
# A changing ocean

## 2012-2014 report

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# EXECUTIVE SUMMARY

The **cluster of excellence LabexMER** was created in November 2011 in the framework of the French "investments for the future" program. It brings together 13 laboratories from the West of France, most of which are located in Brest (France). This nine years project aims to guarantee the excellence of our research in the field of marine sciences, and to increase our international visibility on a long term basis.

Five programs have been implemented to achieve the objectives of LabexMER.

**Research axes** aim to develop original projects, bringing together different disciplines, time or space scales and approaches in order to better understand the functioning and evolution of the ocean and coastal zones. At least two laboratories participate in each axis, their complementary expertise leading to truly interdisciplinary projects that address fundamental questions "at the frontier". These projects seek to overcome conceptual or technical obstacles in a better way than could be achieved in conventional projects.

The research axes are the heart of LabexMER. Their impact is strengthened by the other programs of LabexMER. The **international chairs program** aims at attracting the best worldwide experienced researchers, bringing new skills to research axes. To date, three international chairs are currently active and two others will begin shortly. An ambitious **international post-doctoral fellowship program** is designed to attract the brightest young researchers in LabexMER. So far, 14 post-docs have been recruited in the international fellowship program. Since 2012, LabexMER initiated 20 post doctoral positions (some are also funded by the chairs or the research axes), and not less than 35 PhD students (mostly granted through additional funds leveraged from the Brittany Region). LabexMER also supports research at sea, through a program that aims at providing opportunities to bring added value to existing open-ocean or coastal cruises, or to propose original work at sea.

Ensuring the excellence of research over the long term implies to invest in **Higher education and Training**. The LabexMER training program helps to organize thematic schools (3 since 2012), and co-funds workshops, conferences or short courses (ca. 15 events from 2012) designed to benefit master and PhD students. This program also allows local students to gain international experience, or to welcome foreign students, through a specific call for incoming/outgoing international mobility. Moreover, this program also invests in educational innovation: support for a "University at sea", new course on science and society issues, promotion of innovative teaching based on the new technologies of information. Finally, as the best way to promote education is to teach the teachers, LabexMER created a yearly "marine science university" for secondary school teachers.

LabexMER is now at the beginning of its fourth year of existence, and has already led to major achievements. Its creation has been a major turn that strongly impacted the whole LabexMER scientific community. With the new international chairs, post-docs and Ph.D. students and the strengthening of international networks initiated during the first phase, this impact should not only grow in the coming years, but should pave the way for major scientific advances and establish the LabexMER community as a key player in the field of marine science worldwide.

# OBJECTIVES AND STRUCTURE OF LABEXMER

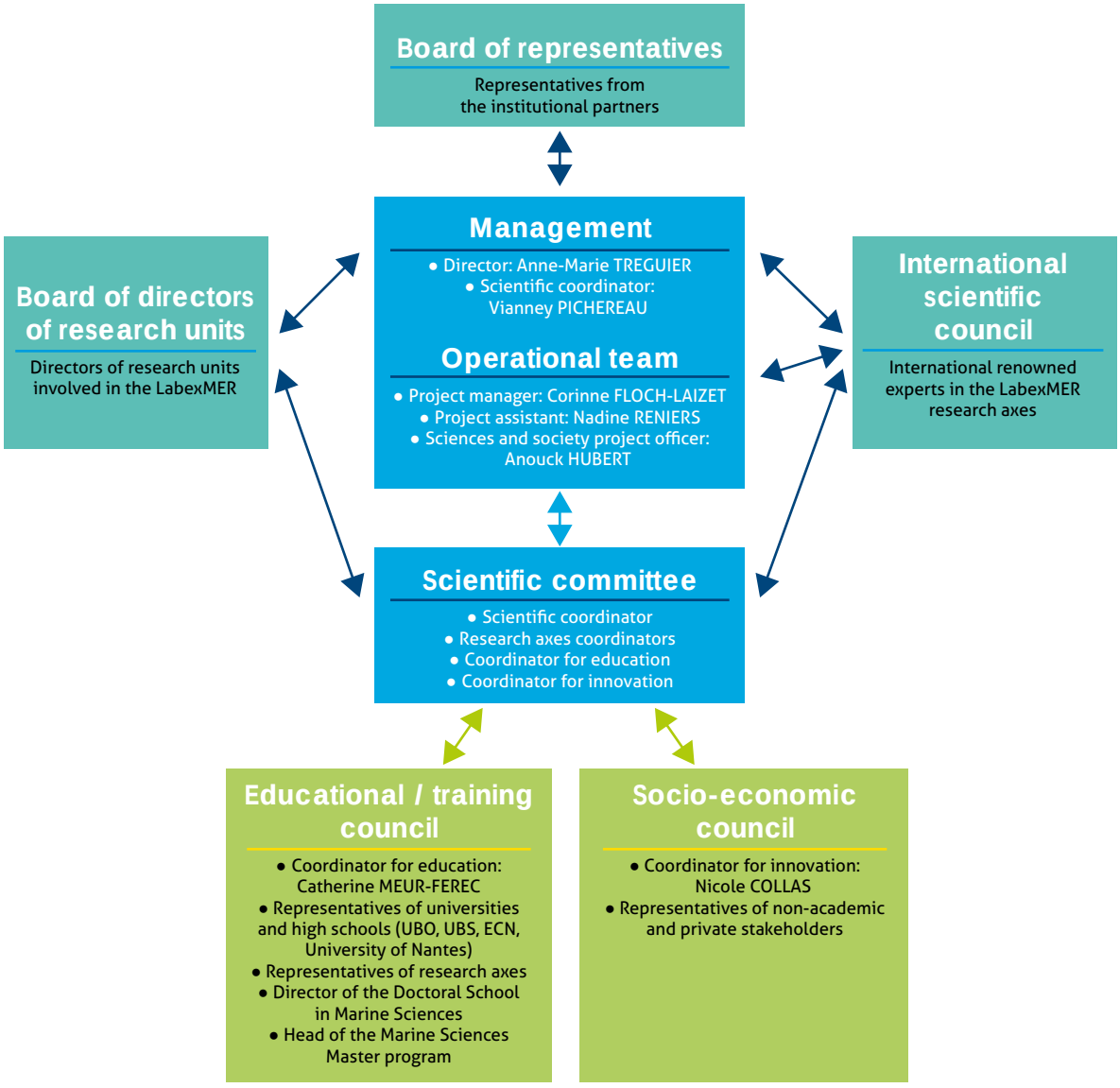
LabexMER is a cluster of Excellence («Labex») funded by the French «Investment for the future» program launched in 2011. LabexMER is a consortium that combines the best research teams and laboratories in marine sciences in western France, and has the great ambition to propell them as one of the international leaders in this field. LabexMER is coordinated by the Institute of Marine Studies (IUEM), and includes its 7 research units. LabexMER also includes 5 laboratories from Ifremer (French Research Institute for the exploitation of the sea), and one from the ECN (Ecole Centrale de Nantes) Engineering school. LabexMER gathers scientists from different laboratories and disciplines, all looking in the same direction and driven by the same eagerness to understand the functioning and evolution of the ocean.

The expected outcomes of labex projects are (i) to increase the excellence and international visibility of research within its laboratories, (ii) to ensure the excellence of education, especially at the PhD and master levels, and (iii) to create new synergies within their community. In order to reach these objectives, the LabexMER is organized into 5 programs:

- **Development of seven research axes**, to answer fundamental scientific questions. Axes were built on at least two LabexMER laboratories, and proposed a project aiming at advancing knowledge in a key area and/or bring in new international expertise through visiting fellowships and/or supporting the development of new techniques. Each axis received a seed funding which should be used to leverage more funding from various agencies;
- **The international chairs program**, to attract key competences that are currently missing in the Labex to tackle new high-profile scientific questions. These chairs also aimed at building bridges between the axes;
- **The international postdoctoral fellowship program**, to attract the brightest young scientists who wish to develop their own research project in relation with the LabexMER axes;
- **The educational/training program**, to promote innovative training, and strengthen the international visibility of marine sciences education in Brest. Amongst other initiative, this program invests in supporting the international mobility of master and PhD students, as well as the organization of summer schools, workshops and courses;
- **Support for research at sea**: an internal call is issued each year to fund small projects providing a strong added value to sea cruises.

Synergy between the research axes is developed through the international chairs, the organization of international schools and workshops jointly organized by two axes or more, and also by developing scientific exchanges involving the invited scientists and local students. A specific call has been devoted to inter-axes initiatives.

The project covers the 2012-2019 period, and is organized in two phases (2012-2015, and 2016-2019). After the first 3 years of existence, LabexMER is currently at the end of its first phase. This document presents a synthesis of the actions of each program, and the main achievements during the first three years. This document was prepared in the context of the evaluation of the program by its funding agency, the ANR (Agence Nationale de la Recherche), evaluation which will be held in June 2015. It provides a strong basis to prepare the second phase.

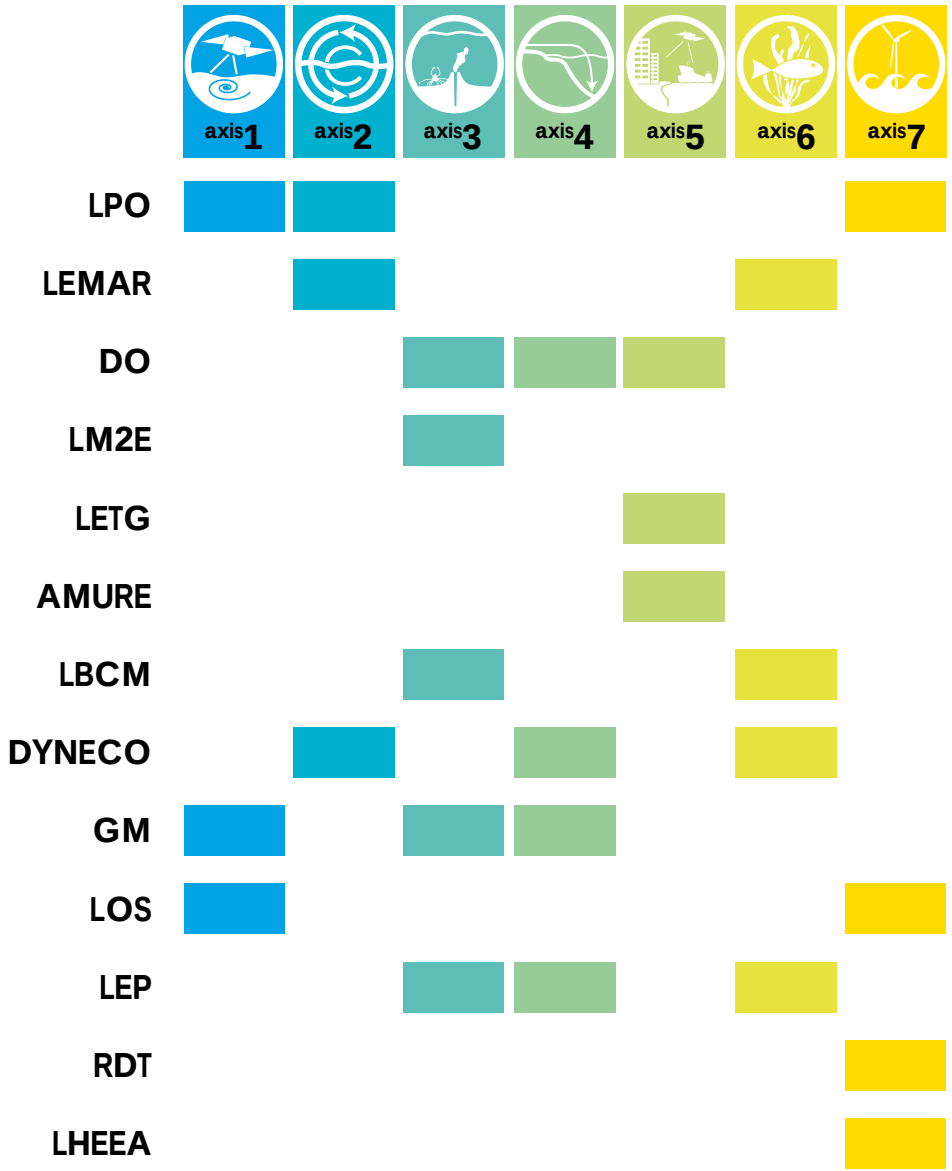



**Governance structure of LabexMER**

The project is managed by the director of IUEM (Y.M Paulet, then A.M. Treguier since August 2014) and the scientific coordinator (A.M. Treguier, and now Vianney Pichereau). Catherine Meur-Ferrec has recently replaced Annie Cudennec as the head of the LabexMER training program. She is also in charge of the marine sciences master program at IUEM.

# EVOLUTIONS IN LABEXMER DURING THE FIRST PERIOD

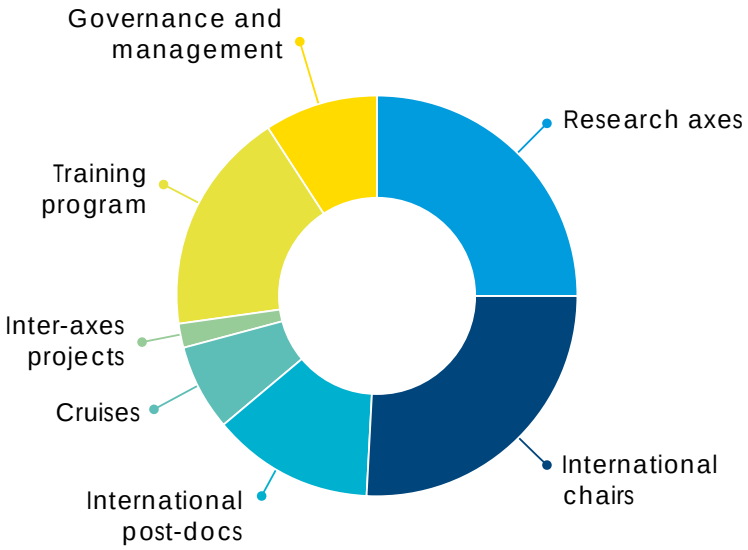
During the first phase, two new research units joined the LabexMER: AMURE and RDT. AMURE is a joint unit between UBO and Ifremer, which develops a top-quality research in the fields of economics and maritime law. This unit joined the LabexMER in 2012, as a partner of axis 5. The integration of RDT is more recent (2014). RDT is an Ifremer unit specialized in instrumentation and technology development, which will be involved in axis 7 and 3.




**Participation of laboratories in the research axes**

# RESOURCES

The total budget granted to LabexMER is 11M€. Most of this allocation (73%) has been devoted to actions for research, ie. Research axes, international chairs and post-doc fellowship programs, sea cruises, and promotion of inter-axes projects. 18% were dedicated to the educational and training program, and 9% for the governance and management costs.




**LabexMER budget breakdown**

The LabexMER was officially launched on November 5th, 2011. It was split in two four-years phases. The bugdet distribution is the following:

| | Phase 1 : 2012-2015 | Phase 2 : 2016-2019 | TOTAL (k€) |
|---|---|---|---|
| **Training program** | **960** | **960** | **1920** |
| **Research axes** | **1400** | **1400** | **2800** |
| **International Chairs** | **2880** | | **2880** |
| **International post-docs** | **700** | **700** | **1400** |
| **Research at sea** | **400** | **400** | **800** |
| **Governance** | **290** | **290** | **580** |
| **Management costs (4%)** | **210** | **210** | **420** |
| | | | **11000** |

## Significant co-funding from the Brittany region

LabexMER benefits from co-funding from various sources, the most significant is from the Brittany Regional Council. During the first phase, it supported the post-doctoral program (600 k€) and provided a co-funding of 1M€ to complement Ifremer and UBO Ph.D. grant programs in support of LabexMER.

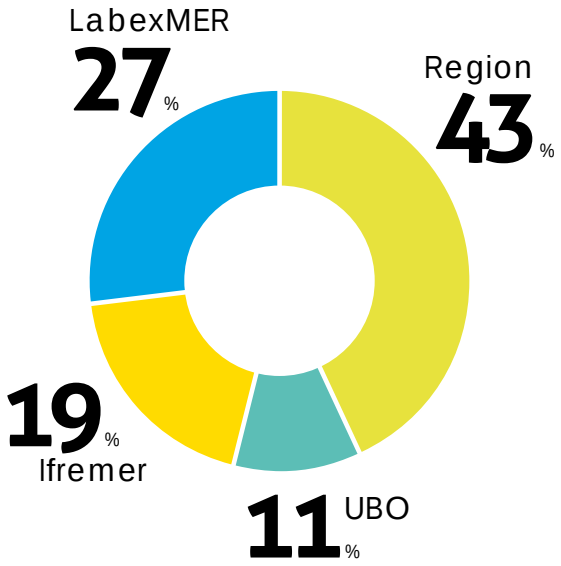
# INTERNATIONAL ATTRACTIVENESS

*The international post-doctoral and Chairs programs are pivotal for the accomplishment of the international attractiveness objective of LabexMER. Both programs aim at attracting the best international researchers in LabexMER laboratories, to develop original projects in the fields of the research axes.*

## INTERNATIONAL POST-DOCTORAL FELLOWSHIPS

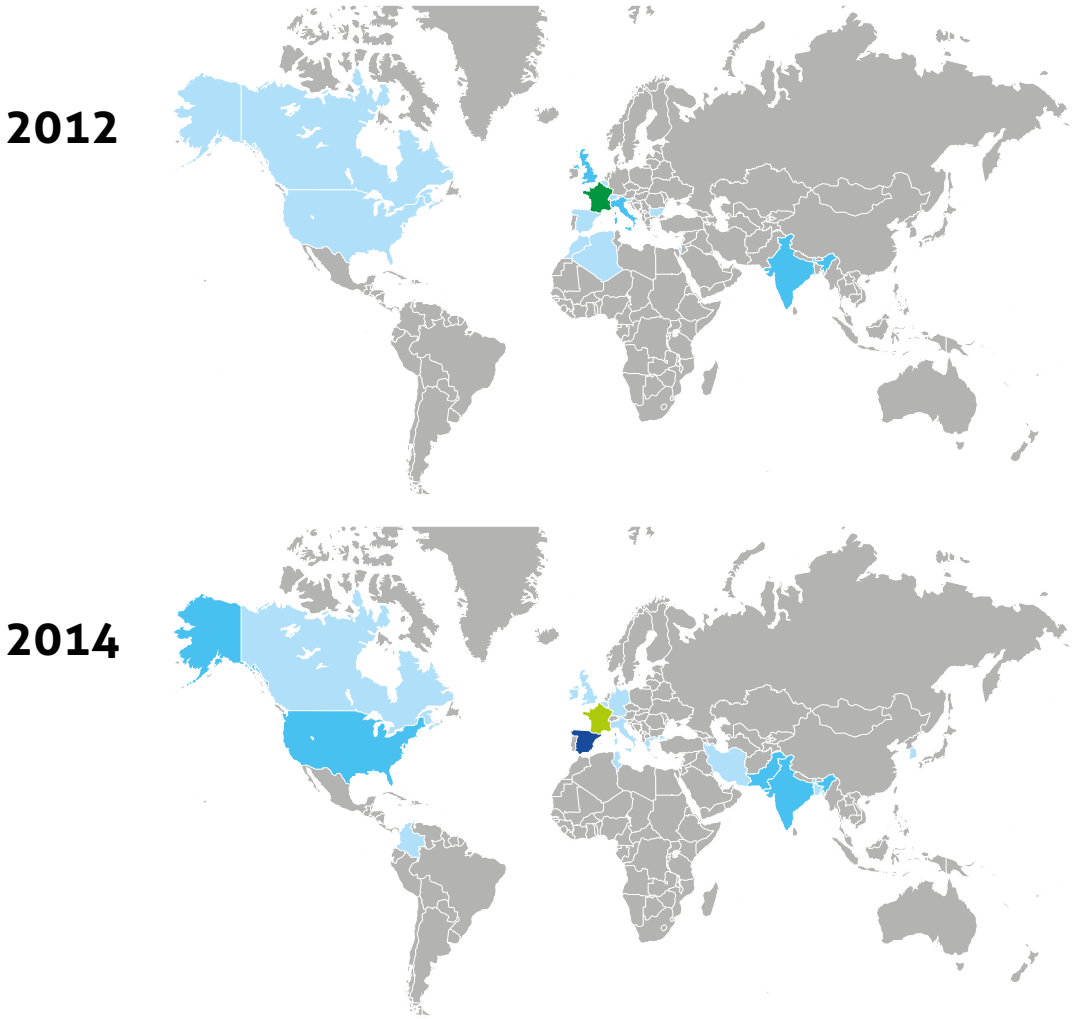
A major objective of LabexMER was to set-up an attractive fellowship program for the brightest and the most creative young international scientists. This has been made possible by pooling resources from the regional council of Brittany, Ifremer, the University of Brest, and LabexMER funding.

The existing fundings for post-doctoral researchers in France is generally targeted on very specific projects that do not leave enough opportunities for independent research and creative ideas. To overcome this problem, the LabexMER partners have created a new post-doctoral program. It is inspired by successful similar programs such as the U.S. NOAA Climate Change and Global Change post-doctoral program, or WHOI post-doctoral fellowship. Recipients of the awards receive a net salary of about 2,200€ per month for two years. In addition, support is available for travel expenses, equipment, and supplies (5k€ per year).




Total budget for 14 post-docs : 1526 k€
Région Bretagne co-funding: 600 k€
LabexMER : 508 k€

5 two-year fellowships awarded in 2013, 4 in 2013, 5 in 2014. Each year, one of the fellows is first recruited by Ifremer for 18 months and then by UBO for 6 months.




## Recruitment procedure

Eligible applicants must have received their doctoral degree within the past 3 years. Since this program is targeted for international young scientists, applicants holding a French doctoral degree are eligible for the award only if they demonstrate extensive international research experience acquired during or after their PhD. The competitive awards are designed to further the education and training of the applicant with primary emphasis placed on the individual's research promise and relevance to LabexMER research Axes. In order to apply, candidates must identify and contact a researcher («sponsor») in the LabexMER research units, and propose their own research project in marine sciences (within the LabexMER research axes) to be carried out in collaboration with the sponsor, who ensures the feasibility of the project. Candidates are selected by a jury composed of research axes representatives. Olivier Rouxel (Ifremer) headed the jury for the period 2012-2014. The postdoctoral appointment is for a period of two years and can be initiated at any time after notification of the award and before March 31st of the year following the notification of the award.

About 30 applications have been received each year. The comparison between the nationality of the candidates in 2012 and 2014 shows an increased international attractiveness of the program (13 French candidates in 2012 (44%), as compared to 6 in 2014 (20%)). The first three cohorts allowed to recruit 14 fellows.

## Key figures

**14** Young researchers

**7** Men **7** Women

**10** are not of ~~FRENCH~~ nationality

**12** obtained their **PhD** in another country

**9** **peer reviewed** publication/person on average (at the time of their recruitment)

## Research project


**3 fellowships**: ocean acidification and trace metal sensitivity; complex ecosystem modelling; iron and manganese co-impacts in marine environments


**1 fellowship**: isotopic signatures of Fe and Mo as tracers of limitations in marine ecosystems


**2 fellowships**: deep sea meiofauna; genomics of symbiotic deep-sea organisms


**2 fellowships**: interactions between climate, weathering and humans; South East African past climate from sedimentary fluxes


**1 fellowships**: storm effects on sediment fluxes


**4 fellowships**: behaviour and energetics of benthic organisms; adaptability to climate change; predicting fish-plancton interactions; origin, transport and fate of carbon in the Guiana mangrove.


**1 fellowship**: swell dissipation and dispersion

## Highlights

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### Stefan Lalonde

Stefan obtained his PhD in geochemistry in Canada in 2010. He joined LabexMER in 2012, and has developed a project on the isotopic signatures of Fe and Mo, a topic at the interface of research axes 2 and 3. He pursued his work on paleo-oceans, addressing questions such as the rise of atmospheric oxygen. Between 2013 and 2014, he co-authored 11 publications including 1 in the journals Proceeding of the National Academy of Sciences of the USA (PNAS) and 1 in Nature Geosciences. In 2015, he is the leading author of another article in PNAS («benthic perspective earliest evidence of the Earth for oxygenic photosynthesis», PNAS 2015). Stefan is one of the most promising young scientists of his generation, and he will now be able to develop his research on the long term within a LabexMER laboratory. Indeed, only one year after he joined the international post-doctoral program of LabexMER, he was hired as a permanent CNRS researcher in the laboratory Domaines Océaniques (DO).

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### Daniela Zeppilli

Daniela received her PhD in Italy in 2010, and joined LabexMER in 2012, to explore the colonization and ecological connectivity of meiofauna in extreme environments. Meiofauna (organisms of size between 45µm and 1mm) is one of the fundamental components of benthic communities and is characterized by a high abundance and diversity, fast turnover rates, and occupies a key position in the food web. Daniela has been very active to develop the study of this specific compartment in LabexMER. She organized an international workshop in Brest, Meioscool2013, which attracted the best international researchers in this field. She is editor of a special issue of the journal «Marine Biodiversity», that will be published in June 2015. Daniela received in 2014 the L'Oréal-UNESCO prize for Women in Science, awarded by a jury chaired by the president of the French Academy of Sciences.

# INTERNATIONAL CHAIRS

The main objective of the International Chairs program is to attract the best international researchers with skills essential for the implementation or the projects of LabexMER research axes. To date, four International Chairs have been recruited, 3 of which have started. An international announcement describing the expected scientific objectives has been advertized, followed by a rigorous selection and an interview of candidates. Each chair benefits from a LabexMER funding of 300 to 600k€ for three years, depending on the available co-funding. This funding includes the salary of the chair holder.

The first International Chair in Evolutionary Ecology aims at reinforcing the themes developed in axis 6. It is held by a junior researcher, Flavia Nunes, who started in late 2012. The second chair started in october 2014. It is held by an experienced researcher, Linwood Pendleton, specialized in Marine Ecosystem Services. This chair was initiated by axis 5 but it will cover a wide range of topics related to the deep-sea environment, acidification or ecosystem services of great interest to other axes. The third chair is held by Aradhna Tripati, who will develop stable isotopes geochemistry, and will bring LabexMER research to an unprecedented level in the fields of paleo-climate and paleo-oceanography (mainly covered by axes 3 and 4).

## International Chair in Evolutionary Marine Ecology

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**Flavia Nunes**

Flavia Nunes is a young researcher who obtained her PhD in 2009 at Scripps institute of Oceanography (UCSD), and then held two post-doctoral positions in Europe. Her previous work on coral evolution, biodiversity and population connectivity has led to papers in outstanding journals such as Nature and Molecular Ecology. For LabexMER, she is developing an original project that aims at examining the mechanisms of acclimation and adaptation of marine organisms and populations to global changes. In this context, she combines in vivo and in vitro experimentation to the study of natural populations, using the latest genomic tools based on next-generation DNA sequencing (eg., RNASeq, RADSeq) together with classical ecophysiological studies, to perform truly integrative studies on the following themes:

- Effects of thermal stress and Ocean acidification on the larval development of marine molluscs, including genetic and non-genetic transgenerational effects of these stressors;
- Adaptation and acclimatization of the reef-building worm, Sabellaria alveolata, to temperature and a changing climate;
- Disease resistance in natural populations of the European abalone, Haliotis tuberculata;
- Smaller projects on symbioses and population connectivity, on various model organisms (projects for which she leveraged additional funding).

In the framework of this project, she recruited two international two-years post-docs (Anna Muir and Ewan Harney), one PhD student and four master students. She has federated a strong collaborative network at the local- (between LEMAR and Dyneco, but also with the local hatchery industry), national- (MNHN, Univ. Perpignan) and international- (with several researchers from D, BR, MO, UK) levels. In addition, she has organized a series of workshops in evolutionary ecology that has stimulated interactions among the regional scientific community. After two years, her team has gathered an impressive amount of new knowledge and several publications are now being submitted.

## International Chair in Marine Ecosystem Services

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### Linwood Pendleton

Until September 2014, L. Pendleton occupied a Senior Scholar permanent position at the University of Duke, USA. He has a strong record of achievements and distinctions, and worked as NOAA's chief economist. He has co-authored more than 40 peer-reviewed international publications, including 2 in the world reference journal Nature. After a first stay in 2014 as a LabexMER visiting professor in Brest, he was recruited in October 2014 as the LabexMER International Chair of Excellence for Marine Ecosystem Services within the AMURE laboratory. He is gathering a new research team which goal is to develop the use of ecosystem services theoretical framework and data to improve the management of coastal and marine areas. This includes the following projects (with associated co-funding):

- Using Impact Analyses and the Vulnerability Framework to understand the impact of Ocean Acidification on human communities (paper forthcoming in Nature Climate Change);
- Applying an Ecosystem Services Approach to Marine Management (VALMER);
- Blue Forests and Blue Carbon: $435,000 from the Global Environmental Facility;
- Extra-Local Ecosystem Services, 63,250€ from the Mapping Ocean Wealth Program;
- Combining Earth Observations and Ecosystem Data to Monitor the Impact of Protected Areas on Ecosystem Services: 350,000€ from the European Commission's H2020 program.

## International Chair in Stable Isotope Geochemistry

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### Aradhna Tripati

A. Tripati is a young scientist (35y old) who already displays an exceptional and impressive list of major achievements. She co-authored 50 publications, including exceptional issues published in the world leading scientific journals (eg. 5 in Science, 3 in Nature, Nature Com. or Nature Geo., 2 in PNAS), making her one of the leading worldwide scientist in the field of stable isotopy. She has started her work within the LabexMER in January 2015. During the next three years, she will spend part of her time in Brest while keeping her Assistant Professor position at UCLA (USA).

The fields of paleoclimate and paleoceanography have the potential to undergo a period of growth over the next two decades that is fostered by technological innovations. The project of A. Tripati will focus on the application of new tools that allow to visualize the evolution of conditions on land and in the oceans with clarity, in order to probe climatic and diagenetic processes. In concert with geochemists, geologists, oceanographers, stratigraphers, dynamicists, and modellers, A. Tripati is engaging in a number of collaborative projects that span the entirety of the geologic record – from the Archean to the Last Ice Age. Specifically the chair is used to develop techniques including the barium/calcium proxy for river outflow, the magnesium/calcium and clumped isotope proxies for temperature, the boron isotope proxy for seawater pH, and molybdenum isotope proxy for paleo-redox.

# RESEARCH AXES

The Scientific Core of LabexMER is organized in seven research axes, each bringing together members of at least two laboratories, creating truly interdisciplinary teams which aim at answering fundamental questions about the functioning of ocean at different scales. The first two axes focus on the understanding of the global Ocean, by tackling two questions:

- the role of small scales in energy transfer in the Ocean,
- the influence of the quality of organic matter and food web complexity in carbon transfer from the productive zone.

Axes 3 and 4 focus on questions relating to the deep Ocean, to:

- improve knowledge on geobiological interactions in extreme environments, and foresee reasonable use of their resources,
- understand and quantify the impact of factors (continuous or extreme) on the transfer of matter from continents to the depths of the Ocean.

Axes 5 to 7 focus on the functioning of the coastal Ocean:

- to build models of interactions between nature and societies' dynamics in order to produce reliable scenarios illustrating the evolution of the continental interface,
- to analyse, model and simulate the evolution of marine biodiversity in order to advance prediction, conservation and restoration tools for marine habitats,
- to model fluid-structure interaction in the coastal environment.

During the first phase, each research axis received a seed funding of 200 k€. Axes developed many initiatives to reach their goals, such as:

- recruiting researchers,
- inviting foreign researchers,
- organization of workshops and thematic schools (in association with the educational program or independently), thus allowing to build new – or strengthen existing – international collaborative networks.

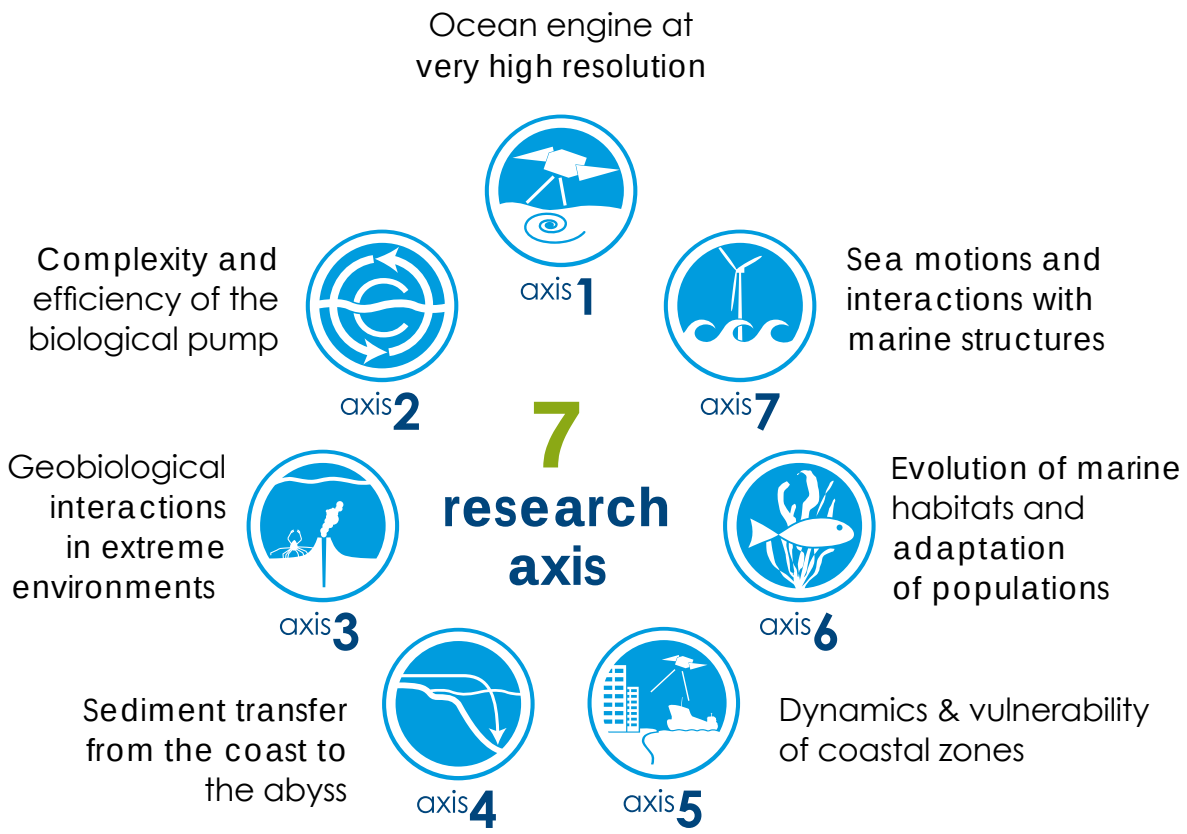
Several axes have also taken the initiative to fund small risky projects opened to the LabexMER community, to address essential questions in relation to their core project. It is noteworthy that this kind of risky projects is not easily funded by classical calls, and in some cases could leverage bigger projects. In addition, it led to increased appropriation of the specific objectives of LabexMER by the whole community.

The axes projects aim at pushing the frontiers of knowledge beyond its current boundaries. They address key scientific questions quite unsolvable through conventional project calls. This kind of objective cannot be achieved in a short time, and LabexMER gave us the unique opportunity to consider these questions over a 10-years period. Therefore, quantifying successes after only 3.5 years of the project is not an easy task. However, we can already note major quantifiable achievements, which are revealed by the ca. one hundred publications related to the activity of LabexMER. Indeed, 76% of these publications are in journals ranked Q1 (first quartile) in their respective fields, and show an average impact

factor of 3.8*. One could also note some breakthrough advances, published in the world's top scientific journals such as Science, Nature Communication, Nature Geosciences or PNAS, as well as one of the most cited papers published in 2013 (according to the WOS, i.e. Treguer & De La Rocha, 2013). Another important point to note is the ratio of publications involving international collaborators (65%), thus revealing the strength of international networks that have been built by research axes.

Beyond the specific activity of research axes, LabexMER is now fully integrated in the laboratories, and has deeply impacted their whole research activity. Its implementation has obviously instilled a positive dynamics that triggered very beneficial side effects for the whole community, and strengthened its overall ambition and effectiveness, and we strongly believe that this will be amplified in the next few years.

*calculated from the 90 publications referenced in Web of Science (see ref. list)




**The Scientific Core of LabexMER is organized in seven research axes**

# THE OCEAN ENGINE AT VERY HIGH RESOLUTION

axis 1

Coordinators: **Patrice Klein** (LPO, CNRS) and **Bertrand Chapron** (LOS, Ifremer)

**Research units**
- Laboratoire de Physique des Océans (LPO)
- Laboratoire d'Océanographie Spatiale (LOS)
- Unité Géosciences Marines (GM)

**Research scientists:** 24
**Research engineers:** 3
**Post docs:** 2
**PhD:** 4
**Publications** (2012-): 24

## Scientific objective

Through an integrated approach (new observations, theory, frontier numerical simulations), elucidate the interaction between the ocean gyre scales, mesoscales and smaller scales (internal waves, filaments), and quantify energy pathways that connect small and large ocean scales.

## Science highlights

Axis 1 of LabexMER has allowed LPO and LOS to be among the main world contributors to the future SWOT altimeter mission, an international mission at the frontier of ocean sciences, whose main objective is to observe mesoscale eddies and finer-scale structures with a global coverage.

A new vision of the dynamics of the upper ocean has emerged in the last four years: analysis of realistic simulations at very high resolution by LPO has allowed to identify, not one but, several different dynamical regimes through which fine scales strongly impact the mesoscale kinetic energy. This has led to develop with LOS new diagnosis methods to recover the 3D dynamics from high resolution satellite observations.

The interaction between LOS and LPO has allowed to address the question of the mismatch between satellite datasets because of the different time and spatial resolutions. This has led to new and original techniques, based on robust dynamical frameworks, to exploit the synergy from existing and future satellite datasets.

Very high resolution models guided by the analysis of seismic data from GM, highlight that both critical layer instabilities and stirring mechanisms are involved in the route from submesoscales to the dissipation scales of kinetic energy.

Analysis of new in-situ experiments combined with satellite observations) allow to quantify the impact of meso / submesoscale motions on the global heat and salt transport through the marginal sea outflows.

### Workshops
- Workshop: Vertical exchanges at submesoscales and their impacts (2012)
- Workshop : Ocean 2Dto3D dynamics from space (2013)
- Symposium: Ocean scale interactions (2014)
- Workshop: Lagrangian methods (2015)

### International collaborations
Collaborations with UCLA (U.S.A.), JAMSTEC (Japan)....

### Invited scientists
Joseph Pedlosky (WHOI), Shafer Smith (NYU), Shane Keating (UNSW), Wataru Ohfuchi, Jeroen Molemaker (UCLA), Hideharu Sasaki, Yoshi Sasai

### Related projects
- SWOT satellite mission,
- ANR: RedHots, ASIV, OLA, SIMILA
- CNES-Ifremer: OCEAN 2Dto3D

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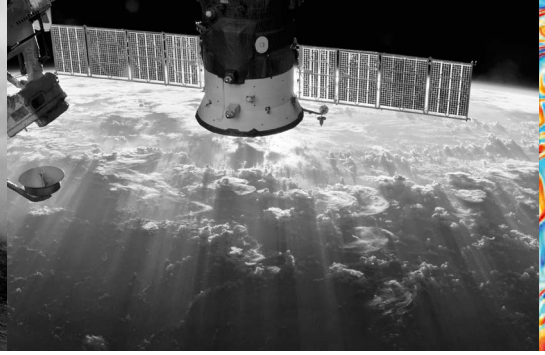

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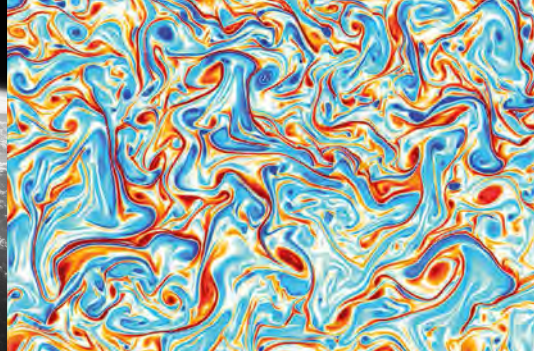

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## OBJECTIVES

Ocean dynamics is driven by motions involving a large range of scales from 10,000 km to a few meters and even a few centimeters. However geostrophic eddies (with diameters ranging from 100 km to 300 km), the building blocks of the Ocean Weather, are now known to contain almost 80% of the total kinetic energy (KE) of the flow.

Among the major scientific advances resulting from the power increase of supercomputers but also from the new satellite and in-situ observations, we can mention three breakthroughs:

- In the upper 500m of the ocean, submesoscales (such as 10km-wide filaments ubiquitous on high resolution satellite images) explain more than 50% the vertical velocity field, an important component for the ocean biological system.
- In the ocean interior, seismic reflection methods have been successfully used to map the internal structure of the entire water column with an outstanding vertical resolution of 10 m, over sections of several hundreds of km length.
- At the ocean surface, the dynamics of breaking waves is better understood to a point where their statistical properties may be predicted, and applied to upper ocean mixing.

The next step to significantly deepen and strengthen these scientific advances within the next years requires to use an integrated approach. The combined and detailed analysis of the most recent high resolution numerical simulations with high resolution experimental data (including in-situ and satellite data) and the resulting interpretation is a major challenge for the next years. The existence of strong numerical, theoretical and experimental expertises in these new fields on the Brest campus means that all ingredients exist to meet this new challenge by following the integrated approach mentioned before, which is the originality of Axis 1.

## SCIENTIFIC RESULTS

[References listed in this section concern referee publications (not all) from Axis 1]

### High resolution dynamics of the upper ocean: a contribution to the SWOT international satellite mission

Axis 1 of LabexMER has allowed LPO and LOS to be one of the main world contributors to the SWOT mission, a mission at the frontier in ocean sciences and whose main objective is to observe mesoscale eddies and smaller-scale structures. The refereed publications produced by Axis 1 in this topic have a high impact on the organization of this international mission.

### A – Impact of fine scales on mesoscale and larger scale KE in realistic numerical simulations

One of the main contributions of Axis 1 concerns the new vision of the dynamics of the upper ocean that has emerged in the last four years. Our results, using new realistic simulations at high resolution (Sasaki & Klein, 2012) combined with idealized ones, emphasize the strong regional and seasonal dependence of the dynamical impact of ocean fine scales on mesoscale eddies. For example, we have shown that the strong production of small-scale eddies by atmospheric forcings in winter leads in the

western part of ocean basins to a mesoscale KE peak at the end of spring (Sasaki *et al.*, 2014). This is the first explanation of the mesoscale KE seasonality (with a factor two amplitude) well observed with satellite altimetry starting in the early 2000s. The realistic numerical simulations performed on the Earth Simulator (collaboration Ifremer-Jamstec), further reveal in the eastern and northern parts of ocean basins quite different energy pathways (or dynamical regimes) involving fine scales (Qiu *et al.*, 2014; Sasaki *et al.*, in prep) that significantly affect the magnitude of the mesoscale KE. The existence of these different dynamical regimes should have strong consequences (still to be investigated) on the physical biological interactions, the 3D tracer dispersion as well as on the interannual variability of the ocean circulation. These results have motivated the analysis of other numerical realistic simulations at high resolution, such as the existing MIT/JPL global simulation (that includes internal tides) and the future North Atlantic simulation (LGGE, France).

Besides their original and fundamental aspects about the existence of several dynamical regimes involving fine scales, these results are used to better assess the observability of small-scale features (and their associated dynamics) by the SWOT mission. Within this context, these results have led to develop (in cooperation with LOS scientists) new diagnosis methods that allow not only to estimate surface currents, but also the 3D motions (including the vertical velocity field) in the first 1000m below the surface (Ponte *et al.*, 2014; Ponte & Klein, 2014, Chavanne & Klein, in revision). A strong collaboration on these methods is currently under development with Shafer Smith (NYU, USA) supported by the Axis 1 of LabexMER (Xiao *et al.*, submitted). Finally, a new research direction has been set up recently. It concerns the interaction between internal tides and mesoscale and submesoscales motions, a question never addressed before, but quite important for SWOT: internal tides may have a significant signature on SSH in the eastern part of ocean basins. First results can be found in Ponte & Klein (2015).

## B - Satellite observation analysis in connection with numerical results

LOS scientists are international experts in the analysis of satellite observations from different sensors. The interactions between LOS and LPO has led to develop new and original methods, based on robust dynamical frameworks, to exploit the synergy from existing and future satellite datasets. It should be noted that this is the first time that such synergy is investigated by exploiting the ocean dynamics revealed by high resolution numerical models. This is a real challenge, but it deserves to be met! The potential outcome is that all these satellite observations (including SWOT), using the diagnosis methods mentioned before, may allow to retrieve the fine scale 3D dynamics within the upper oceanic layers on a global scale. This will be a major breakthrough from SWOT, leading to a much better knowledge of the ocean circulation.

The mismatch between the high spatial resolution (about 1km) and moderate temporal resolution (10 days) of SWOT measurements presents a challenge for constructing time-continuous maps of SSH. The lack of measurements between swath tracks is another challenge. A similar problem exists for other satellite observations such as those from Jason, Sentinel 1 and 3, Altikaa, AMSR, SAR imagery... that have space and time scales quite different from SWOT measurements). Soa question is : can all these heterogeneous global datasets be used to recover the ocean dynamics at high spatial and temporal resolutions (a prerequisite to use diagnosis methods of the 3D ocean dynamics) ? In other words, how to exploit the synergy from the use of all these datasets ? The Axis 1 has started to address this question and substantial results have been obtained.

The strong relationship between satellite SAR and SST images at high resolution has been confirmed using a new dynamical framework (Kudratyev *et al.*, 2013). SAR images are clearly the signature of active small-scale oceanic fronts driven by the eddy deformation field (Rascle *et al.*, 2014). High resolution infrared SST images are mostly contaminated by clouds, which is a problem since energetic ocean regions are closely related to the atmospheric stormtracks. However, using appropriate Lagrangian techniques allows to retrieve high resolution SST images from low resolution images provided by AMSR (Dencause *et al.*, in prep). Another promising methodoly consists of retrieving high resolution SST images from low resolution

images provided by AMSR using some appropriate spectral laws based on the dynamical similitude between SSH and SST at mesoscales (Autret, PhD thesis). International collaborations with scientists Shane Keating (Australian scientist) on stochastic interpolation methods, Shafer Smith (NYU) on diagnosis methods (Xiao *et al.* 2015 submitted and Clément Ubelmann (JPL/NASA) on dynamical interpolation technics (Ubelmann *et al.*, 2015)) have been stimulated during a workshop organized by our Axis 2013 (http://www.LabexMER.eu/en/research/ocean-at-high-resolution/workshop-2dto3d-ocean-dynamics-from-space). Another workshop on Lagrangian methods will be organized by Axis 1 in September 2015 on "New insights on the impact of mesoscales and submesoscales on the Lagrangian advection of oceanic tracers ». It should involve scientists from RMAS (Miami).

## New in-situ observations of oceanic fine scales combined with satellite observations

Observations of fine ocean scales require to develop new observational strategies, based on real-time satellite data analysis and involving appropriate in-situ sensors. Axis 1 organized in November 2012 a workshop on "Diagnosis of vertical exchanges at submesoscales - and their impacts on ecosystems - from satellite and in-situ observations ». The first conclusions were drawn about a future experiment dedicated to fine scales. It should take into account the lessons from previous ones in terms of strategy based on real-time satellite data analysis and in terms of choice of appropriate in-situ instruments. Some promising instruments, such as underwater acoustics and seismic for biology, appear now essential. Design and programming of such an experiment is presently discussed within the SWOT international Science Team.

Axis 1, jointly with Axis 2 (LEMAR), is supporting an original study (involving both LPO and LOS scientists) that combines the analysis of the high resolution data obtained from the Elephant Seals in the Antarctic Circumpolar Current and analysis of satellite data. These animals are equipped with different sensors that allow to get high resolution vertical sections (2km on the horizontal and 1m on the vertical) of different physical and biological parameters on distances of up to 2000km and depth down to 1000m. These data have been analysed by LEMAR, LOS and LPO scientists (PhD thesis of Thomas Jaud) in connection with satellite data (principally SST from AMSR). Since AMSR data have a low spatial resolution (50-100km), high spatial resolution SST fields have been retrieved using Lagrangian technics developed by LOS. Results are amazing: they indicate a strong relationship between SST fronts retrieved from the Elephant Seal data and HR SST diagnosed with LOS approaches. Data analysis reveal that the Elephant Seals feed preferentially within submesoscale fronts. A paper whose title is "Life of elephant seals in a field of submesoscale fronts" is in preparation for PNAS (Jaud *et al.*). The joint analysis of the high resolution vertical sections with the SST field at high resolution (reconstructed from the AMSR data at low resolution using SSH data) is presently used to test our diagnosis methods (mentioned above).

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## Mapping the internal structure of the ocean and the energy pathways to dissipation involving fine scales

A strong cooperation has been developed between GM and LPO within the context of axis 1. It concerns the dynamical interpretation of the thin layers (10 m to 80 m thick and about 50 km long), surrounding mesoscale eddies, well revealed by the seismic images in the water column. The key question is: are these fine scale structures - ubiquituous in the ocean interior - the relay route from meso-submesoscales to mixing and dissipation scales of kinetic energy? Answer to this question will enhance understanding of the energy dissipation and its consequences on the ocean circulation.

The seismic data analysis performed in strong collaboration with GM has been done within the context of an ANR project (SIMILA). Results (Menesguen *et al.*, 2012 and also Piete *et al.*, 2012) have been used to configure very high resolution simulations using in particular non-hydrostatic models (with the context of the JAMSTEC-IFREMER MOU). Comparison between the two classes of results (observational and numerical) has allowed to better understand the mechanisms involved. This has been undertaken through another ANR project OLA (2011-2015) sponsored by the LabexMER.

Numerical simulation of these phenomena requires to explicitly represent the scale interactions over a large spectral range, from geostrophic scales (100km) to fine scales (1 km). Resolution on the vertical is of the order of one meter. This explains the very high resolution configuration needed (~ $1000^3$ grid points), which is possible only through advanced massively parallel machines (Earth Simulator and PRACE). The first class of results (Hua *et al.*, 2013) indicate that the layering is principally forming in the vicinity of critical layers. These authors argued that layering was thus consistent with a windup of potential vorticity around the latter. Meunier *et al.* (2015) further show that the stirring mechanisms are the leading process of the generation of very thin layers surrounding the eddies. These results highlight that both critical layer instability and stirring mechanisms are involved in the scale interactions. The second class of results concerns the energy budget and in particular the intensity of the direct cascade of energy down to very small scales (Hua *et al.*, 2013; Menesguen *et al.* in prep). An ANR project «Young researchers» should be submitted in 2015 on this topic.

To move forward on the seismic data analysis, part, Axis 1 will submit a proposal to the LabexMER for the partial funding of a PhD thesis (the other part being already funded by Ifremer). The topic will be on the seismic data processing of the water column. Motivation of this topic is to make a real breakthrough in the analysis methods to better exploit the full potential of the existing and future datasets.

## Understanding the dynamics of the marginal sea outflows.

Marginal seas, such as the Mediterranean Sea, the Red Sea and the Persian Gulf, are the favoured locations for the formation of warm and salty waters that then outflow into adjacent oceans characterized with colder and fresher waters. This emphasizes the importance of these outflows for the global (thermohaline) ocean circulation. The Mediterranean outflow has been studied since 1995 by the Brest team (via several in-situ experiments from 1999 to 2001). The outflow of the Persian Gulf has been studied since 1999. However several important questions have still to be addressed. They concern the impact of the mesoscale eddies and submesoscale structures on the dynamics of these outflows. This requires a new and original experimental approach and in particular to collect in-situ observations with much higher spatial resolution than before. Within this context, two in-situ campaigns have been conducted in the last four years: Physindien 2011 and 2014. Physindien 2011 also collected data on the Red Sea. Analysis of the new data are in progress.

The specific questions to be addressed are:

- What is the origin and fate of the meso/submesoscale structures that affect the dynamics of the outflow?
- How do these meso/submesoscale structures impact the global heat and salt transport associated with these outflows ? What is the impact of the finer scale mechanisms such as those associated with the layering and thermohaline staircases and how are these finer scale mechanisms related to the meso/submesoscale structures?
- Is there an interaction between the Persian and the Red Sea outflows?
- What is the typology of the mesoscale eddies typical of outflows and what are their signature at the surface (in terms of SSH, SST, ...) ?

To answer these questions, we are presently analyzing the hydrological and current meter data and use remote sensing data (altimetry, infra red and scatterometer). Analysis of these observations will carried out with the analysis of the outputs of numerical models performed at very high resolution of this area. The mechanisms involved will be identified by using academic models based on the quasi-geostrophic and

surface quasi-geostrophic dynamics. As such, this new and original approach of the dynamic of the outflows takes advantage of the complementary expertises (and the resulting synergy) existing within Axis 1 as described above.

### Air-sea interactions at fine scales

The existence of LabexMER axis1, and the arrival of Jean-Luc Redelsperger in Brest in 2012, has allowed to develop a new project on Air-Sea interactions that involves LPO and LOS scientists. An original coupled Ocean-Atmosphere model based on MesoNH (that includes non-hydrostatic and LES versions) has been developed and tested. This model should be coupled soon with a surface wave model and will be used to understand the non-hydrostatic dynamics in relation with satellite data with the same resolution (such as the SAR images). This will allow to address the questions related to the vertical mixing with the ocean mixed-layer. The Axis 1 is the only group in France and in Europe to develop this new project whose results will be determinant for the future realistic coupled OA models.

## CONFERENCES AND SUMMER SCHOOLS CO-SPONSORED BY LABEXMER

- « Diagnosis of vertical exchanges at submesoscales - and their impacts on ecosystems - from satellite and in-situ observations» 28-29/11/2012
- «Ocean 2Dto3D dynamics from space» (cf : http://www.LabexMER.eu/en/research/ocean-at-high-resolution/workshop-2dto3d-ocean-dynamics-from-space): December 2013
- International symposium, a tribute to Lien Hua: « Ocean Scale Interactions » (cf : http://www.ocean-scale-interactions.org/): June 2014
- « New insights on the impact of mesoscales and submesoscales on the Lagrangian advection of oceanic tracers": September 2015.

## ENHANCING SYNERGIES

Collaboration between Axes 1 and 2 : "Life of elephant seals in a field of submesoscale fronts"

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# COMPLEXITY AND EFFICIENCY OF THE BIOLOGICAL PUMP

axis 2

Coordinators*: **Thomas Gorgues** (LPO, IRD) and **Hélène Planquette** (LEMAR, CNRS)

**Research units**
- Laboratoire des sciences de l'Environnement MARin (LEMAR)
- Laboratoire de Physique des Océans (LPO)
- DYNamiques de l'Environnement Côtier (Dyneco)

**Research scientists**: 20
**Research engineers**: 1
**Post docs**: 7
**PhD**: 8
**Publications** (2012-): 15

## Scientific objective

The set of processes that transports particulate organic carbon to the deep sea and sediments is collectively known as the "biological pump". Axis 2 investigates the geochemical and ecological controls on the quantity, quality and character of biogenic materials produced in relation to primary production, and how this quality impacts the export of carbon to the deep sea. The second objective it to determine the fate of biogenic materials, the degradation processes inside sinking particles and the interaction between these particles and mesopelagic organisms.

## Science highlights

The LabexMER has significantly promoted the contribution of several members of the research units involved in the axis 2 to international cruises and field work programmes that were mostly scheduled over the last two years. Although not published yet, first results will provide further insight into the major nutrient and trace metal biogeochemistry in constrating environments such as the North Atlantic, the Mediterranean Sea, or the western part of the Pacific Ocean. Additionally, LabexMER has been a key "player" in promoting the convergence of different disciplines, notably biogeochemistry and molecular biology. This last point resulted in ongoing joint programmes (already started or in preparation), both at the level of the LabexMER (between axis 2 and axis 6 for example), but also at the national and international level. These newly built programmes will certainly lead to a better knowledge on several aspects of the major nutrient (C, N and Si) and trace metals cycles, and on the influence of the life history traits of marine organisms on these cycles.

*Coordinators during phase 1 were Olivier Aumont (LPO, IRD) and Philippe Pondaven (LEMAR, UBO)

### Workshops, schools, invited scientists
- Summer school AIMEN (Innovative approaches in marine environment modelling), 2013
- Workshop Silica Day (2014)

### International collaborations
NIOZ (Netherlands); WHOI, MIT, University of California, University of Merced (USA); Ludwig Maximilian University (Germany), Norwegian Polar Institute (Norway); University of Tasmania (Australia)

### Related projects
GEOTRACES (Mediterranean and Black Sea section GA, North Atlantic section GA 01), FP7 Eurobasin, FP7 MICRODIVE, Arctic Field Grant / Research Council of Norway PREDIC, EC2CO MICROPOP, ANR GEOVIDE, AWA, UPSEN-2 and ECOAO, KEOPS2, MACROES

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## OBJECTIVES

The set of processes that transports particulate organic carbon (POC) to the deep sea and sediments is collectively known as the «biological pump» and includes the primary production of POC, the packaging of POC, via coagulation or other processes, into large, rapidly sinking particles versus its recycling or entrainment into marine food webs. With a quantitative understanding of these processes, we could better evaluate the role of the biological pump in the oscillation of atmospheric CO2 concentrations from 280 atm to 190 atm over interglacial and glacial cycles and how the biological pump will respond to (or could be harnessed to sequester) the CO2 added to the atmosphere by humankind.

At present, there is no consensus on the mechanisms that control the efficiency of the biological pump (Boyd and Trull, 2007). Contributing to this lack of understanding is the fact that the complexity of these mechanisms, which reside at the intersection of ocean dynamics, biogeochemistry and ecology, has not yet been successfully incorporated into ocean models which could then be used to test hypotheses and validate experiments. In this project, we aim to address the complexity involved in the production, export and fate of biogenic materials by working at different scales (from individual particles and organisms up to ecosystems) and combining field studies, experimental and modeling approaches (micro- and mesocosms, inverse modeling, virtual reality). Two main scientific objectives are addressed: (1) Investigate the geochemical and ecological controls on the quantity, quality and character of biogenic materials produced in relation to primary production, and how this quality impacts the export of carbon to the deep sea; (2) Determine the fate of biogenic materials sinking as aggregates and fecal pellets by studying degradation processes inside sinking particles and the interaction between these particles and mesopelagic organisms.

## SCIENTIFIC RESULTS

### Objective 1: Geochemical and ecological controls on the quantity, quality and character of biogenic materials

**Action 1**: Investigate interactions between zooplankton, phytoplankton, viruses and bacteria and their role in controlling organic matter production and fate.

A large mesocosm experiments has been undertaken in the Bay of Hopavågen in Norway (part of the HYDRALAB IV set of European facilities). The goal of this work was to identify differences in the export fluxes depending (1) on the phytoplankton communities and (2) on the presence of grazers. The first results showed that the export is linked to the development of diatoms and is more efficient when there is a daily input of nutrient compare to other studies where they added one major input of nutrient at the beginning of the experiment (de La Rocha *et al.* under review). Simultaneously laboratory experiments in rolling tanks further investigated interactions between zooplankton, phytoplankton, and bacteria and their role in controlling the formation, sinking, solubilization, fragmentation and remineralization of marine snow (i.e., the overall capacity and export efficiency of the biological pump). Analysis of the results are underway, and 3 publications are in preparation.

**Action 2**: Impact of the presence of grazers on the silicification by diatoms

The efficiency of the frustule to protect diatoms from grazing by zooplankton has been recently demonstrated with increasing cell-wall silicification in diatoms growing in seawater that has contained copepods, even if the latter are

absent (Pondaven *et al.*, 2007). Starting from these studies, a series of mesocosms experiments were designed in 2012 to test the impact of different grazers on the silicification of different species of diatoms. In a second step, the impact of the higher silicification on the fate of the diatoms was studied, first by observing the behavior of the grazers in front of this higher silicification and then by measuring how this affects the preservation of biogenic silica by making dissolution experiments in laboratory. Experiments on the impact of high silicification on grazer behaviors shortly followed the first experiments while dissolution experiments were undertaken in late 2012. Publications are currently in preparation.

## Action 3: Biodiversity and ecosystem productivity

The ecological consequences of biodiversity loss and its consequences on ecosystem functioning and services is a central issue in ecological and environmental sciences. The "PHYTODIV" project was motivated by the need for a better understanding of biodiversity - ecosystem functioning in coastal pelagic habitats. Landlocked marine lakes (Palau Republic, Micronesia) offer a unique possibility to study these two processes; otherwise difficult to investigate and disentangle in open marine environments. Preliminary results show, for example, that phytoplankton community were more diverse, and mortality rates from microzooplankton grazing were higher in oligotrophic lakes. This survey also revealed the puzzling diversity of life-history strategies in jellyfish, a major zooplanktivore top predator in Palau's marine lakes. Indications were found that some species of Palau's jellyfish could host different types of endosymbiotic algae, including N2-fixing cyanobacteria (Behl *et al.*, in prep). This ongoing study involved collaborations with the Ludwig Maximillian University (LMU, Munich, Germany) and the University of Merced (California, USA); via the FP7 Microdive (PI : Pr. Herwig Stibor, LMU) and a NSF grant (Award Number: 1241255, PI/co-PI(s): Michael Dawson, John Beman, University of Merced). This work has also stimulated new collaborations between members of the axis 2 and the axis 6 of the LabexMER.

## Action 4: The distribution of the pelagic habitats and biodiversity

Numerous hypotheses have been proposed to explain the pelagic microbial biodiversity and the species co existence. The seminal work undertaken by M. Follows (MIT, USA) brings a new approach to the representation of biodiversity in models: it is based on the seeding of the ocean by several tens of virtual phytoplankton characterized by their traits randomly defined within a range of realistic parameters (growth, co-limitation, mortality/grazing, sedimentation). Using this approach and model framework, this action aimed at understanding the processes that drive the distribution of the pelagic habitats and biodiversity at meso- and sub meso-scale. This study is focusing on the Rade de Brest and Mer d'Iroise modeled using ROMS-AGRIF and carried out by a PhD student supervised by L. Mémery (LEMAR) and M. Sourisseau (DYNECO). This study involves collaborations with LOCEAN, Paris (M. Lévy), University of California (C. Edwards) and MIT (M. Follows). The ROMS-AGRIF dynamical model has been successfully coupled to the biogeochemical model DARWIN. With this newly developed tool, she was able to relate diversity patterns with dynamical features. This work has led to one communication at the European conference in ecological modeling in October 2014.

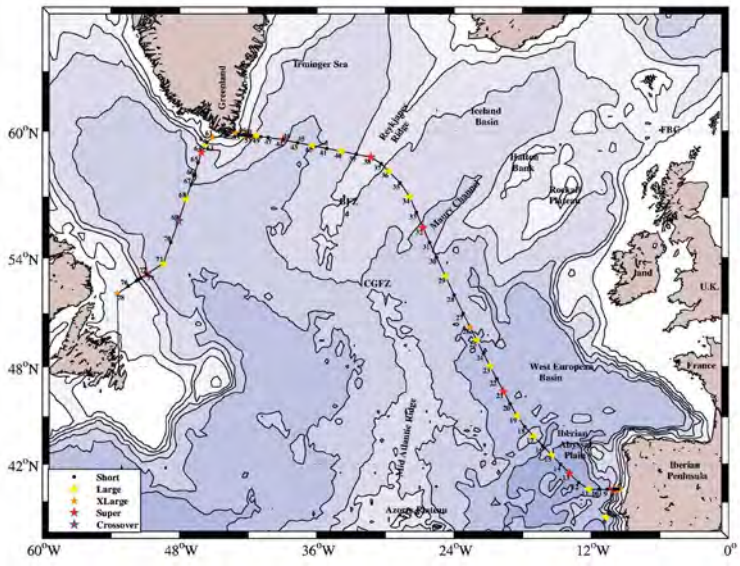
## Action 5: Ocean acidification and trace metals sensitivity of phytoplankton

In this action, it was proposed to test the sensitivity of marine biomineralizers to future climatic scenarios under variable micronutrients involved in the cellular metabolism of carbon and partial pressure of CO2 that leads to ocean acidification. This should help to further understand and predict consequences of these changes on the biological carbon fixation and on the production of biogenic particulate matter. As a first step, lab-experiments have been conducted in climatic turbidostats settled at LEMAR using oceanic coccolithophorid and diatom grown under variable trace metals and CO2 scenarii. Two different pCO2 were tested: one representing the present day pCO2 (380 ppm) and a future pCO2 (800 ppm) in a "business as usual scenario" (IPCC, 2007). Several concentrations and ratios of Co, Cd and Zn were concomitantly tested in order to assess the potential of trace

metals co-limitation and substitution. This action is underway with international post-doc Jill Sutton (2014) and PhD student Nina Delebecque. First results have been presented at AGU 2014 and ASLO 2015.

### Action 6: A field study to investigate the impact of trace metals on the complexity and efficiency of the biological pump: GEOVIDE

Trace elements and isotopes (TEIs) play a crucial role in the ocean. Some of them are essential for the living organisms while others are toxic. They can also help us to understand key processes of past and present oceans. Studying their cycles, together with oceanic circulation, has thus direct implication on numerous studies such as the oceanic carbon cycle, the climate, marine ecosystems and environmental contamination. The North Atlantic is a crucial region for Earth climate, as well as for the meridional overturning circulation (MOC). Moreover, the TEIs in this region present highly contrasted sources and their cycles are not well known. The GEOVIDE project is the French contribution of the international GEOTRACES programme (www.geotraces.org) in the North Atlantic. The characteristic and variability of the MOC have been studied within the OVIDE (http://wwz.ifremer.fr/lpo/La-recherche/Projets-en-cours/OVIDE) project since 2002. GEOVIDE is an international collaborative project, involving 18 laboratories from 9 different countries. The general objectives are to better constrain the uncertainties on the biogeochemical fluxes and processes as well as on the water and heat fluxes. To achieve these objectives, a 47-day oceanographic cruise was carried out on board R/V Pourquoi Pas? (15 May - 30 June 2014), from Lisbon (Portugal) to St. John's (Canada). The first results acquired on board are very promising. These results together with all the other parameters that will be analysed during the GEOVIDE project will provide a comprehensive view of the physics and biogeochemistry of the North Atlantic. GEOVIDE is funded by CNRS-INSU (programme LEFE), ANR Blanc and RPDOC, LabexMER and IFREMER. For the logistics: DT-INSU, IFREMER and GENAVIR. First results have been presented at the ASLO 2015.




Map of the GEOVIDE stations

## Objective 2 - Determine the fate of biogenic materials sinking as aggregates and fecal pellets

### Action 1: Development of a virtual plankton model of the mesopelagic domain

During the first year of Quentin Carlier PhD, localized entities that represent POC, plankton, 1D water column, a POC generator, and instruments measuring export and remineralisation have been developed. Particles interact by sedimenting, remineralising, aggregating, desagregating and densifying, while planktons gaze at particles, excrete fecal pellets, vertically migrate and remineralise because of their metabolism. The computer system is conceptualized so that the biogeochemical model description intricates its computing realisation, while versionning any of the models and the resulting operational system. These first simple models allowed the observation of the qualitative influence of the zooplankton migration on the biological pump, but the model still needs to be benchmarked. To this aim, in interaction with B. Moriceau (LEMAR), some of the mesocosm experiments realised in the Bay of Hopavagen during the EURO-BASIN project will be used in order to calibrate and validate the models built from this approach. A computer science M2R student will provide assistance during 4 months in 2015 for making easier the calibration of the multiagent system, so that it could agree with real data coming from mesocosm experiments.

### Action 2: Biogeochemical processes inside sinking particles

The two main contributors to the sedimentation fluxes are the aggregates and fecal pellets. As export is the result of sinking and recycling, these two processes are largely studied. However large uncertainties remain as shown by the large range of estimation of carbon export. While sinking is generally measured on the large particles forming the sinking flux, most of the recycling processes are studied on small isolated particles. In this action research was focused on the biogeochemical processes occurring in the most abundant sinking particles: diatom aggregates. Aggregation increases the sinking rate of the phytoplankton cells by two orders of magnitude. Additionally, aggregation processes contribute to (1) slow-down of the bSiO2 dissolution and (2) the export of up to 20% of dissolved organic carbon and nitrogen. A recent study showed that neither the high dSi concentrations found in aggregates nor the high viability of the aggregated diatoms totally explained the low dissolution rate. High dissolved silica concentrations may be due to adsorption processes of dissolved silica onto the aggregate matrix which can contribute to as much as 20% of the total Si export (Moriceau *et al.* in press).

### Action 3: The role of higher trophic levels and vertical migration on the production of particles and their fate in the water column

Diel vertical migration of zooplankton and micronekton is a very common phenomenon in aquatic systems. Typically, many marine organisms feed close to the surface at night and descend in the mesopelagic zone at day to escape visual predation by planktivorous fishes. This migration induces an active transport of carbon from the surface to the surbsurface which has been estimated to be between 10 to 30% of the total export of carbon. Within the framework of the ANR-CEPS program MACROES (P.I. O. Aumont), an end-to-end ecosystem model representing the full marine trophic food web has been constructed based on a classical NPZD model PISCES (Aumont and Bopp, 2006) and an ecosystem model APECOSM (Maury *et al.*, 2007). The model reproduces different marine communities, including diel migrating organisms. In this action, it was proposed to use this model to study the impact of the higher trophic levels of the carbon cycle, within and below the euphotic zone.

These funds, together with Labex IPSL funds have been used to hire a post-doc (Tilla Roy) to work for 10 months (part time contract) on this project in 2014 and 2015. In a first step, the role of migrating organisms has been estimated using the end-to-end ecosystem model. Active transport of carbon represents globally between 12 and 18% of the total export of carbon from the euphotic zone and may represent up to 50% of this export in the tropical regions. These results have been presented at the AMEMR meeting in June 2014 and at a seminar at IPSL in November 2014. A manuscript is in preparation and will be submitted in the first half of 2015. In a second step, the post-doc researcher will work on the potential biomixing effect induced by the migrating organisms. Preliminary simulations indicate a small but significant impact on the thermal stratification in the tropical regions, especially in Eastern Boundary Systems.

## CONFERENCES AND SUMMER SCHOOLS CO-SPONSORED BY LABEXMER

Supported by the CNRS, Ifremer and University of Brest, AIMEN was the second thematic school organized by the LabexMER in 2014. Over 70 young and established scientists assembled at IUEM and contributed to the success of this summer school, with the common aim to strengthen knowledge and understanding of marine ecosystems functioning, within global change framework. Scientists from the axis 2 of the LabexMER were involved in the organising committee, notably Laurent Mémery and Olivier Aumont.

The LabexMER allow the organization of the first Silica day in 2014 that gathered together different specialists of the Si cycle working on different aspect of this cycle. From this day, a Si-group has been constituted with the objective to write new proposals. This event was also precursor of a bigger action that will be held at the

end of the summer 2015. Recognizing some of the crucial gaps in the study of the silicon cycle, SILICAMICS will help to identify key questions by favouring the encounter between international specialists of the many disciplines and tools involved in the study of silicification and silicifiers in marine ecosystems.

## ENHANCING SYNERGIES

Axis 2 has contributed to both the Research and Formation objectives of LabexMER. Regarding the international attractiveness, the axis 2 supported the development of sustainable collaborations at the national or international levels.

Axis 2 favored these collaborations by co-financing post-doctoral fellowships or by supporting the participation of members of the axis 2 to international cruises.

The general research objectives of the axis 2 had also attracted young foreign researchers, which have successfully obtained post-doctoral fellowships from LabexMER (J. Sutton, B. Ward, R. Shelley , A. Gonzalez Gonzalez).

The axis 2 also supported new and risky research projects through two internal calls. Some of these projects have been a starting point to gather together different specialists of the silica biogeochemistry working on different aspect of this cycle (e.g. SILICAMICS workshop). In the same inspiration, many members of the axis 2, in close collaborations with members of the axis 6, participated to the organisation and the animation of the international summer school AIMEN, which took place at the IUEM. As said above, over 70 young and established scientists contributed to the success of this summer school at IUEM, with the common aim to strengthen knowledge and understanding of marine ecosystems functioning, within global change framework.

LabexMER also favoured and financed some citizen sciences and public outreach initiatives in collaborations with Oceanopolis (Brest). The operation "Objectif plancton", initiated by Oceanopolis, is such a citizen science operation, which aims at surveying the evolution of the composition of phytoplanktonic communities, primary production (along with other parameters such as temperature, salinity, secchi depth...), in a specific area, the bay of Brest. This is done with the help of amateur sailors under the supervision of Oceanopolis and scientists from the axis 2 of LabexMER. In the same way, members of the axis 2 have worked together with the Navy to participate to a cruise in the arctic on the military vessel "Le Tenace". LabexMER supported the participation of a post-graduate student to this cruise which took place from 20/08 to 15/10 2014.

## LABEXMER INTERNATIONAL POST-DOC FELLOWSHIPS

- **Jill Sutton** (PhD Australia, 2011) "Ocean acidification and trace metals sensitivity of phytoplankton"
- **Rachel Shelley** (PhD UK, 2011) "Atmospheric deposition of trace elements in contrasting regions of the North Atlantic"
- **Ben Ward** (PhD UK, 2010) "Applying Occam's razor to a complex marine ecosystem model"
- **Aridane Gonzalez Gonzalez** (PhD Spain, 2011) "Iron and manganese co-impact in marine environments"

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# GEOBIOLOGICAL INTERACTIONS IN EXTREME ENVIRONMENTS

axis 3

Coordinators: **Olivier Rouxel** (GM, Ifremer), **Marcia Maia** (LDO, CNRS), **Pierre-Marie Sarradin** (EEP, Ifremer)

**Research units**
- Laboratoire Microbiologie des Environnements Extrêmes (LM2E)
- Laboratoire Domaines Océaniques (LDO)
- Unité Géosciences Marines (GM)
- Unité Etude des écosystèmes profonds (EEP)
- Laboratoire Biotechnologie et Chimie Marines (LBCM)

**Research scientists**: 30
**Research engineers**: 15
**Post docs**: 3
**PhD**: 7
**Publications** (2012-): 20

## Scientific objective

Characterize and quantify fluid circulation and geobiological interactions in the deep-sea environments, evaluate their role on the dynamics and the functioning of deep-sea ecosystems as well as their contribution to global geochemical cycles.

## Science highlights

- Mantle exhumation can be related either to extensive or to compressive stresses along major transform boundaries. Exceedingly low melt rates contribute to these processes, whether linked to unusual mantle composition or to very low potential temperatures (Maia *et al.*, in preparation).
- Trace element records of Earth's surface redox evolution have been generated in unprecedented detail (Partin *et al.*, 2013) along with models that better reveal the microbial role in Earth's earliest sulfur and nutrient cycling (Reinhard *et al.*, 2013; Robbins *et al.*, 2013). Recent work by Axe 3 researchers has now pushed back the origin of cyanobacteria (and thus oxygenic photosynthesis) by 500 million years, to over 3 billion years ago (Planavsky *et al.*, 2014).
- Experimental studies using microbial colonization devices deployed at the seafloor of the Guaymas basin reveal that the large bacterial diversity observed is primarily linked to the deployment duration as well as the depth, but interestingly, not for Archaea. This study gives new insights into the colonization steps of volcanic rock substrates and the capability of microbial communities to exploit new environmental conditions (Callac *et al.*, 2013).
- At hydrothermal vents, variability in microhabitat conditions and biological interactions appear to interact jointly in shaping new faunal communities on organic and inorganic colonisation substrata (Cuvelier *et al.* 2014a). Results from the Neptune deep-sea observatory showed the presence of semi-diurnal and diurnal periods both in fauna and environment, revealing the influence of tidal cycles at great depths (Cuvelier *et al.* 2014b).
- New studies of meiofaunal benthic organisms at the Condor seamount that seafloor topography and specific environmental conditions contribute to significantly enhanced ecosystem diversity (Zeppilli *et al.*, 2014).

### Workshops, schools, invited scientists

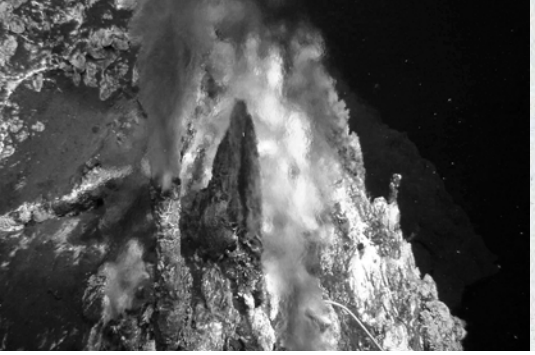
- Organisation of summer school and workshops: GEOCEAN 2012, MEIOSCOOL 2013, DSM2014, SFIsotraces 2014, MOVE 2014.
- International chair in stable isotopes biogeochemistry: Aradhna Tripati (UCLA)

### International collaborations and projects

Collaborations with WHOI, ONC, Yale University, MIT, University of Alberta, University of Ghent, University of Azores, University of Modene, University Federal Fluminense, University of Montreal, University of Moscow.

### Related projects

- EMSO-Açores, Ocean Networks Canada
- Submitted projects: ANR GEO2BIO, ERC GISMO, ANR BICOSE, ANR GENIE.
- Accepted projects: ANR Luckyscales, Region Bretagne SADv2 S-GEOBIO.



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## OBJECTIVES

Deep sea environments, including seafloor and subseafloor environments feature extreme variations in temperature, pH, pressure, salinity, and both inorganic and organic compounds leading to a complex interplay between metabolic activity and diversity, and geochemical changes. The objective of Axis 3 is to characterize and quantify - using the most efficient tools at sea and in the laboratory - fluid circulation and geobiological interactions in the still-poorly understood deep-sea environments to evaluate their role on the dynamics and the functioning of deep-sea ecosystems as well as their contribution to global geochemical cycles. This research will lead to a better management of activities that involve the exploration or exploitation of deep-sea biological, mineral or energy resources by providing the scientific arguments to best define the conservation strategy for these unique ecosystems that harbor major economic and societal interests.

Three major questions are addressed by axis 3:

- What are the tectonic, magmatic and sedimentary processes that control fluid circulation and its spatial and temporal variability?
- What are the environmental factors that control the dynamics of biological and functional diversity of deep-sea ecosystems?
- What impact does microbial community activity have on the environment and the major biogeochemical cycles?

## SCIENTIFIC RESULTS

### Technological development and new approaches for the study of fluid-crust interactions

The LabexMER and Axis 3 funded several projects that enhanced our current capability of high-resolution imaging and understanding of the structure of the crust subsurface (e.g., high- temporal and spatial resolution seismicity survey) and movement of the deep ocean floor (e.g., seafloor geodesy). Geodetic experiment allowed measuring seafloor movements, especially movements related to dike intrusion, magma chamber volume changes, movements along faults etc... Combined with high resolution bathymetry, this approach ultimately allows investigating the relationships between faults, magmatic events and fluid circulation at deep ocean environments. This methodological development has been integrated into one field program investigating gas seeps in the Sea of Marmara (Cruise MARSITE, 2014). Gravity and gradiometric measurements will bring valuable information on the sub-surface density distribution as well as on the distribution of structural features such as faults, fissures and altered areas. The prototype is currently under construction and the first cruise dedicated to the tests is scheduled for August 2015.

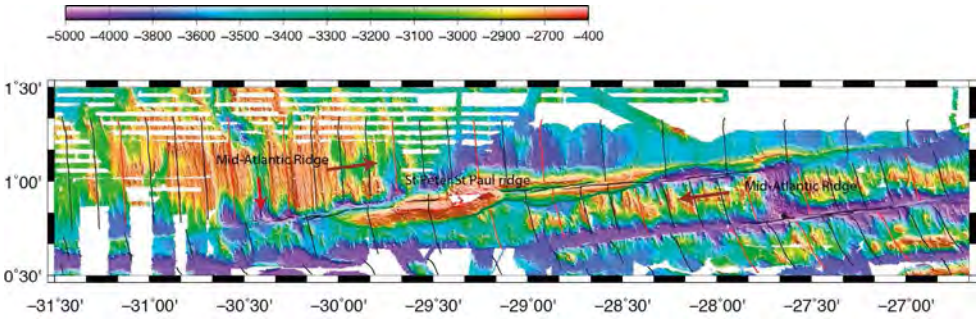


Figure 1: Multibeam bathymetry of the St Paul transform fault and the St. Peter St. Paul mylonite ridge. The fault is marked by thin black lines and the compressive thrusts by the green thick line. The ages of the plate are indicated by black and red lines, each million year. The red arrow shows the sense of propagation for the Mid-Atlantic ridge segment and the brown arrows show the plate movements. The unusual propagation of a ridge segment into a 20 m.y. age offset is due to a robust magmatic supply at the ridge axis, enough to counteract the cold barrier effect of the offset. Such kind of ridge propagation is extremely rare at slow spreading ridges.

## Tectonic and magmatic processes at Mid-Oceanic ridges and transform boundaries

The COLMEIA project involved two cruises, the first with the French vessel L'Atalante, in January/February 2013 and the second with the Brazilian vessel Araguari, in May 2014. The first cruise allowed to map and sample the St. Paul fracture zone and to deploy five autonomous hydrophones while the second allowed the recovery of the five instruments. The project is a joint French-Brazilian effort to unravel the processes at the origin of the ultramafic ridge of St. Peter St. Paul (Fig. 1). Our first results revealed that compressive stresses have been active in this major transform fault for the last 10 m.y. Although transpression is currently observed at some transforms following plate adjustments, the magnitude of the stresses observed here is unusual. They resulted on the 3000 m uplift of a 200 km long mylonitic peridotite body. The origin of these compressive stresses is to be found in the propagation of a segment of the Mid-Atlantic Ridge inducing displacement of the transform fault and formation of a multi-segmented shearing boundary. The area is highly active and the spatial and temporal seismicity recorded by the hydrophones will allow understanding the areas that are currently deforming. A PhD student (N. Ferreira) is working on the geophysical data acquired and another will start working with the samples in the fall of 2015.

## The evolution of marine metal biogeochemical cycling throughout geological times - modern and ancient

The geological past constitutes an extreme environment in itself due to the dramatically different atmospheric, marine, and surface conditions experienced by the Earth system. Understanding past changes in biogeochemical cycling is key to projecting future responses of the Earth system to climate change, and furthermore provides fundamental knowledge regarding the cradle of biological evolution that is Earth's past oceans. LabexMER axe 3 researchers have been particularly active and visible at the international level in this regard, having contributed to the reconstruction of the marine histories of the bioessential elements cobalt (Swanner *et al.*, 2014) and zinc (Robbins *et al.*, 2013) as well as the biogeochemical redox tracers uranium (Partin *et al.*, 2013a, 2013b), sulfur (Reinhard *et al.*, 2013a), molybdenum (Planavsky *et al.*, 2014, Reinhard *et al.*, 2013b), and chromium (Reinhard *et al.*, 2013b), all in top-tier international journals. The emerging view of marine metal biogeochemical cycling through geological time from these works is more nuanced than previously thought. Biogeochemical redox tracers now reveal the oxygenation of Earth's oceans in unprecedented detail (Partin *et al.*, 2013a, 2013b; Fig. 2), as well as place new temporal constraints on the evolution of oxygenic photosynthesis, extending

it back to approximately 3,000 Myr (Planavsky *et al.*, 2014). In the case of trace metals such as zinc that are essential bio-limiting nutrients, a mulit-pronged approach leveraging both marine sedimentary and meta-genomic archives have permitted for the first time an evaluation of the degree of coupling between marine chemistry and biogeochemical evolution at the enzymatic level (Robbins *et al.*, 2013) – such cross-disciplinary fertilization exemplifies the novel lines of inquiry made possible by LabexMER Axe 3 initiatives.

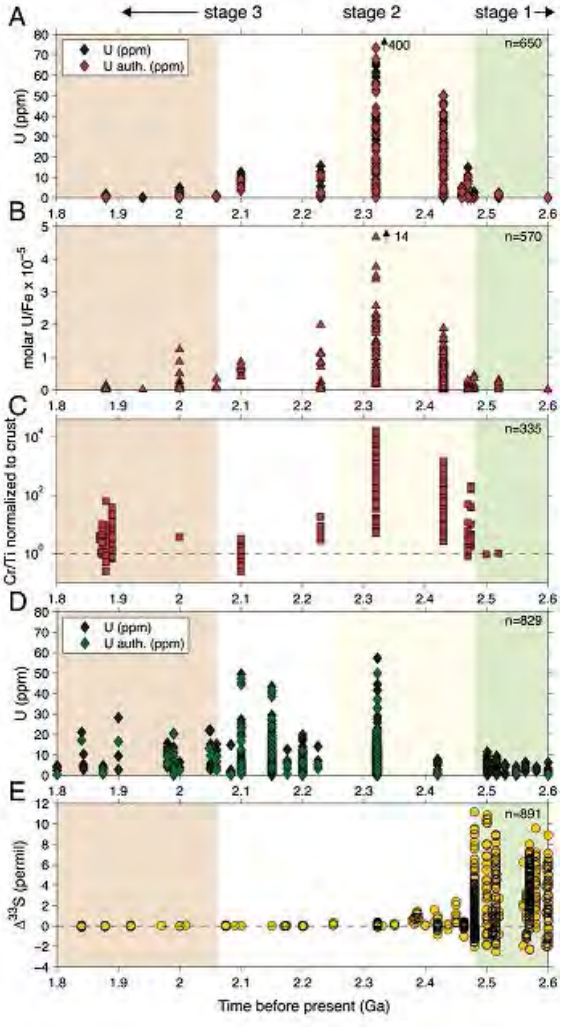


Figure 2, Oxygenation of Earth's oceans ca. 2500 Myr as revealed by multiple biogeochemical tracers (after Partin *et al.*, 2013): (A) Secular variations in U content and (B) U/Fe ratio of ca. 2.6 to 1.8 Ga IF together with other relevant surface redox proxies (C–E): (C) Cr/Ti ratios in IF, (D) absolute and authigenic U content of shales, and (E) sedimentary Δ33S values.

## Biogeochemical processes at the microbiological-mineral interface

This action aims to determine the relationships between microbial community structure and activity, and the mineral, chemical and stable isotope characteristics in deep-sea extreme environments such as hydrothermal vents and cold seeps. In such environments, chemolithoautotrophic micro-organisms are the main primary producers, using reduced compounds from the fluids or the minerals. Microbial communities attached on mineral surfaces are generally organized into biofilms; their structure and function need to be examined through the use of sophisticated bioreactors (operating in continuous culture) or in situ incubations. One important focus concerns the role of microorganisms both for the formation and destruction of minerals in different types of rocks as well as their symbiotic roles such as: nutrition, detoxication, parasitism or population control. In particular, Axis 3 is currently supporting a project aimed at resolving the recognition system and cell-cell communication between host and symbionts and between symbionts themselves.

Seafloor oceanic basalts are exposed to seawater for millions of years, become colonized by dense microbial communities and undergo radical chemical and mineralogical transformations. Chemical reactions of basalt with seawater flowing through veins release energy that can potentially support chemosynthetic communities. In order to study the microbial colonization on basaltic glasses and their potential biotic/abiotic weathering products, two colonization modules called AISICS ("Autonomous insitu Instrumented Colonization System") were deployed in hydrothermal deep-sea sediments at the Guaymas Basin. Although no specific glass alteration texture was identified, results showed large microbial diversity in all colonizers. mcrA gene sequences belonging to the ANME-1 mcrA Guaymas cluster were found sometimes associated with their putative sulfate-reducers syntrophs depending on the colonizers, suggesting microbial origin for the observed secondary pyrite precipitated within basalt vesicles (Callac *et al.*, 2013). By drilling into 3.5-million-year-old subseafloor basalt, we also demonstrated the presence of methane- and sulfur-cycling

microbes on the eastern flank of the Juan de Fuca Ridge (Lever *et al.*, 2013). We combined sequencing of genes diagnostic of microbial methane and S cycling with geochemical and isotopic analyses of C and S pools and laboratory-based incubations to directly identify for the first time microbial ecosystem components in deep subseafloor basalt.

## Temporal and spatial dynamics of hydrothermal vent ecosystems

This action aims to investigate temporal and spatial variations in abundance, community structure, and biodiversity of benthic fauna, including meiofauna, and its relationship with environmental variables. Hydrothermal site assemblages are distributed in a patchwork mosaic that is strongly influenced by physical, geological, and chemical processes operating at different scales in time and space. Our approach includes in particular time-series studies to reveal the variability of hydrothermal systems in terms of geological and environmental parameters and the biological communities associated with them. LabexMER provided funding to lead several studies on contrasted hydrothermal environments, concurrently with a high-temporal-resolution data acquisition approach.

In order to understand the persistence and periodicities of the local faunal populations at hydrothermal vents, intra- and inter-annual temporal variations studies of faunal abundances and community dynamics are fundamental. In this perspective, various colonization substrata were deployed to help us better comprehend colonization and recruitment patterns of taxa present in the local or regional species pool. In 2006, wood and slate panels were deployed at the Eiffel Tower hydrothermal edifice of the Lucky Strike vent field (Mid-Atlantic Ridge, MAR), at varying distances from visible hydrothermal activity (Fig. 3). Wood was chosen due to its organic nature and known abundance in the deep-sea and slate was chosen as a basalt-like smooth and inert substratum. The main hypotheses tested were the following: (a) there is a difference in colonization (recruitment and survival) between organic and inorganic substrata, (b) there is a difference in colonization between locality and proximity of hydrothermal fluids influences faunal colonization, and (c) temperature (and associated chemicals) influences composition and abundance of recruits. For this two-year deployment period, the composition of colonising organisms (both macro-and meiofauna) was assessed, along with image analyses of the deployment sites in 2006 and 2008. Very few significant differences in colonisation between organic (wood) and inorganic (slate) panels were revealed. Rather, the locality of deployment and the local environmental conditions and hydrothermal activity were found to influence taxonomic composition. Variability in microhabitat conditions and biological interactions were hypothesised to interact jointly in shaping new faunal communities on the colonisation substrata (Cuvelier *et al.* 2014a).

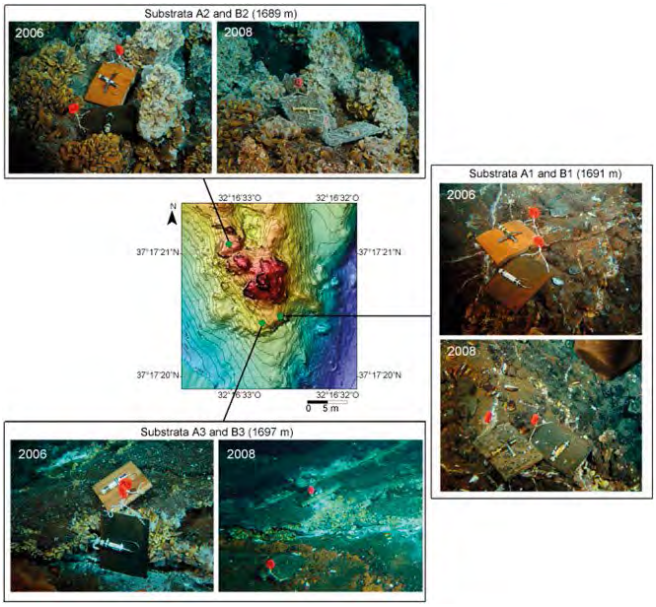


Figure 3. Location and depth of the sites at the Eiffel Tower edifice (MAR) where different substrata were deployed in 2006 and recovered in 2008. On each locality a panel of slate (A) and wood (B), each equipped with a NKE temperature probe, were deployed. Note the change in location of panel A3 in 2008.

The NEPTUNE cabled observatory network hosts an ecological module called TEMPO-mini that focuses on hydrothermal vent ecology and time series, granting us real-time access to data originating from the deep sea. In 2011-2012, during TEMPO-mini's first deployment on the NEPTUNE network, the module recorded high-resolution imagery, temperature, iron (Fe) and oxygen on a hydrothermal assemblage at 2186 m depth at Main Endeavour Field (North East Pacific).

23 days of continuous imagery were analysed with an hourly frequency. Community dynamics were analysed in detail for *Ridgeia piscesae* tubeworms, *Polynoidae polychaetes*, *Pycnogonida* and *Buccinidae*, documenting faunal variations, natural change and biotic interactions in the filmed tubeworm assemblage as well as links with the local environment. Semi-diurnal and diurnal periods were identified both in fauna and environment, revealing the influence of tidal cycles (Fig 4). Species interactions were described and distribution patterns were indicative of possible microhabitat preference. The importance of high-resolution frequencies (< 1 h) to fully comprehend rhythms in fauna and environment was emphasised, as well as the need for the development of automated or semi-automated imagery analysis tools.

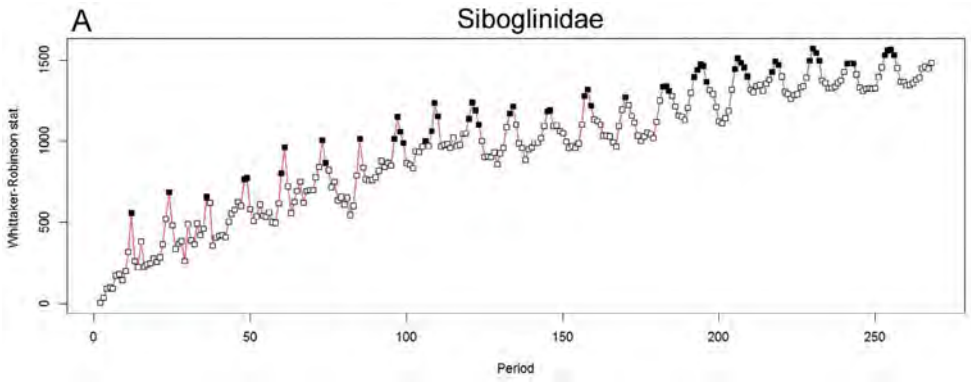


Figure 4. A Whittaker-Robinson periodogram computed for the siboglinid tubeworm densities revealed significant periods at 12 and 24 h as well as their harmonics at 36 and 48 h. The harmonics were neatly recognisable all along the periodogram. Abscissa: periods in hours. Black squares are significant periods for $p<0.05$.

## CONFERENCES AND SUMMER SCHOOLS CO-SPONSORED BY LABEXMER

**GEOCEAN** Symposium and Summer School « Geodynamic processes and biochemical interactions at seafloor spreading ridges » (August 27-31 2012, Brest). Convenors: Jean-Yves Royer (IUEM), Olivier Rouxel (Ifremer). This conference and school, held in tribute to Jean Francheteau, gathered over 100 young and established scientists. Invited lectures covered fundamental aspects of geodynamics and petro-geochemical processes at seafloor spreading ridges and

flanks, as well as fluid-rock interactions and geochemistry of seafloor hydrothermal systems. New advances in the field of geobiological interactions in extreme environments were also presented.

**MEIOSCOOL**: « Meiofauna international workshop - A dive in a microscopic world » (November 26-29 2012, Brest). Convenors: Daniela Zeppilli and Jozée Sarrazin (Ifremer). More than 25 oral presentations were given, including 9 keynotes from invited speakers, about meiofauna: biodiversity, biogeography, ecosystem functioning, anthropogenic impacts... Two days practical sessions at Oceanopolis concluded the workshop. A special issue of Marine Biodiversity gathering 15 papers will be published in June 2015.

**DSM2014**: 4th International Workshop on Deep Sea Microbiology (September 15-17 2014, Brest). Convenors: Anne Godfroy, Didier Flament, Mohamed Jebbar, Claire Geslin, Karine Alain, Gwenaelle Le Blay (Ifremer & IUEM). The workshop gathered international experts in the field of deep sea microbiology. The meeting gave young scientists the opportunity to meet and discuss with experts. A short course on new methods for microbial community analysis concluded the symposium.

**SFIsotraces**: First joint National symposium on Stable Isotopes (SFIS) and Workshop in geoanalytical techniques (ISOTRACE), (8-12 September 2014, Brest). Convenors: Emmanuel Ponzevera (Ifremer), Jérôme Chmeleff (Isotrace), Franck Poitrasson (SFIS). The meeting brought together the national community of geochemists and analysts to discuss both scientific and technical aspects of trace elements, stable isotopes and radiogenic isotope analysis. Two «short courses» on the themes of Marine Biogeochemistry and Paleoceanography were proposed.

**MOVE**: Multidisciplinary Observatories in Vent Ecosystems workshop (24-27 November 2014, Brest). Convenors: Marjolaine Matabos and Jozée Sarrazin (Ifremer). The objectives of the meeting were (1) to review and present recent progresses on two deep sea observatories: MOMAR and Ocean Networks Canada / Endeavour; (2) to build multidisciplinary data integration: within a vent field and between vent fields; (3) to bolster collaborations, student exchanges, cruise participation, and funding opportunities in this field.

## ENHANCING SYNERGIES

Although there has been a strong tradition of multidisciplinary study of ocean ridges, continental margins and submarine volcanoes between the Labex scientific teams, an immediate and central challenge is establishing even stronger links and interdisciplinary fertilization between Axis 3 themes. Current initiatives such as internal calls for team-spanning projects and organization of scientific meetings greatly facilitated this synergy.

**LDO (IUEM) and LGM (Ifremer)** have both ample experience in the multidisciplinary study of ocean ridges, continental margins and submarine volcanoes. They are both actively developing innovative instruments and methods for imaging the crust in deep-sea environments. It is clear that the LabexMER facilitated even further interactions between those laboratories, in spite of the recent opposition of the Ifremer direction to merge LDO and GM into a joint research unit.

**Ifremer and IUEM** share, through the Ocean Spectrometry Cluster (PSO), one of the most efficient analytical facilities in France for analysing major, trace and isotopic elements. The support provided by the LabexMER (e.g. workshops, international chair) has allowed even stronger interactions.

**LM2E** is the only French laboratories exclusively dedicated to study of deep-sea microbiology, including at high pressure/high temperature. LBCM has expertise in culturing and monitoring biofilms and in the analysis of bacteria-bacteria communication molecules. Hence, new synergy and collaborations have been naturally developed between those two laboratories: axis 3 has provided cost-sharing for the funding of a PhD project in 2013: «recognition system and cell-cell communication between host and symbionts in extreme environments: the case of *Rimicaris exoculata*».

## LABEXMER INTERNATIONAL POST-DOC FELLOWSHIPS

- **Stefan Lalonde** (PhD Canada, 2010) « Iron and Molybdenum stable isotope signatures of diazotrophic bacteria as potential tracers of nitrogen and metal cycling »
- **Daniela Zeppelli** (PhD Italy, 2010) « Colonization and ecological connectivity of meiofauna in deep-sea extreme ecosystems »
- **Julie Reveillaud** (PhD Belgium, 2011) « Génomique comparative de la symbiose Rimicaris spp de la fosse des Caïmans à la dorsale Medio-Atlantique».

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# SEDIMENT TRANSFER FROM COAST TO ABYSS

axis 4

Coordinators: **Marina Rabineau** (LDO, CNRS), **Stephan Jorry** (GM, Ifremer)

**Research units**
- Laboratoire Domaines Océaniques (LDO)
- Unité Géosciences Marines (GM)
- With contributions from DYNECO, LEMAR, LMEE.

**Research scientists:** 17
**Research engineers:** 2
**Post docs:** 5
**PhD:** 12
**Publications** (2012-): 13

## Scientific objective

Sedimentary processes occuring along continental margins are complex and result from the interaction between deep processes (Tectonics with Subsidence/Uplift) and surficial processes (Climate, Sealevel and Hydrodynamic).

The main objective of Axis 4 is to understand and quantify, using marine sediment archives, all changes related to natural parameters (climate, sea level, hydrodynamic and paleoceanographic, tectonics) and decipher their relative impact and timing on sedimentary fluxes from continental erosion, sediment transport and deposition.

## Science highlights

In phase 1 of the LabexMER, Axis 4 decided to divide its actions into 3 major compartments (3 themes) of the Source to Sink system themes : the Source (Erosion processes), the transfert processes along the course of sediment movement and the Sink.

Results from team members enabled to show :
- The link between Source and Sink : the need to compare methodologies to quantify continental erosion in source areas to sediment deposition in the deep sea (Leroux *et al.*, in press ; Molliex *et al.*, submitted)
- Deep-sea turbiditic environments can be used to study the climate impact on Land to Sea transfers (Toucanne *et al.*, 2012; Bonneau *et al.*, 2014; Skoniezny *et al.*, submitted)
- The novel use of sedimentary markers to quantify sediment budgets, subsidence and isostatic rebound (Rabineau *et al.*, 2014; Leroux *et al.*, 2014; Leroux *et al.*, in press )

### Workshops, schools, invited scientists
- Participation to Organisation of summer school Geocean 2012, SFIsotraces workshop 2014,
- Organisation of PALEOCEAN 2015
- International chair in stable isotopes biogeochemistry: Aradna Tripati (UCLA)

### International collaborations and projects
Univ. Barcelona, Delft Univ., Univ. Rio de Janeiro (UERJ, UFF)

### Related (international) projects
- IODP Pre 857A
- ICDP CURVE
- Building Marine Brazil (Buzios and Brest)

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## OBJECTIVES

Sedimentary processes occuring along continental margins are complex and result from the interaction between deep processes (Tectonics with Subsidence/Uplift) and surficial processes (Climate, Sealevel and Hydrodynamic). Such processes, their origins and cons.quences are only partially known so that global models remain extremely limited and simplistic (Trincardi and Syvitski, 2005; Allen, 2008; S.mme *et al.* 2009).

Major questions remain unanswered as far as quantifying sedimentary fluxes are concerned as well as modeling precisely both solid matter transport from source to sink zones and their consequences on building margin architecture. Conditions of erosion, timing and processes of sedimentary bodies deposition and preservation as a function of paleoenvironmental and paleoclimatic conditions are still a challenge in earth science. This axis aims at reconstructing 4D sedimentary fluxes from the coast to the absyss.

The main objective of Axis 4 is to understand and quantify, using marine sediment archives, all changes related to natural parameters (climate, sea level, hydrodynamic and paleoceanographic, tectonics) and decipher their relative impact and timing on sedimentary fluxes. Among essential questions:

- Can we quantify the Source of sediment produced through time ? Fluxes at the terrestrial-coastal interface are still, in fact, very poorly known. The relative role of extreme events (storms, floods, cyclones for example) compared to more continuous record (annual, pluriannual or millenial) is still undetermined. We will therefore concentrate on the reconstruction of these events at present and in the past. Those paleoenvironmental and paleoclimatic reconstruction will be useful to test models used for predictions.
- Another important question concerns transfer of sediment towards the deep domain during phases of erosion/transport/deposition on the shelf, by gravity processes via submarine canyons but also more generally through open-slope. Scientific questions in this topic concern at the same time the characterization of the processes at the origin of the fluxes (how are canyons fed , What are the sources and triggering factors for gravity flows ?) and their role in the formation and evolution of canyons through time (What are the volumes involved, the timing, and the impacts on ecosystems) but also the biogeochemical composition of these fluxes (C and associated biogenic elements), their evolution through time and impact on global biogeochemical cycles.
- Can we quantify the amount of sediment arriving in the Sink through time?
- Can we establish real Source to Sink budgets and model the role of the different parameters ?

These questions are related to different time scales: from an event-scale (hours, day to weeks with possible direct measurements and instrumentation) to years, thousands years and million years for which internal earth processes (e.g. thinning of the crust) that govern subsidence plays a fundamental role in preservation of sediments and ought to be further understood.

**In the first phase of LabexMER, Axis 4 has been organized with 3 themes to better address these objectives.**

## Objective I – Quantifying the erosion products: the source of sediment

This theme is dedicated to the quantification of denudation of the reliefs, which are the source of the sedimentary supply. This process results from complex interactions between tectonic, climate, morphology and rock erodability. The main problem is to define those amounts on long time-scale as there are often no archives in the continental realm, and to compare them to the marine record. The other problem is to decipher the relative role of parameters.

Following this idea, Axis 4 has granted a postdoc research project dedicated to the quantification of denudation rates in two study areas: the Corsica mountains, and the drainage basin of the Gulf of Lion which are both connected to an outstanding and well-known offshore "sink" system. The aim was to define and apply different standard but also new methodologies at different time-scale using geomorphology, geochemistry (10Be ), basin stratigraphy and compare their results in a "source 2 Sink" approach.

### Results

**In the Gulf of Lion**

The Inner Alps exhibit significantly larger denudation rate values (~ 700 mm ka-1) than those estimated in other structural domains: 150-250 mm ka-1 in the foreland Alps, ~100 mm ka-1 in the Pyrenees and 55-75 mm ka-1 in the Massif Central. The alpine domain provides at least 75 % of the total eroded volume supplied towards the Gulf of Lion by all catchments. Throughout Plio-Quaternary, variations in denudation rates are highlighted including a doubling of the values since the middle Pleistocene revolution (~ 0.9 Ma). A quantitative geomorphology study shows that the relief evolution is controlled at the first order by denudation processes, a satisfactory exponential correlation between catchment morphologies and denudation rates suggesting the main role of glacial imprint over the Quaternary or present-day time periods.

**In Corsica**

(1) the amount of regolith formation through weathering is the main process responsible for denudation since it seems to be controlled by bedrock strength and vegetation cover. Al/K measurements used as a proxy to infer catchment-wide chemical weathering support this assumption. (2) The repartition of vegetation in Corsica seems to be controlled by morpho-climatic parameters (sun exposure and direction of the main wet wind). (3) Long-term denudation rates are also calculated from eroded volumes deduced from the morphology and are compared with short-term cosmogenic ones. This comparison suggests that denudation in Corsica is less efficient during glacial or deglacial periods than interglacial such as Holocene.

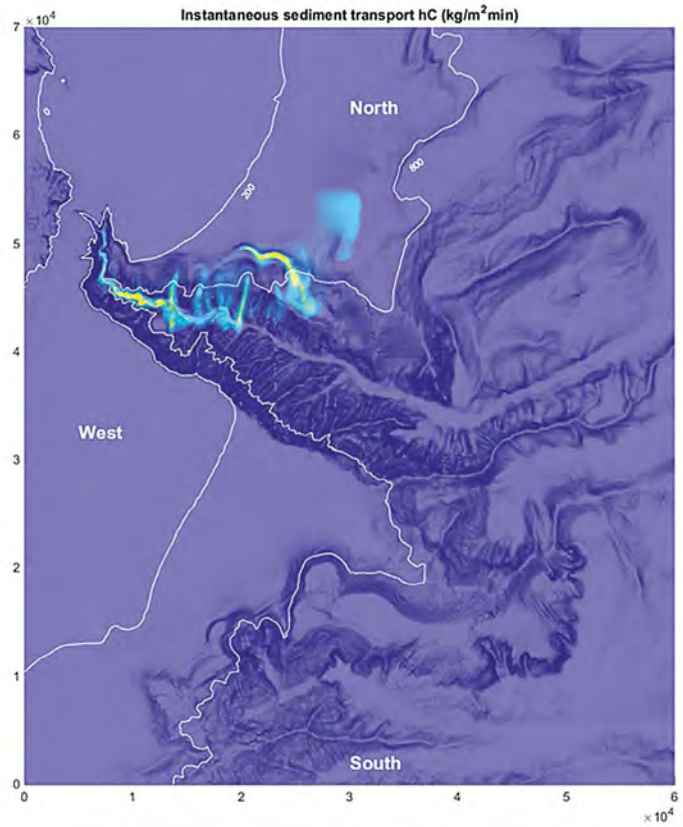
© Stéphane Molliex

Golo River in Corsica and its watershed: The «source-to-sink» seen from the source

## Objective II – Sediment transport: processes and controlling factors

This theme aims to study factors and associated processes involved in the sediment transfer focusing on modern environments, in order to predict those observed in the fossil record.

Priority has been given to innovative projects proposing to acquire some new data on river mouths, shelf or canyons in order to study mechanisms and processes at their origin. Studies conducted on the shelf of Brittany showed important results on the recent dynamic of dunes (PhD Franzetti, 2014). Studies conducted on the canyons in La Réunion also enabled to study the direct transport processes from land to Sea through canyons (Babonneau *et al.* 2013). In 2014 Axis 4 decided to explore in more details the modeling of sediment transport in canyons through a PhD thesis conducted by Marta Payo Payo (co-funded by the Axis 4) dedicated to




Model output in terms of instantaneous sediment transport (Kg/(m^2min)) due to trawling-induced turbidity currents in La Fonera submarine canyon (Northwestern Mediterranean Sea). Yellow and blue tones represent respectively, higher and lower values of sediment transport

"Modelling sediment transport and geomorphological interactions by turbidity currents in submarine canyons from western Mediterranean".

This PhD project is a collaboration between the University of Barcelona (Spain), the University of Western Britanny (France) and Ifremer (France) in a framework of an international "co-tutelle". Its aim is the application of a numerical processes-based model specifically adapted to and developed for under-water sediment-laden flows. The model is implemented to a set of French and Spanish largely studied canyons in the North-western Mediterranean Coast. The different canyons issued are geographically close; meanwhile they are submitted to contrasted controlling forcings.

## Preliminary results

A detailed review on submarine canyons and associated turbiditic depositional systems, which includes turbidity currents and state of art of numerical modelling of turbidity currents and advancement, has been made.

A numerical modelling of sediment-loaded fluxes triggered by trawling and their interaction with the sea floor was implemented to La Fonera submarine canyon. Data analysis, definition of methodology, numerical modelling of turbidity currents due to trawling has been accomplished. A good agreement between model and monitoring data has been found, with modelled peaks of suspended sediment concentration values exceeding 120mg/l and current measurements of up to 40cm/s at the mooring site. Moreover we have quantified fishing activity over the canyon flanks through modelling and have obtained the propagation pattern of sediment flows from the fishing ground downward the canyon. Our results confirm the value of numerical models to complete and enlarge our understanding of the sedimentary transfer processes from the shallow to the deep in the ocean.

## National and international conferences

- Journées Projets LES-IFREMER, Brest, Feb. 2014 - oral presentation
- RST2014 Réunion Sciences de la Terre, Oct.2014 (funded by Project INSU Action Marges - Canyons)
- Interdisciplinarity in Marine Sciences, Brest, Nov. 2014
- EUG meeting, April 2015

# Objective III - Tracing sediment sources in deep-marine environments using high-resolution stratigraphy, geochemistry and paleoenvironments

The study of deep turbiditic environments has long been considered as unsuitable for paleoenvironmental, paleoclimatic and chronostratigraphic studies. However, very recently, our teams in Brest have proven that using the very detailed knowledge of sedimentary processes in a turbiditic sequence, it was possible to apply conventional chronostratigraphic and paleoclimatic analysis using carefully sampled, specific layers within a turbidite.

A number of studies including PhDs were conducted in Brest on this subject (led by Jorry, Toucanne, Babonneau, Cattaneo, Dennielou) among them, several projects were directly funded or supported by LabexMER and the Axis 4: G. Ratzov/A. Cattaneo/Babonneau, Samuel Toucanne, and Charlotte Sckoniesny within the framework of her postdoctoral fellow. Objectives and preliminary results of this postdoc entitled "Characterization of the Ogooué River terrigenous inputs to the equatorial Atlantic during the Holocene: Interactions between climate, weathering and humans in Central Africa" is given hereafter. The initial objectives were to:

- Better constrain forcing influencing the terrigenous inputs on the african equatorial Atlantic margin during the last glacial/interglacial cycle.
- Try to discriminate the influence of Climatic and Human forcings on the transfers of sediments from the Ogooué basin to the Gulf of Guinea margin during the Holocene.

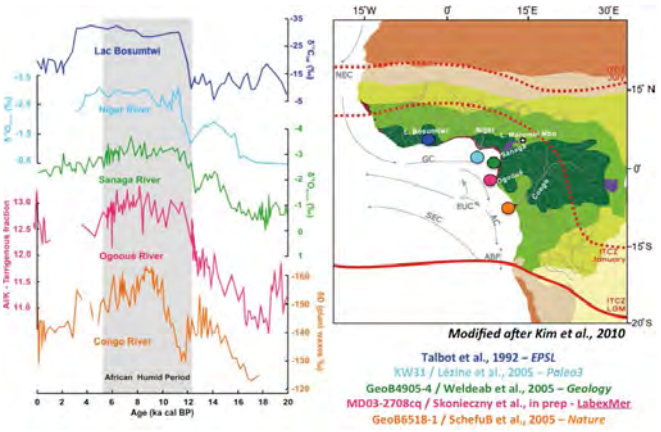
First results suggest a strong climatic forcing recorded in the terrigenous fraction of the sediments transferred from the Ogooué River to the West African margin during the last 25ka , with in particular:

- A well-marked Holocene African Humid Period (AHP-maxima of insolation) signal in the chemical alteration proxies.
- An interesting correlation during AHP between the signal of weathering of the Ogooué basin with the hydrological and weathering proxies changes recorded in the Niger, Sanaga and Congo neighboring basins.

## Diffusion of the results

**International conferences as first author:**
Skonieczny *et al.* - International Congress on Dust - Italy, June 2014 - Oral Presentations
Skonieczny *et al.* - International Congress on Quaternary - Japan, July 2015 - Oral + Poster Presentations

Finally, in the most mature area, studied in Brest for a number of years: i.e. the Gulf of Lion the "Source to the Sink" approach, supported by the LabexMer initiative, led to a number of key synthetic papers dealing with the quantification of key controlling factors, published in 2014 or 2015




**Gulf of Guinea paleorecords for the last 25kyr. Each color corresponds to a core plotted on the map and a paleorecord (curves) together with the corresponding reference. The grey band corresponds to the African Humid Period.**

# CONFERENCES AND SUMMER SCHOOLS CO-SPONSORED BY LABEXMER

Axis 4 has contributed, with axis 3, to the organization of the **summer school GEOCEAN** (August 27-31th 2012, Brest) with Invited lectures covering fundamental aspects of geodynamics and petro-geochemical processes.

Axis 4 has contributed, with axis 3, to the organization of the **workshop SFIsotraces** (8-12th September 2014, Brest), with two «short courses» on the themes of Marine Biogeochemistry and Paleoceanography were proposed.

Axis 4 organized **PALEOCEAN**, a 3 days national conference that brought together the national community on Paleoceanography (4-6th February 2015, Brest) with international high level lectures prior to the meeting. This conference and school gathered over 95 young and established scientists. Invited lectures covered fundamental aspects of Paleoclimate Modeling and Emerging Geochemical Proxies in Paleoceanography. This was the first time that this national meeting (held every 3 years) was held in Brest, recognition of the new development of that field here.

## INVITED SCIENTISTS

Axis 4 and Axis 3 have co-sponsored the LabexMER lecture series, and invited 5 candidates to the "Stable Isotopes International Chair", giving them an opportunity to visit our laboratories and give a lecture. (Thibaud Caley, Aradhna Tripati, Johann Etourneau, Mickaël Hermoso, Nicolas Chevalier). Accomplishment of this effort is the recruitment of Aradhna Tripati (Assistant Professor at UCLA), who will conduct the Chair for the next three years. Collaborations between Aradhna Tripati and Axis 4 research team are well under way.

## ENHANCING SYNERGIES

An attempt has been made in order to trigger collaborations with continental geologists (e.g. Stéphane Molliex's postdoc), which is a real added value for the LabexMER geoscientist community, exclusively focused on marine environments. This effort will stimulate discussions to develop further research projects integrating a view from land to deep sea.

In close collaboration with Axis 3, Axis 4 has contributed to initiate the project of the International Chair in Stable Isotopes. The venue of Aradhna Tripati in Brest should give a strong scientific impact on local, national, and international scientific communities.

## CRUISES SUPPORT

Cruises at sea are a key component of axis 4. LabexMer supported a number of key international cruises at sea during phase 1 :

- 2012 MARLBORO2 (P. Leroy)
- 2013 BATHYBAB (N. Babonneau)
- 2013 AMED-1 (M. Rabineau)
- 2014 DIONYSUS (M.-A. Gutscher)
- 2014 MISMARMARA (D. Birot)

## LABEXMER INTERNATIONAL POST-DOC FELLOWSHIPS

- **Charlotte Skonieczny** (PhD Lille, France, post-doc in Belgium) "Characterization of the Ogooué River terrigenous inputs to the equatorial Atlantic during the Holocene: Interactions between climate, weathering and humans in Central Africa"
- **Thibaut Caley** (PhD Bordeaux, post-doc Amsterdam) "Revealing South East African past climate, its link to sedimentary fluxes and Hominid evolution"

## PUBLICATIONS


Babonneau N. *et al.* (2013). Mar. Geol. 346, 47-57.

Bonneau L. *et al.* (2014). J. Geol. 122, 687-703.

Courgeon S. *et al.* (2015). AAPG Bull. In press.

d'Acremont E. *et al.* (2014). Tectonophysics 632, 160-166.

Deschamps A. *et al.* (2014). Geophys. Geosyst. 15, 2128-2150.

Franzetti M. *et al.* (2013). Mar. Geol. 346, 17-30.

Le Saout M. *et al.* (2014). Geochem. Geophys. Geosys. 15, 4380-4399.

Leroux E. *et al.* (2014). Terra Nova 26, 230-238.

Pellegrini C. *et al.* (2015). Mar. Geol. 362, 43–59.

Piete H. *et al.* (2013). J. Geophys. Res. Oceans 118, 2329-2344.

Rabineau M. *et al.* (2014). Earth Planet. Sci. Lett. 388, 353-366.

Ratzov G. *et al.* (2015). Geology In press.

Reis A.T. *et al.* (2013). Geomorphology 203, 25-45.

# DYNAMICS AND VULNERABILITY OF COASTAL ZONES

axis 5

Coordinators: **Serge Suanez** (GEOMER, UBO), **Nicolas Le Dantec** (LDO, CEREMA)

**Research units**
- LETG-Brest-GEOMER
- Laboratoire Domaines Océaniques (LDO)
- AMURE (law and economy)
- Collaboration with LPO (Ifremer)

**Research scientists:** 25
**Research engineers:** 4
**Post docs:** 2
**PhD:** 10
**Publications** (2012-): 11

## Scientific objective

As our world's population has been increasingly concentrating on a narrow coastal strip, the "**coastal challenge**", i.e., developing coherent and long-term strategies for an integrated management of the coastal zone, is one of the major challenges in the coming decades. The objective of axis 5 is to **observe and understand coastal vulnerability** arising from the **combination of natural and complex social dynamics**, so as to devise sustainable management strategies addressing social and economic stakes. Physical, social and economical observation relying on multi-system approaches and providing integrated data to dedicated GIS (Geographic Information Systems) will yield a knowledge base of coastal vulnerability.

## Science highlights

**Coastal hydrological and morphological dynamics**
- Large infragravity wave events contribute to the extreme water levels involved in quarrying, transport and deposition of cliff-top storm deposits (CTSD)
- Observations and predictions of wave runup related to dune erosion

**Coastal vulnerability:** Interdisciplinary approach aiming at devising and implementing methodologies dedicated to improving strategies for management of coastal risks (ANR COCORISCO)

**Automatic cartography applied to coastal management:** Creation and implementation of an Open Source GIS tool to quantify human activities (example of marine traffic fluxes based on semaphore data (CARTAHU project)

**Marine and coastal ecosystem evaluation** (International chair of Linwood Pendleton): Development strategies and protocols to identify opportunities for marine restoration and protection to counter the effects of climate change on coastal areas.

### Workshops, schools, invited scientists
- SAGEO 2013, COCORISCO summer school 2014
- Prof. Suzanne Moore (Australia)
- Prof. Giovanni Coco (New-Zealand)

International chair in marine and coastal ecosystem evaluation (Linwood Pendleton, Duke University).

### International collaborations and projects
- Québec (Canada): coastal risks and land use
- Australia: tourismin coastal zones
- Morocco: coastal morphodynamics and resources assessment
- Island: coastal morphodynamics
- Plymouth University: beach modeling

### Related projects
GEF "Blue Forests", ANR COCORISCO, CARTAHU

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© Serge Suanez / UBO

## OBJECTIVES

Coastal vulnerability results from the combination of natural and complex social dynamics. The development of coherent and long-term strategies concerning coastal management issues is one of the major challenges in the coming decades. In a context of global environmental change, variability of climate-ocean conditions and continental hydrology at various scales of time and space and extreme societal pressures of recent decades, vulnerability to various natural and social hazards is an essential parameter to consider for an integrated management and sustainable development of the coastal zone. Studying the dynamics and the vulnerability of the coast mobilizes a large number of stakeholders from different fields to address both natural and social components of the stressors and of the associated coastal stakes: weather events, erosion, flooding, pollution, overfishing, coastal planning (urban and agricultural), touristic pressure, ecosystem preservation, etc. A deep knowledge of the anthropic systems and the services provided by the resources is required to evaluate the acceptable pressure threshold and estimate the pressure contribution in a more general level through synthetic indicators.

The axis 5 is following both scientific and operational objectives. On one hand, it concerns enhancing the understanding and comprehension of the coastal dynamics and the induced vulnerability of coastal territories. This is achieved through taking into account the variability of both natural and anthropogenic forcing acting on different spatio-temporal scales. On the other hand, and based on this in-depth knowledge, it concerns bringing out elements to support public policy for the management of coastal vulnerability, such as erosion or coastal flooding, coastal environment pollution (hydrocarbons, heavy metals, etc.), taking into consideration the effects of climate changes.

To achieve this, the research realized in this axis needs to develop our knowledge of natural and social dynamics affecting coastal territories:

- The work is based on observing and measuring the mechanisms leading to critical situations in areas with high pressure. The complexity of the research's subject imposes using in synergy different observation tools (field measurements, sociological investigations, economic evaluations, satellites images, airborne, naval, and terrestrial) and developing observation methodologies accordingly.
- As such, the vulnerability issue of the coastal territories is spatially and economically quantified though dynamic analyses of the ground use and occupation, and social and economic issues.
- It also concerns identifying and analyzing coastal representations of coastal vulnerabilities by different social groups present in these territories, and to study the modalities and the role of different actors in the governance and decision-making.
- Based on this knowledge, the final aim is to model these dynamics and their impacts. This will allow us predict different scenarios and reliable prospective that may be used in a managerial context.

# SCIENTIFIC RESULTS

Actions were declined under 5 main topics.

## 1 - Analysis of natural and anthropogenic forcing factors affecting the vulnerability of coastal areas. Several actions were lead to address this question

- **Hydrodynamics**: run-up, set-up: ANR COCORISCO and DYNATREZ1 project
- **Coastal morphodynamics**
  - multitemporal evolution of the morphology of sedimentary structures including submarine dunes: R. Cancouët's engineering position and SPEEDUNES project
  - kinematics of coastline with E. Blaise's thesis on «Dynamic coastline sandy shore in Brittany. The measurement of dynamic morphosedimentary to the establishment of an operational and sustainable observatory»
  - issues on the morphodynamic of the Moroccan coast ; the EXTREVENT project on morphodynamics of megablocks, including R. Autret's thesis on «Extreme events and their morphosedimentary signatures across the North Atlantic basin: study of the dynamics of morphosedimentary megablocks»
  - CLIFF project on characterization of coastal cliffs in Brittany
- **Dynamics of suspended particulate matter**: seasonal fluxes in the Aulne Estuary
- **Fate of pollutants**
  - dynamics of trace metals in the Gulf of Morbihan from isotopes analysis
  - transformation of hydrocarbons from accidental pollution in collaboration with Russian colleagues
- **Mapping of anthropic usages in the coastal zone**
  - Sustainable management of holothuries along Morocco's Atlantic coast
  - modeling urban sprawl: MetalUrbain project
  - comparative study on tourism and recreational activities in coastal areas between Australia and France
  - spatiotemporal analysis applied to automated mapping of fisheries: DACTARI project)

## 2 - Development of tools and methodologies for the observation and understanding of coastal natural and anthropogenic dynamics

- **Forcings and physical dynamics**
  - shallow water bathymetry for diachronic studies on kinematics and budgets for sediment dynamics
  - initiation of a collaborative project on ROV autonomous navigation using multibeam data
  - conception of an experimental tank to improve inversion algorithms for turbidity measurement with the TURBID-EX Project)
- **Spatial analysis and mapping**
  - A. Le Bris' thesis on «Space and airborne remote sensing of the coastal colonization by wild oysters»
  - the CARTAHU project with A. Minelli's post-doc

## 3 - Socio-economic Assessment of Vulnerability

- International Chair of Linwood Pendleton
- Thesis of O. Marcone on «Strategic use of economic evaluation in the development of a program of measures for the European Water Framework Directive Strategy for the Marine Environment»
- Thesis of J. Timor «The vulnerability as a framework for economic analysis of the relationship between risks and impacts. The case of the crisis of excess mortality of oysters in France»
- Thesis of A. Comte on «Strategies to minimize the impacts of ocean acidification»

## 4 - Perception And vulnerability management

- Coastal Risk Management with the thesis of L. Mineo-Kleiner in collaboration with UQAR (Canada) on «The option of relocating goods and activities deal with coastal hazards: territorial strategies and issues in France and Quebec»
- ANR COCORISCO

## 5 – Modeling

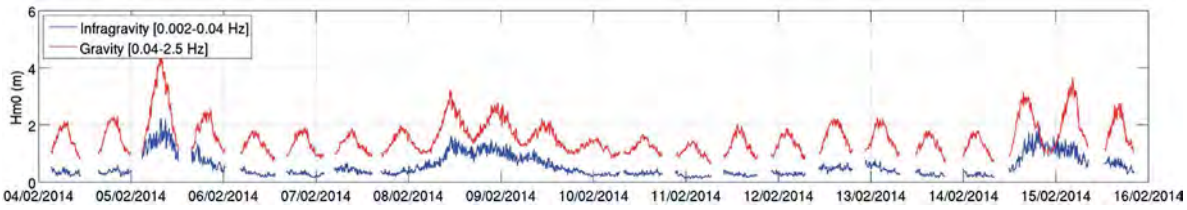
- Modeling of socio-ecosystems issues with the thesis of K. Bentorcha on «Socio-ecosystem modeling shellfish specialization within an ecosystem approach»
- Modeling of physical forcings (beach hydrodynamics waves and morphodynamics)

# FOCUS ON SELECTED RESULTS

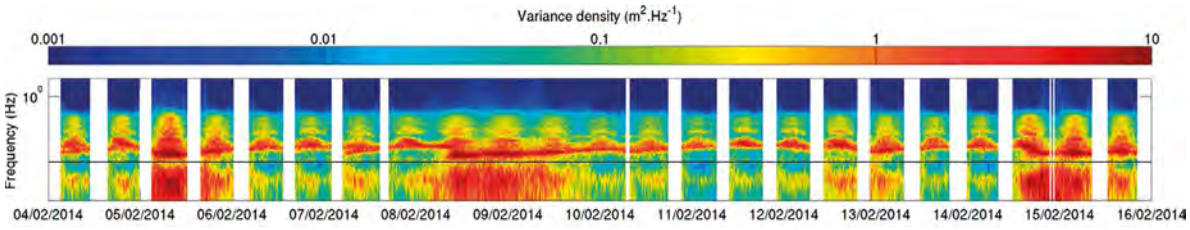
## Coastal hydrological and morphological dynamics

### Large infragravity wave events contribute significantly to the extreme water levels involved in the formation on cliff-top storm deposits at Banneg island.

On February 2014, several major storms hit the coasts of Brittany and caused large waves in the Molene Archipelago. Based on pressure sensor measurements in the intertidal zone at Banneg islands, variance density spectra were computed and significant wave heights for the gravity (0.04 – 2.5 Hz) and infragravity bands (0.002 – 0.04 Hz) were estimated. Infragravity significant wave heights over 2 m were observed on February 5 (Fig). These long period oscillations of the water surface are likely to explain the extreme water levels observed on Banneg island through morphogenic evidence [Suanez *et al.*, 2009].



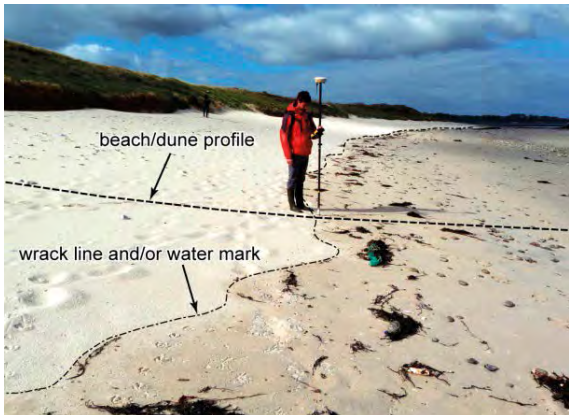

Time series of significant wave heights for the gravity (red line) and infragravity (blue line) bands, estimated from pressure measurements at Banneg islands 04-16/02/2014.



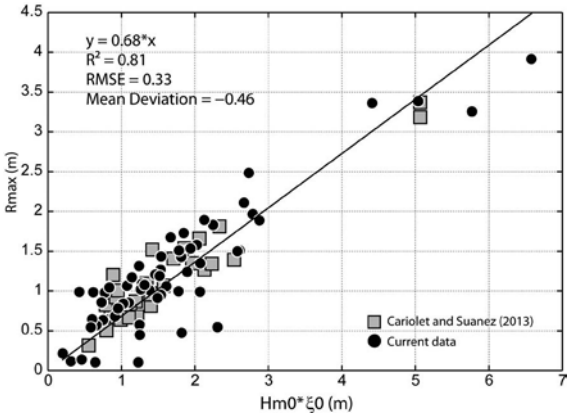

Time series of variance density spectra estimated from pressure measurements at Banneg islands between 04/02/2014 and 16/02/2014.

## Observations and predictions of wave runup

The research is related to dune erosion during storm conditions. It is based on swash elevation (wrack line and/or water mark), and morphological (beach profile) and hydrodynamic (wave and water level) measurements, under different meteorological conditions. This allowed to assess runup formula effectiveness on a macrotidal sandy beach and to determine the best slope parameters to estimate runup. The results suggest that on that macrotidal sandy beach the slope of the active section of the upper beach should be used instead of the entire slope of the foreshore, the latter resulting in an underestimation of runup elevations when used in predictive equations from the literature. Results obtained were enabled the calibration of a runup estimation formula with a relatively good fit to the study site (r2 = 0.81).




DGPS Measurement of beach/dune profile and the limit reached by the maximum swash elevation.




Correlation between observed runup (Rmax) and Hmoξo. Equation Rmax = 0.68Hmoξo is obtained.

Suanez S.*, Cancouët R.*, Blaise E.*, Floc'h F.**, Ardhuin F.***, Delacourt F.*
* LETG-Best-Géomer UMR 6554, ** LDO UMR 6538, *** LPO Ifremer

## Coastal vulnerability

COCORISCO (Knowledge, Understanding and management of Coastal Risks, COnnaissance, COmpréhension et gestion des RISques CÔtiers (erosion and submersion)) is an interdisciplinary project aiming at devising and implementing methodologies dedicated to improving strategies for management of coastal risks.

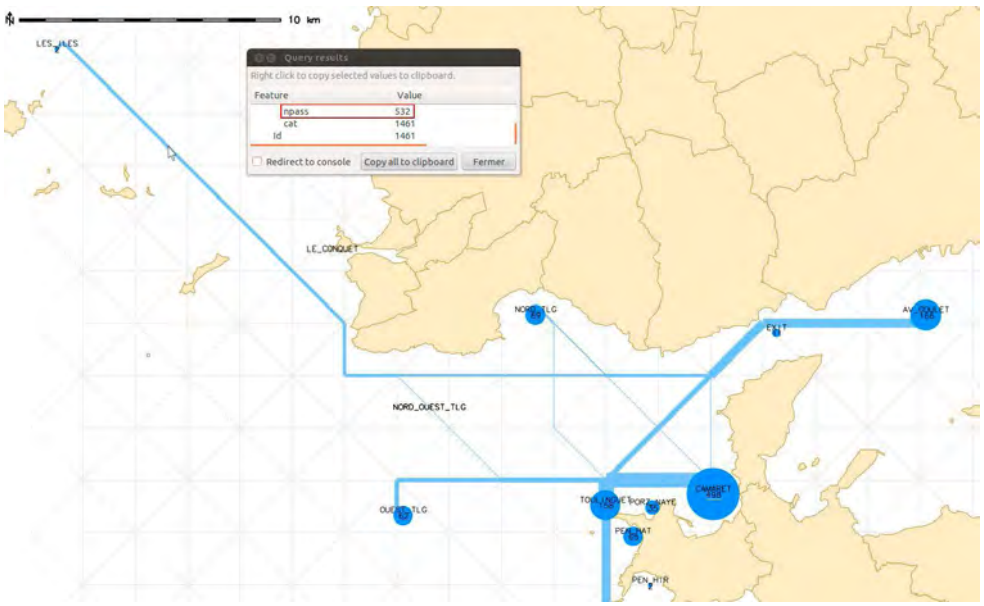
The four components of systems vulnerability: coastal dynamics and hazards, stakes and their assessment, representation of coastal vulnerability and current management approaches of coastal risks, have been analyzed through discipline-specific and interdisciplinary approaches. The main results of this project consist of three doctoral dissertations, the organization of an international workshop and summer school on Coastal Risks and the publication of a methodological guidebook for management of coastal risks of erosion and submersion: Hénaff A. (Ed.), Philippe M. (2014).


Gestion des risques d'érosion et de submersion marines, guide méthodologique. Projet Cocorisco. 156 p. Online : http://www.risques-cotiers.fr/fr/boite-a-outils/guide-cocorisco ISBN: 978-2-9549569-0-9.

## Automatic cartography applied to coastal management

### A GIS tool to evaluate the spatiotemporal evolution of marine traffic using sémaphore data. Application to French coastal zones

Monitoring of marine activities and integrated management becomes a priority for marine spatial planning. In the frame of the CARTAHU project, we have created an Open Source GIS tool which quantifies the marine traffic fluxes on specific routes based on sémaphore data of boat registration. Automated generation of synthetic path based on boat traces allows grouping traffic fluxes and achieving a spatiotemporal continuity of the traffic.




The output of the model is a set of maps like the one shown above, each one with its own timestamp, carrying the traffic information in each segment of the net and each gate (start/ending point of the route) through the parameter « npass».

## CONFERENCES AND SUMMER SCHOOLS CO-SPONSORED BY LABEXMER

International conference SAGEO 2013 (Spatial Analysis and Geomatics) - 23-26 September 2013, organized jointly by F. Gourmelon (LETG-Brest-Géomer) and R. Thibaud (IRENav - Ecole Navale) (http : //sageo2013.sciencesconf.org/). LabexMER helped support one of three speakers (R. Devillers of Memorial University of Newfoundland, Canada). A special issue of the International Journal of Geomatics together the six best papers of the conference has been published: Gourmelon F., Thibaud R. (Eds.). Traitement de l'information et prospective. Revue internationale de géomatique. Lavoisier. 25 (1/2015), 143p.

Summer school and international symposium on coastal risks organized at IUEM as a the culmination of the COCORISCO project: Proceedings of the International Symposium « Connaissance et compréhension des risques côtiers : Aléas, Enjeux, Représentations, Gestion ». 3-4 July 2014, IUEM, Plouzané, 486 p. Online : http:// cocorisco.sciencesconf.org/

## INVITED SCIENTISTS

Prof. Susan Moore, head of the «Nature Based Tourism Research Group» at Murdoch University (Perth, Australia) was invited at LETG-Geomer in April 2014. Her research activities mainly revolve around the following topics that are common with the LETG-Geomer: areas (marine) protected and tourism, environmental impacts, study and attendance tracking, management, development, regulation, perception and representation, integrated management of the coastal zone. The visit was organized around work meetings (presentation of the two respective thematic labs, discussions on joint research projects) and field trips, including the workshop area Brest iroise (Zabri) and a LabexMER series seminar «Observation and modeling of human activities in coastal sea». A partnership agreement has now been signed between our two universities to facilitate future collaborations.

Dr. Giovanni Coco, researcher at the University of Cantabria, now Prof. at the University of Auckland, was invited by LabexMER in June 2016 in the framework of the International Chair in coastal dynamics. The project PITS (Patterns in the Sand) initially designed to accompany that chair, will still nourish interdisciplinary collaborations between G. Coco and involved researchers of axes 1, 5, 6 and 7. PITS addresses the future of our coastlines, studying how their morphology changes over time, from the development of mesmerizing patterns to altering hazards and risks related to storms and flooding. The underlying scientific work consists in examining how feedbacks and nonlinear interactions (including the ones resulting from the combination of physical and biological processes) shape natural environments over a variety of spatial and temporal scales.

## ENHANCING SYNERGIES

Among the main satisfactions, note the diversity of projects and actions financed, meeting the objectives of the roadmap: post-docs and project engineer recruitment, (ii) support for ongoing or starting projects (including support for the organization and / or participation in scientific events), (iii) outgoing and incoming mobility, (iv) stipend for Master2 internship abroad. The actions undertaken allowed the initiation of new collaborations with foreign research teams (Canada, Australia, Iceland, Morocco, Plymouth University, Duke University). The leverage effect was particularly significant, especially for projects that have received little support for their launch and now lead to new areas of research, sometimes with thesis projects already engaged. From the point of view of project funding, the actions supported by axis 5 during the first phase also enabled to federate synergies around key questions and to build momentum and material for applications to national and international agencies (ANR, INTERREG project, project PICS CNRS, regional programs) on multidisciplinary projects.

## INTERNATIONAL CHAIR IN MARINE AND COASTAL ECOSYSTEM EVALUATION

During the course of the first phase of LabexMER, the research unit AMURE (law and economy of the sea) has been associated to LabexMER. As such, the ripple effect allowing research structures of the second circle to integrate the structure LabexMER fully worked for the axis 5. This has made possible the development of a new research theme and the recruitment of an international chair, Linwood Pendleton, on the development of strategies and protocols to identify opportunities for marine restoration and protection to counter the effects of climate change on coastal areas. Linwood Pendleton (University of Duke, U.S.A., former NOAA Chief Economist) is the leader of the international community on marine ecosystem services component of the Partnership for Ecosystem Services (ESP www.fsd.nl/esp). The assessment and conservation of marine ecosystem services is the heart of the work program of the International Chair. The concept of ecosystem services provides a conceptual framework to identify the links between ecological and social well-being. The work program of the chair includes a research component projects and a training component on the issue of information and assessment for the prioritization of public action for the conservation of marine and coastal ecosystems. The first part of the work involves a critique of how the analysis of the vulnerability is currently being mobilized globally in response to the expectations of the IPCC, to rethink the link between global approach and local approach. Applications include the assessment of socio-economic impacts of ocean acidification and exploitation of the deep ocean. The other component is the economic valuation of ecosystem services has resulted in the development of the triage concept in the Interreg project VALMER (www.valmer.eu) and continues in various international projects: Blue Forest (GEF financing on the blue atoms) SYNTEC (measurement and mapping of non-local ecosystem services, financing Nature Conservancy).

## LABEXMER INTERNATIONAL POST-DOC FELLOWSHIPS

**Susanne Moskalski** (PhD USA, 2010) "Storm effects on suspended sediment flux and marsh sediment deposition in two estuaries in Brittany"

## PUBLICATIONS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Chaibi M. *et al.* (2014). Physio-Géo 8, 101-119.

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Gourmelon F. & Thibaud R (2015) Sageo 2013, ed Lavoisier (Lavoisier), 143 p.

Maanan M. *et al.* (2015). Sci. Total Environ. 511, 407-415.

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Sheremet A. *et al.* (2014). Geophys. Res. Lett. 41, 976-982.

# EVOLUTION OF MARINE HABITATS AND ADAPTATION OF POPULATIONS

axis 6

Coordinators: **Cedric Bacher** (Dyneco, Ifremer) and **Christine Paillard** (LEMAR, CNRS)

**Research units**
- Laboratoire des sciences de l'Environnement MARin (LEMAR)
- DYNamiques de l'Environnement Côtier (Dyneco)
- Laboratoire Biotechnologie et Chimie Marines (LBCM)

**Research scientists**: 38
**Research engineers**: 2
**Post docs**: 5
**PhD**: 8
**Publications** (2012-): 24

## Scientific objective

In the frame of global changes, major disturbances of marine ecosystems result in individual responses to environmental stress which affect biological traits, behavior and adaptative capacities. The objective of axis 6 is to analyse and simulate the evolution of marine habitats, taking into account the adaptation of populations.

## Science highlights

An International Chair in Evolutionary Marine Ecology has started in 2012. Its objective is to examine processes of acclimatization and adaptation of marine organisms to global change. Five projects are associated with the ICEME and examine a number of processes in order to better understand how marine organisms are likely to fare under environmental change.
Three series of small risky projects have been funded by Axis 6 (2012, 2014, 2015). Such projects allow to explore new ideas and test new methods. Topics address genomics and transcriptomic issues, paleo-ecology and -epidemiology, host-parasits interactions in phytoplankton, trophic and habitat ecology and ecophysiology. ANR and international projects were submitted based on the first results of these small projects.
Axis 6 has also established links with other axis, benefited from the Inter-Axis Labex funding scheme, and contributed to joint workshops and Summer schools. Through the organisation of scientific seminar on topics of interests (e.g. modelling, connectivity, NGS, symbiosis), Axis 6 also contributed to the scientific activity of Labex and non-Labex partners.
International collaborations have been facilitated by Axis 6 funding of the mobility of young scientists, invitation of foreign scientists, participation to an international research network and joint projects.

### Workshops, schools, invited scientists

- AIMEN summer school 2013 (with axis 2) International workshop «Microplastics», 2014
- Universités d'été Mer-Education «Risques Côtiers» (2013) et «Changement climatique « (2014)

Invited professors: J. Lapeyre (LSU, U.S.A.) and M. Lapeyre (USGS, U.S.A.), E. Hoffman (ODU, U.S.A.), G. Marques (U Lisboa, Portugal), L. Firth (U Ireland)

International chair in Evolutionary Marine Ecology: Flavia Nunes

### International collaborations and projects

- Danish Council for Independent Research / Natural Sciences: ArcheoSHELL
- Louisiana Sea Grant College Program: DEB-virginica
- French-Canadian International Group of Research «RECHA-GLO» (2014 2018): Responses of exploited fish and shellfish populations, communities and habitats to global changes.
- EU- H2020: AQUASPACE

**Related projects**: ANR BIOMANGO, EC2CO MODICREP, EC2CO PALMITO, EC2CO MICROPAL

**Submitted projects**: ANR OSMOSE, ANR CREPIDULE, ANR ADRECO, EU-H2020 VIVALDI

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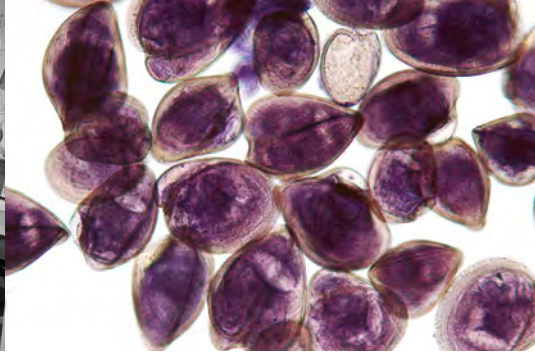

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## OBJECTIVES

We propose to analyse and simulate the changes of marine biodiversity due to environmental and anthropogenic pressures by integrating multiple scales of drivers/responses. Disturbances of marine ecosystems result in individual responses (behaviour, physiology, evolution, ontogeny) to environmental stress which therefore affect biological traits (growth, reproduction, fecundity, immunity, etc.), adaptive capacity of living organisms and spatio-temporal dynamics of populations. At a larger scale, physical habitats, distributions of populations and structure of communities are also modified by environmental changes (e.g. temperature, contamination by chemicals, eutrophication, hydrodynamics and morphodynamics).

For this purpose, specific objectives have been identified:

- Assess adaptive and physiological responses through (i) the reconstruction of past evolution by using sclerochronology, sclerochemistry, molecular and physiological proxies, (ii) the quantification of adaptive capacity and evolution by combining experimental approaches, molecular biology and quantitative genetics.
- Characterize habitats and biological communities through analysing and identifying structuring factors (e.g. morphosedimentary and hydrodynamics forcing, engineering invasive species, implantation of marine renewable energy technologies, etc.), mapping habitats mosaics and studying species assemblages in different types of environment.
- Formulate and couple interactions to simulate (i) physiological responses, (ii) changes of biotopes, distributions and ecological niches for target species, (iii) benthic and pelagic population dynamics, (iv) distribution of communities.
- Reconstruct past changes, test hypotheses and simulate scenarios of future changes by integrating models at different scales (organism, population, and habitat).

## SCIENTIFIC RESULTS

### International Chair in Evolutionary Marine Ecology - F. Nunes

The central theme of the International Chair in Evolutionary Marine Ecology is to examine processes of acclimatization and adaptation of marine organisms to global change. Organisms can respond to changes in their environment in three ways: by evasion, acclimatization or adaptation. Organisms can evade suboptimal conditions by migration or changes in behavior that allows the organism to survive in a new or modified niche. For example, range shifts towards cooler regions have been observed in some species in response to increasing sea surface temperatures. The ability to evade suboptimal conditions depends on the dispersal ability of the species, the availability of suitable habitat in the new location, and the process of becoming established. Acclimatization is an organisms' ability to adjust to a new or changing environment, and depends largely on the phenotypic plasticity of the organism. Some organisms are capable of adjusting to a large range of environmental parameters, while others are more constrained in their response. Acclimatization usually refers to processes occurring during an individual's life span, and can vary among individuals as well as populations of the same species. Finally, organisms can adapt to new environments via natural selection, a process occurring over multiple generations, and acting at the level of populations. The projects associated with the ICEME will examine a number of these types of responses in order to better understand how marine organisms are likely to fare under environmental change.

## Project 1: Effects of thermal stress and acidification on larval development in marine molluscs

Increasing global temperatures and ocean acidification are chronic stressors to marine ecosystems today. To better understand how marine molluscs will respond to the changing climate, global gene expression profiles and accompanying morphological change during early larval development can be compared under different temperatures and acidities. Comparisons during early development are essential because this is when organisms begin calcification processes, whilst remaining sensitive to environmental change. It is also unclear how different species will respond to climate change, and to date few multi-species comparisons investigating the effects of thermal and acidic stress have been carried out. A major aim of the project is to use RNASeq to provide a quantitative and qualitative assessment of changing patterns in gene expression during development, across thermal and acidity treatments and among species. Target species concern Pacific oyster, European abalone, Manila clam and Great scallop. For instance, *C. gigas* larval phenotype after 38 hours reveals interactive effects of pH and temperature on larval size and calcification. Proteomics data for *C. gigas* reveal that pH reduces expression of key metabolic proteins including arginine kinase and ATP-synthase, as well as expression of extra-cellular matrix proteins.

## Project 2: Adaptation and acclimatization of the reef-building worm, *Sabellaria alveolata*, to temperature and consequences in a changing climate.

The honeycomb worm, *Sabellaria alveolata*, is an ecosystem engineer responsible for the construction of some of the most extensive biogenic reefs in the temperate coast of Europe. Assessing the potential impacts of environmental change on the honeycomb worm is of high importance in understanding and conserving littoral biodiversity. Furthermore, the latitudinal range of this species, occurring from Scotland to Morocco, makes it an ideal study system for examining the effect of climate on different populations. The aim of this project is to assess local adaptation and phenotypic plasticity of *S. alveolata* in relation to local environmental parameters in order to make predictions about evolutionary and acclimatisation potential in a changing climate. Sampling of 13 populations for evaluation of neutral population genetic structure, and identification of genes under selection have been conducted. Experimental work include : DNA extraction for RADSeq, phenotypic plasticity during larval development of 5 populations of Sabellaria alveolata, adaptive gene expression profiles (RNASeq) in adults from 5 populations along a latitudinal gradient.

## Project 3: Disease resistance in natural populations of the European abalone, *Haliotis tuberculata*

In Europe, over the last few decades, an emerging disease has caused high mortality in natural populations of the European abalone *Haliotis tuberculata*. Mortality is associated with a bacterial pathogen, *Vibrio harveyi*, capable of infecting its host only when it is mature and when the water temperature surpasses 17°C. In light of the strong association of virulence and temperature, climate change is threat of great concern for this species. The goal of this project is to understand the mechanisms of disease resis-



**The European abalone *Haliotis tuberculata***

tance in European abalone, including genetic resistance, immune priming or even an immune memory. Experiments and analyses address the identification of a resistant population, the characterization of cellular immune response of individuals in sensitive and resistance populations, the gene expression profiles (RNASeq) of hemolymph of healthy and diseased abalone.

## Project 4: Symbiotic relationships in jellyfish of the marine lakes of Palau

This project is a small contribution to an ongoing larger project led by Philippe Pondaven and Herwig Stibor (Axis 2) on trophic structure in the marine lakes Palau. This is a pilot study to determine whether a grant proposal for future work on this system could be envisioned over the course of the ICEME.

The marine lakes of Palau are an exceptional natural experiment for examining evolution in marine organisms. Jellyfish in the lakes have experienced rapid species evolution as a result of isolation from the main lagoon population into a series of lakes of different geological ages and of contrasting environmental characteristics.

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**Jellyfish in the marine lakes of Palau**

Jellyfish in these marine lakes therefore provide an extraordinary example of rapid adaptation to new environments.

Symbiotic relationships represent equilibrium of the interaction between host and symbiont. These interactions can change over time, because of changes in the cost and benefits of the interaction, and there are known examples of shifts from mutualism to parasitism, the reverse, or to a breakdown of the relationship (Sachs et al). In the context of the marine lakes, as jellyfish in isolated lakes are now exposed to a new set of environmental variables, we hypothesized that symbiotic interactions could evolve alongside species evolution. In addition, we explore the question of whether symbiotic associations help or hinder adaptation into a new environment, thereby influencing the rate of species evolution.

## Project 5: Adaptation along a latitudinal gradient: genetic diversity, population connectivity and phenotypic plasticity in the amphi-Atlantic coral *Madracis decactis*

This project was recently funded by Europole Mer. The project was originally envisioned as an opportunity to strengthen collaborations between the Institut Universitaire Européen de la Mer (IUEM) and laboratories working on coastal marine invertebrates in Brazil. There are also plans to include collaborators from Naturalis Museum in Leiden and University of Milano-Bicocca in Italy, making this a fully international project. This project will serve as a starting point for collaboration, by providing the partners the opportunity to develop an initial pilot study, which could then be used as a starting point for a larger grant proposal.

The goal of this project will be to establish a baseline for genetic connectivity and genetic diversity in Madracis decactis across its range, to search for genes which may be under selection in populations inhabiting contrasting environmental conditions, and to examine morphological characters that may distinguish these populations. A number of marine invertebrates exhibit an amazing ability not only to traverse thousands of kilometers of ocean, but also to settle and thrive in highly contrasting environments. The mechanisms by which organisms

can achieve this incredible plasticity are a focal question in evolutionary ecology today. Among more than one hundred species of reef-building Atlantic corals, only 9 species are considered amphi-Atlantic, with M. decactis being the main reef-builder of the southernmost reef community in the South Atlantic. This species has the ability to tolerate colder temperatures, higher seasonality and higher sediment load present in these southern reefs, while also being common in the Caribbean, where temperatures remain high year round and water turbidity is generally low.

## Responses of individuals to environmental changes

### Combined effect of *Vibrio tapetis* infection and temperature challenge on enzymatic activities in the manila clam, *Ruditapes philippinarum*. Richard G., Le Bris C., Lambert C., Guérard F., C. Paillard.

In this study, we highlight that host-pathogen interaction in a varying environment affects the enzymatic response of the host, investigating the coupled effect of *Vibrio tapetis* and temperature on two particular enzyme-systems involved in immune response in manila clam: Phenoloxydase system (PO) and superoxide dismutase (SOD). This coupled effect was detected 30 days after the injections and resulted in pathogenicity differences. At 15°C, enzymatic activities reveal a higher pathogenicity of CECT4600 strain. At 22°C, PO and SOD activities show no differences in pathogenicity between both Vibrio strains.

These findings were supported by disease stage (CDS) determination in clams, which indicate that the most advanced disease stages (CDS≥3) are obtained with CECT4600-injection at 15°C but no differences occur between the two strains at 22°C (lower CDS than at 15°C in the same proportions for the two strains). Additionally, CDS determination leads us to think that temperature affects CECT4600 pathogenicity more importantly than LP2.

Another result of this study is the increase of PO and SOD basal activities as clams are exposed to warmer temperature. As clams are dependent on external factors to regulate body heat, it could be questioned if enzymatic basal activities will rise/drop in a climate change context.

### The interactions between temperature and activity levels in driving metabolic rate: theory, with empirical validation from contrasting ectotherms. Halsey *et al.*, 2015. Oecologia, In press.

Energy expenditure is a foundation stone of animal ecology, which is closely linked with survivorship, reproductive success and hence fitness. Based on the comparison of metabolic rates (MR) in three marine ectotherms, this paper support a model showing that thermal effects on total MR will deviate from predictions based solely on RMR. Then, to develop mechanistic, predictive models for species' metabolic responses to temperature changes, empirical information about the relationships between activity levels, MR and temperature, such as reported here, is required.

### Adaptative process of invasive marine macrophytes face to climate change along latitudinal gradient from Portugal to Norway. G. Surget (PhD), V. Stiger-Pouvreau, N. Poupart.

One of ecological consequences of invasive species involves the modification of the native flora at a large scale. In Brittany, *G. vermiculophylla* an invasive red alga, has invaded the bare areas of brackish waters in saltmarshes from the 2000s. In the bay of Brest, the algae forms dense monospecific mats on mud surface and occupies a free ecological niche near the invasive macrophyte, *Spartina alterniflora*. The impact of *G. vermiculophylla* is studied in various ways, first by a seasonal monitoring of biomass, density and size of fragments. In parallel to this demographic monitoring, ecological data are complemented by the monitoring of carbon flows on the mud surface and chlorophyll content under two conditions: bare mud or mud colonized by *G. vermiculophylla*, in order to determine the productivity of biocenosis in these two conditions. It is observed that productivity is not statistically different with or without *Gracilaria* whatever the season considered. In addition, seasonality of this productivity is observed with a decrease in winter, less pronounced in the presence of *Gracilaria*. These results, put in relation

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**Invasive species *Spartina alterniflora* and *Gracilaria vermiculophylla* in Le Faou, near Brest**

with biomass variations of this species make it possible to better understand the impact of *G. vermiculophylla* in terms of carbon flows on the native saltmarsh. Further analysis also showed an effect of this species on benthic macrofauna.

## Reconstruction of past changes

### Multidisciplinary paleoecological approach unveiled toxic phytoplankton species invasions and the eutrophication status of coastal ecosystems. ISOBAY14. Klouch *et al.*, 2014.

Coastal sediments integrate and archive ecosystem modifications caused by natural or anthropogenic events. Our multidisciplinary paleoecological approach combines radiochronology, genetic, biological (ancient resting stage germination) and chemical analyses on sediments to test hypotheses of toxic species invasions and chemical/biological proxies of past eutrophication. Sediment core collected in December 2012 in the Bay of Brest spans across a time period of 70 years, far beyond the industrial development period. Genetic analyses and the presence of viable cysts suggest that *A. minutum* invaded the studied ecosystem at the beginning of the 90's. A peak of Total Organic Carbon was detected in sediments of 1993, confirming literature information which reported high biomass production in 1995. Concomitantly, higher values of the Acid Volatile Sulfide/Pyrite ratio would indicate an increase in the intensity of anoxia/hypoxia and chemical conditions of the sediment habitat would cause damages to specific biological organisms.

### Paleo-epidemiology in molluscs? A pilot study for identification of pathogenic vibrios in ancient shells. International Vibrio 2014. Edinburgh. UK- Paillard, Pichereau, et al.

Emerging new diseases raise major questions such as the geographic origin of the pathogens, their impact on host population, and evolutionary processes associated to the complex environment-host-pathogen interaction systems. The present possibility to sequence DNA from ancient calcified samples opens new ways to address these questions. Using a NGS-based metagenomics analysis, we could recently show that 25y-old clam shells still contain DNA from the mollusc itself, but also from environmental microbes and its pathogens. In particular, we could sequence the full genome of a *V. tapetis*, the causative agent of the brown ring disease, from a diseased shell. Paleo-epidemiological study of ancient shells is opening possible reconstruction of the co-evolutionary arms race between the host and the pathogen at a genomic scale, through the analysis of diseased shells along temporal gradients.

## Modelling individual responses to environmental changes

### Multi species estimation procedure for Dynamic Energy Budget models. G. Marques (IST, Portugal), L. Pecquerie (LEMAR/IRD, France).

The objective of this collaboration project is to go to the next level on parameter estimation procedures for standard Dynamic Dynamic Energy Budget (DEB) models. DEB theory is currently used in a number of projects developed by researchers based in LabexMER. A common

goal shared by these different projects is to better understand how perturbations (climate, habitat changes, pathogens, chemical contaminants, exploitation) impact energy acquisition and allocation schemes and biological traits of marine organisms. Ultimately, these projects aim to evaluate responses to these perturbations at the population level and DEB theory provides a conceptual and quantitative framework to address this question.

This group of researchers and associated students all located in Plouzané formed a group in 2013 to share questions related to the application of DEB theory to marine organisms and on parameter estimation procedures in particular. Estimating the parameters of a mass and energy budget model such as the standard DEB model requires a number of datasets in controlled conditions, throughout the life cycle of the organisms, that is rarely available for marine mollusks and fish species. The full panel of predictions that a standard DEB model can provide is therefore rarely used due to this lack of information at the species level. Discussions regarding the datasets that could be used from these different related species to constrain the parameter values of a given species lead to the organisation of a training session in 2014 to introduce the estimation of DEB-parameters for multiple species with a new set of Matlab scripts that apply to the following cases:

- Reduction of parameter number when estimating several species. DEB models are seen by an important number of people as being too complex due to the large amount of parameters. Although DEB is a consistent theory where one can understand each parameter, the reduction of the number of parameters will help tackle this criticism while strengthening the theory.
- Estimation of species parameters with less data. By estimating several species simultaneously the data from all species is used together. Although there is not enough data for an independent estimation of the parameter set of a given aspecies, the estimation of that parameter set is achievable due to the constraints laid down by the data of the other species

## Effect of climate change on population growth rate: some insight using DEB models of 2 benthic species. C. Bacher, A. Kasmi.

Predicting the distribution of species is a major challenge for the management of coastal areas and the evaluation of potential changes due to perturbation (e.g. environmental drivers, pressures due to human activities, climate change). In this context, the Dynamic Energy Budget (DEB) modelling framework can be used to simulate the life traits of species and assess response to environmental changes. We fist selected a range of potential habitats, relying on physical habitat maps and presence / absence data, for the mussel *M. edulis* and the oyster *C. gigas* in the English Channel and the Bay of Biscay area. In a second step, we developed an Individual Based Model (IBM) of population dynamics and estimated the growth performance of populations on the selected habitats. Reference simulations used temperature and chlorophyll a forcing variables based on the outputs of biogeochemical models averaged over 10 years. Another series of simulations were run with time series of temperature extrapolated from trends estimated over the past 25 years. The comparison of the new and the reference simulations showed an increase of populations growth rates for the 2 species, but the range differed according to the habitat and the species.

## Assessing the effect of environmental drivers on the oyster *Crassostrea virginica* using a Dynamic Energy Budget model. C. Bacher, M. La Peyre (U.S. Geological Survey), J. La Peyre (Louisiana State University).

In estuaries along the northern coast of the Gulf of Mexico, *C. virginica* provides significant ecological benefits, including provision of habitat, water filtration, shoreline protection, and economic income through its fishery. Globally, such shellfish reefs are considered imperiled with over 85% of historic reefs considered to be functionally extinct. It is critical to understand how environmental factors control *C. virginica* survival, reproduction and growth in order to better manage these populations. For this reason, a Dynamic Energy Budget model has been applied for the first time to *C. virginica* in the Gulf of Mexico. Using datasets of oyster

growth and water quality collected over the last 10 years in two different Louisiana estuaries, along with data from an extensive literature review on eastern oyster respiration and filtration rates, we developed a model which was adapted to explicitly test salinity effects on filtration and respiration. First results showed that salinity effects are expected to increase oyster metabolism by 50% and decrease growth by 10 % for the studied site. This initial model building and evaluation provides critical guidance in designing experiments to assess key physiological parameters under salinity and temperature conditions found in coastal Louisiana waters. Ultimately this will enable improved model predictions and contribute to DEB model development in general. In a second stage a novel approach to assess the effects of environmental changes on oyster populations (location, production).

## 5. Modelling at ecosystem scale

### Modelling Benthic Biodiversity. N. Alexandridis (PhD)

The complexity and number of interactions in biological systems are often described by statistical approaches which do not account for spatial and temporal dynamics. The objective of the thesis is therefore to build a model of benthic habitats using large existing datasets to generate mathematical formulations of functional components. The initial data set included one-time measurements of benthic macrofauna abundance over sites which represent habitat variability of Rance estuary (France) in the years '71, '76 and '95. The goal of reproducing the spatial and temporal dynamics of benthic macrofauna diversity has led us to adopt a mechanistic modelling approach, centred on the processes which are responsible for the observed biodiversity patterns. Aiming at a tractable version of the system, which would still retain most of the information on its functioning, we applied the emergent group hypothesis, based on 15 biological traits, which represent the most important community assembly mechanisms. The grouping of the 240 species observed in 1995 into 20 functional groups and the assignment of trait values to them based on the mass ratio hypothesis were found to preserve biodiversity patterns and were upheld, though not invariably, against both niche and neutral predictions of the emergent group hypothesis.

In a second step, functional groups and rules of interaction have been combined into qualitative models of benthic macrofauna in the Rance estuary, generating an understanding of the system which will be employed for the construction of an agent-based model of functional diversity dynamics. The first set of rules is derived from the values of 15 traits, which were selected as representative of key community assembly mechanisms. These rules define prey-predator interactions, dispersal potential and the regulating role of the organisms' position in the sediment. Another set of rules is derived from observed associations between traits and environmental variables and represents processes of environmental filtering along with the way the environment modulates biotic interactions. Finally, ecological theories, like the concentration reduction and the mobility-mode hypotheses, which are supported by associations among relevant traits, are employed to describe processes, like resource competition and biogenic habitat modification. The validity of these rules has been tested through the analysis of qualitative models, which combine them with the previously built functional groups.

### Computing connectivity in physical systems using Markov Chain based algorithm. C. Bacher, R. Filgueira (DFO, Canada), T. Guyondet (DFO, Canada).

Temporal and spatial scales of biological and physical process are generally driving the behaviour of ecosystems. Because of the spatial boundaries of the system, any matter (salt or fresh water, carbon, nitrogen or any substance) flowing through the system will stay during an amount of time depending on the interactions between the process which are involved and the type of matter. Therefore, assessing matter cycling, pathways and residence time within ecosystem compartments help in understanding its properties. We applied the algorithm previously published to estimate residence time, transfer time, transfer rate and connection strengths between biological or physical systems. The algorithm has been applied to three sites recently investigated on the Eastern Coast of Canada for their interest in shellfish aquaculture: Tracadie Bay, Richibucto Estuary,

Malpeque Bay. An unstructured grid made of triangular elements is used for the simulations of the hydrodynamics using the RMA suite of models (Resource Modelling Associates, http://ikingrma.iinet.net.au). Volumetric flows for all time steps are averaged as a daily average for each link and provide the input data to the computation of residence time, transfer time and transfer rate. Other results have also allowed to compute and map the connectivity with respect to existing aquaculture leases for the 3 sites. We propose to use the same method to assess the connectivity between benthic habitat in other ecosystems.

# ENHANCING SYNERGIES

The increase of synergies relies upon multiple actions, listed below

## 1. LABEX funded projects

The Inter-Axis Project «Marine Microbial BIodiversity PATterns (MOBIPAT)» links axes 2 (Laurent Mémery / LEMAR, Marc Sourisseau / DYNECO), 6 (Laurent Chauvaud, Aude Leynaert, Christine Paillard / LEMAR, Raffaele Siano / DYNECO) and 3 (Mohamed Jebbar, Lois Maignien / LM2E).

The Inter-Axis Project «Caracterization of the sedimentary paleo-microbiodiversity using metagenomic analysis of calcareous microfossils (Paleo-MICRO)» links axis 6 (V. Pichereau & C. Paillard/LEMAR), Axis 4 (M. Rabineau & P. Sans-Jofre/LDO, G. Jouet & S. Jorry/LES-Ifremer), axis 3 (K. Alain/LM2E, Stefan Lalonde/LDO).

A new project on Environmental Genomics «Les coquilles de mollusques marins: de nouvelles archives paléogénétiques retraçant l'histoire évolutive des interactions biotiques et des processus adaptatifs en milieu marin ( PALEOCOQ)» funded by the APEGE call from l'INEE CNRS associates LEMAR (C. Paillard & V. Pichereau) and GEOMIX (L. Orlando, Univ. Copenhagen).

A federative project on Integrated Modelling has been setup by Axis 6 to increase the effort and synergies on Modelling. It associates LEMAR and DYNECO, focuses on the Bay of Brest and addresses several scales of modelling: physical, pelagic biodiversity, benthic biodiversity, distribution of species, species bioenergetics.

## 2. Scientific animation

One day seminars have been organised or supported by Axis 6 on selected topics.

- Genomics and Molecular Biology (January 2013)
- Bioenergetics Modelling (February 2013)
- Axis 6 Projects (November 2013)
- «Symbiosis in the Sea», in association with the Roscoff Biological Station (January 2014)
- «Marine connectivity», in association with the Roscoff Biological Station (July 2014)

## 3. Networking

Axis 6 is active in the newly created International Group of Research «Responses of exploited fish and shellfish populations, communities and habitats to global changes (RECHAGLO)» (2014-2018) which associates teams from Canada and France.

## 4. Mobility of young scientists

Several Axis 6 PhD students have benefited from the LabexMER call for international mobility: R. Morvezen (LEMAR), N. Alexandridis (DYNECO), C. Le Bris (LEMAR), G. Richard (LEMAR), S. Artigaud (LEMAR).

Two PhD students have found a post-doc position in Louisiana State University thanks to collaborations between Axis 6 scientists and foreign scientists who have benefited from Axis 6 call for Invited Scientists.

# TESTING NEW IDEAS

Axis 6 funded 3 series of small projects to facilitate the testing of new ideas (2012, 2014, 2015). Such risky projects allow exploring new ideas and testing innovative methods. They have been right levers for getting interdisciplinary projects of larger magnitudes at the national

and international levels. Topics address genomics and transcriptomics issues, paleo-ecology and -epidemiology, host-parasites interactions, phytoplankton, trophic and habitat ecology and ecophysiology.

## LABEXMER INTERNATIONAL POST-DOC FELLOWSHIPS

- **Anthony Robson** (PhD UK, 2009) "Behaviour & energetics of the green crab *Carcinus maenas*"
- **Coraline Chapperon** (PhD Australia, 2012) "Behavioural adaptive ability of intertidal ectotherms to compensate global warming: bridging gaps in climate change models"
- **Raghab Ray** (PhD India, 2013) "Origin, transport and fate of total organic carbon along the mangrove dominated coastal forest of French Guiana"

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Surget G. *et al.* (2015). J. Photochem. Photobiol. B 143, 52-60

# SEA MOTIONS AND INTERACTIONS WITH MARINE STRUCTURES

axis 7

Coordinators: **Fabrice Ardhuin** (Ifremer-LOS/LPO), **Aurelien Babarit** (ECN-LHEEA)

**Research units**
- Laboratoire d'Océanographie Spatiale, (LOS, Brest)
- Laboratoire de Physique des Océans (LPO, Brest).
- Laboratoire Hydrodynamique, Energétique et Environnement Atmosphérique, (LHEEA, ECN Nantes)
- Laboratoire Comportement des Structures en Mer - unité Recherches et Developpements Technologiques, Brest

**Research scientists:** 11
**Research engineer:** 1
**Post docs:** 4
**PhD:** 5
**Publications** (2012-): 12

## Scientific objective

Axis 7 objective is to better understand, measure and forecast properties of sea states as well as their interactions with structures at sea. Targeted processes are dissipation rates, pressure waves, and infra-gravity waves.

## Science highlights

New properties related to waves and sea states in general, in their influence over their environment through diagnosis made in various different fields of science have been particularly illustrated over this period.

Following for instance Ardhuin *et al.* (OM, 2014) and Rawat *et al.* (2014) comprehensive review of the sources of infra-gravity waves over the ocean basins, Ardhuin *et al.* (2015) emphasized how this signal was primarily contributing to the micro-seismic activity of the earth, the hum, in the 13 to 300s period range, in addition to a secondary forcing mechanism of sea states, mostly effective in the period range below 13s.

### Workshops, schools

Wave Schools 2013, 2014,2015 (Ifremer); MARINET Short Course, 2014; Short Course on Wave Energy Converters (ECN), 2015; OMAE 2013 (ECN); EWTEC 2015 (ECN).

### Visiting scientists

A. Benetazzo, G. Farrell, G. Coco

### International collaborations and projects

FP7 SWARP

### Related projects

ERC IOWAGA

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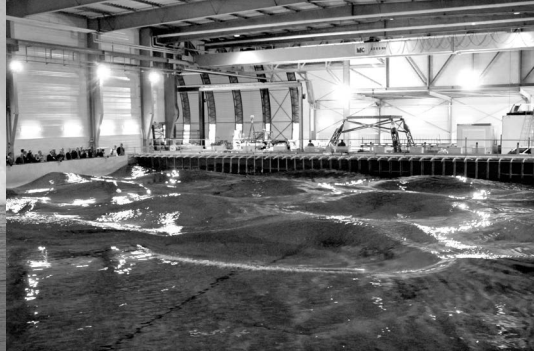

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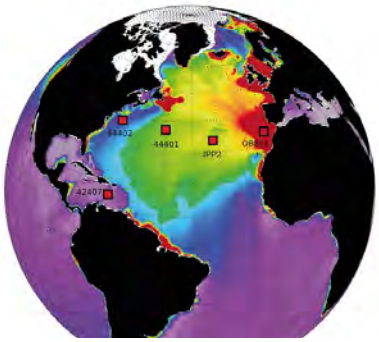

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## OVERVIEW

At small scales typically less than a kilometer, the motion of the oceans is mainly accounted for by sea waves. Their interactions are predominant with any natural system or artificial structure such as vessels, platforms, marine renewable energy converters, dams or piers, etc. The high stakes at play in term of economic and human impact imply to properly assess and understand the role of processes from small hydrodynamic to geophysical scales.

Long sought goals refer to the ability to produce reliable numerical simulations for air, sea and solid interactions, for typical length of processes ranging from few centimeters to kilometers. Efforts will be pushed toward the transfer from those small scale simulations to large scale modeling, including oceanic circulation and meteo-oceanic prospects.

For now, research fellows in the axis 7 have emphasized five innovative themes at the crossing of their respective domains of competences and interests. All five are directly related to the understanding, measurement and forecast of sea states. Those themes are dissipation rates, pressure waves related to sea states, generation, evolution and climatology of infra-gravity waves, breaking probabilities, and short-term deterministic prediction. Research partners have chosen to specifically focus their efforts on the first three themes, seen as major themes for the next three years.

Starting from occasional collaborations between the ECN group and the groups at Ifremer, Axis 7 has created a collaborative framework that has been beneficial to both the research output and the teaching in existing curricula or new forms of training, such as the 1-week « wave short courses » around the use of the WAVEWATCH III numerical model. Difficulties arising from the Nantes-Brest distance and the limited number of permanent staff involved in the beginning of the project on the Brest side have been mitigated by the broadening of participating labs to RDT-LCSM team at Ifremer and the recent hire of a research engineer at Ifremer/LPO.

## SCIENTIFIC RESULTS

### Theme 1 - Dissipation

#### Dissipation rates at the air-sea interface, accounted by viscous shear and turbulence

The investigations have been conducted on the mechanism responsible for an increase of dissipation previously observed over steep swells and supposedly related to the turbulent nature of the induced shear flow. The increase has been numerically characterized by extensive CFD analysis, and a parameterization of the decay rate established (Perignon *et al.* 2014). It has been shown that the candidate mechanism could not explain by itself the observed decay rate of steep swell across oceanic basins.

The research is still ongoing both at Ifremer (International LabexMER Post-Doc) and ECN (PhD student, national grant), and new numerical tools are currently been developed to address the question of swell dissipation, and more generally of the dynamic coupling of a sea state and an overlying atmospheric flow.

#### Dissipation rates in a breaking wave, and its spectral signature

The Ph.D. thesis of Fabien Leckler has provided novel detailed observations of wave spectra together with wave breaking, using stereo video

imagery (Leckler *et al.*, submitted to J. Phys. Oceanogr.). For the dominant waves, these data confirm previous analysis by Banner *et al.* (2000) on the relationship between mean wave steepnesses and breaking probabilities. Video processing has also been advanced to provide a better rendering of short waves that reveal the extension of a very strong directional bimodality up to 5 times the peak frequency. There is no spectral parameterization today that is capable of reproducing these spectra and we are investigating the possible roles of short wave modulation by long waves, and the generation of short waves by long breaking waves. These results have direct implications for the understading of ocean remote sensing in ocean fronts (see Axis 1 and paper by Rascle *et al.* 2014). It also lays the foundation for a more detailed analysis of 3D movies of the sea surface towards the quantification of dissipation rates. This is the topic of the joint ECN-Ifremer thesis starting in December 2014. Combining previously acquired stereo-video datasets and advanced numerical assimilation and modeling for the characterization of dissipation budgets might provide a novel set of tools for the understanding of this bottleneck process.

On the mean time, advanced validation procedures have been explored (PDL Regional PostDoc grant at ECN) to evaluate in depth the capabilities of latest numerical techniques (i.e. Smooth Particle Hydrodynamics - SPH) to cope with the specific problem of the momentum transfers and energy dissipation during single breaking events (1 paper under final revisions, 1 paper submitted).

## Theme n°2 : Wave breaking and pressure waves

The analysis of novel data acquired by J.-Y. Royer in the Indian ocean (supported by LabexMer) and the re-analysis of the ALOHA Cabled Observatory data of Duennebier *et al.* (2012) has shown that the absolute level of acoustic power in the band 0.2 to 3 Hz and large depths is difficult to invert directly in terms of wave properties, because of bottom sediment influences on the propagation wave guide. However, in relative terms, the variability of the acoustic power bears the clear signature of the directional broadening of the wave spectrum when the wind increases. These long time series can be used to generalize the stereo-video observations performed on coastal platforms, and are driving us to reconsider the energy balance in the "tail" of the wave spectrum. This has a clear connection with Axis 1 for the remote sensing of small-scale currents using surface roughness. This energy balance in the tail is the topic of the Ph.D. work by Charles Peureux. Also, a new ANR-funded project "MIcroseism Modeling for Oceanographic and Seismic Applications" (MIMOSA), will involve the deployment of near-surface acoustic measurements, in collaboration again with J.Y. Royer. These measurements should be dominated by acoustic-gravity waves that are insensitive to the bottom sediments, thus providing an absolute measurement of the "overlap integral" that links the directional wave spectrum to the acoustic power.

## Theme n°3 : Infragravity (IG) Waves

Waves with periods between 25s and 10 minutes have poorly known properties that limit the design of platforms at sea and also the design of the next generation of satellite altimeters. Key issues are the coastal amplification of these waves and their reflection to the open ocean, but also the mechanical response of moored systems to these low-frequency excitations.

The planned work has involved the analysis of historical data (DART network + marine geoscience experiments) new data on cliffs (in collaboration with Axis 5, see paper by Sheremet *et al.* 2014) and the development of numerical modelling capabilities for the generation of a global (IG) climatology, providing frequency-directional IG spectra. This unique new capability has already been applied to the problem of long period microseisms (known as hum, see Ardhuin *et al.*, 2015).

In parallel, application work has been performed to collect data on the SEMREV (Marine Renewable Energy Test Site) through a joint experiment between Ifremer and ECN during winter 2013-2014. This is followed up by theoretical and practical work at LCSM-RDT to be able to use such observed spectra to specify the response of moored systems (ECN Research Engineer, at Ifremer).

## INTERNATIONAL COLLABORATIONS, VISITING SCIENTISTS

- A. Benetazzo (Fall 2013) – Stereo-video reconstruction of the sea surface
- B. Farrell (Fall 2014) – Wave induced acoustic signal
- G. Coco (March 2015) – Workshop on infra-gravity waves

## ENHANCING SYNERGIES

The LabexMER axis 7 has been able to create a new formal context at the interface of existing labs and fields of expertise, all related to the sea states and their associated process, from so called stochastic geo-scales to the local scales of the deterministic physics. Thus, this interface is the place for new exchanges, diagnosis and specific structuration in the Labex context.

In addition to common seminars from LabexMER scientists as well as invited talks, which enhance the state of the art diagnosis about the understanding of the process, tools, datasets of interest, challenges, etc. for the geo-scientists and hydro-dynamists, research teams make a constant effort to add this scientific axis at the interface to their development path. This is characterized by joint efforts (ECN-Ifremer) on PhD thesis (co-financing and direction of one thesis, shared comity for one ECN thesis), specific post-doctoral positions (Wave breaking at ECN, Swell dissipation at Ifremer with integration of former ECN tools), and new implications by several permanent scientists (long term scientific roadmap impacted by the new possibilities offered by Labex – Axis 7 joint effort).

## LABEXMER INTERNATIONAL POST-DOC FELLOWSHIPS

**Justin Stopa** (PhD USA, 2013) "The evolution of swell - dissipation and dispersion"

## PUBLICATIONS


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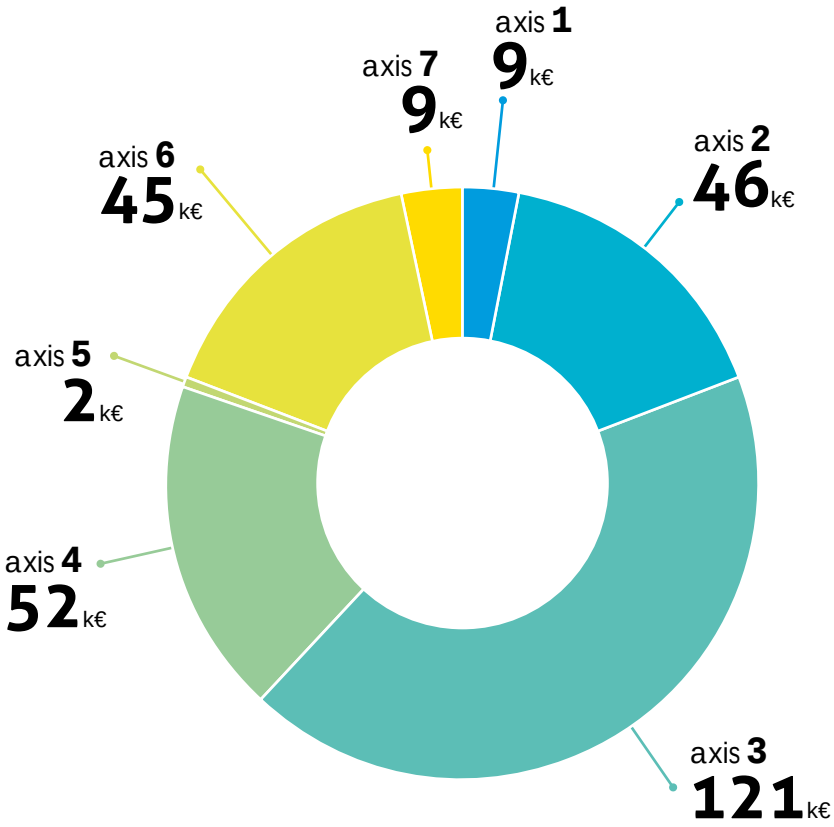
# SUPPORT FOR RESEARCH AT SEA

LabexMER provides financial support to facilitate and encourage research work or training «at sea» (e.g., projects using national or international sea-going vessels in the deep sea or the coastal environment), in the framework of the scientific axes of LabexMER. A call is issued every year (funding: 100k€ per year) to support projects «at sea» contributing to the goal of the LabexMER scientific or training program:

- Projects adding value to a planned cruise (e.g., deployment of a new experimental sensor for measurements, complementing the objectives of the cruise), or proposition of technical tests by the LabexMER teams;
- Innovative contribution to an oceanographic cruise in the deep sea or coastal environment;
- Participation of LabexMER members to international cruises on foreign ships;
- Collective «Training at sea» projects, such as «university at sea», complementing the training program of LabexMER.




**22 projects have been supported for a total amount of 283k€**

## Four major actions (20K€ or more) have been supported in 2012-2014

**Colmeia, 2012**, (J.Y. Royer, axis 3, 30k€): This project is a joint French-Brazilian effort to unravel the processes at the origin of the ridge of St. Peter St. Paul. LabexMER funding has allowed the mooring of hydrophones to monitor low level seismic activity.

**Mangroves in Guyana**, 2013 (E. Michaud, axis 6, 35k€). This project complemented the ANR young researcher Biomango project. The aim was 1) to characterize the changes in benthic biodiversity associated with the development of Guyana coastal mangroves; 2) identify groups responsible for bioturbation; 3) identify the biotic and abiotic factors supporting the benthic communities; 4) testing innovative measurement strategies in a difficult coastal environment.

**GEOTRACES-Mediterranean and Black Sea**, 2013 (M. Boye, axis 2, 20k€). This project is part of GEOTRACES, an unprecedented effort to map the trace elements and isotopes in the global ocean. LabexMER funded the participation of LEMAR and GM scientists, PhDs and master students in a cruise coordinated by NIOZ (NL).

**MARMARA-MARSITE**, 2014 (D. Birot, A. Deschamps, axes 3 and 4, 29.3k€). The European program MARsite (FP7) aims at monitoring the region of the North Anatolian fault in the Marmara Sea, a region of high seismic risk. LabexMER funding was allocated to test new sensors for measuring methane seeps in the deep ocean (GM), and to deploy new geodetic stations (OBS) as part of a long-term observatory of seismicity (LDO).

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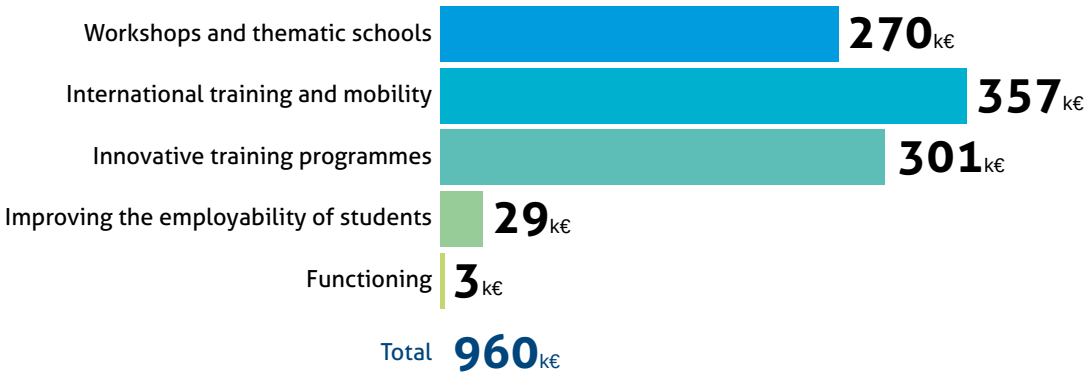
**Biomango mission in the Guyana mangroves**

# TRAINING AND HIGHER EDUCATION

The LabexMER training and higher education program is built upon the post-graduate study programs of IUEM: master courses gathering different disciplines in a unique domain, "marine and coastal sciences". It has also been developed in close collaboration with the PhD program EDSM (Ecole Doctorale des Sciences de la Mer, Marine science graduate school). The budget of 960k€ for the first phase of LabexMER is distributed among three major groups of actions: organisation of international workshops and schools, international training and mobility for master and PhD students, and creation of innovative training programmes. A small amount of funding has also been devoted to helping master students to discover the job market in the field of marine sciences and the marine economy.




**LabexMER training actions (2011-2015)**

# INTERNATIONAL WORKSHOPS AND SCHOOLS

In 2012, LabexMER organized the symposium and summer school **GEOCEAN**. A 2-days symposium, in tribute to **Jean Francheteau**, gathered more than 100 participants. It was followed by a 3-days summer school on "**Geodynamic processes and biochemical interactions at seafloor spreading ridges**", with about 40 participants, students and scientists (see program and report on www.labexmer.eu). Another school, "**Time-series analysis in marine science and applications for industry**", co-sponsored in September 2012 by Europole Mer and LabexMER, has led to a special issue of the Journal of Marine Systems (Puilhat *et al.*, 2014). In August 2013, the summer school **AIMEN** (Innovative approaches in Marine Ecosystem Modelling) gathered 70 participants, from 17 countries. Almost all the speakers, world-class experts in their respective fields, stayed the whole week to interact with the students. In July 2014 LabexMER co-sponsored with the ANR the «**ECORISC**» week, a 3-days summer school followed by a 2-days international colloquium on coastal risks. ECORISC brought together scientists, students, engineers and managers working in coastal communities.

LabexMER has supported many workshops organized by the LabexMER research units, with the requirement that these international workshops should benefit to students. For example, the "**Arctic days**" meeting in November 2012 organized a special session for master students to interact with international scientists working on Arctic Research.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**AIMEN thematic school, held in Brest in 2013**

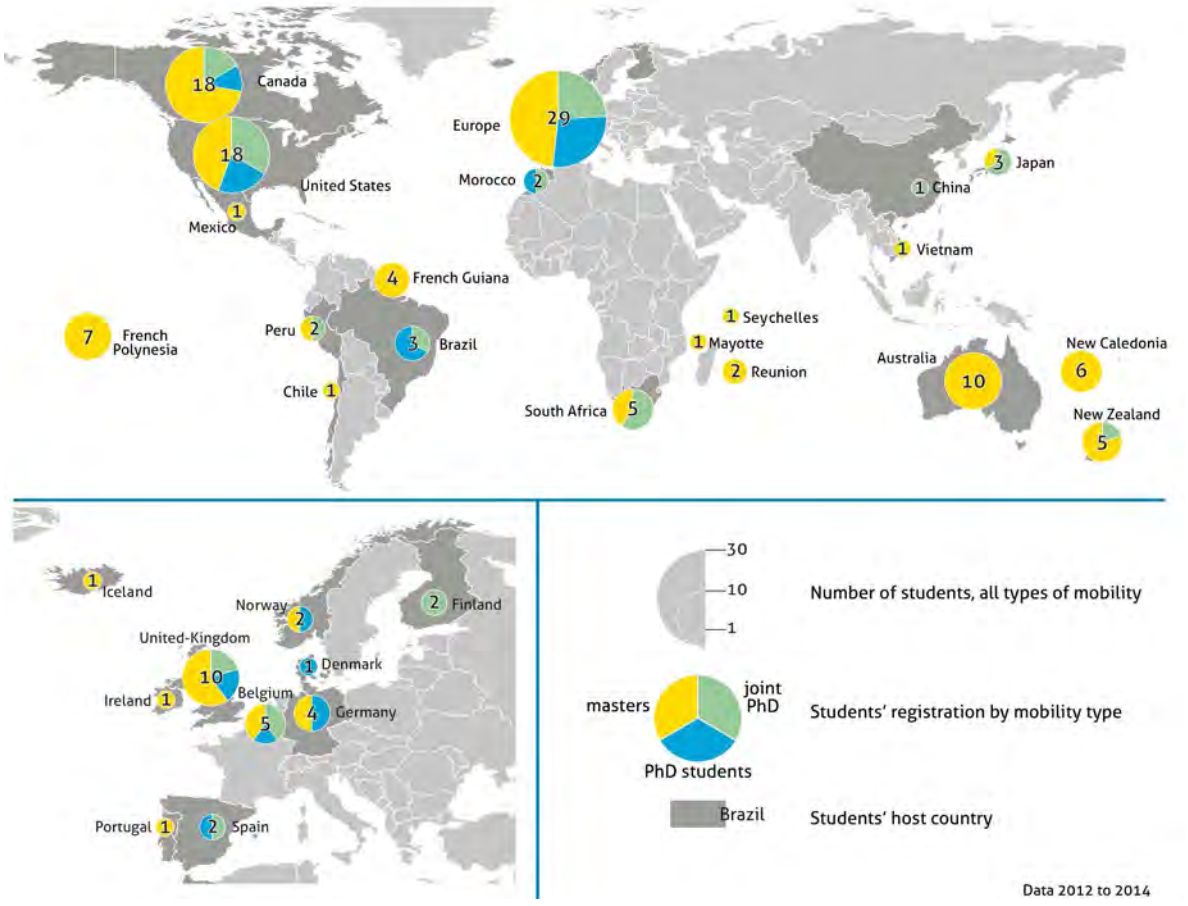

**Artic Days international workshop**

# SUPPORT FOR MOBILITY OF PHD AND MASTER STUDENTS

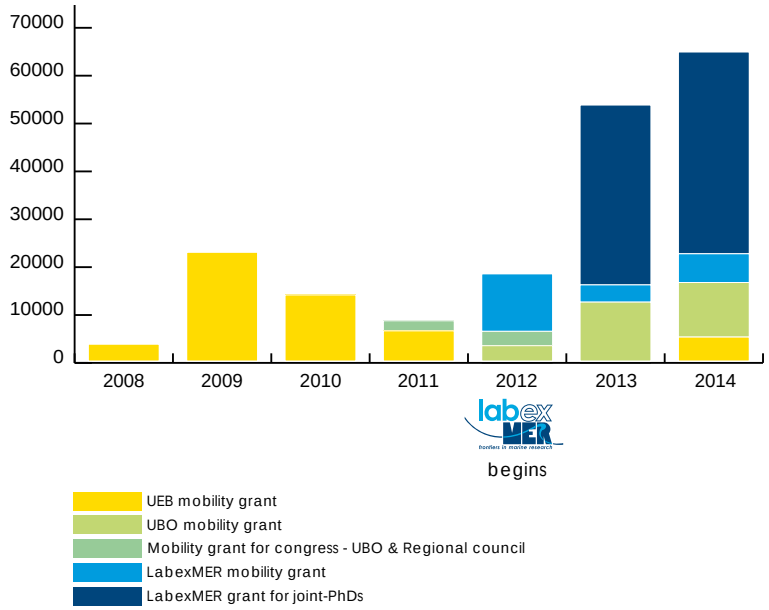
LabexMER provides grants for incoming and outgoing mobility of master students and PhDs. The map of achieved outgoing mobilities demonstrates the wide range of destinations, with a preference for Europe and North America. Four annual calls have been issued from 2011 to 2014, allowing for example 76 master students to go abroad for their internship and 4 master students to be hosted in LabexMER research units.

A budget of 130k€ has been allocated to the doctoral school of Marine sciences (EDSM) to support projects of international co-supervision and co-tutelle of PhDs. This budget is managed by the EDSM council and benefits to all research units involved in EDSM, even those that are not part of LabexMER, thus contributing to the labex «pull effect». LabexMER has dramatically increased (ca. 3 fold) the funding available for international mobility of EDSM students.

LabexMER has also supported the mentoring of foreign students, and acquired a new video-conference equipment to allow examiners to participate remotely to PhD defenses.




**The map of achieved outgoing mobilities**




**Total outgoing international mobility for Ph.D's in EDSM, on the 2008 to 2014 period**

## INNOVATIVE TRAINING PROJECTS

LabexMER supports training at sea and original field trip projects for students. LabexMER master students have participated in «**universities at sea**», or have received funding to participate in cruises as part of their training. For example, in 2012, 4 master students have participated to the University at Sea organised during the MONOPOL cruise on the «Marion Dufresne» research vessel, in the Indian Ocean.

A new «**Science & Society» master course** has been initiated for all the master SML ("Sciences de la Mer et du Littoral") students. It aims at raising the awareness of students to the challenges of interdisciplinarity and dialogue between researchers and society. The training is mainly targeted to interdisciplinary teams of second year master students (M2) in Marine Sciences, but it also involves PhD students from the doctoral school (who propose interdisciplinary Science & Society subjects related to their thesis, and coordinate the M2 teams) and first year students (M1) who attend the memorable and fun final event (workshops, debates, games...). This innovative course will be presented at the 8th Colloquium "Questions de pédagogie dans l'enseignement supérieur" held in Brest in 2015 (Hubert *et al.*, 2015).

Last but not least, LabexMER sponsors the first Massive Open Online Course (MOOC) of the University of Brest, **FlotRisCo**. This MOOC, in French, will be available in spring 2015 on the FUN (France Université Numérique) platform. The aim is to create around the «Coastal Risk» theme an international community of learners, university students, risks stakeholders, and public at large. The MOOC is based on scientific results and expertise gathered during the «Cocorisco» ANR project. It will be widely advertised, especially in France, and other French speaking countries such as Quebec and Senegal.

# OUTREACH, LINKS WITH SOCIO-ECONOMIC PARTNERS

## INNOVATION AND KNOWLEDGE TRANSFER

The partnerships between LabexMER members and the socio-economic sphere are strongly anchored around marine research, and are structured through mutual participation of LabexMER partners in the governing bodies of the SATT Ouest Valorisation, IFREMER-EDROME Carnot Institute, the cluster Pôle Mer Bretagne Atlantique (PMBA) and in science and technology parks (Technopôle Brest-Iroise, Nantes-Atlanpole).

The Innovation roadmap for the first phase of the project was elaborated by the Socio-Economic council of LabexMER. This council is composed of the president of the cluster PMBA, the director of Ouest-Valorisation, the directors of innovation and industrial partnerships of Ifremer and Centrale Nantes, and other LabexMER members and partners. It is presided by PMBA. No specific LabexMER budget has been allocated for innovation and transfer to industry. The roadmap was therefore focused on communication actions and joint organization of conferences gathering researchers and other actors of the socio-economic world (communications towards companies, to gather the view and hear the expectations of the socioeconomic world).

Examples of communication actions towards the socio-economic world:

- Seminar "**A dive into innovation**", during the Innovation Week, organized by PMBA, SATT and LabexMER, June 20th, 2013 in Brest. Scientists from LabexMER research axes 1 and 5, as well as representatives of NKE and CLS have discussed collaborative projects.
- Round Table "**partnerships**": CIFRE and transfer of technology, during the training "**professionnal integration**" JPSML, november 2013 in IUEM.
- Participation to the "**Sea Tech Week**" held in Brest every two years, in October 2012 and October 2014. This international event (~40 countries) attracts more than 1,000 participants and covers multiple marine-related disciplines, including innovation and technologies for the exploration and prospection of deepwater energy and mineral. The 2014 Sea Tech Week focused in particular on deep sea challenges. The «Deep Blue Days» symposium was co-organized by Ifremer Carnot institute EDROME and LabexMER research axis 3. Current challenges in the development of energy, mineral and biological resources were presented and discussed by covering the entire value chain: research and development, technologies, environmental issues, social sciences including law and economics, governance and defense (security). The cross-cutting approach helped to create new interactions between participants from different professional sectors (academia, industry, governmental organizations, public institutions...) and disciplines.

# SCIENCE & SOCIETY

## The relations between science and society in the institutional landscape of the research.

Nowadays, the relations between science and society have to be considered in big European and international research programs. Approaching in an innovating way the societal challenges (food, health, environment...) is a theme at the heart of the Horizon 2020 EU Research and Innovation programme. Before 2012, various initiatives were envisioned at IUEM and other LabexMER partners to approach these societal challenges: by bridging the gap between basic- and applied- research, by stimulating the necessary interdisciplinarity in particular between the "natural"- and human and social- sciences, by inviting the civil society to increase its participation to the production of knowledge, and even in the process of decision itself, by inviting to rethink the border between sciences and politics. However, LabexMER funding clearly played a catalytic role, by enabling many projects to emerge and by making "Science & Society" a highly visible theme. Besides the new training course (see "training and higher education" section), the tree main actions are:

- Interdisciplinary summer school for secondary school teachers
- Arts & Sciences
- Citizen sciences: Participative observation in marine sciences

## Interdisciplinary summer school for secondary school teachers

The "**Sea-Education" summer school** led by LabexMER was designed in close collaboration with our scientific partners UBO, Ifremer, and Océanopolis. The shared objectives are to participate in the training of secondary school teachers, to contribute to develop the link between high schools and the University, and to increase the visibility of Brittany's excellence's in terms of research in marine and coastal sciences in both natural and human and social sciences.

The "Sea-Education" summer school offers to teachers of any teaching discipline an immersive experience with researchers at the heart of the «Science being made», to discover new approaches and scientific tools, which they can reinvest in innovative and/or interdisciplinary educational projects. This school is open to about 50 teachers of all disciplines, nationally and internationally (participants from French Guyana, Benin and Morocco attended the first two summer schools).

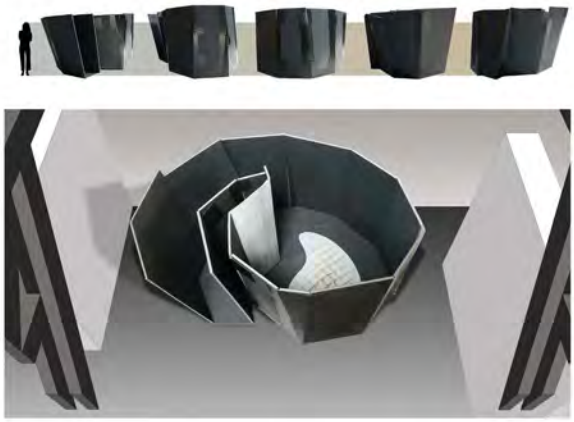



**The 2013, 2014 and 2015 Sea-Education summer schools posters**

## Arts & Sciences

"By combining the art and science looks, the limits and boundaries of disciplines break, the sensitivity of each researcher can state its views and new avenues of research can be explored".

A variety of projects have been carried out at IUEM for about ten years. Since 2011, "**Art and Science Breakfast**» brainstormings gave unique opportunities to discuss issues common to artistic and scientific research. **Residences of student in fine arts** are also underway with the agreement between the IUEM and the "École Européenne Supérieure d'Art de Bretagne" (EESAB) established in 2013. With labexMER, an «Arts & Sciences» community is structuring since 2014, which involves several laboratories of the IUEM, i.e. AMURE, LETG, IFREMER, LDO, LEMAR, LM2E as well as partners in the world of Culture. An example of what could be done in recent years is "**Auris Maris**", a transdisciplinary project on Abalone "A sea ear to listen to the global change", gathering two artists (Plastic and Acoustic art) and researchers from the institute (Biology and Ethnology), has received a financial support from LabexMER. Other transdisciplinary projects are currently developed with other financial support such as TOTAL foundation and France foundation.



**«AURIS MARIS-AURIS TERRAE» exhibition by Anne Le Mée**

## Citizen sciences: Participative observation in marine sciences

During the last decade, the interest in facilitating citizen participation to science has greatly increased, leading nowadays to specific calls for proposals at the European and international levels. The project "**Prospective Observation Participative en Sciences de la Mer et du Littoral" (POP-SML)** supported by the LabexMER Inter-Axis actions, aimed (i) to coordinate and support IUEM actions of citizen observations and (ii) to increase the insertion of Marine and Coastal Sciences into the national initiatives of citizen observations structuration.

POP-SML supported a pilot initiative in collaboration with Oceanopolis (Brest). The operation «**Objectif plancton**» aims at surveying the evolution of the composition of phytoplanktonic communities in a specific area (the bay of Brest) with the help of amateur sailors.

Within the POP-SML, IUEM organized the final preparatory meeting of the national "**65 Million of Observers**" project, devoted to the development of a global set of tools dedicated to citizen observations set up and results analysis and exploitation, whatever the discipline. "65 MO", leaded by the Museum of Natural History (MNHN) is now funded (4 M€ for 4 years) and IUEM will be associated, as a member of the **"Vigie-Mer" Steering Committee**. LabexMER members are now in a strong position to leverage H2020 funding on the theme of Citizen Sciences.

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**The operation «Objectif plancton» is supported by LabexMER and Oceanopolis**

# LABEXMER RESEARCH UNITS

## AMURE

### Centre for the Law and Economics of the Sea

UBO, Ifremer

Research at UMR AMURE can be defined as the analysis and the economic and legal assessment of public policies and institutions in the areas of territorial development and maritime activities, exploitation of resources and conservation of marine and coastal ecosystems.

Work undertaken at the UMR follows three main lines of research and an observation mission:

- Appropriation and responsibility
- Sustainability of socio-ecosystems and public policy
- Territories and new uses of the sea
- Transversal legal and economic observation mission

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## LDO

### Oceanic domains laboratory

UBO, CNRS

The LDO takes a multidisiplinary approach to the question of the origin and evolution of oceanic domains (continental rifts to ocean ridges, coasts to deep basins via continental shelves, hotspots to volcanic islands and finally, passive and active margins). The laboratory also works on developing new methods and instrumentation for use in the marine area and has a successful analysis centre in petro-geochemistry, sedimentology and palaeontology.

Four research areas are currently investigated:

- Ridges and rifts
- Margins and arcs
- Land-sea transfers
- Structure, evolution and dynamics of telluric mantles

## DYNECO

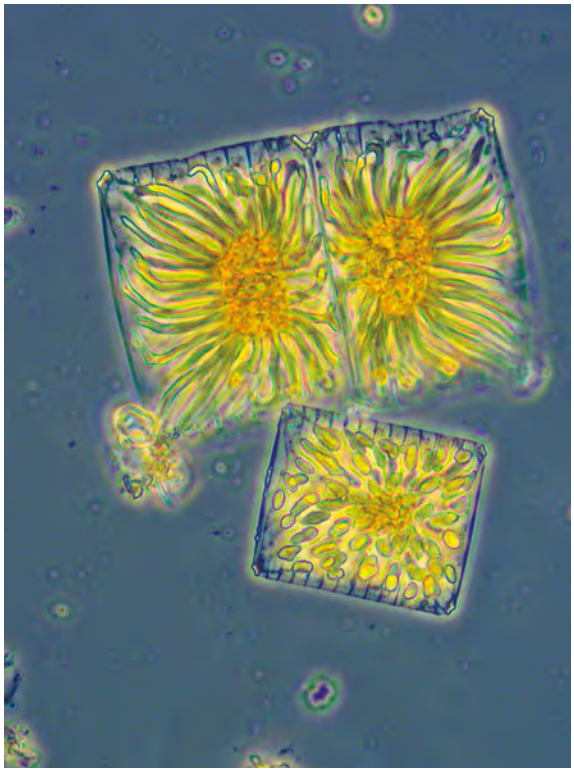
### Department of Coastal Environment Dynamics

Ifremer

Within Ifremer, the DYNECO Research Unit deals with the understanding and modelling of the physical and biological dynamics in coastal areas. DYNECO projects combine experiments, field studies and bio-physical modelling to address the following issues :

- hydrodynamical responses and sediment transport in relation to environmental and meteorological drivers,
- distribution of benthic species, ecosystem functioning and dynamics of invasive species,
- eutrophication, harmful algae blooms and long term changes of phytoplankton biodiversity,
- habitat mapping and spatial ecology.

DYNECO is maintaining the ECOMARS modelling platform and the Quadrige2 environmental database. It has also been coordinating Ifremer phytoplankton observation network and is strongly involved in the implementation of the European Water Framework Directive.



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## LEMAR

### Marine Environmental Sciences Laboratory

UBO, CNRS, Ifremer, IRD

LEMAR's main objective is to understand the interactions that take place within the marine biosphere. This joint research laboratory brings together biologists, physicists and chemists studying a variety of environments, from the poles to the tropics and from the coast to the open ocean. Diverse scientific approaches such as observations, modelling and experiments are conducted in both the laboratory and in the field.

The laboratory structure integrates its scientific teams following these three research themes

- Organism responses to global change
- Biotic interactions and environmental variability
- Integrated study of ecosystem functioning

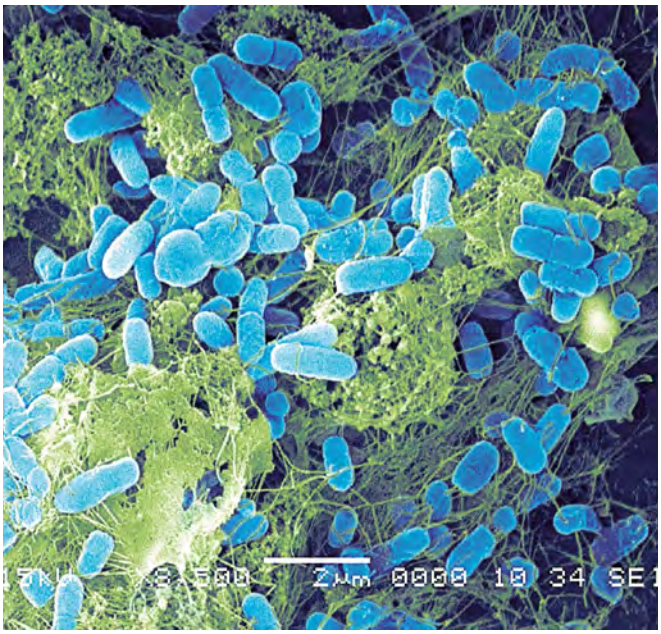
## LBCM

### Marine Biotechnology and Chemistry Laboratory

UBS

LBCM has developed specialised scientific expertise in the study of marine biofilms. Using a variety of tools and approaches combining genetics, analytical chemistry and cell physiology, this laboratory studies the interactions of living cells and organisms with abiotic surfaces, and develops biotechnological applications.

- Interactions between organisms and abiotic surfaces
- Biotechnology - applications of marine molecules
- Cell-cell interactions

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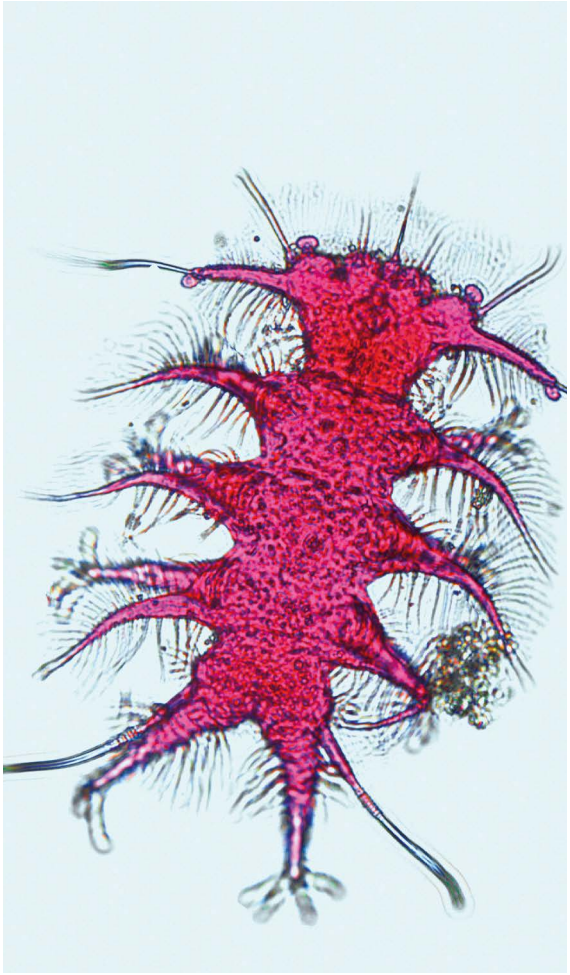
## GM

### Marine Geosciences research unit

Ifremer

The Marine Geosciences research unit of Ifremer coordinates the activity of three laboratories (Geochemistry and Metallogeny, Geophysics and Geodynamics, and Sedimentary Environments) and a technical service handling cartography, GIS, data processing and instrumentation. The unit conducts multi-disciplinary, basic research on the evolution of ocean ridges, basins and margins; on the interaction between geochemical and biological processes at mid-ocean ridges; on the formation of deep-sea, energy and mineral resources; on sediment transfers in relation to tectonic and paleo-climate forcing; on geological hazards (earthquake, tsunamis, slope instability). The unit also contributes to the elaboration of permit requests for the exploration of mineral deposits in international Waters, in relation to the International Seabed Authority of the United Nations; to the promotion of deep-sea exploration programs; and to the development of submarine monitoring systems.



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## LEP

### Deep-Sea Lab / Studies of deep-sea ecosystems research Unit

Ifremer

Ifremer's Deep-Sea Lab conducts multidisciplinary research on the ecology of deep-sea ecosystems including those that are sustained by surface photosynthetic production (canyons, cold corals, abyssal plains) and those relying on chemosynthetic processes such as cold seep and hydrothermal vents. The major objectives of LEP research are to describe the biological diversity and to understand its structure and dynamics in relation to environmental variability, at different spatial and temporal scales. Understanding the interactions between the biological compartment and local physico-chemical conditions requires an original approach that needs to integrate different scientific disciplines, to develop specific experimental and sampling strategies and innovative tools and to apply dedicated statistical approaches.

- Exploration of biological diversity from megafauna to meiofauna,
- Study of ecosystem functioning (species interactions, trophic network, connectivity, larval cycles, reproduction),
- Analysis of spatial distribution (habitat mapping, links with environmental conditions, species niches),
- Evaluation of temporal dynamics (species behaviour, links with variations in abiotic conditions),
- Ecosystem modelling.

# LETG

## Coast, Environment, Remote Sensing, Geomatics

### Geomer : LETG Brest team

UBO, CNRS

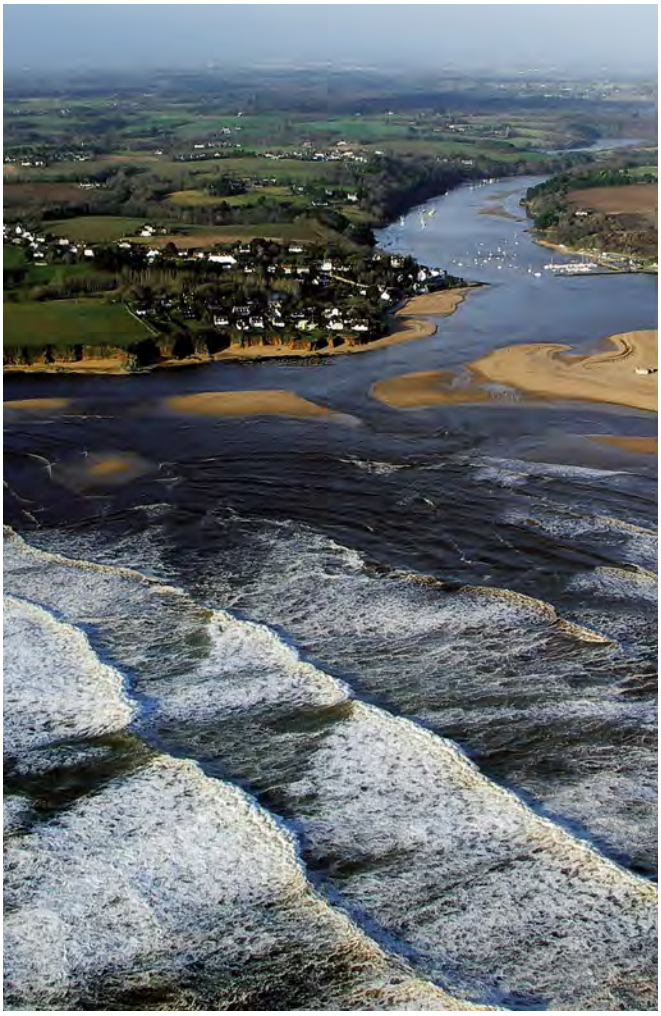
The research activities of Geomer cover physical, human and social geography, remote sensing and geomatics, which are applied the study of man-nature interactions in coastal and marine environments and are organized around two teams:

- Changes in use, conflicts and territorial changes at the land / sea interface
- Environmental and anthropogenic forcing on the dynamics of «sensitive» environments.

### Geolittomer : LETG Nantes team

University of Nantes, CNRS

The research activities of Geolittomer are focusing on the coastal and oceanic functions at the interface with a sensitive and fragile nature (coastal morphology, environmental protection, integrated management). These researches use technical methods of analysis and develop decision-making support models.



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# LHEEA

## Laboratory of Hydrodynamics, Energetics and Atmospheric Environment

Ecole Centrale de Nantes, CNRS

LHEEA conducts research and R&D collaborative projects related to free surface hydrodynamics, fluid-structure interactions, ocean engineering, modelling of the lower atmosphere, modelling of internal combustion engines and hybrid propulsion systems. The corresponding developments are based on a combination of numerical modelling, model experiments and full scale testing. LHEEA operates the largest set of experimental facilities in hydrodynamics in France, and has also developed the first operational test site at sea for marine renewable energy prototypes (SEMREV).

The main applications of these activities are the following:

- Marine Renewable Energy,
- Security and performances of Marine structures,
- Limitation of pollution in maritime and terrestrial transport,
- Air quality in urban zones, ...

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## LM2E

### Microbiology of Extreme Environments

UBO, CNRS, Ifremer

LM2E conducts research on the microbiology of extreme environments, such as hydrothermal vents, and cold seeps on the continental margins and ocean floor. LM2E's scientific approach is made possible by equipment and skills that are unique in France, for the sampling, analysis and exploitation of microbial samples collected during numerous oceanographic cruises.

Research activities carried out at LM2E include:

- Exploration of microbial diversity: bacteria, archaea and viruses
- Study of the functioning of microbial communities and their interactions with mineral and biological environments
- Analysis of basic adaptive processes, notably those involved in the maintenance of genomic stability of certain model organisms.

## LOS

### Space oceanography research unit

Ifremer

The Laboratory of Space Oceanography (LOS) is an Ifremer research unit bringing together researchers, engineers and technicians, with expertise in

- Surface ocean physics and air / sea interactions,
- Management, analysis and treatment of global ocean observations and measures.

The LOS incorporates and relies on a data center, the CERSAT (Centre ERS d'Archivage et de Traitement), originally created in 1991 as a node of the ESA (European Space Agency) ground segment for the ERS-1 and ERS-2 Earth observation satellites. The CERSAT has then evolved towards a multi-mission data centre for archiving, processing and validating data from spaceborne sensors (such as altimeters, scatterometers, radiometers, SAR, ...) with a focus on sea surface parameters and air-sea interactions.

## LPO

### Laboratory of Ocean Physics

CNRS, Ifremer, IRD, UBO

LPO's main objectives are to understand and to model ocean dynamics on different spatial and temporal scales. Through a combination of oceanographic cruises, collection and analysis of data on the ocean and continental slope, and physical modelling based on fluid mechanics of the global ocean, LPO contributes to major advances in the understanding of ocean-climate relationships and, more generally, on the variability of the ocean system.

Research activities are focused on:

- Mechanisms of ocean dynamics on different scales
- Role and impacts of the ocean and thermohaline circulation on climate changes
- Understanding coastal-ocean exchanges in order to examine the regionalisation of climate change impacts on margins and ecosystems

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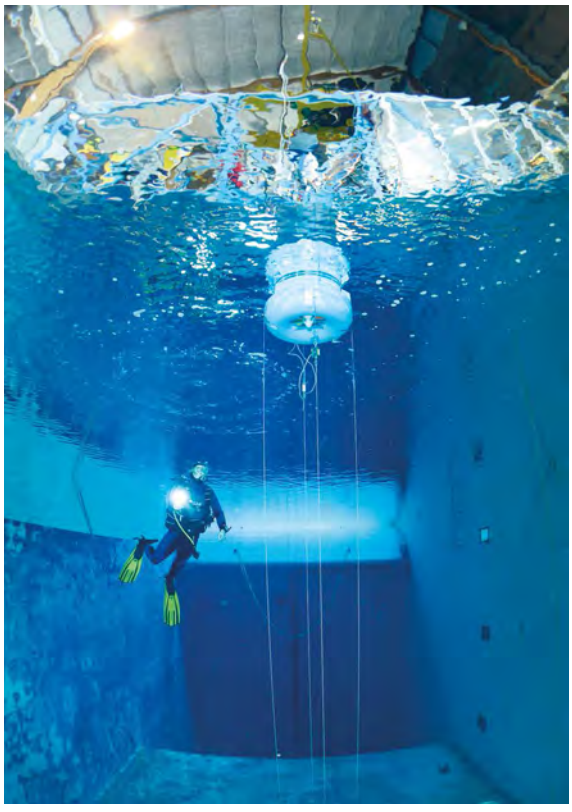

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## RDT

### Research and Technological Development Unit

Ifremer

As part of the Department of Physical Resources and Deep-Sea Ecosystems, the RTD unit is conducting studies with the aim of:

- contributing to the exploitation of oceanic mineral and energetic resources, a better understanding of oceanic geological processes, studies on biodiversity and on the dynamics of deep-sea ecosystems or observation of the global ocean for studies on climate change ;
- developing and integrating marine devices adapted to the needs of exploration, production, scientific observation, environmental monitoring or for industrial developments ;
- qualifying devices, materials and structures to marine environment; developing innovations so as to improve their response and behavior.

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1 2 3 4 5 6 7 Formation


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