Use of radionuclides as tracers to study the ocean

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LEGOS, Toulouse, France / LAFARA underground lab

LAFARA
underground radiolab

SOUHAUT Marc

Ingénieur d'études CNRS, Responsable technique et financier

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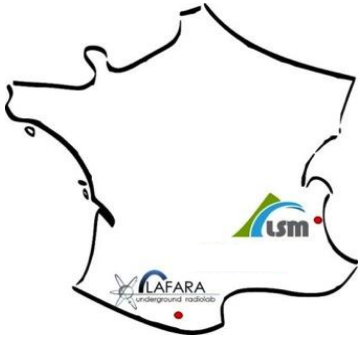
Professeur des universités, Responsable Laboratoire

ZAMBARDI Thomas

Ingénieur de recherche - Responsable qualité et développement

https://lafara.obs-mip.fr

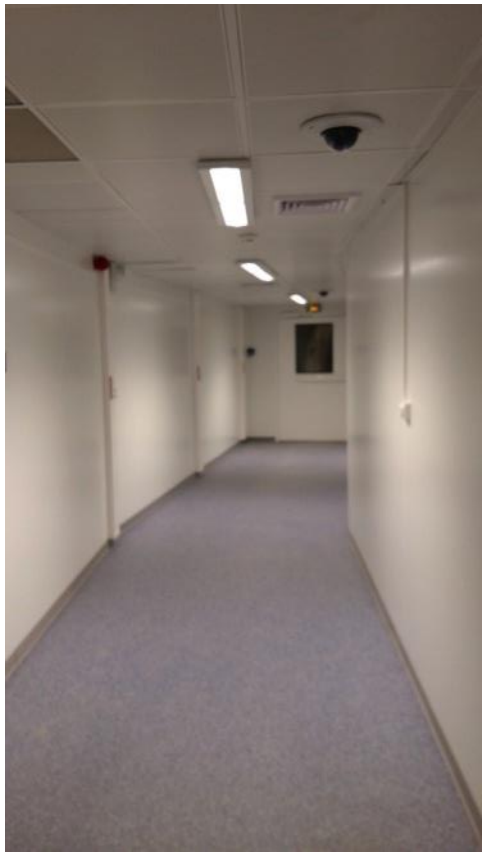


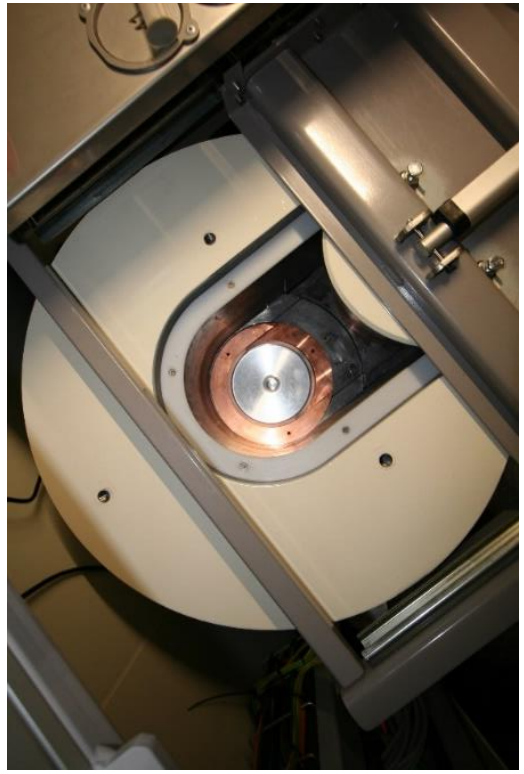
- **Lab created in 2007, Ferrières-sur-Ariège, French Pyrénées (University of Toulouse III)**

- **2007: two gamma spectrometers placed under 85 m of rock in a room of 8 m^2**
- **Liquid nitrogen ; autosamplers**
- **New facility created in 2016**

van Beek et al., JENV 2013

- **New facility created in 2016 (FEDER funding)**





- **5 gamma spectrometers (2 planar ; 3 SAGe-Well detectors)**

Detector ID	HT (kV)	Type	Cap	Supplier	Cooling system	Ge crystal volume (cm^3)	Relative Efficiency (%)	Resolution (keV @ 122 keV)	Resolution (keV @ 1332 keV)
SP	3	Semi-planar	Carbon	Ortec-Ametek	Mirion CP5+	183	54	0.72	1.72
CX	- 3.2	Planar co-axial	Aluminum	Mirion Canberra	Mirion CP5+	230	53	0.95	1.97
P21-1	- 3.5	SAGe Well, Ø21 mm	Aluminum	Mirion Canberra	Mirion CP5+	430	105	0.75	1.85
P21-2	- 3.5	SAGe Well, Ø21 mm	Aluminum	Mirion Canberra	Mirion CP5+	430	107	0.75	1.80
P32	- 4.4	SAGe Well, Ø32 mm	Aluminum	Mirion Canberra	Mirion CP5+	450	114	0.86	2.35

- **Large lead castles** (24 cm)

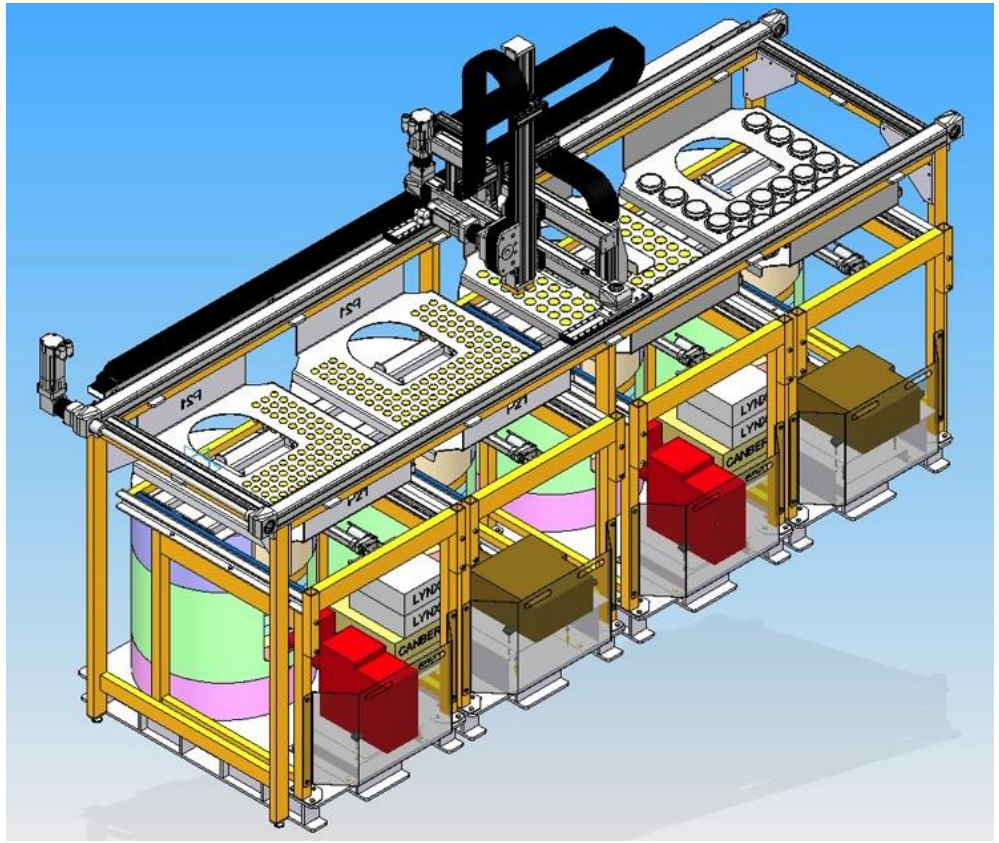
1 cm plexiglass/ 3 cm OFHC copper (Carlier)/ 5 cm VLA + 15 cm LA lead

- **CP5+ electric cooling systems**
- **LYNX electronics ; APEX software**
- **Remotely controled from Toulouse / Use of autosamplers**

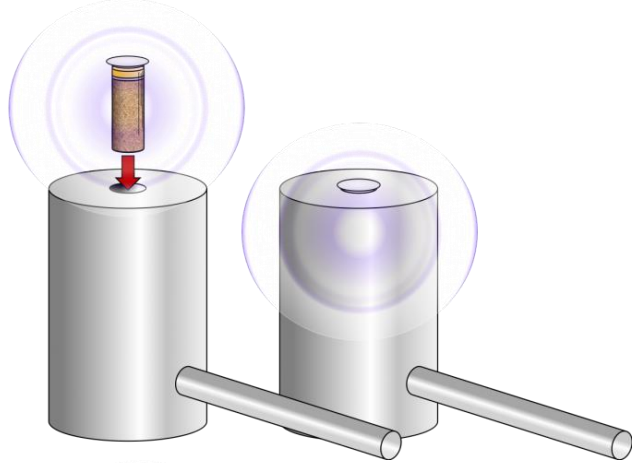
- **Calibration via multi-gamma sources (LEA or CMI) and RGU1, RGTH1, IAEA 447 (IAEA)**
- **Two detectors soon characterized (Labsocs)**
- **ISO/CEI-17025 Norm ; certifications from ASN, French nuclear safety agency**

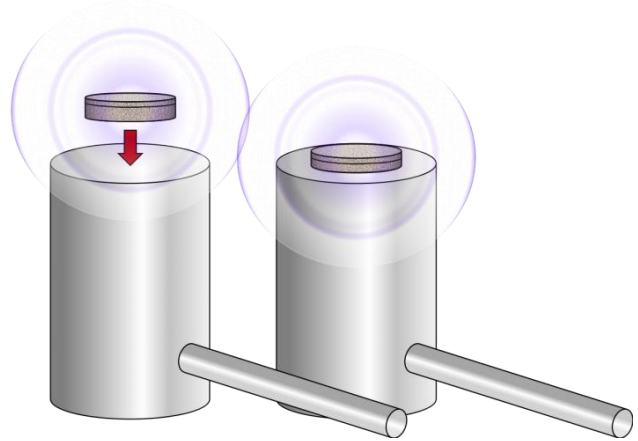
LAFARA underground radiolab

- **Autosampler developped with 2EI company, Tarascon-sur-Ariège, France**
- **Run via APEX software**
- **Large capacity (360 samples)**



LAFARA
underground radiolab





Quality at LAFARA

- **Quality management system**
- **ISO/CEI-17025 Norm – certifications from ASN**
- **11 certifications (water, soil, gas**); need to be renewed regularly
- **Inter-laboratory comparaison exercises (EIL) organized by the French institution IRSN**

TYPE	MATRICE	CATEGORIE	REF.	VALIDITE
1	Eaux	Radium-226 et descendants	1_11	31/12/2024
1	Eaux	Radium-228 et descendants	1_12	31/12/2024
1	Eaux	Uranium pondéral	1_17	31/12/2024
2	Sol/ sédiments	Émetteurs gamma > 100 keV	2_01	30/06/2021
2	Sol/ sédiments	Émetteurs gamma < 100 keV	2_02	30/06/2021
2	Sol/ sédiments	Radium-226 et descendants	2_11	30/06/2025
2	Sol/ sédiments	Radium-228 et descendants	2_12	30/06/2025
2	Sol/ sédiments	Uranium pondéral	2_17	30/06/2025
5	Gaz	Émetteurs gamma > 100 keV	5_01	30/06/2022
5	Gaz	Émetteurs gamma < 100 keV	5_02	30/06/2022
5	Gaz	Gaz halogénés	5_14	30/06/2022

LAFARA underground radiolab

ANALYSES at LAFARA underground radiolab

- Analysis of the low radioactivity levels in **environmental samples** and **various materials**

- Specialized in **Marine geochemistry**

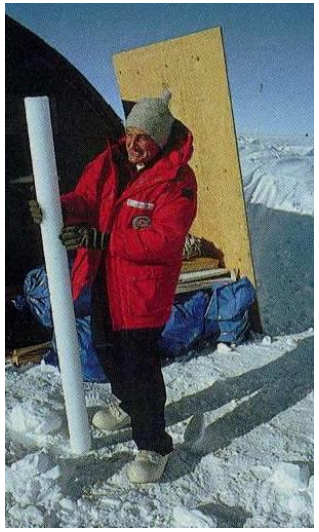
- Study of the **ocean circulation** (climate)

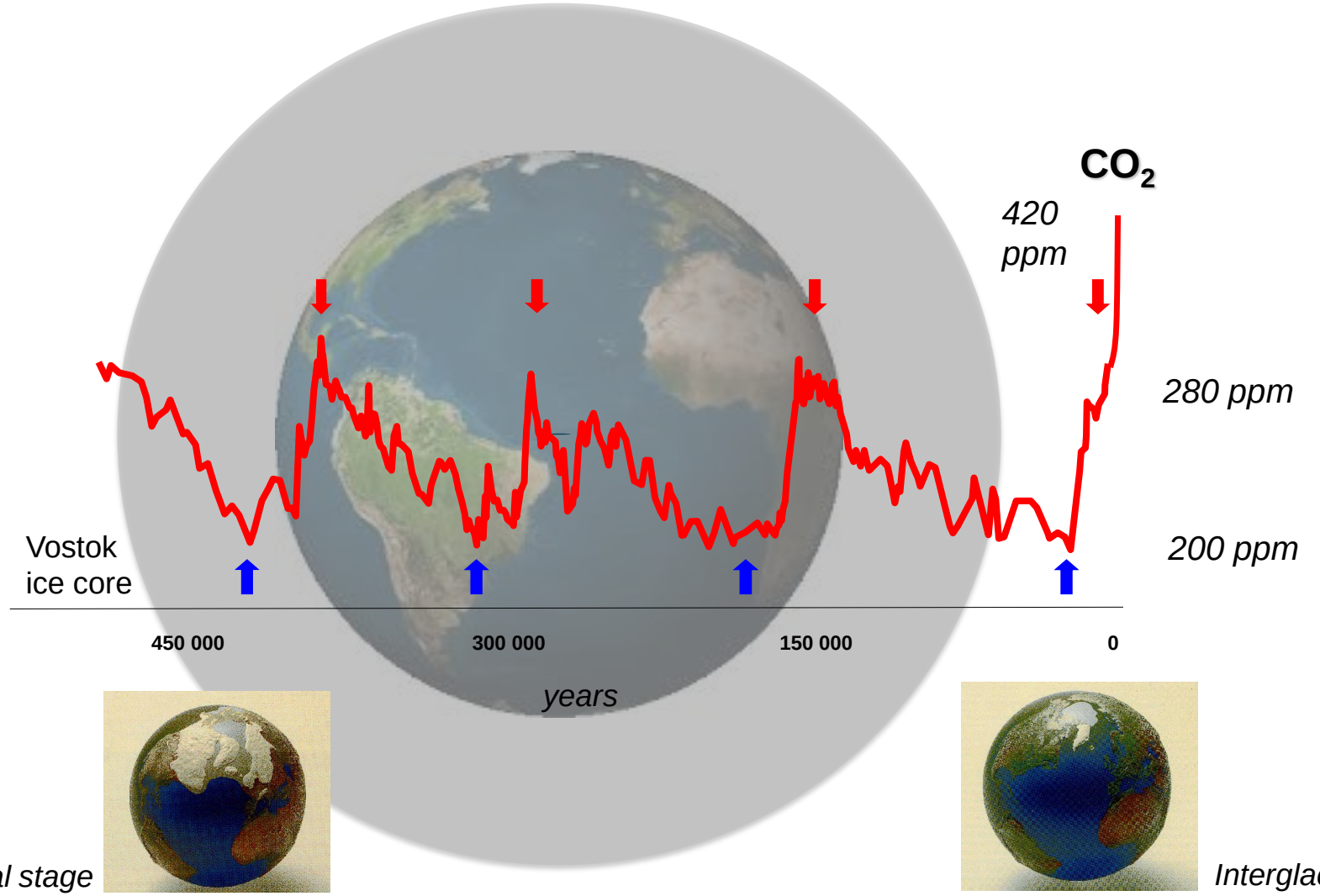
- Study of the **chemical fluxes** in the ocean

= water samples / marine particles / sediment cores

Climate change

The ocean contributes to regulate climate - The ocean acts as a pump for CO_2





Ocean studies

Atmospheric inputs

Submarine groundwater discharge

Pollution

Ocean circulation

Mixing

River plumes

Chemical fluxes

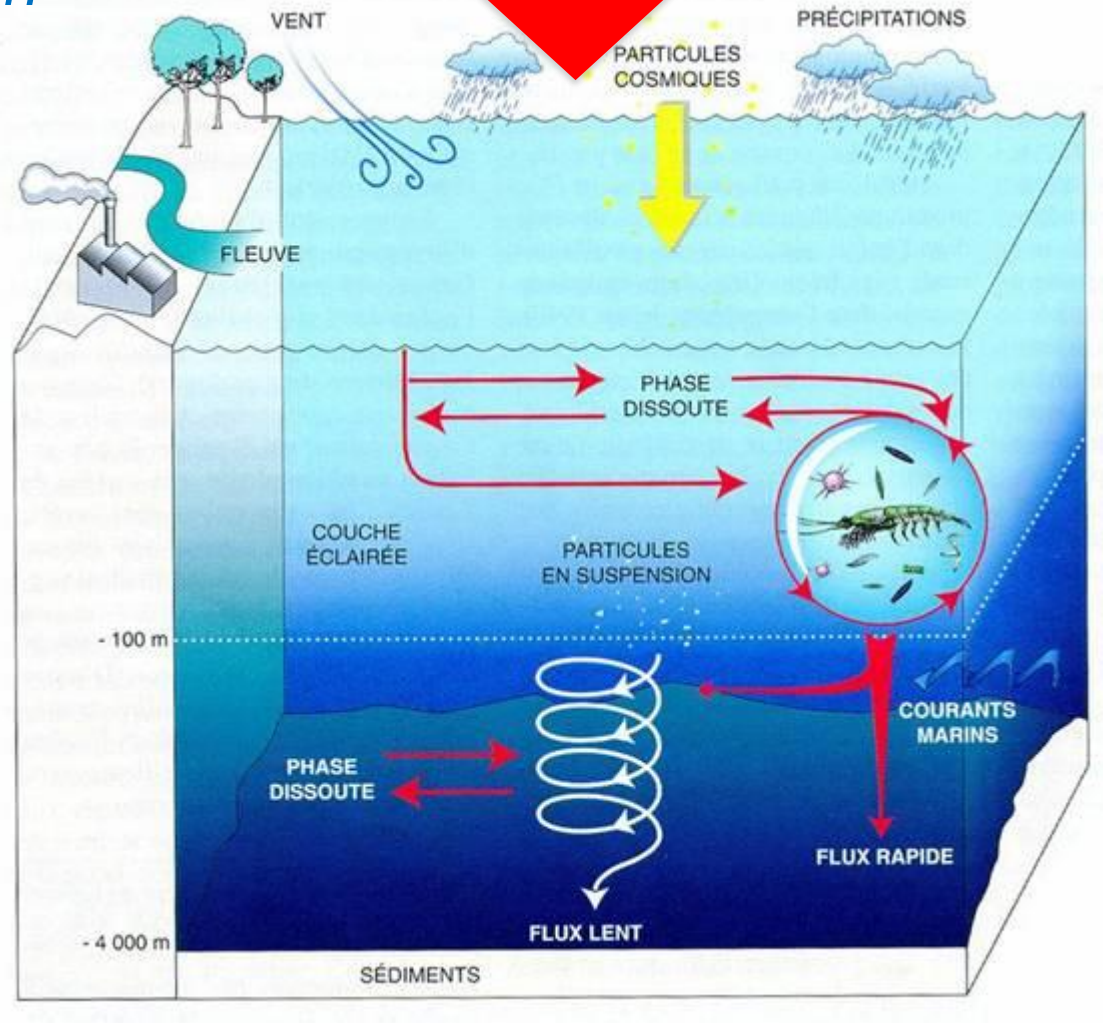
Settling speeds

Accumulation rates

Hydrothermal vents

Bioturbation

CO_2



Uptake of CO_2 by the ocean
Fate of C in the ocean ?

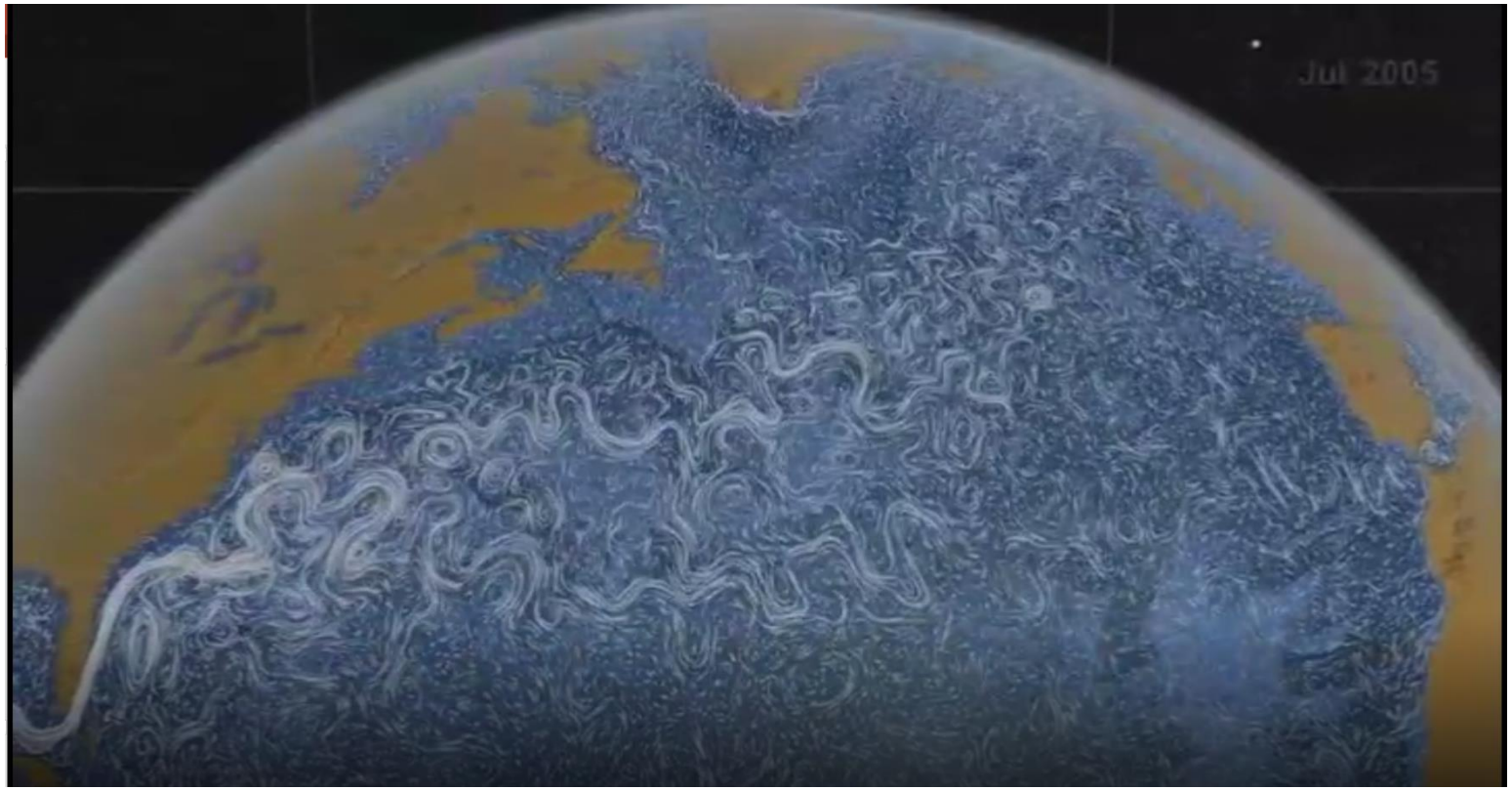
Biological pump

Transfer of C to the deep sea

TRACING WATER MASSES

USING RADIONUCLIDES AS A CLOCK

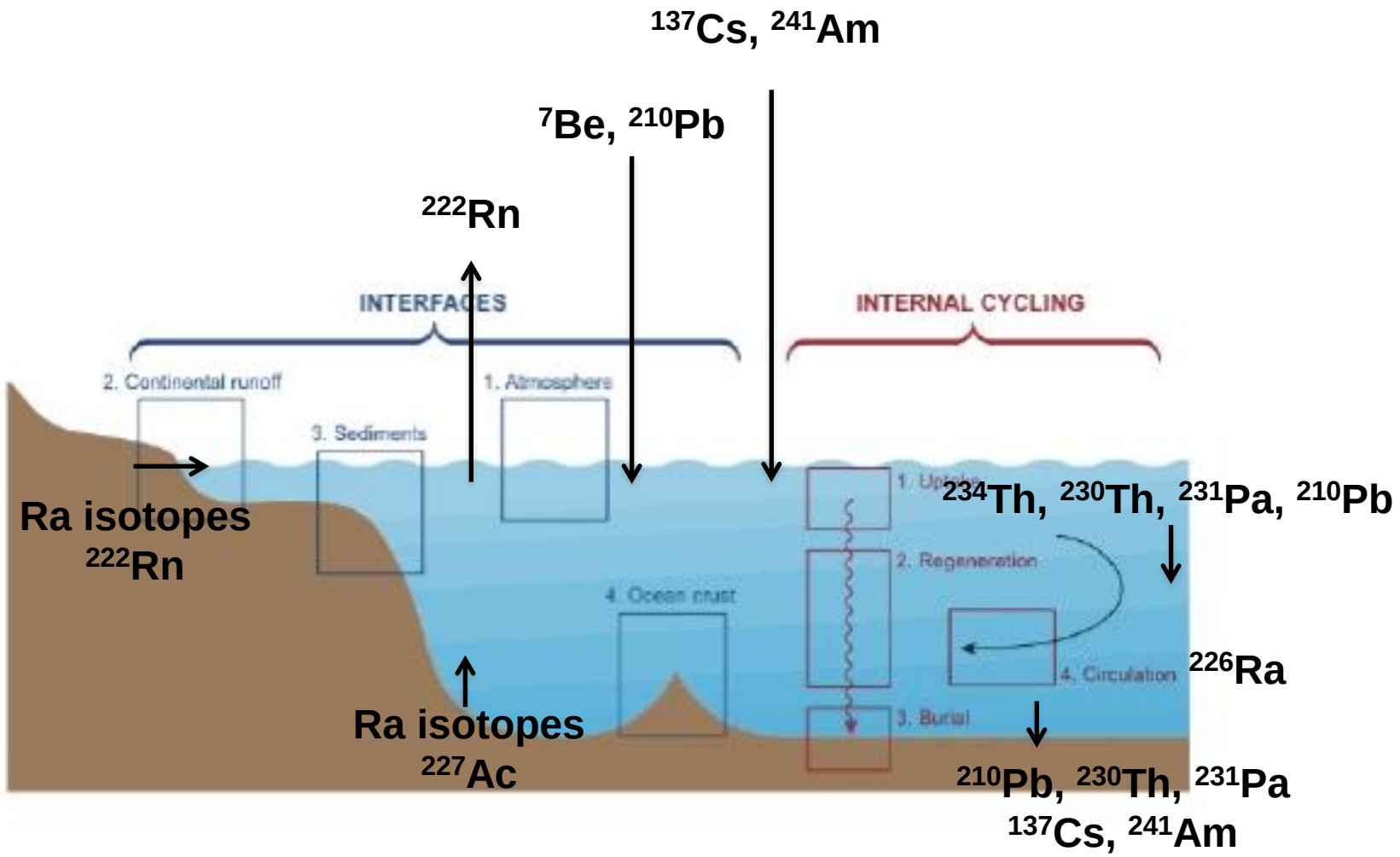
QUANTIFYING FLUXES



NASA | Perpetual Ocean

https://youtu.be/CCmTY0PKGDs

Use of radionuclides as tracers to study ocean processes



These tracers carry unique information but are difficult to analyze

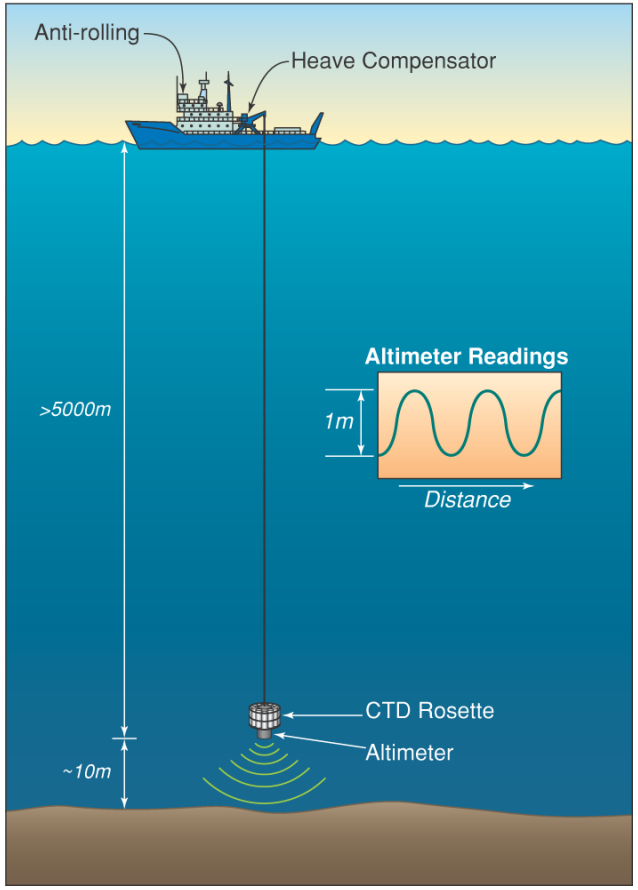
^{226}Ra (1600 a)	^{228}Ra (5.75 a)	^{227}Ac (21.8 a)
~ fg kg^{-1}	**~ ag kg^{-1}**	**830 - 83 000 atoms kg^{-1}**
	(atto : 10^{-18})	**10 kg in the entire ocean**

Low concentrations
- **Sensitive instruments**
- **Large volumes of seawater**

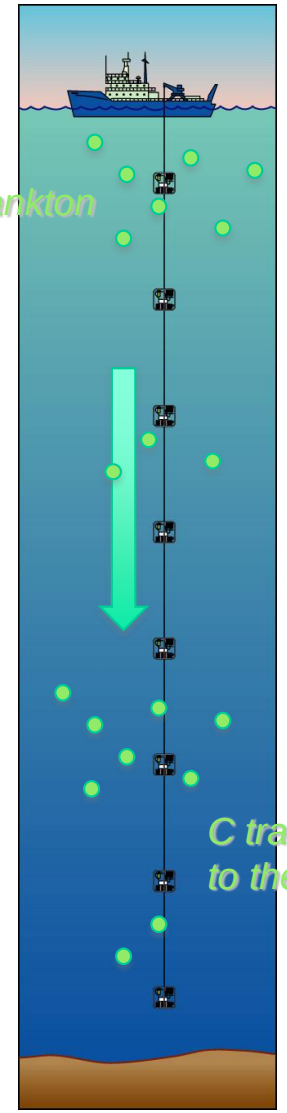
Up to 250 - 500 L for an ocean water sample
A few L for a groundwater/pore water samples

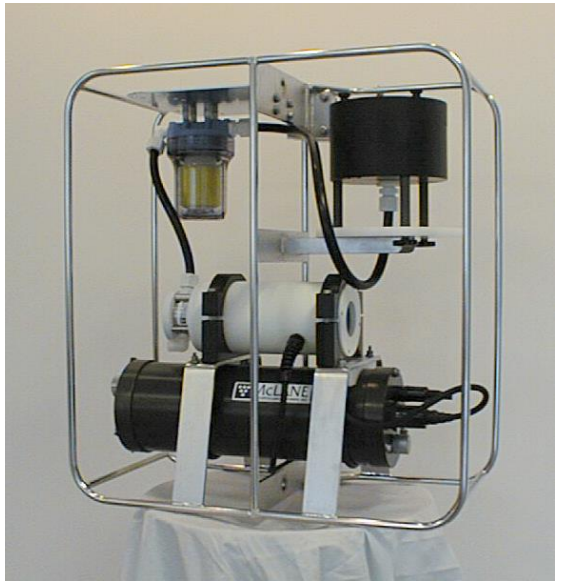


Water sampling



Sampling at sea





In situ pumps
to collect suspended particles
that sink to the deep sea

Courtesy,
Susumu Honjo
JAMSTEC

Sediment traps

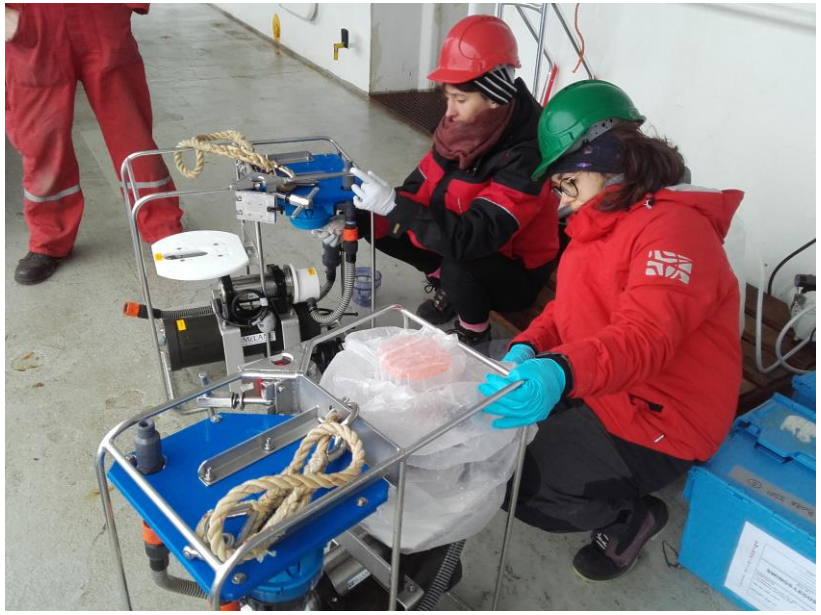
phytoplankton

C transfered to the deep sea

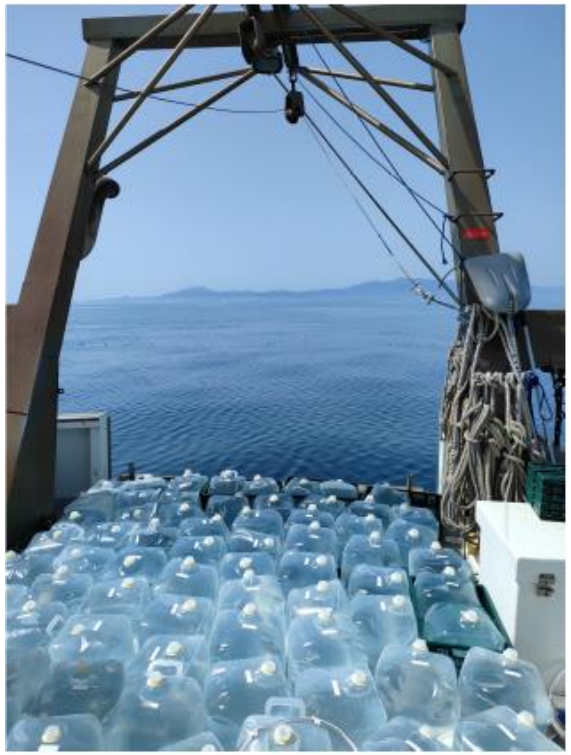
Courtesy,
Susumu Honjo
JAMSTEC

Work at sea

RV
Marion Dufresne
Southern Ocean

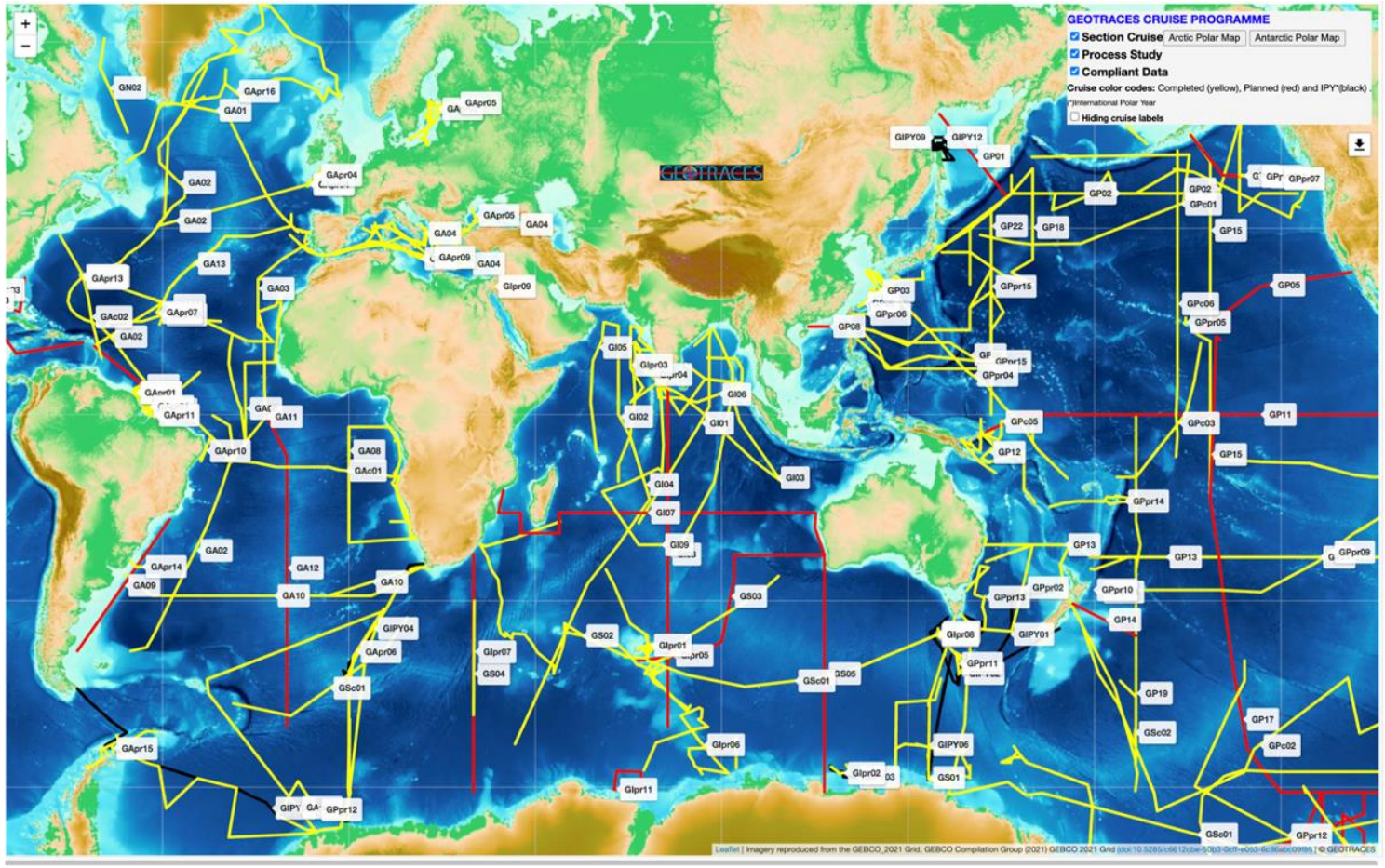


Work at sea

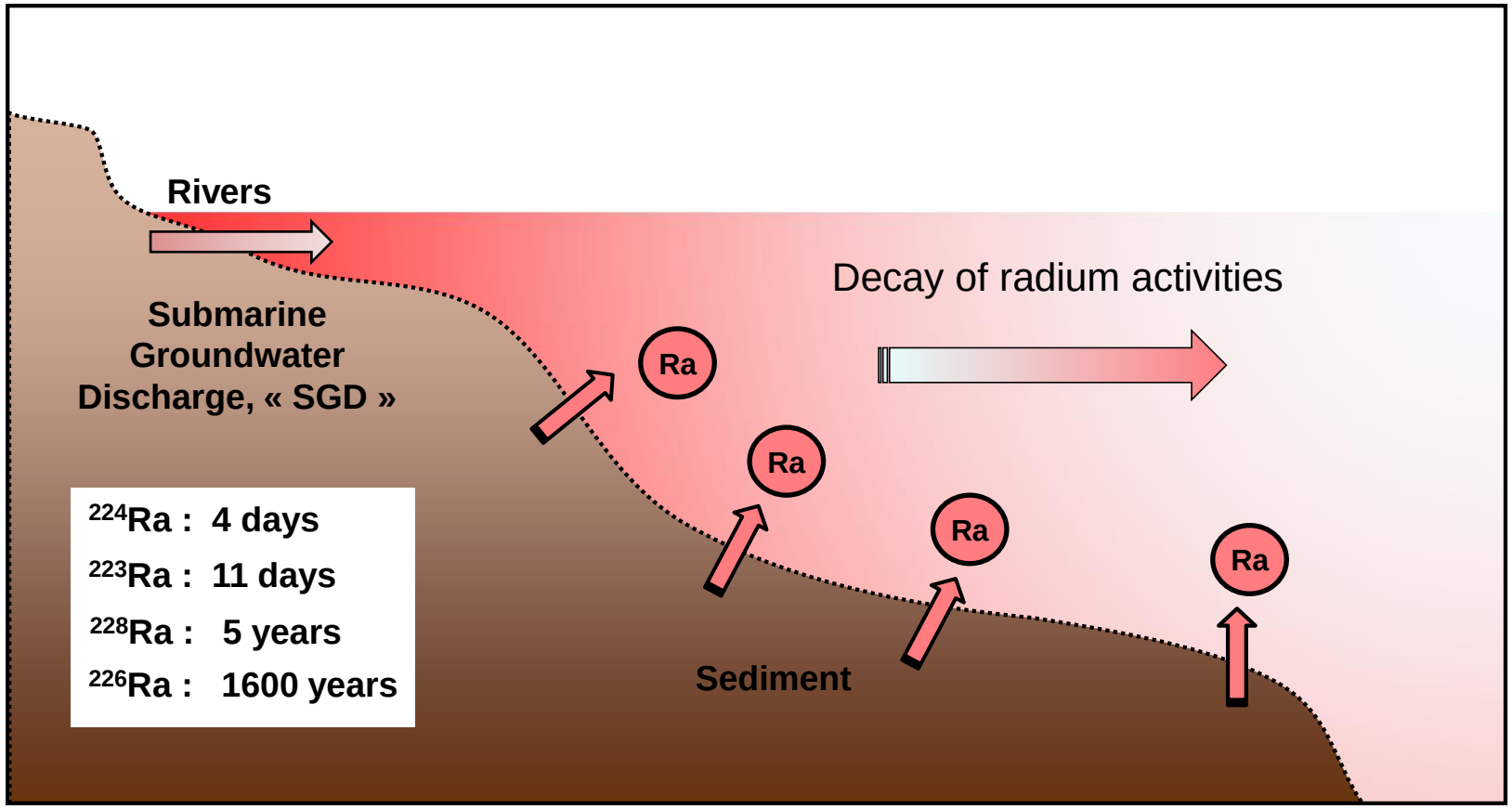


RV
NEREIS II
Mediterranean Sea

“To identify processes and quantify fluxes that control the distributions of key trace elements and isotopes in the ocean”



Radium isotopes

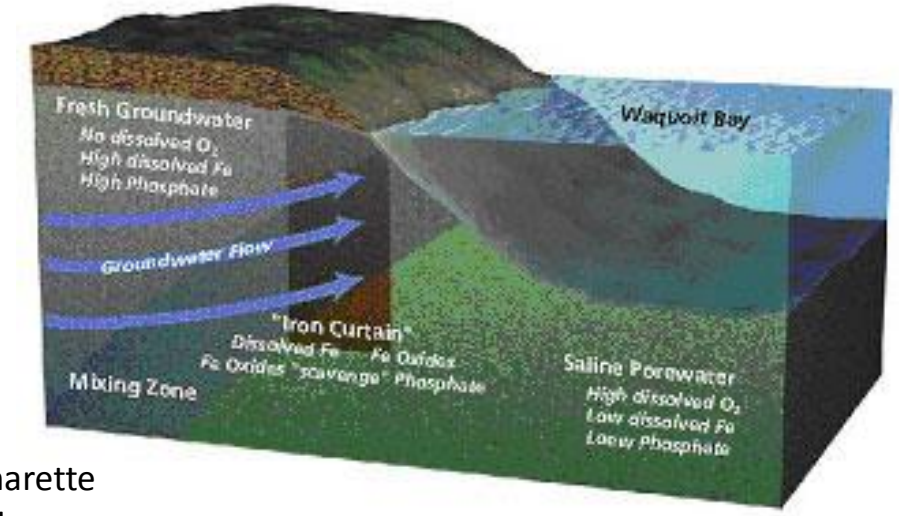


➡ Estimate of the **transit time of water masses** (coast => open ocean)

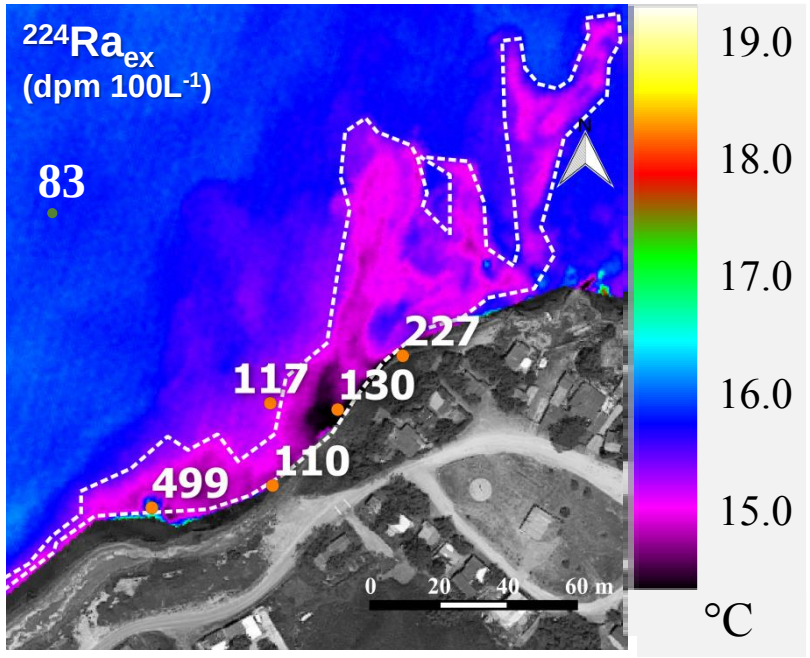
➡ Quantification of **mixing in the ocean** (K_z, K_h)

➡ Quantification of **fluxes of Submarine Groundwater Discharge**

Ra isotopes to quantify fluxes of Submarine Groundwater Discharge

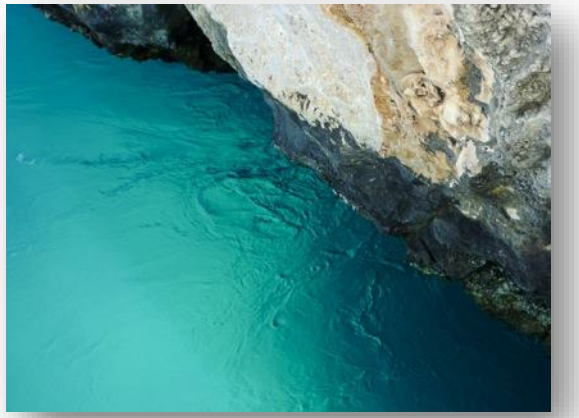


M. Charette
WHOI



Airborne TIR images (CNES)
+ radium isotopes

Mediterranean coastline: many springs / few studies



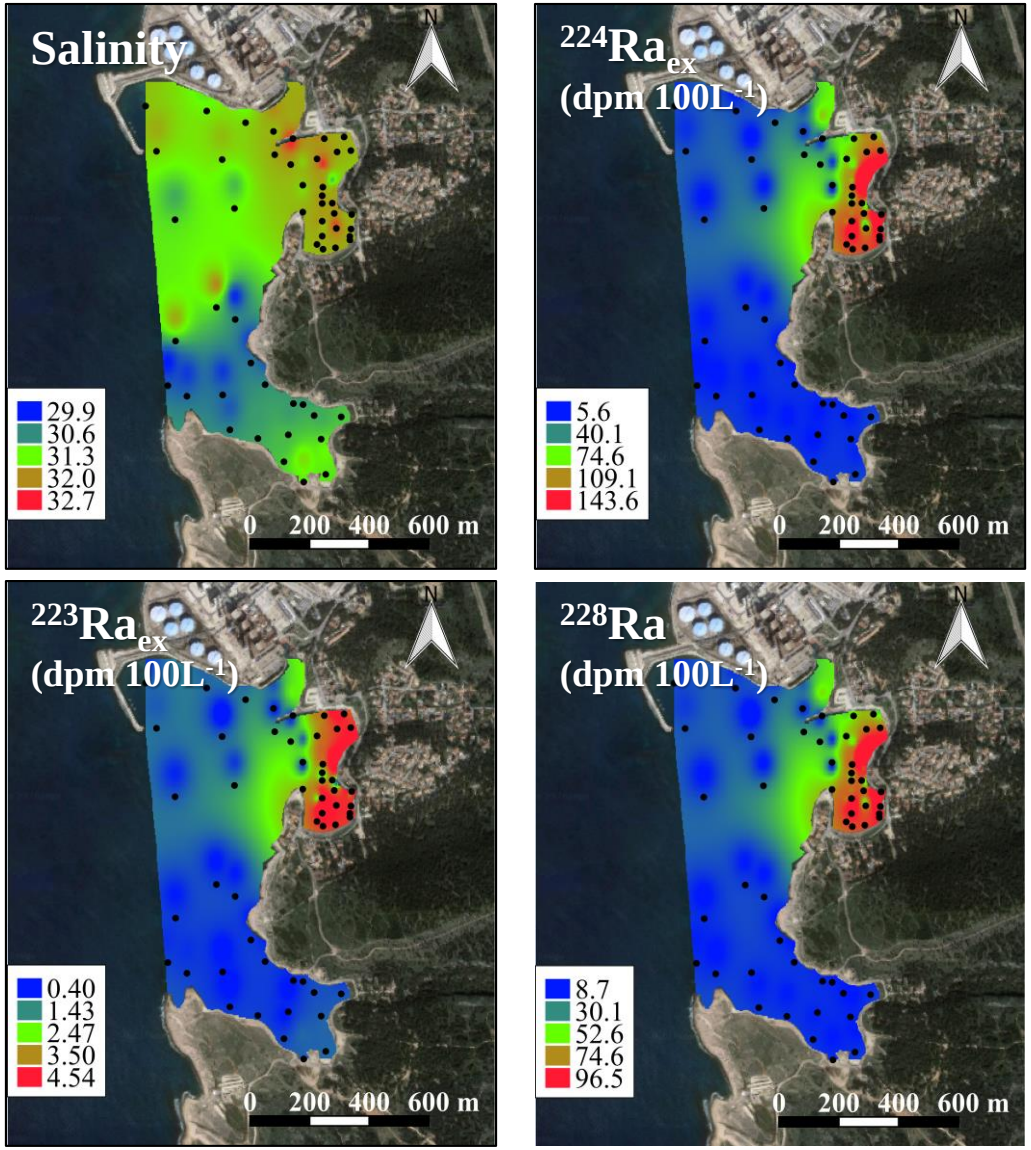
Calanques Marseille

Thau lagoon

Salses-Leucate lagoon

Salinité résurgences :

27,0 ± 0,9



^{223}Ra : $T_{1/2}$ = 11,4 j

^{224}Ra : $T_{1/2}$ = 3,6 j

^{228}Ra : $T_{1/2}$ = 5,7 a

Ra mass balance to quantify fluxes

INPUT=LOSS
(steady state)

Côte bleue, Med Sea

Béjannin et al., in prep

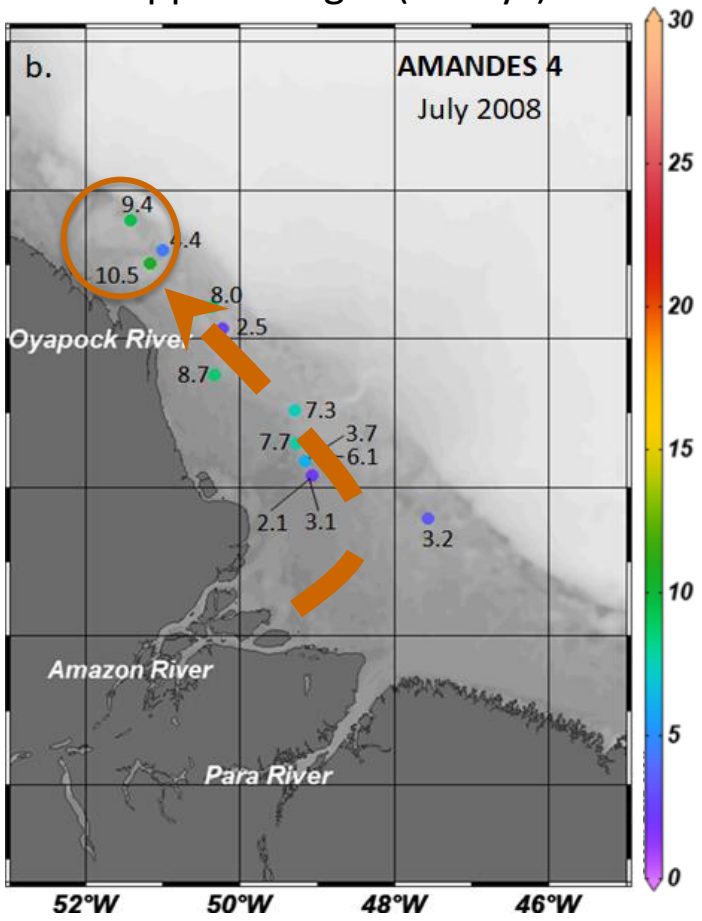
Radium isotopes to study the plume of the Amazon on the Brazilian continental shelf

Half-lives :
^{224}Ra : 4 days
^{223}Ra : 11 days

$$\left[\frac{^{224}Ra}{^{223}Ra}\right]_{obs} = \left[\frac{^{224}Ra}{^{223}Ra}\right]_{i} \frac{e^{-\lambda_{224} t}}{e^{-\lambda_{223} t}}$$

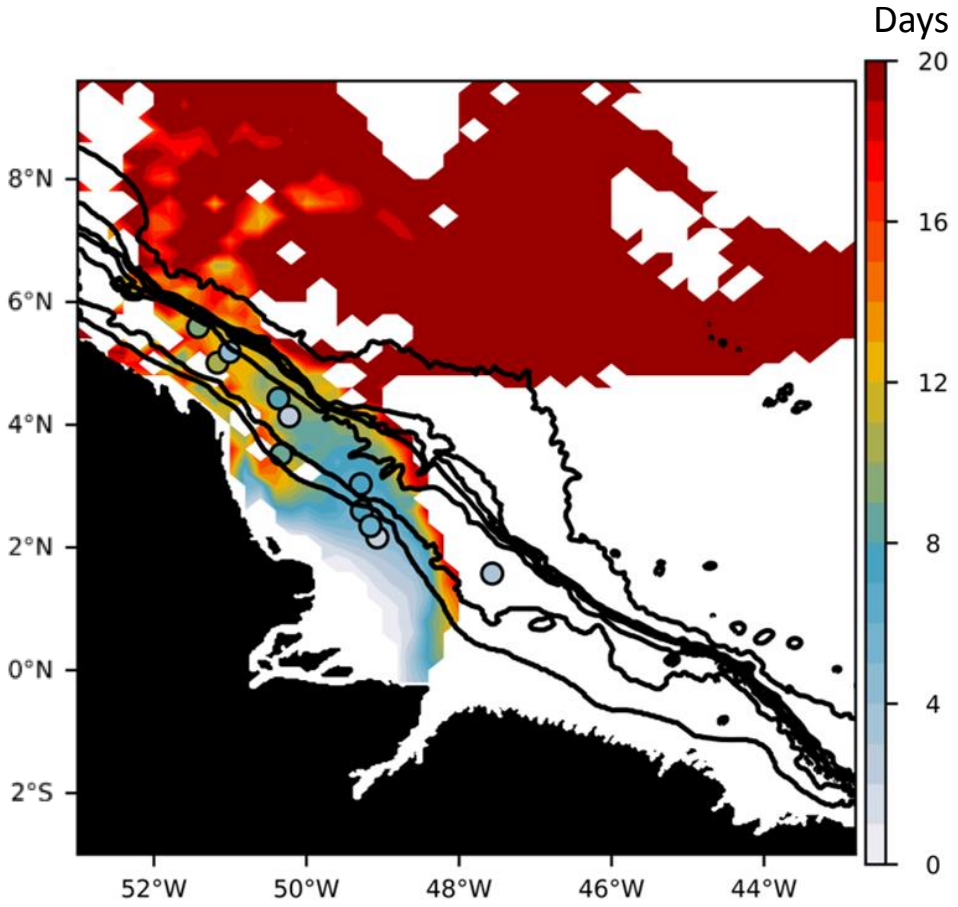
$$t = \ln \frac{\left[\frac{^{224}Ra}{^{223}Ra}\right]_{i}}{\left[\frac{^{224}Ra}{^{223}Ra}\right]_{obs}} * \frac{1}{\lambda_{224} - \lambda_{223}}$$

Apparent ages (in days)



➢ **10 days** to reach French Guyana (Residence of Amazon waters on the shelf)

➢ **Apparent velocity : 29.7 ± 1.4 cm. s^{-1}**



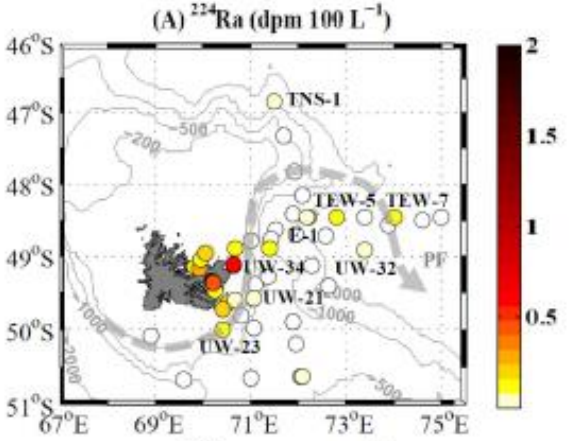
➢ Collaboration Julien Jouanno

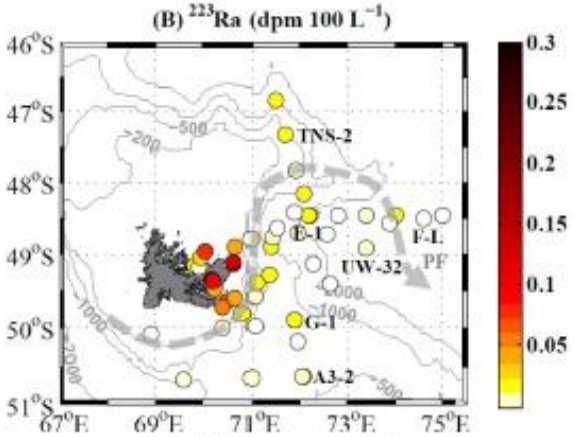
➢ NEMO 3.6 : 1/36° resolution taking into account mesoscale turbulence and tropical basin-wide circulation

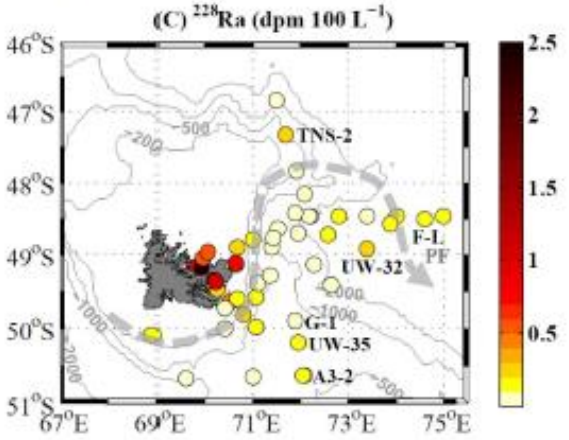
Léon et al., Limnology & Oceanography 2022

Ra isotopes to estimate apparent ages

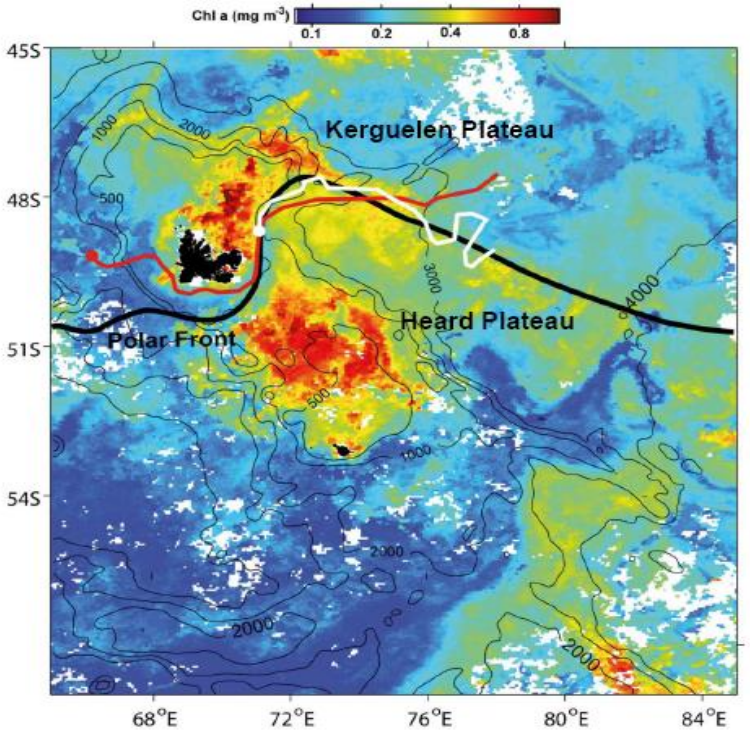
(Kerguelen islands, Southern Ocean)

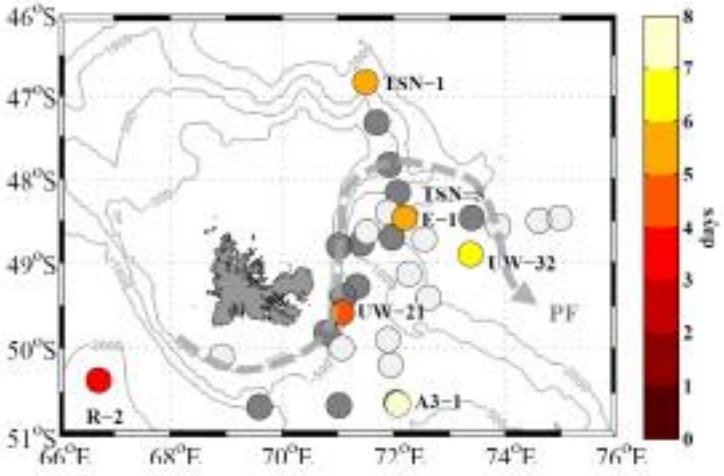






Kerguelen Island



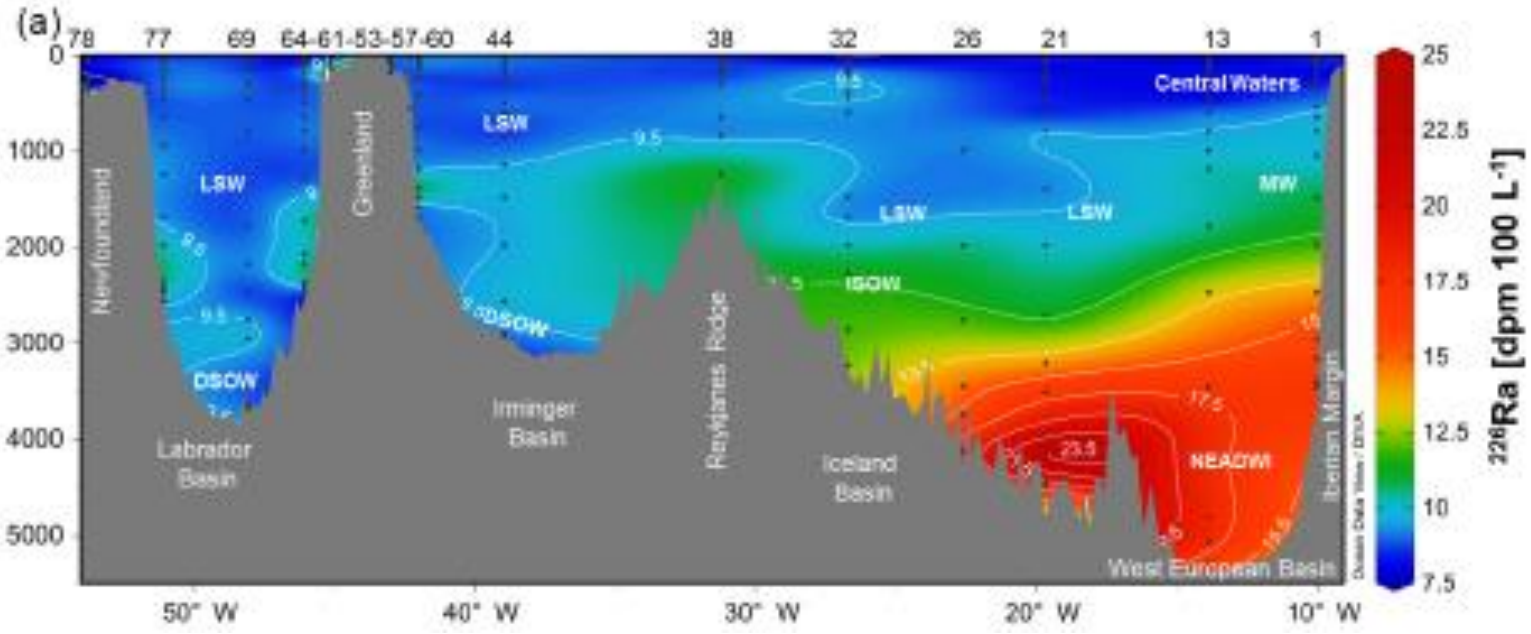


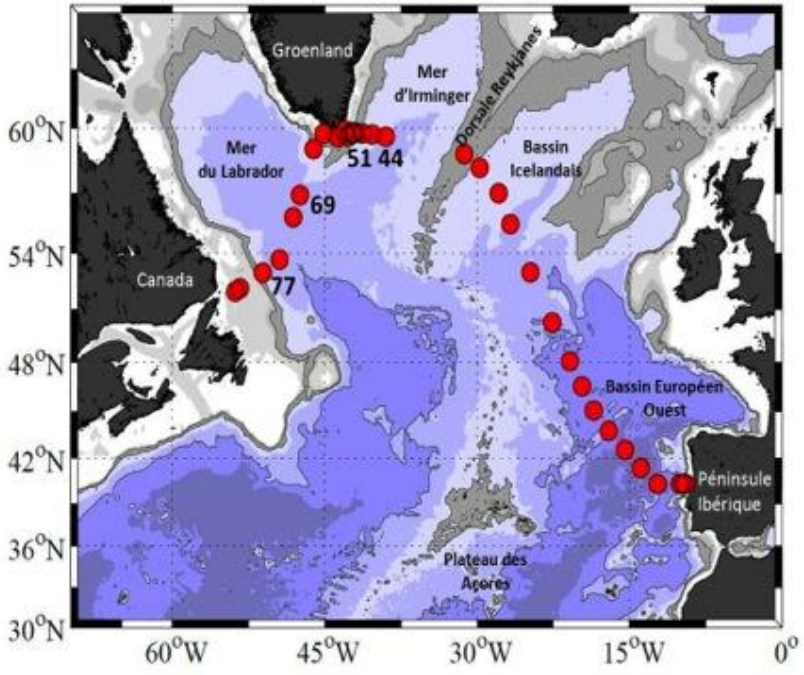
Sanial et al., 2015

Ocean circulation in the North Atlantic (GEOVIDE)

GEOTRACES

^{226}Ra





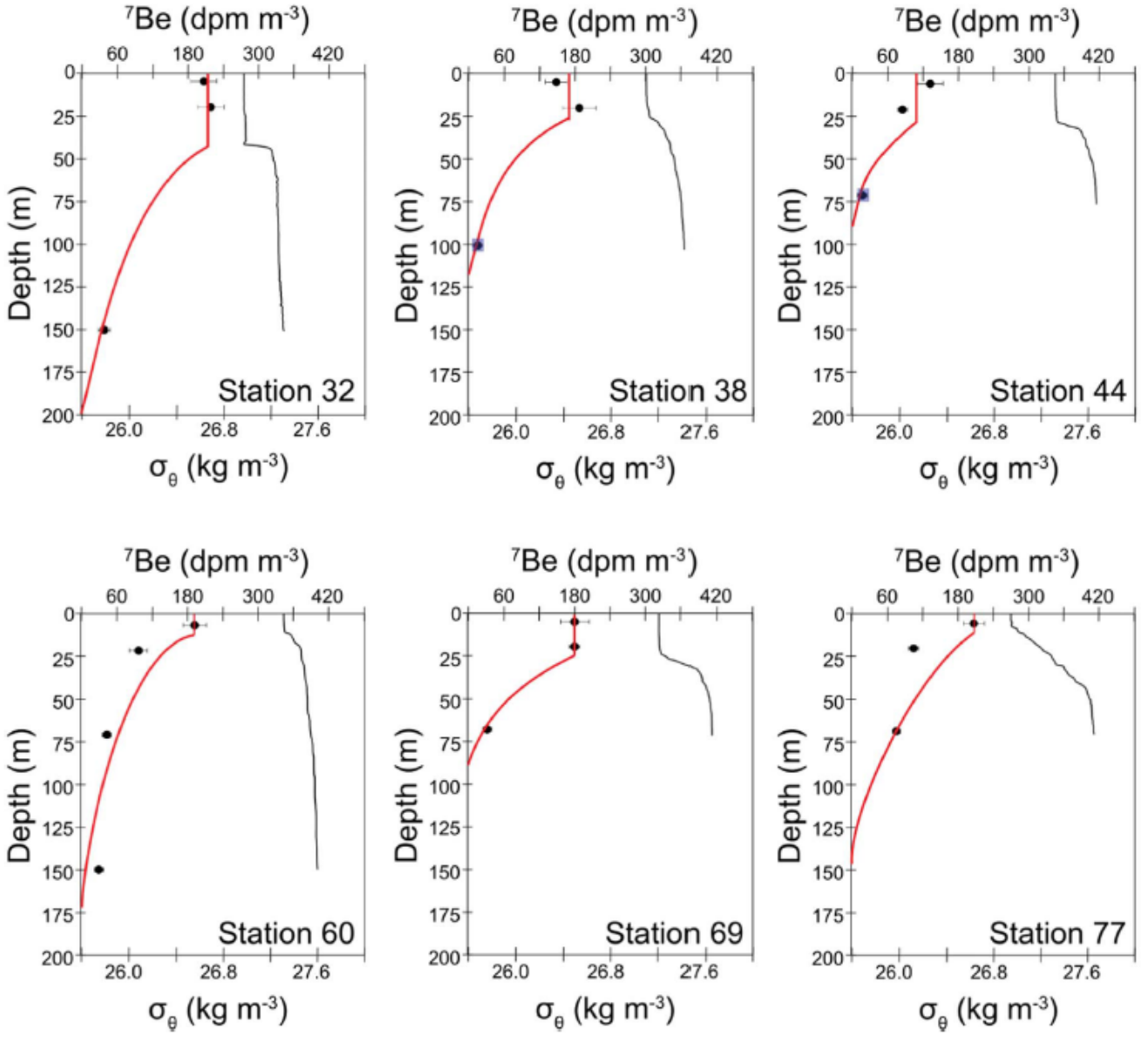
Le Roy et al., 2018

http://www.egeotraces.org/

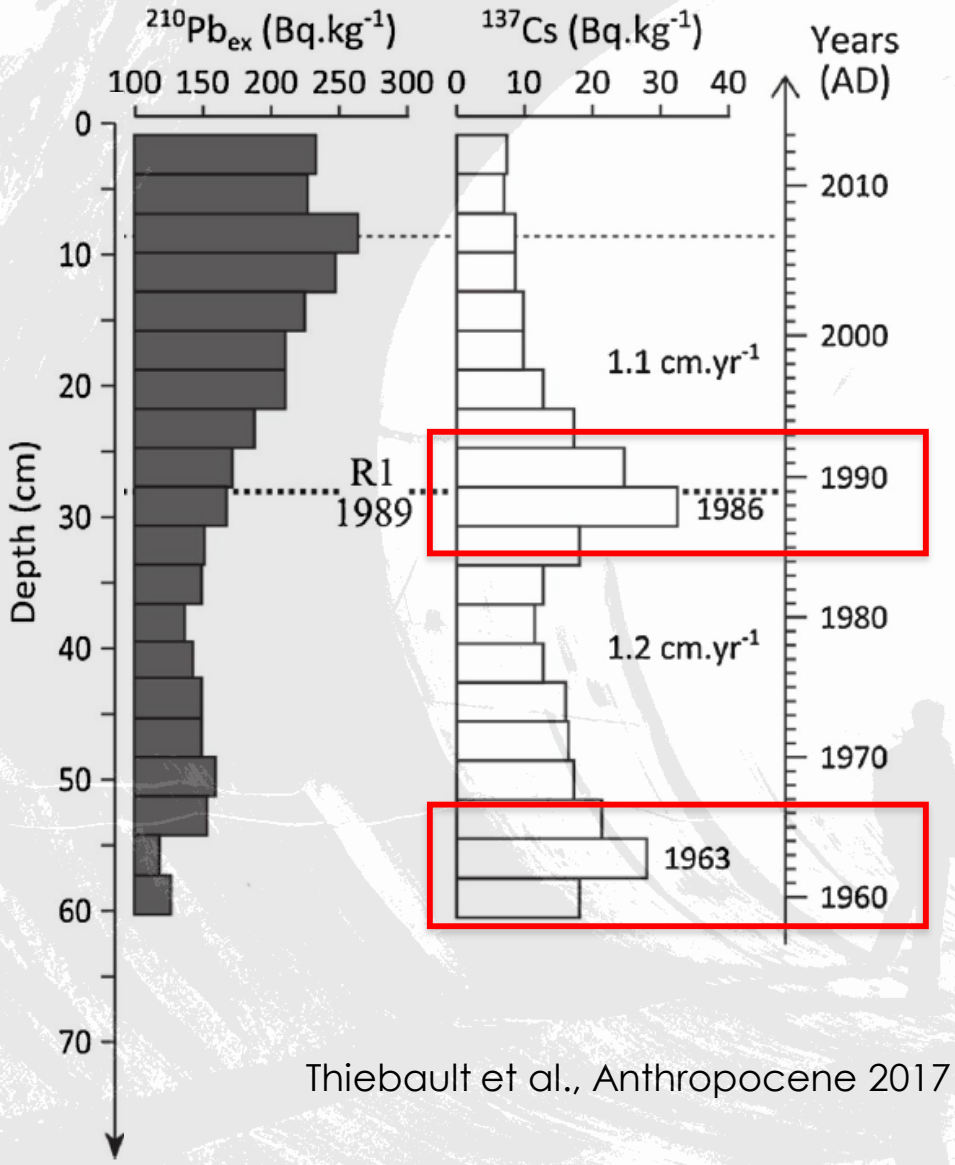
Quantification of trace element atmospheric deposition fluxes to the Atlantic Ocean (> 40°N; GEOVIDE, GEOTRACES GA01) during spring 2014☆

Shelley et al. (2017)

^{7}Be (53 days)



Dating of marine/ lake sediments

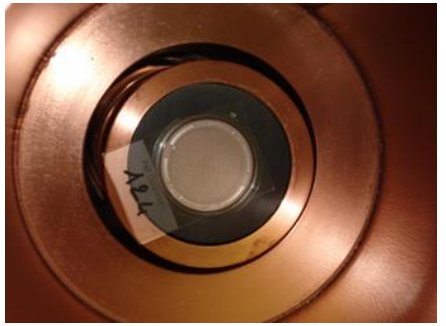


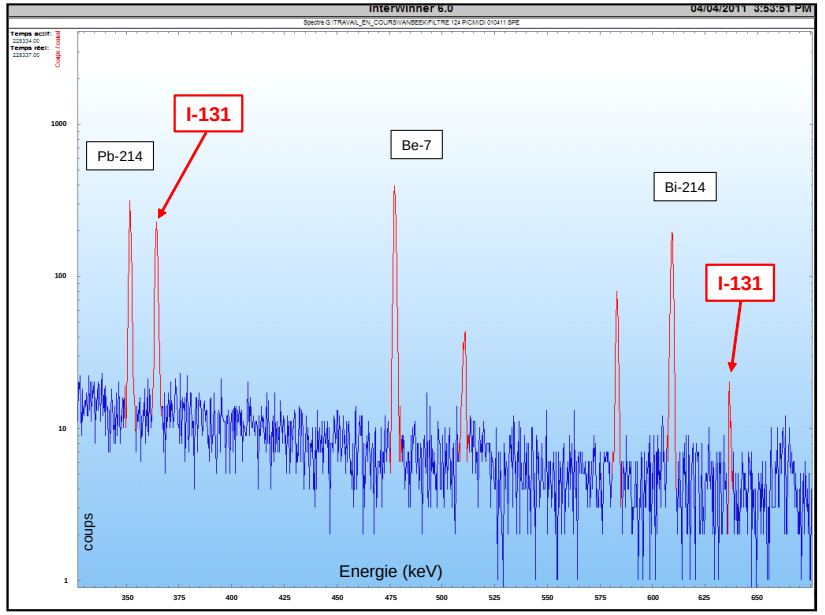
Thiebault et al., Anthropocene 2017

Dating

^{210}Pb, ^{137}Cs, ^{241}Am

Radioactive pollution, Pic du Midi, French Pyrénées
(Fukushima)





22/03 - 29/03/11 : 200 µBq m^{-3} ^{131}I

29/03 - 05/04/11 : 10 µBq m^{-3} ^{137}Cs
7 µBq m^{-3} ^{134}Cs

Evrard et al.(2013)

CONCLUSION

- Radionuclides : powerful tools
- Various applications in the ocean
- Low activity in the ocean
- Need for low background gamma spectrometers

I like them very much !

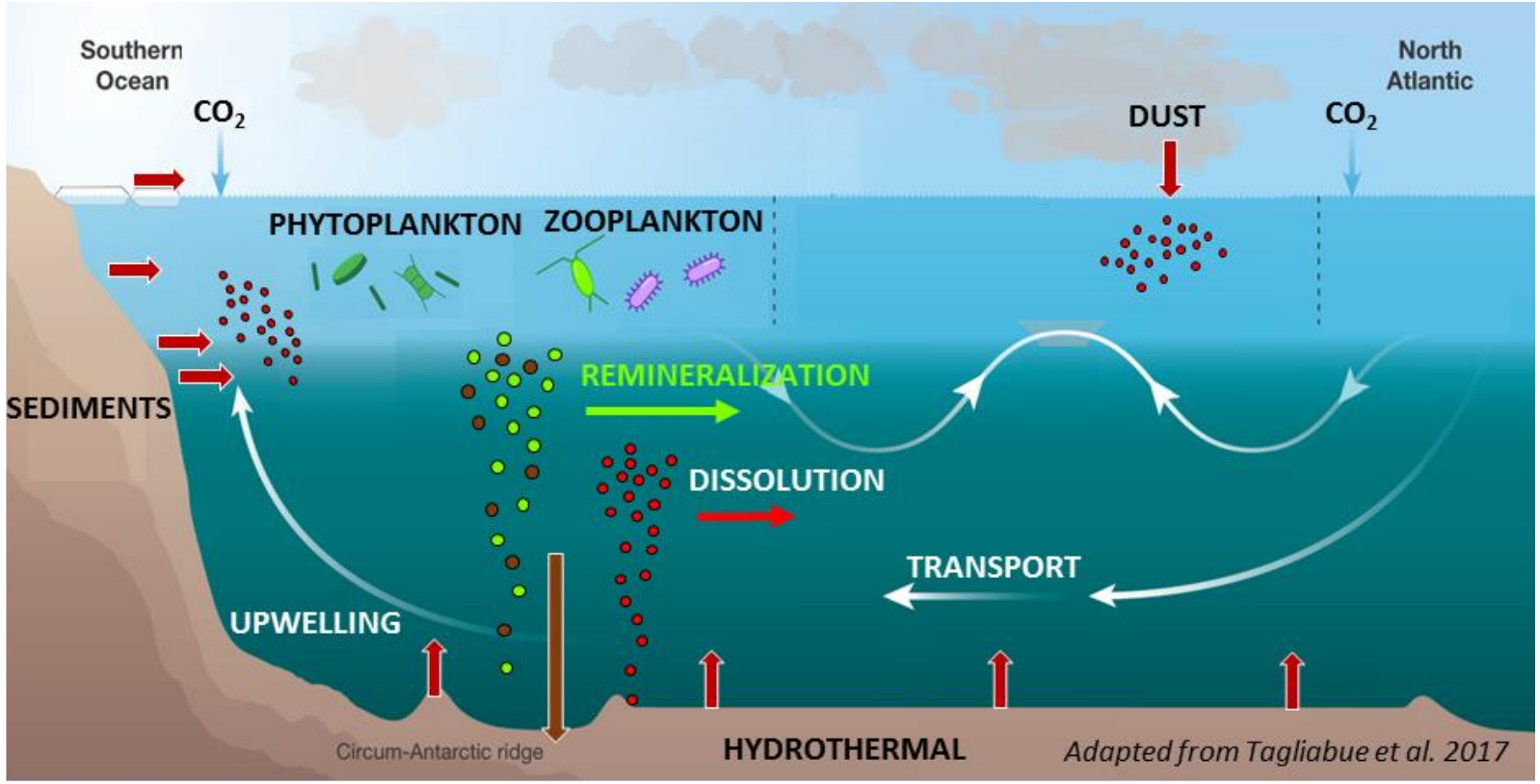
Possible collaborations

- **Collaborative paper : updates CELLAR 2022**
- **Inter-laboratory comparison exercise (sample, reference material, multi-gamma source, etc…)**
- **European project**
- **European funded network with exchange/ training of students**
- **Summer school**
- **…**

Thank you

Scientific objectives & questions

- Sources and sinks of chemical elements (+ fluxes) ?
- Study of the distribution of chemical species in the ocean (mixing, advection)
- What are the time-scales involved ?
- Study of the impact of these fluxes on the carbon biological pump (climate)



Courtesy, F. Lacan

"To identify processes and quantify fluxes that control the distributions of key trace elements and isotopes in the ocean"