ANNUAL REPORT ON GEOTRACES ACTIVITIES IN FRANCE
April 1st, 2020 to April 30th, 2021

New GEOTRACES or GEOTRACES relevant scientific results

- Residence time of particulate elements in the upper layer in the North Atlantic (GA01, GEOVIDE)

Combining elemental analyses on large (>53 µm) particles and ^{234}Th measurements, we determined downward export fluxes from the upper layers (40–110 m) of pTEs (Al, Cd, Co, Cu, Fe, Mn, Ni, P, Ti, V, Zn) and mineral phases (lithogenic, Fe- and Mn-oxides, calcium carbonate, and opal) (Lemaitre et al., 2020). The shortest residence times (dissolved + particulate) are generally observed where lithogenic particles control the pTE fluxes (as low as 2 days for Fe) whereas pTEs seem to be longer retained when the contribution of biogenic particles become greater (residence times up to 147 days for Fe).

- Surprising spread of lithogenic particles inferred by rare earth elements (REE) in the North Atlantic (GA01, GEOVIDE)

The first basin scale section of particulate REE concentrations was determined at epipelagic (ca. 0–200 m) and mesopelagic (ca. 200–1500 m) water depths across the North Atlantic Ocean using GEOVIDE samples (Lagarde et al., 2020). The results reveal the surprising westward spread of intermediate nepheloid layers identified by the percentage of lithogenic neodymium (Nd) (Fig. 1). This snapshot also enables us to highlight that absorption processes are dominant at the surface. Deeper, adsorption become predominant as shown by the holmium/yttrium (Ho/Y) and ytterbium/neodymium (Y/Nd) ratios and a progressive enrichment in cerium (Ce) in particles. In the deepest layers, the two ratios and the Ce positive anomaly are becoming constant, showing an equilibrium between adsorption and dissolution processes. This equilibrium is reached at a greater depth in the basin located east of the Labrador Sea. This difference likely reflects the contrasted surface productivity and export rates characterizing the areas: the Labrador Sea is marked by a strong bloom, high remineralization rates and thus low export. In this area, heavy REE concentrations (from terbium, Tb, to lutetium, Lu) show a sensitivity to biogenic silica (BSi) concentrations during the diatom bloom that is not observed for light REE concentrations (from lanthanum, La, to gadolinium, Gd).

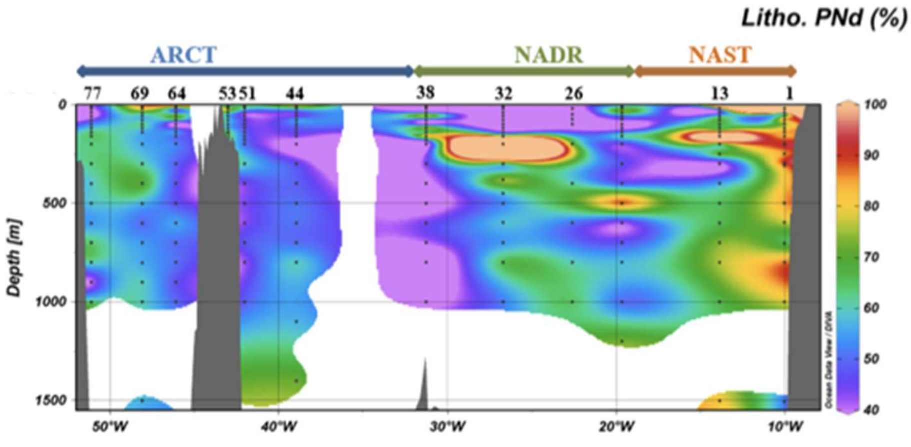

Fig. 1. Fraction of lithogenic particulate Nd along the GEOVIDE transect, in percent of the total particulate Nd concentrations, highlighting important lithogenic inputs at the Iberian margin (Lagarde et al., 2020)

- Processes controlling the dispersion and redox speciation of dissolved iron of hydrothermal origin at the Mid-Atlantic Ridge (GA13 and GAPr07)

Until recently, the role of hydrothermal activity in the Fe cycle has been largely underestimated. In particular, the contribution of slowly spreading ridges remained poorly resolved. We combined observations, experiments and modelling, to deepen our knowledge of the iron (Fe) cycle in these environments (González-Santana et al, 2021). The concentrations and oxidation rates of iron(II) was determined around six hydrothermal sites along the Mid-Atlantic Ridge, in collaboration with the QUIMA group at the University of Las Palmas. This work was carried out as part of the FRidge campaign (GA13, PIs A. Tagliabue and M. Lohan, UK, 20/12/17-01/02/18) in the frame work of the David Gonzalez-Santa's PhD. Our results allowed us to extend the temperature range of previous Fe(II) oxidation rate (k') equations (Millero et al., 1987; Santana-Casiano et al., 2005; Santana-González et al., 2019) and to better constrain the rates in the deep ocean where the seawater temperature is below 2°C (Fig. 2). Furthermore, our results showed that organic matter and particles generally contribute to decrease the k' inducing a longer Fe (II) half-life.

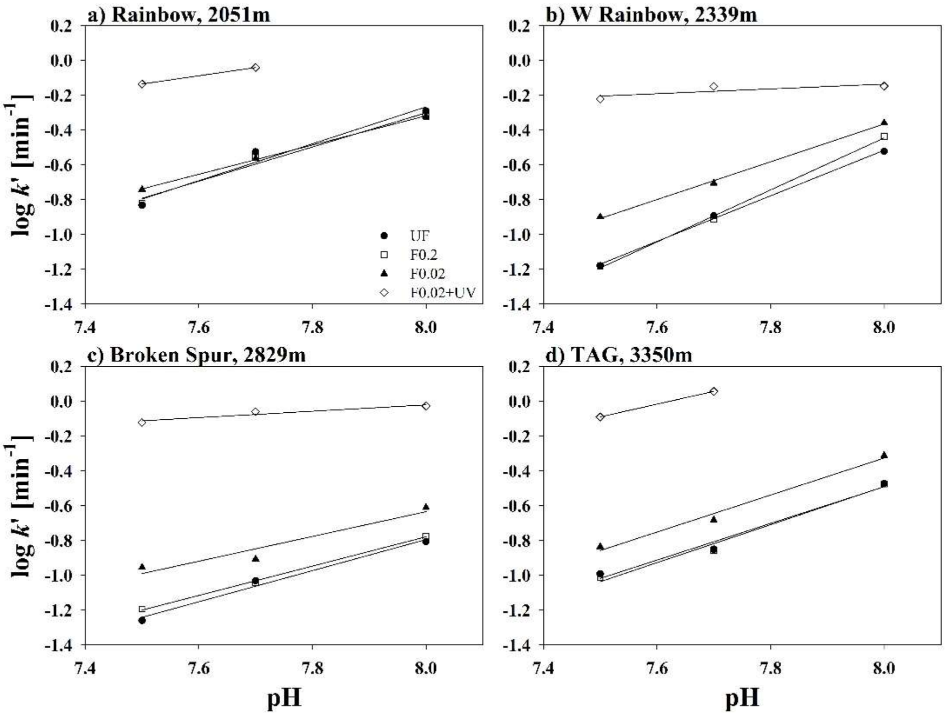

Fig. 2. Fe(II) oxidation rates at different pH values (7.5, 7.7 and 8), for unfiltered (UF, filled circles), 0.2 μm filtered (F0.2, open squares), 0.02 μm filtered (F0.02, filled triangles) and 0.02 μm filtered followed by UV irradiation (F0. 02+UV, open diamonds) at four different sites during the FRidge campaign a) Rainbow (Stn 16, 2051 m), b) West of Rainbow (Stn 13, 2339 m), c) Broken Spur (Stn 24, 2829 m) and d) TAG (Stn 35, 3350 m) (González-Santana et al, 2021).

In the framework of the HERMINE mission (GAPr07, PIs Y. Fouquet, C. Cathalot and E. Pelleter, Ifremer, 15/05/17-30/06/17) and of David Gonzalez-Santa's PhD, we performed high spatial resolution analyses of dissolved dFe and manganese (dMn) samples (González-Santana et al., 2020). Our data combined with those of particulate iron and Al (Cheize et al., to be submitted) were used in a box model to study the effect of different processes such as dispersion/dilution, particle fall, aggregation/disaggregation (Fig. 3).

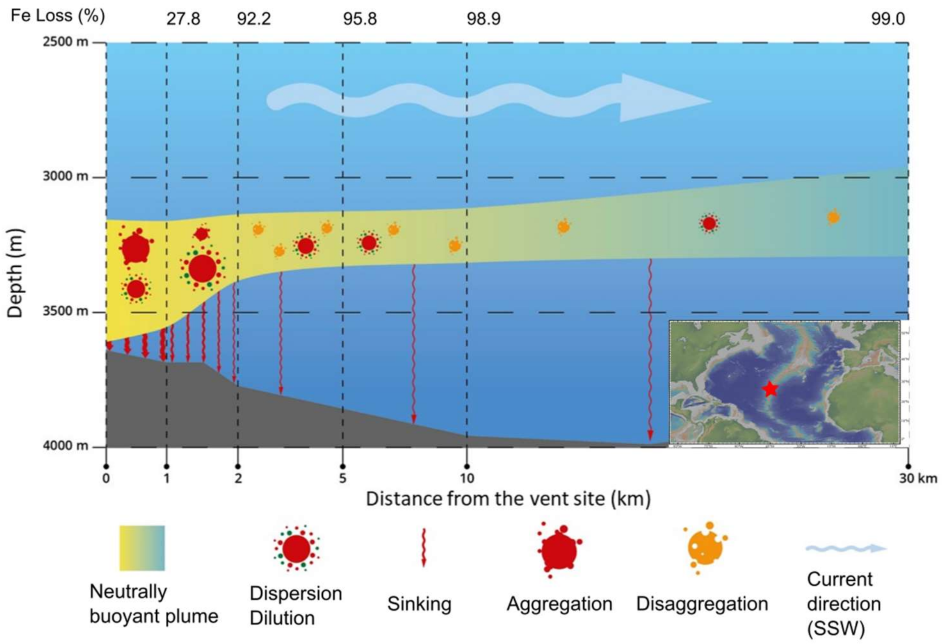

Fig. 3. Schematic of the main processes taking place within the neutrally buoyant hydrothermal plume. The size of the symbol is representative of the importance of the process in relation to each section of the plume but is not to scale (from González-Santana et al., 2020).

The approach allowed defining the distances where the main reversible exchanges between dissolved and particulate phases start: while aggregation predominates within the first 2 km, disaggregation prevails beyond 2 km. In addition, the results reveal that the loss of Fe by sinking particles is due to particles with radii ranging from 2 to 20 µm, with decreasing sizes as the hydrothermal plume is transported away from the vent site. They also show that the dFe and dMn hydrothermal signal can still be seen 75 km from the TAG vent site, despite a rapid decrease in particle content in the first 2 km.

- Major role of water transport to dissolved Al distribution in the subtropical North Atlantic (GApr08)

New dissolved aluminum (dAl) data were obtained from the 2017 GEOTRACES process study GApr08 along 22°N in the subtropical North Atlantic Ocean (Artigue et al., 2021). To separate the component of the dAl signal derived from water mass transport from its biogeochemical component, we used a model considering advection in the surface and an optimum multi-parameter analysis below 200 m. The new result show that water mass transport plays a major role from the surface to the sea floor in this area (Fig. 4) even if the dAl distribution is usually considered to be dominated by atmospheric dust input and removal by particle scavenging. At the surface, advection and dust dissolution are equally important as dAl sources. Below 200 m, the water mass transport remains dominant. Dissolved/particle interactions act as a moderate dAl sink from 200 to 1000 m whereas they are a moderate dAl source from 1000 to 5500 m (grey shaded area in Fig. 4).

Overall, these results evidence that the effect of advection cannot be neglected in areas where a conjunction of significant horizontal dAl gradients and significant horizontal currents is found.

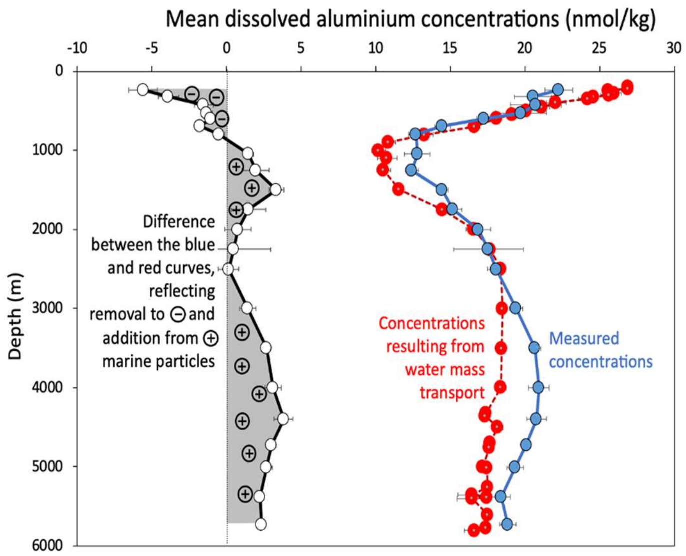

Fig. 4. Mean measured dissolved aluminum concentration (dAl) profile (blue dots), mean water mass transport dAl profile (red dots), and mean 'biogeochemical' dAl profile (difference between the blue and red curves, white dots) of the seven stations of GApr08 cruise. Error bars are standard errors from the 7-station mean. Modified from Artigue et al. (2021).

- <u>Variable dissolution rates and fates of lithogenic tracers at the air-sea interface (PEACETIME)</u>

Lithogenic elements such as Al, Fe, REEs, thorium (^{232}Th and ^{230}Th, given as Th) and protactinium (Pa) are considered to be insoluble. The dissolution from Saharan dust reaching Mediterranean seawater was established by tank experiences included dust seeding under present and future climate conditions (+3 ◦C and −0.3 pH; Roy-Barman et al., 2021). The maximum dissolution was low for all seeding experiments: less than 0.3 % for Fe, 1 % for ^{232}Th and Al, about 2 %–5 % for REEs and less than 6 % for Pa (Fig. 5). Different behaviors were observed: dissolved Al increased until the end of the experiments, Fe did not dissolve significantly, and Th and light REEs were scavenged back on particles after a fast-initial release. The constant ^{230}Th/^{232}Th ratio during the scavenging phase suggests that there is little or no further dissolution after the initial Th release. Comparison of present and future conditions indicates that changes in temperature and/or pH influence the release of Th and REEs in seawater, leading to lower Th release and a higher light REE release under increased greenhouse conditions.

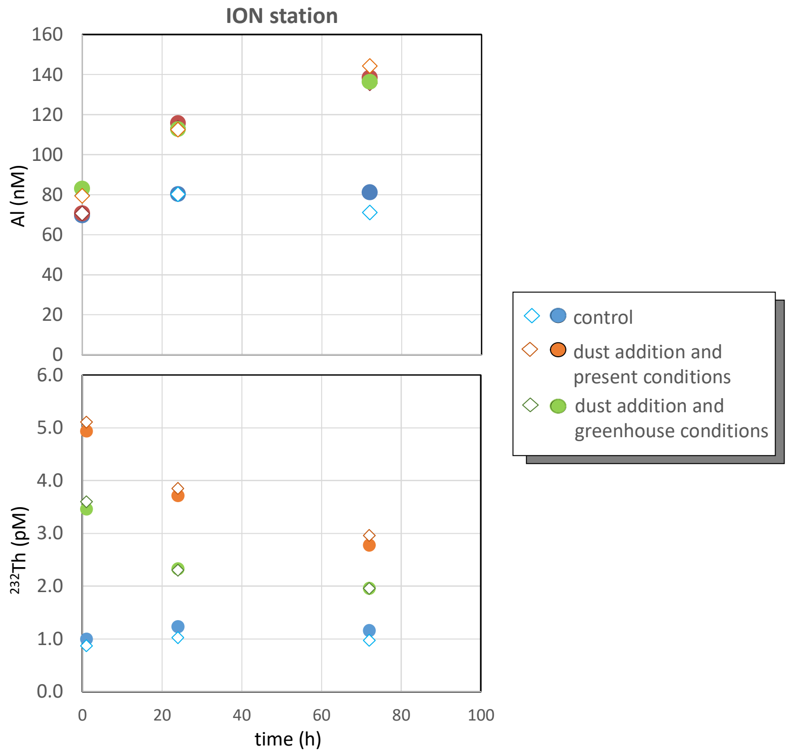

Fig. 5. Contrasted evolution of dissolved Al and dissolved ^{232}Th after dust deposition in Mediterranean seawater (Ionian Sea station) during tank experiments. No dust was added for the control experiments. Future climate conditions correspond to +3 °C and −0.3 pH unit compared to present conditions. The diamonds and circles indicate the results of different tanks (Roy-Barman et al., 2021).

- New method of ^{227}Ac determination in seawater by isotope dilution and mass spectrometry

By diffusing from the deep sediments into the ocean, ^{227}Ac (half-life = 21.8 y) is a powerful tracer of vertical mixing in the deep ocean on decadal timescales. However, its use is limited by its very low concentration resulting in large volumes (hundreds of L) of seawater required for its analysis by nuclear spectroscopy. A new method of ^{227}Ac analysis has been developed by isotope dilution and MC-ICPMS (Levier et al., accepted). It significantly improves the measurement accuracy and reduces the sample size (10-30L). After spiking water samples with ^{225}Ac milked from a ^{229}Th solution, actinium isotopes are preconcentrated by manganese co-precipitation, purified by chromatographic methods and then measured by MC-ICPMS. ^{231}Pa (^{227}Ac progenitor) was also co-precipitated from the same water sample, recovered during the chromatography and analysed by MC-ICPMS. An internal quality control was carried out to validate the method by repeated measurements of 2L of surface seawater doped with a ^{227}Ac homemade standard solution and by duplicates of river water. Archived 10 L seawater samples from the Weddell Gyre collected during the Bonus GoodHope cruise, were also analysed, with ^{227}Ac concentration ranging from 4.2 ± 0.4 ag/kg to 10.9 ± 1.0 ag/kg (1 ag/kg= 10^{-18} g/kg = 0.161 dpm/m^3= 6.23 ag/k) in good agreement with previous measurement in the Weddell Gyre (Fig 2). The detection limit for 10 L seawater samples is ~ 0.8 ag/kg (Fig. 6).

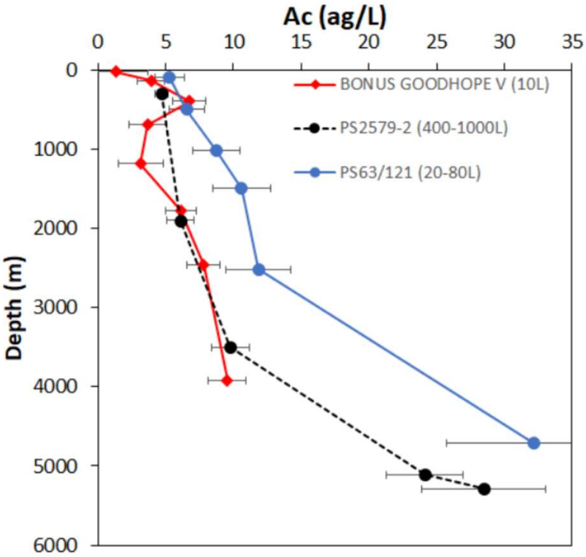

Fig. 6. Seawater ^{227}Ac profiles in the Weddell Gyre, at station Super V from Bonus GoodHope cruise, measured by mass spectrometry (red diamonds, Levier et al., accepted) and at station PS2579-2 (Geibert et al., 2002) (black dots) and PS63-121 measured by alpha-spectrometry (Geibert and Vöge, 2008) (blue dots). All uncertainties are expressed at $2\sigma_n$. Levier et al., accepted.

GEOTRACES or GEOTRACES relevant cruises

- SWINGS Cruise: PIs Catherine Jeandel (CNRS, LEGOS, Toulouse) and Hélène Planquette (CNRS, LEMAR, Brest)

SWINGS is a multidisciplinary 4-year project dedicated to elucidate trace element sources (sedimentary, atmospheric and hydrothermal), transformations and sinks (biogenic uptake, remineralization, particle fate, and export) along a section crossing key areas of the Southern Ocean containing the numerous fronts at the confluence between Indian and Atlantic Oceans (https://www.geotraces.org/follow-the-french-geotraces-swings-cruise/). It involves ca. 80 scientists (21 international laboratories, 7 countries#).

#SWINGS partners: CNRS_UPS_LEGOS (PI, Toulouse), CNRS_UBO_LEMAR (PI, Brest), AMU_MIO (Marseille), CNRS_UVSQ_LSCE (Saclay), CNRS_SU_LOCEAN (Paris), CNRS_SU_LOMIC (Banyuls), CNRS_UPS_GET (Toulouse), CNRS_SU_AD2M (Roscoff), CNRS_CECI (Toulouse), CSIR-SOCCO (Cape Town, South Africa), ULB_Bruxelles (Belgium), WU-SO (Washington Univ, USA), WHOI-MBC (Woods Hole, USA), FU-DEOAS (Florida State Univ, USA), Florida International University (USA), University of Southern

Mississippi (U.S.A), GEOMAR (Germany), PEO and ETH (Zurich, CH), University of Liverpool, University of Plymouth (UK), Universidad de Las Palmas de Gran Canaria (Spain)

The SWINGS cruise (R/V Marion-Dufresne, MD229, GEOTRACES section GS02) started from La Reunion on 11 January and ended at La Reunion 8 March 2021 (Fig. 7).

The strategy relies on the strong coupling between physical oceanography, biogeochemistry and modeling with special attention on the characterization of the physical, biological and chemical particle speciation in suspended and sinking particles.

A high spatial resolution sampling was realized for the dissolved and particulate phases (73 stations in total). Th and Pa isotopes will be analyzed to characterize the particle dynamics. Ra isotope will be measured for the quantification of land-ocean transfers while Nd isotopic composition will be used to trace the origin of the dissolved and particulate matter. These tracers will help identifying and characterizing hydrothermal source occurrences. Specific attention was paid to the ocean interfaces: atmospheric and land (Marion & Prince Edward, Crozet, Heard & Mc Donald, Kerguelen) contacts, and a segment of the South West Indian Ridge (possible active hydrothermal sites) were explored.

In addition to the characterization of phytoplankton biomass and community structure composition, we conducted dedicated biology experiments, such as nitrification, calcification or iron uptake experiments throughout the cruise. Prokaryotic community composition, metagenomics and metatranscriptomics analyses will be investigated.

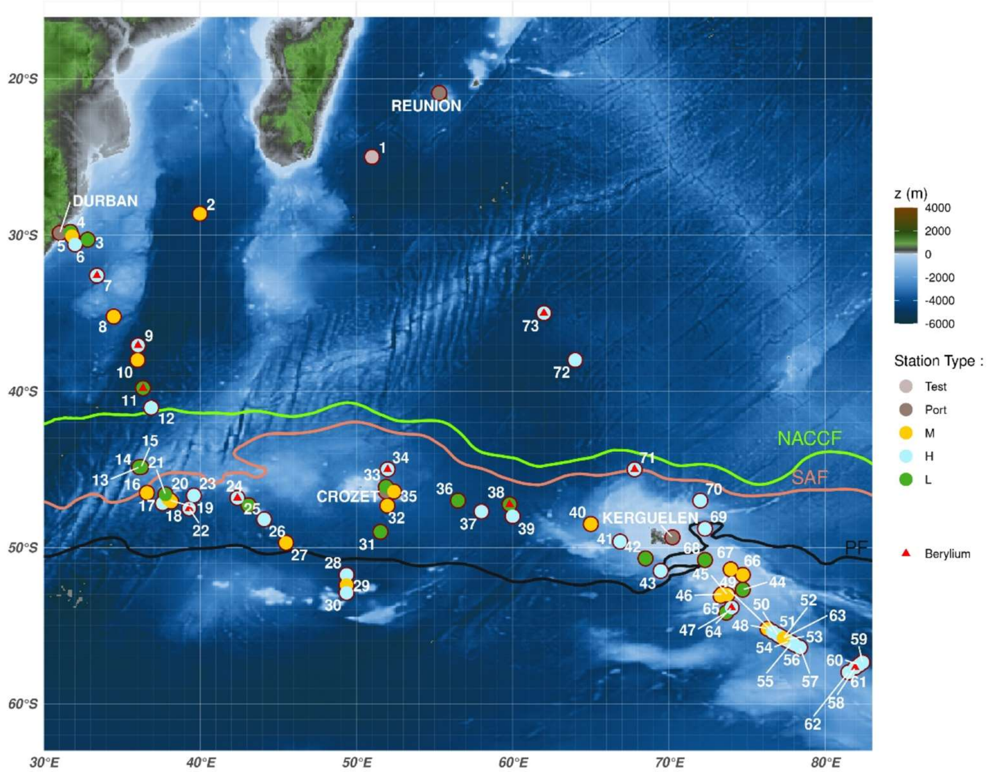

Fig. 7. Final map of the SWINGS cruise track, edited by Corentin Clerc and Sara Sergi. PF=Polar Front, SAF=SubAntarctic Front, NACCF=North Antarctic Circumpolar Current Front.

The cruise track –at the Atlantic-Indian boundary- crossed up to 6 currents or fronts, among which the 3 majors are reported in Figure 7. These jets are major pathways of the general circulation, critical for chemical species transport: our navigation strategy was regularly adapted using the Scheduler for Oceanographic Samplings application in order to characterize these current dynamic (geostrophic calculation) as well as their trace element and isotope contents.

- TONGA-RECUP

One year after the TONGA cruise (DOI 10.17600/18000884) endorsed as a process study by GEOTRACES during which a fixed mooring has been deployed in the SW Pacific (20°42S / 177°52 W), the TONGA-RECUP cruise took place in oct-nov 2020 on the R/V Alis. All the samples were safely recovered: 11 months of exported material at 200 m (24 samples) and 1000 m (24 samples) are currently being analyzed for mass flux, carbon, LSi, BSi and metals. The fixed mooring line has also been instrumented below the 200 m-depth trap with 2 automatic sequential passive samplers (THOE) recently developed and patented by AEL (N. Caledonia) and Technicap (France). The chelating resins (DGT) chosen for this study binds the following elements: Al, Fe, Mn, Co, Ni, Cu, Zn, Cd, Sr, Ba, Pb and REE (Sampler 1), and, Hg and MMHg (Sampler 2).

GEOTRACES workshops and meetings organized

- First national workshop to prepare the French contribution to the international program BIOGEOSCAPES (Ocean metabolism and nutrient cycles on a changing planet, www.biogeoscapes.org) organized by videoconference on 7th and 8th December 2020.

Outreach activities conducted

- In relation to SWINGS

The SWINGS outreach activity is structured by 1) a documentary on the cruise. Videos and rushes will be finalized on land; 2) an online journal, eXploreur from the Toulouse University that was weekly edited (8 articles); 3) a daily web site, maintained in Toulouse, which received 28 articles from the cruise participants; 4) a special communication towards the schools, including an exchange with convicts.

The on-land edition of the web site (https://swings.geotraces.org/) and the journal eXploreur (https://exploreur.univ-toulouse.fr/) are two sources of information used by many actors like the CNRS, the IUEM at university of Bretagne Occidentale, the professors of schools and the journalists.

The list of articles and broadcasts, including a long article in the national newspaper "Le Monde" and a one-hour broadcast at the national public Radio is accessible https://www.geotraces.org/geotraces-french-swings-gs02-cruise-press-review/. Some examples of media coverage of GEOTRACES SWING GS02 cruise are listed below.

- EXPLOREUR journal (Université de Toulouse): Expedition SWINGS. This journal has followed the SWINGS expedition publishing one article per week: https://exploreur.univ-toulouse.fr/swings-expedition-english
- News, University of Liverpool, UK (25 February 2021): Studying iron cycling in the Southern Ocean

- Embassy of France in Australia (24 February 2021): Let's swing together on the Southern Ocean!
  Download the pdf version of this article.
- CNRS, News: Exploring the world's largest ocean current (26 January 2021): Exploring the world's largest ocean current
- News, Florida International University (21 April 2021: 52 days at sea — with someone else's research
- IPSL blog on the participation of LOCEAN lab at SWINGS GEOTRACES cruise: https://www.archives.ipsl.fr/Actualites/A-decouvrir/Carnet-de-campagne-SWINGS-South-West-Indian-Geotraces-Section

- In relation to TONGA
  - In the framework of the Mon Ocean et Moi project https://twitter.com/monoceanetmoi, the two BGC ARGO floats launched during TONGA have been adopted by students by 3 new schools (one in Vallon-Dore in New-Caledonia, one in Brest and one in Menton). http://www.monoceanetmoi.com/web/index.php/fr/adopt-a-float. This 'adoption' was the occasion to initiate the classrooms about ocean science in general and TONGA project in particular, and also to train the teacher during a specific session. Tweet about these activities can be found at https://twitter.com/tongaproject
  - The movie realized on board the TONGA expedition is available both in French https://www.youtube.com/watch?v=e5kAd0i6Dck and English https://www.youtube.com/watch?v=UeABf-cVR-k. Check it out!

New GEOTRACES or GEOTRACES-relevant publications (published or in press)

- Artigue, L., Wyatt, N. J., Lacan, F., Mahaffey, C., and Lohan, M. C., 2021. The Importance of Water Mass Transport and Dissolved-Particle Interactions on the Aluminum Cycle in the Subtropical North Atlantic. Global Biogeochem. Cycles 35, e2020GB006569, https://doi.org/10.1029/2020GB006569.
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- González-Santana, D., Planquette, H., Cheize, M., Whitby, H., Gourain, A., Holmes, T., Guyader, V., Cathalot, C., Pelleter, E., Fouquet, Y., and Sarthou, G., 2020. Processes Driving Iron and Manganese Dispersal From the TAG Hydrothermal Plume (Mid-Atlantic Ridge): Results From a GEOTRACES Process Study. Frontiers in Marine Science 7 10.3389/fmars.2020.00568.
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Submitted by Kazuyo Tachikawa (kazuyo@cerege.fr).