Ocean engine at very high resolution

LabexMER Research project	**2016-2019 axis 1 roadmap**	**January 2016**

Ocean engine at very high resolution

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List of participating laboratories:

- LOPS - UMR 6523 (Laboratoire d'Océanographie Physique et Spatiale), Ifremer, UBO, CNRS/INSU, IRD
- LEMAR – UMR 6539 (Laboratoire des sciences de l'Environnement MARin), UBO, CNRS, Ifremer, IRD
- GM (Laboratoire de Géochimie et de Métallogénie), Ifremer

1. Scientific context, scientific questions

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. Geostrophic eddies (with diameters ranging from 100 km to 300 km) however are known to capture almost 80% of the total kinetic energy (KE) of the flow and are the fundamental building blocks of the Ocean Weather. Smaller scales on the other hand were assumed for a long time to have almost no impact on these eddies and larger scales, except as a sink of kinetic energy.

A new vision of the ocean dynamics has however emerged in the last ten years thanks to high resolution numerical simulations. It highlights that oceanic scales from 100 km down to 1 km (also called sub-mesoscales) have a strong dynamical impact – in terms of source of kinetic energy - on mesoscale eddies (100-300km) and larger scales. This impact is mostly explained by the strong vertical velocity field associated with sub-mesoscales, a new characteristic highlighted by recent studies. This new vision emphasizes the existence of a much richer variety of energy pathways, or "dynamical regimes" strongly related to sub-mesoscales: depending on the season and on the region, sub-mesoscale impact leads to increase the total eddy kinetic energy by a factor of two. Other consequences of this intense small scale activity are that sub-mesoscales significantly enhance the 3D dispersion of any tracers and strongly affect physical-biological interactions and the ocean biodiversity.

These major advances point to the need for more repeated global observations at finer space and time scales than is presently available with conventional altimeters, which is a real challenge. Wide-swath altimeters such as SWOT (expected to be launched in 2020) should meet this challenge. The next generation of super-computers (exascale machines) should also allow to better understand the scale interactions implying sub-mesoscales in the global ocean. Such space and numerical observations may confirm or infirm present results, but they certainly will lead to surprising and startling discoveries not predicted.

Axis 1 of LabexMER has been, in the last five years, one of the main world contributors to this breakthrough concerning the sub-mesoscale impacts on the ocean dynamics. In that context it has used an integrated approach (new observations, theory, frontier numerical simulations) to elucidate the interaction between the ocean gyre scales, mesoscales and smaller scales (filaments, internal waves), and quantify energy pathways that connect small and large ocean scales. This approach principally relies on Geophysical Fluid Dynamics frameworks and innovative methods of analysis of frontier satellite and/or in situ observations. Within this context, our Axis 1 received a very positive evaluation from the CSI for its phase 1 activities. A summary is the following : *« At the onset of Phase 1, many of the worldwide leaders in this field were already working at labs located near Brest, but clearly the LabexMER umbrella and funding have served as a catalyst to create increased synergy and collaboration between these and new individuals, and their respective laboratories, together with PhD candidates or postdocs. This critical mass of highly qualified scientists has led to very impressive results, some of which have already been widely published at the highest level… It is clear that this work, which involved many collaborations and frequent exchanges with groups that are also international leaders in this field (e.g., NCAR, NASA, JPL, NOAA), is of the highest international standards and visibility. This work has stimulated mobility, within Europe and beyond, of both early career and confirmed researchers… Moreover, on the educational and training sides, a number of very successful workshops were organized by this axis. All of the above-listed achievements well fulfill objectives of excellence set by LabexMER. We can only encourage this axis to continue their good work during phase 2.»*

Accordingly, our axis plans to closely follow the integrated approach, based on very high resolution observations (numerical, in-situ and from space), that led to its success during phase 1. This includes a continued emphasis on exploratory on-going research projects and strongly relies on the existing very active international context.

2. OBJECTIVES FOR THE NEXT FOUR YEARS AND SPECIFIC ACTIONS

2.1. SCIENTIFIC OBJECTIVES

The main CSI recommendation for axis 1 is to continue developing our on-going projects on the Ocean at Very High Resolution using the same scientific approach as that followed during phase 1. We plan to follow this recommendation. Two scientific objectives will mostly continue as during phase 1. Others have been added or have evolved thanks to the work achieved during phase 1. An example of such evolution is the new pluridisplinary scientific objective related to physical-biological interactions which will be significantly developed during phase 2.

i. Objectives maintained

1 - Impact of fine oceanic scales on mesoscale eddies and larger scales in realistic simulations at very high resolution.

Again, the purpose of this objective is to explore the dynamical regimes within an oceanic basin (such as the North Atlantic and North Pacific Oceans) that exist because of the impact of fine oceanic scales. This exploration will rely on numerical simulations at very high resolution that are presently performed in Japan, in the US and in France. This emphasizes the strong international context of this objective (involving JAMSTEC, Caltech/JPL and the LabexMER).

2 - Ouflows dynamics of marginal seas

This activity relies on ambitious experimental campaigns and high resolution numerical modeling. Its main objectives consists in estimating the impact of submesoscale structures to oceanic salt sources (cf axis summary)

ii. New or evolving objectives

1 - A major contribution to the future international space mission SWOT

SWOT is a new generation altimeter with a resolution ten times higher than conventional altimeters. This joint mission NASA-CNES (at a cost of one billion dollars) will estimate sources and transfers of energy between oceanic scales in the first 1000 meters below surface whereas conventional altimeters allow only to map kinetic energy at the ocean surface. This is a major breakthrough whose impact on the physical-biological interactions, air-sea interactions, 3D tracers dispersion (or pollutants) and on the energy balance of the oceans are priceless. Several members of the axis 1 of LabexMER (including the LOS and LPO) are leaders of this international mission. One of our important contributions to SWOT will be to develop reconstruction methods of the 3D dynamic in the first 1000 meters below surface based on high resolution satellite data and in situ data of the interior ocean (either climatological data or low resolution). These methods will be based on the numerical results previously mentioned and on concepts of Geophysical Fluid Dynamics.

2 - Physical - biological interactions.

A first attempt to estimate the impact of very fine oceanic scales on physical - biological interactions from observations from sensors installed on sea Elephants was successful. We plan to explicitly incorporate this scientific component in our axis and take the co-leadership with axis 2. This objective will be carried out by several researchers of LPO, LOS and LEMAR and will benefit from the hiring of Fanny Chenillat thanks to a Labex postdoctoral fellowship. It will be achieved in collaboration with axis 2. The main issues concern the impact of very fine oceanic scales on higher trophic levels. This approach is relatively new and stands out from studies done elsewhere on the impact of fine scales on primary production.

3 - Experimental investigations of oceanic fine scales

This topic was initiated during phase 1 through a workshop organized at the end of 2012. Laboratories such as LPO benefit from strong teams for the technical support of at sea experiments and several researchers motivated by the prospect of leading experiments dedicated to the observation of oceanic fine scales. Such experiments require innovative platforms of observations as well as a strategy radically orthogonal to classical strategies. We propose to carry efforts in order to identify and characterize such platforms and strategies and take the international leadership on the development of experimental observations of oceanic fine scales. This would be achieved with the partnership of other national teams (LOCEAN) as well as international teams (University of Sendai, Japan). The long term goal is to prepare our active participation in the future grand experimental campaigns that will take place in the context of the launch of the SWOT satellite mission (2020-2021)

4 - Air - Sea Interactions at very fine scales

This theme emerged during Phase 1 and has a two main objectives. On one hand it aims at improving our fundamental understanding of the multi-way coupling between the ocean circulation (mesoscale/submesoscale), surface gravity waves, and the lower atmosphere at scales lower than a couple of hundreds of kilometers. This includes efforts towards improved quantifications of air-sea fluxes of momentum and tracers as well as of the impact that this coupling could have on both longer and shorter space and time scales. The second and very original objective of the theme is to possibly build on this refined representation of the ocean-atmosphere system to use available and future very high-resolution satellite data, especially new sea surface roughness measurements, to improve our understandings of fine-scale physical processes near meso- and sub-mesoscale fronts. This theme has become quite mature over the course of phase 1 and currently relies on ocean-atmosphere coupled regional simulations at very high resolution in a non-hydrostatic framework of type "L.E.S" (Large Eddy Simulation). It benefited and will continue to benefit from the unique gathering of expertise in ocean/wave/atmosphere dynamics present at the LOPS which is unique in France. The chair of excellence for our axis that started this year (2015) will allow to develop this theme further during phase 2. Finally, axis 7 has a related scientific objective ("Atmospheric flows and their coupling with conditions at free surface") that focuses on smaller spatial scales and collaborations between axis 1 and 7 with via use of common numerical tools will provide a leveraging effect.

5 - World Atlas of sub-mesoscale turbulence.

This is a very recent and original initiative whose goal is to work toward the realization of a world atlas of submesoscale turbulence. The atlas envisioned would rely on high-resolution spatial data (e.g. SAR, SST) as well as on in situ (Argo) data and should provide for the first time in the world a quantitative description of the ocean at spatio-temporal scales previously impossible to reach (sub-mesoscale). The atlas woud map the intensity and seasonality of the sub-mesoscale turbulence and would constitute an invaluable tool in order to validate realistic simulations which are been performed more and more often these days.

6 - Dynamical interaction between submesoscale and topography

This activity was initiated recently and benefited from cooperation with axis 3. It is also currently the topic an ANR accepted in 2014. The goals are to better understand the impact of the interactions between submesoscale structures with topography on mixing and dissipation in the abyss.

7 - Distinguishing balanced and unbalanced motions in high resolution oceanic observations

This is yet another recent activity developed by axis 1, which aims at providing original methods for the analysis of high resolution satellite observations of the ocean surface. Multiple processes (e.g. balanced motions such as mesoscale/submesoscale structures, and unbalanced motions such as internal waves) simultaneously contribute to these observations and the disentanglements of their relative contributions is of paramount importance to missions such as SWOT. The proper reconstruction of the three-dimensional ocean dynamics is at stake if such separation cannot be performed.

2.2. INTERDISCIPLINARITY AND SYNERGIES BETWEEN TEAMS

Our objective is to develop the strong potential present on the Brest oceanographic scene in terms of high resolution. One aspect of our prospective thus concerns the maturity of the activity related to bio-physical interactions in which researchers from LEMAR will be involved. Another aspect deals with education and the mentoring of Ph.D and postdoctorates for which an effort will be made during phase 2. Purely scientific brainstormings and informal seminars will gather scientists from axis 1 and will be conducted on a monthly basis.

2.3. INTERNATIONAL VISIBILITY

Our axis has a widely recognized international visibility (see report of the International Scientific Committee). This results from numerous international collaborations as well as from the workshops that have been organized by axis 1.

Among the formal collaborations, we must mention the M.O.U IFREMER-JAMSTEC (Earth Simulator) that has enabled us for nearly ten years to make significant progress on the impact of fine oceanic scales on the larger scales.

In addition, several members of our axis are driving forces of the Science Definition Team SWOT which will be transformed into Science Team in 2016.

The new chair of excellence obtained by our axis (which the holder is Jeroen Molemaker) should lead to future international collaborations including with UCLA in Los Angeles (USA) and the University of Miami (USA) through the future in-situ experience "CARTHE" to be held in the Gulf of Mexico in 2016 and 2017.

In the future we want to strengthen the links between our axis and institutes located in Pasadena (University of Caltech and JPL (NASA)) in the USA. This could result in the exchange of students and post-docs formalized through the signing of a MOU.

An emphasis (see budget) will be put on the organization of workshops in frontier areas relevant to axis 1 (e.g. a workshop about high resolution global simulations is planned for March 2016).

2.4. LEVERAGING EFFECT

The activities of our axis should have a catalyst and leveraging effect to create a synergy and collaborations between Brest teams and national and international teams working on the same theme. We previously cited international teams that will be involved. On a national level, our axis should serve as leverage to structure activities around the fine oceanic scales particularly with our colleagues from IPSL (Paris) with whom we work for over ten years. This may result in a formal agreement between the LabexMER and the IPSL Labex. The latter is particularly favorable to this rapprochement.

Another leveraging effect of our axis concerns cooperation with Labex from other disciplines, especially with the Labex CominLabs and the Labex Lebesgues (via the SEACS inter-Labex project.

2.5. Governance

Organisation and governance of our axis will be subject to several developments.

1 - The number of scientists involved in axis 1 increased significantly during phase 1. This is due to the arrival of new researchers (7) in Brest involved in the topic of fine oceanic scales. This also concerns the integration of researchers (2) involved in the physical-biological interactions from the LEMAR.

2 - Taking into account the fact that our axis wants to take the co-leadership with axis 2, on a theme related to the physical-biological interactions especially involving researchers from LEMAR. The LEMAR will thus become one of the laboratories participating in the axis 1.

3 - The current axis coordinators will be in 2016 even more involved in future international space missions (including SWOT). Two young researchers of axis 1, Clément de Boyer Montegut and Aurelien Ponte agreed to replace them in January 2016. Generally, the International Scientific Committee strongly recommended some support for the new coordinators by more "senior" members. We follow these recommendations by operating with four coordinators until January 2016 to ensure a smooth handover. Besides, an office of the axis including new coordinators and more senior members will be established in January 2016.

3. Answers to CSI recommandations

Our Axis 1 received a very positive evaluation from the CSI for its phase 1 activities. A summary is recalled in paragraph 1 (scientific context).

Following the CSI recommendations, our axis plans to closely follow the integrated approach, based on very high resolution observations (numerical, in-situ and from space), that led to its success during phase 1. This includes a continued emphasis on exploratory on-going research projects and strongly relies on the existing very active international context. The organization of international workshops and the invitation of international experts will contribute to maintain the aura of axis 1.

4. Implementation plan and resources

Given the success of our politic in the matter of budget during phase 1, we will conduct a similar strategy. Our priority will therefore be around scientific animation through the organization of international workshops and invited researchers.

A second activity will deal with the formal development of targeted international collaborations, which turned out to be crucial for our axis as past actions have shown.

Two international workshops originally planned for 2015 will take place in 2016 because of the large number of international conferences that took place in 2015. 2016 will therefore be especially rich, which explains the higher budget requested compared to previous years (see table below).