

Real-time and continuous monitoring of magmatic fluid emissions in the Mayotte sea using a SeaExplorer glider

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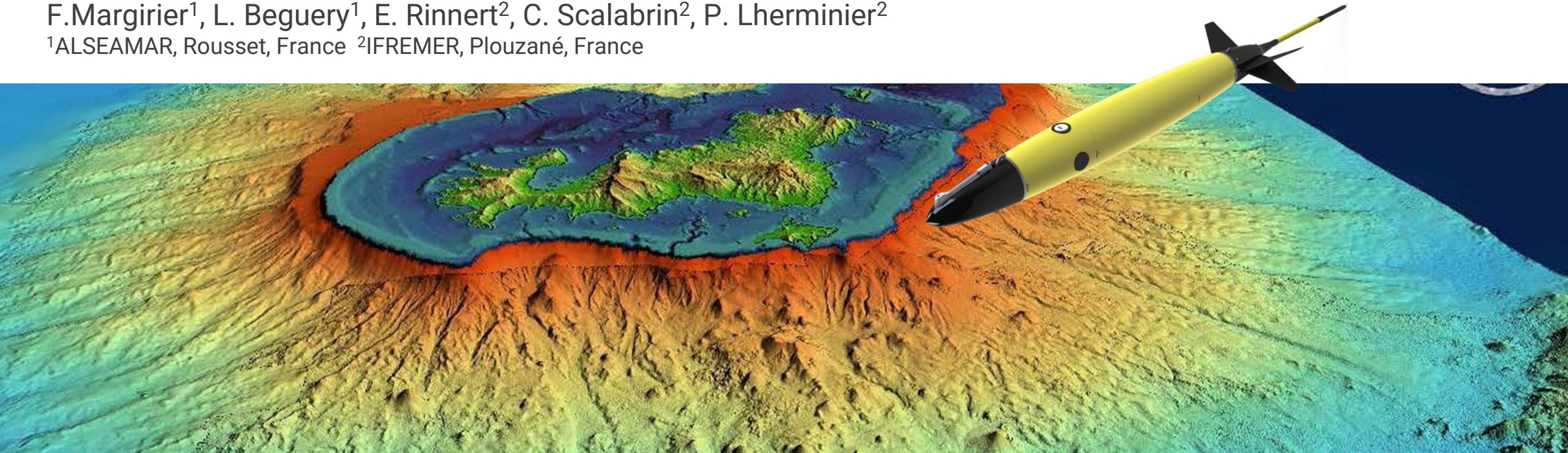
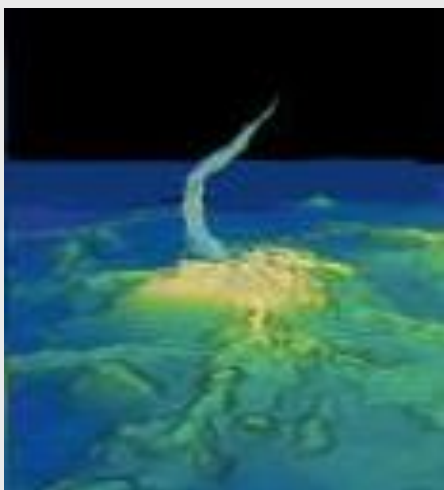


Image credit: C. Poncelet and C. Scalabrin, IFREMER



Multi-beam image of Mayotte volcano

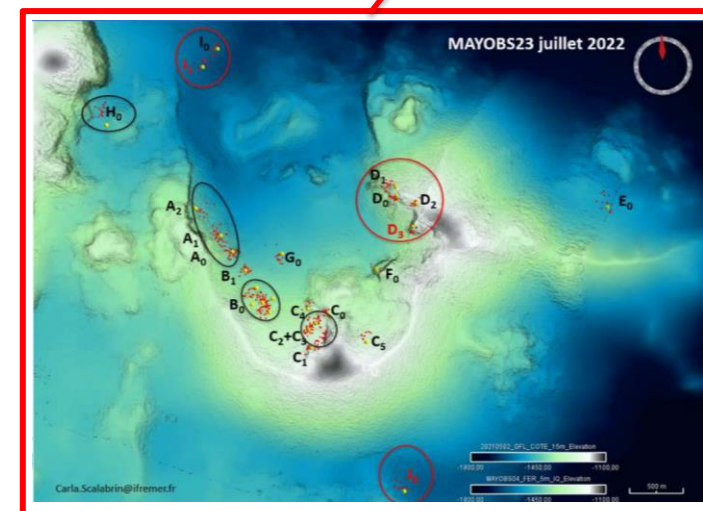
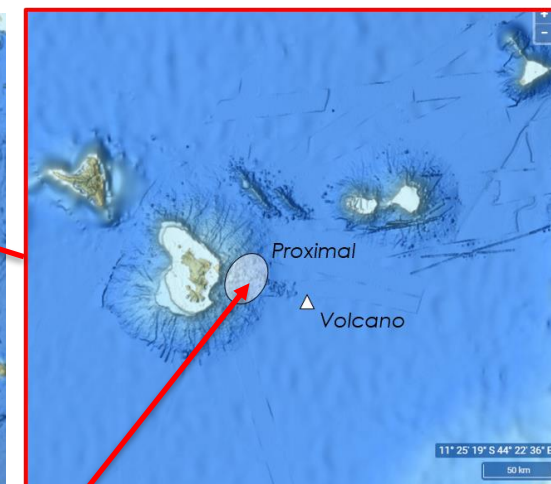
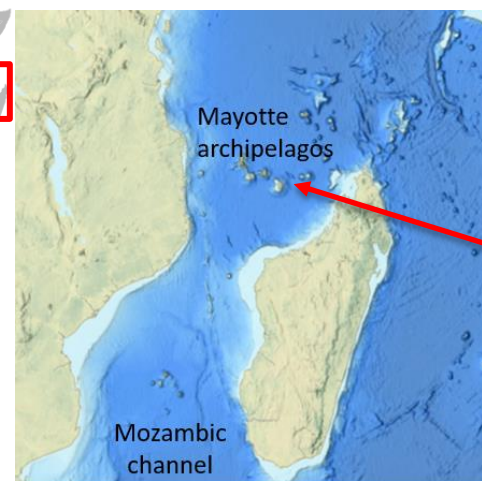
An outstanding area

- Regional context
- Unprecedented seismo-volcanic crisis at Mayotte
- Implementation of the REVOSIMA observing system both on land and at sea (20 MAYOBS cruises)
- 2018 : Discovery of a new volcano located ~ 50 km away from the coast (Feuillet et al., 2021, Nature Geoscience) at a 3500m depth
- 2019 : Discovery of active hydrothermal vents located just 10 km from the coast (proximal)
- 2020-2023 : Continuous emergence of several active sites at proximal

REVOSIMA
doi:10.18715/MAYOTTE.
REVOSIMA

MAYOBS
doi:10.18142/291

Data credit: B. Lambrieu and C. Scalabrin
IFREMER

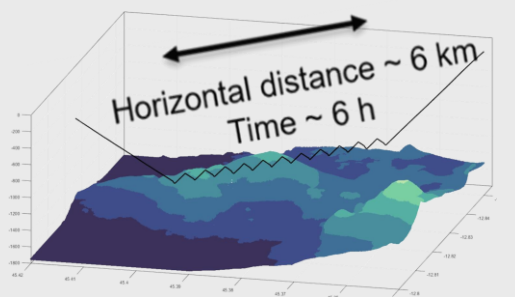


Active sites map at proximal (22 sites)

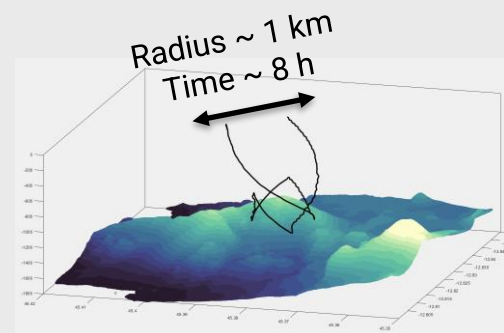


A unique glider mission

In September 2021, IFREMER requested for the deployment of 1 SeaExplorer glider with the given aim to ensure an operational and continuous monitoring of the proximal area



Navigation strategy (multi-yos) chosen for the 1000 m depth survey

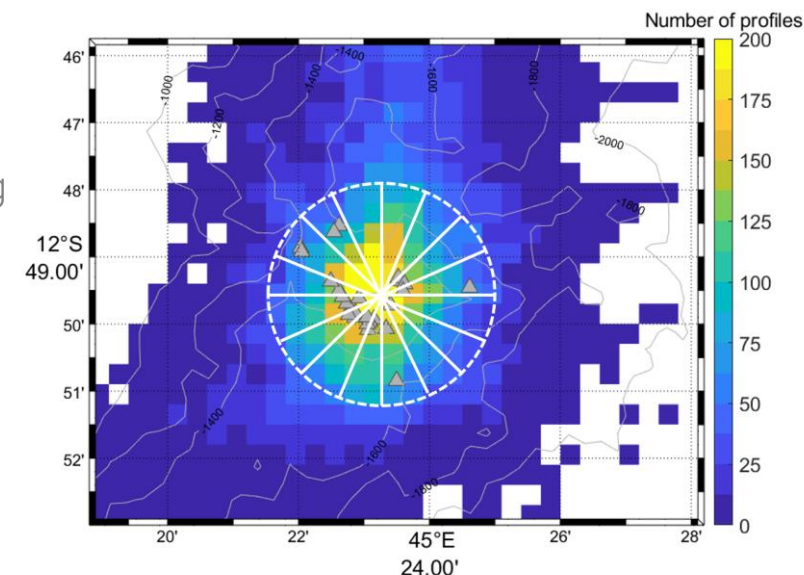


Navigation strategy (spiral) chosen for the 1250 m depth survey

- Glider monitoring
- 1000m glider survey
- Radial sampling strategy
- Focus on the 900-1000 m layer (seafloor ~ 1400m)
- 27 months of acquisition (~ 20k profiles, 2M measuring points)
- 1250m glider survey
- 1250m version of SeaExplorer deployed in August 2023
- Spiraling sampling strategy focused on the Fer à Cheval area
- Focus on the 800-1250 m layer



R/V Marion Dufresne used by IFREMER for oceanographic cruises MAYOBS

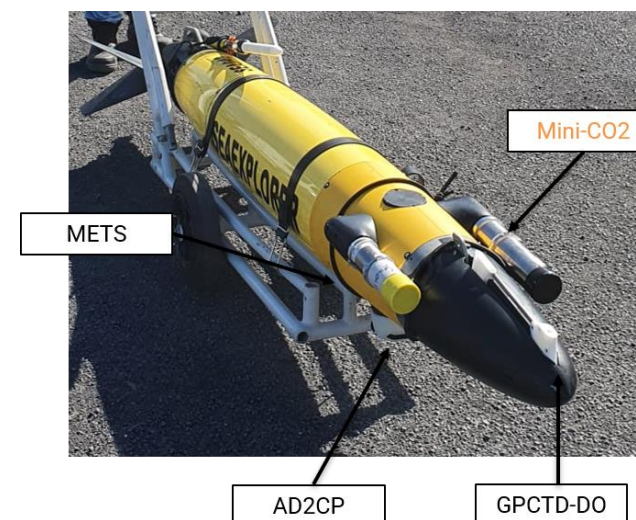


Sampling effort based on the number of profiles acquired in rectangles of 0.5 km²

Novel sensors integration

Sensor	Manufacturer	Measured parameters	Sampling period (s)	Data processing
CTD + DO	RBR / JFE (Seabird Scientific for spare)	Conductivity, pressure, temperature and dissolved oxygen	4	Thermal-lag correction
MiniCO2	Pro-Oceanus	Carbon dioxide partial pressure	1	Time-lag correction
METS	Franatech	Dissolved methane concentration	2	Thermal / time-lag / hysteresis correction
AD2CP	Nortek	Water-current, acoustic backscatter index and vertical velocity anomaly	5	Shear algorithm Sound scattering algorithm

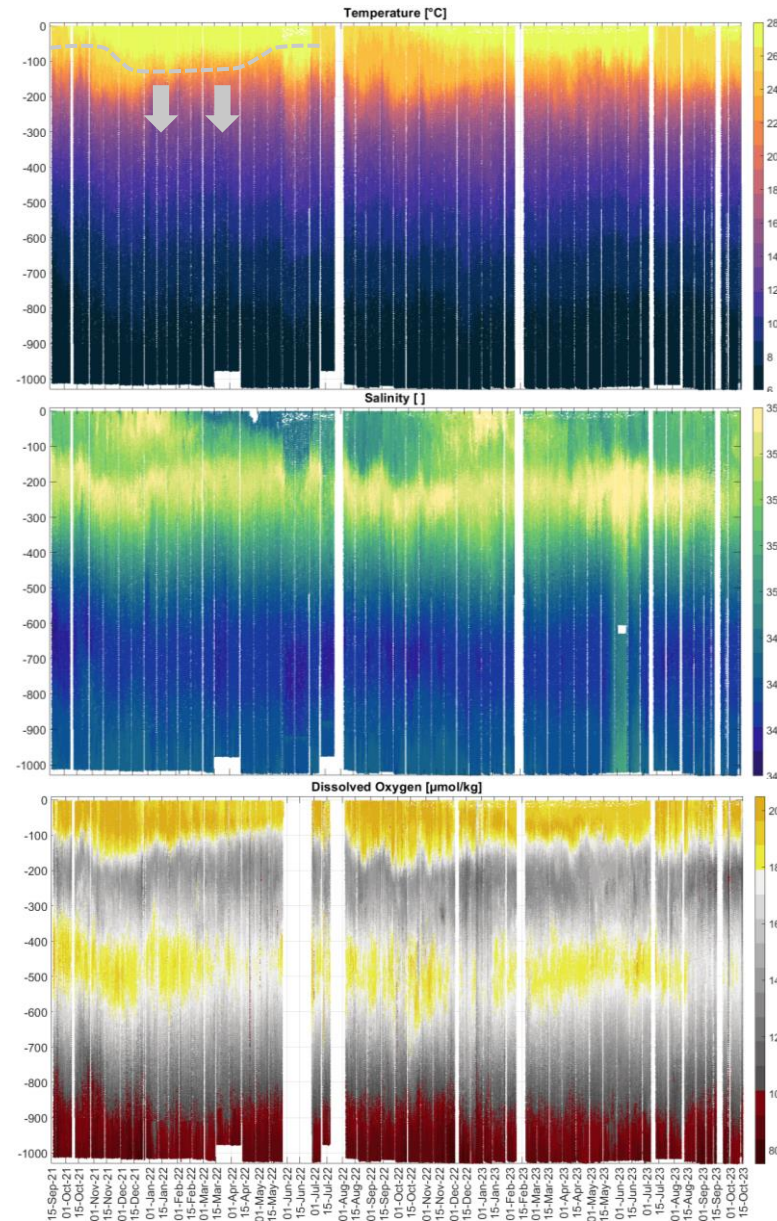
- Processing algorithms
- Data were converted in physical units, TLC, adjusted from drift and QC (factory calibration)
- ADCP (current) : (Visbeck, 2002)
- ADCP (backscatter index) : (Many et al., 2018 ; Mullison, 2017 ; Homrani et al., submitted ;)
- pCO₂ (Fiedler et al., 2013 ; Fietzek et al., 2014)
- CH₄ (Meurer et al., 2021)
- GPCTD (Garau et al., 2011)



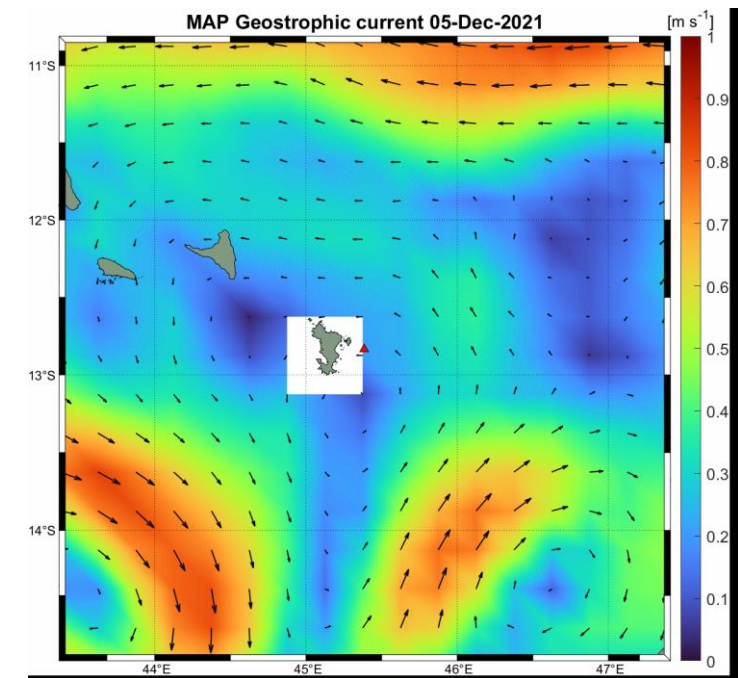
Usual sensors and dedicated gas payload



Oceanographic baseline in a poorly documented area



- Flow in the Mozambique channel
- Ocean dynamic of tropical region
- Anticyclonic eddies crossing the area (Schouten et al., 2003 ; Miramontes et al., 2019 ; Di Marco et al., 2022) affecting the vertical distribution

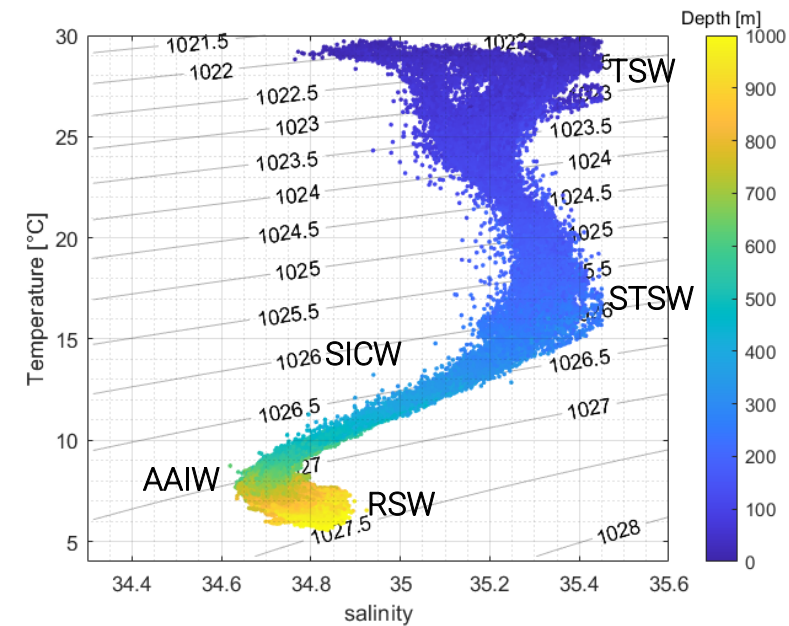
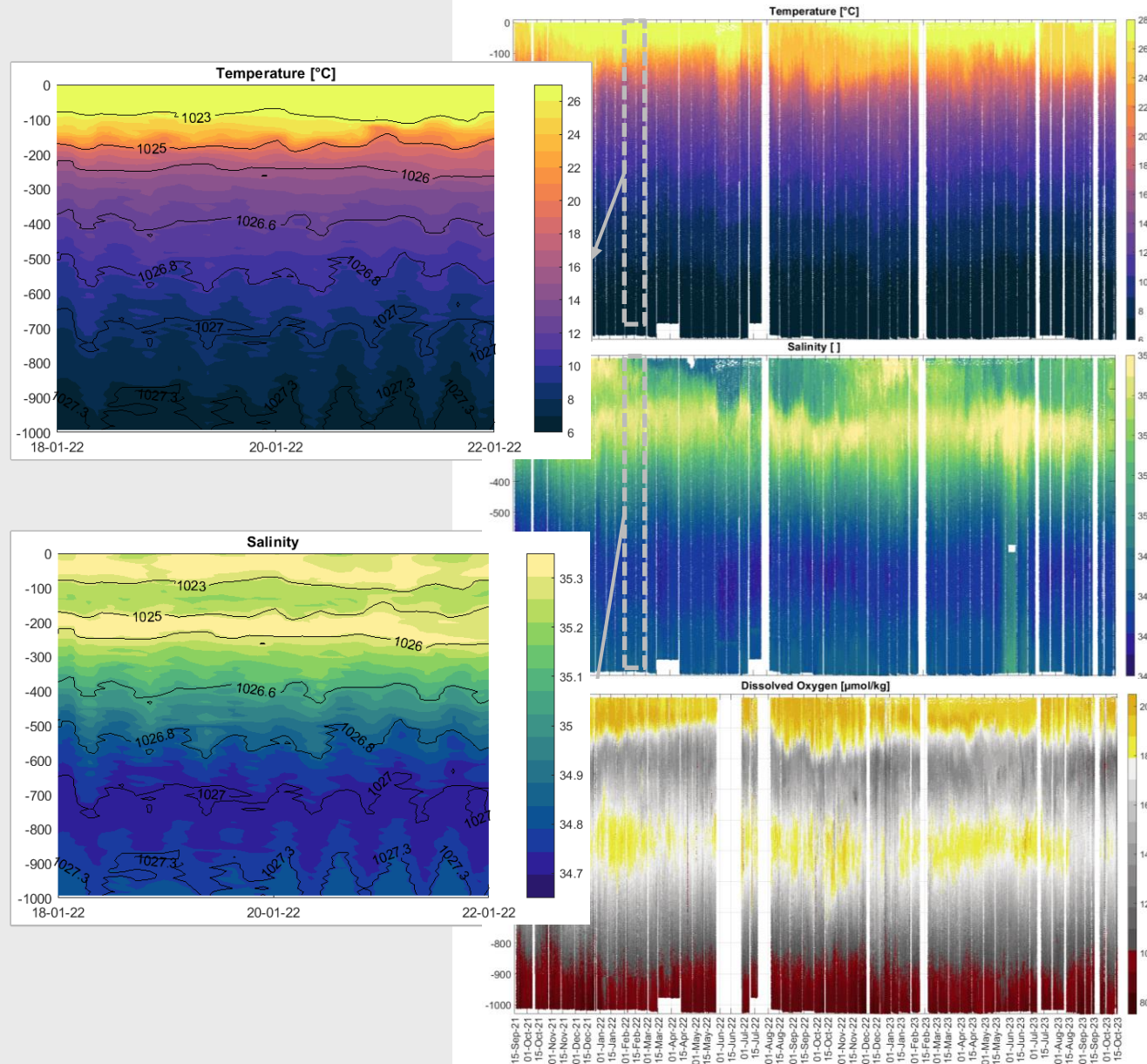


Map of geostrophic current in the Mayotte area. The survey area is indicated by the red triangle



Oceanographic baseline in a poorly documented area

- Daily to hourly fluctuations
- Daily fluctuations
- High-frequency variability
- Surface variations

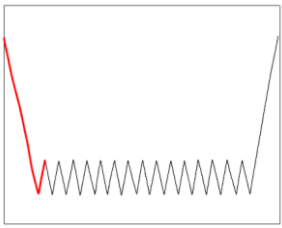


Temperature-salinity diagram and water masses

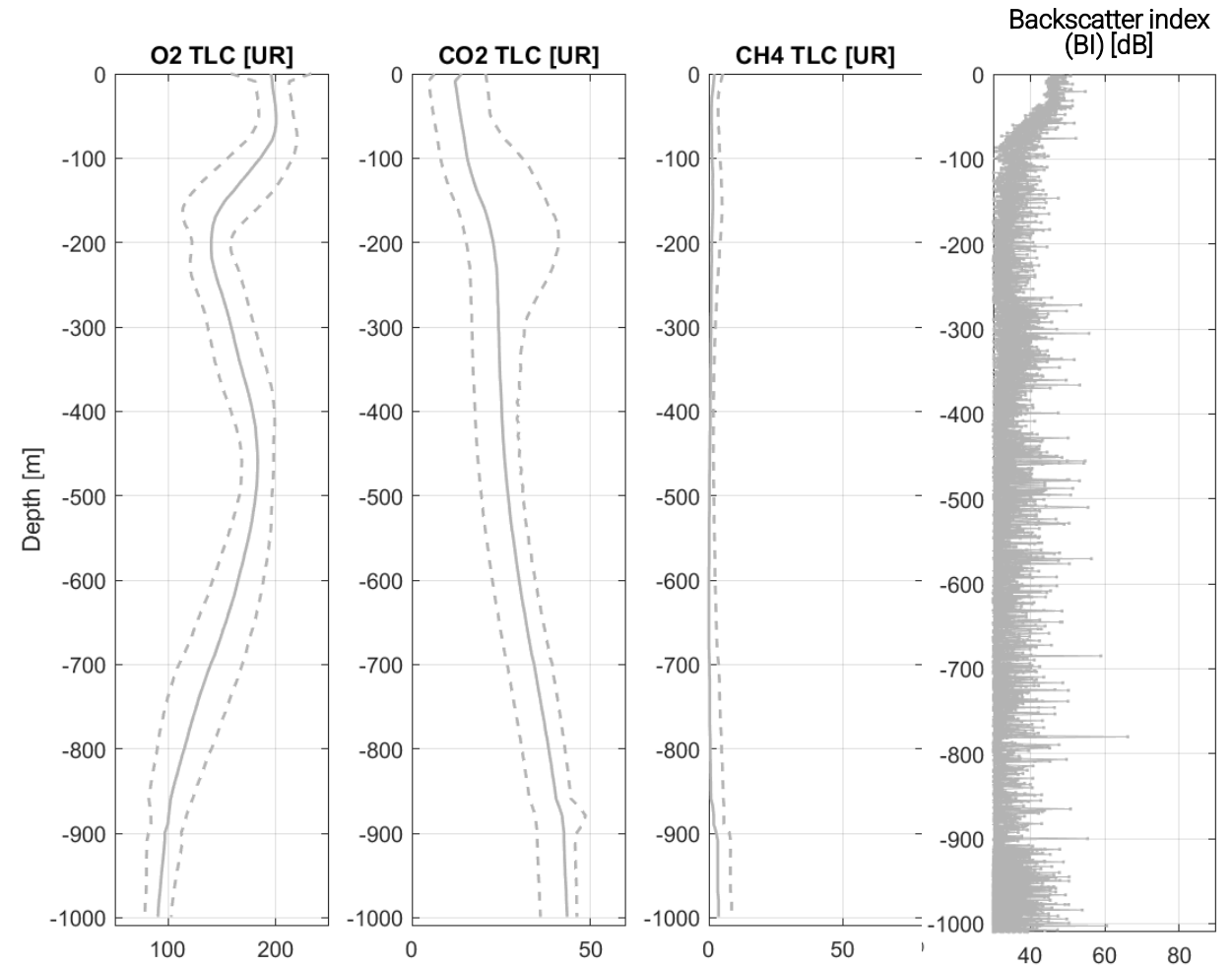
TSW : Tropical Surface Waters
STSW : Subtropical Surface Waters
SICW : South Indian Central Water
AAIW : Antarctic Intermediate Water
RSW : Red Sea Water
(Miramontes et al., 2019)



Parameters of interest to track fluid emissions

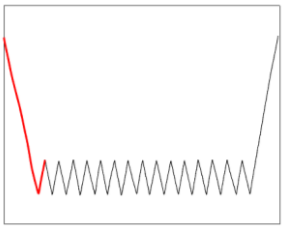


- Dissolved gas average vertical distribution
- Increasing $p\text{CO}_2$ concentrations with depth and mirrors O_2 distribution
- Water column naturally depleted in CH_4
- Spiky signal for backscatter index

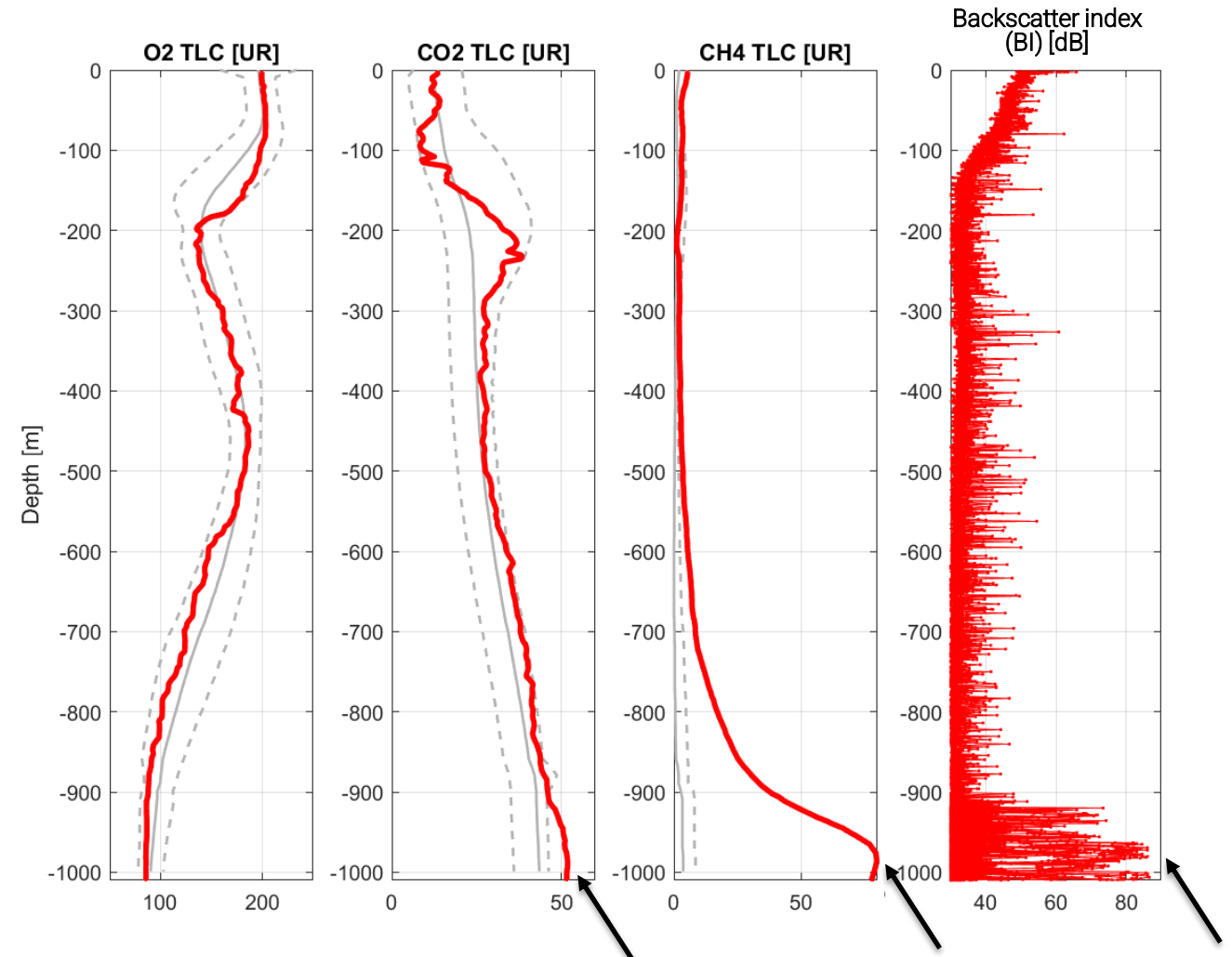




Parameters of interest to track fluid emissions

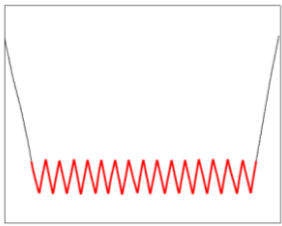


- Example of vertical profiles with anomalies

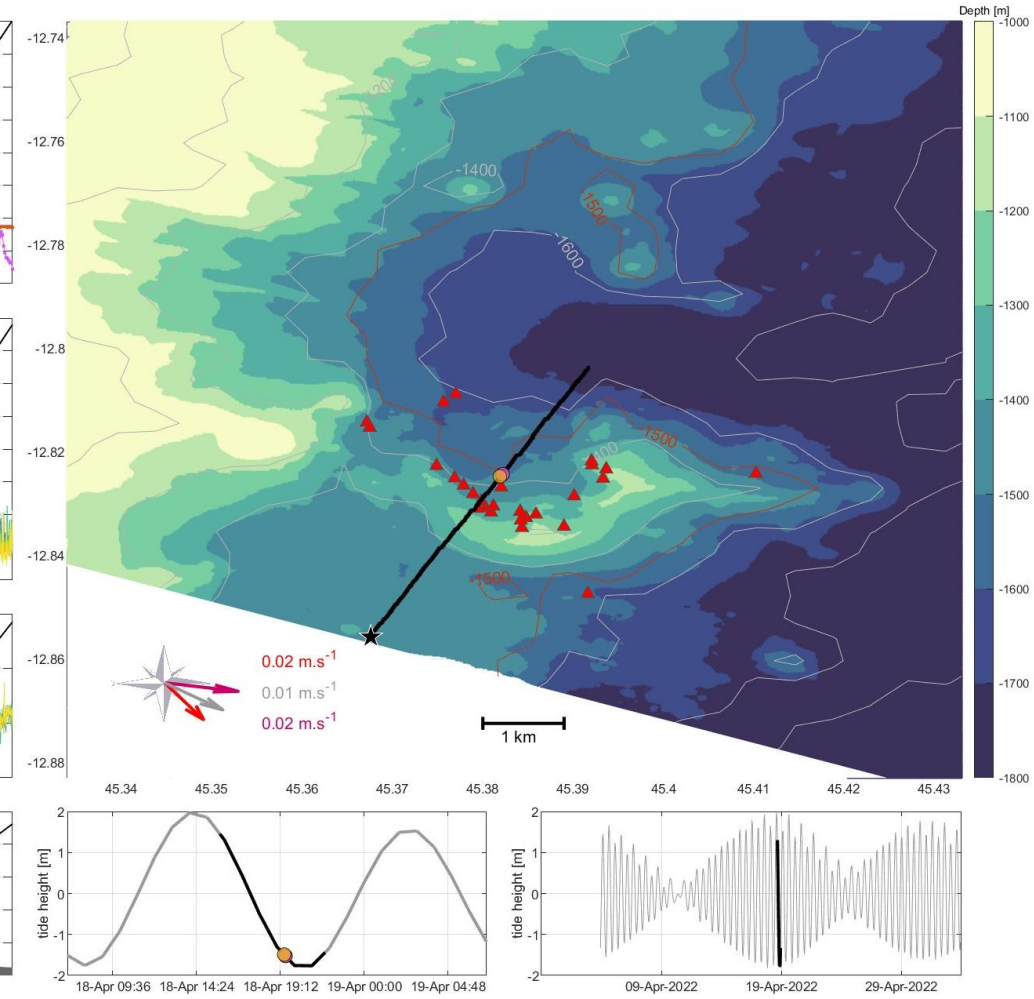
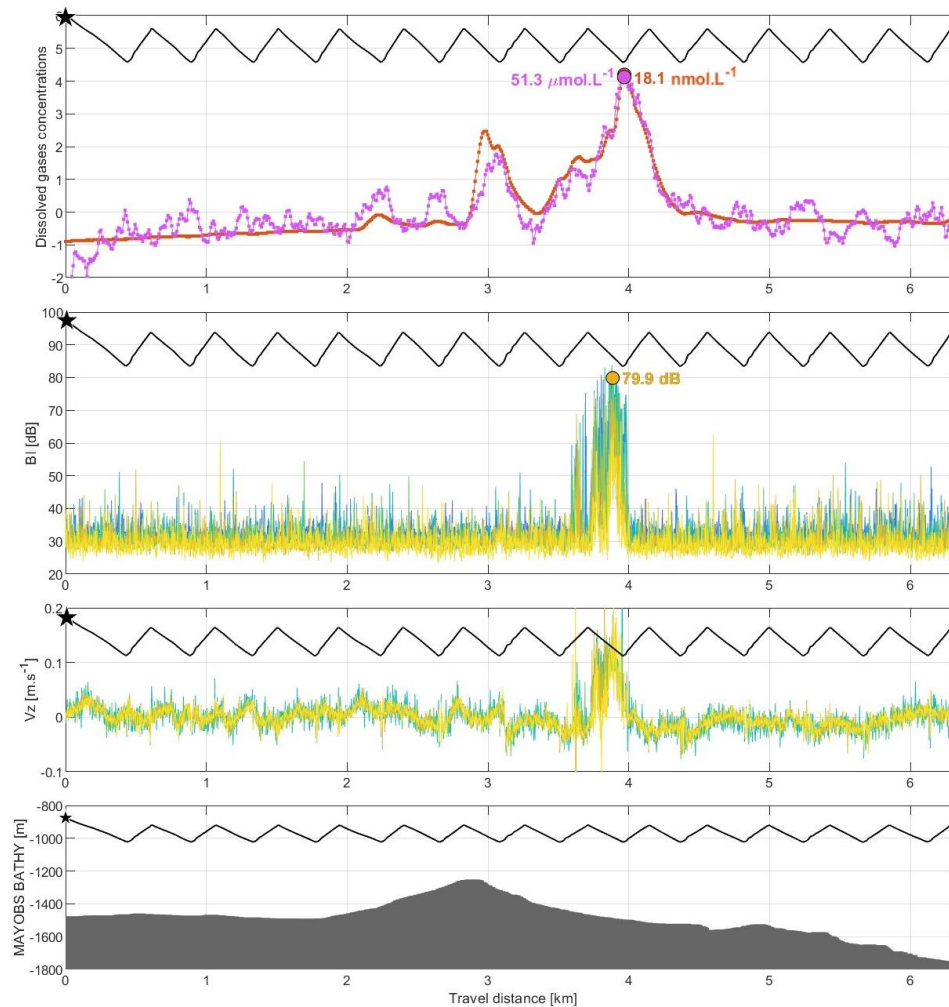
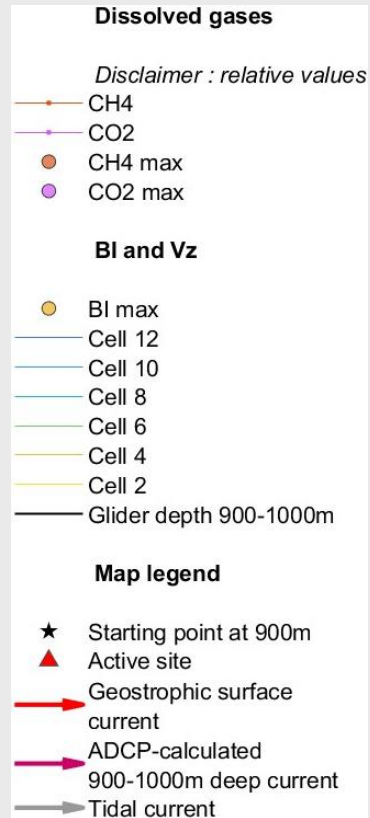




Parameters of interest to track fluid emissions

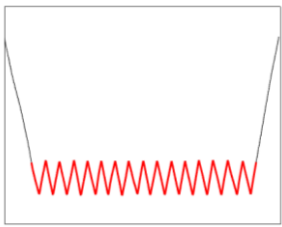


- Example of deep 900-1000 m transect

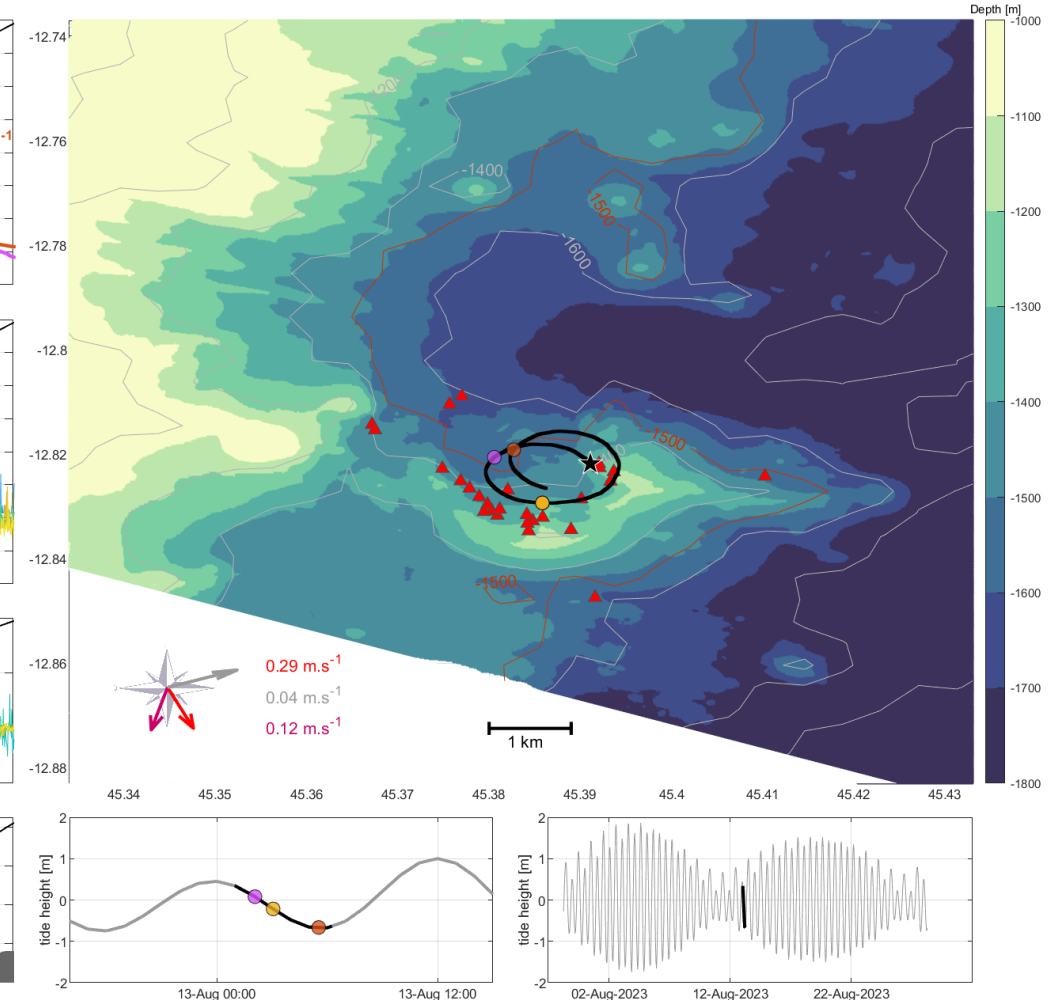
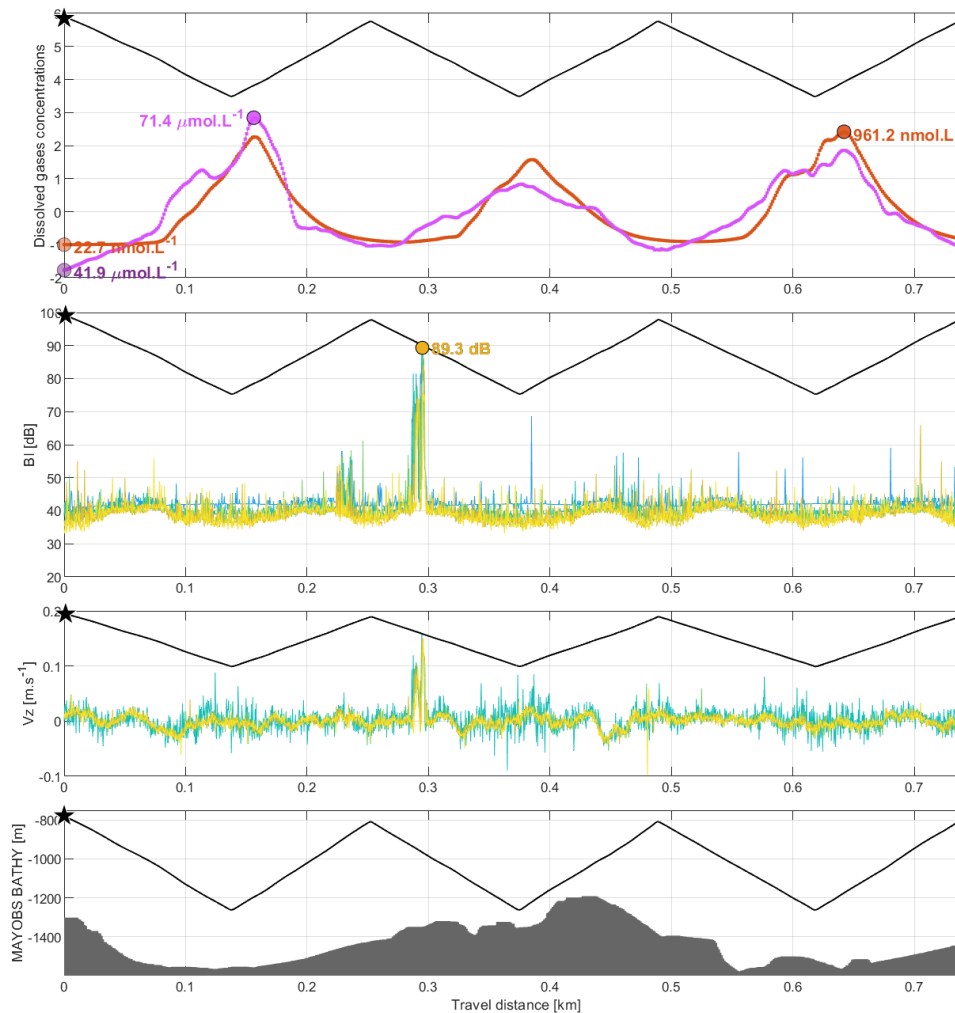
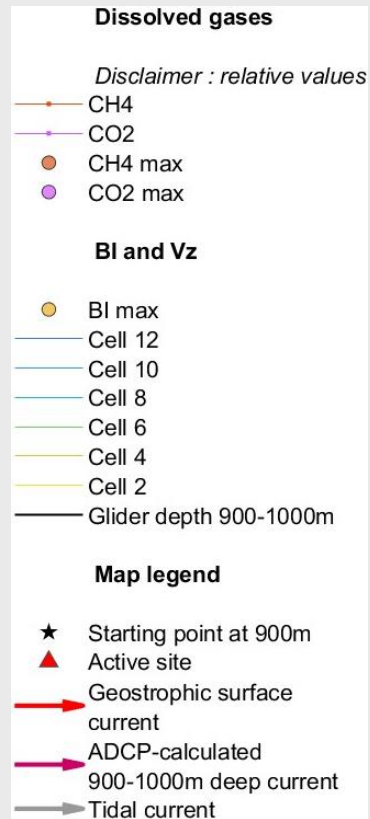




Parameters of interest to track fluid emissions



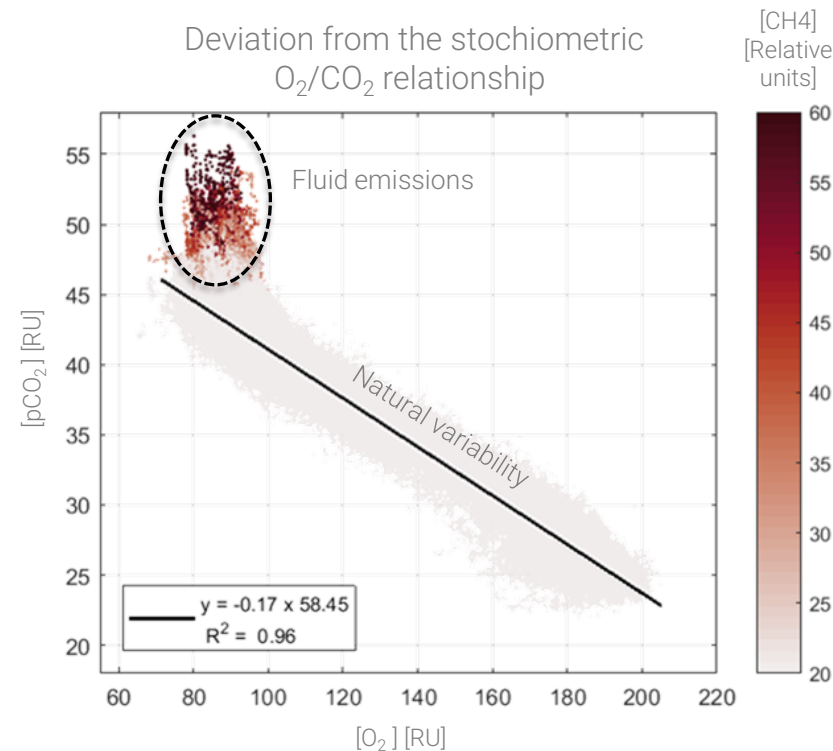
- Example of deep 800-1250 m spiral



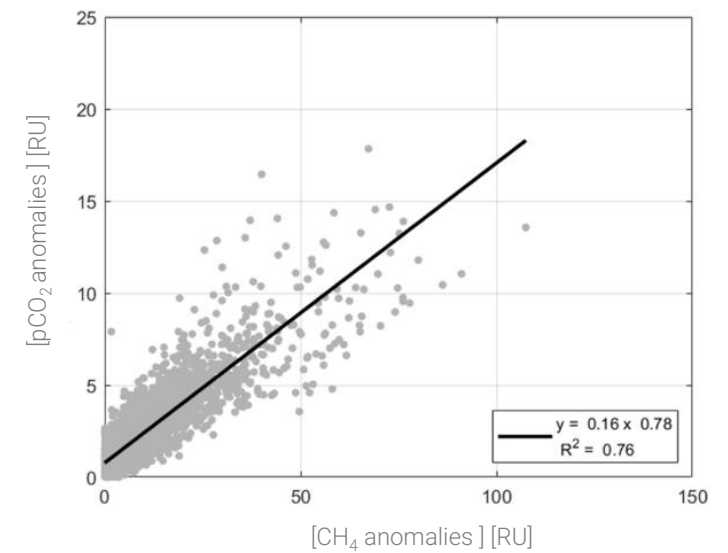


Parameters of interest to track fluid emissions

- Strong relationships
- Deviation from the stoichiometric O_2/pCO_2 ratio
- Correlation between CH_4 and pCO_2 anomalies
- ~ 85% of the transects associated with gas anomalies
- Sporadic detections of BI anomalies (~ 2 % of transects) in the water deep-layer (900-1000 m)
- ~ 95% of the BI anomalies associated with gas anomalies



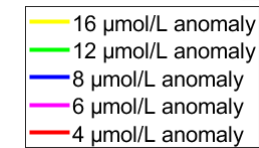
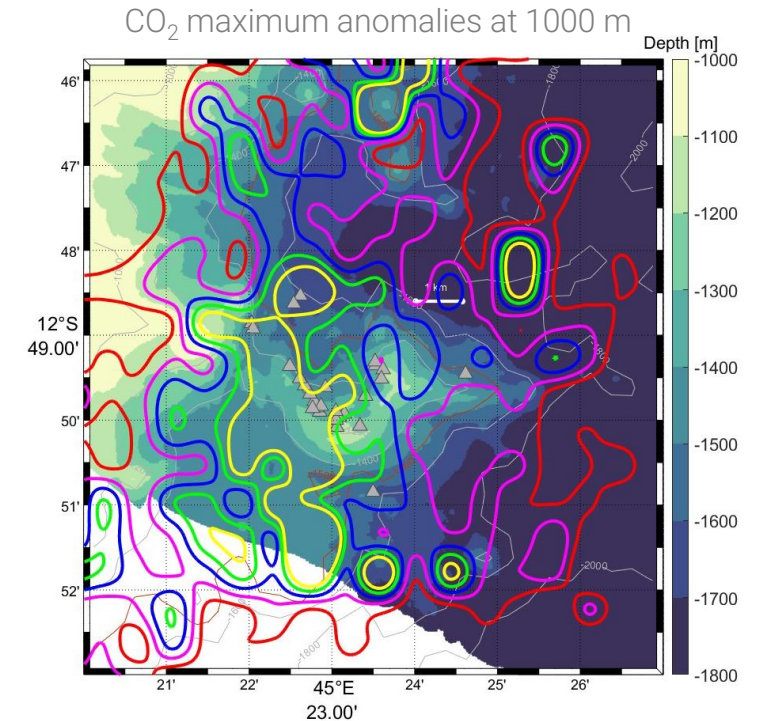
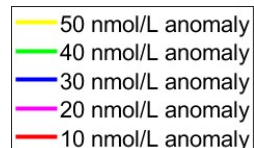
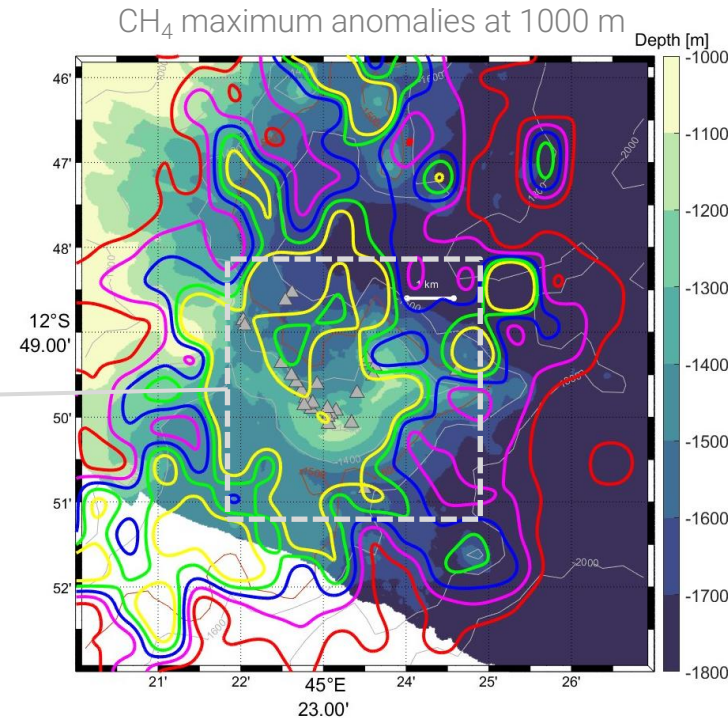
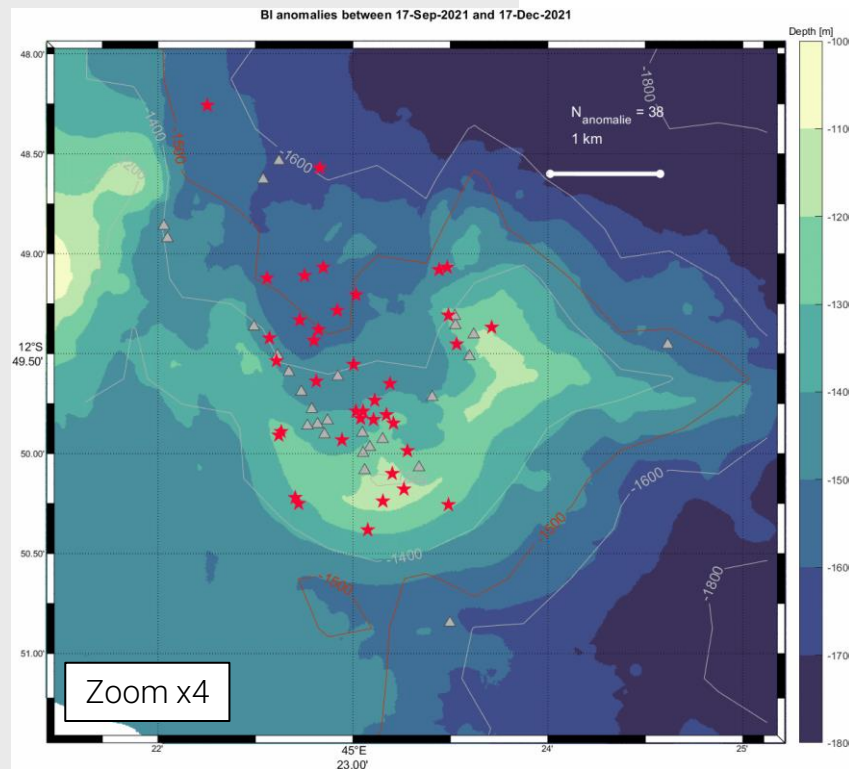
Scatterplot of individual CH_4 vs pCO_2 anomalies





Parameters of interest to track fluid emissions

- Affecting a large area
- Spatial footprint of leak-related anomalies in the 900-1000 m layer impacting a 300 km² area
- Strongest dissolved gas anomalies measured close to know active sites (~ 2 km)
- ~ 95 % of acoustic anomalies are observed in a smaller area (560 m from an active site)
- Farthest acoustic anomaly from an active site detected at ~ 1 km



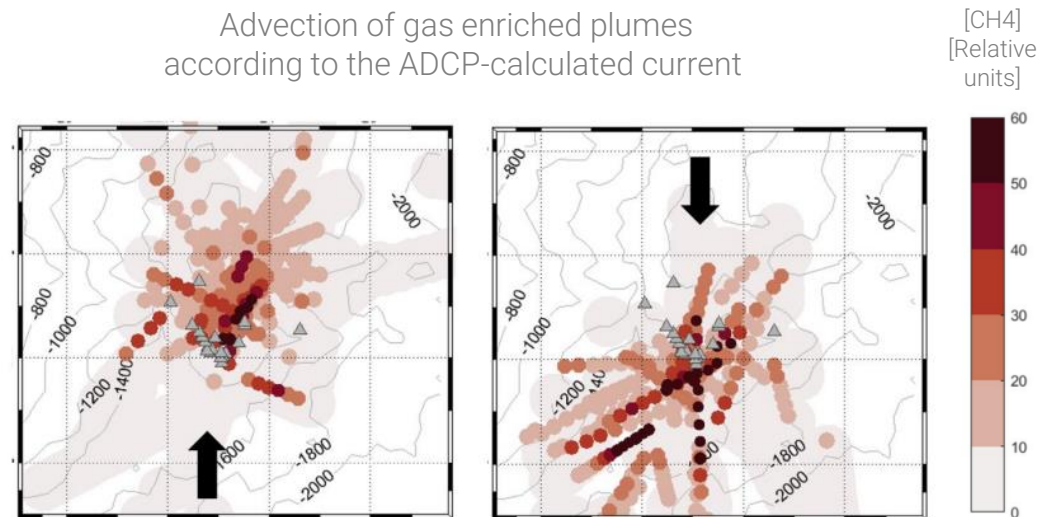
Going further

- New focal areas through a PhD thesis
- Data assessment for dissolved gases sensors
- Dissolved inorganic carbon estimation with a pH sensor integration
- Dissolved gas droplet evolution using a UVP6 (Underwater Vision Profiler)
- Plume dynamics evolution :
 - advection of dissolved gases and droplets
 - dissolved gas flow
 - biogeochemical impact of dissolved gas emissions



1250m SeaExplorer glider

Advection of gas enriched plumes
according to the ADCP-calculated current



Data assessment for monitoring

- Methane sensors calibration with in situ measurements
- Performed at IFREMER facility (Brest, France)
- Pressure cycles up to 150 bar for approx. 24 hours
- Methane concentrations up to 1.5 $\mu\text{mol/L}$ by gas bubbling
- Headspace GC FID HID / Purge&Trap GC FID analysis



Gas chromatography analysis tools

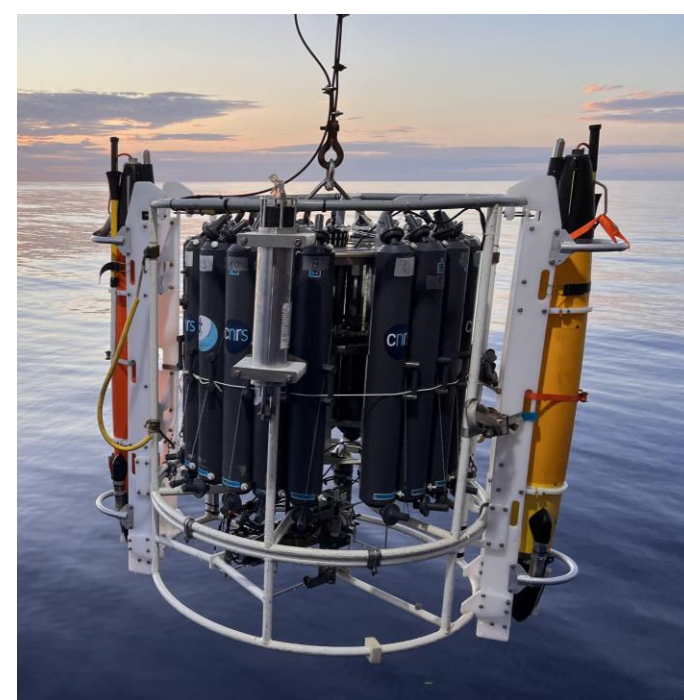


Sensor installation in the hyperbaric chamber

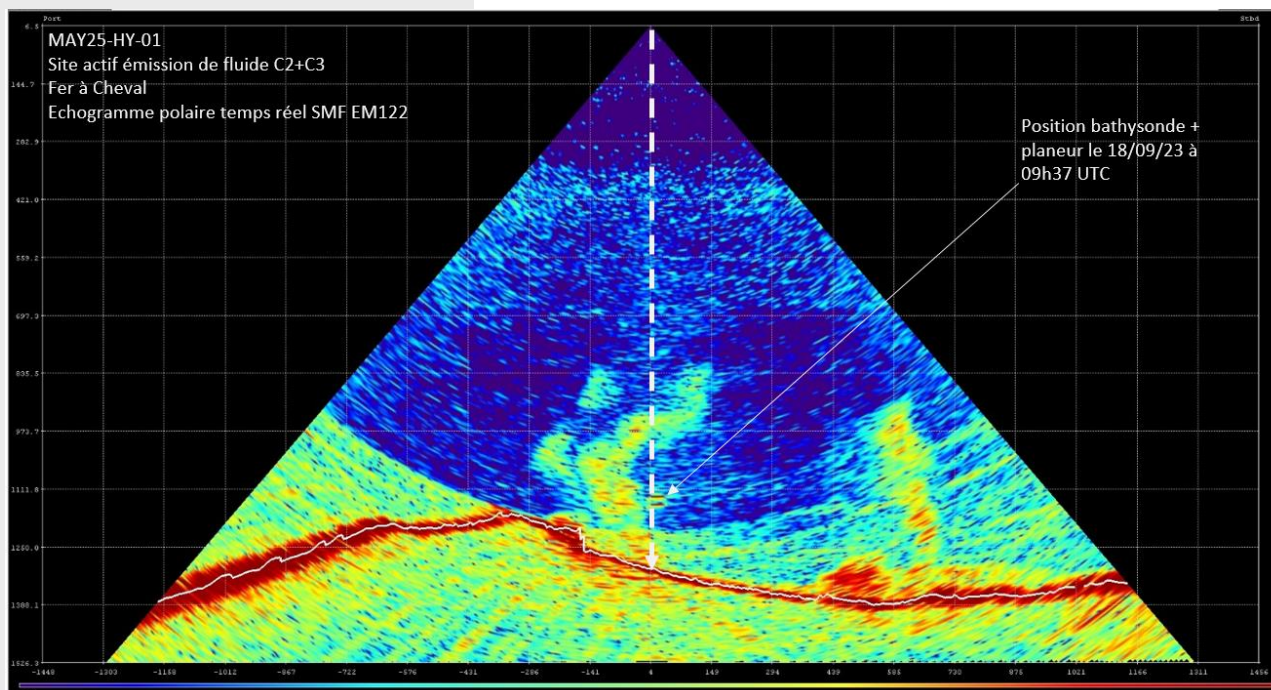
Data assessment for monitoring

- Dissolved gases sensors calibration with in situ measurements
- Carried out during MAYOBS25 cruise (September 2023)
- 3 CTD cast performed at 1000/1250 m depth
- Water samples analyzed with Headspace GC FID HID / Purge&Trap GC FID
- Echogram obtained with EM122 multibeam echosounder

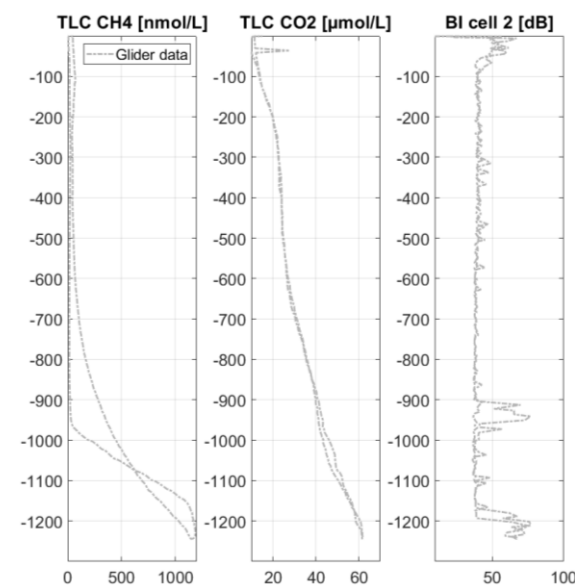
Image credit: C. Poncelet and
C. Scalabrin, IFREMER



Glider installation on the CTD cast



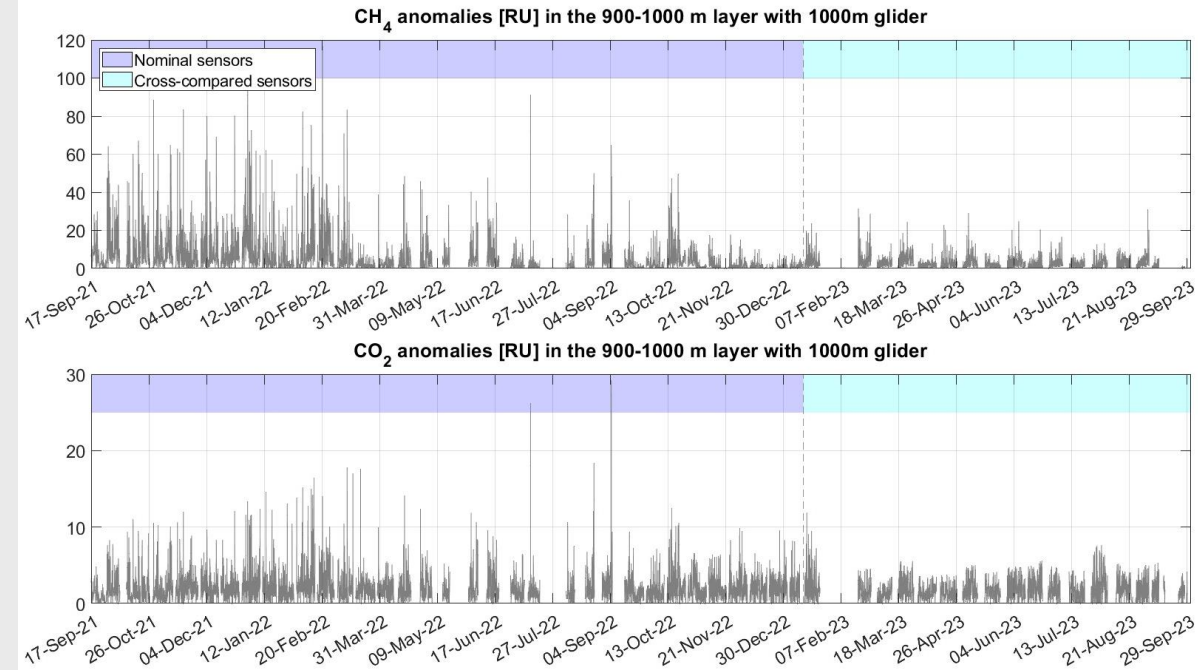
Echogram obtained during the first CTD cast



TLC dissolved gases and ADCP data



Conclusions



- Take-home messages
 - A glider equipped with a large suit of sensors is a relevant tool to continuously monitor volcanic fluid emissions with a potential to be a real-time warning system
 - Newly integrated sensors (CH₄ (2014), ADCP (2016), CO₂ (2019)) and related algorithms were efficient in detecting significant anomalies using both chemical and physical sensors
 - Long-term series show important variability in the dissolved gas anomalies
-
- What's next ?
 - The mission is still ongoing and the data are still under analysis
 - Synergy with other platforms (ROV, CTD cast, models, seismic data) to better understand the underlying processes (dispersion/advection/dissolution)
 - Interaction with a large scientific community (earth science to oceanography and chemistry) studying this 5 years old volcano



Acknowledgements

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