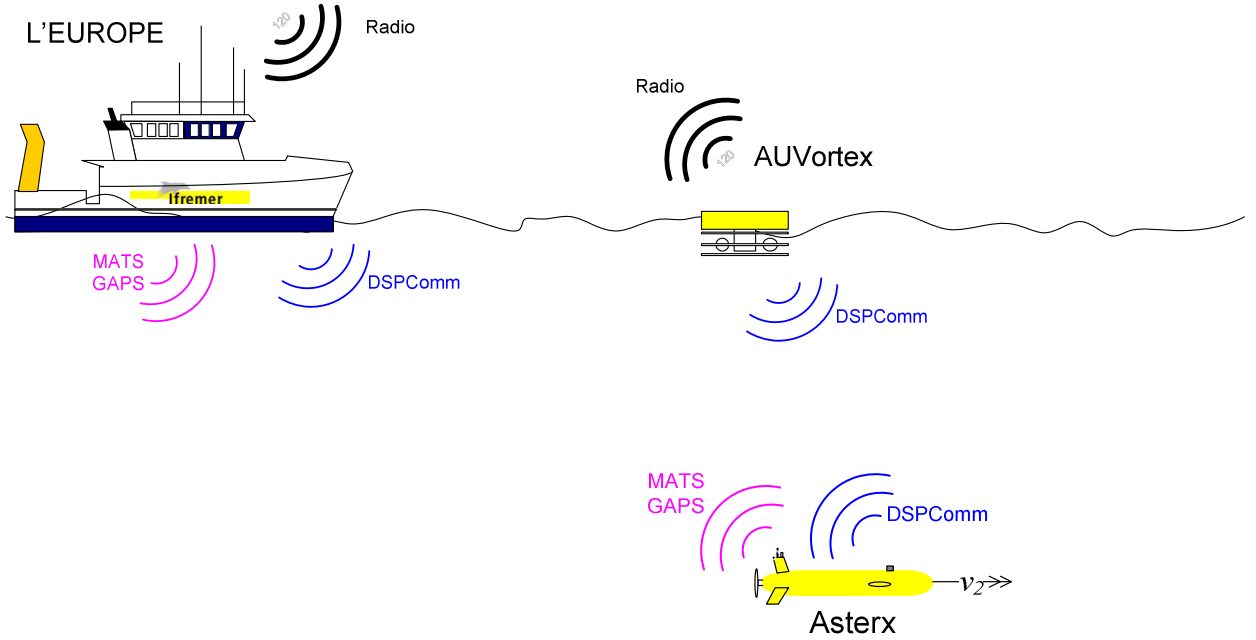
Asterx AUV

- Survey type operational AUV
- 3000m max depth,
- 3.0 m/s max speed
- Radio, proprietor acoustic communication and DSPComm
- INS based NAV + USBL

Sea Trials Asterx architecture



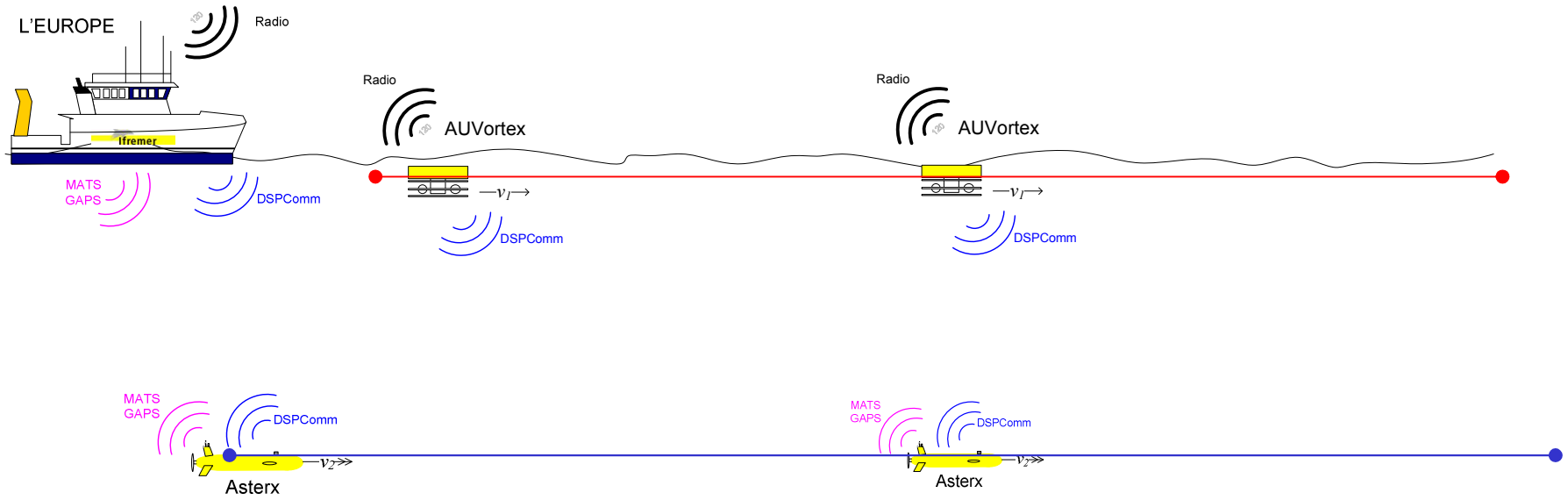
Requirements: Scenario 0



Features:

- Vortex is in DP at surface
- Asterx is at approx 60m depth on a closed preplanned mission path
- Vehicles exchange data packets on acoustic channel (TDMA)
- Exchanged data is simply logged on both vehicles

Requirements: Scenario 1a and 1b

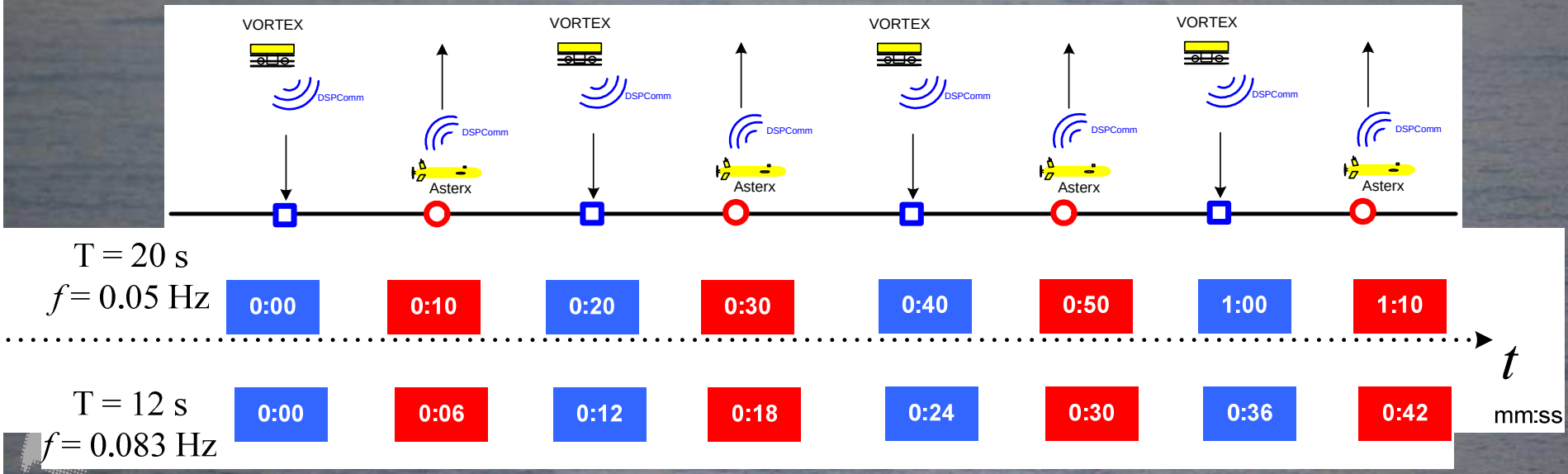


Features:

- Both vehicles navigate on predefined paths
- Top down data is used to compute relative distance between vehicles
- On exceeding distance threshold, Asterx starts wait circle (1a and 1b) and issues meeting point coordinates (1b)
- On successful top-down and bottom-up communication exchange vehicles continue their preplanned trajectories (1b)

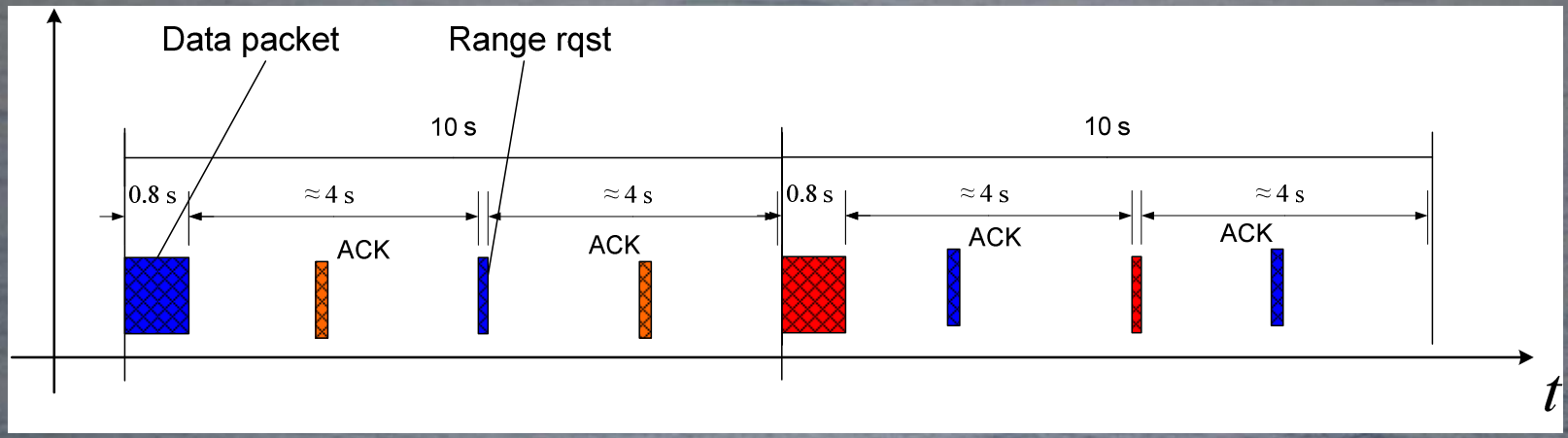
Requirements: Communication strategy for Media Access

- **Time division multiple access** (TDMA) : channel access method for shared medium networks. It allows several users to share the same frequency channel by dividing the signal into different time slots



- Both vehicles exchange same data packets (i.e. same length)
- Data Tx occurs at set interval defined to avoid collisions
- No retransmissions
- Communication period depends on acoustic modem own *TIMEOUT* parameter, data packet length and use of range measurement

Requirements: Communication strategy for Medium Access



- Data packet: VehicleNavData structure (8 doubles = 64 bytes) + 2 bytes
- After compression : 18 bytes
- ATO on current DSPComm modem is about 4 seconds
- ATO applies to both data sends and range requests

Results: some statistics

Whole Day Testing

	IX TX	IX RX	Success Rate
nov-10	237	43	18.14345992
nov-12	596	116	19.46308725
nov-13	306	206	67.32026144
nov-14	631	186	29.4770206

Whole Day Testing

	VX TX	VX RX	Success Rate
nov-10	237	29	12.23628692
nov-12	546	0	0
nov-13	307	0	0
nov-14	629	271	43.08426073

WaitOnDistance summary

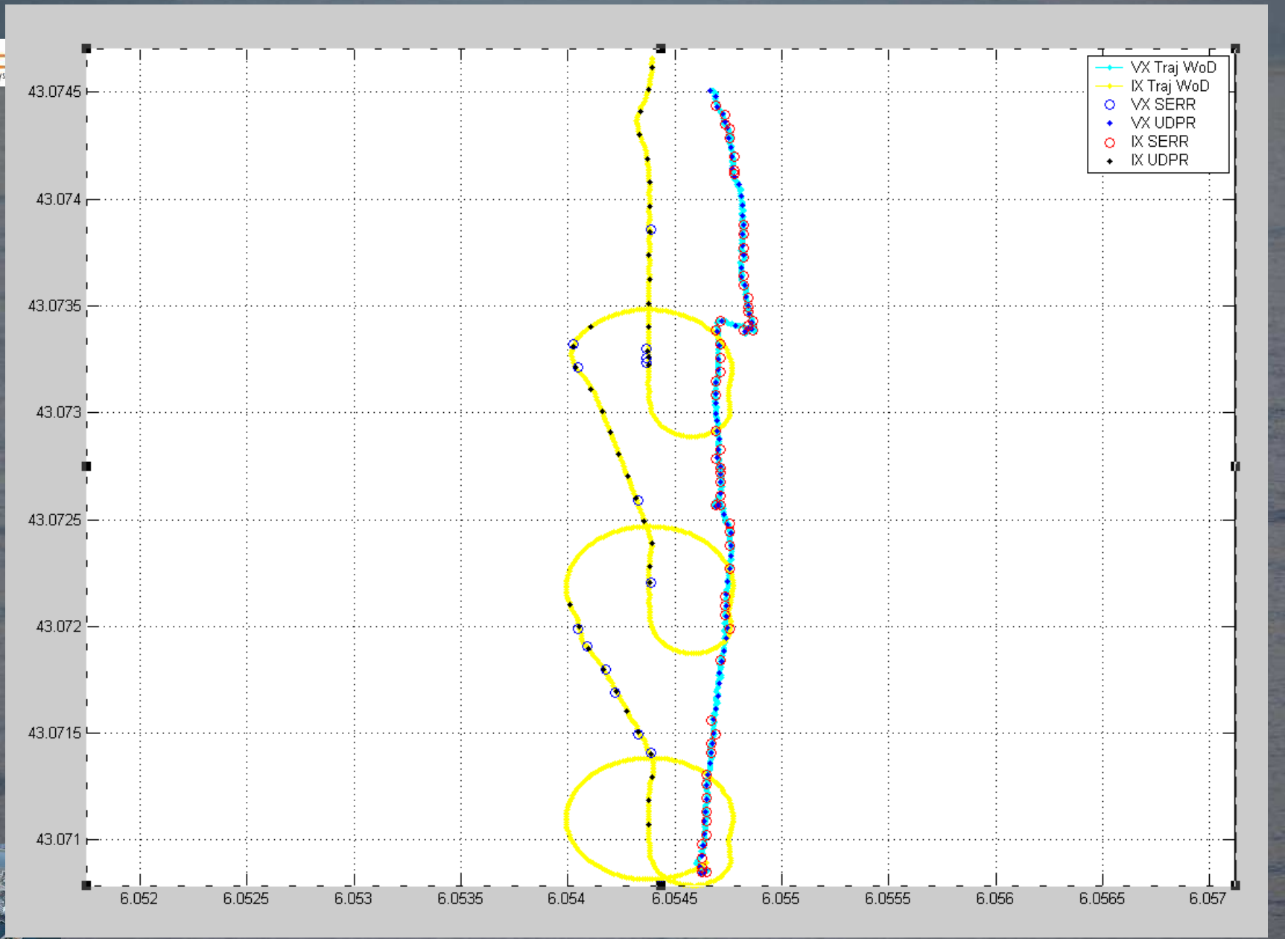
	Wod IX TX	WoD IX RX	Success Rate
nov-10	0	0	0
nov-12	132	71	53.78787879
nov-13	75	55	73.33333333
nov-14	87	61	70.11494253

WaitOnDistance summary

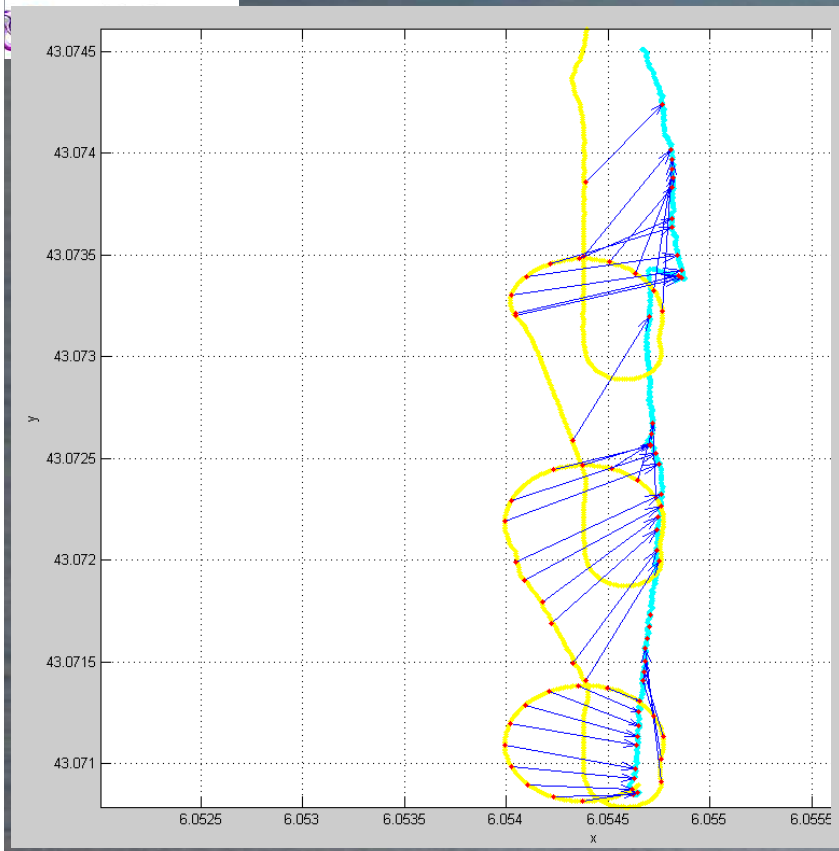
	WoD VX TX	WoD VX RX	Success Rate
nov-10	0	0	0
nov-12	132	0	0
nov-13	75	0	0
nov-14	86	43	50

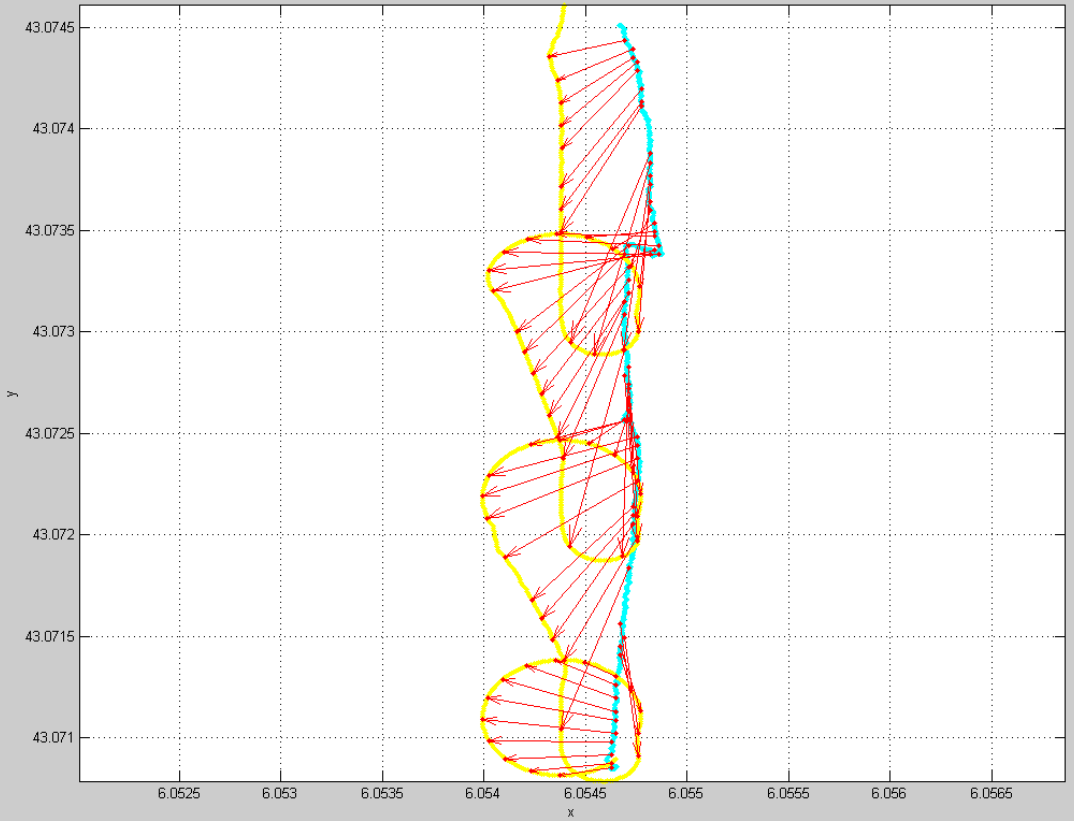
note : TX == UDP_R on the acoustic Handler
RX == SER_R on the Acoustic Handler

Results


VX Traj WoD
IX Traj WoD
VX SERR
VX UDPR
IX SERR
IX UDPR
43.0745
43.074
43.0735
43.073
43.0725
43.072
43.0715
43.071
6.052
6.0525
6.053
6.0535
6.054
6.0545
6.055
6.0555
6.056
6.0565
6.057

Results





Bottom up successful communication
(Asterx to Vortex)

Top down successful communication
(Vortex to Asterx)

Results summary

1. Valuable experience made on two-way acoustic communication between AUVs

2. Identified issues with power supply to modems

3. Identified other issues with modems for upgrade design

4. Valuable experience on TDMA

5. Data was successfully exchanged between vehicles and used for coordination

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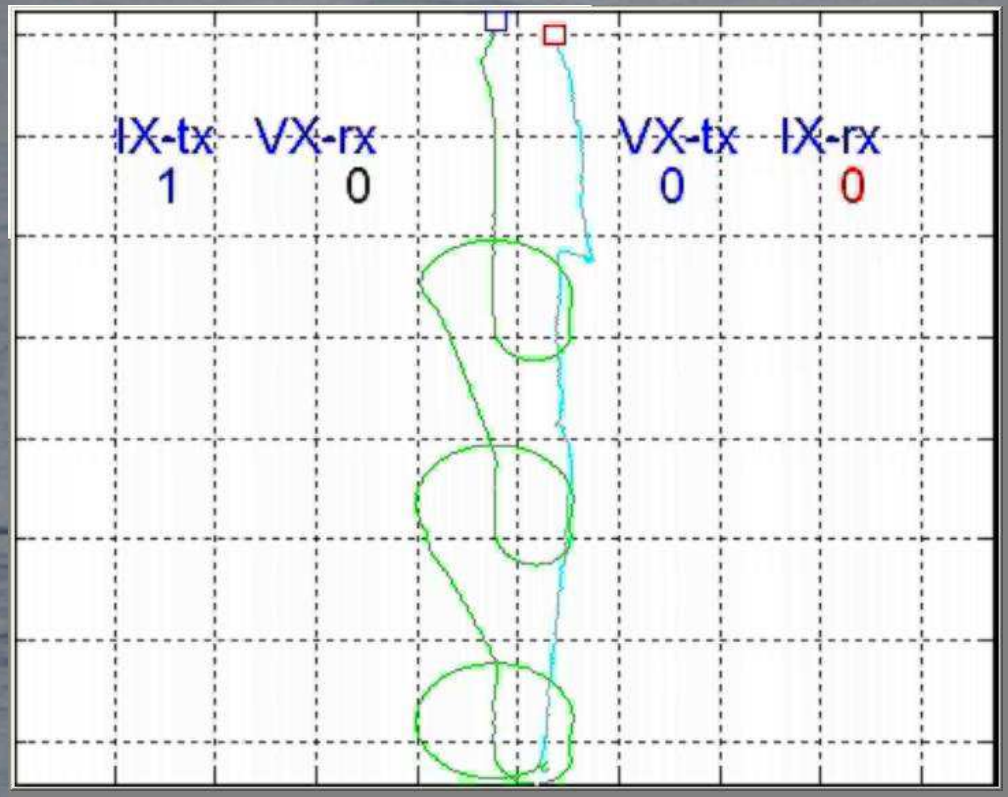
6. First sea trial validation of Vortex AUV

7. Integration and validation of NEMO-PSE supervisory control software on Ifremer AUV

Results



Multi Vehicle coordination

Objectives
Requirements
Trial schedule
Results
Further work

Thank you for your attention

Any questions?