Brief overview of the

Interdisciplinary School for the blue planet (ISblue)

research themes

SUMMARY

The Earth is also called the blue planet. Its ocean covers more than two thirds of its surface, regulates essential processes such as climate, and plays a pivotal role in the sustainable future of humanity. At the same time, ocean ecosystems are fragile and are rapidly changing, mainly due to shifting climate, altered ocean-atmosphere-land interactions, and overexploitation of resources. To address the increasing challenges facing ocean and coastal ecosystems, the **"Interdisciplinary graduate School for the blue planet" (ISblue)** was created to train the next generation of ocean innovators and science leaders and place them at the forefront of research to answer the needs of the growing blue economy through top level research-based training.

ISblue gathers most of the forces in marine science and technology in West and South Brittany, belonging to the universities (UBO, UBS), research national organisms (CNRS, Ifremer, IRD), engineering schools (IMT-Atlantique, ENSTA Bretagne, ENIB) and the French naval academy. ISblue includes 15 research units and teams showing an internationally recognized expertise in many disciplines (eg. physical and spatial oceanography, geosciences, biogeochemistry, ecology, microbiology, data analytics but also geography, economics, law, and engineering), all dedicated to tackle questions related to the ocean in all its dimensions and interfaces. ISblue will move interdisciplinarity to an unprecedented level to push back the frontiers in marine science and technology and ocean innovation.

The research program of ISblue is divided in five interdisciplinary themes designed to address the major ocean-related challenges for the blue planet in the 21th century: ocean and climate regulation, ocean-Earth interactions, sustainable coastal systems, living ocean and ecosystem services, and long-term observing systems for ocean knowledge (short description of ISblue themes scientific contents is given thereafter).

SHORT DESCRIPTION OF THE SCIENTIFIC THEMES

Theme 1: Ocean and climate regulation

Scientific context. Climate variability directly constrains the ocean, sea ice dynamics and biogeochemical fluxes, which in return affect atmosphere and climate. The ocean modulates the intensity of climate change by absorbing part of the heat excess and greenhouse gas increase resulting from human activities. The processes driving the behaviour of the complex system of ocean / biogeochemical components / marine ecosystems are nonlinear and work on large spatial and time - scale spectra, from thousands of kilometres (ocean basin) to several kilometres (fronts), down to centimetres (turbulence). Interactions and feedbacks between the global ocean,

climate change and human activities are numerous and complex, ranging from the energy efficiency of maritime transport to mitigation strategies involving marine ecosystems and the ocean carbon pump.

The ISblue community has expertise in fine-scale ocean dynamics (LabexMER axis 1- remote sensing at high resolution, leadership in ESA-CNES satellite missions such as SWOT or Sentinel, and numerical modelling); observation of ocean circulation and global climate (OVIDE observatory of the meridional overturning circulation, Euro-Argo and equipex NAOS); distribution and global cycle of trace elements (e.g. GEOTRACES cruises); process-based studies of the ocean carbon pump (LabexMER axis 2); evolution of sea state, sea ice and icebergs under climate change, and their impacts on maritime transport (e.g. IOWAGA ERC project on surface waves); and efficiency of marine shipping (IRDL and IRENav).

Specific objectives. Theme 1 will support projects such as:

- Modelling and observing the dynamics of the ocean–ice–atmosphere interface at high resolution, including surface waves, to improve the safety of human activities and the accuracy of regional climate scenarios;
- Coupling between dynamics, minor and major chemical elements, biogeochemistry and plankton ecology in the open ocean, from the scale of energy dissipation to large-scale thermohaline circulation, and their modifications linked to climate change;
- Integrating instrumental, archaeological and historical datasets with sedimentary records of climate variability over the last millennium combined with physiological knowledge of present and fossilized marine organisms such as bivalves, to extend time series of climate into the past;
- Improving the safety and climate impact of global shipping, taking into account changes in the physical environment, legal issues, and energy efficiency of ships (through improved propellers, clean energy production, and better ship resistance to rough seas).

Theme 2: Ocean-Earth interactions

Scientific context. The Earth's sediments, crust, and mantle are in constant interaction with the ocean. This interaction drives a global bioreactor, where animal and microbial life thrive in close association with geological substrates including sediments, seeps, vents, and the crust itself. Deep earth and tectonic processes shape ocean structure and material transfer at the largest of scales. On the one hand, these processes may pose geological hazards, yet, on the other, they give the ocean floor abundant petroleum, mineral and even biotechnological resources.

This theme relies on our strong track record of deep sea exploration and discovery (leadership of major international cruises using manned and unmanned underwater vehicles): studying geobiological interactions and life in extreme environments (LabexMER axis 3, ERC EARTHBLOOM, MICROBSEA international laboratory, CNRS-INEE); quantifying source-to-sink sediment flows along the continent-ocean continuum (LabexMER axis 4; PAMELA project with TOTAL); monitoring tectonic activity and associated hazards (Maregami ANR project in the Marmara Sea near Istanbul).

Specific objectives. Theme 2 projects will include:

- Understanding the generation of the Earth's crust, its structure, and its fate at ocean margins, through ship-based surveys, seismic and hydroacoustic observation, modelling, and geochemical studies.
- Developing our capacity to explore and exploit deep ocean mineral resources by understanding their genesis and distribution, legal and economic issues and potential impacts if exploited, and by developing new materials and instruments to operate at depth.
- Providing more robust assessments of geological hazards at sea and at the land-ocean interface (e.g. volcanism, submarine landslides, earthquakes, tsunamis).
- Describing and understanding the unique biology of the deep ocean microbial and animal biosphere through in-situ monitoring of species and their physical and chemical deep ocean environment, physiological studies, lab culturing and enrichment experiments, and meta- omics techniques.
- Examining economic and legal dimensions of regulations applying to deep sea exploitation.

Theme 3: Sustainable coastal systems

Scientific context. Coastal systems have long provided human societies with a multitude of services: maritime transport and trade, fossil and renewable energies, tourism and buffering of land against hazards such as floods and storms. At the same time, coasts are among the most heterogeneous, dynamic and fragile environments on Earth. Coastal vulnerability is partly related to physical forcings such as meteorological hazards, sediment budget and transport processes in the coastal zone, or sea level rise related to climate change. However, coastal vulnerability is also directly related to human settlement on coastal territories and watersheds, which acts as "human forcing". The growing social and economic activities due to coastal urbanization and the emerging blue economy are accompanied by new anthropogenic forcings such as pollution and habitat loss.

Theme 3 will tackle the so-called "coastal challenge", which aims at developing coherent and long- term strategies for integrated coastal zone management. It relies on experience in interdisciplinary projects from geomorphology to psychology (ANR Cocorisco, LabexMER axis 5), expertise in wave- structure interactions, mechanical design and durability of naval structures (LabexMER axis 7 and Gustave Zédé laboratory between French groups DCNS and IRDL); leadership in E.U. projects (IMCORE, Innovative management for Europe's changing coastal resource). It will benefit from collaborations with private partners (in remote sensing and marine energies), government agencies (CEREMA, SHOM) and the Copernicus Marine services to improve coastal monitoring and forecasting.

Specific objectives. Theme 3 projects will include:

- Describing and understanding the kinematics of shoreline morphodynamics, including impacts of natural hazards and artificial structures: from the effects of transient hydrodynamic processes on sea level changes (setup, runup) and sediment fluxes in the swash zone, to the reliability, durability and life cycle of floating or immersed structures, and the impacts of these structures

on coastal functions.

- Combining physics, chemistry, biology, economics and law to characterize the impacts of emerging pollutants (microplastics, chemicals, etc.) and habitat degradation on coastal ecosystems and human welfare, as well as studying options to manage these impacts.
- Understanding the emergence and evolution of new human activities in the coastal zone (e.g. marine renewable energies) taking into account economic factors, regulations, environmental responsibility and human behaviour, by combining geomatics, environmental modelling and social science studies.
- Implementing an interdisciplinary coastal risk observatory for erosion, flooding and pollution hazards, integrating the societal dimensions (cost, governance, human perception) for mitigation and adaptation of coastal vulnerability in order to implement integrated coastal zone management.

Theme 4: The living ocean and ecosystem services

Scientific context. The ocean hosts some of the most diverse ecosystems on Earth, supporting multiple ecosystem services. Among these is the provision of food for human consumption with the associated benefits for human health and nutrition, economic returns and coastal livelihoods, but several other marine bioresources and ecosystem services have yet to be fully-described and quantified. Human activities increasingly impact marine ecosystems and their ability to sustain functions, processes and their direct and indirect effects on ecosystem services.

Theme 4 proposes fully integrative approaches in marine biology and biotechnology, evolutionary ecology, ecological economics, maritime law and politics, geography and modelling. It relies on LabexMER axes 6 (Evolution of marine habitats and adaptation of populations) and 8 (Management of social-ecological systems), CNRS and IRD international laboratories (BeBEST, DISCOH, ECLAIRS), as well as several H2020 and ANR projects (ResponSEAble, SUCCESS, Vivaldi…), cutting edge facilities (biodimar, lipidocean, PSO, Genomer, Epigen-Brest…) and infrastructures (e.g. "OceanoLab" with the Brest aquarium Oceanopolis, and Ifremer infrastructures in Argenton and Brest), as well as a highly favourable socioeconomic environment (the Brittany territory was recently ranked 3rd French region in terms of Biotechnology, with more than 120 businesses related to marine biosciences).

Specific objectives. Interdisciplinary projects in this theme will address critical science priorities, namely:

- Understanding the consequences of ecosystem changes on marine organisms and populations, to develop new pertinent indicators of ecosystem health;
- Characterizing ecological support systems (from genomic observation to the understanding of food webs and physical-biological coupling) and improving the knowledge of how these are linked to the provision of goods and services which benefit, and are utilized by humans;
- Developing marine biotechnology to give access to sustainably produced and renewable biomass to face a growing demand spanning from protein sources to bioremediation and novel industrial processes, based on marine organisms and chemical ecology;

- Identifying the drivers and assessing the consequences of ecosystem changes for economies/societies, identifying the associated risks, investigating and developing mitigation and/or adaptation options;
- Developing new methods to assess and monitor marine and coastal ecosystem services.
- Evaluating the advantages and limitations of alternative ecosystem conservation policies, including the use of economic incentives and governance arrangements.

Theme 5: Long-term observing systems for ocean knowledge

Scientific context. Ocean-observation technologies are constantly evolving, as are the way we process and exploit the data. We are currently facing a two or three order of magnitude increase in data flow coming from AUV missions or satellites (e.g. the data hub of the Copernicus Sentinel Constellation has delivered 2.5 Petabytes of data in just one year of service) and biological and genetic data are increasing exponentially. To ensure rapid scientific benefits, it is vital to realize the full potential of these capabilities as well as to refine and anticipate new sensor and processing developments with advanced experimental strategies. From the scale of the global ocean to coastal domains, a major goal is to reduce sampling gaps and better reveal interactions between physical, biological and ecological components.

This theme relies on established leadership in long-term observation of the ocean floor (EMSO), global high sea (ARGO/NAOS), coastal ocean at high frequency (COAST-HF), coastline dynamics (IR ILICO) and benthic ecosystems. It also benefits from expertise in marine data management (national oceanographic data centre and portal operated by Ifremer), technology for marine energy harvesting (ITE France energies Marine), innovative data-driven techniques for ocean remote sensing data (ANR MN EMOCEAN 2013–2017)

Specific objectives. This theme will address four specific objectives:

- Develop new monitoring technologies and strategies for under-resolved ocean components, especially chemical, biological and ecological variables, through the development of novel integrated sensors (e.g. taxonomics, genomics, acoustics...) and cross-sensor cueing methodologies;
- Design and implement integrated observatories (e.g. water quality; physical, chemical and geological environment; biodiversity; human pressures), focusing on the inference of climate trends and examination of extreme events;
- Extract, reconstruct, forecast and emulate physical, chemical, biological, geological and ecological essential ocean variables (EOVs) from multi-source ocean data streams to uncover local and remote interactions at both short-term and climate time scales, with a focus on data-driven and model–data-coupled strategies, for operational oceanography applications and research purposes;
- Design and implement thematically-relevant data management and dissemination facilities to favour the access and exploitation of multi-source marine data for the dissemination of knowledge and the creation of novel high added-value services.

RESEARCH UNITS

LOPS	Laboratoire d'Océanographie Physique et Spatiale (CNRS-UBO-Ifremer-IRD)
LEMAR	Laboratoire des sciences de l'environnement marin (CNRS-UBO-Ifremer-IRD)
LGO	Laboratoire Géosciences Océan (CNRS-UBO-UBS)
LM2E	Laboratoire de Microbiologie des Environnements Extrêmes (CNRS-UBO-Ifremer)
AMURE	Aménagement des Usages des Ressources et des Espaces marins et littoraux (CNRS-UBO-Ifremer)
LETG	Littoral, Environnement, Télédétection, Géomatique (CNRS-UBO)
LBCM	Laboratoire de Biotechnologie et Chimie Marines (UBS-UBO)
DYNECO	Dynamiques des Ecosystèmes Côtiers (Ifremer)
GM	Géosciences marines (Ifremer)
LEP	Laboratoire Environnement Profond (Ifremer)
RDT	Recherches et Développements Technologiques (Ifremer)
STH	Sciences et Technologies Halieutiques (Ifremer)
IRENav	Institut de Recherche de l'Ecole Navale (Ecole Navale)
Lab-STICC	Laboratoire des Sciences et Techniques de l'Information, de la Communication et de la Connaissance TOMS team (CNRS-IMT-A-UBO-UBS-ENIB-ENSTA)
IRDL	Institut de Recherche Dupuy de Lôme, Marine team (CNRS-UBS-ENSTA-UBO-ENIB)