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

A.Heumann[1,2]

F.Margirier[1], L. Beguery[1], E. Rinnert[2], C. Scalabrin[2], P. Lherminier[2]

[1]ALSEAMAR, Rousset, France [2]IFREMER, Plouzané, France

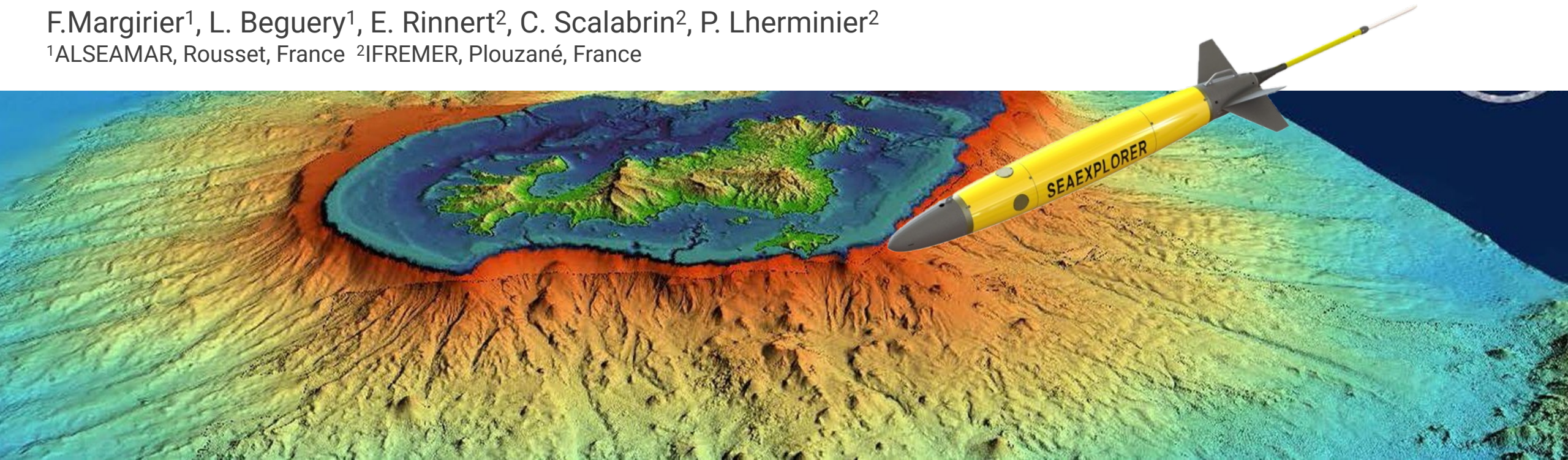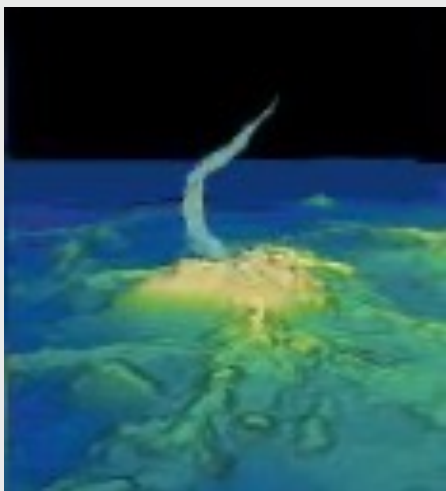Image credit: C. Poncelet and
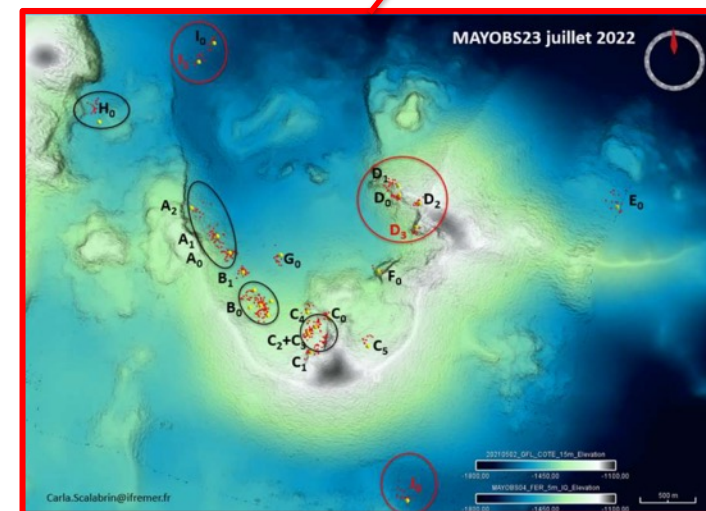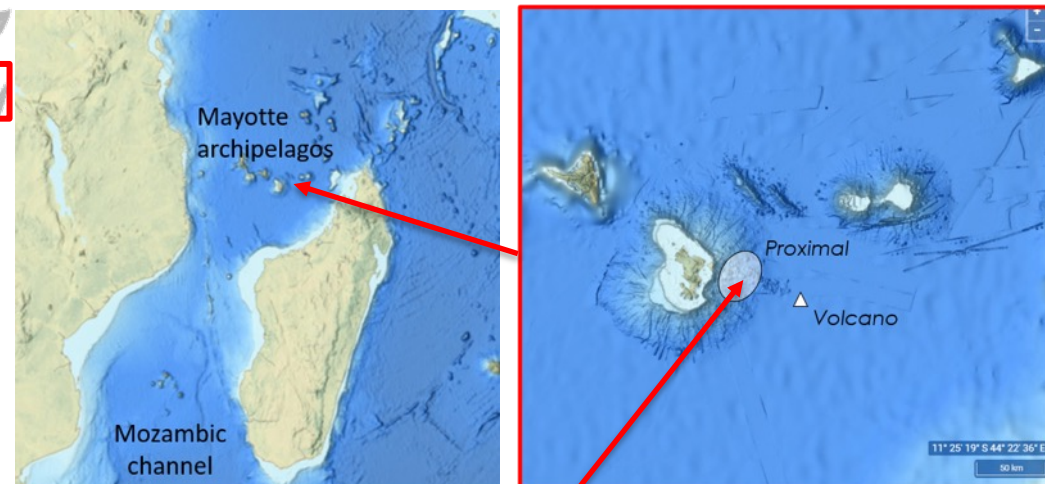C. Scalabrin, IFREMER

Multi-beam image of Mayotte
volcano

An outstanding area

Data credit: B. Lambrieu and C. Scalabrin
IFREMER

- Regional context

- 2018 : Unprecedented seismo-volcanic crisis at Mayotte

- 2019 : Discovery of a new volcano, Fani Maoré, located ~ 50 km away from the coast (Feuillet et al., 2021, Nature Geoscience) at a 3500m depth

- 2019 : Discovery of active seafloor fluid emissions located just 10 km from the coast (Horseshoe area)

- 2019 : Implementation of the REVOSIMA monitoring network both on land and at sea (25 MAYOBS cruises)

- 2020-2023 : Continuous emergence of several active sites in the Horseshoe area

REVOSIMA
doi:10.18715/MAYOTTE.REVOSIMA

MAYOBS
doi:10.18142/291

Active sites map at proximal
(Horseshoe area, 23 sites)

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A unique glider mission

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

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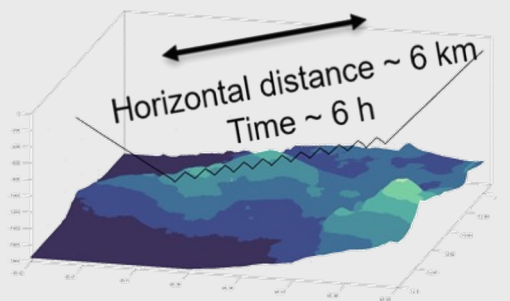
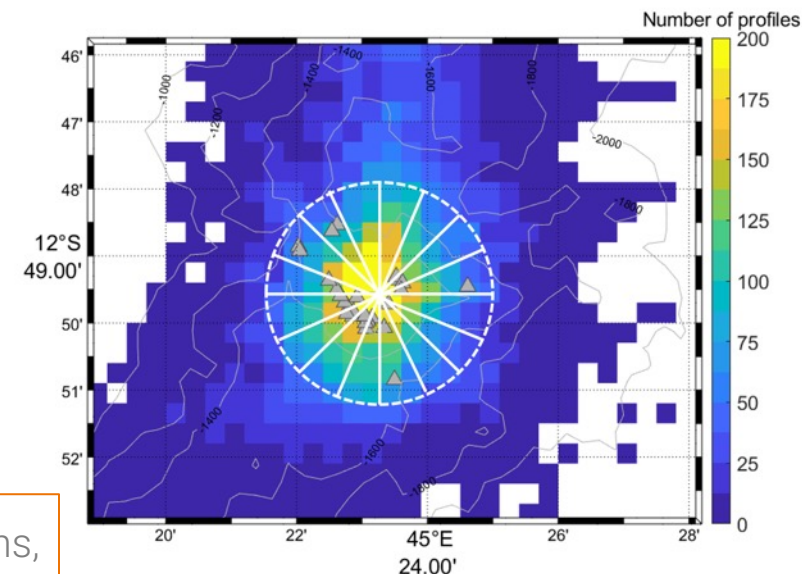Navigation strategy (multi-yos) chosen for the 1000 m depth survey

- Glider monitoring

- 1000m glider survey
- Radial sampling strategy
- Focus on the 900-1000 m layer (seafloor ~ 1400m)

- 1250m glider survey
- 1250m version of SeaExplorer deployed in August 2023
- Spiraling sampling strategy focused on the Horseshoe area
- Focus on the 800-1250 m layer
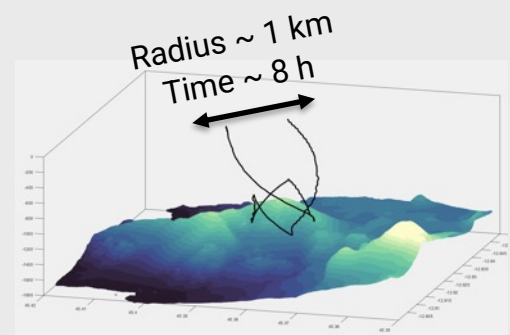
Navigation strategy (spiral) chosen for the 1250 m depth survey

→ 29 months of quasi-continuous acquisition (77 glider missions, ~22k profiles, 2M2 measuring points)


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

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Glider payload

| Sensor	Manufacturer	Measured parameters	Sampling period (s)	Data processing
CTD + DO	Seabird Scientific	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 ;)
- pCO_2 (Fiedler et al., 2013 ; Fietzek et al., 2014)
- CH_4 (Meurer et al., 2021)
- GPCTD (Garau et al., 2011)
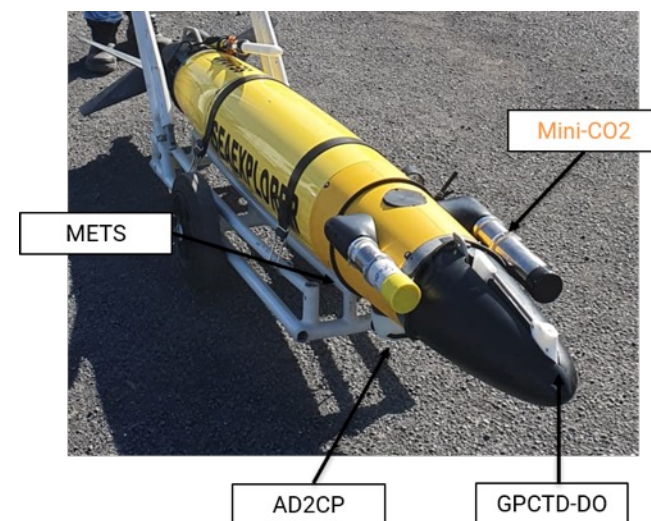
Usual sensors and dedicated gas payload

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Oceanographic baseline in a poorly documented area
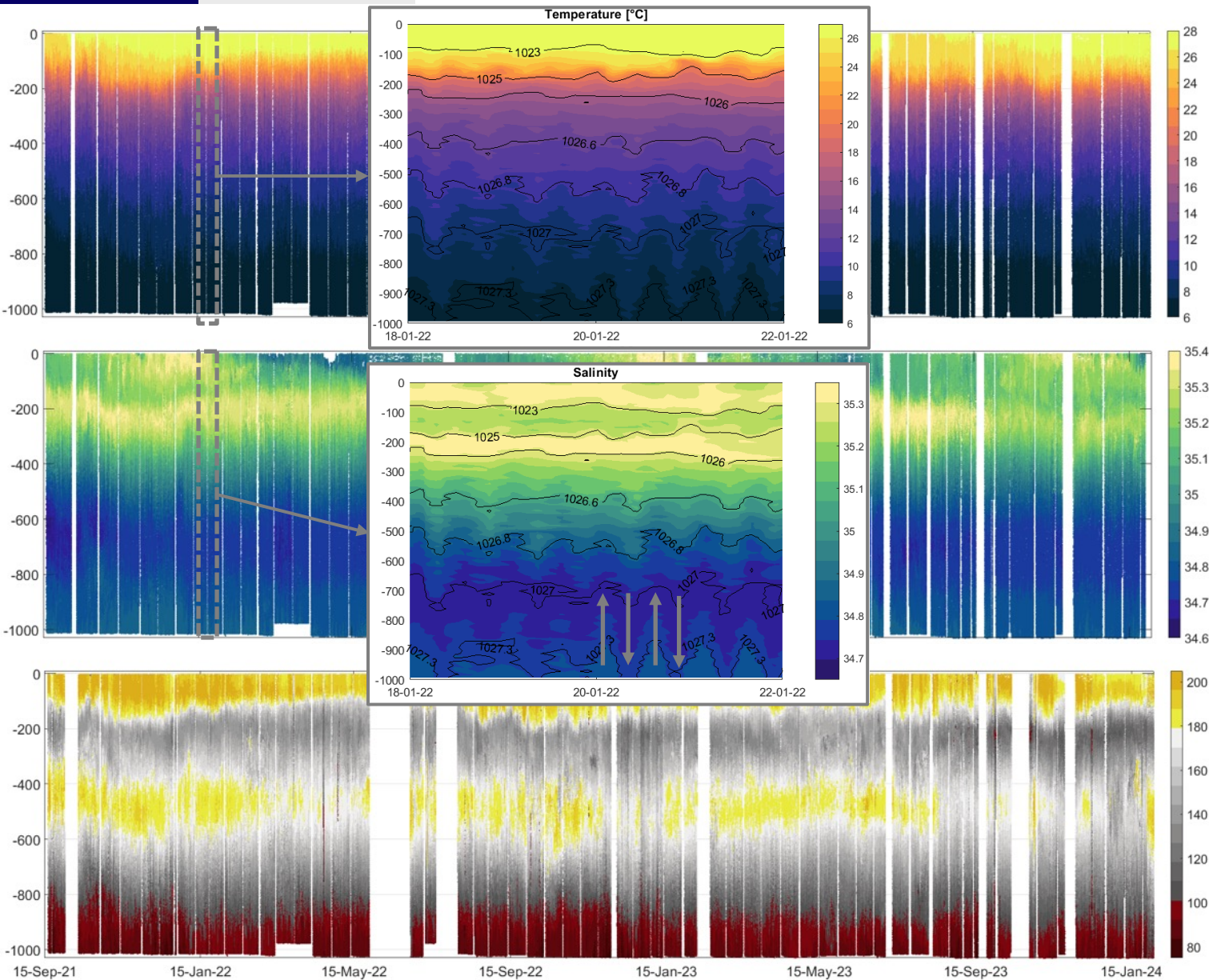

Temperature [°C]

Dissolved Oxygen [μmol/kg]
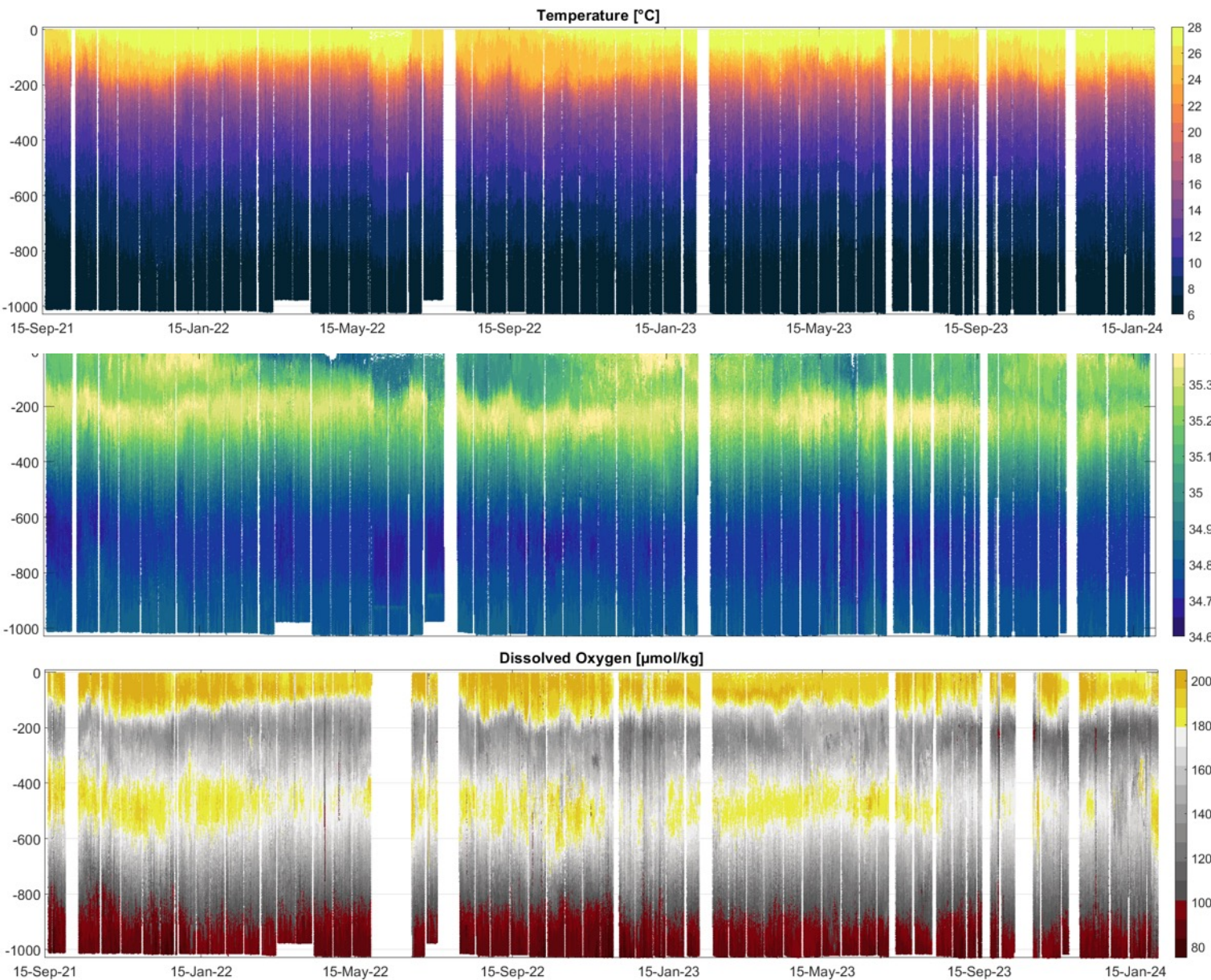
- Flow in the Mozambique channel

- 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
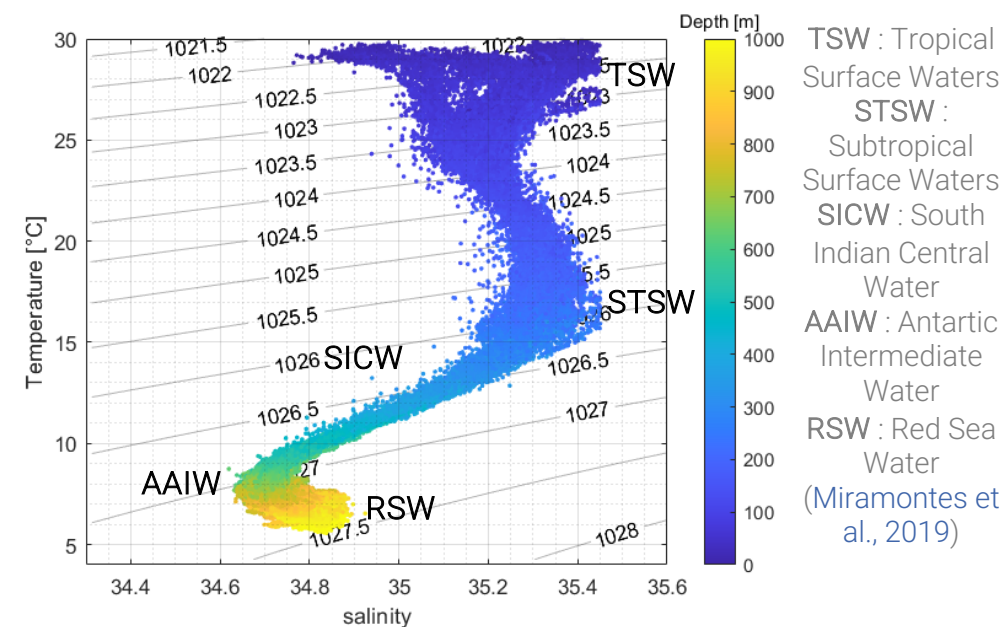

MAP Geostrophic current 05-Dec-2021
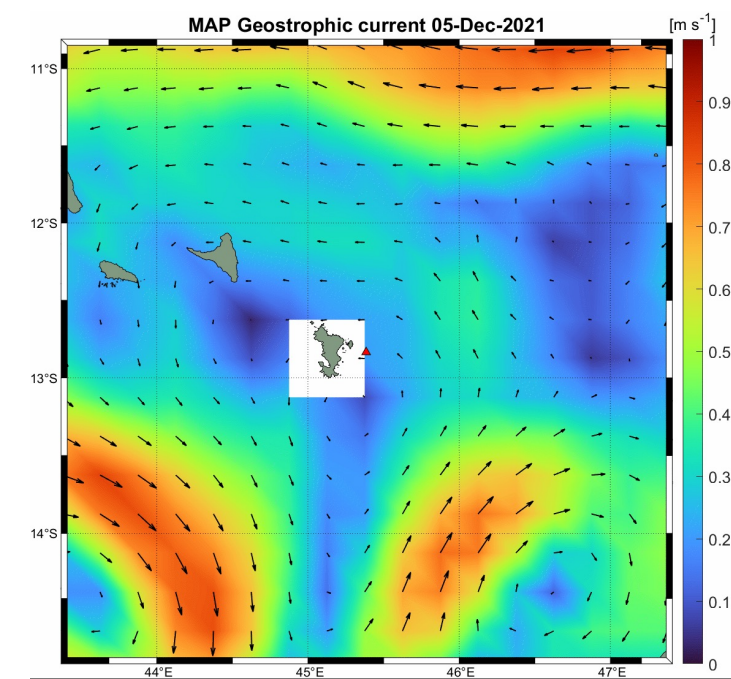
Map of geostrophic current in the Mayotte area. The survey area is indicated by the red triangle

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# Oceanographic baseline in a poorly documented area

- Daily to hourly fluctuations

- Daily fluctuations
- High-frequency variability
- Surface variations

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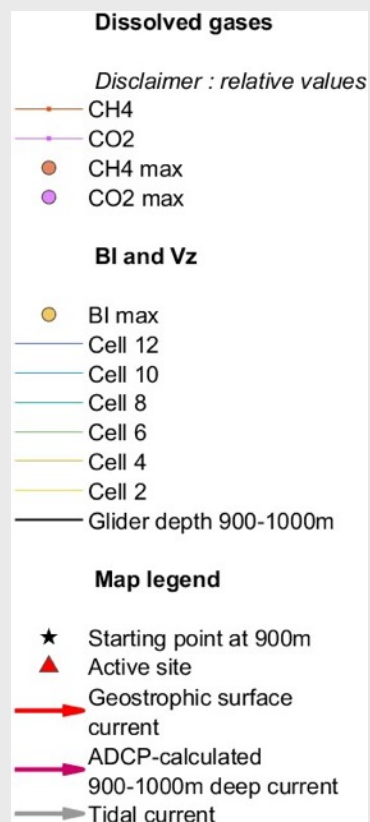(Miramontes et al., 2019)

Temperature-salinity diagram and water masses

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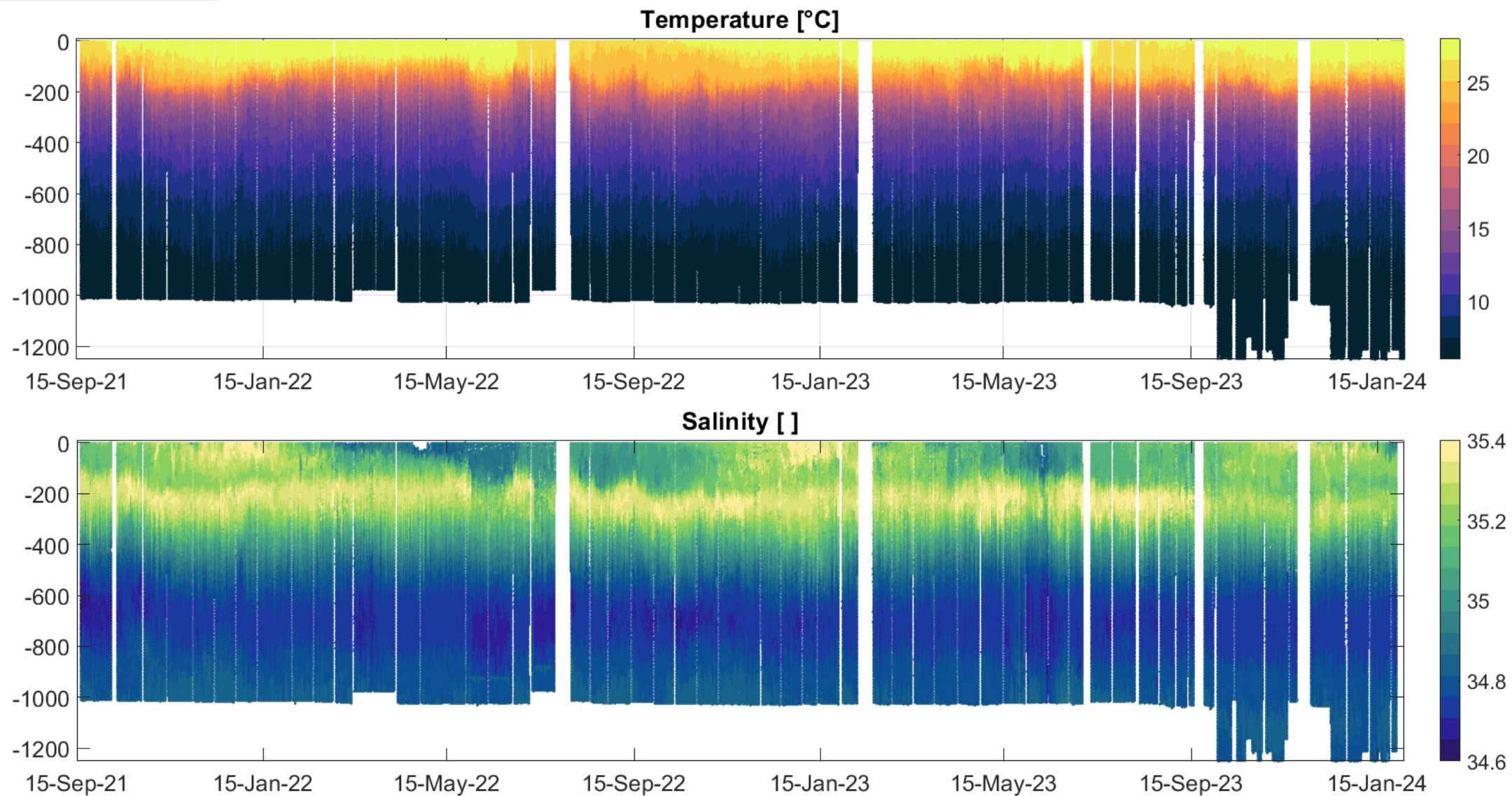# Parameters of interest to track fluid emissions
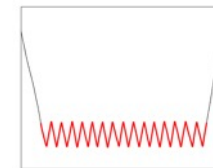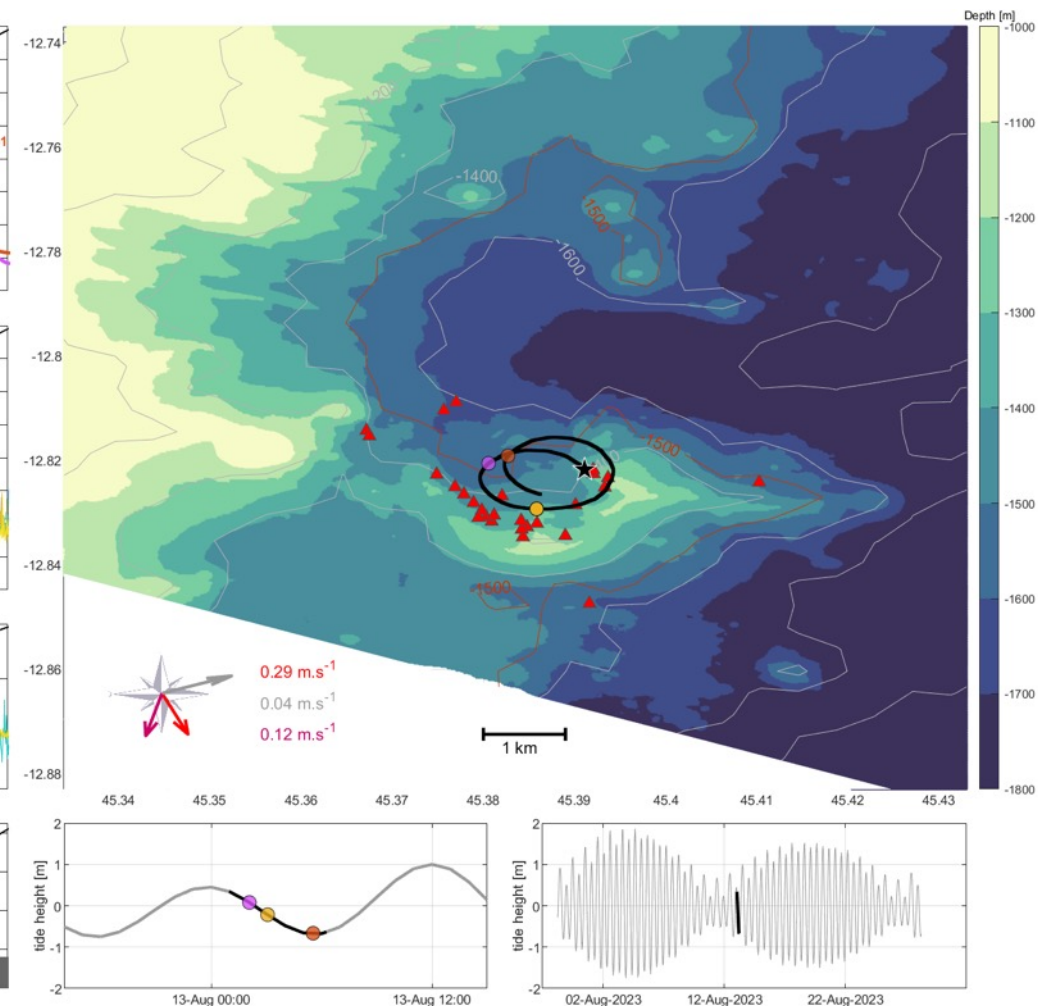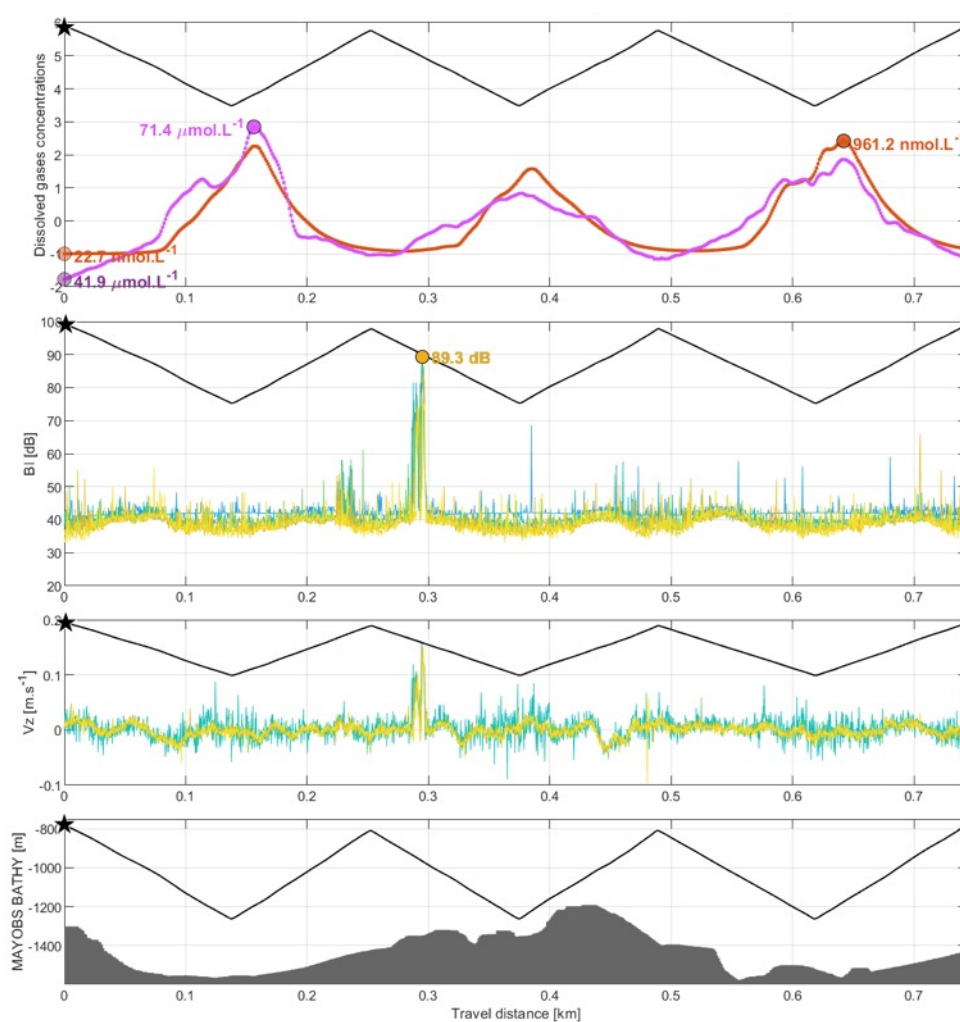
- Example of deep 900-1000 m transect
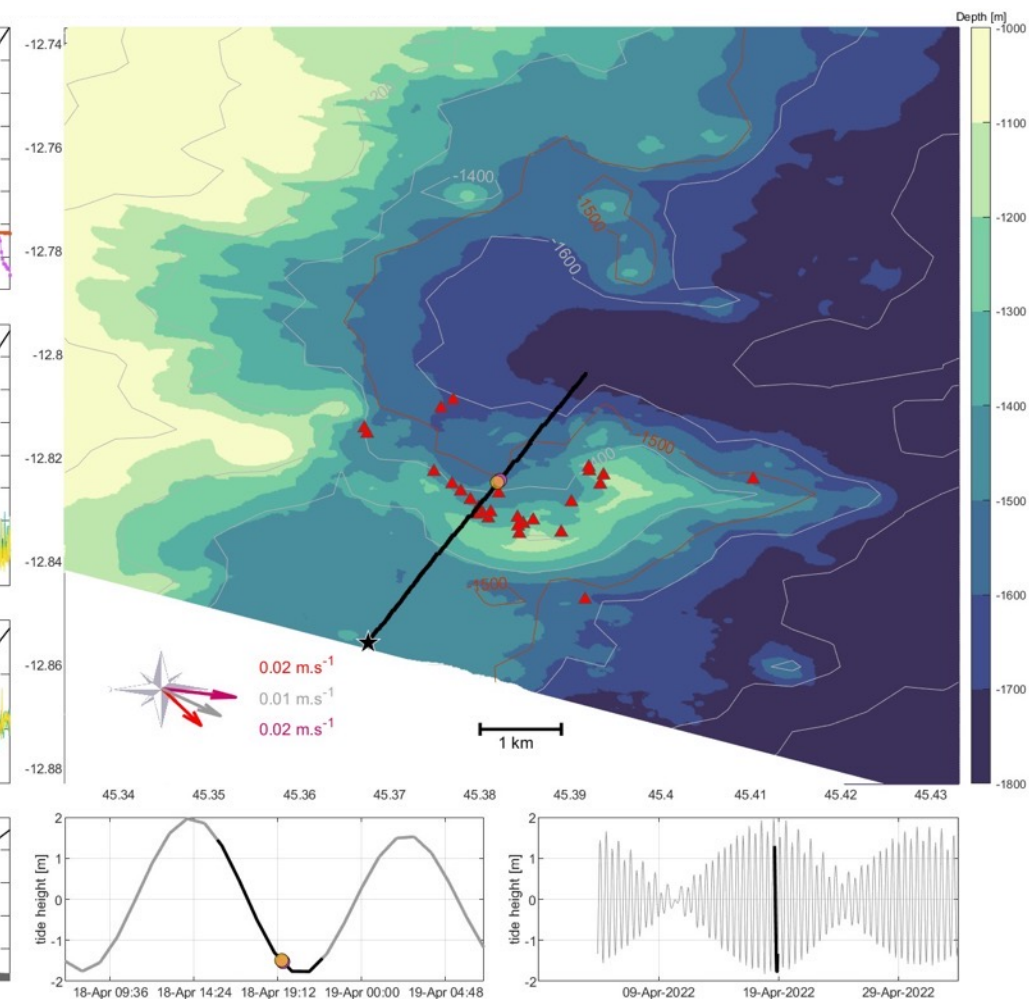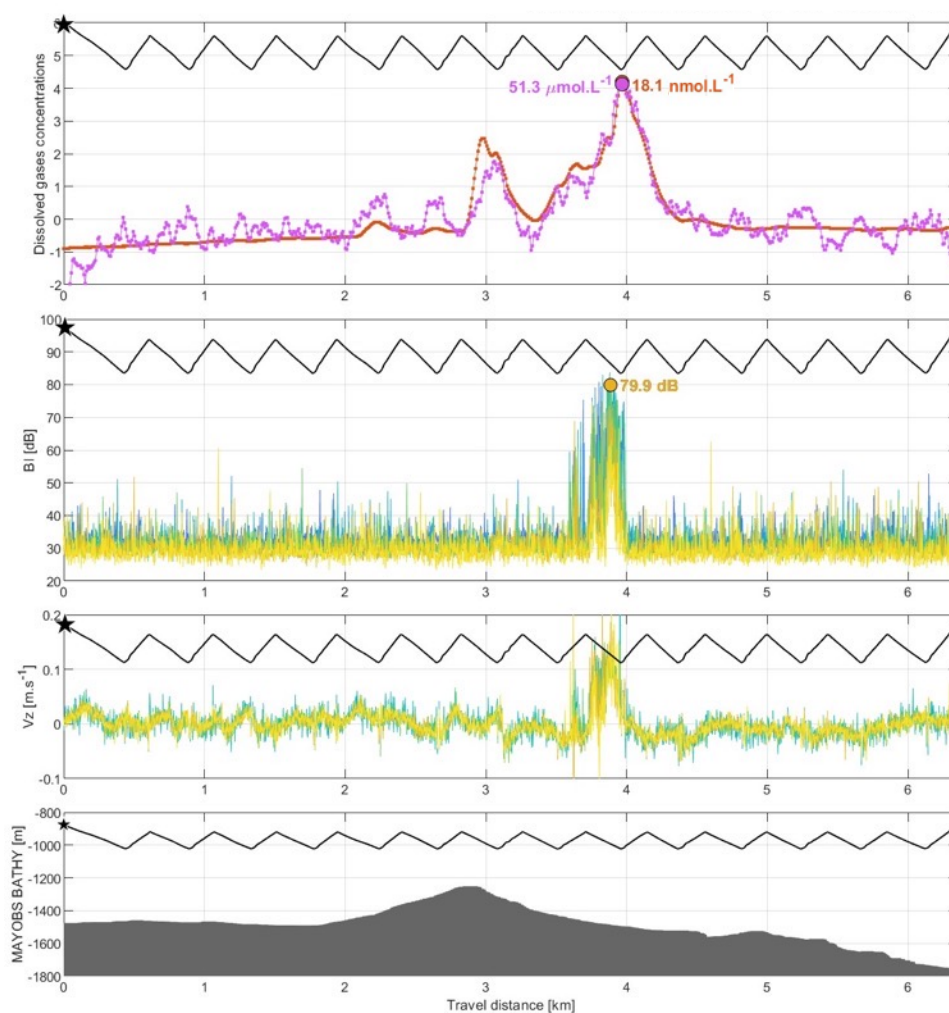
1250m glider currently tested in Mayotte

Parameters of interest to track fluid emissions

- Example of deep 800-1250 m spiral
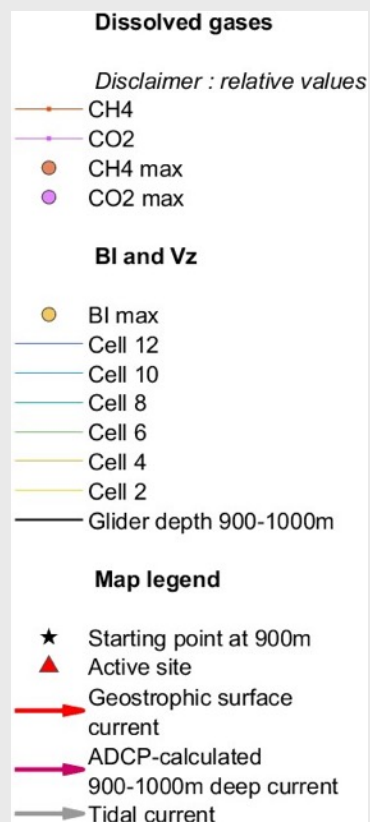
Parameters of interest to track fluid emissions
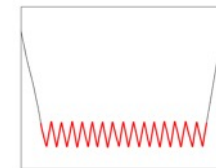
- Dissolved gas average vertical distribution
- Increasing pCO_2 concentrations with depth and mirrors O2 distribution
- Water column naturally depleted in CH_4
- Spiky signal for backscatter index

TLC : Time-lag corrected
UR : Relative units

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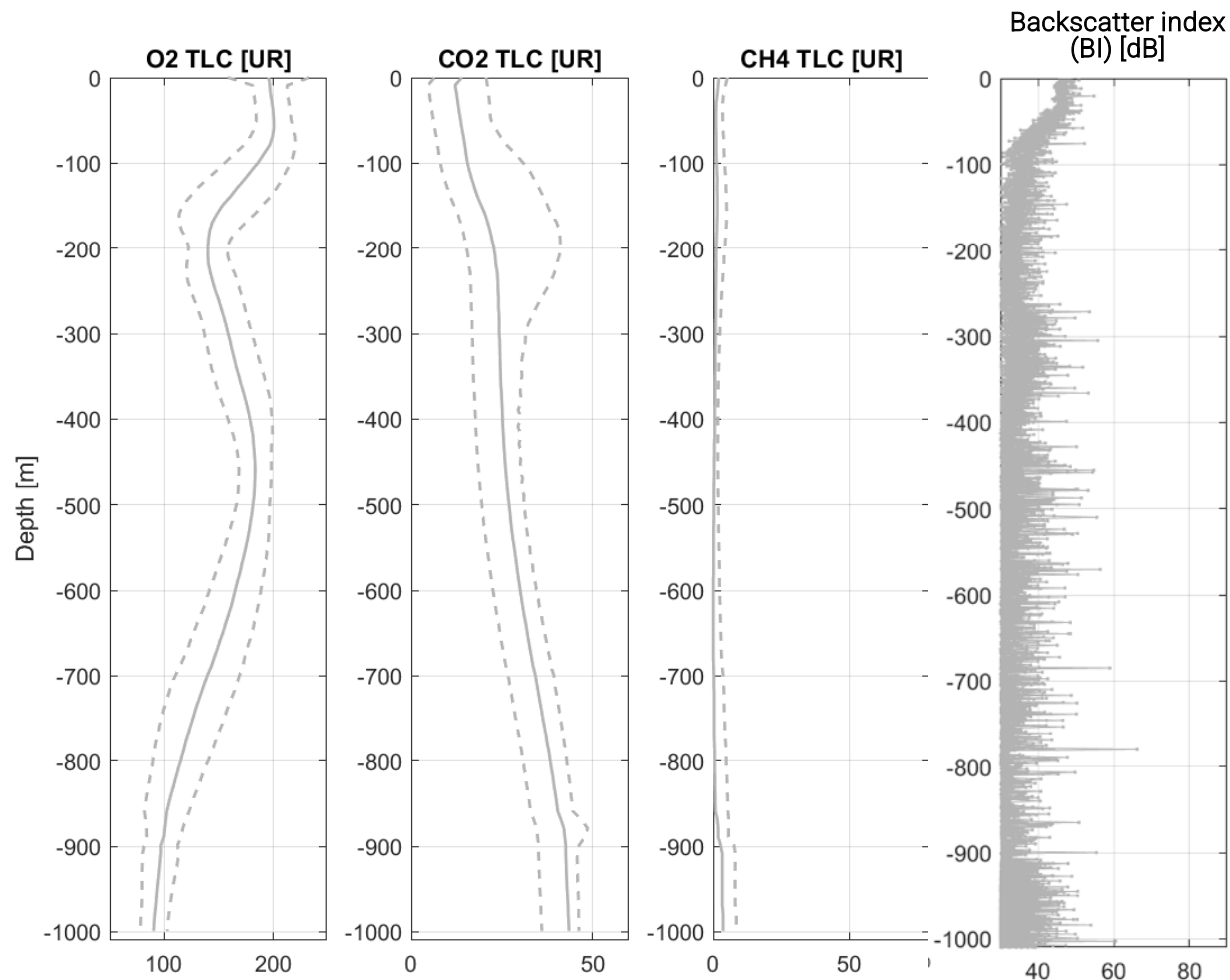
Parameters of interest to track fluid emissions

- Example of vertical profiles with anomalies
- Scale factor of 15 for anomalies observed at 1250m

TLC : Time-lag corrected
UR : Relative units

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)
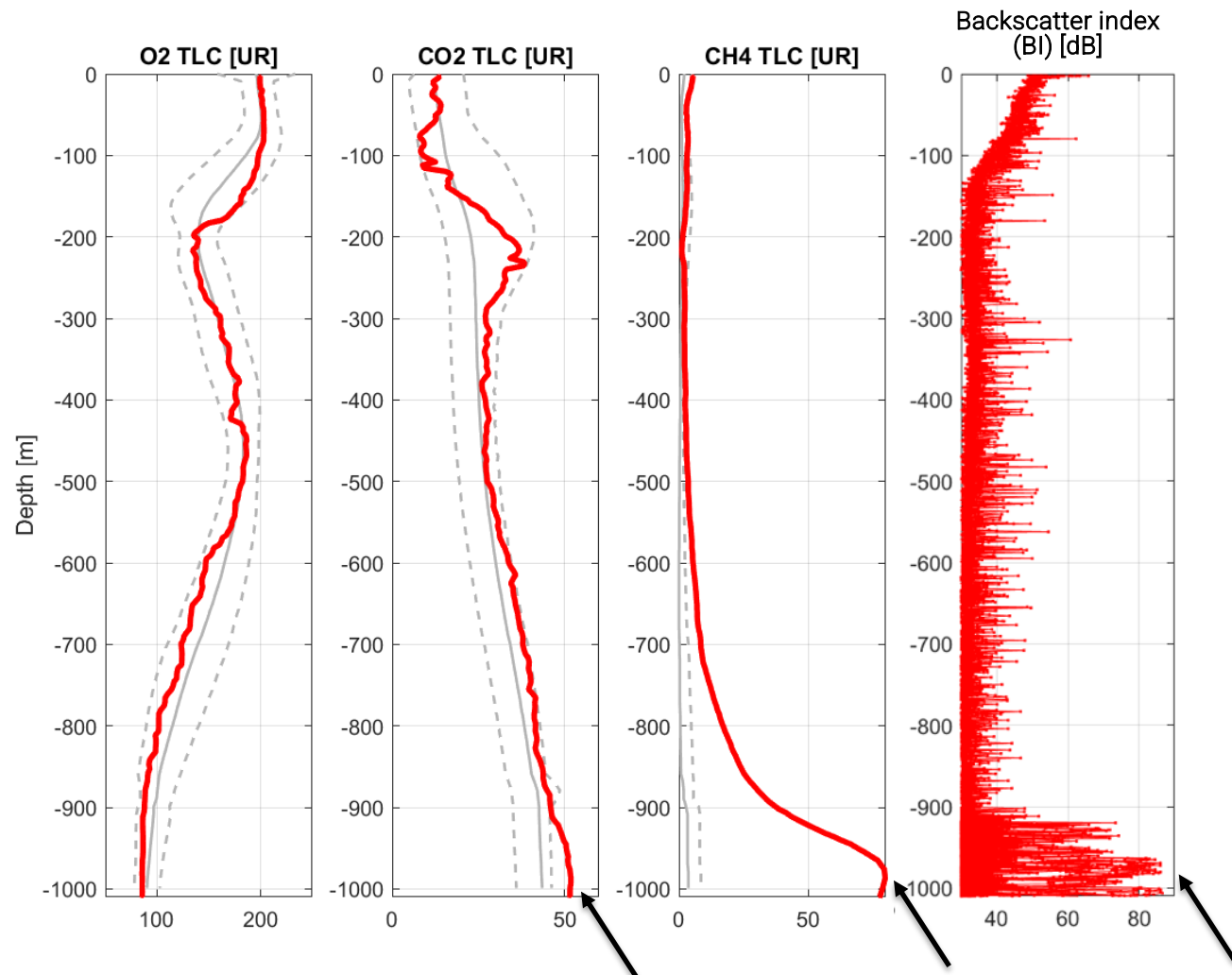- ~ 95% of the BI anomalies associated with gas anomalies

Deviation from the stochiometric
O_2/CO_2 relationship

[CH4]
[Relative
units]

Fluid emissions

Natural variability

$y = -0.17 \times 58.45$
$R^2 = 0.96$

[pCO$_2$] [µmol/L RU]

[O$_2$] [µmol/L]

Scatterplot of individual CH_4 vs pCO_2 anomalies

$y = 0.16 \times 0.78$
$R^2 = 0.76$

[pCO$_2$ anomalies] [µmol/L RU]

[CH$_4$ anomalies] [nmol/L RU]

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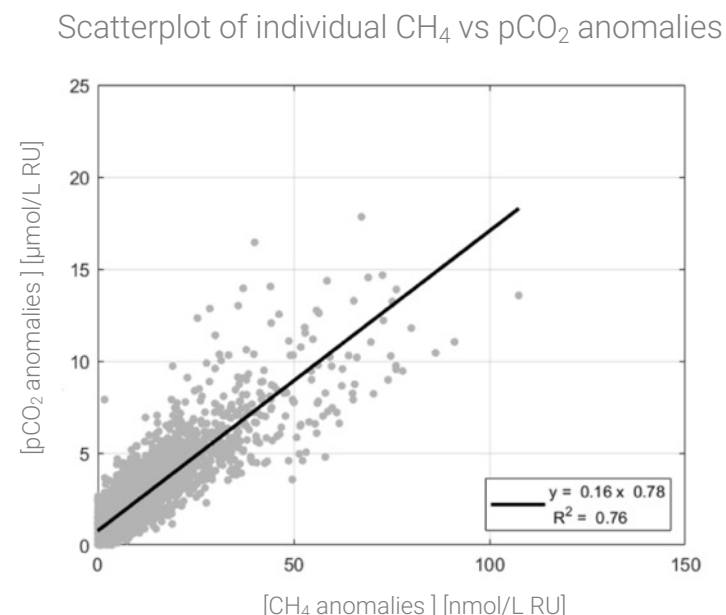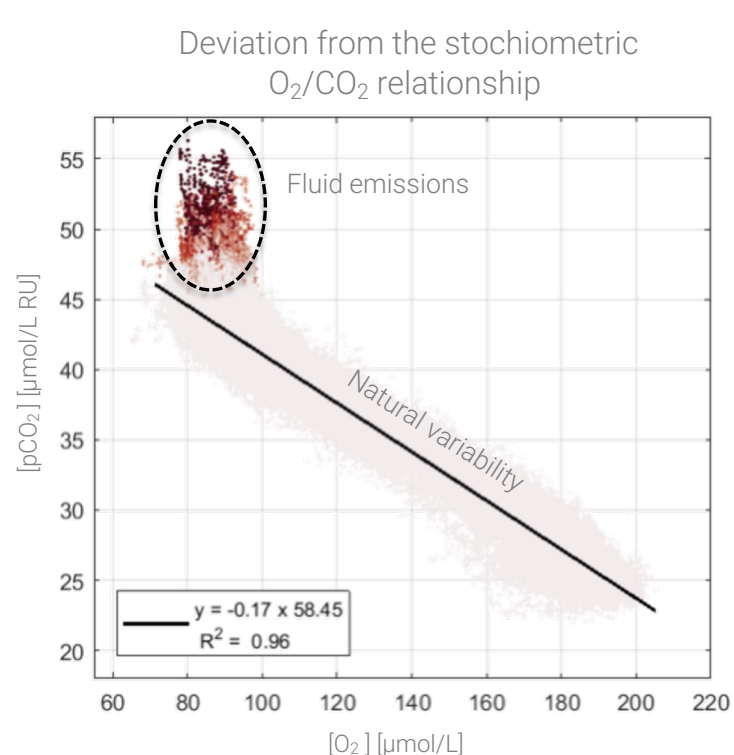
Parameters of interest to track fluid emissions

- Affecting a large area

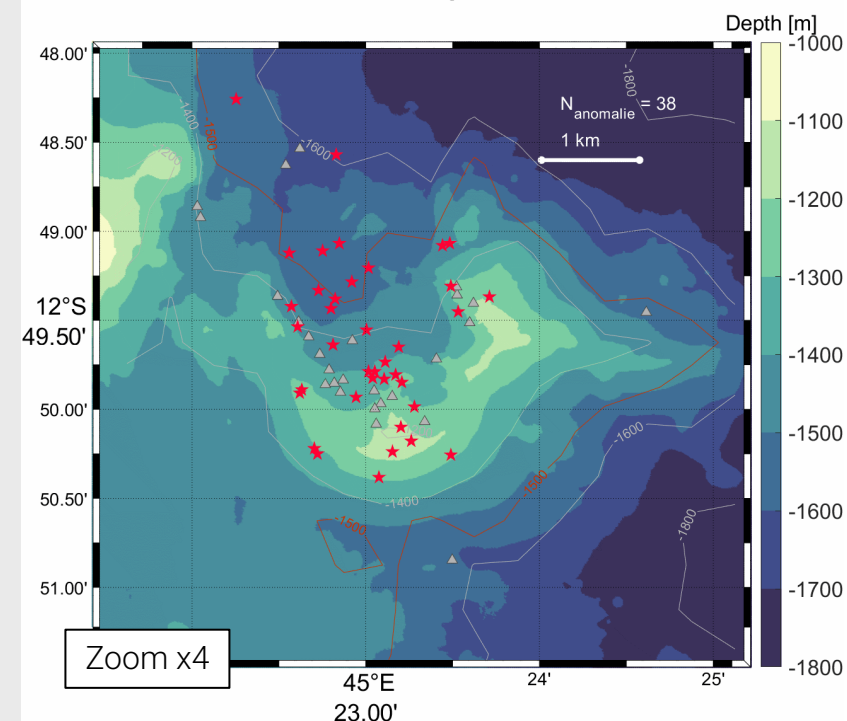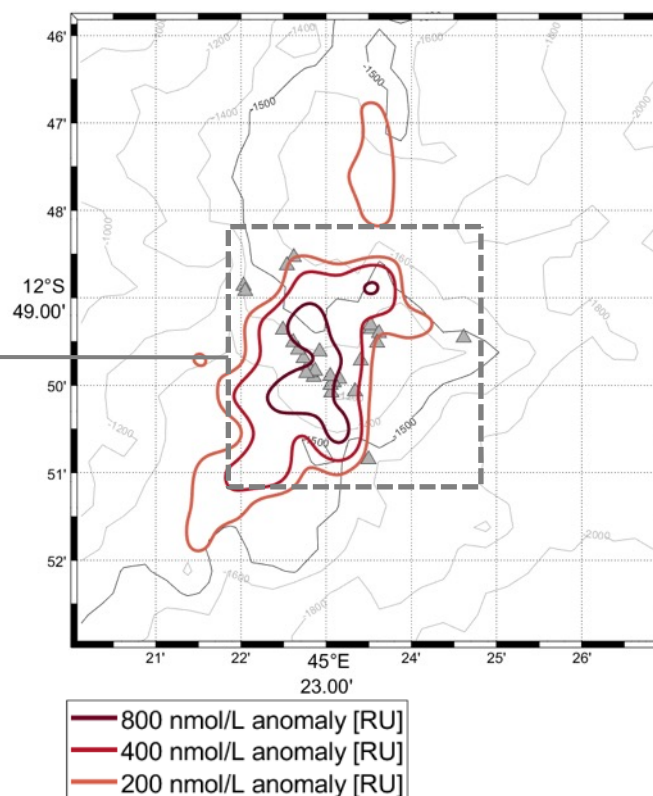- Spatial footprint of seep-related anomalies impacting a 300 km² area
- Strongest dissolved gas anomalies measured close to known active sites (~ 2 km)
- ~ 95 % of acoustic anomalies are observed in a smaller area (560 m from an active site)
- Farthest acoustic anomaly from an active site detected at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

BI anomalies between 17-Sep-2021 and 17-Dec-2021

$N_{anomalie}$ = 38

1 km

Zoom x4

CH_4 maximum anomalies at 1250 m

CO_2 maximum anomalies at 1250 m

— 800 nmol/L anomaly [RU]
— 400 nmol/L anomaly [RU]
— 200 nmol/L anomaly [RU]

— 12 µmol/L anomaly [RU]
— 10 µmol/L anomaly [RU]
— 8 µmol/L anomaly [RU]

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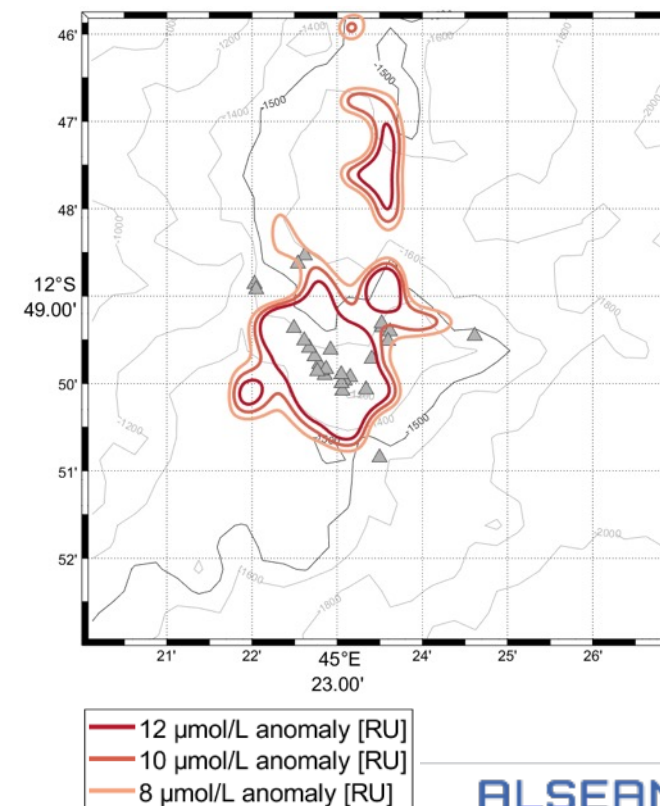
Data assessment for monitoring

- 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 µmol/L by addition of CH_4 saturated solution
- 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 casts 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
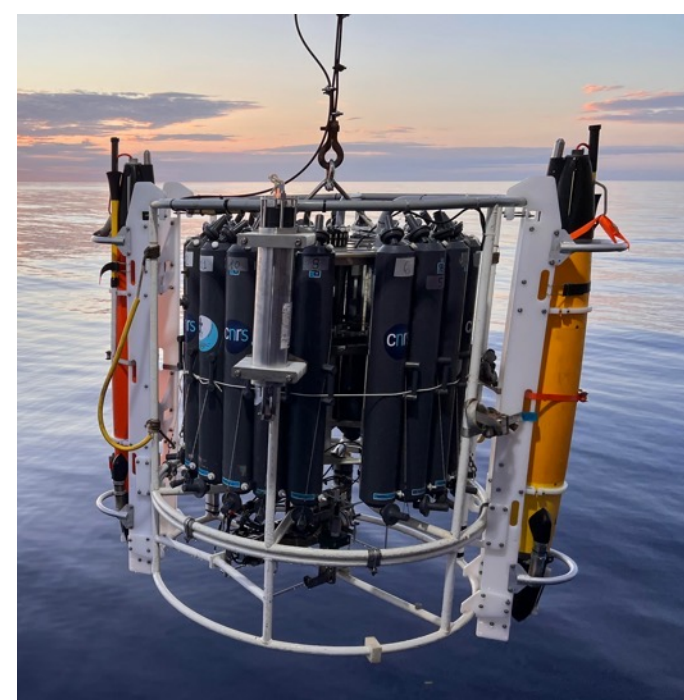
Glider installation on the CTD cast
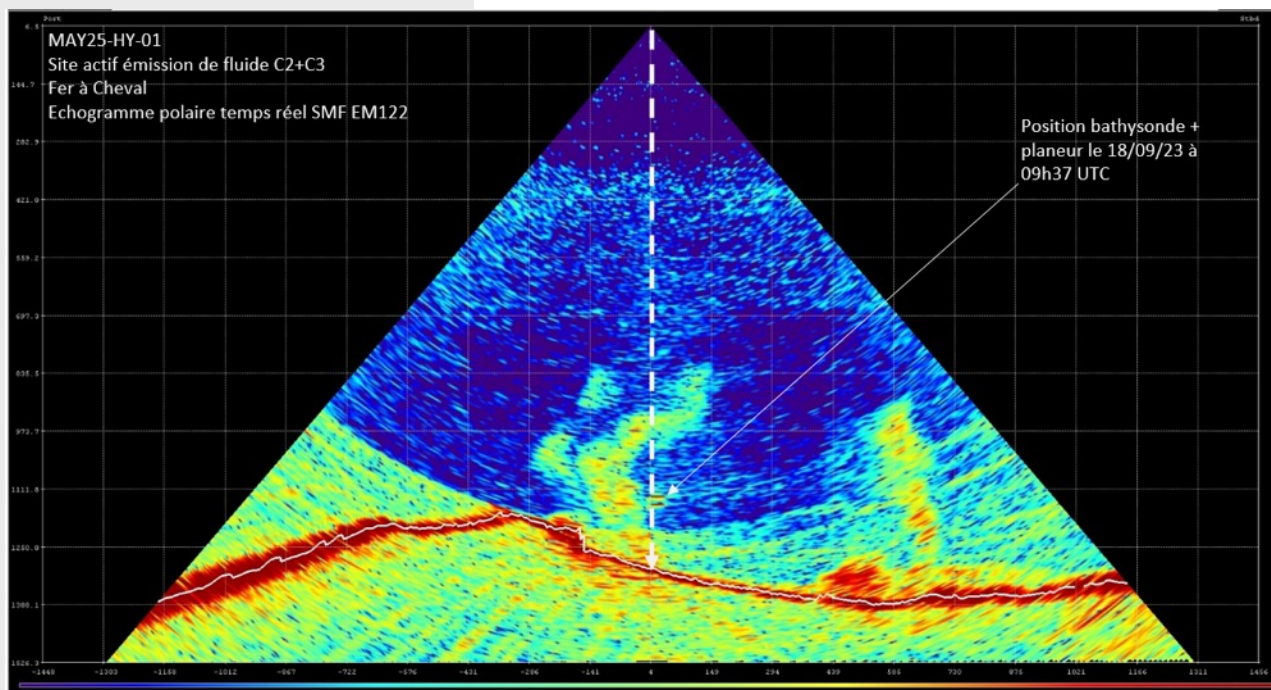
Echogram obtained during the first CTD cast

TLC dissolved gases and ADCP data

Going further

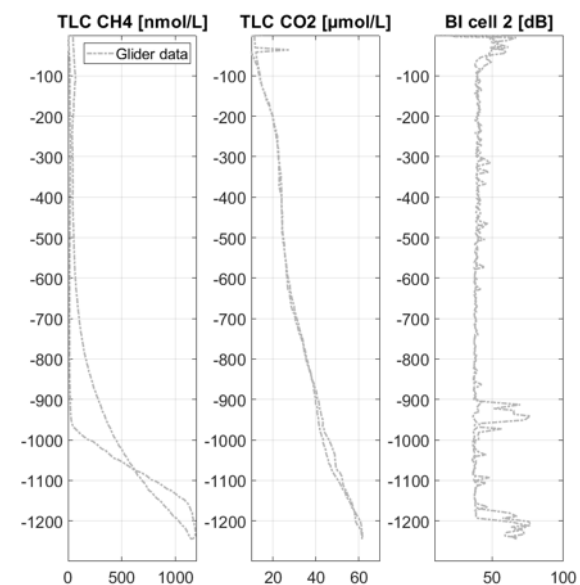- New focal areas through a PhD thesis

- Data assessment for dissolved gases sensors
- Dissolved inorganic carbon estimation with a pH sensor integration (ANB OC1250)
- Dissolution of CO_2 droplet 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

[CH4]
[Relative units]

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Conclusions
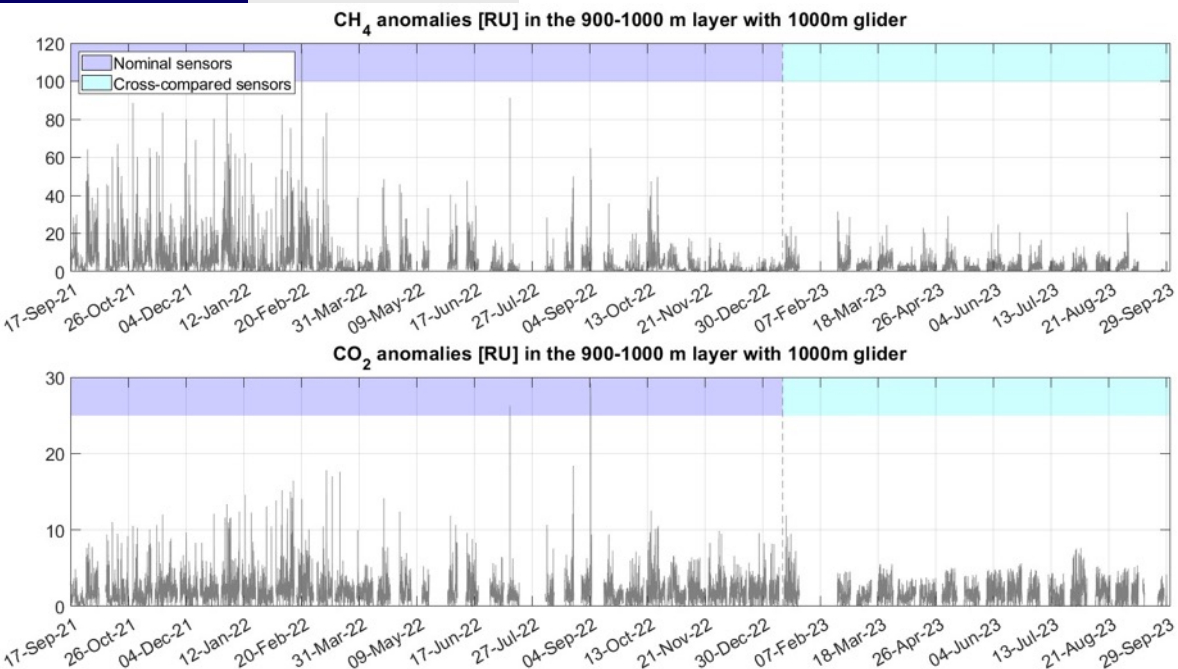
CH$_4$ anomalies [RU] in the 900-1000 m layer with 1000m glider

CO$_2$ anomalies [RU] in the 900-1000 m layer with 1000m glider
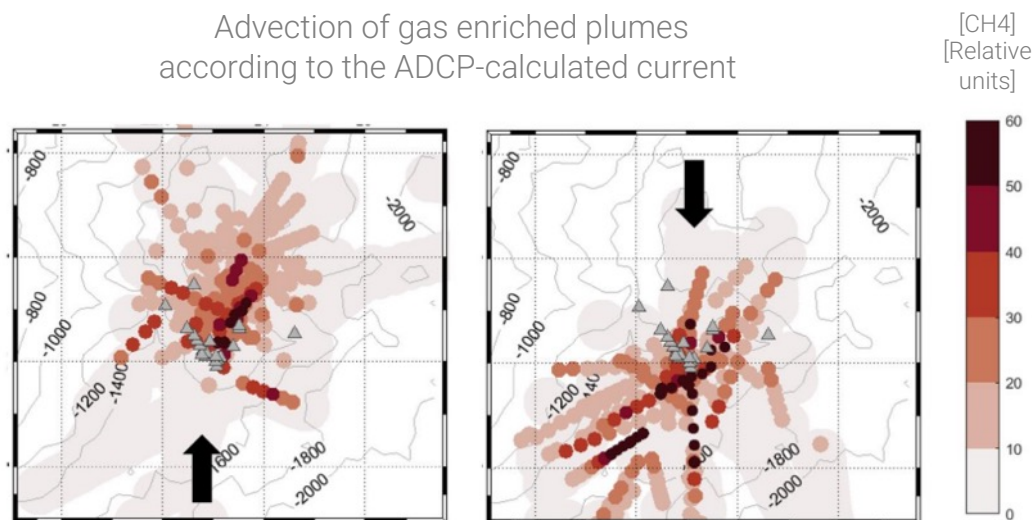
- ▪ Take-home messages
- ▪ A glider equipped with a large suit of sensors is a relevant tool to continuously monitor volcanic fluid emissions with a potential to be a real-time warning system
- ▪ Newly integrated sensors (CH$_4$ (2014), ADCP (2016), CO$_2$ (2019)) and related algorithms were efficient 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

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- IFREMER for their support in the data analysis

Tack tack !

Alexandre HEUMANN
AHEUMANN@alseamar-alcen.com