

# Networked robotic systems: the Douro River plume case study



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# Presentation Outline

- Douro River Plume
- Work in progress using Autonomous Systems
- The role of local and interdisciplinary side projects
- Conclusions

## River/Estuarine Plume

**Coastal water masses** of lower density carrying several dissolved and suspended riverine materials **with distinct properties from surrounding ocean waters**



**Ocean**

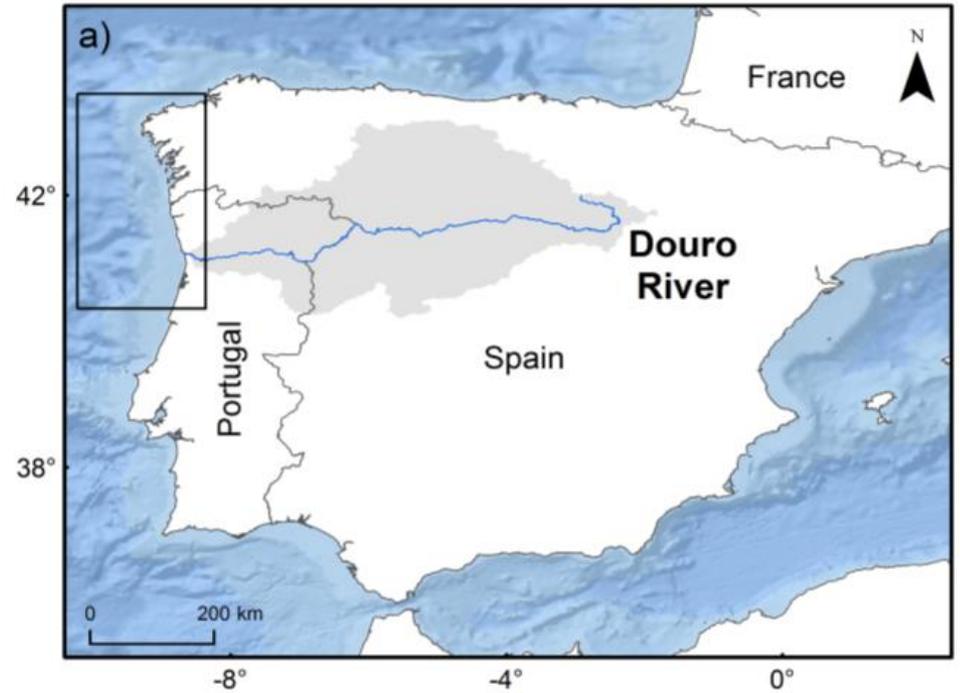
**Plume**

Fraiser River, Vancouver, Canada

## Case Study

### Douro River

- 927 km length
- Watershed of 97 682 km<sup>2</sup>
- More than 50 dams
- Monthly River Flow: ~100 m<sup>3</sup> s<sup>-1</sup> (August)  
~1000 m<sup>3</sup> s<sup>-1</sup> (January)



### Douro Estuary

- Near Oporto city
- Area of 9.8 km<sup>2</sup>
- Length of 21.6 km
- Tide: semidiurnal and mesotidal
- Residence Time: 8 hours – 15 days



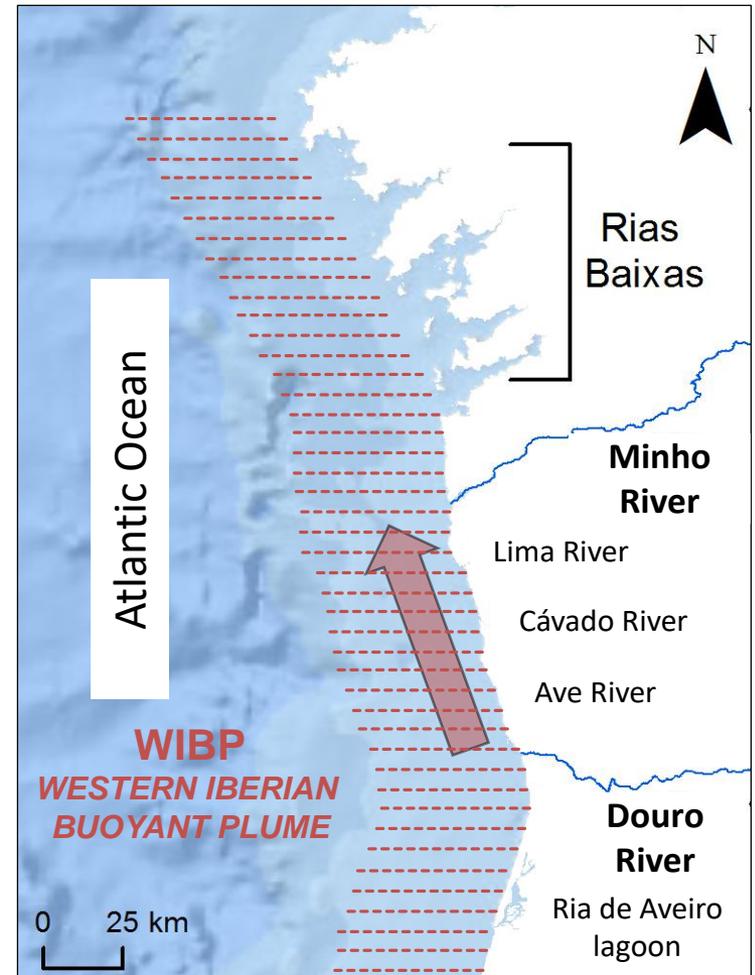
## Area of Study

### Coastal Region

- Estuarine discharges in the region of influence of Douro Plume:
  - ✓ North:
    - Ave River (20 km)
    - Cávado River (45 km)
    - Lima River (60 km)
    - **Minho River (85 km)**
    - **Rias Baixas (100 km)**
  - ✓ South:
    - Ria de Aveiro Coastal Lagoon (55 km)

### The importance of Douro River

- It is the main freshwater contributor to the Atlantic Ocean in Northwestern Iberian Peninsula
- Nutrient and sediment source to the ocean



## Background

Remote Sensing

A methodology to detect the Douro estuarine plume under different conditions using **remote sensing imagery**;

Numerical Modelling

Study the **inter-annual and seasonal variability** of the Douro estuarine plume;

Traditional in-situ data

Characterize the Douro estuarine plume dynamics under **different conditions of river discharge and wind** forcing;

Study the **interaction** between the Douro and Minho estuarine plumes

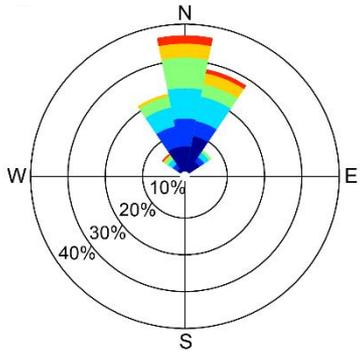
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limited

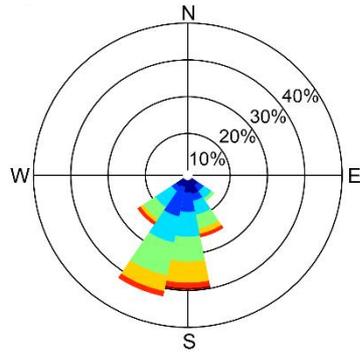
different objectives

# Remote Sensing

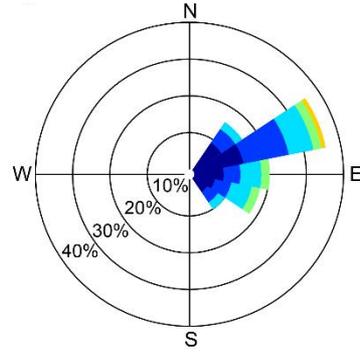
## Northerly



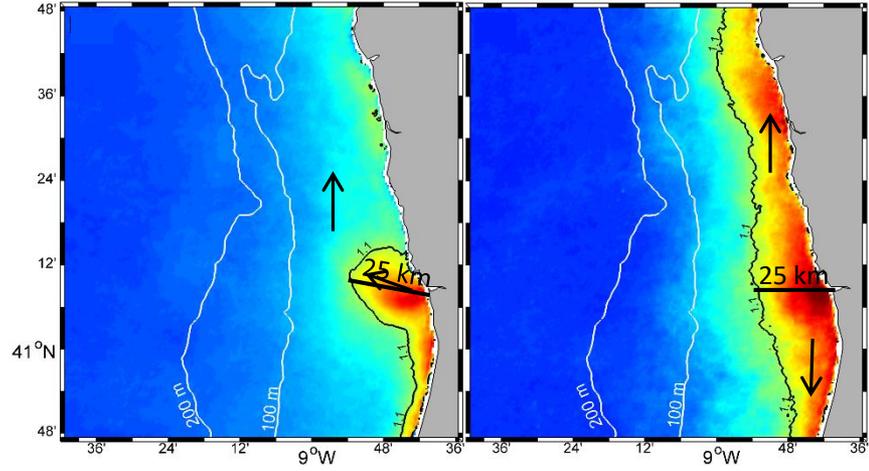
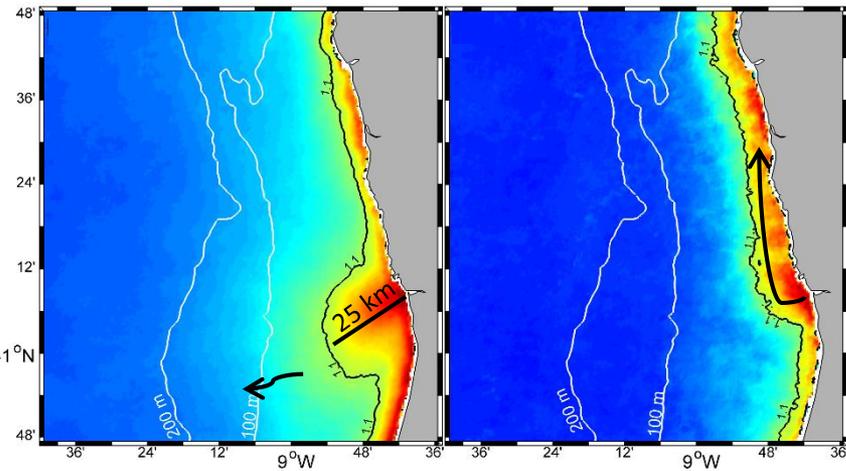
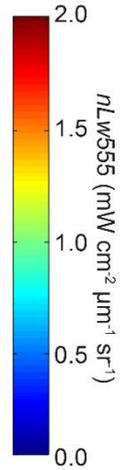
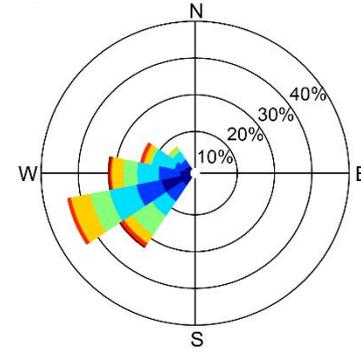
## Southerly



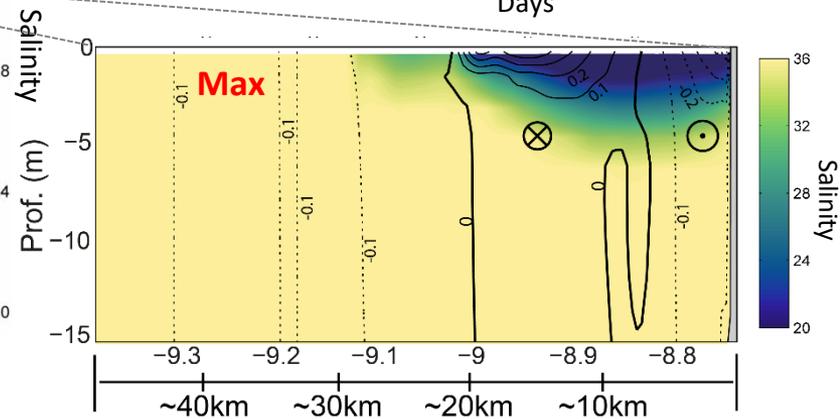
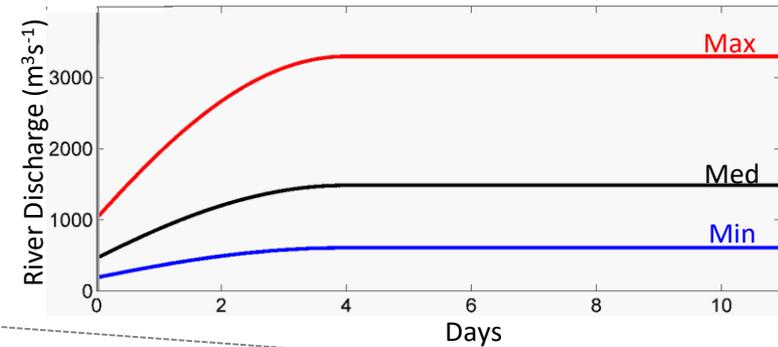
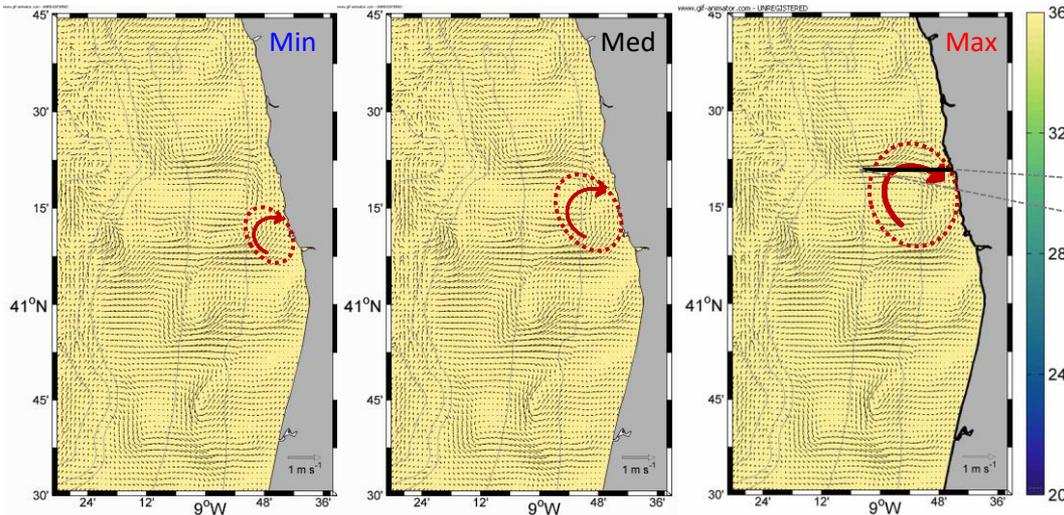
## Easterly



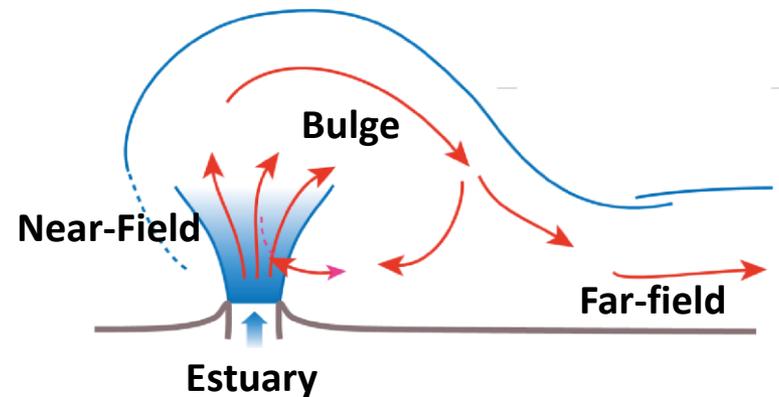
## Westerly



## Numerical Modelling: River discharge



- Offshore expansion at 30 km
- **Recirculating bulge** near the river mouth
- Northward coastal current generation in high and moderate discharge scenarios ( $0.2\text{-}0.3\text{ m s}^{-1}$ )
- **Large-scale and surface advected plume**
- **Prototypical plume**



Adapted from: Horner-Devine, et al. (2015). Mixing and transport in coastal river plumes. *Annual Review of Fluid Mechanics*, 47, 569-594.

# Work in progress

## Small-scale processes in the Douro River

1. Bulge regions have been rarely observed in coastal environments
2. Wave breaking and tidal variation impact in the plume propagation
3. Nonlinear IW generation was only fully documented for the Columbia River plume
4. Low-salinity plume detachment is another rarely documented river plumes feature
5. Full characterization of transition between estuary to near field and then from near to far-field plume was never performed in Douro Plume



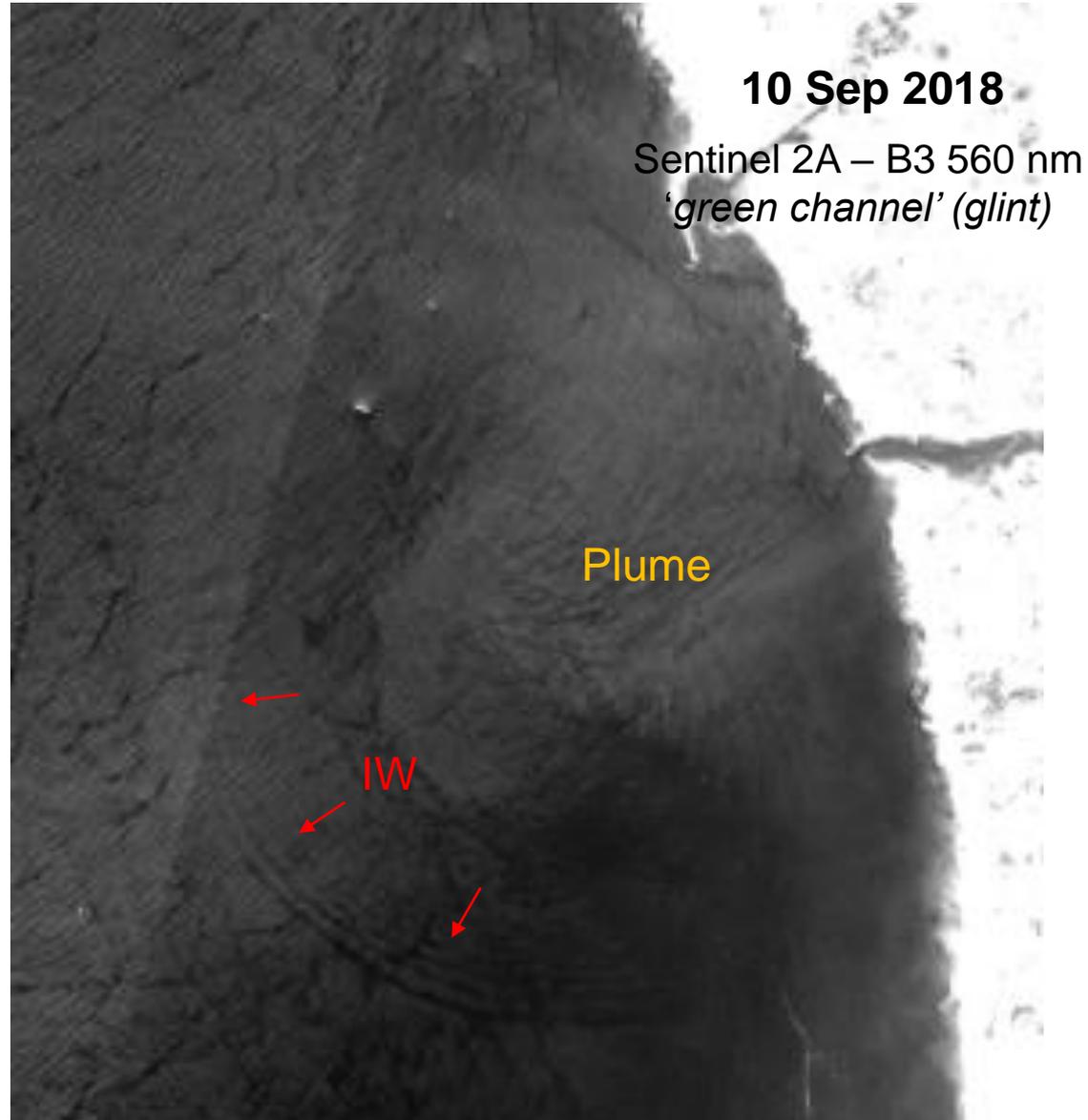
# Work in progress

## Oceanography

Several satellite images present evidence of **non-linear internal waves generation** in Douro River Plume

Only possible to see on high-resolution **satellite missions** such as Sentinel-2 or SAR (TerraSAR-X and Sentinel-1)

Need for **coincident in situ data** about coastal ocean stratification (out of the plume / inside the plume)



# Work in progress

## Technology

“Real” sea trials

Develop algorithms and strategies which **increase the autonomy of the systems**

Scientific feed-back

Identification of **flaws** and **opportunities** in systems, software and procedures

Objective-oriented tests

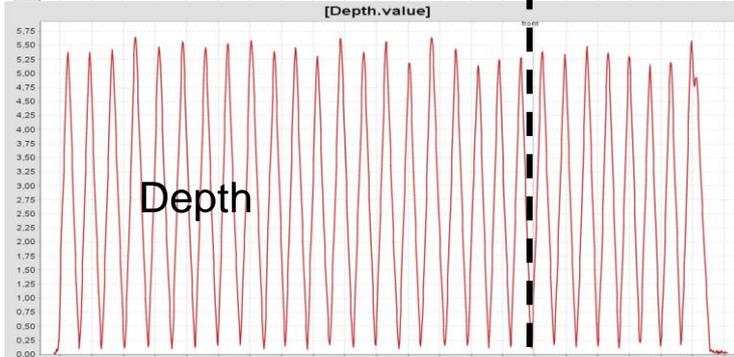
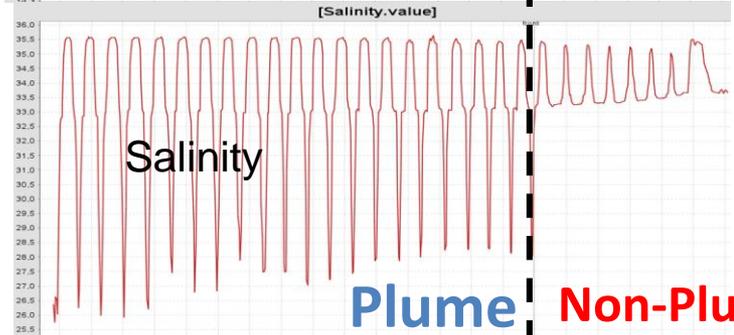
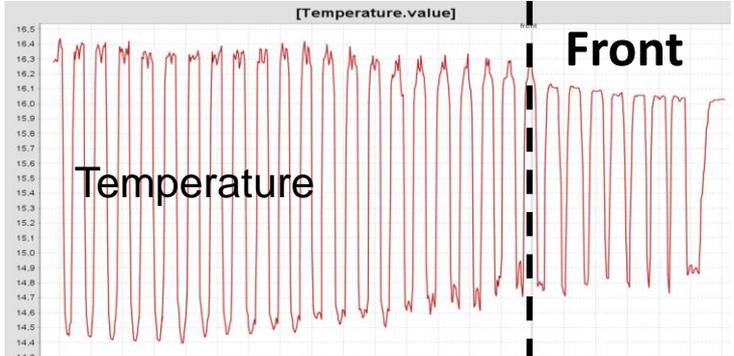
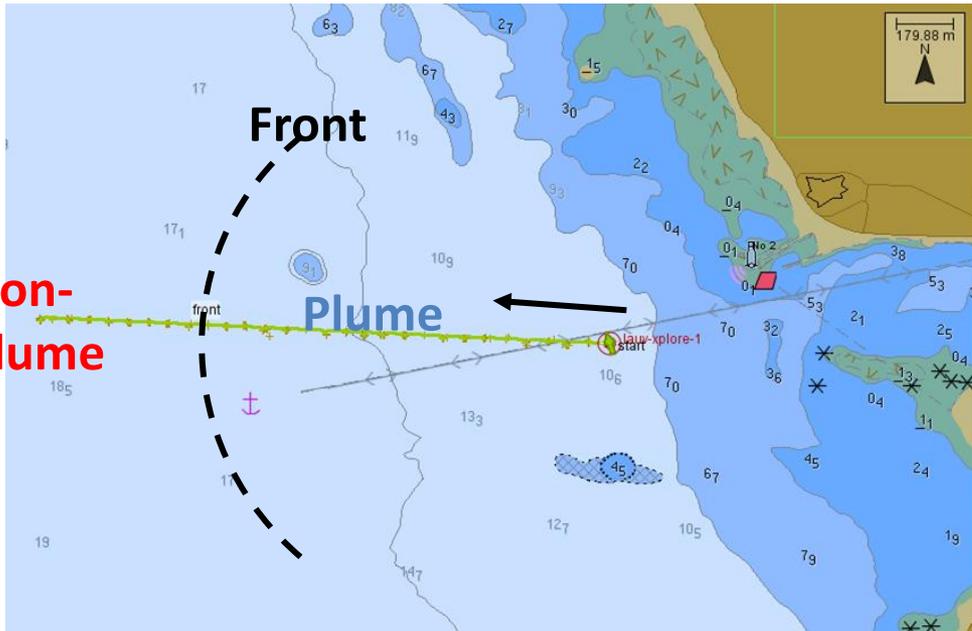


# Step 1

## Deployment of 1 LAUV in Douro River Plume Zonal Transects

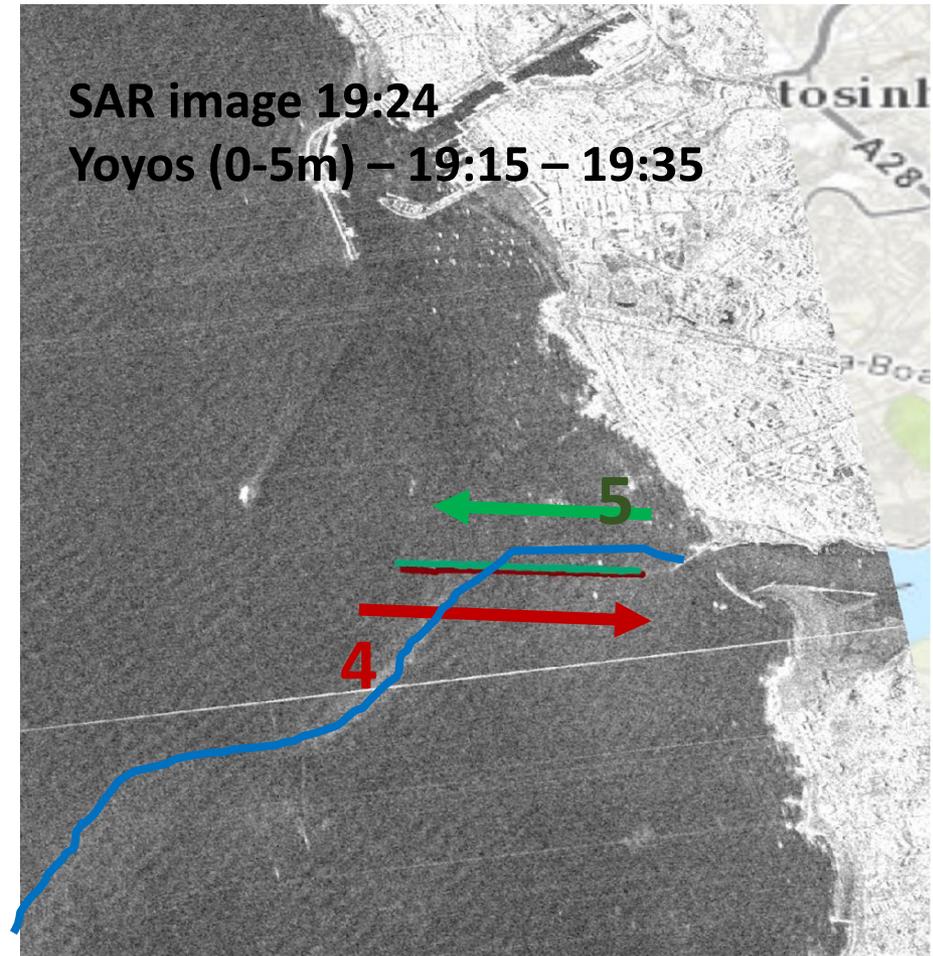
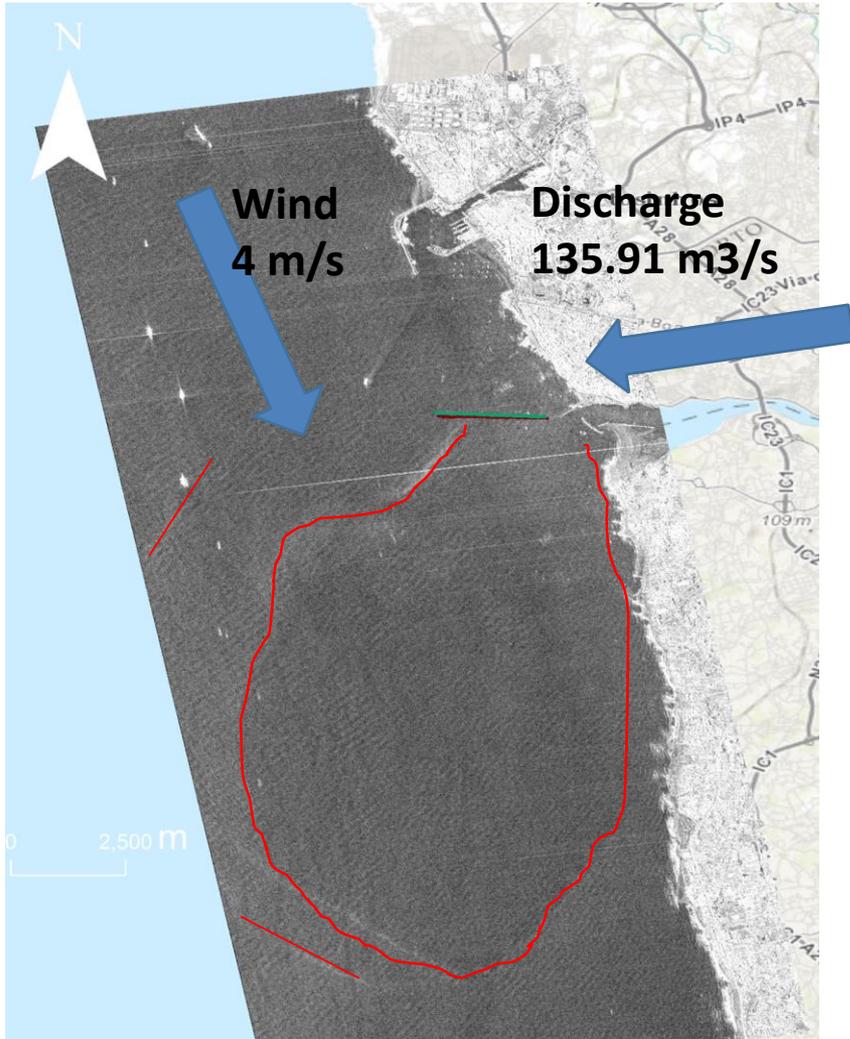
CTD data coincident with satellite imagery

Testing LAUVs on real coastal environments



# Step 1

## Deployment of 1 LAUV in Douro River Plume Zonal Transects



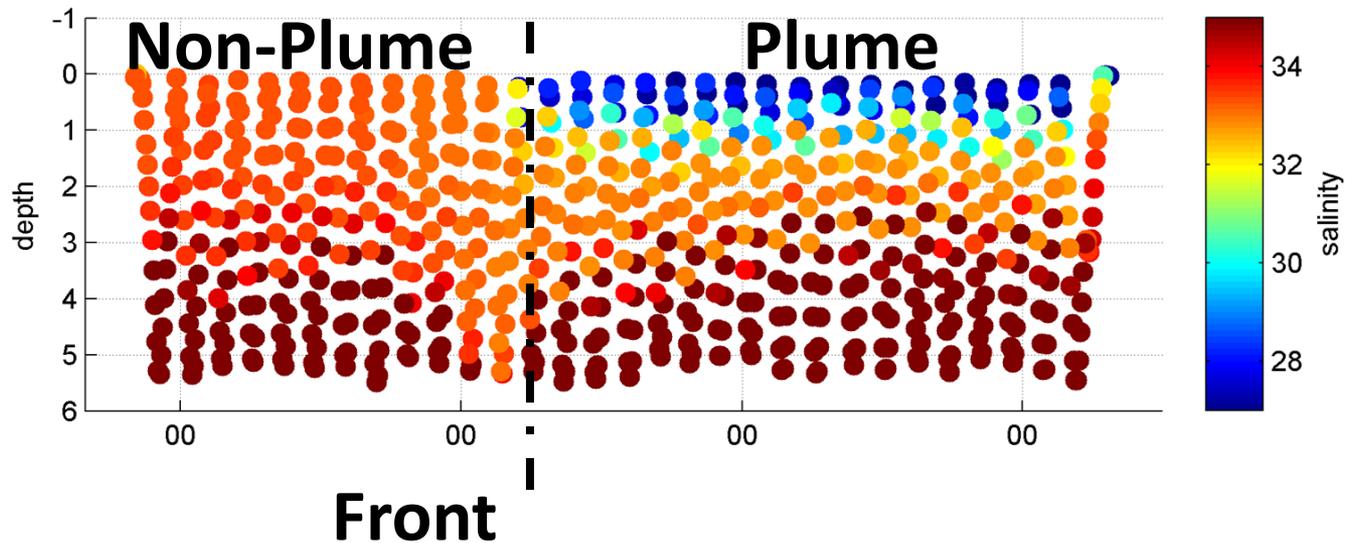
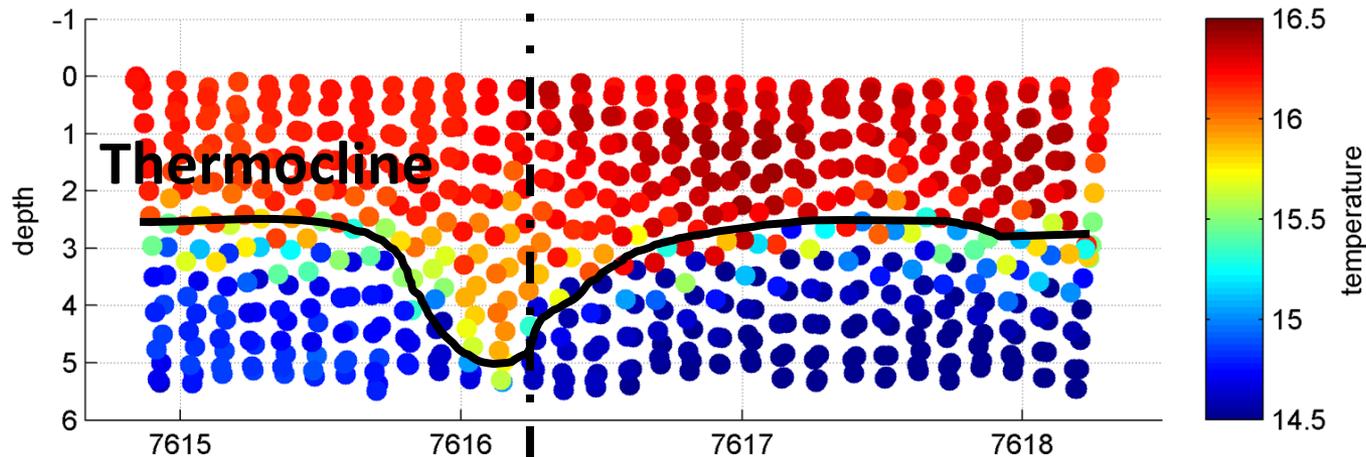
# Step 1

## Deployment of 1 LAUV in Douro River Plume Zonal Transects

Surface currents were very strong near the river mouth (>2 m/s)

We noticed that the vehicle was extremely heavy (almost not buoyant)

Only 2 transects crossed the front



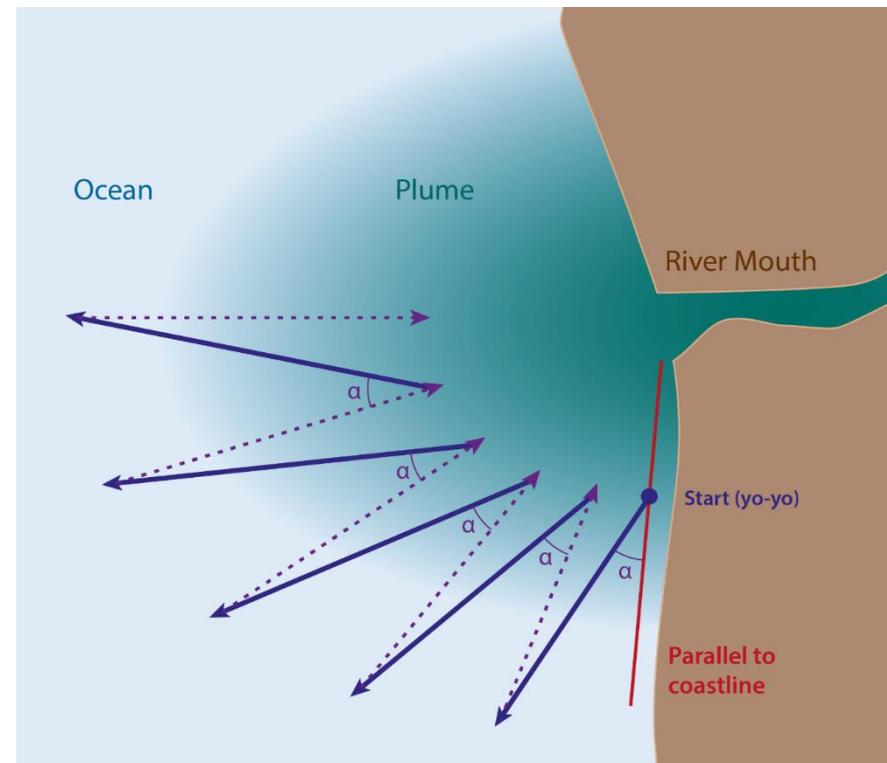
## Step 2

### Create an Algorithm for autonomously detect, track and survey the plume front

- 1 The tracking algorithm was implemented by **horizontal zig-zag** paths (**yo-yo when done vertically**)
- 2 AUV's zig-zag alternate between seaward and landward sweeps, to **radially track** the front as it moves over time
- 3 **Five yo-yos** are done after the AUV crosses and detects the front, and the vehicle makes a turn to cross it again
- 4 AUVs landward trajectories always go in the **river mouth's direction**
- 5 Detection scheme is based on a surface **salinity threshold** (~30-35) defined by a prior analysis
- 6 This way, the AUV maps the river plume's front vertically, at the surface, along with time data

CTD data coincident with satellite imagery

LAUV autonomy increment



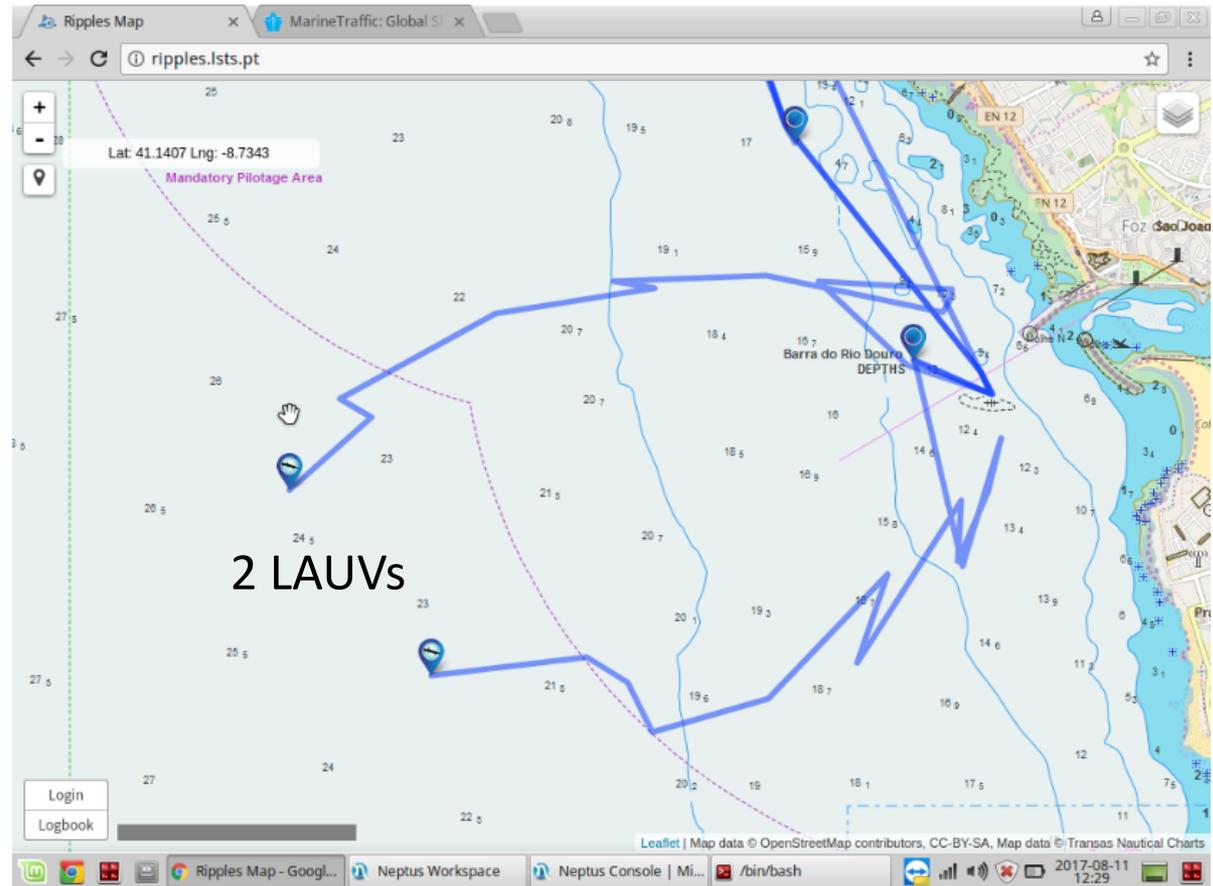
## Step 2

# Create an Algorithm for autonomously detect, track and survey the plume front

Real-Time LAUVs trajectories in a webservice

Acoustic communications limited

SMS and Iridium control & command



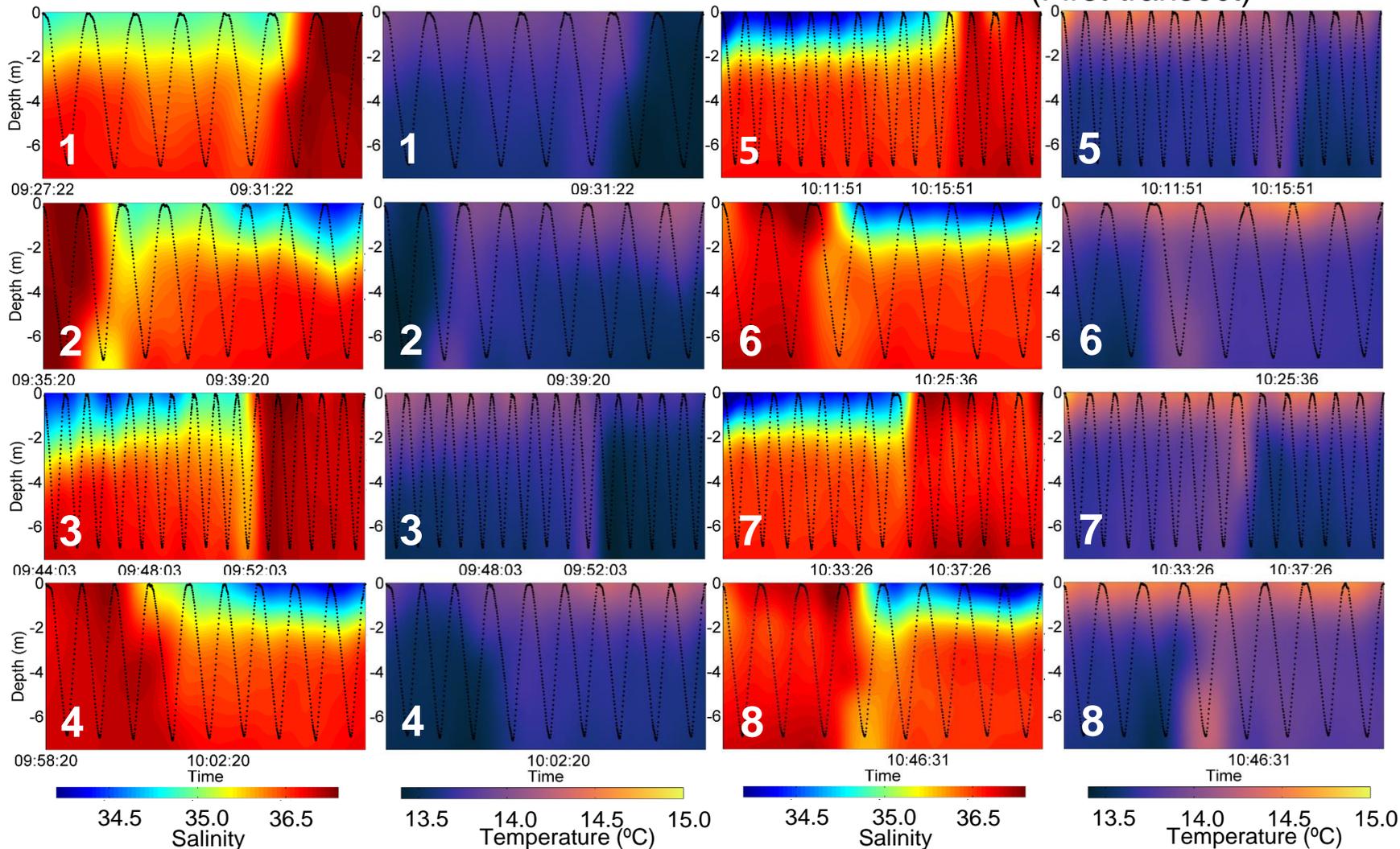
# Step 2

## Create an Algorithm for autonomously detect, track and survey the plume front

Good results but too much wasted time finding the front

### LAUV Cross-front Transects

(First transect)



# Step 3

## Coordinated AUVs and UAV missions

CTD data coincident with satellite imagery

Surface plume signature (propagation)

Control and coordination of multiple robotic assets



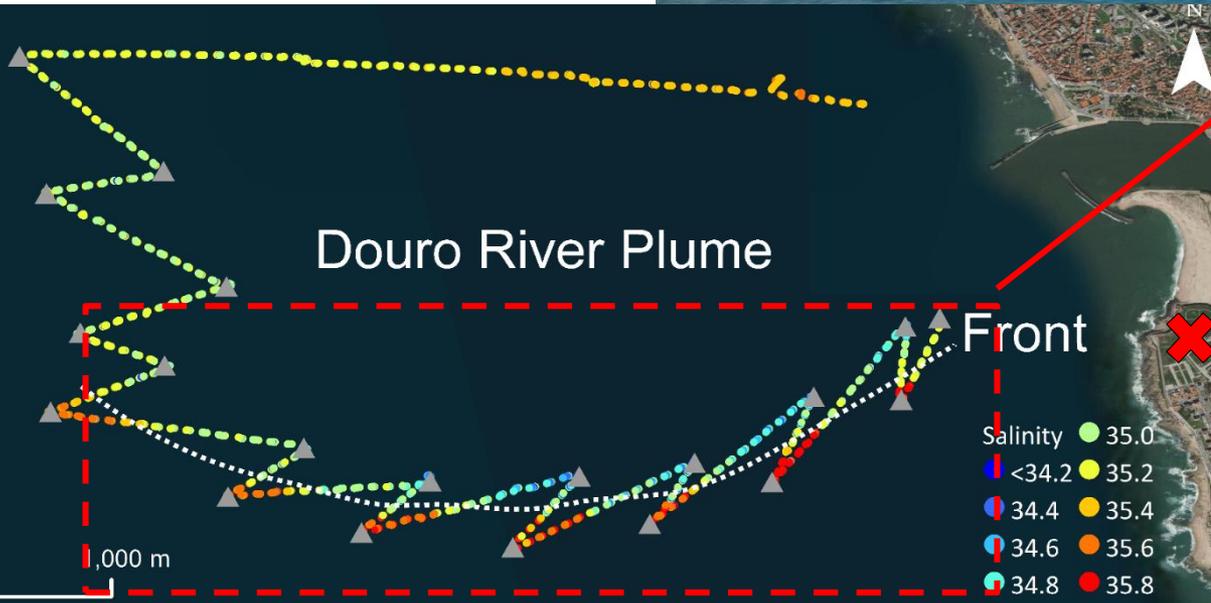
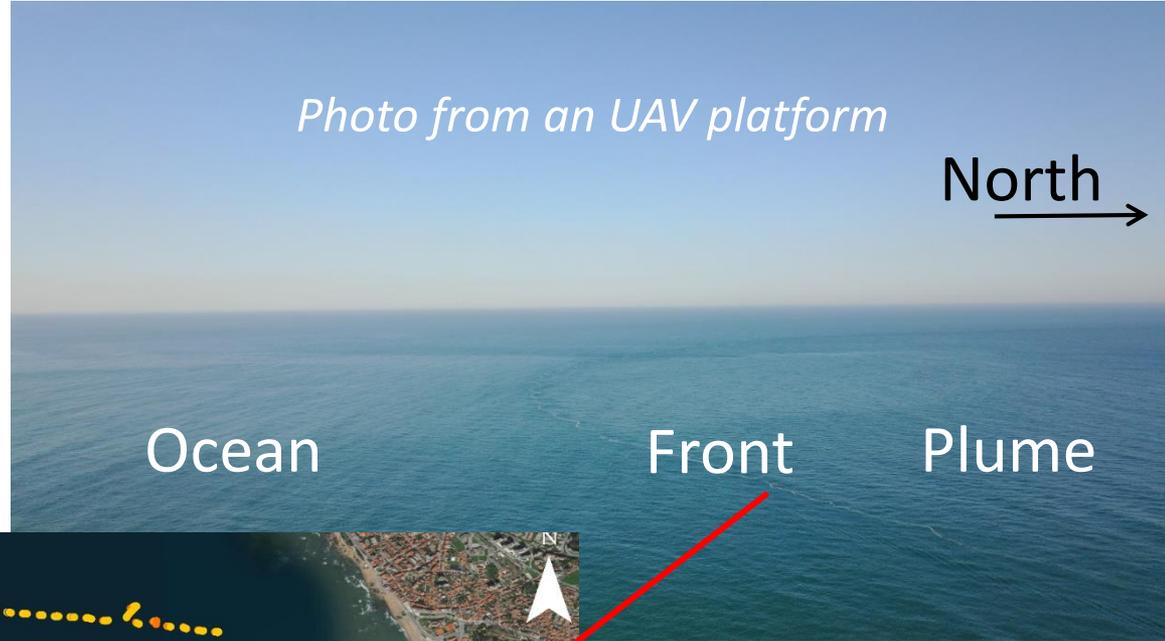
# Step 3

## Coordinated LAUVs and UAV missions

1- Assessment of the front location using a UAV picture (manual)

2- Deploy the LAUV close to the front to start the survey

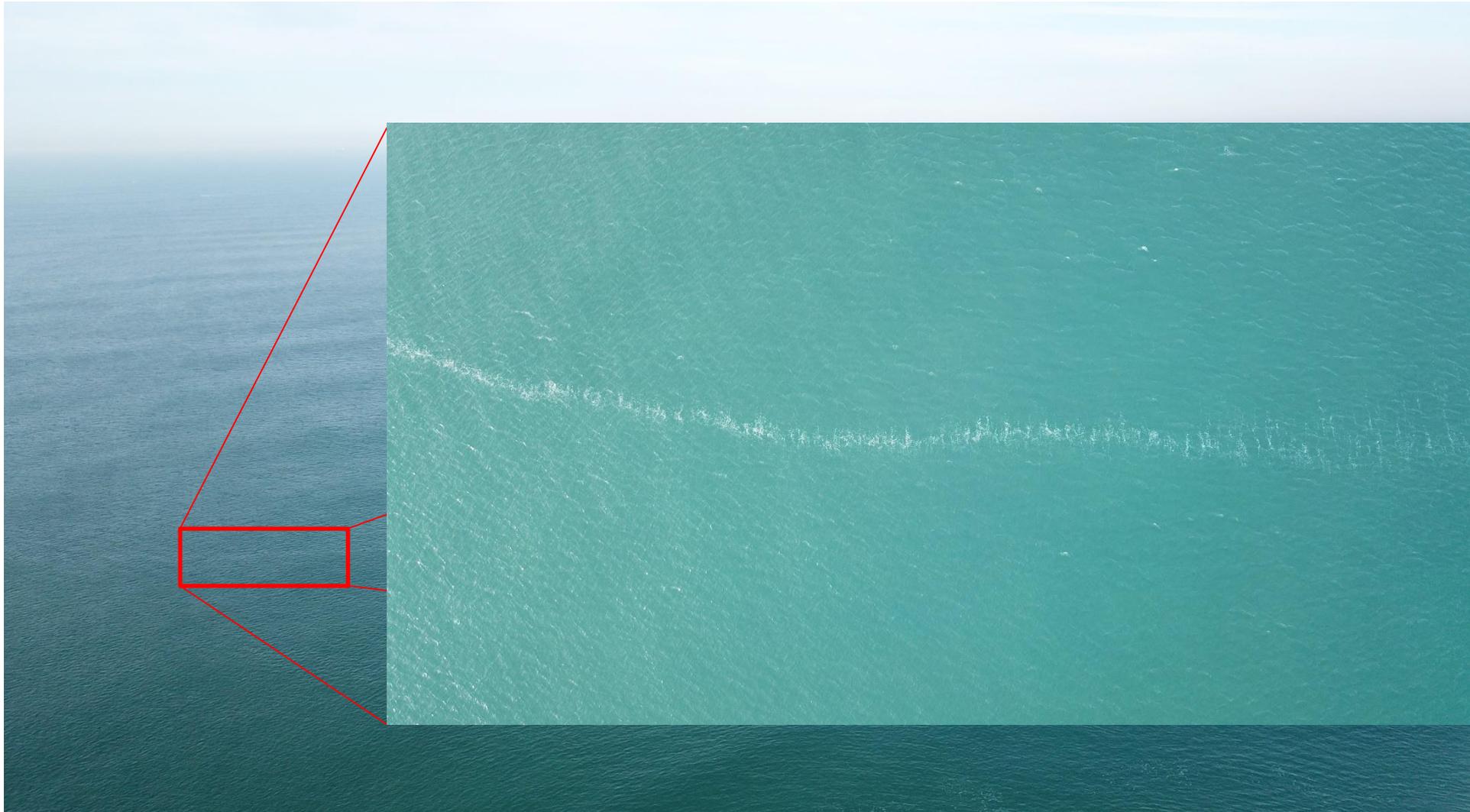
3- Validation of the results



Take-off and landing operations

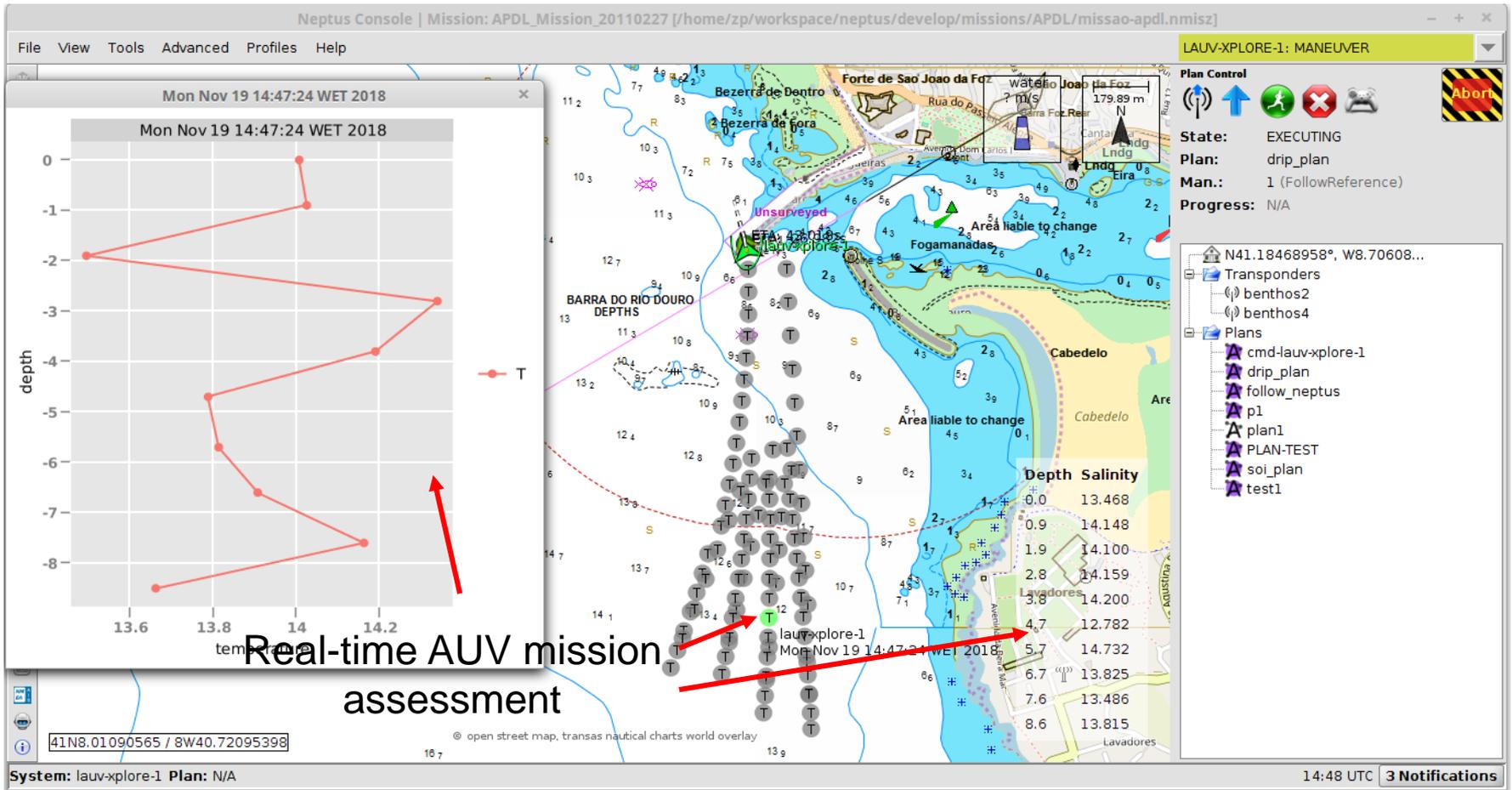
# Step 3

## Coordinated LAUVs and UAV missions



# Technology Developments

Real-time data (TS profiles) based on Iridium communications in Neptus



# Future Developments

- A dynamic threshold based on **salinity gradient** instead of a single value
- Testing other possibilities out of the zig-zag algorithm to have **perpendicular cross front** transects.
- **Front speed estimation** using two coordinated AUVs
- **Land based** operations
- Front **detection from UAV** (thermal or RGB imagery)
- Autonomous coordination and communication between **UAVs, ASVs, and AUVs**
- Autonomous possibilities to deal with **marine traffic (No-AIS)**
- Create an **historical dataset** from a specific transect/line off Douro Estuary
- AUV **adaptive planning** based on numerical modeling predictions
- Real-time **assimilation** of AUV data in coastal numerical models

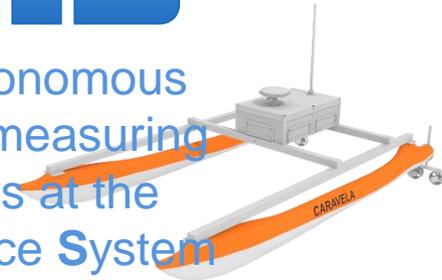
# The role of local and interdisciplinary side projects

- Promote **dialogue** between scientists and engineers in a stress-free environment
- Easiest and fastest **feedback** from end users
- Increase the **local collaboration** among different institutions
- **Brainstorming** for new and large-scale projects
- **Sea-experience opportunities** for undergraduate students
- Improve **dissemination** and local **outreach**
- Establish new procedures to deal with **bureaucracy** (i.e. flight authorizations, boat rental, etc..)
- Improve **engineering team engagement** → Objective-oriented missions

## Oceanography

# DORIS

Developing an autonomous surface vehicle for measuring marine surfactants at the Ocean-River Interface System



Funded Project!

## Biology



# CETUS PROJECT

Cetacean monitoring in the Macaronesia

Monitoring dolphins in the coastal region off Douro Estuary

## Multimedia

**Francisca Rocha Gonçalves**

PhD Student in Digital Media at FEUP under the program UT Austin | Portugal CoLab,

*“Combining her interests in sound, technology, art and science, she aims to raise aural and environmental awareness, promoting environmental education through artistic practices and sound art.”*

## Journalism

DOURO

### Seguindo a pluma do Douro (foz acima, foz abaixo) com submarinos autónomos

Uma equipa de cientistas está a tentar traçar as fronteiras entre a água do Douro e a do mar junto a foz, com a ajuda de pequenos submarinos não tripulados. O trabalho pode ajudar a detectar e prever as consequências de casos de poluição fluvial, antecipando para onde vão as águas contaminadas.

BEATRIZ SILVA PINTO - 18 de Agosto de 2017, 8:14

278

PARTEILHAS



Há uma equipa de investigadores a tentar traçar a pluma do Douro na foz utilizando submarinos. A pluma, que se forma quando águas de diferentes densidades (como o rio e o mar) se encontram, tem uma espessura que varia entre os dois e dez metros e a sua forma está constantemente a mudar, consoante o vento e o caudal do rio. Esta massa de água localizada perto da costa é o principal modo de transporte de nutrientes e poluentes. *des são nem a*

# Conclusions

Results from several frontal crossings demonstrated the **AUVs capability to autonomously detect and survey the front** structure of the plume

Salinity remained a consistent identifier. Although, future missions should apply a **detection scheme based on gradients** instead of a specific salinity value

This study contributes to establish **new methods to track and survey coastal features** like river plumes. Future work will be focused on **multi-vehicle missions** using aerial and more submarine platforms coincident with high-resolution satellite imagery acquisitions, such as Sentinel-1/2 and TerraSAR-X

# Conclusions

Coastal oceanographic phenomena (i.e. River Plumes, Coastal Upwelling, Blooms, etc.) can be the base for small, local and opportunistic objective-oriented technological tests

- ✓ Logistics
- ✓ Low-cost
- ✓ An intermediary step between the harbor and offshore operations

Smaller/side projects give the opportunity to engineering and science teams work together in a stress-free environment

- ✓ Better preparation for priority and larger projects/cruises
- ✓ People engagement and more collaboration opportunities
- ✓ Better outreach and paperwork planning

# Thank you!



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