ANNUAL REPORT ON GEOTRACES ACTIVITIES IN FRANCE

April 1st, 2019 to March 31st, 2020

New GEOTRACES or GEOTRACES relevant scientific results

- The Fe biogeochemical cycle and the role of humic substances

The dissolved iron supply controls half of the oceans' primary productivity. A new *in situ* particle interceptor/incubator (TM-RESPIRE) has been designed to investigate the drivers of dissolved Fe (DFe) resupply within the mesopelagic zone. Concurrent oxygen consumption, DFe and Fe-binding ligand replenishment rates were compared between the Southern Ocean and the Mediterranean Sea, two contrasting biogeochemical provinces characterized by differing contributions from biogenic and lithogenic sinking material (**Bressac et al., 2019**). Mesopelagic iron regeneration efficiencies were heavily influenced by particle composition with 10- to 100-fold higher values in low-dust subantarctic waters relative to high-dust Mediterranean sites (Fig. 1). Such wide-ranging regeneration efficiencies drive different vertical patterns in DFe replenishment across oceanic provinces. Analyses of released ligands revealed that the pool was largely dominated by electroactive humic substances (74 ± 28%, **Whitby et al., 2020a**). The release of ligands during remineralization ensured that concurrently released iron remained in solution, which is crucial for iron regeneration.

Ligands within humic-like substances have long been considered important for iron complexation, but their role has never been explained in an oceanographically consistent manner. By analyzing samples from the North Atlantic, Northeast Pacific and the Southern Ocean, we show iron co-varying with electroactive humic substances at multiple open ocean sites, with the ratio of iron to humics increasing with depth (**Whitby et al., 2020b**). We demonstrate how maximum dissolved iron concentrations could be limited by the concentration and binding capacity of humic ligands, and provide a summary of the key processes that could influence these parameters (Fig. 2). If this relationship is globally representative, humics could impose a concentration threshold that buffers the deep ocean iron inventory. This study highlights the dearth of humic data, and the immediate need to measure electroactive humics, dissolved iron and iron-binding ligands simultaneously from surface to depth, across different ocean basins.

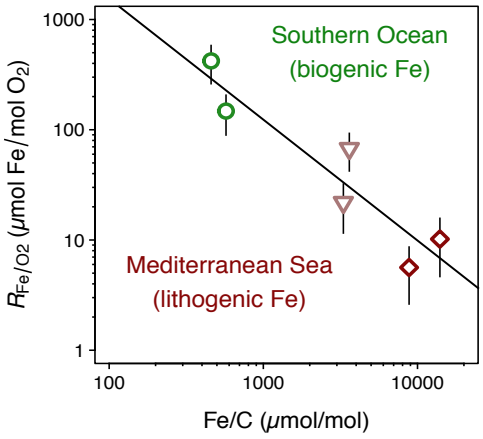

Figure 1. Iron regeneration efficiencies versus the Fe/C molar ratios of intercepted particles (a proxy for the PFe flux composition in which higher ratios have more lithogenic Fe) Adapted from Bressac et al. (2019).

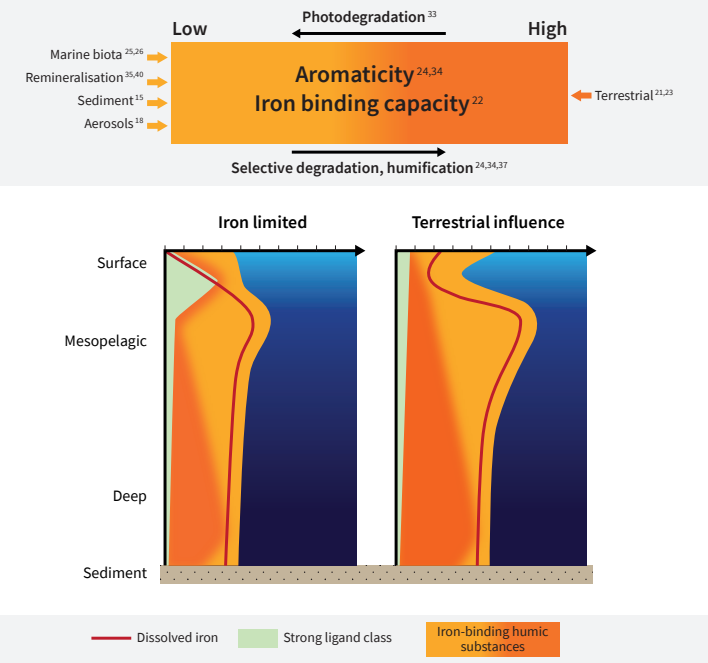

Figure 2. Our proposed schematic of the processes influencing the supply and iron-binding nature of humic substances in seawater. Above represents the continuum of iron binding by humics linked to aromaticity, along with the contributors of humic-like material to ocean waters. Below, our hypothesis for the potential contribution of humics to iron complexation and the iron ligand pool in two scenarios: iron limited regions (left) and terrestrially influenced regions (right). From Whitby et al. (2020b).

- ^{231}Pa-dissolved silica correlation in the Arctic Ocean.

While the biogenic silica (BSi) tests of diatoms are well known to strongly scavenge ^{231}Pa, until now, no relation between ^{231}Pa and dissolved silica (DSi) had been reported in the ocean. Two distinct correlations exist between DSi and dissolved ^{231}Pa in the deep waters of the Nansen/Amundsen (station 4,18, 32, 40, 50, 125, 153, 161) and the Makarov (station 101) Basins (Fig. 3). These positive correlations are likely due to ^{231}Pa is scavenging by BSi in surface waters and ^{231}Pa release as BSi sinks and dissolves in the deep waters (**Gdaniec et al., 2019**). The steeper slope of the dissolved ^{231}Pa versus DSi correlation in the Makarov Basin compared to the Nansen Basin is likely due to accumulation of in-situ produced ^{231}Pa (in addition to the BSi dissolution effect) during the longer aging of the deep Makarov waters.

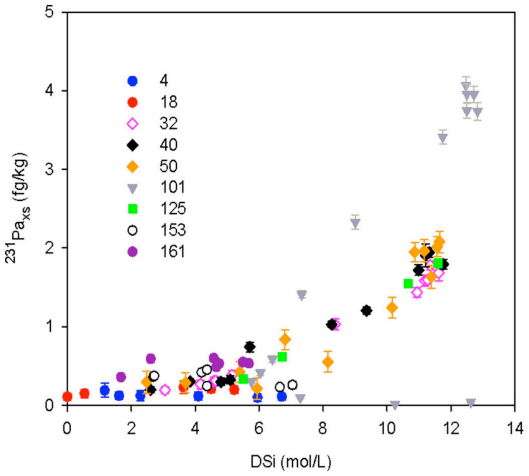

Figure 3. Dissolved $^{231}Pa_{xs}$ versus DSi. Diamonds: Nansen Basin, squares: Amundsen basin, triangles: Makarov Basin and circles: shelf stations (Gdaniec et al., 2019).

- Thorium scavenging during water mass mixing along neutral density surfaces.

The distributions of dissolved and particulate ^{230}Th and ^{232}Th were established along the

BONUS GoodHope IPY-GEOTRACES section in the SE Atlantic sector of the Southern Ocean (**Roy-Barman et al., 2019**). Total ^{230}Th and ^{232}Th versus salinity plots illustrate departures from binary mixing and provides evidence for non-conservative behavior of both isotopes along the section. We propose a model for total ^{230}Th and ^{232}Th scavenging and mixing along isopycnal surfaces (red curves, Fig 4). Data-model comparison suggests particle settling velocities in the range of 400–700 m/y and isopycnal eddy diffusivity of the order of 2000 m^2/s.

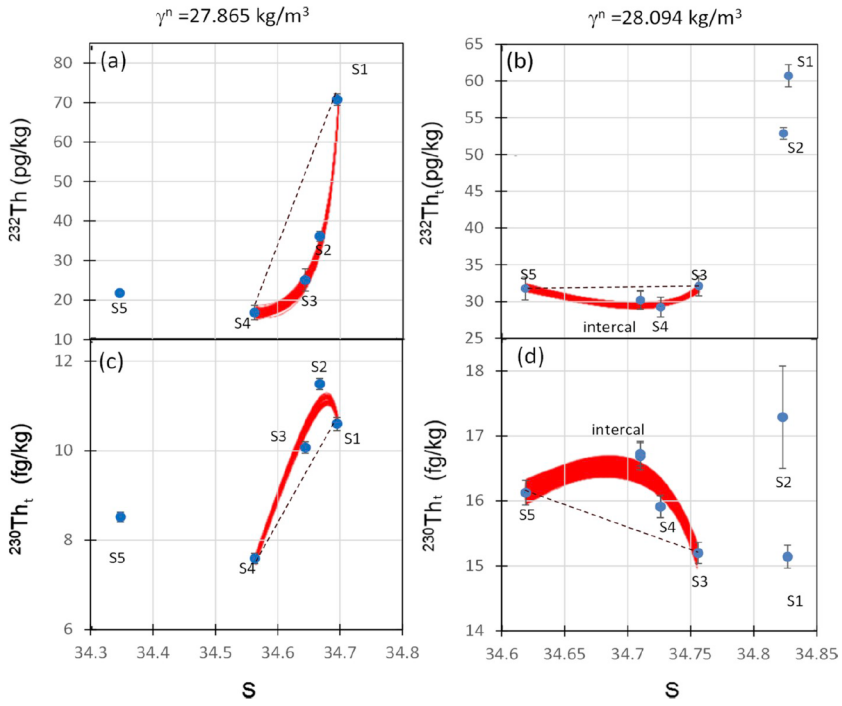

Figure 4. Advection-diffusion modelling of salinity (S) and total (dissolved+particulate) ^{230}Th (Tht) isotopes compared to data (Roy-Barman et al., 2019).

- Partition coefficients of ^{234}Th on particles

^{234}Th (a half-life of 24.1 days) is a particle-reactive isotope and its vertical gradient in the ocean can be used to constrain the intensity of the biological pump. It is necessary to constrain the partition coefficients of ^{234}Th on particles, a parameter that can vary by several orders of magnitude depending on the type of particles. Using the outputs of a global coupled dynamic (NEMO) / carbon cycle (PISCES) model, the inversion of dissolved and particulate ^{234}Th data is performed to best estimate these partition coefficients (**Le Gland et al., 2019**). The major findings are i) small particles (living and detrital) have a much lower affinity than large particles and lithogenic dust; ii) this affinity must increase by an order of magnitude with depth to correctly represent the vertical profiles of ^{234Th}; iii) the lack of consideration of 3D ocean dynamics and seasonal variability (spring bloom), generally neglected in the interpretation of observations, leads to significant biases (up to 30%) in the export estimate.

- Vertical profiles of dissolved ^{227}Ac activities along GEOVIDE section

In the framework of her PhD thesis, Emilie Le Roy reported vertical profiles of excess Actinium-227 activities in the North Atlantic (Portugal-Greenland-Canada) in the framework of the GEOTRACES program (GA01 section - GEOVIDE cruise, May-July 2014). ^{227}Ac is delivered to the ocean via diffusion from deep-sea sediments and was thus shown to be a powerful tool to study vertical mixing in the ocean. However, because ^{227}Ac activities are especially low in the ocean, relatively few studies have been conducted so far using this

tracer. The simultaneous determination of ^{231}Pa and ^{227}Ac activities along the section (^{231}Pa being the mother nuclide of ^{227}Ac) allowed us to report several vertical profiles of excess ^{227}Ac activities (^{227}Ac$_{ex}$) that contribute to significantly increase the ^{227}Ac data in the Atlantic Ocean (**Le Roy et al., 2019**). These new ^{227}Ac data complement the ^{226}Ra section that was reported earlier.

GEOTRACES or GEOTRACES relevant cruises

- **TONGA** (shallow hydroThermal sOurces of trace elemeNts: potential impacts on biological productivity and the bioloGicAl carbon pump): (chef scientists Guieu C., Bonnet S.; oct. 31/2019 to dec 6/2019, *R/V L'Atalante*, DOI 10.17600/18000884. Participation of LEMAR group. LEGOS group sent containers to collect samples for the measurements of dissolved iron isotopes, dissolved REE concentrations and Nd isotopes.
- Participation to the **SCALE cruises** (collab. CSIR, South Africa): two cruises sailed from Cape Town to Antarctica in winter (July 2019) and Spring (Oct 2019) on board the South African RV Agulhas II. Samples have been collected for trace metal speciation. Analyses and interpretations will be conducted as a collaborative project between South Africa (CSIR) and LEMAR.

New projects and/or funding

- The SouthWest Indian Geotraces Section (**SWINGS**; PI C. Jeandel, Co-I Hélène Planquette) was funded by Agence Nationale de la Recherche in 2019, is supported by CNRS and IFREMER and is planned to start from La Reunion on the 5th of January 2021 and to end at La Reunion on the 5th of march 2021 on the French *R/V Marion-Dufresne*. The year 2019 was dedicated to seek for the main funding (ANR, CNRS, IFREMER).
- CEELT: TGIR FOF (PI H. Planquette) for the acquisition of a new sampling container (Fig. 5). The new sampling container which was built in 2019, is now operational and has been successfully used for the first time during the TONGA cruise.

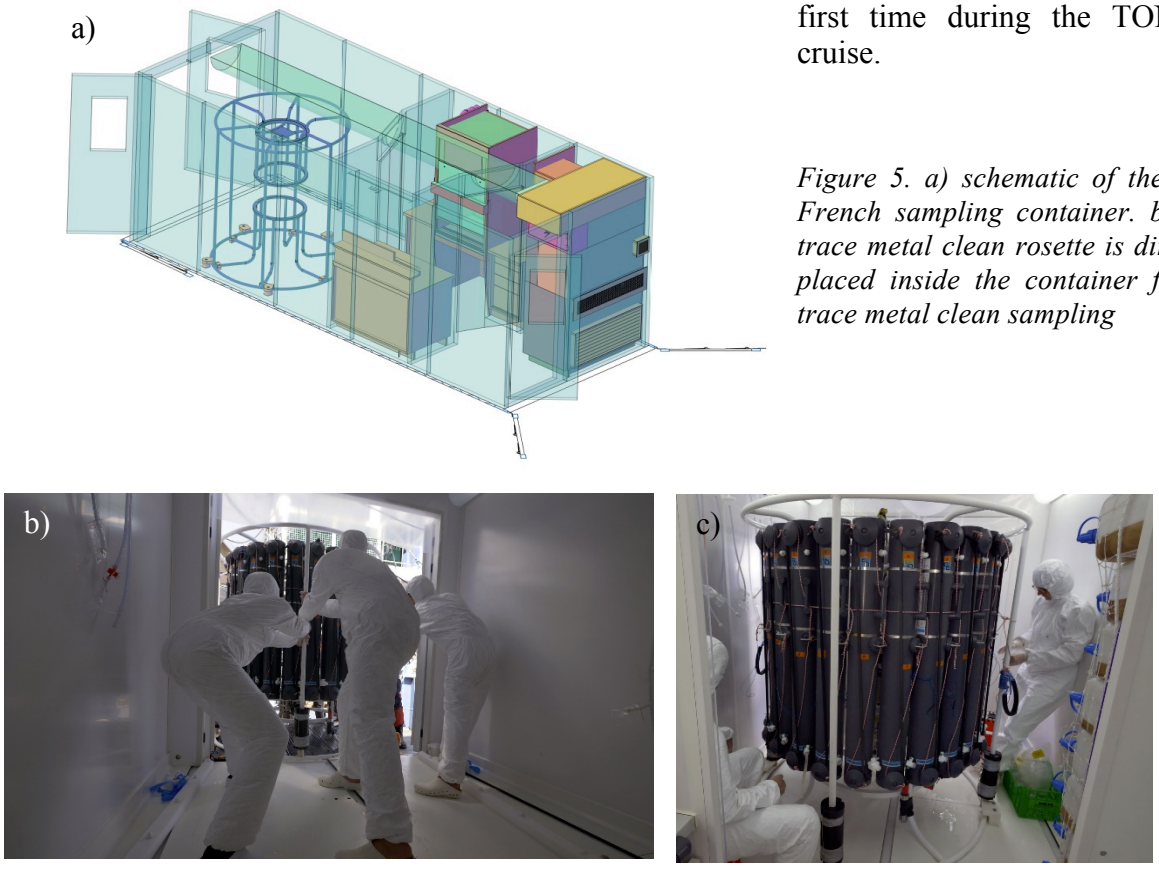

Figure 5. a) schematic of the new French sampling container. b) the trace metal clean rosette is directly placed inside the container for c) trace metal clean sampling

- A MSCA H2020 **ITN project** (www.gmos-train.eu) of which Lars-Eric Heimbürger-Boavida is leading the marine WP, and one of the 15 PhD students will be based at MIO and is in direct support for SWINGS and if possible the other hydrothermal samples.
- BIODOMPO: Biogeochemistry of dissolved organic matter in the Pacific Ocean. (30k euros + 1 PhD funding, PI G. Dulaquais) project based on US-GEOTRACES GP 15 and TONGA GEOTRACES cruises.

GEOTRACES workshops and meetings organised

- S&I meeting: Norfolk, U.S.A. 11th-13th June, 2019 (H. Planquette).
- DMC (C. Jeandel) and SSC (C. Jeandel and K. Tachikawa) meetings in Hobart, early September 2019.
- Lecture at GEOTRACES summer school in Cadiz (C. Jeandel), end of September 2019.

Outreach activities conducted

- In the framework of the Mon Ocean et Moi project https://twitter.com/monoceanetmoi, the two BG ARGO floats launched during TONGA have been adopted by students from 2 schools (one in Abu Dhabi and one in Nouméa). http://www.monoceanetmoi.com/web/index.php/fr/adopt-a-float. This 'adoption' was the occasion for the TONGA PIs to initiate the two classrooms about ocean science in general and TONGA project in particular. Tweet about these activities can be found at https://twitter.com/tongaproject.
- The preparation of the Silica School Consortium (in partnership with the University of Brest; UBO). It will be offering an e-learning experience (a small private online course or SPOC) on the subject of "Silica: from stardust to the living word" that will examine the role of silica under four major themes: (1) Silica in the Universe, (2) Silica in the Ocean, (3) Silicifiers in the living world, and (4) Silica in the future. The theme 2 (Silica in the Ocean) will be using published GEOTRACES data as learning material in certain courses. The SPOC is in the final phase of development and is anticipated to be available as an online course in the fall of 2020 (J. Sutton is the project coordinator).
- Four outreach activities related to mercury cycle
  - https://www.insu.cnrs.fr/fr/cnrsinfo/qui-methyle-le-mercure-dans-locean-global
  - https://www.axa-research.org/en/news/how-does-mercury-end-up-in-our-plates
  - https://www.liberation.fr/planete/2019/12/04/malgre-la-reduction-des-emissions-de-mercure-il-pourrait-y-en-avoir-davantage-dans-le-poisson-a-l-av_1766808
  - https://www.youtube.com/watch?v=DTe725DiIY0&t=14s

Other GEOTRACES activities

Potal DoOr and IDP 2021

- As member of the Parameter Definition Committee (PDC, with Bob Anderson and Bill Landing) and in the framework of the realization of a GEOTRACES data portal (DoOR) which will be operational for the GEOTRACES IDP 2021, C. Jeandel regularly interacted with the other members of PDC, the IPO executive director, the team of the SEDOO in Toulouse: the first version of the portal was launched in December 2019, together with a formation for the users at the SCOR booth during OS Sciences in San Diego.

- As IPO senior scientist, C. Jeandel seeks funds for Elena Masferrer Dodas' salary; she contributes to the website animation, mostly through the writing of the scientific highlights.
- Collaboration with University of Liverpool (Hannah Whitby now got a permanent lecturer position there), notably in the framework of the TONGA, SWINGS, and SCALE projects (collaboration as well with Leo Mahieu in the framework of his PhD and Pascal Salaün).
- Collaboration with University of Las Palmas (Aridane G. González now got a permanent lecturer position there) and LEMAR group continues the collaboration, notably in the framework of the TONGA and SCALE projects.
- Collaboration with CSIR, South Africa for the SCALE project and with the Universities of Cape Town and Stellenbosh in the framework of the Natasha Van Horsten's PhD (co-tutelle).
- Collaboration with Ifremer (E. Pelleter, C. Cathalot) in the framework of the HERMINE cruise and University of Southampton / National Oceanography Centre (Maeve Lohan), in the framework of the FRidGE cruise both involving the PhD of David González-Santana (1 article to be submitted soon).
- Collaboration with Florida State University (B. Landing), ETH (D. Vance, N. Lemaitre), Washington University (P. Barrett, J. Resing), WHOI (M. Saito), CSIR (S. Thomalla, R. Ryan-Keogh), Duke University (N. Cassar), MPI (F. Fripiat) in the framework of the SWINGS project
- Collaboration with Stanford University (K. Casciotti) in the Framework of the BIODOMPO project
- 2019 IMBER Open Science Conference, (http://www.imber.info/en/events/osc--imber-open-science-conference/osc-2019/2019-imber-open-science-conference), 17-21 June 2019, Brest. G. Sarthou; Member of the local and international scientific committee.

New GEOTRACES or GEOTRACES-relevant publications (published or in press) 34 peer-reviewed journal articles (France GEOTRACES investigators are lead authors or co-authors).

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Completed GEOTRACES PhD or Master theses

- Emilie Le Roy (PhD). « Distribution des radionucléides naturels (^{226}Ra et ^{227}Ac) le long de la section GA01 dans l'Atlantique Nord ». Supervisors: Pieter van Beek & François Lacan; Defense on 15/02/2019 (University of Toulouse); Link: https://tel.archives-ouvertes.fr/tel-02454460

GEOTRACES presentations in international conferences

AGU Fall Meeting 2019, San Francisco (USA) December 2019

- Schartup, A., Heimbürger-Boavida, L.E. Soerensen, A., Sonke, J.E. and Sunderland, E. Processes controlling the vertical distribution of methylmercury in the Arctic Ocean.

Ocean Sciences Meeting, San Diego (USA) February 2020

- Barbot S., Lagarde M., Lyard F., Jeandel C., Internal tidal wave energy responsible of lithogenic inputs along the Iberian shelf.
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- Gorgues, T., Beghoura, H., Aumont, O., Planquette, H., Tagliabue, A., Auger, P.-A. Impact of Inorganic Particles of Sedimentary Origin on Global Dissolved Iron and Phytoplankton Distribution.
- Klar J., Fabre S., Lacan F., Jeandel C., Estrade N., Yefsah H., Artigue L. Experimental study investigating the abiotic dissolution kinetics of iron during lithogenic particle-water interactions in high-energy regions.
- Michael S.M., Resing J., Baumberger T., Buck N.J., Lacan F., Pradoux C., Sedwick P., Sohst B.M., Wilkinson C.M. Examining the Importance of Shallow Hydrothermal Sources for Iron Delivery to the Surface Ocean in the Mariana Back-Arc.
- Nicholas S.L, D. Ceburnis, M. Iris Heller, M. A Marcus, G. Sarthou, P.L Croot., Speciation of Iron in Aerosol Particles Entering the Irish Shelf at Mace Head measured by μXAS and cathodic-stripping voltammetry.
- Whitby H., D. González-Santana, M. Cheize, A. Gourain, T. Holmes, Y. Germain, C. Cathalot, E. Pelleter, Y. Fouquet, G. Sarthou and H. Planquette, Humic substances and dissolved iron in the TAG hydrothermal vent plume

Goldschmidt 2019, Barcelona (Spain) 18-23 August 2019

- Anderson Robert F., Francois Roger, Frank Martin, Henderson Gideon M., Jeandel Catherine, Mukul Sharma. GEOTRACES: Inspired by GEOSECS to investigate trace elements and their isotopes in seawater Invited Talk.
- Dulaquais, G., Crampond, K., Waeles, M., Gerringa, L., Middag, R., Rijkenberg, M., Boye, M., Riso, R. Links between the biogeochemical cycles of iron and humic substances in the ocean.
- González-Santana D., Cheize M., Planquette, H., Whitby H., Gourain, A., Holmes, T., Germain, Y., Cathalot C., Pelleter E., Fouquet Y., and Sarthou G., The TAG hydrothermal iron budget: diving inside the TAG neutrally buoyant plume
- Jeandel C, Fabre, S. and Regard V. Revisiting lithogenic land-ocean inputs Invited Talk.

- Lagarde M., Lemaitre N., Planquette H., Grenier M., Belhadj, M. Pham, V., and Jeandel, C. Rare Earth elements scavenging in the North Atlantic (GEOVIDE cruise).
- Lemaitre N, Planquette H, Dehairs F, Planchon F, Sarthou G, Lherminier P, and Vance D. Trace Element Cycling in the North Atlantic
- Van Horsten N, Bucciarelli E, Planquette H, González-Santana D, Mtshali T, Roychoudhury A, and Sarthou G. Early Winter Dissolved Fe Distributions in the Southern Indian Ocean (GEOTRACES GIpr07 Cruise) 2019

European Geosciences Union General Assembly 2019, Vienna (Austria) 7-12 April 2019

- van Beek P., Tamborski J.J., Bejannin S., Souhaut M., Stieglitz T., Radakovitch O., Claude C., Garcia-Orellana J., Monnin C., Pujo-Pay M., Conan P., Ghiglione J.-F., Odobel C., Crispi O., Petrova M., Heimbürger L.-E., Seidel J.-L., Lacan F., Jeandel C., Charbonnier C., Anschutz P. Chemical fluxes (nutrients, trace elements) of groundwater discharge into the coastal Mediterranean Sea: A comparison between coastlines with different lithologies (coastal karstic systems vs permeable sands).

Chemical Oceanography Gordon Research Conference. Holderness (NH, USA) July 2019

- Artigue L., Wyatt N., Lacan F., Van Gennip S., Lohan M. Invited talk. Dissolved aluminium distribution in the subtropical North Atlantic coupled with an OMPA and modeled backward trajectories: implications for North Atlantic biogeochemical cycling.
- Le Roy E., van Beek P., Lacan F., Sanial V., Souhaut M., Charette M.A., Henderson P.B, 227Ac distribution along the GEOVIDE section in the North Atlantic, Chemical Oceanography Gordon Research Seminar (GRS): Novel Approaches for Investigating Marine Biogeochemical Cycles.
- Le Roy E., van Beek P., Lacan F., Sanial V., Souhaut M., Charette M.A., Henderson P.B, 227Ac distribution along the GEOVIDE section in the North Atlantic, Chemical Oceanography Gordon Research Conference (GRC): Discovering Chemical Processes and Mechanism in a Changing Ocean.

IMBER Open Science Conference, Brest (France) 17-21 June 2019,

- Dulaquais, G., Crampond, K., Boye, M., Riso, Sarradin, P-M., Riso, R. Refractory dissolved organic matter along the conveyor belt, sources, sinks and implications for carbon sequestration

14th International Conference on Mercury as a Global Pollutant, Krakow (Poland) Sept 2019

- Desgranges M.-M., M. Petrova, A. Dufour, B. Oursel, P. Layoun, C. Guieu, D. Point, G. Sarthou, S. Jacquet, L.-E. Heimbürger, Methylmercury: a new tracer for the remineralization of organic matter?
- Dufour, A., Petrova, M.V., Desgranges, M.M., Roberts, M., Oursel, B., Malengros, D., Lafont, M., Bhairy, N., Grenz, C. and Heimbürger-Boavida, L.E. GEOTRACES intercalibration exercises and development of reference material for the community.

The 13th International Conference on Paleoceanography, Sydney (Australia) September 2019

- Tachikawa, K. 2019. Neodymium isotopic composition as a proxy of water mass provenance in the Atlantic Ocean: the modern ocean and the past 1200 kyr. Invited.

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