Prospective
Flotte Océanographique Française
2017-2030

Coordonnée par *Catherine Jeandel*
CNRS, LEGOS, Université de Toulouse

Mai 2017

French Oceanographic Fleet (FOF) prospective

Aknowledgements

The first prospective for the "French Oceanographic Fleet" (FOF) Very Large Research Infrastructure (TGIR) could not have been completed without voluntary, active participation from many representatives from the FOF user community. As the FOF is multi-purpose, this prospective has received contributions from players in fundamental research in all fields of oceanography, teachers who run on-board teaching, engineers and technicians in charge of instrument and RTD pools, and finally, public service mission players, particularly fisheries scientists and engineers overseeing framework directive constraints (on water, on the marine environment strategy namely WFD and MSFD).
This work took place between November 2016 and the end of April 2017, 6 intensive months during which the members of 10 work groups have interacted actively either within their group or with their colleagues in the labs, spreading the enquiry as wide as possible. This involved many multi-site video conferences. Group leaders were particularly active in terms of sending me feedback from all levels. Meetings took place regularly with the fleet mission team commissioned by the CEO of Ifremer. Exchanges also took place with members of the National Global and Coastal Fleet Commissions, with members of the Strategic and Scientific Guidance Committee and members of the FOF Management Committee. More unexpectedly, I have met several innovative project managers from private ships and champions of possible proposals for the scientific community.

This introduction gives me the chance to express my thanks to all these players who were dynamic, sincere and constructive to work with. The complete list of participants appears in appendix 2 of this document.

This exercise was carried out with great freedom among all FOF users to say what they thought and led to numerous contradictory and constructive conversations. I would particularly like to thank *François Jacq, Pascale Delecluse and Frédéric Ménard* for their respectful support in completion of this work.

I would also like to specifically offer warm thanks to *Felipe Artigas, Jérôme Aucan, Thomas Changeux, Valérie Chavagnac, Patrick Farcy, Eric Foucher, Jacques Grelet, Antoine Gremare, Cécile Guieu, François Lallier, Pascal Morin, Patrick Raimbault, Emmanuel de Saint Léger, Daniel Sauter and Virginie Thierry*, namely the "group leaders" who always met my doubtlessly demanding, tedious pressure with resourcefulness and enthusiasm! I would like to thank all of you for your unwavering support and your very welcome good humour.

All my gratitude to the persons involved in re-reading and co-edition of this document, particularly *Valérie Bout-Roumazeille, Thomas Changeux, Patrick Farcy, François Lallier, Gilles Reverdin* and *Virginie Thierry.* Their attentive reading and Thomas's layout have given this document its current appeal.

A specific mention should go to *Olivier Lefort and Emmanuel Alessandrini* for their implication in drafting the PIA3 sheets during the prospective reflection and for their enlightening opinions on more technical matters…such as the ratio between a ship's length, draught and stability!

Philippe Bertrand, Lise Fechner and the members of the "Fleet" team are also thanked for listening so carefully during our meetings. The same recognition goes to *Eric Humler* for his presence at the prospective symposium.
I would also like to thank *Fredéric Merceur, Alain Zasadzinski* and the teams from La Pérouse Library and from the INIST whose compilation and bibliographic update work throughout 2016 made it possible to produce the eponymous chapter of this document.

The prospective symposium of 8 and 9 March 2017 took place at the Paris Globe Physics Institute thanks to our invitation and warm welcome from *Javier Escartin*.

Finally, *Nadine Rossignol* has supported us most effectively throughout this prospective process by setting up meetings, monitoring missions and of course organising the symposium. Thanks Nadine!

Catherine Jeandel
President of the COSS
Coordinator of the FOF prospective

French Oceanographic Fleet (FOF) prospective

Executive Summary

The first scientific prospective for the French Oceanographic Fleet took place between 30 October 2016 and 31 May 2017. It brings together the thoughts and opinions of over 100 players and users of the FOF, divided into 10 work groups, each run by one or two scientists who were experts on the group topics (details in Appendix 2). These work groups covered all FOF activities: scientific, teaching, technological or Public Service. A symposium organised at the Paris Globe Physics Institute on 8 and 9 March 2017 gave group leaders a chance to meet, discuss, identify gaps in the documents produced so far, and discuss prospective questions in each field and regarding interfaces between the communities. This symposium also brought about open, constructive and particularly dynamic discussion on the current role of the FOF, the distribution of ships in response to these roles, needs in terms of ships, deep sea vehicles and expected changes in the future.

The scientific report highlights the dynamism and quality of the work performed by the 3600 players who make up the body of the FOF's direct and indirect users. The vessel activity report covers the last 5 years, between 2000 and 2014. The stakes of the major scientific fields (Marine Geosciences, Physics-Biology and Element Cycles, Biology-Ecology-Biodiversity, Fisheries) were recapped and illustrated by two results selected for each field, one coastal and one open sea. The labelled observation services are described and also illustrated by three recent results. The on-board teaching activity is described. Strengths and difficulties are discussed on a community scale, then expressed a little more specifically by field of activity.

The prospective, firstly presented by scientific area, gives over a large proportion to interdisciplinary matters (ocean-atmosphere exchange and climate, continent-ocean exchange, deep-sea hydrothermalism, chemical elements and living cell) and to needs for resources expected to meet the issues of tomorrow.

This summary does not aim to repeat the content of the reports and scientific prospective. It intends rather more to list in a few lines the strengths and essential difficulties encountered by the community to work today and the needs in terms of vessels and changes in the FOF over the coming 15 years.

Overall community strengths

- A significant community of around 1800 people in situ (3600 counting PhD students and non permanent scientists), divided into 1/4 geosciences, 1/3 in physics-chemistry-cycles and just under half in biology-ecology-biodiversity and fisheries.
- A strong impact from the French community within major international programmes, where they work as leaders or active members.
- Numerous publications, in high-impact peer-reviewed journals (JGR, Science, Nature, Nature Géosciences, PNAS…)
- High-quality training for students and young researchers thanks to on-board teaching.
- Expertise and high technical skills among technical teams associated with very high-quality R&D.
- A highly demanding peer review system that guarantees quality.
- *A posteriori* monitoring of campaign assessment that gives FOF activities great visibility.

Operating difficulties and suggestions

- Major difficulties for scientific teams to fund campaigns at sea and the subsequent scientific work. This financial block hinders the dynamic and competitive nature of the French research teams. This funding is relatively low compared to the costs of the days at sea, but essential to allow teams to produce high-level research within competitive deadtimes. Satisfying scientists' demand to have a

single point of contact to fund research projects relying on the TGIR (Very Large Research Infrastructure) is crucial for the future and for the TGIR to work properly.
- Need for specific organised and effective help within the FOF for campaign logistics and organisation.
- Need for institutional communication relays that can give the FOF media visibility. This visibility is too often lost behind private and yet scientifically-marginal actions (some are even barely scientific).
- Strongly supported need for the entire community: it is essential for an on-board engineer to also attend campaign preparation meetings and oversee the land-sea link.
- Urgent need to harmonise the operation of instrument and OBS pools, and for an available equipment inventory and details of its provision (on US IMAGO and DT INSU models).

Current context of the FOF composition and alerts

- Within the year, the *Thalia* will leave the fleet, shortly after the *Gwen Drez* and the *Suroit*, whilst the *Côte d'Aquitaine* has never been replaced.
- This ageing is worrying in terms of safety for the *Alis,* plus an increase in its running costs.
- Need to expand and develop the *Côtes de la Manche* with acoustic and high-technology equipment and make it more multidisciplinary.
- Need to meet the demands for shallow-water work.

Summary of requirements from deep-sea vessels and machinery

- Station fleet: it is particularly urgent to replace the *Sépia II*.
- The need has been identified for TWO intermediate sized ships (detailed description in appendix 8)
  - Atlantic-Mediterranean, around 40m, 15 scientists, coast-shelf edge reach.
  - Pacific-Indian Ocean, around 35m, 12 scientists, reach from Vietnam to New Zealand.
- Modernisation of the *Côtes de la Manche* restated: increase in the number of places, autonomy, possibilities for trawling, high-quality geoscience sounders, possibility of sediment coring.
- Need for a vessel operating in shallow waters for fisheries, coastal geosciences and public services. 25-30 m, 10-12 scientists, low draught coastal zones. The ramp-up of Public Service constraints is evaluated at around 150 days a year for the MSFD and around 100 as well for safety at sea (SHOM, SOLAS): this must be addressed.
- A strong message on deep-sea equipment: the committee recommends keeping two deep-sea (6000 m) submersibles operational, HOV Nautile and ROV Victor, whose complementarity and association with the AUV 6000 (currently being manufactured) will guarantee all types of intervention.
- Envisage replacing the Téthys II by 2030.

French Oceanographic Fleet (FOF) prospective

TABLE OF CONTENTS

0. Introduction

Oceanography in its widest respect aims to understand how oceans worked in the past and today and how they interact with the atmosphere and the continents. Specifically, this refers to understanding the dynamics of the fluid, its chemistry and its role on the climate but also development of life in the oceans, its diversity, the structure and functioning of numerous ecosystems that develop there and that provide an essential source of food and money for humanity; storing this information over geological time in the sediment and this sediment's movements; the tectonics and geodynamics of the seabeds, mirroring terrestrial activity. Consequently, all fundamental disciplines are implicated in these challenges, physicists and chemists, biologists, fisheries and ecologists, geologists and geochemists, even mathematicians in terms of developing often complex models. Legal experts are also greatly required referring to laws on the sea that are ever-changing. Geographers, sociologists and anthropologists are involved in matters of global change (land development, coastlines, etc.), ethics and sociology. Considering the size of the ocean in question, covering 71% of the Earth's surface, and the importance of its associated issues, oceanographers' work is essentially international and collaborative. The major research programmes involved are co-opted worldwide, academic and guarantee independent research. For the benefit of society, it is essential that the measurements taken in a place or time or for a given period can be integrated with data acquired by other players in the worldwide community, in order to feed knowledge requirements from this hard-to-access environment. Beyond publications in top journals, this diffusion also relies on building interactive data centres.

Oceanography is a multidisciplinary approach of choice for teaching from School to Universities, and within them, in general and specialist teaching for scientific research training, from Degree to Doctorate level, alongside training for technicians and engineers. Finally, oceanographic research topics increasingly concern civil society as people become worried about keeping the ocean in good ecological condition, monitoring it and sustainable use of its resources. Oceanographic research therefore is material of choice for many public scientific dissemination centres and their promotion events.

This research and its associated teaching and scientific dissemination rely on data and sampling acquired in situ (water, sediment, organisms, rocks) and, for certain topics, on spatial data and digital models. The in-situ data and sample acquisition is based on very high-technology naval resources, oceanographic vessels and dedicated vehicles to explore the deep-ocean floors.

The Very Large Research Infrastructure French Oceanographic Fleet (TGIR FOF, presented in appendix 1) groups together all French naval resources belonging to the four founding organisations (CNRS, IFREMER, IPEV, IRD). It mainly comprises global, coastal and local vessels (over 10m long), associated heavy equipment (Nautile, ROV Victor 6000), and common mobile equipment (non-contaminating seawater sampling system, seismographs, sediment corers, etc.). The FOF's specific feature within the international panorama of oceanographic fleets lies in its multiple functions (academic research, operational, observation, teaching, public service, private contracts), whilst in most other countries, oceanographic fleets are only academic.

As its users come from different scientific areas, the equipment must be appropriate for these wide-ranging uses. The diversity and complexity of research topics, the implementation of these heavy resources and the very size of the ocean in question require national and/or international collaborative projects which are complicated to coordinate. Furthermore, the FOF plays a major role in oceanographic research run by Southern countries, possibly through international joint projects or French overseas commitments. This issue is important, as overseas territories represent 97% of the EEZ and 68% of the French coastline in 4 different oceans (Atlantic, Indian, Pacific, Southern). Because it is very far away, research run in overseas territories imposes specific constraints, particularly logistics, for the oceanographer researchers and engineers. As part of reorganising the FOF, on request from the Secretary of State for research, and in an attempt to optimise use of this infrastructure, it seems relevant to propose a scientific long-range planning dedicated to the TGIR FOF.

This refers to expressing scientific issues and obstacles for the coming 15 years, to formalise the functions expected by the different TGIR platforms, outline developments and resources required to maintain this research and let the national community strengthen its place in the upper echelons of the worldwide oceanographic panorama.

This long-range planning relies on i) the different long-range plans discussed over the last 3 years within the INSU (that have the advantage of being trans-organisational) for the coastal and open-sea environment, particularly including geosciences, physical, chemical and biological oceanography, functioning of the earth's climate, constraints on national observatories on the French mainland and in its overseas territories; ii) the INEE long-range planning as specified in a symposium in late February 2017 on biology, ecology and biodiversity, from the coast to the deep-ocean floor; iii) national and international fishing issues; iv) conclusions from the "techno-fleet" symposium that was held at INSU in 2015; v) other FOF constraints, particularly regarding teaching and public service needs. It worked with 10 topical work group leaders. These groups were defined (between 10 and 20 members) as outlined in appendix 2. A symposium made it possible to gather feedback from the groups on 8 and 9 March at the IPG in Paris. In total, more than 100 FOF users worked to brew up ideas for this long-range planning.

To make it effective, this document is an overview. Links and original documents are provided in the appendices (1 to 9).

1. Part 1: Report

1.1 The strengths of oceanography in France, international issues

1.1.1 Strengths

There is a list here of all permanent staff, researchers, teacher-researchers and physicists in the observatories, engineers and technicians who use the FOF (see table in Appendix 3) either directly (on-board) or by working on the data or samples from the campaigns. This inventory, conducted using the "FOF" filter, had never been performed before and required involvement from all relevant unit directors. The diversity of the feedback meant that it could not be treated with the expected granularity (for example, we cannot reliably identify the number of teacher-researchers).
Without claiming to be exhaustive, it seems that most of this staff are spread over sixty labs all over the country, mainland and overseas territory. These labs are three quarters Mixed Research Units (MRU) attached mainly to the INSU (30) or the INEE (16) and more than twenty Universities. These MRU are mainly owned by Ifremer, IRD and MNHN, but also CEA, CNES, BRGM or EPHE. The last quarter is essentially made up of Ifremer's own units (15).

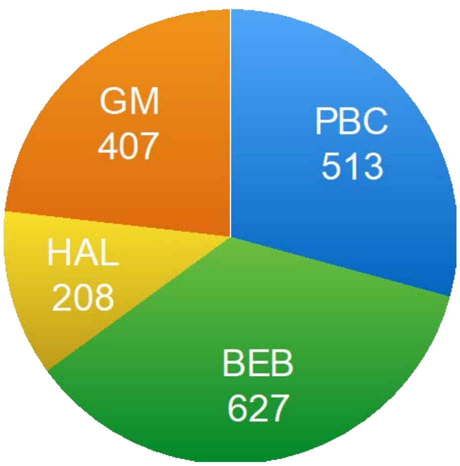

Figure 1. Topic-based distribution of permanent staff using the FOF PBC Physics-Biology-Cycle, BEB Biology-Ecology-Biodiversity. HAL Fisheries. GM (MG) Marine Geosciences. See data table in appendix 3.

Out of 2600 researchers and 1500 engineers and technicians from these laboratories, just over 40% work with the FOF, so almost 1800 people with an IT/C ratio of a little over 1:2. If we included contract workers - engineers, PhD students and post-docs - this workforce would double to around 3600 users of the FOF.
Their distribution in terms of general topic is illustrated opposite, namely a little under a quarter from Marine Geosciences and paleo-environments (MG), just under a third in Physics-Biology-Cycles (PBC) and almost half in biological, fisheries and ecosystem research altogether (HAL & BEB).
All the FOF resources are used as the oceanographic cruises are run on the local vessels (35 labs out of 60) and on the coastal fleet (47) and global fleet (49). If we cross topics and ship category, we can see quite naturally that there is a slight preference for the open-sea fleet in PBC, considerable use of station ships in the BEB community but most of the labs use all the FOF resources. This can doubtlessly be explained as strengthening the activities with both geographic (continent-coast-open sea) and topic interfaces.

In terms of topics, finer analysis can be found in long-range planning work by several parent organisations, particularly the Solid Earth prospective 2016-2020, the Ocean-Atmosphere prospective (due to appear in 2017) and the INEE prospective (due to appear in 2017).

1.1.2 International and national programming

International Framework

Oceanography requires heavy, expensive resources (satellites, ships, autonomous instruments, etc.) to study complex objects. Regardless of whether they specialise in physics, biogeochemistry, biology or marine geosciences, the researchers from these disciplines are structured on a worldwide scale to make progress intelligently and rationally on knowledge of a given object. Although complicated to implement, joint programming has progressively emerged since the early 90s. It is associated with setting up international coordination helping to avoid situations such as key regions being left out of observation. The decisions to develop observation networks or major measuring programmes are made under the aegis of umbrellas such as academies, the World Meteorological Organisation or even the United Nations via UNESCO. These decisions are based on international scientific councils in a "bottom-up" approach, where implemented structuring responds primarily to requirements imposed by the need for knowledge. Some of these programmes propose a layout plan discussed by all partner countries, a data acquisition discipline and putting data in open data centers. Other programmes simply play the role of scientific activities and monitoring actions. The summary diagrams in Appendix 4 attempt to shed some light on this necessarily intricate architecture. These different programmes provide coherent national structuring with these worldwide issues.

In marine geosciences, the community takes active part in international programmes and networks (European Consortium for Oceanic Research Drilling; http://www.ecord.org), EMSO (European Multidisciplinary Seafloor and water-column Observatory; http://www.emso-eu.org), JERICONEXT (European network dedicated to coastal observation; http://www.jerico-ri.eu) and EMODNet (European Marine Observation and Data Network; http://www.emodnet.eu). It contributes to International Research infrastructures such as INTER-RIDGE and IODP and national infrastructures such as IR-EMSO France (EMSO-Açores, EMSO-Ligure and EMSO-Marmara) and IR I-LICO (Inshore and Coastal) via services and observation networks (labelled or being labelling DYNALIT and SOMLIT). These international, European and national networks and programmes help provide elements to meet society's demands (climate, georisk hazards, renewable energy, mineral resources, etc.) and the fundamental problem issues concerning how the Earth's system works on all geological time scales.

In physical, chemical or geochemical oceanography, the international community has been heavily involved over the last 20 years in developing in situ ocean observation networks and coordinated campaigns at sea. These coordinated networks and in situ observation programmes provide information on oceanic variables identified as essential to tackle issues related to climate change, operational oceanography and the health of the oceans, but also for process studies (e.g. temperature, salinity, current, pH, CO_2, water isotopes, nutrients, chlorophyll, etc.). These networks rely on different types of platforms that might be mobile (boats, floats, gliders) or fixed (moorings, etc.), autonomous (floats, buoys, gliders), satellite or in situ, etc. (Appendix 4). Thanks to its oceanographic fleet, France is particularly active, even a driving force, within the Argo programmes for autonomous profiler floats (http://www.argo.ucsd.edu/), Go-Ship (maintaining a network of hydrographic sections, http://www.go-ship.org/) and GEOTRACES (study of the biogeochemical cycles of trace elements and their isotopes, http://www.geotraces.org/). These three programmes propose an integrated approach, from drafting scientific aims with campaign implementation to producing databases, with data validated by strict protocols. National researchers are also very active in running IOCCP programmes (worldwide network of oceanic carbon observations; http://www.ioccp.org/) SOLAS (for questions on the ocean-atmosphere interface, http://www.solas-int.org/), IMBER (for integrated study of the marine biosphere) and in the observation systems for tropical oceans (PIRATA, TPOS2020).

In marine biology, ecology and biodiversity, the international programming context has been structured more recently, particularly following the boost from the Census of Marine Life (CoML 2000-2010). All organisms are involved, from the microbial world to major predators, from the beach to the deep-ocean floor and at all latitudes. Concerning biodiversity, and under the aegis of the major international authorities (UNESCO-UNEP & IOC, ICSU, IUCN, IUBS, IODE), these are the research coordination programmes (Future Earth and programmes coming from Diversitas – bioDiscovery, bioGenesis, ecoServices), from the observation (GEOBON and its break down into topics – MarineBON – or regions – ECOSCOPE in France) and from bankarisation (GBIF, OBIS & WoRMS) which have appeared over the last few years (Appendix 4). All biological samples taken during the FOF campaigns on ocean-going, in-shore or station vessels, as well as data from functional or evolving analysis from any that intend to contribute to these programmes via their national or European organisations or entry points. The sequencing data (DNA, RNA or proteins) from these samples is added other worldwide data centers, such as GenBank or UniProt. Please note the former programmes UE EurOceans, MarBEF and Marine Genomics for which the communities are now grouped into EuroMarine which, with the European Marine Board and JPI Ocean structure the research and the community at European scale. As far as marine biology resources are concerned, the IR EMBRC (and its European organisation ESFRI EMBRC) opens up access to Roscoff, Banyuls and Villefranche station ships to a wider community of biologists.
Marine biologists and fisheries ecologists also mobilise the FOF for methodological clarifications and to implement campaigns supporting public policies that are entirely or partly funded by the French State or by Europe. These campaigns, initially focussed on stock assessment within the framework of the Common Fishing Policy, were extended to the whole ecosystem tied in with the Water Framework Directive (WFD 2000) and the Marine Strategy Framework Directive (MSFD-2008). As these campaigns are often recurring, they geographically fix these FOF ships making it impossible to move them to other oceans (e.g. the *Thalassa* has been anchored in the North Atlantic for a long time).

National Framework
French researchers participate actively in these international scientific councils and bring in their own scientific priorities. Consequently, it makes sense that, in France, the calls for tender from the INSU, INEE, IFREMER or IRD, coordinated within the ALLENVI Sea Group, intend to pass on these major programmes and to stimulate scientific work in line with these worldwide aims.
Regardless of the disciplinary field (geology, physics, biology, chemistry, etc.), the scientific topics covered by the national community are based on oceanographic campaigns run on the station vessels and the coastal and global fleet and in all oceans. Projects are put together with support from the organisations (INSU and INEE at CNRS, IRD, IFREMER, IPEV…) and from the ANR, which too often need to be completed by Labex, Idex or even regional or private funding (in this respect please refer to 1.6.1 and 2.5), on responses to calls for bids.

1.2 Topics, issues and a few recent results

1.2.1 Marine Geosciences

General topics and issues
The MG community is active on a very wide range of topics and sites such as how the coastline is evolving, the dynamics of oceanic ridges and formation of the oceanic lithosphere, subduction zones, volcanic arcs, seismic and gravitational hazards, the interface between the oceanic lithosphere and the ocean, analysis of sedimentary archives to study transfer processes and deposit of particles that settle in layers and for paleoclimatic and paleo-oceanographic reconstructions. Society's concerns regarding the ocean, coasts and associated hazards have been

amplified over the last few years by further questioning that is not only scientific but also economic regarding:

- The type of links between geodynamic and tectonic changes and the oceanic dynamic, climate, erosion and sedimentary recording;
- Using the sediment and fossil archive, establish a report on the realistic/complete Source-to-Sink material and modelling of the different parameters and forcings that govern this dynamic;
- Seismic and gravitational hazards possibly in relation to the genesis of tsunamis; coastal hazards linked to anthropic impacts and to climate change (such as coastline erosion);
- Mineral and marine energy resources (granulates, renewable marine energies)
- The reconstruction of paleoclimatic and paleo-oceanographic fluctuations working from the study of sediment and coral series; these reconstructions help identify the processes and interactions that control climate change and the ocean's role in how atmospheric carbon is evolving over time scales associated with the dynamics of the ocean and glacial icecaps or much longer for orbital modifications of exposure to sunlight or from internal geodynamics;
- The tectogenesis of active or passive margins and the migration of fluids from the mantle and the crust up to the surface in a sedimentary context and associated hazards;
- The study of processes and water-rock interactions in the ocean depths and the impact of hydrothermal flux on major global biogeochemical cycles and marine ecosystems.

Furthermore, French teams are historically highly implicated in passive margins (Atlantic, Mediterranean, Indian ocean) and active margins (Northern Andes, Japan, Mediterranean, SW Pacific, Indian Ocean, Antilles).

Illustrative results

The scientific community has innovated in four booming areas: (1) reducing risks and adapting to climate change in coastal areas, by contributing to quantified assessment of erosion and marine submersion factors modifying the coastline (please also refer to the prospective document "Surfaces et Interfaces Continentales 2013-2017" by the INSU), (2) deep-sea instrumentation, particularly in geophysics, by developing sensors and new devices for electromagnetism (ACEM), gravimetry (GRAVIMOB), geodesics and seismic observation, (3) *in-situ* data acquisition in the deep-sea environment via innovative instrument developments (PERISCOP, AUV 6000 on-going, ...) and seabed observatories (EMSO programme: 11 marine observatory sites; IR EMSO-France with 3 sites targeting the Azores (MOMAR), in-shore Liguria and Marmara; and (4) the development of very deep sediment corers that would make France lead the world in terms of mass collection of long sediment series by sediment core boring. This specific aspect has allowed the scientific community to be active within the PAGES/SCOR (IMAGES) programmes by contributing to very important progress concerning climate and oceanographic variability over the last 300,000 years (Waelbroeck et al., 2010; Gottschalk et al., 2016). The Actions Marges programme (coll. INSU-Ifremer-BRGM-Total; http://actionsmarges.fr) has coordinated national laboratories in three major areas: 1) the continental break in the Gulf of Aden-Afar (Leroy et al., 2011), 2) paleoclimatic reconstructions and the Messinian salt crisis in the western Mediterranean basins (Druissi et al., 2015) and the sedimentary "source to sink" reconstructions of passive margins (Rouby et al., 2013).

In parallel, the issue linked to the deep-sea mining exploration permit zones (>3000m) brought about oceanographic campaigns associated with heavy deep sea vehicles (HOV Nautile, ROV Victor).

Among vast scientific progress made over the last few years, we might mention the links between the seismic and gravity hazards and the geodynamic and tectonic changes with the following demonstrations: 1) a correlation between deep-sea or coastal earthquakes and accumulation on the seabed of turbidity current deposits generated by the movement of the seabed and sediment suspension (MARADJA2, PRISME, Figure 1; Babonneau et al., 2016); 2) coupling between dynamics and deep-sea structure of the subduction zones and the origin of major earth tremors (Singh et al., 2011; 2017); 3) links between volcanic eruptions, neotectonics and collapse of volcanic slopes and tsunamis in the French Antilles (ODEMAR, GWADASEIS, BATHYSAINTES; Escartin et al., 2016; Leclerc et al., 2016).

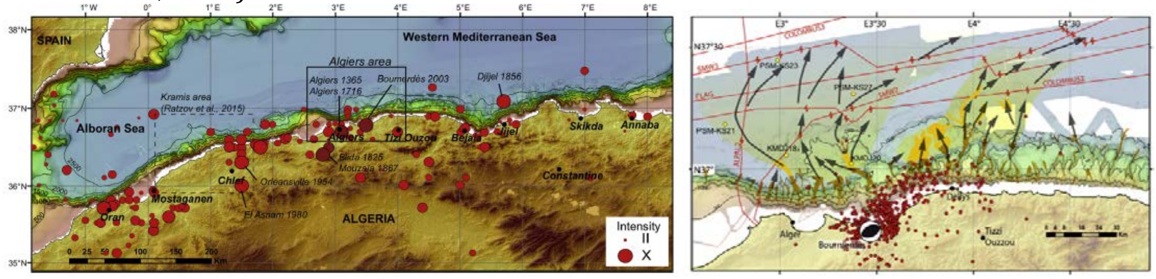

Figure 1: Left: Topographical and bathymetric map of the Algerian margin on which historical earthquakes have been reported from this area in the red circle. Right: Map interpreting turbidity currents in the coastal area following the 2003 earthquake. The results of this study are presented in Babonneau et al. (2016).

Furthermore, understanding the formation, dynamics and evolution of the oceanic lithosphere remains a fundamental problem issue for geoscience research, revealing complex interactions between magmatism and slow and ultra-slow deformation around oceanic ridges. The results obtained during the latest open-sea campaigns demonstrate that the mechanisms being observed are 1) a local mode with no magmatic feed on the axis where plate divergence accommodation takes place via tectonic blooming of the lithospheric mantle over several tens of km (SMOOTHSEAFLOOR, SWIR, Sauter et al., 2013; Cannat et al., 2009), 2) the rise and exhumation of the mantle all along a transpressive transform fault due to the nature of the subjacent lithospheric mantle rather than a kinematic change (COLMEIA, Maia et al., 2016), and 3) the formation of detachment faults creating "Oceanic Core Complexes" (MOMARDREAM, ODEMAR, Figure 2; Andréani et al., 2014; Escartin et al., 2017).

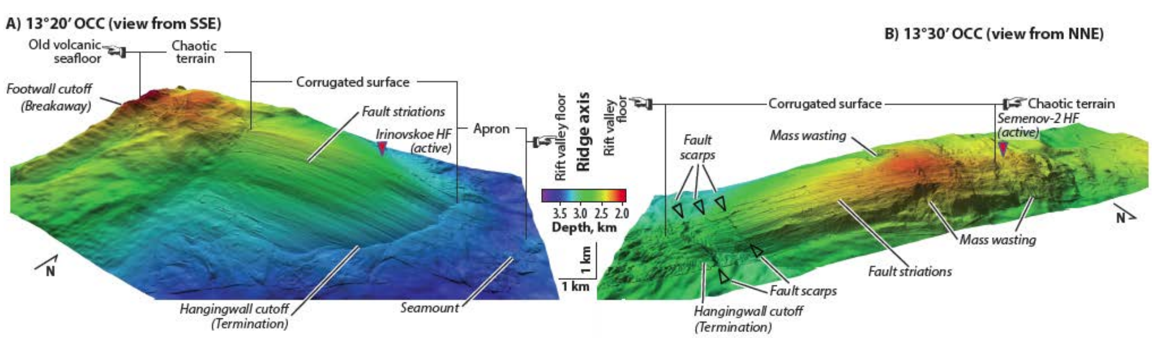

Figure 2: Micro-bathymetric 3D views of the "Oceanic Core Complex" at 13º30'N and 13º20'N on the mid-Atlantic ridge revealing the different structural areas and associated morphological features. The red triangles pinpoint the active hydrothermal sites (Escartin et al., 2017).

1.2.2 Physics-Biology-Cycles

General topics and issues

The major aim of research in these fields is to better understand:

- the physical and biogeochemical oceanic processes

- their variabilities over different scales of time and space;
- their possible feedback with other compartments of the earth system (continent, atmosphere, ice, lithosphere):
- the impact of climate change and anthropic pressure on the physical and biogeochemical ocean, leading to important, fast environmental modifications for some (modification of the stratification, circulation, ice melting, rising sea levels, acidification, change in the volumes of minimum oxygen zones, continental and atmospheric provisions including the arrival of new pollutants, etc.).

To meet these aims, the community is running research projects dedicated to

- studying the ocean's internal processes, its interfaces, and its links with external forces;
- diagnosis of the current average status, of variability and long-term evolutions (trend, break, cycles) of circulation, oceanic content of heat, salt, CO_2, and O_2, but also large cycles of chemical elements for quantification of the biological pump, etc.

So, the Physics-Biology-Cycles community relies on FOF coastal and global vessels to run major mono-disciplinary (e.g. RREX, CASSIOPEE) or multidisciplinary projects (e.g. AWA, AMOP, GEOVIDE, OUTPACE, JERICO-NEXT, CIGESMED, HYMEX-MERMEX-DEWEX). Without counting Observation Services (Section1.2.5), several tens of projects were run over the last 5 years thanks to the FOF.

Monodisciplinary campaigns, essentially in the field of coastal and open-ocean physics, look at the physical processes with an impact on masses of water, their dynamics and their variability in contrasting regions such as the North Atlantic Ocean, the Bay of Biscay, the Southern Ocean or even the Western Pacific. The physical processes being considered are the large-scale circulation and meso-scale structures, current-topography interactions, formation of deep waters, upwellings, turbulent mixture.

Multidisciplinary campaigns look at certain key physical or biogeochemical processes and the role of physical processes on biogeochemistry and the ecosystems.

In the open-ocean area, these studies have looked at the minimum oxygen zone in the South East Pacific, the formation of brine in Arctic regions, studies of the carbon processes and flux in the Pacific and Austral Ocean, the hydrology and the biogeochemical features of water masses in the Mediterranean (MISTRALS site) and the influence of atmospheric contribution (dust), sediments from margins and the physical mixing in the trace elements cycles. The contribution of the physical ocean to storage and transport of anthropic carbon, oxygen and the distribution of trace elements and their isotopes has also been studied. The sources, the reaction time and/or the dynamics of the organic matter throughout the continent-ocean continuum, related to the environmental forces (particularly hydrodynamic and sedimentary hydrodynamic) but also contaminants, have received particular attention on the continental coasts and overseas. The physical-biological link (such as hydrodynamic-zooplankton), the response from ecosystems to climate change and to anthropic pressure (including monitoring contaminants in trophic networks for example) have also been the subject of many research projects.

This research is run on different scales of space and time. Certain campaigns cover thousands of km to study the successions of dynamic regions and trophic regimes (e.g. OUTPACE 5000km) whilst others focus on restricted and yet extremely key zones such as the North West Mediterranean (MISTRALS programme), the Bay of Biscay, the Pacific islands or the Gulf of Guinea when considering the sub-basin scale. At an even smaller scale, research has been run alongside coasts by proposing to study a specific ecosystem such as the upwelling region in West Africa (AWA, EPURE) or a set of ecosystems. Certain campaigns are carried out just once whilst others are

performed several times a year to study the seasonal cycle (SPOT, MOOSE-GE), or even, for those based on observation services, they are run frequently and interannually (e.g. MOSLIT project). Others, without being labelled as Observation Services, have existed for almost 20 years (OVIDE). This research is generally associated with other platforms deployed at sea (autonomous vehicles, moorings) and are joined on to satellite observations and modelling work.
Finally, these projects fall within the scope of the aforementioned international programmes such as GO-SHIP, CLIVAR, GEOTRACES, SOLAS, etc. where the French community is highly implicated, active and acknowledged

Illustrative results
The study of the annual hydrological and biogeochemical cycle in the north-west Mediterranean within the DEWEX-MERMEX/HYMEX project (Figure 3) illustrates the beauty of getting the Ocean and Atmosphere communities to work together, the point of seasonal monitoring and an important validation of the use of several FOF ships.

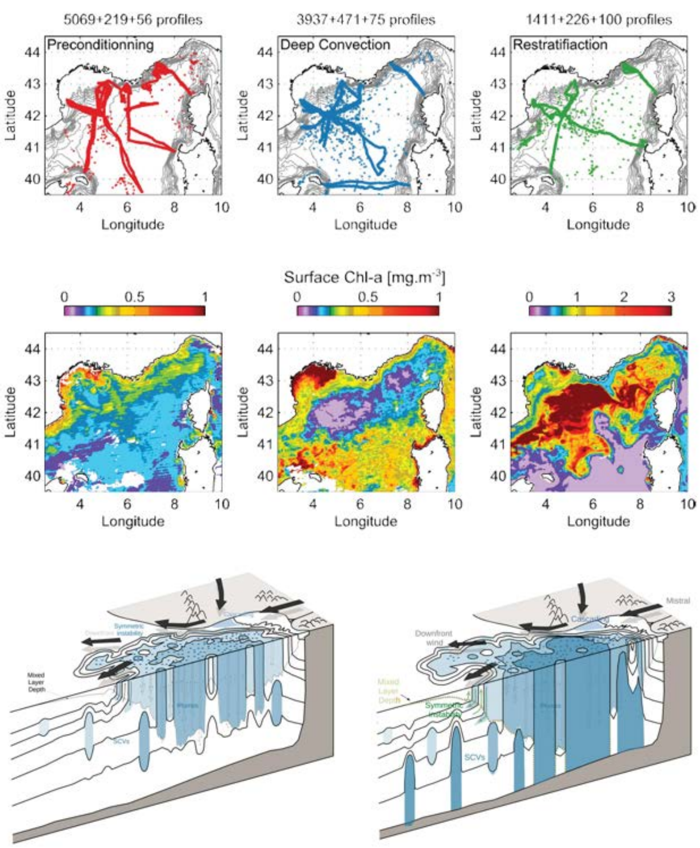

Figure 3. All the SNO MOOSE summer campaigns and the 6 seasonal DEWEX campaigns performed between June 2012 and July 2013 have allowed annual monitoring to be performed on atmospheric and oceanic conditions to study the multiple physical processes involved in the formation and dispersion of dense water in the Gulf of Lion and their impact on the planktonic ecosystem. The maps present the position of the CTD stations and the gliders transects, and the surface concentration of Chlorophyll-a obtained for different periods of the convection (autumnal pre-conditioning, winter mixing and spring restratification/dispersion). The diagrams (lower figures) outline the evolution of the convection zone and the volume of fluid mixed by convection during the violent mixing phase in a period of 1 to 2 weeks with different processes demonstrated (from Testor et al., JGR Ocean, Special Issue).

http://www.insu.cnrs.fr/environnement/dewex-impacts-of-deep-water-formation-on-mediterranean-pelagic-ecosystems-mermex ; http://www.insu.cnrs.fr/node/4893

The MOSLIT project (EC2CO-DRIL Figure 4) illustrates the link between research projects, observation services and the French Oceanographic Fleet as it relies on data and logistics from the SNO SOMLIT and so over around 900 sea trips from FOF local and coastal vessels between 2007 and 2014.

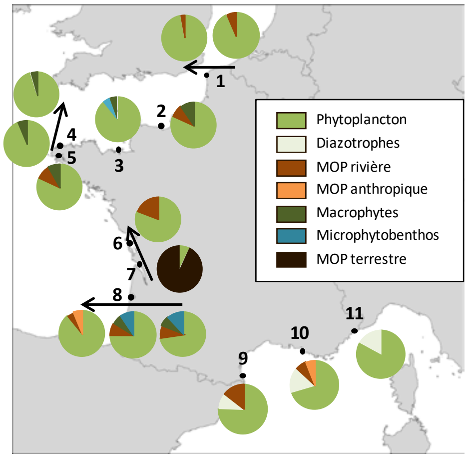

Figure 4: Composition of the particulate organic matter in the coastal ecosystems monitored by the SNO SOMLIT (MOSLIT project; EC2CO-DRIL). 1: Eastern Channel; 2: Bay of Seine; 3: Rance Ria; 4: Western Channel; 5: Bay of Brest; 6: Charente narrows; 7: Gironde estuary; 8: Arcachon Lagoon; 9: Bay of Banyuls; 10: Bay of Marseille; 11: Bay of Villefranche
The results illustrate 1) the dominance of phytoplankton outside the estuaries, 2) the importance of diazotrophs in the Mediterranean (oligotrophic system), 3) the continent-ocean gradient within the same ecosystem or along a continuum (black arrows), and 4) the major forcings: sediment hydrodynamics (in itself linked to the meteorology and the climate) and the trophic status (oligotrophy vs meso/eutrophy) of the ecosystems (Liénart et al., 2017).

1.2.3 Biology-Ecology-Biodiversity

Topics and issues

Although the fundamental concepts of biology remain identical on land or ocean, the marine environment features impose different ways of working and specific reactivity of the ecosystems. As for other areas, exploration and experimentation are strongly constrained by access and specific resources, particularly the fleet, structure the community into a coherent and interactive group.

The major issue remains to characterise the biodiversity and its dynamic, in a context of global changes and diversified anthropic impacts, an issue that the sequencing technologies (NTS), just like real-time, non-invasive observation methods (such as biologging, animals equipped with sensors) and high-resolution space and time sensors such as those associated with the JERICO-Next joint European coastal infrastructures network, can allow us to envisage whether it is for research on biological evolution, the biogeography or how the ecosystems work. The integration of this important flood of data with physical and chemical oceanography contributions is on-going on different scales which are pertinent to be able to include ecology in holistic models.

In the pelagic area, the study of the biological component (plankton) is generally included in the multidisciplinary biogeochemical campaigns (e.g. KEOPS2, MERMEX, etc.) including biodiversity studies in the wider sense: phylogeography, trophic network, adaptive mechanisms.

The exploration of biodiversity in deep-sea environments by French teams remains at the international forefront particularly thanks to the FOF's submersible machines (section 2.4.1 and Appendix 5). This concerns chemosynthetic ecosystems (e.g. MESCAL, BIG, BIOBAZ, BICOSE, WACS, CONGOLOBE), often linked in with geoscience campaigns, and ecological studies associated with the EMSO-MOMAR (MOMARSAT) deep-sea observatory. However, there are also deep ocean floor ecosystems on continental slopes or sea mounts (particularly the current Tropical Deep Sea Benthos programme by the MNHN http://www.mnhn.fr/fr/recherche-expertise/lieux/tropical-deep-sea-benthos that provides access to 40 years of sampling during the MUSORSTOM campaigns on deep-sea environments around large tropical islands with a focus on French overseas territories but also BOBECO, MAD, etc.) that are being developed.

The ecology of communities and trophic networks provides a specific response to the demand for diagnosis on the ecological status of coastal environments, and soon further out to sea, to monitor the overall marine space (WFD or MSFD) and more particularly for Marine Protected Areas (MPA) that are currently under development. Clarifying indicators requires access to reference zones that are not affected by humans using FOF resources (*cf.* PRISTINE programme and Scattered Islands).

The population connectivity study, using marking and telemetric monitoring or genetic tools, constitutes an essential element for establishing and monitoring MPAs.

All these approaches are also implemented in the intertropical zone, where the exceptional concentration of biodiversity in the coral ecosystems and the threats looming over them due to climate change draw particular attention (POSTBLANCO campaign monitoring coral whitening in New Caledonia and SUPERNATURAL, CARIOCA campaigns on the effect of acidification on the ocean in the coral reef ecosystem).

Illustrative results

Among the numerous biology, ecology and biodiversity campaigns carried out in all oceans and at all latitudes or depths, here are two contrasted examples. One from the coastal area using a local vessel to study parasitism in a commercial species, the cockle; the other in the deep benthic area, using a global vessel and a submersible to study the adaptation to an extreme environment of a chemotrophic symbiosis.

Competition *vs.* Parasitism in cockles

Since 1998, the cockle population (bivalve) has been sampled monthly on the Arguin sandbank (Gironde) from cruises organised on the local vessel Planula 4. It has been demonstrated that there is a reverse relationship between cockle density and the number of trematode parasites infesting them (Figure 5-A). Thereby a strong density of cockles, classically demonstrating competition (less growth, increased mortality) can also have beneficial effects for the host population by removing certain parasites from them. The underlying mechanism being proposed relies on the effect of dilution: for a given parasite stock in water, the larger the number of hosts the more parasites will be diluted among the cockle population and the less individuals will be infested (Figure 5-B).

A B

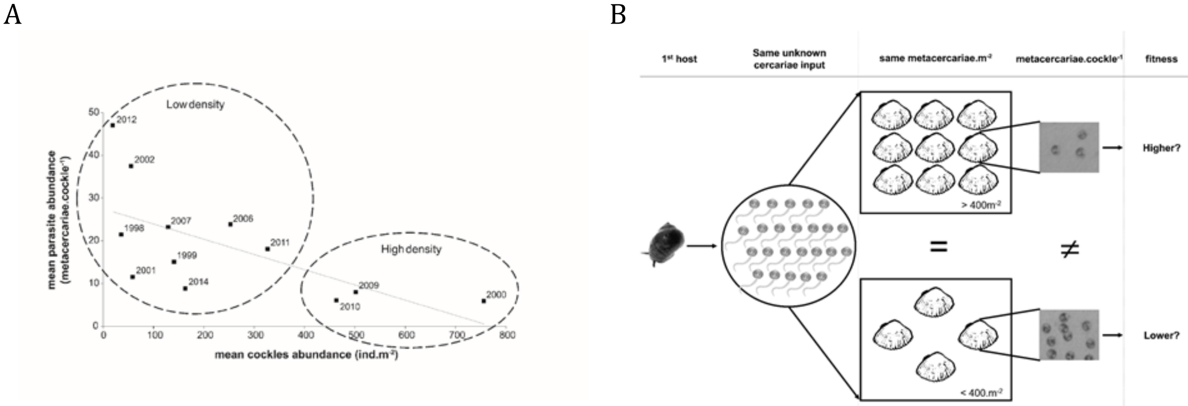

Figure 5 A. Average number of parasites per cockle depending on the average annual density of cockles (adults). B. Conceptual diagram illustrating the hypothesis according to which, with a constant quantity of cockles, the cockle density influences the individual infestation. Magalhães et al. 2016.

Bringing up hydrothermal fauna in isobar conditions

One of the major criticisms of studying the biology of deep-sea organisms is that when bringing up the samples, the pressure variation affects their physiology in supposedly damaging proportions. For the last fifteen years, B-Shillito's team (UPMC) has been developing a set of hyperbaric instruments to attempt to get around this problem. For the first time, during the BIOBAZ campaign in 2013, the ROV Victor was able to sample mussels on Mid-Atlantic ridge sites between 800 and 2400m down, and place them in PERISCOP, a device that can maintain seabed pressure until on board the ship, the Pourquoi-Pas? The first analyses show an abundance of bacterial symbiots from these mussels that do not vary compared to mussels brought up without pressure control (Szafranski et al., 2015). However, analysis of the differential expression of genes between these two conditions clearly shows an effect of bringing them up without controlling the pressure for the deeper site, but not below, thereby validating certain studies carried out to date but encouraging us to consider the effect of bringing samples up from more than 2000m (Tanguy et al., comm. pers.).

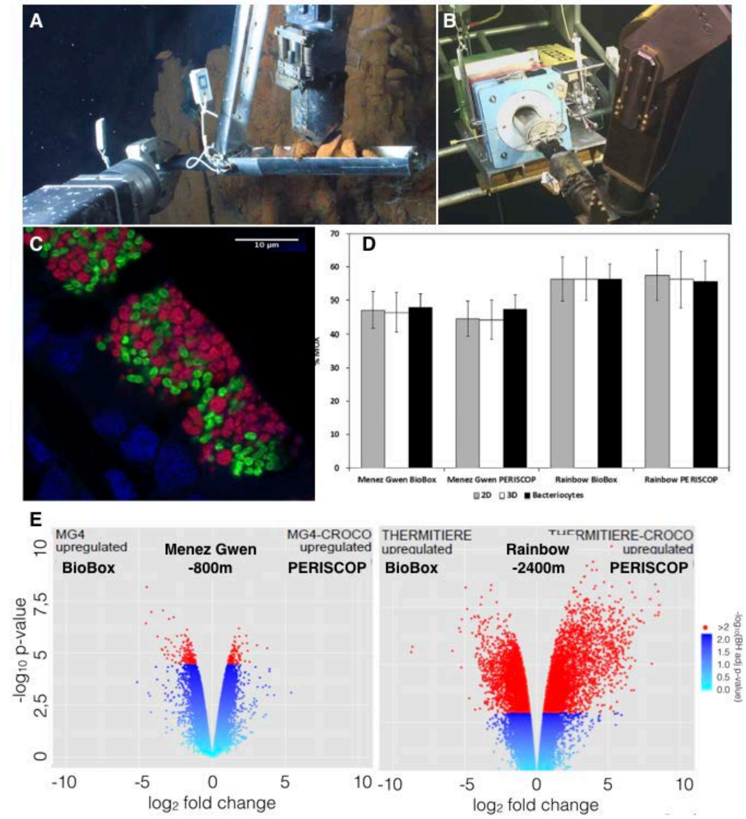

Figure 6:
A. Sampling mussels on an "alligator clip" by the ROV Victor on the Rainbow site (-2400m). B. Insertion of the sample in PERISCOP for isobaric ascent. C. Fluorescent marking of the two types of bacterial symbiots in a branchial filament of the mussel. D. Abundance of symbiots after isobaric ascent (PERISCOP) or not (BioBox) from the Menez Gwen (-800m) or Rainbow (-2400m) sites. E. Differential expression of genes for these same conditions. The red dots show a significantly different expression.
A, B © Ifremer, BioBaz 2013
C, D Szafranski et al., 2015
E Tanguy et al., comm.pers.

1.2.4 Fisheries

General topics and issues

In addition to one-off research campaigns, most fishery campaigns run over the last few years are providing data for long chronological series (the longest date from the 70s), at annual frequencies. Most of them are institutional (IBTS, PELGAS, EVHOE, CGFS…), funded in a community framework and not evaluated by the scientific community. However, a few valorisation actions are evaluated. They can be carried out on global vessels (RV *Thalassa* for IBTS campaigns for example), or coastal vessels (they can also be financed locally). The coastal campaigns are carried out on board the RV *Thalia* for scallops, *Côtes de la Manche* for ORHAGO campaigns and *Europe* in the Mediterranean. Small professional vessels might be required for estuary areas, when an oceanographic vessel is required with capacity for basket trawling on the Channel-Atlantic sides. All these campaigns must be run in imposed periods (linked to the species' biological cycle) and explained in detail in international protocols, when appropriate. This refers mainly to biological data collection that will provide the basis of the status assessment of the main stocks of species being exploited. Over time, these campaigns have diversified and now allow us to also collect data on all sampled species and on the environment; this refers more generally to contributing to observation of all compartments of the continental shelf ecosystems (from hydrology to primary production, right up to top-level predators).

So, the major areas of research tackled by the campaigns cover a very wide field: individual-environment interactions, spatial distribution, habitats and connectivity of fish populations, dynamics of fish populations, space-time dynamics of ichthyological communities and their diversity, how marine trophic networks work, fishery resources-fishing fleet interactions, ecosystem-multiuse interactions, etc. Observation method issues are also tackled by certain campaigns (study on observability, the acoustic "Target Strength" of pelagic fish, etc.) plus automation methods for sampling and determination (e.g. the CUFES combination on RV Thalassa and ZooCAM for continuous sampling and semi-automated recognition of fish eggs and zooplankton).

Illustrative results

In the Mediterranean

Historically, fishery campaign protocols were built to supply the databases used to produce indicators on stock status. These chronological series are then used in a wider scientific framework and constitute basic data for research work with widely-diffused results (doctoral dissertations, M2 Masters, referenced publications, symposiums, etc.).

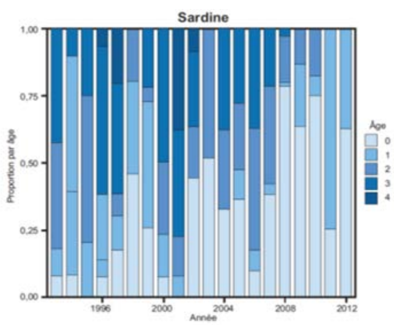

Figure 7 Proportion of the sardine population in each age bracket from 1993 to 2012. The clearer the awning, the younger the individuals. See Van Beveren et al. 2014

As an example, data from the PELMED campaigns revealed demographic and biological changes in the small pelagic populations in the Gulf of Lion over the last twenty years. Whilst anchovy biomass has fallen considerably, leading to a fishing crisis, the abundance of sardines has remained the same or even increased. At the same time, an important change in the size structure of these species has been observed. The sardines and the anchovies were a lot smaller after 2008 than before. This drop in sardine size is the result of a drop in growth and a loss of the oldest individuals (loss of 2+ years age brackets; Van Beveren *et al.*, 2014, Figure 7, opposite), whilst only growth seems to be questioned for anchovies.

Fisheries and marine biodiversity in the South-West Pacific

The IRD has been working actively with the CPS since 2005 on the topic of pelagic fishery resources. Tuna is a primordial resource for most small countries in the Pacific and represents an important proportion of the local economy in the territories of New Caledonia and French Polynesia. The total tuna captures in the western and central Pacific have been constantly increasing since the 1980s, reaching a total of 2.7 million tonnes in 2015 (namely 80% of captures in the Pacific and 56% of worldwide captures). The work focusses on understanding how the pelagic ecosystem works and on interactions between tuna and its environment. Since 2011, in particular, studies have looked at trophic intermediate levels (zooplankton and micronekton) that represent the food of superior predators such as tuna and marine birds. On the topic of micronekton for which there is very little field data, the NECTALIS (1 to 5) series of multidisciplinary oceanographic campaigns was performed around New Caledonia between 2011 and 2016 on board the *Alis*. The MOM-ALIS and INTERCASTEAUX campaigns were able to enlarge our work to marine birds. This data-collection work was performed within the BIOPELAGOS project (Best 2.0 programme funded by the European Union) that took place over 3 years (2016-2019) in New Caledonia and in Wallis and Futuna with 2 other campaigns: PUFFALIS programmed in 2017 and WALLALIS requested for 2018, always on board the *Alis* collecting physical, chemical, biological (phytoplankton, zooplankton, micronekton) and acoustic data.

1.2.5 *Observation services*

General topics and issues

In Environmental Sciences, time series of observations made over long periods were and appear to be an increasingly essential device to accompany the research and support contractual commitments to the State. For each of the natural environments, it is actually necessary to understand the fundamental mechanisms of how they work, to foresee possible changes on different scales and to build forecasting models that should assimilate reliable data. To run this research properly and meet society's expectations, the Environmental Science community is involved in **systematic observation of natural environments, in order to follow their evolution, understand it and model it.** This mission is the basis for forecasts within the ambition of this scientific work.

Structuring of national observation (SNO, SOERE, Research Infrastructures) has helped support long term studies of marine environments that might be mainly affected by changes in the climate (ocean/atmosphere interaction), directly subject to the influences of human activity such as coastal or in-shore waters or even in specific benthic environments. The observatories and observation networks are now acknowledged as essential to obtain long term data to determine changes in the environment and in the processes (physical, biodiversity, ecosystems, biogeochemical cycles) linked to global change and the anthropic impact. Over the 2011-2016 period, over 600 days a year have been dedicated to observatory operations labelled from ocean-going, in-shore and station vessels. For the time being, very few national observation structures cover the French overseas EEZ, leaving an important vacuum.

In parallel, the ramp-up of operational oceanography (MERCATOR/Coriolis project) requires a greater flow of data in almost real time via automated observation systems (moorings, surface measurements in transit, ARGO profilers, CTD station profiles, XBT probes, SVP derived buoys, etc.). These developments require boat time, particularly to implement and maintain autonomous equipment.

Observations using the station fleet (marine stations and OSU)

Observations made from easily-accessible areas (after a few hours of sailing at the most) essentially use the INSU and IFREMER in-shore vessels but also constantly use the Marine Stations vessels. **The current total for the station fleet, regarding the number of days dedicated to observation operations is around 260 days (Table 1).**

These in-shore and coastal studies are also increasingly often multidisciplinary to correctly apprehend the physics-chemistry-biology couplings in these anthropized environments with complex dynamics. This flotilla is also requested to maintain moorings and instrumented sites in the coastal environment (CoastHF national network from the ILICO Research infrastructure). Its local programming helps it react quickly which is an essential quality to ensure the logistics associated with autonomous measuring equipment (instrumented moorings, AUV, gliders, floats), new technology that is currently integrated in all on-going programmes. The flexible, user friendly programming mode for this fleet is generally satisfactory. It is imperative to maintain this flexibility for use and the quality of this flotilla that on its own provides support for recurring research and teaching activities in marine stations and ensures diving missions for biological and ecological observations.

Service d'Observation	Type navire	Zone géographique	Navire FOF	Durée Mission jours	Mission/an	Total jours dédiés	Travaux
OISO-CARAUS	**Hauturier**	sud indien et Austral	MD II	TRANSIT + stations	3,5	7	Hydrologie/mesures en route sur 3 semaines
NIVMER ROSAME	**Hauturier**	Austral	MD II	TRANSIT	1		transit relevage/mouillage
MEMO	**Hauturier**	Austral	MD II	TRANSIT	1		transit
SONEL	**Hauturier**	Indien sud	MD II	2	1	2	maintenance marégraphes
SONEL	**Hauturier**	Indien sud	MD II	transit			transit
OHASIS-BIO	**Hauturier**	Océan austral	MD II	transit			transit
MDCPR	**Hauturier**	Océan austral	MD II	transit			transit
MINERVE	**Hauturier**	Polaire Antarctique	Astrolabe	14	3	42	Mesures en route/hydrologie
SURVOSTRAL	**Hauturier**	Polaire Antarctique	Astrolabe	14	2	28	Mesures en route
PIRATA	**Hauturier**	Atlantique équatorial	Suroit/Thalassa	40	1	40	Hydrologie - Mouillage - Mesures en route
MOOSE-GE	**Hauturier**	Méditerranée	Suroit/Thalassa	25	1	25	Hydrologie - Mouillage
HYDROMOMAR	**Hauturier**	Atlantique Nord	Thalassa, Suroit	14	0,5	7	Hydrologie - Mouillage
MOMARSAT	**Hauturier**	Atlantique Nord	Thalassa-Atalante, Pourquoi Pas?	21	1	21	maintenance observatoire fond de mer
OVIDE	**Hauturier**	Atlantique Nord	Thalassa-Atalante, Pourquoi Pas?	34	0,25	8,5	Hydrologie - Mesures en route - déploiement flotteur
					Total	**180,5**	
MOOSE-ANTARES)	**Façade**	Méditerranée	Téthys II	1	12	12	Hydrologie - chimie - Biologie
MOOSE - DYFAMED	**Façade**	Méditerranée	Téthys II	1	12	12	Hydrologie - chimie - Biologie
MOOSE(BILLION)	**Façade**	Méditerranée	Europe/tTéthys II	8	1	8	maintenance mouillage
BOUSSOLE	**Façade**	Méditerranée	Téthys II	3	12	36	Hydrologie
EMSO	**Façade**	Méditerranée	Téthys II	6	1	6	maintenance mouillage
Molit -coast-HF	**Façade**	Littoral Atlantique	THALIA	3	2	6	Mouillage/relevage annuel
					Total	**68**	
MOOSE-MOLA	**station**	Méditerranée	Néréis	1	12	12	Hydrologie - chimie - Biologie
SOMLIT-Villefranche	**station**	Littoral méditerranée	Sagitta	1	48	48	Hydrologie-chimie-biologie
SOMLIT-Banyuls	**station**	Littoral méditerranée	Néréis	1	24	24	Hydrologie-chimie-biologie
SOMLIT-Wimereux	**station**	Littoral Manche	Sépia II	1	24	24	Hydrologie-chimie-biologie
SOMLIT-Brest	**station**	Littoral Atlantique	Albert Lucas	1	24	24	Hydrologie-chimie-biologie
SOMLIT-Roscoff	**station**	Littoral Manche	Néomysis	1	24	24	Hydrologie-chimie-biologie
SOMLIT Arcachon	**station**	Bassin d'Arcachon	Planula IV	1	24	24	Hydrologie-chimie-biologie
SOMLIT Arcachon	**station**	Estuaire de la Gironde	Côte de la Manche	3	10	30	Hydrologie-chimie-biologie
SOMLIT Marseille	**station**	Baie de Marseille	Antedon II	3	10	30	Hydrologie-chimie-biologie
Mesurho - coast-HF	**station**	Littoral méditerannée	HELIOS	1	10	10	Maintenance métrologique - hydrologie
SOLEMIO - coast-HF	**station**	Littoral méditerannée	Antedon II	1	10	10	Maintenance métrologique - hydrologie
Phytobs	**station**	Toute façade		en cours de définition			Suivi phytoplanctonique
					Total	**260**	
ARGO	TOUS/opportunité	océan mondial	TOUS/opportunité				largage flotteur
SSS	navires marchands	océan mondial	navires marchands				Mesures en route

Table 1: Total days at sea for the fleet dedicated to labelled or recurrent observation services (OVIDE, MDCPR).

To date, there is no actual station vessel located overseas. Currently, a single OSU has been set up and could be used for support, in La Réunion, but there is no boat. On the other hand, two ships cover or have covered this function, but this cover is sporadic or under-sized (*Amborella* from the government of New Caledonia and *La Curieuse* in La Réunion).

Observations using the in-shore fleet

Programming of so-called in-shore vessels (essentially coastal) is currently evolving with an increase in recurring requests within the labelled scientific observation services but also from public service development (e.g. MSFD). Apart from regular sampling (monthly to annually) on reference stations (SOMLIT and MOOSE networks), the needs refer to maintenance of instrumented sites, increasingly numerous and complex, particularly in the north-west Mediterranean (BOUSSOLE, MOLA, ANTARES, …). **The current overview shows a need for around 70 days.**

The in-shore fleet must necessarily be modernised to implement "seabed" stations and to meet emerging needs from operational oceanography, particularly on-board installation of automated measurement systems (ferry box type) and fast communications.

Observations using the ocean-going fleet

The ocean-going fleet is also in great demand to cover operations linked to scientific observation activities with a demand of around 180 days per year:

- For specifically dedicated campaigns (PIRATA, MOOSE, OVIDE…)
- For added-value transits (MINERVE, OISO, SURVOSTRAL…).

- For "seabed" observatories overseen by France and included in a Europe Consortium ERIC (European Research Infrastructure Consortium), which ensures creating a network between 11 multidisciplinary marine observation sites (geoscience, biology, oceanography), EMSO-France has become a Research Infrastructure (IR) with 3 target sites: Azores (MOMAR), Liguria and Marmara shore. These three sites involve around 120 users over 15 labs, of which almost 2/3 are working on marine geosciences.
- It should be noted that all these observation operations allow transits to be made the most of (see below). Consequently, the total number of days reported for the OISO-CARAUS, MEMO, NIVMER, SONEL… services is given as a guide.

Ocean-going observation campaigns regularly host other operations by pooling ship time and upgrading transits.

- PIRATA, in view of its annual campaigns and according to the radials repeated in the same region, constitutes a platform to carry out opportunity operations (instrumented mast, radio-sounding, collection of CARBOCHANGE samples, deployment of gliders, SVP derived buoys and Argo floats, continuous measurement of isotopes).
- For the last 5 years, MOOSE-GE has been providing pooled maintenance of hydrological open-sea moorings of the north west Mediterranean shore. From 2017 onwards, this maintenance pooling was expanded to two ODAS buoys from Météo-France, subject to scientific relevance. Many research programmes rely implicitly on long-lasting observation services (e.g. MISTRALS site with MOOSE and FiXO3).

Without being labelled National Observation Service, the OVIDE project has been contributing since 2002 to observation of subpolar gyre circulation elements in the North Atlantic by carrying out a section of hydrography-geochemistry-currentometry every two years between Greenland and Portugal and by deploying Argo profilers. The OVIDE section was firstly carried out as part of the OVIDE project (every two years from 2002 to 2010) then by the Spanish CSIC lab in 2012 and 2016 and in 2014 during the GEOVIDE campaign by GEOTRACES/France. The OVIDE section is one of the "high frequency" lines on the international Go-Ship programme and contributes to the TGIR Euro-Argo by deploying profilers and to the international OSNAP project. Like PIRATA, OVIDE contributes to the SNO SSS and to GOSUD by systematic sampling to measure salinity and to CARBOCHANGE by taking samples for the CO_2 parameters. Certain observations are sent in almost real time to CORIOLIS (CTD and XBT profiles).

Finally, certain services (SSS, Argo) that rely on the FOF also call on foreign oceanographic vessels or merchant ships to get regular access to zones that are rarely explored by research vessels. Within the framework of SNO Argo France, 56% of floats run by France were deployed by FOF ships, 33% by foreign oceanographic ships and 11% from opportunity vessels (sailing boats, etc.). The SSS service relies uniquely on opportunity vessels, but regrouping can be envisaged in the mid-term with equivalent data released by research ships.

Fisheries

The fishery campaigns, known as "public service", not scientifically assessed and not funded by the FOF budget, are part of the long-running campaigns carried out using both ocean-going and coastal vessels supplying long chronological series (since the 80s and 90s) and they contribute to the Ifremer Fishery Information System observation network (SIH). They also support complementary observations, essentially concerning marine fauna. **The use of the fleet for these state missions covers more than 150 days at sea (Table 2).**

Suivi Halieutique	Type navire	Zone géographique	Date début	Navire FOF	Durée Mission jours	Mission/an	Total jours dédiés	Travaux
PELMED	**Hauturier**	Méditerranée		Europe/Thalasssa	25	1	25	Halieutique -oiseaux et mamifères marins
EVOHE	**Hauturier**	Manche Atlantique		Thalassa	40	1	40	Halieutique -oiseaux et mamifères marins
PELGAS	**Hauturier**	Atlantique		Thalassa	30	1	30	Halieutique -oiseaux et mamifères marins
IBTS	**Hauturier**	Mer du nord		Thalassa	30	1	30	Halieutique -oiseaux et mamifères marins
CGFS	**Hauturier**	Manche	1988	Thalassa	30	1	30	Halieutique -oiseaux et mamifères marins
						Total	**155**	

Table 2: Overview of days at sea for the fleet dedicated to recurring fishery assessment campaigns

Illustrative results

PIRATA:

The utility and accuracy of rain and salinity measurements obtained from ATLAS buoys in the PIRATA network are now well-established, and it is now proven that salinity is an extremely important parameter in the tropics for the heat budget in the mixture layer and the air-sea interface exchanges (severe desalting has been observed in the tropical Atlantic due to strong precipitation and discharge from the world's main rivers - Amazon, Congo, Niger). Since 1999, PIRATA measurements have been able to demonstrate the salt barrier phenomenon in the west tropical Atlantic (Pailler et al., 1999). Understanding the impact of salinity variations on the SST has become a major goal over the last few years. The use of PIRATA data (particularly for validation of new dedicated satellite measures - SMOS Aquarius) has provided a better understanding of the respective impact of precipitation and discharge from major rivers on the mixture layer and the SST and to draw up salt budgets in the Gulf of Guinea (Figure 8, Da Allada et al., 2013, 2014).

Figure 8: Comparison of evolutions (2006-2007) of the salinity at 0°N-0°E obtained by the PIRATA buoy and by a digital model, used to study the salt budget in a mixture layer. (Da Allada et al, 2014)

OISO-CARAUS

The OISO observations, conducted on board the *Marion-Dufresne II* since 1998, have improved assessment of the ten-year variability of oceanic CO_2 wells (Landschützer et al., 2015). Under the influence of wind variability and heating up or cooling down of surface water in certain sectors of the Austral Ocean and depending on the year, the carbon well dropped over the 1990-2000 period, but it rose between 2002 and 2011 (Figure 9). These estimations specifically allow us to review the planetary carbon balance (Le Quéré et al., 2016).

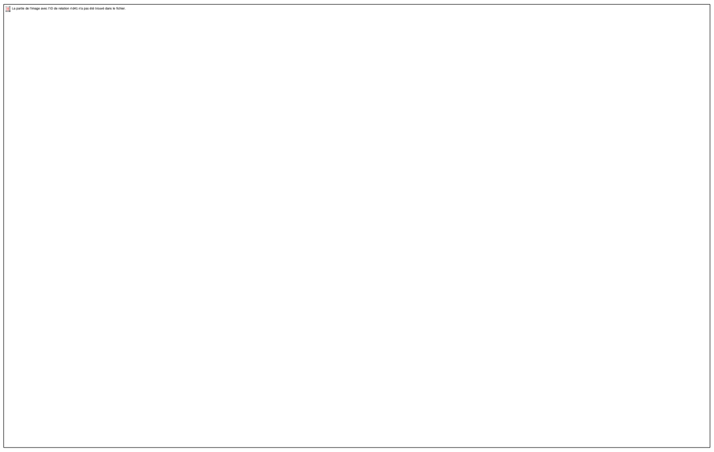

Figure 9: Variability of air-sea CO_2 flux in the Austral ocean, over the 1982-2011 period assessed by Atmospheric Inversion (shaded) and 2 methods (blue and orange) based on the SOCAT base (Landschützer et al., 2015). The trend linked only to the increase in atmospheric CO_2, without considering climatic variability, is also shown in black

SOMLIT

In coastal ecosystems, regional climate (AMO, NHT, SST) and local climate (wind, precipitation, etc.) have a direct influence on how ecosystems work. In particular, a shift in the early 2000s appeared on both climate indices and parameters and on hydrological data on the scale of the three French maritime shores but also more locally (Gironde estuary) on the ichthyological communities (Figure 10). These examples give a perfect illustration of coastal ecosystems' sensitivity to climate change. This sensitivity concerns both abiotic and biotic compartments.

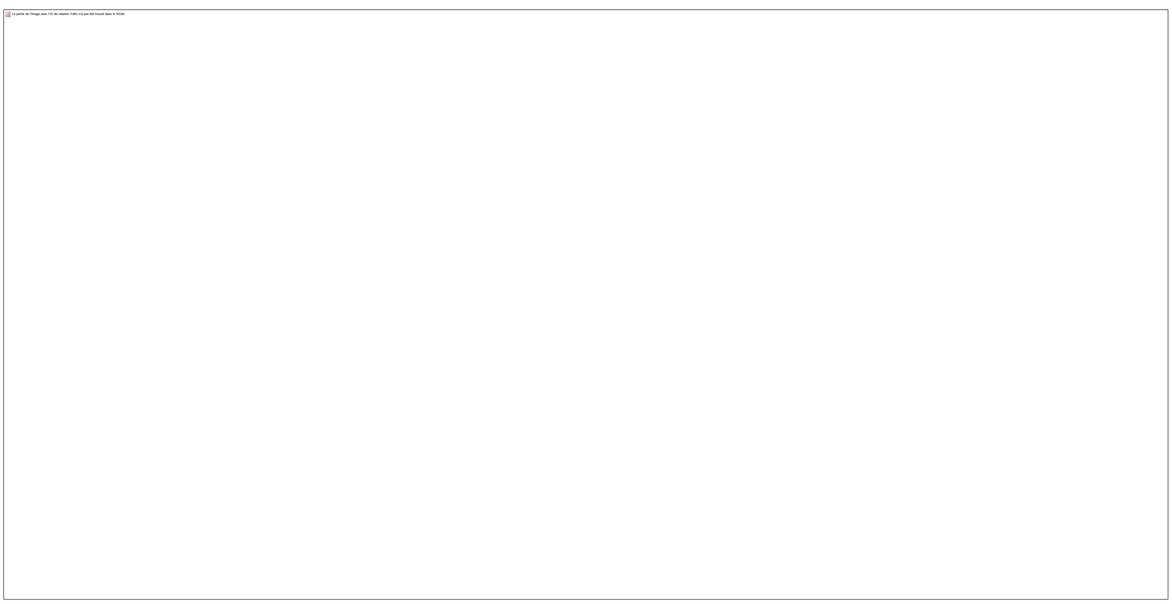

Figure 10: a : evolution over time (1997-2008) of the first principle component of SOMLIT data.
b: correlation of each parameter to each site with the first principle component. c: SOMLIT sites; d: correlation coefficient (r) and p-values (p) of correlations between the SOMLIT data and the climate parameters; e: evolution over time of the principle components of environmental parameters (Env.), of the surface temperature of the North Atlantic (SST) and the ichthyological communities, as well as precipitation anomalies for the Gironde estuary. PC: principle component; NAO: North Atlantic Oscillation; AMO: Atlantic Multi-decade Oscillation; NHT: Northern Hemisphere Temperature. a-d: Goberville et al., 2010. e : Chaalali et al., 2013.

1.3 Activity statement for sea campaigns over the last 5 years

The FOF brings together vessels of different sizes with different commissioning costs. The simple addition of days at sea for this collection barely makes sense and any report should be drawn up using uniform sub-categories. The most widely-accepted and most-used segmentation distinguishes between: (1) vessels said to be ocean-going (l>36m), (2) coastal or "in-shore" ships (l<36m), and (3) station ships (l>10m and managed remotely). The latter is differentiated from the other two by the fact that the programming/use unit is not the campaign but the day, or even sometimes a half-day at sea. This clearly makes it complicated to monitor their activity and has led us to discard the activity of this FOF component in the following statement. However, we would like to recall the essential function of this flotilla supporting all activities in French marine stations. The data presented below was compiled on the basis of information provided by the Fleet UMS for the 2011-2016 period.

1.3.1 Number of days of activities and decommissioning periods

Monitoring days of activity per category of use of the FOF is proposed for each year on the UMS FOF site. Table 3 compiles the average values for these days of activity, set between 2011 and 2016. We can see that the 4 major boats (ocean-going fleet) have allowed 586 days of scientific research, 188 days of Public Service and 161 days of public-private partnership. This distribution is theoretically satisfactory, except that the pressure of "scientific research" has suffered a slight drop over the last 5 years. This drop can essentially be attributed to funding difficulties for oceanographic research relying on the TGIR FOF (see section 2.5). For the entire ocean-going fleet, the decommissioning periods correspond on average to 20% of the potential time of use (Table 3 and Figure 11). This figure nevertheless hides a clear difference between vessels. This proportion is actually low (*i.e.* <10%), or even very low for the *Pourquoi pas ?, Atalante* and the *Marion Dufresne* and, on the contrary, significant for the *Thalassa* (43%) and even more so for the *Suroît* (71%). In the latter two cases, this shows that the chosen activity period included long stand-down periods for major technical modifications (*e.g.* renovation of the *Suroît*) or even a period following definitive decommissioning of the ship (*e.g. Suroît*). Due to these availability limitations, we might consider that the accumulated figures (*e.g.* 586 days for scientific research) constitute sub-estimations of the community's real needs. One important aside concerning the *Marion Dufresne* refers to the number of operable days for the IPEV (only 217/year). The three vessels with the low or very low stand-down rates are ships for which chartering is most important. This is particularly true for the Pourquoi Pas ? for which the 57 days dedicated on average to chartering take up an important proportion of activity time not attributed to the Navy for this vessel.

Table 3: Average number of days (activity programmes at sea between 2011 and 2016) corresponding to each of the classically-recognised major areas: (1) assessed scientific research, (2) public service missions, (3) use by the French Navy, (4) chartering (within public-private frameworks), (5) technical stoppages and test missions, and finally (6) decommissioning periods. **Warning: the number of operable days for the Marion-Dufresne is 217 days/year, as opposed to 365 for the Atlante or the Pourquoi Pas? The days attributed to scientific research by the Navy on the Beautemps-Beaupré are around 5/year.**

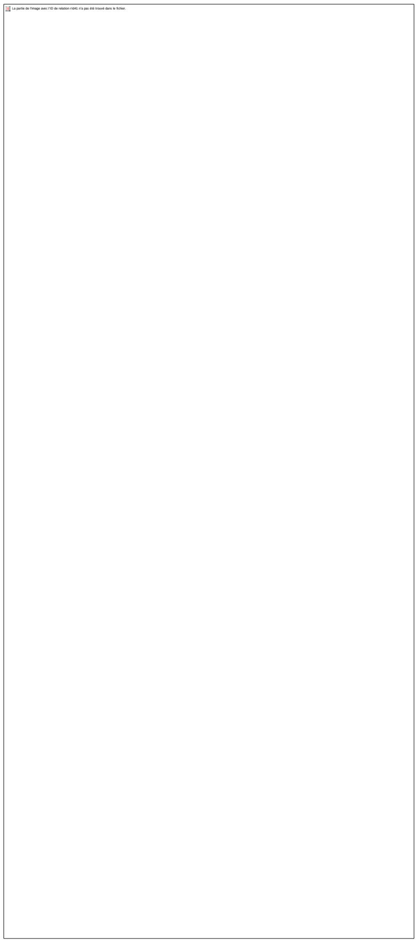

Figure 11: Average distributions of the number of days between the major activity-type areas for the FOF. Note: The "teaching" and "observation" categories were added to the segmentation used for **Table 10**

As far as the coastal or in-shore fleet is concerned, the annual average activity dedicated to scientific research is 1186 days, plus 164 days of Public Service and 36 days of public-private partnership. The average decommissioning rate rises to 40%, namely double the rate for the ocean-going fleet. Even there, we can see big differences between vessels in terms of technical problems (e.g. *Antea*) or decommissioning (e.g. *Gwen Drez*). Nevertheless, it should be highlighted that the lowest decommissioning rate (i.e. 17% for the *Téthys*) is still quite high. This can very probably be translated as: (1) the absence of significant possibilities for compensation by means of chartering for this component of the FOF, and (2) the existence of a moderator ticket that is likely to have limited demands for use during a significant proportion of the 2011-2016 period, moderator ticket removed during 2016. As for the ocean-going fleet, it is best to consider the figures being presented as underestimations of the real needs: this rather more that the new Public Service type uses are actually on the rise (*e.g.* any associated with setting up the surveillance programme for the MSFD). Considering annual variability in terms of scientific topic and/or the geographic programming zone, but also due to the Universities' difficulties to finance this type of campaign, there is under-representation of campaigns at sea dedicated to teaching in the ocean-going area. Nevertheless, Floating Universities are regularly organised on board ships in the fleet during scientific campaigns (e.g. MARCO-POLO).

1.3.2 Distribution between major disciplinary areas

In practice, this aspect is quite difficult to assess due to the difficulty of defining clear borders between areas and due to the essentially multidisciplinary nature of a large number of campaigns (Figure 12).

Ocean-going vessels **In-shore vessels**

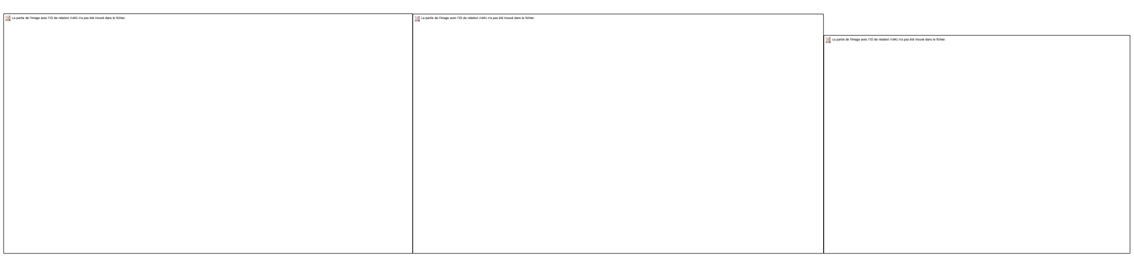

Figure 12: Average distributions of programmed number of days at sea between major disciplinary areas

The long-range planning committee has consequently decided to limit itself to the following four major areas: (1) geosciences-paleo-environments, (2) physics-biogeochemical-cycles, (3) biology-ecosystems and (4) fisheries; ocean-going and in-shore fleet activities for these same disciplines are also compared. We can see clear differences between the two fleets; predominance of geoscience-paleoenvironment and physical-biogeochemical areas for global vessels and the biology-ecosystems area for coastal vessels. There are multiple causes behind this state of affairs, particularly focussing on the significant interest in each of the major topic areas for the open-ocean and coastal ocean that can particularly explain the predominance of the biology-ecosystem area for the use of coastal vessels, and even the geoscience-paleoenvironment area for their ocean-going equivalents. The committee also analyses that the vessels' actual characteristics influence the differential use of these two components of the FOF. So, the greatest use of global vessels by the physical-biogeochemical area can be seen as the need to use sufficiently large vessels to be able to bring on board and implement the necessary technical resources for multidisciplinary teams.

1.4 Report on publications

1.4.1 Introduction

It is clearly a challenge to produce a consolidated report on scientific publications regarding use of the FOF. The use of modern bibliographic search tools and the side-by-side existence of several databases nevertheless allows us to envisage it on sufficiently solid bases for publications directly linked to the original scientific project of oceanographic campaigns. This work was performed by La Pérouse Library and the INIST working with the IRD for global and coastal fleets. Complete dossiers are provided in Appendix 6. However, the report on scientific production linked to the FOF resulting from this work is clearly non-exhaustive for several reasons. One key aspect of underestimating FOF production lies in the quasi-impossibility of considering the component of this production that originates from the "varying" use of station vessels (see above). However, rationalisation has been on-going since early 2017 and will make it possible to produce a consolidated report by the end of 2017. Another element relates to marking the data in the international databases. If the name (or the doi) of the campaign is not explicitly mentioned in the publications, it is impossible to associate the publication with the campaign. In certain cases, the data is even used to provide a more evolved product. When this product is used, it is the product reference that is quoted, and no reference is made to the original data. **For all these reasons, it should therefore be emphasised that the following elements clearly underestimate the level of scientific production linked to the FOF.**

Scientific production resulting from use of the FOF covers many different areas and it is easier to count some elements depending on their type. Consequently, in what follows, we are not limited to only counting A-range articles that are the easiest elements to trace from using keywords.

One last point to consider lies in the time delay between the year that an oceanographic campaign took place and the appearance of its associated scientific publications. In the case of ocean-going vessels, this offset shows a peak between 5 and 9 years but can occasionally take as long as 30 years (Figure 13). Although less pronounced, this phenomenon also exists for in-shore vessels. In all cases, this leads us to: (1) not matching reporting periods for number of days per ship and scientific production, and (2) establishing this latter reporting over a long period (*i.e.,* 2000-2014).

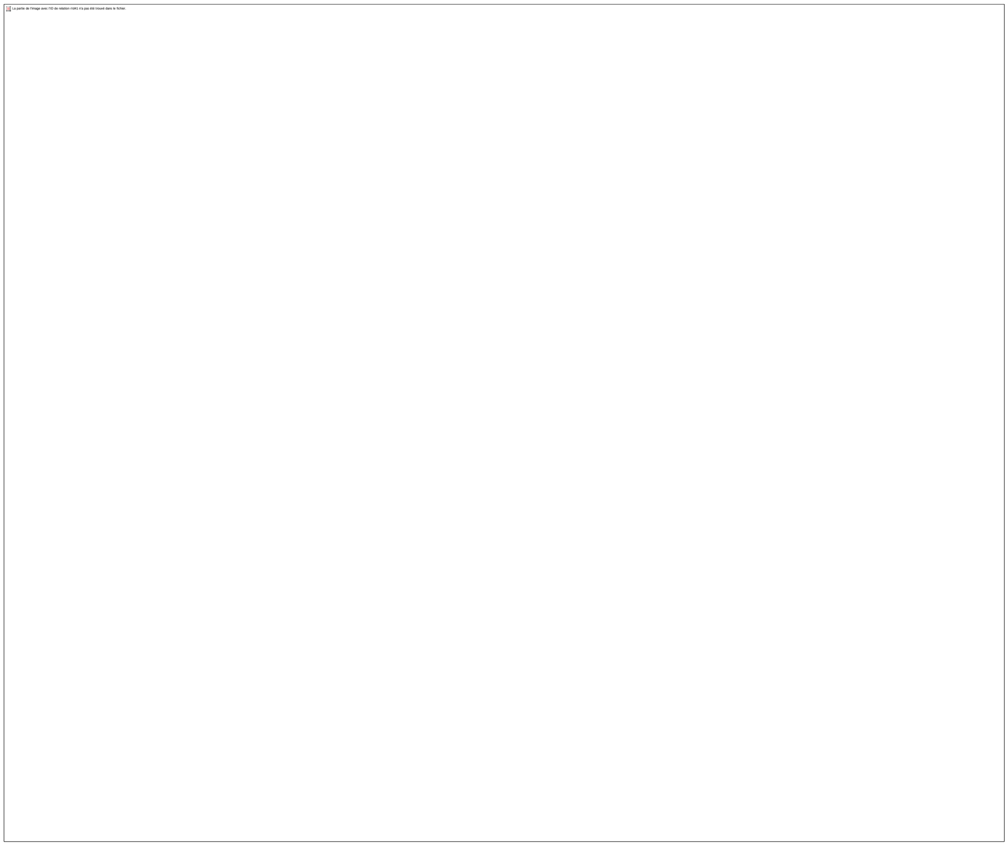

Figure 13: Linking the number of publications from an oceanographic campaign run on an ocean-going vessel or an in-shore vessel and the date that this same campaign took place.

1.4.2 Quantitative and qualitative changes

In total, over 5000 A-range publications were counted over a period of 15 years. A little over three quarters (*i.e.* 78%) originate from the use of ocean-going vessels and a little under one quarter (*i.e.* 22%) from coastal vessels (Figure 14). As an annual average, there are 260 and 74 A-range publications that come from using ocean-going and in-shore vessels respectively. These numbers both show a strong upward trend between 2000 and the 2010s (factors close to 7). This quantitative increase is accompanied by a qualitative improvement: this is illustrated by average factors from the journals publishing works resulting from use of the FOF which, over the same time, doubled for in-shore vessels and increased very significantly (i.e. from 2.92 to 3.77) for ocean-going vessels (Figure 15). Our analysis of this increase is that it is probably the result of a conjunction of factors. On the one hand, setting up the assessment process for best use of campaigns, giving a list of publications that have come from them and on the other hand, progress made with tools leads to more automated, and therefore more complete, monitoring of this development.
Furthermore, campaigns have tended to become more multidisciplinary. Particularly in the open-sea area, there are less campaigns, but they are more significant, longer and bring together more teams, thereby generating a larger number of publications.

In any case, these figures reflect the scientific excellence of the TGIR FOF.

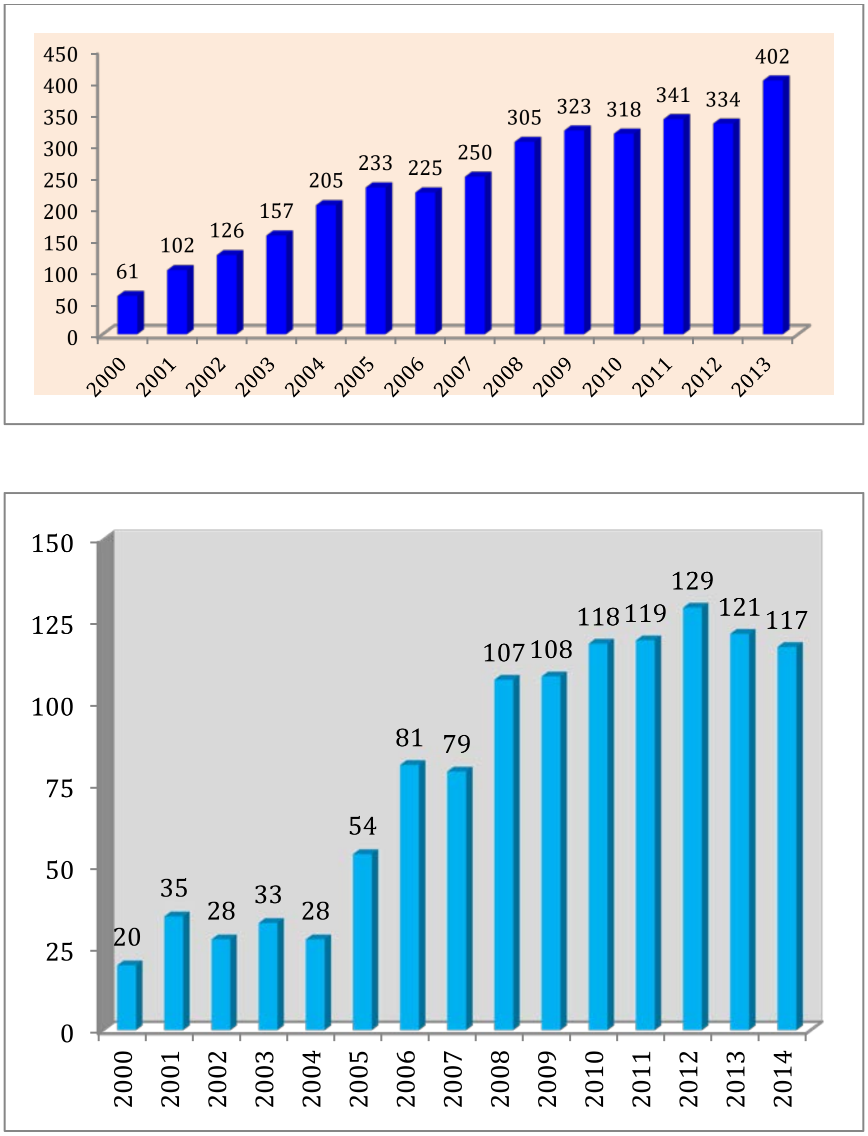

Figure 14: Changes over time in A-range annual publications, originating from the use of ocean-going vessels (high) and coastal vessels (low).

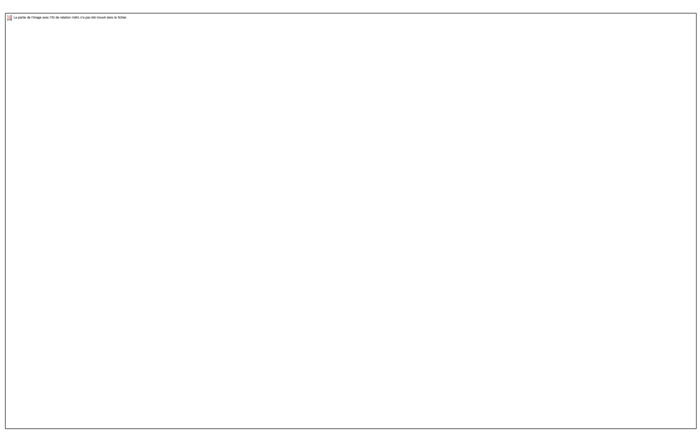

Figure 15: Changes over time in average annual impact factors from journals publishing the results originating from the use of ocean-going vessels and in-shore vessels.

1.4.3 *Structuring role*

The structuring role played by the FOF in national and international terms is very important, as proven by the numbers of A-range publications co-authored by members of French laboratories and/or by foreign scientists. This structuring effect is naturally clearer for ocean-going vessels because of their larger capacity and the eco/geosystems to which they provide access. Over the 2000-2014 period, co-authoring works originating from use of ocean-going vessels involved more than 65 laboratories and 22 research organisations and universities (Figure 16). During this same period, scientists from around twenty different countries have co-authored more than 50 publications originating from the use of ocean-going vessels (Figure 17). The most numerous collaborations were registered in the United States (829 publications), the United Kingdom (618 publications) and then Germany (549 publications). These figures are a good representation of the FOF's contribution to France's positioning in the international panorama of oceanographic research. Figure 18 shows that the number of foreign partnerships outside the EU is equivalent to the same figure inside the EU and that these proportions have been constant over the last 15 years.

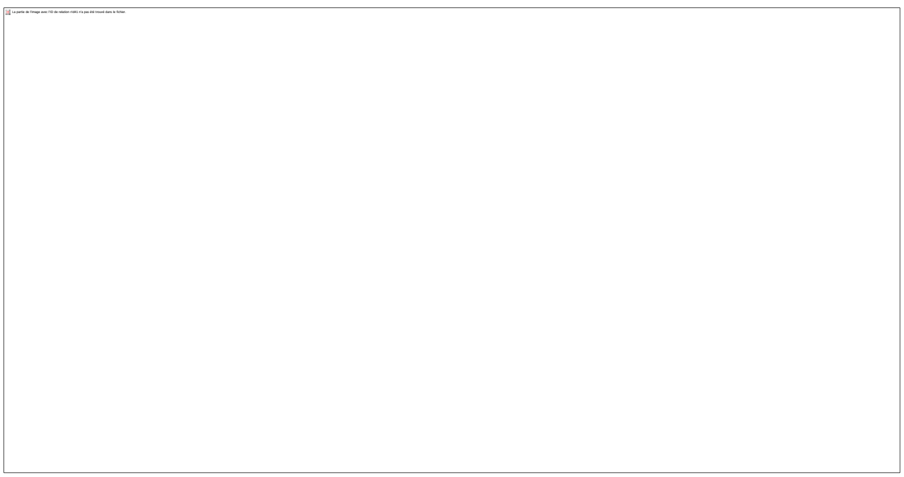

Figure 16: Mapping of relations between research organisations and universities, established on the basis of the number of co-authored publications over the 2000-2014 period and based on use of ocean-going vessels.

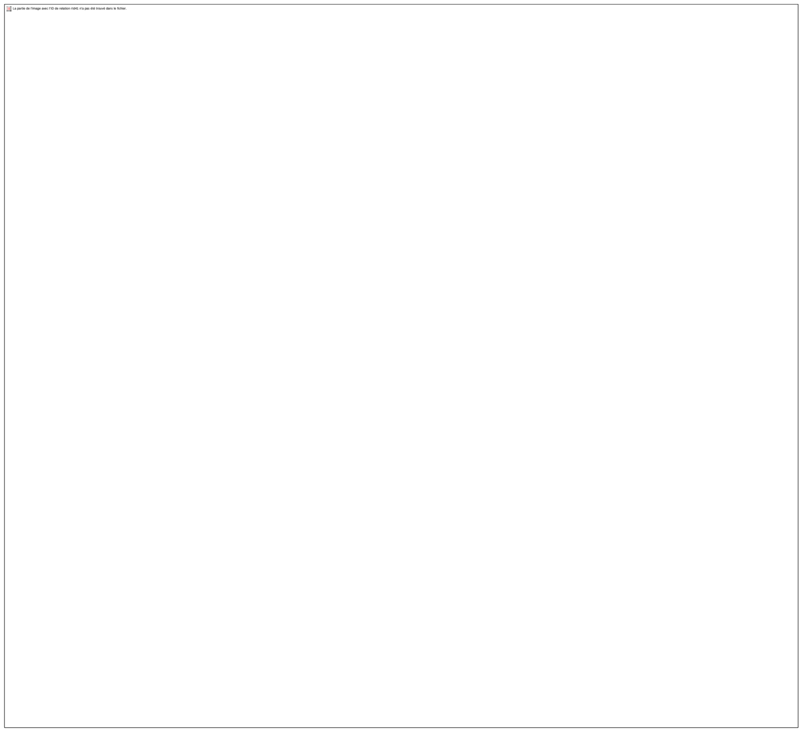

Figure 17: Number of publications over the 2000-2014 period, resulting from use of ocean-going vessels and presenting a scientist from each nation involved as a co-author. The list of countries in question was limited to those for which the representatives have co-authored more than 50 publications during the reference period. The lower part of the diagram shows mapping based on these collaborations.

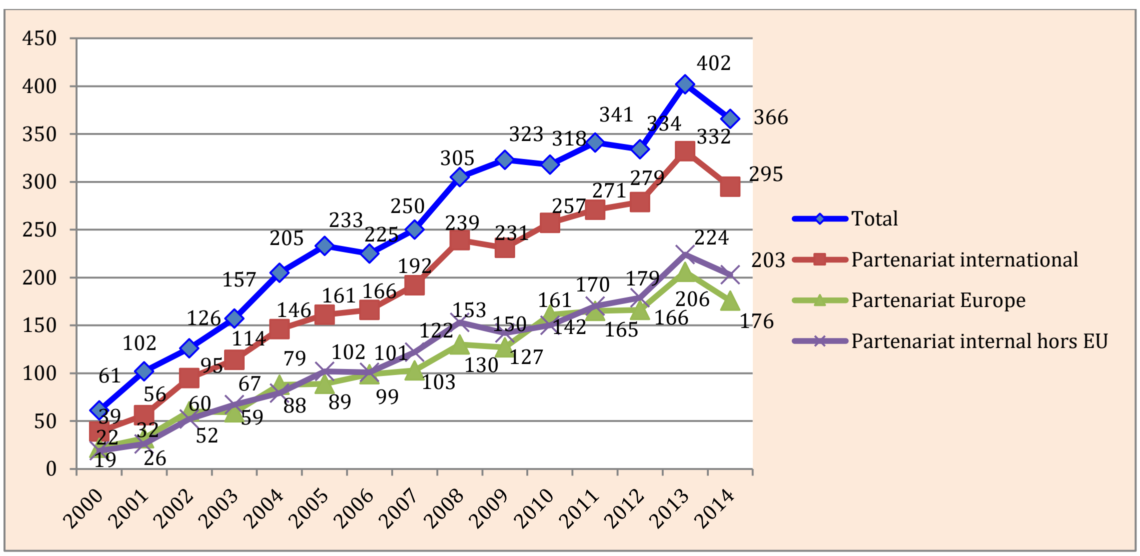

Figure 18: Ocean-going fleet - Annual changes in all production and each type of foreign partnership

1.5 On-board teaching and Mainstream operations

1.5.1 On-board training

The FOF fulfils a primordial teaching mission in training future technicians, engineers and researchers in the different disciplines, via different university-level training such as DEUST, DUT and master's courses and even the PhD and summer schools (intended for French and international students). There is also training at the Engineering Schools and the National Arts and Trades School. This demand not only concerns teaching establishments on the mainland but also in the overseas territories.
Station vessels have always been used in training. In-shore vessels are more rarely made available, but this situation is changing as the moderator ticket has been discarded and changes are being made in training approaches using on-board research (*cf.* Report from the meeting of the Marine Universities and the Marine Board in July 2016, Appendix 7).

There are different methods for technical or analytical training and for marine research. The essential part of this training comes in the form of recurring training sessions, mainly using training models, which is a condition for them to be prioritised during evaluator programming.
The former concerns day trips, essentially dedicated to DUT, DEUST and Degree-level training in different disciplines, mainly on station vessels, although in-shore vessels might be requested, depending on the workforce and the type of techniques used.
Master's degree and Graduate School training can comprise work over several days on in-shore vessels, during missions dedicated exclusively to teaching or benefiting from regular national or European observation missions. The training is then carried out in H24 with quarts systems. Since 2010, MOOSE-GE campaigns have helped to complete training for students on several master's courses by providing practical work experience on board within the "Observation Methods" class on the WAPE master's course from the UPSAY and OACOS from the UPMC. This requires the campaign to be scheduled at a very precise period.
In another register, for master's and PhD students, Floating Universities or Universities at Sea are organised more sporadically, taking opportunities during major research campaigns on-board ocean-going vessels, by pooling several universities and students, within a European and international framework.
Future researchers in oceanography professions are also trained by almost systematically putting master's and PhD students on-board during campaigns at sea carried out by their host team.
Up until 2014 (when stop-offs could be made in Cotonou and Abijan), PIRATA campaigns allowed training on taking measurements at sea for young West African researchers and students (Ivory Coast, Benin, Togo, Nigeria, Senegal, Ghana) and particularly students from the regional master's 2 "Physical Oceanography and applications" from Cotonou in 2009 and 2011.
Finally, in the overseas territories, the universities of La Réunion and New Caledonia have already asked to access FOF oceanographic vessels.

1.5.2 Mainstream Operations

Most campaigns at sea carried out with the FOF keep a logbook on board and run a blog and they send out a press release before and after the campaign leading to interviews on the radio and TV and articles appearing in the press. Many dedicated operations are put together in partnership with a primary school, a middle school or even prisoners as part of a pedagogic project with their Local Teaching Unit (Seysses Prison, GEOVIDE campaign, Pourquoi pas? 2014).

Reports and films are also produced involving media studies and journalism students as well as professional journalists. So, during the BIOBAZ campaign in 2013, the director Jean-Yves Collet came on board with his assistant to make a 52-minute documentary called "Abysses, les alliances des profondeurs", shown on France 5 in August 2014. Apart from access to images from the ROV Victor, during the campaign, the director made the most of several sessions directly supervising ROV operations from the control module. For the last few years, making the most of the vessel's high-speed transmission capabilities, live experiences have begun, such as the Night of the Deep-ocean floor (live broadcast of an ROV dive to the public, followed by a video-conference with the shore team). Since 2012, the Abyssbox permanent exhibition in Océanopolis (Brest) has been presenting deep sea fauna from the MOMARSAT and BIOBAZ campaigns to the south of the Azores in pressurised aquariums (Ifremer, UPMC, Océanopolis partnership). Finally, a few participative science projects aim to get the public involved in data analysis. This is the case of the "Espions des grands fonds" (Deep-sea spies) operation (http://deepseaspy.ifremer.fr) which has just been launched to process videos obtained by deep-sea observatories.
Beyond these specific activities, different manifestations such as the "Fête de la Science" (Science Festival), "Fêtes de la Mer" (Sea Festival), "World Oceans Day" or the "Nuit des Chercheurs" (Night of the Researchers) in Brest and also in Toulouse, Boulogne-Wimereux, Marseille and all the marine stations and labs showcase oceanographic expeditions.

1.6 Strengths and difficulties

1.6.1 Points relating to the whole FOF community

Strengths
We might initially mention the great impact of the French community on international programmes, not only due to leading projects but also because of the vast scientific progress it has made and developed in high-impact publications (Science, Nature, Nature Géosciences, PNAS, etc. see complete bibliography report in Appendix 6). These results reveal the research topics that feature among the leading themes for different international programmes and key questions identified today in national and international contexts. A few outstanding points:

- The total number of researchers and technical personnel, including PhD students and anyone who is directly (on the vessels) or indirectly (tests on land, modelling) involved in FOF activities is around 3600, which makes a very significant community;
- The French community is recognised worldwide as a major partner in certain topics (meso and micro dynamic scale, dynamics of the tropical Atlantic and Pacific, carbon cycle and penetration of anthropic carbon, cycle for trace elements and their isotopes, hydrothermalism and deep chemosynthetic ecosystems, etc.);
- Its scientific production can be found in high-impact journals; there is a considerable effort to communicate with the general public through the campaigns;
- Student and young-researcher training is high quality thanks to teaching access to the fleet's varied resources (station vessels to ocean-going vessels);
- Because of the teams' skills, their expertise and high technical ability, R&D is very high quality and leads to unique technological developments through the world (core boring, AUV, etc.);
- Access to the vessels, machines and heavy equipment is open to all scientists, subject to approval of a high-quality scientific dossier;
- The peer review system is highly demanding and guarantees good quality. *A posteriori* monitoring of the development that gives FOF activities great visibility.

Difficulties

Requesting and actually bringing about a scientific campaign at sea currently involves the following major difficulties:

- The multi-purpose RV *Suroit* has dropped out of the ocean-going fleet, therefore making annual programming less flexible;
- The question of flexibility for interventions at sea, particularly in the coastal area remains an issue in terms of operation and programming. On this last point, it is essential to maintain N+1 annual programming for coastal vessels and an N+2 schedule for ocean-going vessels. The users also wish to be able to make the most of having ship time "in the water" to run an acquisition campaign at sea just after an exceptional and/or major weather-climatic phenomenon (flood, storm, accidental pollution, etc.); all this to answer scientific questions associated with studies on sediment dynamics or coastal environment ecosystems;
- The long search for financial support before, during and after the campaign, as well as the phase offset between campaign assessments and their funding. The number of points of contact to request funding has multiplied, schedules for calls for bids from funding authorities are not in phase with the fleet and do not consider certain specific aspects of the discipline, particularly the campaign programming calendar, that does not depend on the researcher's whim. The ANR for example, main source of funding for French research, does not consider campaign projects approved by the National Fleet Commissions and only follows its own assessment procedure, which very often prevents financial support from being granted in accordance with the investment that these campaigns represent (boat time, personnel time, machines and instruments);
- The organisational aspect of the campaign including preparation of the campaign, work authorisations and relations with the foreign country observers (highlighted because this is getting worse over time), the container transport logistics, access and availability of equipment held by organisations and/or labs (DT INSU or Ifremer), constraints linked to marine parks, to earthquakes, to hazardous zones, vessel interoperability issues, feasibility problems (problems with a winch, lift, etc.); the community highlights the growing risk linked to national and international regulations becoming more complex particularly in terms of work permit applications (difficult geopolitical zones like the Mediterranean, authorisation given at the last minute, etc.), transporting equipment (blocking containers before arrival at shore) and hazardous products, problems concerning access to biological samples (APA), etc.
- Implementation of technical aspects before and during the campaign with the need to coordinate activities from the different ITs spread over the labs or within the DTs and the variable working conditions on board from one vessel to another, highlighting the need for better monitoring between preparation on land and work at sea;
- Growing difficulties have been revealed in terms of running heavy operations such as deployment of on-board instruments by scientific teams, for which operational costs can be high (HROV). One welcome change would be to expand technical support (validation of data from the different equipment being implemented) by IT personnel assigned to the heaviest instruments.
- Although it is not in the FOF's remit, the committee is raising the alarm on the lack of IT personnel in the laboratories for development, maintenance and implementation of on-board equipment and marine instrumentation, as well as for small benthic ecology equipment. Several laboratories also consider that lack of IT personnel compromises their activity in the short term.

Furthermore, alerts have been suggested on functioning and subsequent recommendations:

- Optimisation of the complete data chain, from on-board data acquisition to using it in the labs on land, would make the scientific teams' work considerably easier (establishing an architecture of data provided at the end of campaign that is independent from on-board software, alongside complete management of software for data acquisition and validation). **The wide range of software available including software created by IPEV teams or developed by IFREMER could become a strength, if users are consulted on choices;**
- Currently, communication associated with the oceanographic campaigns is isolated and occasional, on the initiative of the mission leaders or scientific teams, linked in with their own administrative supervision. There is no coordinated, organised communication action on a FOF scale. Setting up a real communication service dedicated to the FOF would make it possible to increase visibility and development of the FOF results.

The most specific strengths/weaknesses for each topic are given in detail below.

1.6.2 More specifically in Marine Geosciences

Strengths

- The "Margin action" programme, for which major results are mentioned in 1.2.1, is held up as an example in the international community (such as the NSF) and contributes significantly to implementing the IODP-GOLD/DREAM drilling plan in the western Mediterranean basin;
- Insertion in European networks is good (example of the ACCLIMATE campaign partially funded by an ERC);
- Participation in observation networks has been structured over the last few years, mainly concerning archiving and data availability;
- The subsequent period has witnessed positive changes (rejuvenation, new equipment) Access to these resources, via the UMS FOF national assessment commission has also become easier to see. Changes to the ROV Victor, the HOV Nautile, and the addition of new machinery, such as the H-ROV Ariane (for coastal/margin jobs) and the AUV Coral 6000 will help develop an "intervention 6000" vector with an AUV Coral - ROV Victor/HOV Nautile partnership;
- In terms of long core boring, significant developments have been made over the last few years (e.g. accelerometer to record the core drill behaviour, CINEMA software, core drill instrumentation, etc.) particularly thanks to IFREMER and IPEV working closely together. These developments have helped to significantly improve the quality of the very long cores (CALYPSO) obtained using a "pistoned" core boring system. Therefore, France remains, now more than ever, at the forefront of long marine series sampling.

Difficulties

- It is necessary to bring the two main deep-sea intervention machines, ROV VICTOR and HOV Nautile, up to standard (HOV Nautile is operated down to 6000 m and ROV VICTOR can work at 4500-6000 m);
- The coastal fleet is ageing, particularly the RV *Thalia* that will soon be 40 years old. Furthermore, several ships left the fleet over the previous years (*Gwen Drez* in 2014, the *Côte d'Aquitaine* previously, and never replaced). This fleet is the right size for studies along the coast but is quickly out of its depth further out to sea on the shelf, in terms of action radius, deployment of tools and scientific personnel, particularly for the Channel-Atlantic shore. Campaigns carried out by the *Thalia*, as far as the edge of the continental shelf, are already problematic.

- Apart from the RV *Thalia*, the in-shore vessels are not equipped with acoustic scientific equipment (multi-beam sounders, hull ADCP), as is the case for all ocean-going vessels, thereby limiting research programmes on the continental shelf (*i.e.* geological reconnaissance, the earth-sea interface, surface sediment layers);
- It is currently very difficult (or even impossible) to sample and recover boring cores at least 5 metres long in rough sandy sediment on the coastal platform. Thought should go into defining the most reliable and appropriate system whilst being deployed from a vessel the size of *Thalia* or *Côte de la Manche* ;
- Care should be taken to allow interoperability of seismic and core boring systems on ocean-going vessels, particularly guaranteeing the presence of systems on board that classically go along with these tools (IT, cutting benches, measuring benches, etc.)

1.6.3 More specifically in Physics-Biology-Cycles

Strengths

- Strong structuring of the national and international community allowing successful major multidisciplinary, multi-lab projects to be submitted. These publications give major international visibility to these campaigns (particularly several special issues of scientific journals associated with recent campaigns such as KEOPS, VAHINE, DEWEX, OUTPACE, GEOVIDE). Acknowledgement and visibility for the community thanks to French implication in Scientific Committees and management of large international programmes (such as GEOTRACES, SOLAS);
- Many national observation services, structured within Research Infrastructures (IR ILICO, IR EMSO, ARGO), that provide the community with qualified data over a long period.

Difficulties

- The phasing between the programming and the period requested by the project is sometimes difficult, due to strong constraints from the biogeochemical context of the area to be studied, generally with strong seasonable variability:
- Due to the fact that the campaigns are essentially multidisciplinary, participants are often involved in setting up at least 2 projects in parallel: given the complexity of financial set-up tied in with programming ships, this can often lead to problems with the community's driving forces that would find it hard to get involved in 2 major campaigns (more than 45 days at sea) in the same year;
- Distribution of ship time between labelled observation services and specific research projects runs the risk of going against the latter, particularly due to lack of positions for physicists in observatories and rising pressure for observation needs.

1.6.4 More specifically in Biology-Ecology-Biodiversity

Strengths

- Strong ramp-up of studies on marine biodiversity with the initiator role of the Census of Marine Life in which the French community has been very active, in all compartments: fauna and flora, macro and microbiology;
- An ocean-going fleet that is suitable for multidisciplinary ecology-biogeochemical projects in the pelagic field, biology-geology in the deep-sea area;
- An in-shore coastal and station fleet to support studies on different scales and to make it possible to test new biological data acquisition systems;
- A well-structured network of stations and marine labs (Resomar) bringing together the specialised scientific communities, among others, in the study of pelagic and benthic

ecosystems, and observation services on which functional ecology or evolving ecology projects can rely:

- Easy access to biodiversity "hotspots" in overseas territory, that represent very significant biodiversity potential that is still very under-explored, except perhaps, in the Pacific thanks to the presence of an RV based there for over 40 years (*Coriolis*, then *Vauban* and now *Alis*).

Difficulties

- Lack of national structuring of the BEB community in the marine field, this being naturally organised over the biological processes regardless of whether the environment being studied is continental or marine. Some examples are GDR Biological Invasions, Chemical ecology, Environmental genomics, Tropic ecology. Partially compensated at a European level (*e.g.* EuroMarine, EMBRC);
- Access to distant zones (Pacific, Indian) remains difficult in terms of programming, considering recurring constraints on the fleet that limit the flexibility of open-sea programming (Observation, SHOM);
- A coastal fleet that limits the possibilities of multidisciplinary campaigns: the biological aspects should be coupled with the biogeochemists' analyses in the water column, or the geologists' analyses in the benthic area.

1.6.5 More specifically in Fisheries

Strengths

- Four FOF ships that are perfectly suitable to collect fishery data (*Thalassa* in open-seas, *Europe* on the coast, *Antea* in mixed circumstances, plus *the Thalia* along the coast for "Scallop" campaigns and line trawling in estuary zones);
- Vessels allowing series of campaigns to be run over long periods with stabilised protocols for many years: internationally validated sampling protocols, standardised and reproducible campaigns, funded 80% from 2017 by the European Commission within the framework of the DCMAP (Data collection to help the common fishing policy). This helps produce reliable affluence figures that can be used directly in international work groups to assess stocks, a direct contribution to civil society (contribution to the common fishing policy by defining the TAC and annual quotas, directly applicable to commercial fisheries) and finally, production of data for scientific research.

Difficulties

- Since the RV *Gwen Drez* left the fleet at the end of 2014, the FOF no longer has a low draught coastal vessel suitable for sampling wide-mouthed nets requirement to sample large mobile species (basket trawling) whilst certain campaigns and research work require sampling of this compartment of ecosystems in the shallow coastal zones (< 20m);
- The perspective of the RV *Thalia* leaving the fleet, scheduled for the coming years (by 2020 in theory), if it is not replaced, would leave a gap of a coastal vessel that can operate drag nets to sample large benthic invertebrates (such as scallops) and line trawling for flat fish (e.g. sole);
- Within the framework of the common fishing policy (CFP), the European Commission (EC) has contemplated the chance of entrusting recurring campaigns for DC-MAP to Member States based on a call for tenders rather than a mandate given to each Member State depending on its contribution to the quota for species targeted in these campaigns (threshold set at 3%). The cost of days at sea for the main vessel used for French fishery campaigns, namely the RV *Thalia*, is greater than the cost of vessels from many Member

States, which does not make the FOF very competitive compared to other Member States if this type of call for tenders came about;

- Within the context of applying the Marine Strategy Framework Directive (MSFD), the theoretically inevitable idea of extending fishery campaigns to an ecosystemic approach might affect work organisation, currently regulated just on the fishing constraints.

1.6.6 Specific points for Overseas Territories

Strengths

- The overseas territories represent France's long-term interests and obligations in the regions and in contexts with very different ways of working and features than the mainland. Knowledge issues are nevertheless important because they concern topics that vary as widely as biodiversity or the climate (see section 2.1.6) and require collaboration with scientific communities from other countries in the region. The presence of French scientists is decisive to do this.
- In the Pacific, the French archipelago of New Caledonia, Polynesia and Wallis and Futuna are among the most important in terms of surface area and economic development in Oceania. The patrimonial value of the reef ecosystems that they house is the origin of important marine protected areas. Thanks to the presence of the *Alis* in Nouméa, and support from a dive team dedicated to studying the reef environment, it has been possible to develop and support partnerships with neighbouring countries through SOUTH-SOUTH and NORTH-SOUTH programmes from French Polynesia to the east as far as Papua New-Guinea, or even Vietnam in the west. (See all the campaigns in Fiji, Salomon, Vanuatu, Papua New Guinea);
- More generally; the presence of multi-purpose, intermediate-size Oceanographic Vessels in tropical zones, the *Alis* in the Pacific and the *Antea* in the Indian Ocean (La Réunion, Mayotte, Scattered Islands) and the Atlantic (Guiana and Caribbean) can cover all research run in the tropical overseas territories. Furthermore, these two RV have the specific feature of being able to simultaneously run campaigns that are open-sea (oceanographic, fisheries and geophysics) and coastal (oceanography and geophysics of lagoons). This explains why they are the only FOF RV for which campaigns can be assessed either by the coastal commission or by the open-sea commission of the FOF (CNFC and CNFH).

Difficulties

- The presence of the French oceanographic community, in the form of platforms or permanent teams, nevertheless remains very poor compared to the EEZ surface area, the overseas linear distance (97% EEZ and 68% linear) and their associated scientific issues;
- In the Caribbean, or even in the tropical part of the Indian Ocean, the significant ecological and economic potential represented by the overseas territory is currently under-exploited/valued because no vessel remains constantly in the area. The occasional passing of the FOF boat (*Antea* or another) fills this gap on an ad-hoc basis. Unfortunately, there is no equivalent of the IPEV, set up to study polar regions, to support the study of tropical regions in overseas territory (in the area run by the TAAFs, the scattered islands are considerably less well known than the sub-Antarctic islands);
- The ageing of the *Alis*, its small size (28.40m) and, above all, its low capacity for scientists (6 persons) considerably limit its working possibilities. The *Alis* will be 30 years old in 2017, its ageing leads to increasingly expensive maintenance and affects safety. Its replacement should be envisaged by the early 2020s.

1.6.7 *Specific points for on-board teaching*

Strengths

- Good insertion in European and international networks (the Marine Universities Network is affiliated with the Marine Board plus agreements with the CONISMA- Italian marine university network, agreements with Brazil and Quebec, beyond agreements between universities or International Master's training);
- The current format for assessing requests and monitoring give equal access to the FOF vessels.

Difficulties

- Need to make the slots for different types of on-board teaching last longer, and the new FOF organisation should ensure that the teaching mission is renewed on station and coastal vessels, as well as opening up to floating universities or seaside universities on-board coastal and ocean-going vessels. To do this, the flexibility of the programming must be maintained, particularly for ships in the station and in-shore fleet, and the possibility of work on H24 developed for the latter as well as making on-board equipment suitable for the different approaches and measurements involved in the different fields of marine research;
- It is important to keep teaching programming options outside calls for tenders (and sometimes even as and when if annual programming allows this), given current difficulties to make the most of places available for students from different fields of training within existing missions (observation, research, public service). Funding complements to allow students to get on-board the fleet's vessels are sometimes lacking and should be researched among different authorities;
- It must be ensured that the on-board models are properly displayed in the training models.

1.7 Conclusive comments on the overview

This overview highlights just how much the fleet and the resources at sea are major assets for French oceanographic research and training on sciences of the sea. The French community has high performance resources and high technology equipment funded by the TGIR FOF. These resources could be improved, completed or should be replaced when they are withdrawn, after consultation with users. The national community described here is dynamic, productive, leader in many projects and strongly represented on the international scene. This report also brings out the spirit of working together, leading to calm, reasoned discussion on the use of the FOF, in addition to future needs, broken down in the long-range planning. Short-term priority actions that would have significantly positive effects and would further boost the scientific community and spread the national oceanography community are:

- Consolidating funding to perform oceanographic research based on campaigns at sea and subsequent scientific activity. This financing covers campaign preparation (logistics and scientific), return transport of scientific teams personnel and equipment, the cost of running and/or purchasing equipment dedicated to the campaign, the cost of consumables, compensation for the observers, the analytical work and the processing of data and samples during and after the campaign, and non-permanent staff salaries (PhD students, post-doc, contractors); this funding is relatively low compared to the cost of days at sea, but essential to allow teams to ensure high level research within competitive deadlines. The request for a single point of contact for the TGIR is crucial.
- Setting up specific, organised and effective help for logistics and for organisation of campaigns.

- Setting up institutional communication relays that can give the FOF media visibility. This visibility is too often lost behind private, well-broadcast and yet scientifically marginal actions (some are even barely scientific).

2. Part II: Issues and the priorities for the years to come

Like the topics, the issues and priorities can also be broken down into research areas, following the ramp-up of needs for multidisciplinary research.

2.1 Research topics and challenges

2.1.1 Marine Geosciences

The scientific challenges to be highlighted in the coming years reveal not only society's concern for the ocean, coasts and associated hazards but also the progress of our knowledge on how the present Earth's system works on a geological time scale.

Among society's concerns, the main challenges are to:

- Encourage coastal studies and earth-sea pairings, particularly in terms of tsunami/seismic/gravitational hazards and underground continent/ocean exchanges;
- Understand the dynamics of the pollutants (metal, metal-organic and organic) tied in with the hydro-sedimentary forcings and exploit the historical sediment archives to characterise the transformations and the persistence of pollutants in geological reservoirs depending on environmental conditions;
- Characterise the morphological response from the coastline and follow how the sedimentary construction of shelves and coastal zones change in response to rising sea levels, weather-climate forcings or anthropic disruptions (migration, construction/erosion, etc.) that modify the flux of available matter;
- Determine tolerable disruption thresholds for the substrate (physical habitat) to maintain or restore the biological habitat (tied in with anthropic impacts);
- Decrypt marine archives (sediment and biological fossils), in high resolution, to better restrict climate change and the anthropic impacts and better date catastrophic, atmospheric or telluric events; improve comprehension and quantification of proxies to help reconstruct past oceanic changes;
- Improve assessment of major oceanic earthquakes, past and present, from mechanisms at source and their recurrences up to the characterisation of ruptures linked to the oceanic floor.
- Study the oceanic methane cycle, from genesis to storage in the sedimentary column and from there its influence on the water column and its potential contribution to the atmosphere as a greenhouse gas.

Among the research on the present Earth's system and on a geological time scale, the following objectives were more particularly identified:

- Restrict the circulation of fluids under the oceanic floor and the marine sediments (hydrothermal circulation, cold seeps, gas, etc.) in space and time in relation to the magmatic, tectonic, sedimentary activity and its impact on the diversity of deep ecosystems and the balance of chemical elements in the ocean;
- understand the magmatism/tectonic relations on slow and ultra-slow moving ridges, as well as the volcanic structures (*e.g.* arcs, underwater mounts…) where a large number of processes and structures remain unknown (deformation linked to transforming faults, tectonic exhumation along the detachments and in amagmatic extension zones, very variable hydrothermal systems), with their impact on the structure, the composition and the thermal regime of the oceanic lithosphere that remain to be determined;

- understand the tectonic/magmatism/sedimentation relations on the passive continental margins, a non-negligible geological element on a global scale and essentially not very well known. In the deep-sea margin area, in a diverging and/or transforming context, the exhumation of the lower crust all along the crustal detachment zone or sub-continental mantle exhumation zone and how it relates to setting up hydrothermal systems in transitional areas are still studied very little. What are the impacts of passing between a continental lithosphere and an oceanic lithosphere on the structure, the composition and the thermal regime of the lithosphere?
- understand the "mud to mantle - source to sink" interconnected relationship, meaning the relationship between the deep-sea processes and the surface processes, or even determine the weight of the structural heritage of the pedestal on the sedimentation (architecture and type of deposits), as far as quantifying the complete sedimentary balance taking into account: (1) role of chemical alteration (*e.g.* dissolution of silicates) *versus* how relief is changing, (2) impact of climate variations, (3) determination of continental sources, (4) quantification of continental capture and (5) deposit in a more or less closed system;
- make progress on tracing the source of marine sediments, by developing geochemical proxies on the mineralogical and/or fossil archive phase;
- for digital modelling, provide dating and constraints from environments of deposits and include the geochemical data from the sedimentary archive and fossils that help assess the erosion of the catchment basins and the origin of the sediments, on a geological time scale;
- study the nonlinear processes in the ocean-atmosphere-biosphere-internal Earth coupled systems;
- continue multi-disciplinary research work by coupling geodynamics, geology, biology and chemistry on characterising sea mounts in the oceans that are still studied very little;
- the other major topics tackled in MG remain current such as the chemistry and the dynamics of the mantle, volcanic construction - time and space scale, the structure of the oceanic lithosphere, and its evolution from formation in diverging continent margins up to subduction.

It is important to highlight that these numerous challenges require physical and chemical seabed instrumentation to be developed in order to obtain long series of high-resolution data and to tackle the process dynamics on a local scale. This implies not only increasing the number of instruments to widen the number of observations but also strengthening R&D to better automate data processing and make it easier to extract useful information.

2.1.2 Oceanic physics and dynamics, Carbon cycles and elements, ecosystems

The major issues of these topics are still observing, understanding modelling the oceanic processes, their variability, their responses to climate change and anthropic pressure and their interactions with other compartments of the "Earth" system. The coastal area, in synergy with environmental issues (potentially high-impact, over-populated areas, such as concerning contribution to pollutants) and society issues (ecosystemic services, resources) are also a major concern for the scientific community. It is urgent to understand the combined issues of marine and atmospheric, physical-chemical and ecological dynamics and contributions from the coastal catchment basins on the natural variability of coastal environments (trophic networks, algae efflorescence) that are connected to each other and to the ocean and land environments.
More specific issues were identified for the coming years.

Physical Processes

The physical processes that control the oceanic dynamic on a large scale and its variability, are currently facing the following fundamental questions:

- What are the mechanisms (seen as physical, geochemical and ecosystemic sequencing and interactions of multiple scale processes) by which the ocean is going to prioritise the space and time structures of their low frequency variations, regardless of whether they are forced by the atmosphere or intrinsic? One of the issues concerns the integration of small-scale space-time processes for large climate variability time scales, particularly in pertinent processes for thermohaline circulation and for the physical (and biological) pumping of carbon as well as for very long pertinent scales for paleo-oceanography;
- How does the ocean redistribute or dilute climate change (i.e. changes in thermal and salt content, CO_2, oxygen or even methane) towards the depths and between the major regions of the ocean? And how do these changes affect and interact with the different ecosystems?
- What particular role is played by the dynamics of major oceanic crossroads (west coast current, thermocline, topographical thresholds, inter-gyre zones, etc.) in these mechanisms? This question is crucial in regions that are as varied as the bifurcation of currents zone in the South-West Pacific or in the Gulf Stream region of the North Atlantic;
- What are the determinisms of the El Niño phenomenon for which the occurrence, dependence on equatorial conditions and "Warm Pool" coastal dynamics are still not understood?
- Which processes determine the genesis of cyclones (dynamics, air-sea exchanges, etc.)?

Lack of knowledge on these matters is a barrier to understanding variations and changes to the climate and to quantify the ocean's energy balance. The dynamics being studied are complex and often have a strong non-linear character, originating from strong scale interactions, and can have a stochastic dimension. In this context, it is now primordial to develop high resolution measurements to get databases that cover a large range of scales.

Chemical elements

Chemical elements in the ocean can be beneficial for the biota (these are the nutritional and micro-nutritional elements) but are also potentially toxic (such as certain metals and metalloids, other organic pollutants or others). The study of their cycle is therefore intrinsically linked to studying their physical transport, by considering interactions with the matrices such as particles and organic matter, and to studying ecosystems.

- How is the structure and the diversity of biological communities regulated by and/or does it regulate the flux of minor and trace elements? What is the importance of nitrogen fixers, particularly in the South-West Pacific?
- How is the biological pump modulated by these exchanges?
- What are the sources of these minor and trace elements, the factors of their bioavailability and their variability?
- What is the feedback towards the atmosphere and particularly, can we improve the quantifications of emissions to the atmosphere of certain greenhouse gases (methane and nitrous oxide)?

High latitudes

Still largely unknown, polar oceans and ice fields are responsible for significant uncertainties in our understanding of the future climate and its impact on the ecosystems and the global sea level (Antarctic polar ice cap melting is the origin of the strongest uncertainty concerning global sea level). Furthermore, they are the scenario for the fastest and most violent climate changes that we know about right now in the world:

- Evolution of ice caps in Greenland and the Antarctic.
- Role of ocean-ice interactions in this evolution.
- Role of the Arctic and Austral oceans in the global carbon sink.
- Evolution of Arctic and Antarctic ice fields.
- Acidification with ecosystems potentially at risk more quickly than in other regions of the globe.
- Change in the distribution of freshwater with impacts on the stratification and the renewal of oceanic seabed waters...

It is therefore fundamental for the national polar research community to be able to access these regions. This implies specialised infrastructures that are crucially missing in France right now and thinking about long-lasting solutions that meet the major challenges posed in these regions.

Micro-plastics

Emerging studies, where the French community is a driving force, look at micro-plastics which are present in all regions of the ocean and their impact on the biota, out at sea or along the coast. As coastal environments are particularly interesting for humans (aquaculture, fishing, tourism), better assessment should be urgently run on how this pollution is transferred to the ocean, to better determine the origin and quantify the flows of pollutants and assess their impact on the quality of water and ecosystems.

In conclusion, acquisition of more in situ observations, often at high resolution, combining fine biogeochemical (e.g. trace elements), physical and biological parameters (provided by automated sensors) in contrasted regions of the ocean is necessary to improve the capacity of the models combining physics-chemistry and biology to represent how life develops at different scales of time (from the extreme event to the scale of the "paleo" recording via the description of a bloom or a ten-year trend) and space (model on a basin scale or on a global scale). These improvements are necessary to reduce uncertainties on climate projections provided by these models, to improve our understanding of changes to cycles, ecosystems, habitats of organisms and ecological niches of species under the effect of climate change and anthropic pressure. And *in fine* this will give us a better quantification of the impact of these changes on the biological pump and therefore on the carbon cycle.

One important challenge will also be to control observation systems on multiple scales, that will also require the use and development of dedicated instrumentation and vectors allowing regular and suitable observation, whether this is in the field (such as adapted gliders, appropriate vessels, etc.) or remotely (satellites, radars, etc.).

2.1.3 Biology-Ecology-Biodiversity

In the field of ecology, we can identify different communities with specific priorities.

- A strong community is concentrated on the coastal and shore area (including internal and medium shelf), on the mainland and in overseas territories. It mainly uses station vessels, the coastal fleet and two multi-purpose intermediate-sized RV dedicated to tropical regions. Regardless of the site, current research is looking at benthic-pelagic coupling and the earth-sea continuum and leaning towards encompassing an ecosystemic scale with a fine space and time resolution in order to complete integrative modelling. The impact of anthropic uses (ecotoxicology, eutrophication, introduced species, development of renewable marine energies) and the context of global change (heating, modifications of oceanic circulation, acidification of oceans, changing biogeography of marine species, erosion of the biodiversity and habitats) furthermore imposing multi-parameter studies, coupled with studies from physicist oceanographers and biogeochemists, requiring more ambitious campaigns in terms of equipment and human resources;

- In the pelagic open-sea area, the breadth of the taxonomic (protists) or metabolic (prokaryotes) diversity brought to light over the last few years implies reviewing certain functional diagrams and including in them the key role of long-lasting biological interactions by identifying a few site zones in contrasted contexts where these processes will be re-examined in detail;
- Access to the dynamics of the planktonic, coastal and high sea communities, in real time, and at fine space and time resolution, in view of the use of sensors and (semi-)automated collection systems, will allow better characterisation of the structure and the operation of coastal and oceanic ecosystems;
- In the study of deep-sea benthic ecosystems, the French community has been widely acknowledged internationally, particularly thanks to its research resources (submersibles: HOV, ROV, AUV). The perspective of future deep-sea energy or mining exploitations nevertheless increases the urgency of expanding our knowledge of these environments and beyond the inventory that remains largely outstanding (explorations in or outside the EEZ), expanding studies on functional dynamics of potentially-affected communities, and on the biogeography and connectivity of species and populations to be preserved. As an example, conservation of deep-sea coral habitats in the Bay of Biscay will be subject to European-scale negotiations in the years to come, following their classification as a Natura 2000 site. Trawling and dragging, likely to cause significant destruction, is increasingly less tolerated by the authorities even within scientific research. Resorting to use of the ROV (SCAMPI type or other) is going to be generalised for sampling;
- Although this activity is “Public Service”, the demand from the public sector to monitor and characterise the ecological condition of benthic and pelagic ecosystems in connection with biodiversity condition describers and trophic networks, as well as the different associated pressures (MSFD), puts a growing constraint on the use of vessels.

2.1.4 Fisheries

Although the ‘classic’ aspect of fisheries remains, marked by an operational purpose of evaluating stocks for fish management, for several years, the fishery research framework has been moving towards the ecosystem approach to fish and more recently for all human activities. This framework has been developed for around twenty years. On the one hand, it relies on improving knowledge in a variety of scientific areas (biology, ecology, physical oceanography, meteorology, etc.) and modern opportunities for modelling and on the other hand, on the resolutions from world summits (Cancun 1992, Reykjavik 2001, Johannesburg 2002…) and the resulting policies (PCP 1992, DCSMM 2008). Therefore, there are many fishery topics: relations between populations and environment (biology-water mass dynamic coupling), identification of essential habitats for renewing resources, multi-scale interactions between fishing and marine biodiversity, impacts of the economic and governance determining factors on fishing work and catch capacities... Use of the FOF to acquire this fishery data coupled with the environmental data, impossible or very difficult to obtain on professional boats, is more than justified here. It is expected that this data collection will be completed in the future from other platforms (fixed stations, gliders, etc.).
Among the scientific challenges and barriers, the most outstanding can be mentioned:

- Integration of geographical and biological scales for a real ecosystemic approach;

- The effects (additive, synergetic, antagonist) of multiple stress factors within global change (global warming, acidification, eutrophication, pollution, biological invasions, alterations to habitats, modification of the biodiversity, over-exploitation, other uses, etc.) on the different organisation levels (individuals, populations, communities, ecosystems);
- Taking into account compromises between ecosystem compartments and between uses/sectors when managing human activities and conserving marine ecosystems;
- Development of observation methods that are not or are barely invasive (replacing trawling, for example, which kills species and destroys habitats).

2.1.5 Questions regarding scientific community interfaces

The ocean is one of the Earth's compartments that constantly exchanges with the others (atmosphere, ice, continent). Quantifying these exchange flows is key for an optimum description of how the "Earth system" works. Furthermore, the whole planet is affected by global changes, regardless of the scale of time and space under consideration: the study of interfaces between oceans, atmosphere and continents should therefore be strengthened over the coming years. Furthermore, recent discoveries regarding the importance of hydrothermal flows of micro-nutritional elements (Fe, Zn, Co, Cu…) plus the role of oceanic margins on their budgets have led to more intense research in these environments. Finally, these interface questions are crucial between disciplines to lift cognitive barriers. This chapter looks at both interfaces between compartments of the earth system and also important "mechanistic" questions between (for example) living and mineral aspects.

Ocean-atmosphere coupling

- Quantify the effects of atmospheric flux on the oceanic dynamic and ecosystems as well as feedback towards the atmosphere (marine emissions, radiative impact, impact on cloud formation and climate) will help improve climate models. Our knowledge on marine biogenic emissions into the atmosphere is very fragmented and this feedback has not been quantified for the time being. **One of the issues is to take these *coupled* measurements of the different flows through this interface to understand the effect of these emissions and their physical-chemical or biological origin.**
- Furthermore, the effects of "Black Carbon" on biogeochemical and microbial functioning of the pelagic ecosystem remain too scarcely documented. Measurements exist on continents and occasionally in the coastal area but not in the open-sea. **One recommendation is to develop this type of measurement more systematically.**
- The role of the Austral Ocean in ocean-atmosphere CO_2 exchanges, the fragility of its biology with regard to acidification of surface waters, micro-nutrition dynamics and identification of factors limiting primary production in these high latitudes are still unresolved points. **It is strongly recommended to give the community the means to explore the Austral Ocean to a greater extent.**

Continent-ocean transition

- The systems generated between the continental and marine waters in estuaries and plumes and within the shelves and margins (dilution fronts, thermal fronts, currents, tide) permanently or temporarily, complexly structure the different pelagic ecosystems, their inter-connection and their connections with the benthic systems: these mechanisms condition and sometimes limit biological production and the diversity of the communities present. **Restricting these highly variable physical mechanisms is complex. They require high-resolution monitoring over time and space;**

- Quantification of transfers of chemical species (contaminating or natural) between continents and oceans is as essential as it is unknown. It refers to identifying flux released from matter discharged by the rivers and/or sediments from margins and/or even by the discharges from underground water and understanding why certain contaminants clog up for a long time whilst others are released from the solid matter when it meets the saline front. The physical mechanisms that favour release of chemical species by putting sediment back in suspension are theoretically intermittent processes (run-off in fracture zones, canyons, pockmarks, small scale whirlwinds, internal waves and mixture, gravitational events, etc.). **Studying these mechanisms and the catchment basin-ocean continuum (particularly in flooding periods, vectors from the majority of the annual sedimentary deposits) require stronger collaboration between physicists and geochemists, between scientific communities, but also vessels capable of fast reactions (during extreme weather events, for example);**
- There are crucial questions relating to the dynamics and the preservation of marine habitats. In a balanced system, the sediment and the mudflats provide a physical habitat that is modified in return by biological activity (diggers, ecosystem engineers, etc.). In the same way, if we see a forcing of sea-grass beds on the substrate, the inverse is also happening. In tropical zones, the coral reefs play the role of substrate construction and house ecological niches. Climate change and rising sea levels, storms and induced erosions cause a reduction in these habitats, with major consequences on marine resources, particularly the coastal economy in the inter-tropical zone;
- Management overseeing port activities and marine and coastal resources, both in terms of fishing, shellfish farming or marine energies, requires a systemic approach, integrating the physical and biological environments and socio-economic aspects. The recent and booming topic of coastal nurseries requires specific data acquisition work to improve knowledge. For example, too little research is being run today on the ecological impact of exploiting marine granulate: the studies are too short, too localised and do not tackle the medium-term effects of turbidity on the nurseries for example. The intensification of surface and deep mining (P, Ni, Cd, metals, etc.) and the disruptions caused by these activities, particularly on the trophic chain (accumulation-detoxification) make these quantifications urgent;
- More generally, the quality of the water, the biodiversity and how the ecosystems work are transverse problems and essential conditions for preserving ecosystems and human activities that depend on this. These are major management issues integrated at the earth-sea interface (WFD, MSFD).

For all these questions affecting the coastal environment, long-range planning discussion has highlighted the importance of working on an ecosystemic scale: very few studies on ecosystems produce a mass balance, involving primary and secondary producers at an ecosystem scale. As field studies are often occasionally in space, the change of scale to the ecosystemic scale should be able to link in using remote detection. New satellites actually have a spatial and spectral resolution that should allow coastal ecosystems (spatial resolution) to be studied using a wider set of parameters (dissolved and particulate organic matter, phytoplankton taxa, spectral resolution), linked in with new sensors and automated collection systems.
Suitable dynamic constraints are required to control the flux of sediment towards the water or of sediment into the air (intertidal zone) and towards the ocean.

The essential development of these ecosystemic studies must be accompanied by vessels allowing multidisciplinary work. Furthermore, vessels should be equipped with resources to deal with the impact of extreme events (floods, storms, coastal submersion). The fleet's

resources and vessel programming do not always allow this type of reaction. The observation services (SOMLIT, MOOSE, Coast-HF), the "ferrybox" deployed on the Brittany Ferry vessels are equivalent resources to "surprise" a sudden event. It is therefore recommended to develop automated sensors to be deployed on the vessels, linked in with development of satellite sensors.

Deep earth-ocean interface: marine hydrothermalism

Hydrothermal circulation is the result of seawater percolating through marine sediments and the oceanic lithosphere. The physical-chemical composition of the water is drastically modified by water-rock interactions. The initial seawater is transformed into a hydrothermal fluid presenting chemical characteristics: either acid, reductive and strongly enriched in metals for high temperature hydrothermalism, or hyperalkaline, reductive and strongly alkaline-enriched for low temperature hydrothermalism (<120°C). Over the last 50 years, research has demonstrated the wide diversity and breadth of these phenomena, at both high and low temperatures, in basaltic, dacitic and peridotitic substrates, in accretion and subduction contexts. The hydrothermal dynamics not only affect the chemical composition of the oceanic lithosphere and the deep ocean but also how the diversity of the deep ecosystems works. To sum up, quantification of transfers of matter and heat linked to the hydrothermal dynamics remains relatively unknown in time and space and needs to be constrained. In this wide multidisciplinary field, the main questions revolve around the future of these hydrothermal flows in the ocean and their role in the biogeochemical balance reports and cycles, the origin and nature of the ligands that may or may not stabilise the micro-nutrients in seawater, their distribution among the dissolved and particulate phases and therefore their bioavailability for deep and surface ecosystems, particularly for diazotrophs in the Pacific Ocean or, by means of circulation, a partial fertilisation of the Austral ocean.

Qualification of the hydrothermal flows, involving characterisation of circulation geometry and whatever is driving this circulation (thermal? tectonic?) and understanding water-rock interaction mechanisms, is one of the major issues of the study of transfers of matter and energy between large geochemical reservoirs. **These studies require access to deep-sea exploration machinery, recurring campaigns, multidisciplinary campaigns and therefore they need to use large ocean-going vessels.**

Chemistry-biology-physics interface (all compartments)

"Micro-nutritional" trace metals are recognised as nutritional elements because, without them, there is no life. However, understanding the conditions that make them bioavailable, their behaviour during remineralisation of organic matter, and their sources (inside and outside the ocean) are also barriers that imply working on the boundary between transport, fine chemical speciation and biological development. Our understanding of the processes in play between the living cells and the chemical substances is still in its infancy. This is a major "mechanistic" boundary that uses the very latest observation techniques on the matter and to identify the chemical and biological speciation.

Biogeochemical studies are indissociable from questions on the ocean's dynamics and the air-sea interface exchanges. In particular, the oceanic meso and sub-meso scale processes affect the major scales through energy exchanges (and particularly vertical flows on a small scale) and one of the issues consists of quantifying their impacts on stratification, on the vertical flux of carbon and all nutriments, that are key factors in climate change. The critical role of sub-mesoscale circulation and vertical mixture in regulation of structuring of planktonic microbial communities, of primary production and of exporting organic carbon is increasingly clear, as shown in recent satellite observations, the field measurements and modelling simulations. Combining these observations with optical instruments will provide a unique glimpse of particle distribution and exports of particles to unprecedented scales. We might also mention the potential impact of primary production (particularly phytoplankton) on the oceanic heat balance via its impact on light penetration in the mixture layer. This type of parameter (Chl*a*, pigments) must therefore be considered and measured more often. This has been done systematically on the PIRATA-Fr campaigns for the last 6 years for example and with Argo floats via the development of the BGC-Argo component.

It will also refer to quantifying the flows of interesting biogeochemical or toxic elements, to understand and quantify exchanges between the particulate and dissolved phases depending on the environment's biogeochemical conditions (T, pH, type and quantity of MOD) and the associated microbial dynamic that will help identify the bioavailability of these elements.

Only multidisciplinary studies bringing together chemists, biologists and ecologists with specialist small scale physicians and their associated equipment at sea (own sampling systems, incubations, particle collection, etc.) will help make progress on these questions.

2.1.6 Challenges from Overseas Territories

The French Oceanographic Fleet is capable of meeting the issues and challenges of the French overseas territory. Although the overseas territories are essential regions for studying global relevance processes illustrated in the preceding chapters *(2.1.1 to 2.1.5),* more specific questions are tackled in collaboration with emerging countries:

- Biodiversity: from the gene to populations/connectivity/inventories of biodiversity in distant zones that are rarely visited, studies on how the associated ecosystems work;
- Bioresources: research into new natural substances (venom, anti-cancerous molecules, etc.), new bacterial species, etc.
- Monitoring coral and associated ecosystems (reefs, sea-grass beds and mangroves) in parallel with the different impacts of global change (coral bleaching crisis, proliferation of predator starfish on the coral, invasive species, relation to marine bird population, etc.
- Analysis of the effects of over-exploitation (small and large pelagic fish, sharks, coral fish, etc.);
- Impact of other human pressure (habitat destruction, pollution, contamination, etc.);
- Improvement of knowledge on open-sea pelagic ecosystems (tunas, sharks, cetaceans, etc.);
- Continue discovering, exploring and studying exceptional singular environments:
    - Ultrabasic source of shallow Hydroprony in New Caledonia;
    - Coral reef on the volcanic island of Ambitle exposed to a simulation of climate change (higher temperature and concentration of CO_2);
    - "Sentry" islands with no human impact to assess the variations of habitats and associated communities with the different components of global change.

Target sites in overseas territory are being developed in the Atlantic (Guiana, Antilles, West Africa) and Indian Ocean (Mozambique) and the Pacific. These questions can affect both the coastal, inland environments and the open sea. In the case of the Pacific, the pressure of research and the length of the obligatory transits make it necessary to keep a vessel available such as the RV *Alis* based in Nouméa.

2.2 A new boom for teaching and training

The recent inventory of on-board training actions within the Marine University Network strengthens the intention to preserve and extend training on research and marine observation, staying on-board for different durations, and encouraging access to the FOF from a larger number of marine students.
Three types of training at sea should be maintained and strengthened: 1. Dedicated training campaigns (time at sea exclusively reserved for training - even if the data could also be used for other goals) - 2. Teaching-observation joint campaigns (or Public Service if recurring); 3. Teaching-research joint training campaigns (such as Floating Universities).
Pooling training on a site or a series of campaigns dedicated to training will be an interesting line to explore. The possibility of offering on-board modules during recurring campaigns (annual or every 2/3 years) on ocean-going vessels (or intermediate size in-shore vessels) and pooling teaching and observation (or public service) missions could also allow better training for students particularly for advanced master's or PhD studies, as a complement to European or international calls from on-board summer schools or floating universities.
The connection between observation-teaching would have to be reinforced. Consequently, the three-fold "pooling-development-optimisation" would give the most equal and complete access to the largest number of students in oceanography teaching given in France, whilst ensuring good quality on-board teaching.

Off-model training (such as summer schools) and training to make the most of transits of FOF vessels should also become more frequent if their visibility and accessibility is strengthened a little (via RUM).
Finally, the modules allowing real time daily monitoring of scientific, observation, public services missions and best use of trips, in direct connection with what has been proposed for the communication/popularisation of these campaigns among Schools/Middle Schools/High Schools/Universities, general public via maritime popularisation, could be strengthened with the use of data continuously acquired within physical-chemical and biogeochemical parameter recording modules. In addition, an innovative pedagogic combination associating the experience at sea with the valorisation/remote digital training would be a line to explore and to reinforce.

2.3 Public service constraints

The fields that are subject to specific demands from state services nowadays are fisheries and the needs linked to the common fishing policy (CFP), the WFD, the MSFD and exploitation permits, and reconnaissance needs for the continental shelf and beyond.

2.3.1 Fisheries

For CFP needs, the current volume of campaign days is 220 days. This volume will remain identical over the coming years, if the financing conditions are not modified and if a replacement solution can be found for the *Gwen Drez/Thalia* pairing. In fact, if the European Commission commits to calls for tenders rather than using the FOF, this number could drop (as well as the funding). This would also imply loss of capacity for campaigns covering MSFD needs (currently carried out via optimised public interest campaigns).

2.3.2 Water Framework Directive (WFD)

For the WFD/ecological status, use of station vessels is specifically suitable for benthos, sometimes complementing Haliotis. For the WFD/chemical status, coastal vessels like Thalia or Europe are requested.

Annual WFD needs are around 16 days on station vessels and 10 to 15 days on in-shore vessels.

2.3.3 Marine Strategy Framework Directive (MSFD)

Fish and cephalopods: within the framework of the MSFD, it is envisaged to create new coastal pelagic and demersal campaigns. For the Channel, professional vessels are already being used (around ten days per year). **From 2018 onwards, an APP coastal campaign will be put on for 15 to 20 days per year;**

- Benthic habitats (BH) and seabed integrity: for surveillance subject BH1 (distribution of the BH from the bathyal stage/regional approach), the specific need in number of days remains to be defined. Surveillance subject BH2 (distribution of the BH from the deep-ocean floor stage) is not used in an initial MSFD phase;
- Pelagic habitats (PH): The need for dedicated campaigns (in seasons not sampled by fishery campaigns), is 2 campaigns per year and per shore**, lasting 12 days per campaign in the Channel, 12-15 days per campaign in the Atlantic, 12 days per campaign in the Mediterranean, namely 70/80 days of in-shore or intermediate vessels.**
- Commercial species: campaign optimisation for MSFD surveillance needs lies in WDF campaigns for stock evaluation: IBTS, PELGAS, MEDITS, PELMED, CGFS and EVHOE;
- MSFD monitoring (waste, birds, marine mammals, gelatinous, noise, etc.) is also counted in the 220 days of open-sea campaigns dedicated to open-sea data collection within the CFP framework.
- Hydrographic changes: the "*Hydrographic changes*" surveillance programme envisages the extension of a "benthic cage" network, set up in its minimum 8-cage configuration (2 per marine sub-region). The benthic stations must be brought up and replaced every 3 to 4 months to collect the data and perform sensor maintenance. **The need in number of days at sea is estimated at 32 days not including transit.**
- Contaminants: deployment of SELI-MED/LOIRE/SEINE campaigns – **need for 10 days per year on a coastal vessel**, subject to water agency funding.

Regarding MSFD needs, in conclusion: the work to identify days at sea was not fully completed. Questions remain regarding issues such as what type of vessel is necessary for each campaign. The possibility of campaign optimisation has not been studied either and the funding has not really been completely identified.

Nevertheless, the trend towards a very strong increase in needs for days at sea is undeniable. This increase relies on FOF resources, in terms of vessels and budget.

2.3.4 Continental shelf mapping

For around fifteen years, the FOF has ensured public service data acquisition missions for the Extraplac project in order to work alongside the United Nations Commission on the Limits of the Continental Shelf (CLCS) to prepare the French continental shelf demands beyond 200 m. The Extraplac project will no longer request a new campaign.

2.3.5 AIFM exploitation permit (nodules and sulphurs)

Concerning the "Atlantic" exploration permit, France has committed to carrying out **three 50-day exploration missions on an ocean-going vessel (one every five years).** The first campaign will take place in March 2017 on the *Pourquoi Pas?* (HERMINE campaign). At least two campaigns therefore remain to be run in the zone by 2029.

2.3.6 SHOM positioning

For SHOM hydro-oceanic needs and its SOLAS obligations, the SHOM identifies the needs of a **hydro-oceanographic coastal vessel to be 100 days per year (90 for the Atlantic Channel shore and 10 for the Mediterranean).**

This further need to meet Public Service demands (not FOF funded), notwithstanding the need to find funding for it, can attain between 100 and 150 days of coastal vessels or in-shore vessels per year.

2.4 The needs in terms of fleet evolution, resources at sea and human support

2.4.1 Needs for vessels and deep-sea machinery

- *Coastal area*: the long-range planning committee highlights the crucial importance of station vessels, requiring accessibility and programming flexibility. A subsequent evaluation of the campaigns is recommended, particularly in terms of archiving and making good use of the data and samples taken on these vessels. **Emphasis is put on the importance of envisaging a replacement for the *Sepia II* station vessel, the oldest vessel in this fleet (1984)**. This vessel plays an essential role in research, observation (SOMLIT, REPHY, SRN, RESOMAR network, future phytoplankton-PhytObs observation network), teaching (at least 3 associated master's courses, Degree teaching unit, national and international hosting placements), as well as public service (WFD, MSFD) and participation from scientific communication and popularisation actions (Sea Festivals, World Ocean Day, Science Festivals) and support for the maritime scientific centres for the public (Nausicaa, MAREIS).
- *Coastal and shelf edge area*: the need for a vessel to access shallow water (estuaries on Channel-Atlantic shores, draught of around 3 m) was expressed and solutions offered, particularly concerning the redeployment of the *Antea*. The need for an intermediate vessel (35-40m, 15 scientists) to be deployed on the Atlantic-Mediterranean zone to carry out multi-discipline coastal campaigns and to complete the majority of scientific observation missions is nevertheless highlighted as paramount (see 1.4.3, 1.5.1, 2.1.5, 2.4.4). A sheet was sent to the MENESR to be sent to the PIA3. A more exhaustive document giving a detailed description of the expected intermediate-size vessel is offered in Appendix 8. The modernisation of the *Côtes de la Manche* (and its "jumboisation"), by installing trawling equipment and multi-beam sounders for sediments and to increase places on board, is considered a priority. An exact definition of the equipment to be installed on board should be drawn up by interacting with INSU outfitting.
- *Replacement of the Alis* (leaving the Fleet in 2025 at the latest) must be envisaged. Theoretically we are also looking at an intermediate vessel (35-40m; 15 scientists) on the Indian-Pacific zone which can work on coastal and open-sea campaigns using a variety of

equipment: trawl, skip, small ROV, etc. Based in Nouméa, the *Alis* regularly runs Physics, Biology and Geophysics campaigns in the South Pacific, from Papua New Guinea to French Polynesia. It has a notoriously small capacity, holding just 6 scientists. The specifications of this intermediate size "Pacific" vessel are also described more precisely in the document proposed in Appendix 8.

- *Ice-covered seas*: The only French ice breaker, *the Astrolabe* (or its future replacement), is not a research boat. Its use for oceanography throughout Adélie Land, subordinated to logistics for provisions at the French base at Dumont D'Urville, has always been limited due to strong logistical constraints weighing on the boat programming, leading to reduced and very occasional boat time on offer for research activities. It is also in a very limited geographic area (the coastal region of the Adélie Land). Access to a polar vessel equipped for scientific research is the essential device for quality research on the oceans and their interfaces in the Arctic and the Antarctic. It should actually be able to rely on controlled sampling strategies and programming, both for equipment deployments and recovery and for major sampling programmes and field measurements. Access devices to countries' boats equipped with polar resources are currently an on-going discussion at European and international levels (particularly for the Arctic, ARICE). They remain backup solutions and are not intended to meet the significant needs of our community at the two poles.
- *More specifically for fisheries* and the growing requirements from public services (MSFD), it is essential to envisage a new medium-sized vessel (25-30 m) allowing trawling (basket trawling and line trawling) and dragging to replace the *RV Gwen Drez* and *Thalia* to assess vertebrate and invertebrate fishery resources on coastal and shore zones (*i.e.* draught adapted to shallow water, namely less than 3.50m). This vessel should be able to hold 10 to 12 scientists and be equipped to cover other compartments as well as fishery trawling for an ecosystemic approach: CTD type vertical hydrological profiles, hydrological sampling (organic and phytoplankton matter: Niskin bottle), zooplankton sampling (WP2 and Bongo net), sampling of ichthyoplankton (MIK net), sampling of eggs (miniaturised CUFES).
- *Deep benthic open-sea area*: the long-range planning committee recommends keeping two deep-sea (6000 m) submersibles operational, HOV Nautile and ROV Victor, whose complementarity and association with the AUV 6000 (on-going production) will guarantee all types of intervention (from exploration to the observation site, see 2.1.3; Appendix 5). The HOV Nautile is a resource with added value (useful load, mobility, direct visual handling) for deep-sea interventions, perfectly complementing the ROV Victor, adapted to site-type approaches with a dedicated elevator in long dives allowing repeated measurements, sampling and video observations. **These two machines must last a long time and be developed to strengthen complementary functions for the next 20 years, not only to meet scientific needs but also to support public policy.** For example, it is recommended to think about operating the ROV Victor whilst deploying other deep-sea equipment by cable (elevator, moorings) in order to limit the mooring ballasts left on the seabed as much as possible. It also highlights the need to improve the range of physical and chemical sensors on the machines and develop digital seismic gear.

2.4.2 Develop equipment on vessels

As far as equipment on vessels in concerned, the following is emphasised:

- The importance of modernising the vessels' equipment, such as acquiring an electricity cable for surface sampling (core boring, etc.) as used to equip German vessels (such as RV

Meteor) and an optics cable for the SCAMPI in order to watch HD video in real time (new camera) and give them the chance to reach 6000m.

- Keeping the complete sampling system in good condition and developing the use of Kevlar cables as widely as possible to operate metal-free CTD Rosettes.
- Developing the feasibility of long core boring on board ocean-going and coastal vessels, an important issue for the FOF. A work group was set up to consider a study of different sampling tools, their improvement and their implementation on IFREMER vessels, and the implementation of the CALYPSO core boring on the Atalante.
- Studying the feasibility of taking systematic sea-bed mapping measurements during transits, that would optimally make up for the lack of data on deep-ocean floor planes, far from the plate borders.
- In the open-sea, and on the pelagic coast, there is a strong wish to develop the optimum use of transits and missions by setting up automated bio-optical and biogeochemical sensors connected to arrival points for clean seawater feeding the (existing) thermo-salinometers and continuous multi-analysis systems like FerryBox or Pocket FerryBox.
- Installing a water purification system that is essential for geochemical and microbiological studies and clean rooms, or at least high-performance laminar flow hoods on all vessels.
- Implementing R&D to process data and information (automation, validation, extraction of useful information, multi-scale approach) for acquisitions along the way and for the observatories.
- The SHOM also outlines needs in overseas territory for a vessel equipped with an SMF and capable of launching a shallow water hydrographical speedboat.

2.4.3 On-board equipment

Several needs for equipment and functional improvements have been proposed:

- Make existing common resources in pools last a long time and improve them with access to all these resources regardless of custodianship, with support for implementing the equipment. **The need is clearly expressed for a consolidated list of these common instruments.** This accompanies the mobilisation of budgetary resources to guarantee the quality and good working order of the common equipment over time, but also develop all tools (OBS, seismic, core drilling, physical, bio-optic, geotechnical and chemical field sensors, etc.).
- Make essential mobile equipment available for non-destructive characterisation of sedimentary core drills (equipment installed in a mobile container including: photography, spectro-colorimetry, speed, gamma-density, magnetic susceptibility, radiography, XRF scanner);
- Produce an operational multi-trace seismic system towed close to the seabed, based on the “SYSIF” prototype made in 2014, in order to infra-metrically identify the sedimentary deformations present in the surface sediments at all depths of water with unbeatable accuracy;
- Set up a remote-operated drilling device by thinking about the possibility of obtaining this type of tool within the FOF or via agreements with European partners (e.g. British Geological Survey).
- Develop these chemical sensors in situ allowing us to trace the impact of the hydrothermal flows on the water column and the development of marine ecosystems; this also implies filling gaps in instruments between sampling the hydrothermal flow - i.e. Sealed titanium syringe, PEPITO and the water column via a clean CTD Rosette.

- Purchase a wave glider for communication with seabed sites. This glider would be operated by the DT INSU.
- Standardisation of protocols between fishery and ecosystemic campaigns positively generates a pooling of instrumentation (CTD, rosette, FerryBox and Pocket FerryBox, automated bio-optical sensors, Zoocam, etc.). It would be sensible for part of the resources to be kept on board or stored by Genavir, that could partly ensure maintenance and calibration every year.
- Autonomous diving beyond 60 m (limit of autonomous open-air diving) is going to be developed leading to the need for specific safety measures (decompression chamber on board).
- In fisheries, application of ethics rules regarding euthanasia of animals for scientific purposes will be applied in the future to sampling fish during fishery campaigns. This leads to developments in observation resources in fisheries either setting up "own" euthanasia systems on board (e.g. overdosed anaesthetic baths) for direct sampling or generalisation of non-invasive observation resources (acoustic, video, eDNA) some of which still have to be invented.

2.4.4 The observatories

One important characteristic in the observatories (station networks or fixed stations, instrumented sites) is the regular return to selected geographic regions. This implies *de facto* a long-term definition of work zones and geographic mobility of vessels and machinery that can be associated with them (ROV Victor, AUVs and HOV Nautile). **Although this recurring programming imposes constraints when allocating days at sea on the French fleet vessels, acknowledgement of this need by assessment authorities represented a great step forward that must be maintained**.

Developing new tools and the need to approach the marine ecosystem as a whole (from the physical-chemical system to the biological communities) tend to develop long term observation strategies towards:

- Multidisciplinary and multi-tool approaches
- The use of heavy machinery (Nautile, Victor, multi-trace seismic gear, penetrometer)
- The use of pools of large numbers of instruments (profilers, OBS, gliders, etc.)
- Regular interventions, concerning implementing permanent observatories in coastal and open-sea pelagic areas, or in deep-sea environments (EMSO programme), for sequencing studies on a site (including PIRATA, MOOSE, OISO, SURVOSTRAL….)
- Taking automatic measurements on workshop sites (instrumented moorings), on derived machinery (floats, gliders, AUV), from on-board instruments
- Renewed interest for the coastal zone and the continent shelf with use of continuously-made automated measurements between the coast and the continental margins (and beyond)
- No chance of having SNO for INEE teams, such as for recurring campaigns that are carried out every year around Kerguelen (THEMISTO, REPCOOAI) and that cannot claim labelling, which would help them avoid having to resubmit a dossier every year.

The essential need to work on the coast-open sea intersection, particularly on the whole continental shelf in the Bay of Biscay and also out at sea in the Channel-North Sea, Celtic Seas, Mediterranean Sea (MOOSE) requires a vessel with long autonomy (20-30 days), also big enough to get through the worst weather conditions and to hold the necessary quantity of equipment for mooring maintenance operations (e.g. 5 MOOSE moorings + 2 Météofrance buoys) It is now impossible to use smaller vessels, or it would mean complicated, very expensive logistics (several stop-overs with mooring equipment despatched in the stop-over port). **The current need**

comprises a semi-ocean-going vessel equipped with suitable lifting capacity to maintain surface buoys and deep mooring lines, able to carry around 15 people.

The ocean-going research vessels are equipped with apparatus that allow on-route acquisition, broadcasting observations in real time to the Coriolis centre. The procedure is operational and must be maintained for the thermo-salinometers, hull ADCP and automatic weather stations. New sensors could be associated with it. The observation services have a high demand for the monitoring measurements that can be provided by these instruments.
In the coastal zone, or on a shallow scale, a similar action is put in place with the "Ferry-Box". Technical progress and growing interest from other disciplines in on-route measurement lead to consideration of other parameters and the extension of other parameters (pCO_2, cytometry in flux, other bio-optical measurements). Free water uptake systems are also desirable.
Maintenance on these instrumental networks is heavy-going and should be structured to guarantee the quality of the measurement and help it last over time-based series: selection of suitable platforms, choice of relevant parameters, identification of maintenance and validation teams, associated recurring credits.
This structuring could doubtlessly be expanded to opportunity vessels to carry out regular radials, often inaccessible by research vessel. These approaches, currently run by research teams, would certainly be easier if they were treated at organisation level.
In the overseas territories, the lack of national observatory should in time be made up for as these territories are particularly affected by climate change (polar and tropical zone).

2.5 Funding: days at sea, campaign preparation and post-campaign research

The general observation is that it is currently too difficult to get the necessary funding to run a campaign at sea and work on it in good conditions. Access to vessel time is obtained through projects submitted to the National Fleet Commissions (CNFs). However, the funding required to carry out a project properly is currently badly organised and random. In 2015, the Ifremer set up a support fund for campaigns with the aim of funding costs directly associated with carrying out campaigns (assignment costs, cost of transporting equipment and samples). This fund is popular, but it does not solve all the problems. Via its pre and post-campaign calls for tender, the INSU generally makes it possible to avoid cancelling the project but does not provide enough resources to finance the consolidated costs relating to data processing and sample analysis (post-campaign support is typically less than €10K per campaign). In 2016, the INSU contributed to this support fund device by reversing the sums initially attributed to pre and post campaign calls for tenders. The laboratories are obliged to jointly finance the campaign's logistics aspects and, in the absence of funding for post campaign science, the data and samples are only partially exploited. The formats of the ANR or European calls for tender are not suitable as they are out of phase with the assessment and scheduling calendar for campaigns at sea, whilst the assessment calendar was brought forward to be in phase with ANR requirements. Furthermore, there is no intermediate funding between the ANR projects and the INSU projects and above all the chronology is almost impossible to build between the CNFs and these other possible sources of funding. There is therefore no coherence between the choice of programming the campaign and making the resources available to exploit it and make good use of it. For example, calls for tender for the United Kingdom, United States and Germany fund the entire project, meaning boat days and machinery, logistics, post-campaign science and the staff (PhD students, post-docs, engineers) and in the long term (projects of ~ 4 years).

To tackle this problem, the consulted community wants the budget linked to the campaigns to be individualised within a single point of contact from the FOF by means of agreements with the ANR and the organisations, boosting exploitation of the data and samples acquired during the campaigns. It would be ideal to copy how our main international partners work (e.g. UK, Germany), providing a single point of contact comprising one or several commissions enabled to evaluate the projects in their entirety and for all disciplines using the fleet. The new FOF structure could be commissioned and these commissions could be set up to assess and completely fund projects, including post docs and contracts (favourable opinion on the research quality ➙ programming ➙ pre-campaign funding ➙ post-campaign funding).

Funding certain campaigns at sea also raises the question of public fund-private fund coordination. These projects financed by private funds are projects such as Pamela-Total (for which the INSU and university representatives participate in the COPIL) run the strict framework of the Ifremer target contract and service provision projects using the large core drill on the *Marion Dufresne* run by the IPEV. The projects linked to exploration of deep-sea mineral resources and to biodiversity studies that are tacked on, are run under inter-ministerial piloting in support of the public policy on institutional own funds and communicate for information purposes with the assessment commissions.

2.6 Needs for human support

2.6.1 Need for dedicated staff

The lack of IT staff is blatant in most disciplines and institutes due to their own recruitment policies. Within the current context of shortages, we must organise ourselves as pragmatically as possible. We would particularly like better articulation between the laboratories and the technical services. For example, in the case of instrumentation projects or certain very technical campaigns, such as observatory maintenance campaigns, putting an AUV 6000 m online, coupled with HOV Nautile and ROV VICTOR requires specific expertise for processing micro-bathymetric and imagery data and therefore staff dedicated to these tasks in order to optimise scientific data exploitation.

Campaigns that are purely dedicated to the observatories do not generally require a significant number of staff on board, **but they must be qualified**, and on the whole permanent, to ensure that data acquisition is long-lasting and high quality. The classic on-board equipment is generally enough, but there might be specific demands for lifting equipment particularly to ensure maintenance of moorings or deep instrumented sites.

However, the rise in pressure on observation services (OS) will quickly suffer from the lack of CNAP posts, that coordinate, run observation services and their scientific exploitation.

Furthermore, in the light of the ever-growing flow of data linked to the deployment of new tools (such as generalisation of the FerryBox) and the multiplication of data acquisition possibilities (such as by systematically making the most of transits between campaigns), we can also highlight the importance of appropriately increasing human resources to manage, implement and supervise data collection and do the initial data processing (in a quality approach).

The data archiving/storage/availability aims also require dedicated personnel, in order to ensure that the data acquired during oceanographic campaigns is in the public area after the moratorium periods. The same goes for the storage/archiving/access to samples of rocks, cores, fluids, organisms, after the moratorium periods.

Finally, systematically adapting fishery campaigns to an ecosystemic approach, particularly to meet the needs of the MSFD, will require certain operators to rework their on-board organisation to increase flexibility of working hours, particularly at night.

2.6.2 Need to identify one person who acts as an interface with the mission chief, on land and on sea

As far as organising campaigns is concerned, the user community is unanimous in highlighting that it is essential to have a person on-board present right from the campaign preparation meetings to (1) make it easier to transmit technical, logistics information, etc. (2) ensure continuity between preparation and carrying out operations on board and (3) ensure an effective interface between the mission leader and the technical personnel on land and on board. This refers to the need for a function, not an extra person.

This type of function would be able to anticipate and alleviate many potential logistics problems (transporting materials, getting through customs, etc.), administration issues (missions, work permit applications), or technical problems (use of equipment on board).

This kind of organisation has been implemented for several years on the *Marion Dufresne* and is preferred by the users.

2.6.3 Need for a logistics department within the fleet

Within the equipment pools and in the user community, the skills do not currently exist to effectively manage customs issues, transport of hazardous products, etc. even in relation to private service providers or via ULISSE. The time given over to these tasks is time not dedicated to other priority basic tasks such as maintenance and preparing equipment for the campaigns.

Repositioning logistics activities within the fleet would be able to create a really specialised department. This department would ensure (funding AND execution) logistics for the operator but also for the scientific teams and equipment from the instrument pools mobilised for an assignment.

This topic also looks at the question of necessary skills as departments dedicated to logistics within the IPEV will not be included in the fleet.

2.6.4 Need for a legal cell within the fleet

Setting up multi-partner projects at sea includes many legal aspects (authorisations to work in not only foreign but also French waters, setting up Nagoya protocols, establishing multi-partner contracts fixing the rights and responsibilities of each one, etc.).

Tougher environmental rules on preserving marine environments and the resulting increase in the number of marine protected areas lead to changes and significant delays in work permit application procedures, not only in foreign waters but also in French waters.

To ensure an effective response, a dedicated cell should be set up within the FOF in order to implement and monitor dossiers; the mission leader only intervenes for questions on the type of research work to be undertaken. Failing that, many regions could become or remain practically inaccessible for French teams.

2.6.5 Need for harmonisation of access to instrument pools

For the instrument pools, at this stage, restructuring the fleet is not going to develop their role and position compared to the current organisation. Nevertheless, all the equipment from these pools is intended to be put on board the FOF vessels and is therefore involved, de facto, in the FOF reorganisation. Accordingly, to ease equipment availability for FOF users, it would be advisable to have a single common interface for all instrument pools which would make it possible to visualise all the different equipment and instruments available for the community.

In fine, it is recommended to increase pooling of technical resources, or even envisage a reconciliation of certain national pools (such as OBS seabed seismometers). For example, it has been considered to include the IPEV mobile equipment intended for core boring (cutting bench, test bench, etc.) in an instrument pool available to all FOF users. There are also discussions on expanding the "long sedimentary core sampling" missions and skills for the existing 'ocean' cell of the C2FN, Centre de Carottage et de Forage National (c2fn.dt.insu.cnrs.fr).

This type of reorganisation requires human resources to be strengthened to harmonise how these pools work: setting up a common interface, ensuring development, adaptation and maintenance of equipment intended for coastal and ocean-going vessels plus their implementation at sea in open-sea campaigns.

It is therefore advisable to reinforce multidisciplinary skills in departments overseeing these pools. For example, current pools lack the skills to manage chemistry equipment. If this type of equipment must be managed in the pools in the future rather than in the labs, the corresponding skills should therefore be developed.

Furthermore, this reorganisation of the pools will simplify international collaboration by making it easier for users to lend and borrow equipment.

2.7 Expectations of IT personnel

The reorganisation of the FOF is going to have an impact on all personnel on board plus the technical departments of IFREMER, the CNRS and the IRD. Although there is no major concern on the future of agents within the current IFREMER departments involved in the FOF reorganisation, it should nevertheless be stressed that these departments are the right size for current needs from the fleet operated by GENAVIR and that these agents emphasise that, on their own, they will not be able to cover the extra work due to including new vessels in the FOF. IPEV agents and any from the CNRS allocated to the IPEV, to the DT-INSU and its equipping are particularly concerned by the FOF reorganisation. This raises a general question on the future of this personnel both in terms of career (status, salary, bonus, recovery, prospects, etc.) and on their future positions, roles and functions in the new structure. The agent annexation organisations concerned by this restructuring should make sure that the new governance quickly proposes a staff reclassification project, answers questions on how the work will be organised and makes it easier to incorporate agents from different organisms.

2.7.1 Urgency of the reorganisation

The long-range planning committee highlights the importance and the urgency of defining the new organisation of services, personnel needs, tasks to be completed (job description sheets) so that each agent can integrate the new structure with full knowledge of the facts **and that the users identify their contacts**. The committee has also perceived that in the absence of future perspectives, the personnel with whom the researchers interact closely when setting up and performing campaigns might be discouraged, which deeply worries scientists. Certain agents have already asked to change assignment. Severe malfunctions can arise if too many people leave.

As far as operations at sea are concerned, the need for a clear vision of the tasks to be carried out on board, their distribution and working conditions is very important in terms of continuing to find motivated on-board support staff. This point is even more true on the scale of CNRS agents who volunteer to work on board and find it hard to get the operational part of their work recognised in their career.

Consequently, the committee recommends that motivating perspectives are offered to the agents very quickly.

2.7.2 Best use of all FOF personnel skills

In general, it is advisable to analyse how all current services work - regardless of their annexation organisation - and to identify all skills to make the most of them and optimise organisation and completion of campaigns at sea.

For example, if there is an attempt to homogenise activities, it is likely that IFREMER will wish to install its own data acquisition, navigation software, etc. on board the CNRS vessels and on the Marion Dufresne, it would also be advisable to analyse existing software on board these vessels and identify which can be kept, integrated, maintained and developed in the IFREMER system. Thanks to being simple, effective and robust, some of this software, has actually been fully satisfactory for the user community.

2.8 Archiving data and samples and making them available

This concern is not the direct remit of FOF long-range planning, only major recommendations have been kept. The community prefers to go paperless for campaigns at sea (entering, assessment, attribution *doi*…) and the work undertaken by the BLP, the INIST and the IRD to monitor bibliographic references relating to the work of the FOF, whose results are illustrated in 1.3. Today, the recommendations focus on improving places to store and archive marine samples, particularly concerning sediment cores collected during oceanographic campaigns. They are immensely valuable, considering the very high cost of acquiring them; consequently, their storage, archiving, inventory, visibility and accessibility must be improved to become available to the whole community. The state of affairs in this matter is explained in detail in Appendix 9.

Several proposals crop up systematically:

- A single searchable website grouping together all the metadata that is accessible to the whole national scientific community, regardless of custodianship (see Cybercaro-library started by the Equipex CLIMCOR, BDD Bigood website, MNHN website, SEANOE by Ifremer).
- Setting up a moratorium (2 years that can be extended to 4 years) during which access is reserved for campaign participants and their staff, before being opened up and providing access to the scientific community. The data should be uploaded (with protected access) as quickly as possible after each campaign in order to allow automatic public availability at the end of the moratorium period.
- An improvement of places to store and archive marine samples, particularly concerning sediment cores collected during oceanographic campaigns. They are immensely valuable, considering the very high cost of acquiring them; consequently, their storage, archiving, inventory, visibility and accessibility must be improved to become available to the whole community.
- Putting complete campaign reports on-line, even back-dated.
- Recovery and uploading of data from post-moratorium campaigns (bathymetry, gravimetry, seismic, etc.) and under restricted access for data in the moratorium period.
- The constraint to link campaign programming and its funding regarding making data available, even back-dated.

3. Quoted References

Andreani, M., Escartin, J., Delacour, A., Ildefonse, B., Godard, M., Dyment, J., Fallick, A.E., Fouquet, Y., 2014. Tectonic structure, lithology, and hydrothermal signature of the Rainbow massif (Mid-Atlantic Ridge 36º14'N), Geochem. Geophys. Geosyst.,15, 3543–3571, doi:10.1002/2014GC005269.

Babonneau, N., Cattaneo, A., Ratzov, G., Déverchère, J., Yelles-Chaouche, A., Lateb, T., Si Bachir, R., 2016. Turbidite chronostratigraphy off Algiers, central Algerian margin: A key for reconstructing Holocene paleoearthquake cycles. Marine Geology. Special issue, doi:10.1016/j.margeo.2016.10.017

Cannat, M., Sauter, D., Escartı´n, J., Lavier, L., Picazo, S., 2009. Oceanic corrugated surfaces and the strength of the axial lithosphere at slow spreading ridges. Earth Planet. Sci. Lett. 288, 174–183.

Chaalali A., Beaugrand G., Boët P., Sautour B., 2013. Climate-Caused Abrupt Shifts in a European Macrotidal Estuary. Estuaries and Coasts, 36 (6), 1193-1205. doi:10.1007/s12237-013-9628-x

Da-Allada, C.Y., du Penhoat, Y., Jouanno, J. et al. 2014. Modeled mixed-layer salinity balance in the Gulf of Guinea: seasonal and interannual variability. Ocean Dynamics, 64: 1783. doi:10.1007/s10236-014-0775-9

Da-Allada, Y.C., Alory, G., du Penhoat, Y., Kestenare, E., Durand, F., Hounkonnou, N.M., 2013. Seasonal mixed-layer salinity balance in the Tropical Atlantic Ocean: mean state and seasonal cycle. J Geophys Res Oceans 118(1):332–345. doi:10.1029/2012JC008357

Driussi, O., Maillard, A., Ochoa, D., Lofi, J., Chanier, F., Gaullier, V., Briais, A., Sage, F., Sierro, F., Garcia, M., 2015. Messinian Salinity Crisis deposits widespread over the Balearic Promontory: insight from new high-resolution seismic data, Marine and Petroleum Geology, 66, 41-54

Escartín, J., Mével, C., Petersen, S., Bonnemains, D., Cannat, M., Andreani, M., Augustin, N., Bezos, A.. Chavagnac, V., Choi, Y., Godard, M., Haaga, K., Hamelin, C. Ildefonse, B., Jamieson, J., John, B., Leleu, T., MacLeod, C.J., Massot-Campos, M., Nomikou, P., Olive, J.A., Paquet, M., Rommevaux, C., Rothenbeck, M., Steinfuhrer, A., Tominaga, M., Triebe, L., Campos, R., Gracias, N., Garcia, R., 2017. Tectonic structure, evolution, and the nature of oceanic core complexes and their detachment fault zones (13°20'N and 13°30'N, Mid Atlantic Ridge), G-cubed, in press, doi 10.1002/2016GC006775, 2017.

Escartín, J., Leclerc, F., Olive, J., Mével, C., Cannat, M., Petersen, S., Augustin, N., Feuillet, N., Deplus, C., Bezos, A., Bonnemains, D., Chavagnac, V., Choi, Y., Godard, M., Haaga, K.A., Hamelin, C., Ildefonse, B., Jamieson, J.W., John, B.E., Leleu, T., Macleod, C.J., Massot-campos, M., Nomikou, P., Paquet, M., Rommevaux-jestin, C., Rothenbeck, M., Steinführer, A., Tominaga, M., Triebe, L., Campos, R., Gracias, N., Garcia, R., Andreani, M., Vilaseca, G., 2016. First direct observation of coseismic slip and seafloor rupture along a submarine normal fault and implications for fault slip history. Earth Planet. Sci. Lett. 450, 96–107, doi: 10.1016/j.epsl.2016.06.024, 2016.

Goberville, E., Beaugrand, G., Sautour, B., Tréguer, P., SOMLIT Team, 2010. Climate-driven changes in coastal marine systems of Western Europe. Marine Ecology Progress Series 408, 129–147. doi : https://doi.org/10.3354/meps08564

Gottschalk J., Vázquez Riveiros N., Waelbroeck C., Skinner L.C., Michel E., Duplessy J.-C., Hodell D., Mackensen A., 2016. Carbon isotope offsets between benthic foraminifer species of the genus Cibicides (Cibicidoides) in the glacial sub-Antarctic Atlantic. *Paleoceanography*, **31(12)**, 1583-1602, doi:10.1002/2016PA003029

Landschützer P., Gruber N., Haumann F.A., Rödenbeck C., Bakker D.C.E., Van Heuven S., Hoppema M., Metzl N.,Sweeney C., Takahashi T., Tilbrook B., Wanninkhof R., 2015. The reinvigoration of the Southern Ocean carbon sink. Science: Vol. 349, Issue 6253, pp. 1221-1224 DOI: 10.1126/science.aab2620

Leclerc, F., Feuillet, N., Deplus, C., 2016. Interactions between active faulting, volcanism, and sedimentary processes at an island arc: Insights from Les Saintes channel, Lesser Antilles arc. Geochemistry Geophysics Geosystems, v. 17, no. 7, p. 2781-2802.

Le Quéré et al., 2015. Global Carbon Budget 2015. Earth Syst. Sci. Data, 7, 349-396. doi:10.5194/essd-7-349-2015

Leroy S., Razin, P., Autin, J., Bache, F., d'Acremont, E., Watremez, L., Robinet, J., Bellahsen, N., Lucazeau, F., Rolandone, F., Rouzo, S., Serra Kiel, J., Robin, C., Guillocheau, F., Tiberi, C., Basuyau, C., Beslier, M.A., Ebinger, C., Stuart, G., Ahmed, A., Khanbari, K., Al Ganad, I., de Clarens, P., Unternehr, P., Al Toubi, K., Al Lazki, A., 2011. From rifting to oceanic spreading in the Gulf of Aden: a synthesis. Arab J Geosciences, 5:859–901.

Lienart C., N. Savoye, Y. Bozec, E. Breton, P. Conan, Va. David, E. Feunteun, K. Grangeré, P. Kerhervé, B. Lebreton, S. Lefebvre, S. L'Helguen, L. Mousseau, P. Raimbault, P. Richard, P. Riera, P.-G. Sauriau, G. Schaal, F. Aubert, S. Aubin, S. Bichon, C. Boinet, L. Bourrasseau, M. Bréret, J. Caparros, T. Cariou, K. Charlier, P. Claquin, V. Cornille, A.-M. Corre, L. Costes, O. Crispi, M. Crouvoisier, M. Czamanski, Y. Del Amo, H. Derriennic, F. Dindinaud, M. Durozier,V. Hanquiez, A. Nowaczyk, J. Devesa, S. Ferreira, M. Fornier, F. Garcia, N. Garcia, S. Geslin, E. Grossteffan, A. Gueux, J. Guillaudeau, G. Guillou, O. Joly, N. Lachaussée, M. Lafont, J. Lamoureux, E. Lecuyer, J.-P. Lehodey, D. Lemeille, C. Leroux, E. Macé, E. Maria, P. Pineau, F. Petit, M. Pujo-Pay, P. Rimelin-Maury, E. Sultan, 2017. Dynamics of particulate organic matter composition in coastal systems: a spatio-temporal study at multi-systems scale. In press. Progress in Oceanography. http://dx.doi.org/10.1016/j.pocean.2017.03.001

Magalhães, L., Freitas, R., Dairain, A., De Montaudouin, X., 2016. Can host density attenuate parasitism? Journal of the Marine Biological Association of the United Kingdom, 1-9. doi:10.1017/S0025315416001107

Maia, M., Sichel, S., Briais, A., Brunelli, D., Ligi, M., Ferreira, N., Campos, T., Mougel, B., Brehme, I., Hémond, C., Motoki, A., Moura, D., Scalabrin, C., Pessanha, I., Alves, E. Ayres, A., Oliveira, P., 2016. Extreme mantle uplift and exhumation along a transpressive transform fault. Nature Geoscience doi:10.1038/ngeo2759.

Pailler K., Bourlès B., Gouriou Y., 1999. The Barrier Layer in the Western Tropical Atlantic Ocean. Geophysical Research Letters, 26: 2069-2072.

Rouby D, Braun, J., Dauteuil, O., Deschamps, F., Robin, C., 2013. Vertical movement of passive margins: interactions between surface transfer, flexural isostasy and 3D thermal subsidence. Tectonophys. 604, 83-103.

Sauter, D., Cannat, M., Rouméjon, S., Andreani, M., Birot, D., Bronner, A., Brunelli, D., Carlut, J., Delacour, A., Guyader, V. MacLeod, C.J., Manatschal,G., Mendel, V., Ménez, B., Pasini, V., Ruellan, E., Searle, R., 2013 Continuous exhumation of mantle-derived rocks at the Southwest Indian Ridge for 11 million years. Nature Geoscience 6, 314–320 (2013) doi:10.1038/ngeo1771

Singh, S.C., Hananto, N., Mukti, M., Robinson, D.P., Das, S., Chauhan, A., Carton, H., Gratacos, B., Midnet, S., Djajadiharja, Y., Harjono, H., 2011. Aseismic zone and earthquake segmentation associated with a deep subducted seamount in Sumatra. Nature geoscience, v. 4, p. 308–311, DOI: 10.1038/NGEO1119.

Singh, S.C., Hananto, N., Qin, Y., Leclerc, F., Avianto, P., Tapponnier, P.E., Carton, H., Wei, S., Nugroho, A.B., Gemilang, W.A., Sieh, K., Barbot, S., 2017. The discovery of a conjugate system of faults in the Wharton Basin intraplate deformation zone. Science Advances, v. 3, no. 1, p. e1601689, doi: 10.1126/sciadv.1601689.

Szafranski K.M., Piquet B., Shillito B., Lallier F.H., Duperron S., 2015. Relative abundances of methane- and sulfur-oxidizing symbionts in gills of the deep-sea hydrothermal vent mussel *Bathymodiolus azoricus* under pressure. Deep - Sea Res. I – Oceanogr. Res. Papers, 101: 7-13. Doi : 10.1016/j.dsr.2015.03.003

Testor P., Bosse, A., Houpert, L., Margirier, F., Mortier, L., Legoff, H., Dausse, D., Labaste, M., Karstensen, J., Hayes, D., Olita, A., Ribotti, A., Heslop, E., D'Ortenzio, F., Mayot, N., Lavigne, H., de Fommervault, O., Coppola, L., Prieur, L., Taillandier, V., Durrieu de Madron, X., Bourrin, F., Many, G., Damien, P., Estournel, C., Marsaleix, P., Taupier-Letage, I., Raimbault, P., Waldman, R., Bouin, M.N., Giordani, H., Caniaux, G., Somot, S., Ducrocq, V.,,Conan, P.,

Van Beveren E., Bonhommeau S., Fromentin, J.M., Bigot J.L., Bourdeix J.H., Brosset P., Roos D., Saraux C. 2014. Rapid changes in growth, condition, size and age of small pelagic fish in the Mediterranean. Marine Biology 161: 1809-1822.

Waelbroeck C., Skinner L.C., Labeyrie L., Duplessy J.-C., Michel E., Vazquez Riveiros N., Gherardi J.-M., Dewilde F., 2011. The timing of deglacial circulation changes in the Atlantic. Paleoceanography, DOI: 10.1029/2010PA002007