CALL FOR PROPOSALS
APPEL A PROJETS : Un océan de solutions
PPR Océan et climat

JUNE 2021 / JUIN 2021

SCIENTIFIC SUBMISSION FORM
DOCUMENT SCIENTIFIQUE

MEDIATION

***Acronym* / Acronyme**	MEDIATION
Project title (in English)	Methodological developments for a robust and efficient digital twin of the ocean
Titre du projet (en français)	Développements méthodologiques pour un jumeau numérique robuste et efficace de l'océan
***Main challenge and its axes* / Défi majeur et ses axes**	Challenge 6. Axes 6.2, 6.3
***Secondary challenge(s) and its(their) axe(s)* / Défi(s) secondaire(s) et son(ses) axe(s)**	Challenge 4. Axe 4.3
***Key words* (min 5 - max 10)**	Digital twins, Numerical modeling, Artificial intelligence, Data masses, Model-data synergy, Observation systems, End-to-End model, French metropolitan coasts, Marine ecosystems, Vulnerability.
Leading institution	Inria
Scientific coordinator	***Last Name, First name, Position, Organisation* / Nom, Prénom, Status, Organisation** Debreu, Laurent, Director of Research, Inria ***e-mail address* / Courriel**: Laurent.Debreu@inria.fr ***Phone number* / Téléphone**: +33457421725
Partner institution(s) involved in the project	1. Institut National de Recherche en Informatique et en Automatique, **199218244V** 2. Centre National de la Recherche Scientifique – Délégation Occitanie Ouest, **201320566C** 3. Centre National de la Recherche Scientifique – Délégation Alpes, **201722374A** 4. Institut Français de Recherche pour l'Exploitation de la MER, **201122276V** 5. Institut de Recherche pour le Developpement, **200317685P** 6. Université Aix-Marseille, **201220349W** 7. Institut National Polytechnique de Toulouse, **199511949P** 8. Ecole Nationale Supérieure Mines-Télécom Atlantique Bretagne Pays de la Loire, **201220091R** 9. Service Hygrodgraphique et Océanographique de la Marine, **202023669V** 10. Université Grenoble Alpes, **200711891Z** 11. Météo-France-DESR-Centre National de Recherches Météorologiques, **201320566C**

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Project duration	60 Months		
Requested funding	2497634€	***Full cost***	10354151€

If applicable: Project links with existing PIA entities (e.g. BTBR, INBS, Labex, MOPGA, etc.) **Le cas échéant : Listes des projets labellisés par le PIA auxquels ce projet est lié (notamment BTBR, INBS, Labex, MOPGA, etc.)**	• Action 1 of the French recovery plan, Inria/ATOS • Labex OSUG@2020 – Hability in changing worlds • Labex Henri Lebesgue • Labex CominLabs • 3IA Institutes : MIAI (Multidisciplinary Institute in Artificial Intelligence), ANITI (Artificial and Natural Intelligence Toulouse Institute) • IA chair (OceaniX) • SWOT (Surface Water and Ocean Topography satellite mission) project CNES/NASA • CARAVELE project • MOPGA : CONtACTS project (Prof. W. Dewar) • MARMOR : Marine Advanced geophysical Research equipment and Mayotte multidisciplinary Observatory for research and Response • GAIA DATA consortium

***List of partner institutions* / Liste des établissements partenaires**

***Name of the research organisations* / Nom des organismes de recherche**	***Legal status* / Statut**
Institut National de Recherche en Informatique et en Automatique	EPST
Centre National de la Recherche Scientifique – Délégation Occitanie Ouest	EPST
Centre National de la Recherche Scientifique – Délégation Alpes	EPST
Institut Français de Recherche pour l'Exploitation de la MER	EPIC
Institut de Recherche pour le Developpement	EPST
Service Hygrodgraphique et Océanographique de la Marine	EPA
Météo-France-DESR-Centre National de Recherches Météorologiques	EPA
***Name of the institutions of higher education and research* / Nom des établissements d'enseignement supérieur et de recherche**	***Legal status* / Statut**
Université Aix-Marseille	EPSCP

Institut National Polytechnique de Toulouse	EPSCP
Ecole Nationale Supérieure Mines-Télécom Atlantique Bretagne Pays de la Loire	EPSCP
Université Grenoble Alpes	EPSCP

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EXECUTIVE SUMMARY OF THE PROPOSED PROJECT

*Abstract - English version (max. **4000** characters)*

Given the challenges that our societies face in terms of environment and climate change, integrated modeling of marine ecosystems is an essential tool. First, it allows us to distinguish the effect of natural and anthropogenic forcing acting on ecosystems, and thus to improve our understanding of their complex dynamics. Secondly, regional projections of the future state of these ecosystems over the next decades can be made according to scenarios. Integrated modeling thus provides useful information to guide management policies. MEDIATION aims to radically transform integrated modeling methodologies by targeting two questions of major societal interest: how will global change impact the functioning of regional marine ecosystems, and how to assess the effect of environmental preservation measures? MEDIATION will focus on highly original methodological research intended to (i) develop scenarios with stakeholders that are consistent with practices, in order to inform decision-makers and guide public policies, (ii) define the appropriate level of complexity of the model chains to evaluate the response of ecosystems to these scenarios, (iii) quantify the uncertainty of models and model projections, (iv) process massive heterogeneous data to evaluate and improve the various modeling components, (v) reduce execution times to explore a large number of scenarios, and (vi) identify representative indicators of ecosystems and associated services in order to synthesize the information.
The developments will be tested with two demonstrators selected in the French Atlantic (MANGA) and Mediterranean (MEDNOW) coasts. This choice is made for complementarity in terms of geomorphology and vulnerability issues (eutrophication, oligotrophication, reduction of fisheries, acidification, larval connectivity, turbidity). A major challenge lies in the optimization of the model chains to handle a large number of scenarios with the required level of accuracy. This will result from advances in multi-scale modeling and new parameterizations, introduction of stochastic dynamics for uncertainty quantification, and relevant design of experiments for scenario management. New data processing will be developed for altimetry / in situ data fusion, object data generation (e.g., blooms, fronts), using artificial intelligence and data assimilation. These advances will be highly dependent on efficiency: scaling up (high performance computing) of learning methods, and construction of emulators for compartments of the simulation chain. The energy cost will be considered in the evaluation of efficiency. Probabilistic simulations are also an important element for a robust evaluation of past and future observing systems. Finally, the dialogue with society will rely on technological advances in the visualization of simulations and associated uncertainties. MEDIATION will set up an interactive platform to educate and familiarize the public on the impact of different scenarios. A series of relevant indicators will be co-constructed with the public authorities to better define the typology of uses and the products to be developed.

The project activities will be organized around five main work packages: 1) Demonstrators 2) Stochastic modeling and uncertainty propagation 3) Representation of physical and biogeochemical processes and scale interactions 4) High performance computing and artificial intelligence 5) Science-Society-Policy interaction. A transverse axis will coordinate all the activities of the project related to data, whether from observations or simulations. Through its partners (CNRS, IFREMER, Inria, IRD, Météo-France, SHOM, Aix-Marseille University), MEDIATION will bring together a large consortium, relying on strong scientific synergy between colleagues from

different disciplines (Applied Mathematics, Computer Science, Oceanic and Atmospheric Sciences, Biogeochemistry, Marine Biology, Economics ...), which has already proven successful in the past.

*Résumé en français (max. **4500** caractères)*

Face aux défis que doivent affronter nos sociétés en lien avec les changements globaux, la modélisation intégrée des écosystèmes marins constitue un outil de premier plan. D'une part, elle permet de distinguer l'effet des forçages naturels et anthropiques agissant sur ces écosystèmes, et d'améliorer ainsi notre compréhension de leur dynamique complexe. D'autre part, des projections régionales des états futurs de ces écosystèmes au cours des prochaines décennies peuvent être réalisés, en fonction de scénarios. Cette modélisation intégrée fournit ainsi des informations utiles pour orienter les politiques de gestion. MEDIATION a vocation à transformer radicalement les méthodes de modélisation intégrée, en ciblant deux questions d'intérêt sociétal majeur : comment le changement global va-t-il impacter le fonctionnement des écosystèmes marins régionaux, et comment évaluer l'effet de mesures permettant la préservation du milieu ? Pour cela, MEDIATION proposera des développements méthodologiques très originaux destinés à (i) élaborer des scénarios avec les acteurs de terrain de manière à éclairer les décideurs et orienter les politiques publiques, (ii) définir le niveau de complexité adéquat des chaînes de modélisation pour évaluer la réponse des écosystèmes à ces scénarios, (iii) quantifier l'incertitude des modèles et des projections qu'elles fournissent, (iv) traiter les données massives hétérogènes permettant d'évaluer et d'améliorer les différents maillons de modélisation, (v) diminuer les temps d'exécution pour explorer un grand nombre de scénarios, et (vi) identifier des indicateurs des écosystèmes et des services associés afin de synthétiser l'information.

Les développements seront testés sur deux démonstrateurs sélectionnés sur les côtes françaises Atlantique (MANGA) et Méditerranéennes (MEDNOW). Ce choix est motivé par une complémentarité en termes de géomorphologie et vulnérabilité (eutrophisation, oligotrophisation, diminution des ressources halieutiques, acidification, connectivité larvaire, turbidité). Un défi majeur réside dans l'optimisation des chaines de modèle afin de traiter un grand nombre de scénarios avec le niveau de précision requis. Celle-ci résultera d'avancées en matière de: modélisation multi-échelles et nouvelles paramétrisations, dynamiques stochastiques pour la quantification des incertitudes, méthodologies de plans d'expériences pour la gestion de scénarios. De nouvelles méthodes de traitement de données seront développées pour la fusion de données altimétriques / in situ, la génération de données objets (e.g. blooms, fronts), en faisant appel à l'intelligence artificielle et l'assimilation de données. Ces avancées sont fortement dépendantes des développements conduits pour les rendre efficaces : passage à l'échelle (calcul haute performance) des méthodes d'apprentissage, construction d'émulateurs pour des compartiments de la chaine de simulation. Le coût énergétique sera pris en compte dans l'évaluation de l'efficacité. Les simulations probabilistes sont également un élément important pour une évaluation robuste des systèmes d'observation passés et futurs. Le dialogue avec la société s'appuiera sur des avancées technologiques en matière de visualisation des résultats de simulations et des incertitudes associées. MEDIATION mettra en place une plateforme interactive pour sensibiliser le public sur l'impact de différents scénarios. Une série d'indicateurs pertinents sera co-construite avec les acteurs relais de la puissance publique pour mieux cerner la typologie des usages et les produits à élaborer.

Les activités du projet seront organisées autour de cinq tâches principales : 1) Démonstrateurs 2) Modélisation stochastique et propagation des incertitudes 3) Représentation des processus physiques et biogéochimiques et interactions d'échelle 4) Calcul haute performance et Intelligence artificielle 5) Interaction Science-Société-Politique. Un axe transverse coordonnera l'ensemble des activités du projet relatives aux données issues d'observations ou de simulations. Au travers de ses partenaires (CNRS, IFREMER, Inria, IRD, Météo-France, SHOM, Univ. d'Aix-Marseille), MEDIATION réunira un consortium large, s'appuyant sur des complémentarités scientifiques fortes entre collègues issus de différentes disciplines (Mathématiques Appliquées, Informatique,

Sciences de l'Océan et de l'Atmosphère, Biogéochimie, Biologie marine, Economie …), qui s'est déjà avéré fructueux par le passé.

1. CONTEXT, OBJECTIVES AND PREVIOUS ACHIEVEMENTS

1.1. CONTEXT, OBJECTIVES AND INNOVATIVE FEATURES OF THE PROJECT

Scientific challenges

In order to meet the current challenges of our societies in terms of environment and climate change, the integrated modeling of marine ecosystems is an essential tool. First, it makes it possible to distinguish the effect of the natural and anthropogenic forcing acting on these ecosystems, and thus to improve our understanding of their complex dynamics. On the other hand, projections of the future states of these ecosystems on a regional scale can be made, according to scenarios of evolution of the different forcings over the next decades. This integrated modeling thus provides useful information to identify possible drivers and to guide management policies. In practice, this virtuous loop is not yet optimal for three main reasons: the current modeling chains are very heavy to operate (which limits the number of scenarios explored), their robustness is not sufficiently questioned in view of the available observations, and the results they provide contain intrinsic uncertainties, difficult to synthesize in a form that can be used by decision-makers. MEDIATION aims to fundamentally transform integrated modeling methodologies in order to overcome these obstacles, by targeting two questions of major societal interest: how will global change impact the functioning of marine ecosystems on a regional scale, and how to quantitatively evaluate the effect of public policies or measures to preserve the environment? Improving these modeling chains certainly requires considering innovative, interdisciplinary and multiscale modeling approaches. To this end, MEDIATION addresses major challenge 6 (axes 6.2, 6.3) of the call for projects "An Ocean of Solutions" of the Priority Research Program (PPR) "Ocean-Climate".[2][3]

Two realistic demonstrators have been selected on the Northwest Mediterranean (**MEDNOW**) and the Bay of Biscay - English Channel (**MANGA**). This choice was made because of their complementarity in terms of spatial coverage of the French metropolitan coasts and the vulnerability issues they face (eutrophication, oligotrophication, reduction of fisheries, larval connectivity, turbidity), which are part of the scientific issues associated with Challenge 4 (axis 4.3[4]). These demonstrators rely on already partially constructed chains including compartments for the atmosphere, the ocean physics, the continent (agro-ecosystems), biogeochemistry/sediments, and intermediate and upper trophic levels of the marine ecosystems. They will provide the response of marine ecosystems to global change and will make it possible to measure the effect of public policies (fisheries, agricultural practices, climate change mitigation, etc.) on marine ecosystems. The construction of regional scenarios (GHG and aerosol forcings, river inputs, atmospheric deposition, public policies on fisheries, agriculture, land use and planning) associated with socio-economic analyses is an essential aspect of the demonstrators. MEDIATION aims to provide concrete elements for the identification of resilient scenarios by focusing in particular on the relevant scales (local, national and regional) of decision making. This project relies on many past and current achievements (see 1.2) both at the national and international levels both in connection with challenge 6 and challenge 4.3 mentioned above. The unique positioning of the MEDIATION project is strongly linked to its strong multidisciplinary aspect and to its balance between fundamental research works,

[2] Removing the scientific, methodological and technological barriers of a digital twin of the ocean

[3] Develop solutions for the management and processing of multi-sources ocean observation and modelling data and the associated socio-economic and geopolitical impacts

[4] Anticipating the resilience of socio-ecosystems

technological developments and applications. This will lead to modeling chains in line with the latest methodological advances and will certainly give them advantages at the international level. This balance of effort will also allow the project to have multiple research and application horizons during the project and beyond.

Open research questions and objectives

Project activities will be organized around five main work packages: 1) Demonstrators 2) Stochastic modeling and propagation of uncertainties 3) Representation of physical and biogeochemical processes and scale interactions 4) High performance computing and artificial intelligence 5) Science-Society-Politics interaction. A cross-cutting axis will coordinate all project activities related to data, whether from observations or simulations. To this end, MEDIATION will focus its research on very original methodological developments intended to (i) develop, with stakeholders, scenarios in line with practices and uses, in order to inform decision-makers and guide public policies that will be implemented; (ii) define the appropriate level of complexity of modeling chains to assess the response of ecosystems to scenarios; (iii) quantify the uncertainty associated with these chains and the projections they provide; (iv) process heterogeneous big data to assess and improve the different models; (v) reduce computational time to explore a large number of scenarios; and (vi) identify indicators, metrics and objects representative of the state of ecosystems and associated services in order to synthesize the information.

One of the major and original scientific questions at the heart of challenge 6 lies in the optimization of the chains described above. This will result from innovative methodological advances in multi-scale modeling and new parameterizations, introduction of stochastic dynamics for the quantification of uncertainties, methodologies of design of experiments for scenario management. Some specific actions will also target the improvement of coupling between low and high trophic levels and on LTH models simplification/acceleration. This constitutes the core of the response to axis 6.2 of Challenge 6. In connection with axis 6.3 of Challenge 6, a strong articulation between modeling chains and observational data will allow the construction of a robust and efficient digital twin. New data processing methods will be developed for the fusion of altimetry / in situ data, the generation of object data (e.g., blooms, plume, eddies, fronts), using artificial intelligence and data assimilation. All these innovative advances are strongly dependent on the developments conducted to make them efficient: machine learning and high-performance computing, construction of emulators for compartments of the simulation chain. The energy cost will be taken into account in the evaluation of the effectiveness of the proposed approaches. Probabilistic numerical simulations are also an important element for a robust evaluation of past observing systems and for the proposal of future systems.

The interaction with society is another essential ingredient of the success of the project. MEDIATION will rely on technological advances in the visualization of simulations and of associated uncertainties. MEDIATION will set up an interactive platform to educate and familiarize the public on the impact of the different scenarios. An idealized, simple and fast chain will be developed to communicate with the general public and decision makers on the basic concepts of modeling in order to be able to interact with them on the priority scientific questions for the project and beyond. A series of relevant indicators will be co-constructed with the actors of the public authority to better understand the typology of uses and products to develop.

Multidisciplinarity and structuration of the community

Through its public partners (CNRS, IFREMER, Inria, IRD, Météo-France, SHOM, Univ. d'Aix-Marseille) and private collaborators (ATOS group), MEDIATION will bring together a large consortium, based on strong scientific complementarities between colleagues from different

disciplines (Applied Mathematics, Computer Science, Oceanography, Meteorology, Biogeochemistry, Marine Biology, Economics ...), some of which have already proven very fruitful in the past. The project will thus strengthen the pre-existing structures between modeling groups (in particular on the coordination of the developments of the CROCO and NEMO systems) and will allow new collaborations between researchers working on French metropolitan coasts. The effort will also benefit communities involved in other ocean regions: deep sea, coastal zone, tropics, French overseas territories. As a major contributor to Challenge 6, the project will propose the organization of workshops to transfer its methodological innovations to all French modeling groups, in particular to those represented in other projects submitted to the Ocean-Climate PPR (MaHeWa, Futurisk, Moïse), but also those belonging to actors from the public authorities (e.g., FEM, OFB) and the private sector.

1.2. *MAIN PREVIOUS ACHIEVEMENTS*

The teams participating in the MEDIATION project have an international reputation on the aspects related to the project. The main previous achievements for each of the project entities are detailed in section 3.2 along with key publications. Here we summarize some of them.
The project is first composed of groups of mathematicians and applied computer scientists of international reputation. They have the particularity to be closely linked to geophysical applications and to have been PI of large projects gathering interdisciplinary consortia. The Inria AIRSEA, Inria Fluminance, IMT Atlantique and INP-Toulouse groups have had major impacts in several areas such as numerical methods, multi-resolution modeling, mathematical aspects of ocean-atmosphere coupling, stochastic modeling, data assimilation and machine learning. In particular, they have lead or are currently leading numerous projects like COMODO (ANR project gathering the whole French ocean modeling community; PI: L. Debreu, Inria/AIRSEA); COCOA (ANR project on mathematical aspects of ocean-atmosphere coupling; PI: E. Blayo, Inria/AIRSEA); STUOD (ERC Synergy project on Stochastic transport in Upper Ocean Dynamics; PI: E. Mémin, Inria/Fluminance); ANITI chair on machine learning and data assimilation (PI: S. Gratton, INP Toulouse); CMEMS project on Data Driven Data assimilation (PI: P. Tandeo, IMT-A). Some of them are already working together on fundamental research on AI approaches through an ANR funded project MELODY (bridging geophysics and MachinE Learning for the modeling, simulation and reconstruction of Ocean DYnamics). These teams are also strongly involved in the development of numerical ocean models with important contributions to NEMO (IMMERSE H2020 project, PI: J. Le Sommer) and CROCO (GdR CROCO, PI: F. Dumas) modeling systems. The IRD/LEGOS, SHOM, CNRS-MEOM, IFREMER/DYNECO groups are probably the most advanced French groups in ocean modeling and in the coordination of the development of the NEMO and CROCO systems; on many aspects of the project (nonhydrostatic modeling; subgrid-scale parameterizations; air-sea interactions; stochastic modeling for ocean physics and biogeochemistry), but also on aspects related to observations (SWOT: IGE and LEGOS projects; OSSE on the Mediterranean Sea: SHOM). In addition, the project involves computer scientists specialized in high performance computing (HPC), especially in connection with machine learning methods, ensemble simulations and data assimilation. The Inria DATAMOVE team is strongly involved in several European projects (EuroHPC, such as the Regale project). Bruno Raffin leads the Inria Challenge HPC BigData on the convergence between HPC, Machine Learning and Big Data. He also co-leads the working group “Sciences et Usages du Numérique” of the French Exascale project proposal. The ATOS partner will be involved in

MEDIATION through three members of its AI4SIM group integrated in the Inria/AIRSEA team (2022-2024) – funded by the French “Plan de Relance”. The AI4SIM group develops machine learning software solutions adapted to high-performance computing and has many collaborations with research teams in geophysical fluid dynamics such as ECMWF or CERFACS. Regarding regional downscaling, the CNRM group is the coordinator of the international Med-CORDEX initiative on the development of coupled regional models and climate change scenarios over the Mediterranean, with also a strong involvement in the observation systems of the area (MISTRALS HyMeX framework, ANR ASICS-MED led by H. Giordani). For the study of ecosystems and applications to fisheries management, MEDIATION includes recognized experts, including the MARBEC group (B. Ernande, co-coordinator of the European project SOMBEE on the modeling of the eco-evolutionary response of marine fish communities to fishing and climate change) and the LBH group (M. Huret, co-coordinator of an integrated project: "France Filière Pêche" DEFIPEL, aimed at proposing new management tools and evolution scenarios for the small pelagic fishing sector in France).
MEDIATION would offer a unique opportunity to leverage all these initiatives for the design of an efficient and robust digital twin of the ocean.

1.2.1 A view of the demonstrators

The Northwest Mediterranean (**MEDNOW**) and the Bay of Biscay - English Channel (**MANGA**) coastal regions have been selected as demonstration areas to evaluate the MEDIATION innovative solutions. These are relevant choices of contrasting mid-latitude systems because ongoing global changes have already been documented on both systems. In a schematic and very simplified way, the very high vulnerability to climate change is clearly established for the case of MEDNOW (e.g., Giorgi & Lionello 2008; Tuel & Eltahir, 2020; Darmaraki et al., 2019a; Soto-Navarro et al., 2020), while for MANGA, there is rather an indirect effect through sediment, nutrient and contaminant fluxes from continental catchments (Menesguen et al., 2019). MEDNOW and MANGA are also complementary in terms of morphology (large vs. narrow continental shelves), ocean dynamics (macro-tidal vs. micro-tidal) and environment (eutrophic vs. oligotrophic). The scientific communities working on these domains were until now separated and used at least partially different modeling chains: the end-to-end integrated modeling chain:
for **MEDNOW,** it combines the CNRM-RCSM6 regional climate system model (Darmaraki et al. 2019b), including the NEMOMED12 ocean model (Beuvier et al. 2012), the agro-ecosystem model LPJmL (Fader et al., 2015), the marine plankton functional types model (low trophic levels, LTL) Eco3M-MED (Baklouti et al., 2021) and the high trophic levels (HTL) model OSMOSE (Moullec et al., 2019).
for **MANGA**, it combines the hydrodynamic model CROCO recently implemented in the area and coupled to the wave model WW3 (Roland and Ardhuin, 2014), the sediment transport model MUSTANG (Mengual et al., 2019, 2021), the biogeochemical model BLOOM, the low trophic level model (formerly) ECOMARS3D (Menesguen et al., 2018), and the high trophic level model DEB-IBM (Huret et al., 2013; Bueno-Pardo et al., 2020). For its external forcing, the chain will be fed by the MEDNOW-compliant CNRM-RCSM6 regional climate system.
Most importantly, MEDNOW and MANGA share the same needs to properly address coastal ecosystem issues in order to contribute to the construction of a numerical twin of the ocean: computational grid agility; definition of the appropriate level of complexity; uncertainty management; construction of surrogate models; rapid adaptation to new or enhanced observations.

2. DETAILED PROJECT DESCRIPTION

2.1. PROJECT OUTLINE, SCIENTIFIC STRATEGY

MEDIATION addresses major challenge 6 and its axes 6.2 ("*Lifting the scientific, methodological and technological barriers of a digital twin of the ocean*") and 6.3: "*Developing solutions for managing and processing masses of multisource data from observation and modelling of the oceans and the associated socio-economic and geopolitical impacts*". It also addresses minor challenge 4 and its axis 4.3: "*Anticipating the resilience of socio-ecosystems by assessing the impacts of pressures (mining, fishing, climate change, etc.) on ecosystems, and of environmental changes on maritime activities and societies, under different global change scenarios*". In order to meet the objectives described in Section 1, MEDIATION is structured around 5 work packages and a cross cutting action.

2.1.1 Typology of the model chains used in the project.

MEDIATION aims both to lead to a realistic integrated ocean modeling and to propose major scientific advances in relation to challenge 6. To this end, different modeling chains will be used and their names and objectives are detailed below.

Chain name	Objectives
RC: Reference Chain	Realistic existing chains and their evolution through the project.
FC: Fast Chain	RC chains where some or all compartments are replaced by fast variants (using AI or simplified models). WP2, WP3, WP4
EC: Emulated Chain	An emulation through AI of the complete chain. It takes as input and output low dimension objects. WP2, WP4, WP5
AC: Academic Chain	A simplified chain dedicated to methodological developments. It can be, e.g., a one-dimensional (vertical) physics/biology model. WP2, WP5.

2.1.2 A global view of MEDIATION's workpackages

Background, context, and ambition of the workpackages
WP1 demonstrators: The two demonstrators MEDNOW and MANGA together cover all French metropolitan coastal ecosystems that are subject to critical human pressure induced by global changes, whether direct (e.g., fisheries and aquaculture, coastal management) or indirect (e.g., the impact of climate change on regional climate, continental land use, and material export to the sea). Projecting future trajectories for these coastal regions in the next 40 years requires robust, reliable, and efficient numerical integrated models to anticipate medium-term resilient scenarios for sustainable coastal socio-ecosystems. This WP is central to MEDIATION as (i) a highlight for numerical challenges, (ii) an integrator of numerical developments (T1.1), (iii) a demonstrator of efficient, robust, high-fidelity innovative numerical solutions for simulating marine ecosystem trajectories (T1.3) including original assessment and analysis tools developed in T1.2, (iv) a provider of regional multi-stressor consistent scenarios (T1.4) and associated projections combining reliability and reasonable computational costs (T1.5) and (v) a provider of original and exportable knowledge at the integrated ecosystem level for the scientific community as well as for society and decision-makers (T1.6).

WP2 Handling of uncertainty and complexity trade-off: Numerical models still exhibit a limiting "irreducible imprecision" compared to measured quantities in the turbulent regimes. Air-sea interactions, small-scale turbulent parameterizations, boundary processes and biogeochemical fluxes are currently poorly constrained in models, leading to large uncertainties in projecting the future evolution of the ocean. In addition, full-chain simulations have too many degrees of freedom to be explored systematically for climate scenarios. Exploration strategies must be developed. To represent uncertainties from physical, biological, and numerical approximations, a general framework based on stochastic fluid particle transport, called modeling under location uncertainty (LU: Memin 2014; Resseguier et al. 2017), will be explored in conjunction with a discrete form already implemented in NEMO by Leroux et al. (2021) (T2.1). The second goal is to study the evolution and propagation of uncertainties in complete model chains. This study should allow us to define trade-off strategies to reach a target accuracy level for a limited computing resource. Global sensitivity analysis must be adapted in this context (T2.2). Selecting the most relevant scenario combinations for a fixed number of simulations is a real problem that we wish to address by advanced experimental design strategies. This methodological work is an essential step towards identifying resilient scenarios (T2.3).

WP3 Representation of physical and biogeochemical processes and scale interactions: To meet the need to test hypothetical scenarios, robust and efficient simulation tools must be developed in two directions: (i) high level of realism and genericity to learn emergent properties and fundamental system behaviors. The ambition here is to improve the capabilities of deterministic (process-based) models to perform complex and high-resolution numerical simulations. This implies improving the model processes, the numerical methods on a multi-resolution flexible grid and the computational efficiency. In this sense, the research is oriented towards complexity. This knowledge can later be represented by parametrizations (Fox-Kemper et al., 2008) or surrogate models by feeding it in an AI approach (Bolton and Zanna, 2019); (ii) On the other hand, we also need simplifications that allow testing simulations of long-term scenarios and ensembles that would not be feasible with a high-resolution/complex model. Part of the effort will thus be on reducing the computational costs (time-to-solution) of the first approach by simplifying the models and model chains without significant loss of predictability. WP3 will address these issues raised for both the physical (T3.1, T3.2, T3.3) and biological (T3.1, T3.4 and T3.5) models.

WP4 Leveraging AI and HPC for Digital Twins of the Ocean: While process-based models still form the foundation of current-generation ocean prediction systems, we have seen in recent years a very fast increase in machine learning (ML) applications to ocean sciences. Applications relevant to digital twins of the ocean include the design of sub-grid closures and numerical schemes, the calibration of model parameters, the downscaling of model predictions, the acceleration of code components or the representation of model errors. In this context, hybrid approaches combining machine learning and process-based models may soon offer a viable strategy for reducing the time-to-solution and the carbon footprint of existing modeling systems, while better exploiting hybrid CPU/GPU computing architectures. In this perspective, surrogate modeling (aka emulation) will be an essential methodology to leverage. But there are still several domain-specific locks to be lifted before this hybridization can be realized. Developments both on the software infrastructure side and their applications are needed. We intend to develop the scientific and methodological underpinnings for leveraging these emerging approaches, with the necessary software solutions to efficiently train and run hybrid ML/HPC models. We propose to focus in priority on what is specific

to ocean circulation and ecosystem modeling, relying as much as possible on the existing broader software stack. WP4 will be strongly connected with WP1-3.
WP5 Science and Society: The issues at stake in MEDIATION obviously concern the role of digital technology as a tool for describing our environment and helping us to make decisions. Such an approach is increasingly present in many fields, and it is important that the public, whether a simple citizen or a decision-maker, appropriates it. A better understanding of how these complex digital systems work, of their advantages and limitations, is essential for everyone to be able to build an informed opinion. Two types of actions will be carried out: (i) towards the general public: design and production of mediation materials. The main objective is to improve the knowledge and the distance of the citizens towards the modeling systems. This will also contribute more widely to the promotion of science in society. (ii) towards decision-makers: development of adequate procedures to synthesize the results of a set of simulations of a complex modeling chain in the most relevant way possible for decision-makers/users. Particular attention will be paid to the appropriation of the notion of uncertainties, with the help of adequate visualization tools.
Cross-Cutting Action Data for Digital Twin Developments: Data of different kinds are ubiquitous in activities supporting the development of a Digital Twin of the Ocean. This motivates specific coordinated actions at project level to: (i) [internally] implement relevant mechanisms to (a) ensure proper feeding, management, and circulation of data sets between MEDIATION partners, and (b) coordinate data science activities across WPs to maximize synergies and seek added value to developments; (ii) [externally] ensure efficient interfacing with external projects, research bodies and infrastructures at national, EU and international level. The data referred to cover all types of digital information used in, or generated by MEDIATION: observation data sets, advanced data products, model simulation data sets, chain productions. A Task Team (TT) will be set up at project level to establish a roadmap during the 5 years of the project, monitor progress and report on advances. The TT will be in charge of organizing internal or open workshops or forums on dedicated data issues. The team will gather data scientists appointed by each WP, in addition to the project coordinator and a data manager part-time funded by entities.

2.2. *SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE PROJECT*

2.2.1 WP1: DEMONSTRATORS. WP leaders: M. Baklouti, S. Somot, R. Verney. AMSE, CNRM, IMBE, LMD, MARBEC, MIO, IFREMER, IMT-Atlantique, SHOM

T1.1: Assembling new end-to-end reference regional modeling chains. PD1. RCs will evolve from a preliminary version of the mere assembly of existing models to more efficient and reliable chains from the developments in WP2, WP3 and WP4 that are mature enough to be implemented. These developments may differ for RCs depending on the relevant scientific priorities. For MEDNOW, the focus will be on implementing, testing and validating a high-resolution zoom over the French coast at 1/60° in the 1/12° NEMOMED platform (T3.1) and on new parameterizations for submesoscales and deep convection (T3.2), and stochastic physics if computationally-affordable (T2.1), while working on model simplification/acceleration that contributes to FCs (T3.4). For

MANGA, the effort will concentrate on implementing multi-resolution (T3.1), from 2.5km to 100m in vulnerable and key areas, on applying coarsening for heavy biological processes, and on plankton compartment upgrade (T3.4). Both RCs will activate a two-way coupling between models of low and high trophic levels (LTL-HTL; T3.5). RCs final versions will be a compromise between the necessary level of complexity and the constraint of computational costs.

T1.2: Developing innovative object-oriented and integrated environmental indicators. PD2, PD3. We will develop assessment and analysis tools in order to go beyond the Eulerian viewpoint for model-data comparison and to aggregate the large amount of information provided by 3D simulations: (i) a tool providing spatial-temporal connectivity patterns for the distribution of coastal populations and the effective network of vulnerable marine protected areas (Le Goff et al., 2017); (ii) object-oriented diagnostics to monitor typical structures of the ecosystem, such as eddies, fronts, plumes or blooms (Gangloff et al., 2017); and (iii) integrated environmental indicators reflecting the health and status of marine ecosystems and their services (Fu et al., 2019) for the analysis/comparison of the different projections. These indicators will be defined in interaction with ecosystem managers and decision-makers (cf WP5). Some of these indicators will be selected as output of the EC developed in T4.2.3. All these methods will rely on already available simulations and applied on the demonstrators.

T1.3: Production and evaluation of historical simulations with RCs. PD4, PD5. The RCs will be run in historical mode over the 2000-2020 period (our present-climate). Based on TA1, this task will benefit from a large panel of in situ and satellite data (currents, salinity, temperature, nutrients, chlorophyll, carbon biomasses, oxygen, dissolved inorganic carbon, fish population distribution, etc.). Historical simulations will have the following objectives: (i) assessing model skills using available in situ data and the original diagnostics developed in T1.2, (ii) allowing deep understanding of the complex dynamics of demonstrators using aforementioned diagnostics, (iii) providing reliable preliminary learning datasets for emulated chains developed in T4.2.3, and (iv) constituting the present-climate state to assess future changes (T1.5). Each development for RCs upgrade will be tested in historical mode to check its added-value for the full chain.

T1.4: Production and selection of regional variants of multi-stressor socio-economic scenarios. PD6. Regional multi-stressor scenarios will be defined for greenhouse gas and aerosol emissions, land use and agricultural practices, waste water management, and fishing policies. These scenarios will be constructed as regional variants of the Shared Socio-economical Pathways (SSP) scenarios defined in the IPCC-AR6 framework and discussed and designed with stakeholders (with T5.2). Scenarios describing political decisions or human practices will be designed at different scales (national, European, regional) so as to explore in T1.5 the impact of the scale of decision. Only scenarios selected to explore the uncertainty and the range of possibilities will be run in T1.5.

T1.5: Production of MEDNOW and MANGA projections with RCs and ECs. The regional scenarios produced in T1.4 will provide consistent forcing to carry out projection simulations with the RCs over the 2020-2060 period. The number of scenario simulations will be decided once the computational cost of the RCs/FCs will be established but we plan to produce up to 10 projections for MANGA and for MEDNOW with RCs. In parallel, ECs (relating scenario forcing to key 2D-indicators developed in T4.2.3) will be run to complementarily explore a larger (100-1000) panel of SSP-based multi-stressor scenarios. They will allow for a better exploration of uncertainty sources in future projections if ECs prove to be relevant outside the domain used for its training.

T1.6: Projection analysis, data sharing and transfer. The different projections provided by the RCs, FCs and ECs will be analysed and compared through the tools developed in T1.2. In the best

case, some information on potentially resilient scenarios and on the relevant scale for political decision will be inferred by this analysis. The projections of the different scenarios will be transferred in an aggregated form to the interactive platform (WP5). The model output of the RCs/FCs, together with integrated indicators from ECs, will be delivered to the international open data centers (e.g., the French nodes of the Earth System Grid Federation) following the FAIR international Climate or Operational Oceanography standards (CORDEX-CMIP6 standard).

2.2.2 WP2: Handling of uncertainty and complexity trade-off. WP leaders: E. Arnaud, E. Mémin. Airsea, Fluminance, MEOM, CNRM, SHOM.

T2.1: Stochastic modeling of a complete chain

T.2.1.1 Physical stochastic parameterization cal/val. PD7. This task concerns the use of stochastic parameterizations to improve the physical consistency and realism of an ensemble simulator of MEDNOW. This simulator will be based on NEMO (1/4° to 1/12°), using 30 ensemble members forced by realistic air-sea fluxes over 40 years (1980-2020). The three main sources of uncertainty (chaotic, external forcing, and unresolved scale LU) will be introduced cumulatively into the system. Different ensembles will be generated and calibrated on previous high-resolution simulations (eNATL60 at 1/60°) and at 1/4° within OCCIPUT. In close collaboration with WP4, machine learning calibration procedures will be explored in complement to more traditional techniques. These ensembles will be analyzed in terms of intrinsic variability, compared to real observations (in-situ probes or satellite data) and assessed through objective probabilistic scores (rank histograms, CRPS, etc.). This will be performed in close interactions with TA1.

T.2.1.2 Biogeochemical stochastic parameterization derivation. PhD1. Unlike ocean dynamics, BGC and ecosystem model formulations in use today are not based on first principles. Therefore, the notion of uncertainty is less straightforward. Stochastic parameterizations have been implemented into NEMO BGC models to account for uncertainties arising from (i) unresolved sub-mesh processes, (ii) poorly constrained BGC formulations, and (iii) intrinsic physical variability cascading toward biogeochemistry (Gehlen et al., 2020). These exploratory works will be extended in several directions: (i) investigation of LU impact on the regional transport of BGC tracers; (ii) design of new stochastic parameterizations to account for uncertainties in turbulent closures (iii) exploration of existing formal frameworks (LU) in ocean BGC and ecosystem modeling.

T2.2 Sensitivity analysis and uncertainty propagation over the full chain. AIRSEA funding. Quantification and propagation of uncertainty in model chains is an open question. Most uncertainty propagation tools have been developed for single models and rely on the availability of a priori uncertainty distribution. Here, this distribution will be affected by upstream model chain links and no analytical formulation will be available. It will remain accessible through samples, but in limited number due to computing cost. Consequently, we will rely on fast reduced-order techniques enabling large size ensembles (Da Veiga et al. 2021). This requires to perform a sensitivity analysis on the full chain (here AC) to learn uncertainty cascade behavior and identify dimension reduction potentials. A tradeoff between affordable computation and a given level of uncertainty must be achieved. before adapting the precision of each chain link to computing resources.

T2.3 Experiment plans for improved regional scenario ensemble design. PhD2. A major practical difficulty consists in exploring the impacts of different regional multi-stressor scenarios as only a very limited number of projection simulations can be performed. The choice of parameter values must be carefully selected, in order to gain a maximum of information. We will tackle this problem from two angles. In the one hand, through the theories of experimental design and multi-

fidelity, we will address the question of the optimality of an experimental design given a fixed number of simulations and objectives (Pronzato et al. 2013). In particular, we will explore the possibility of maximizing the information provided by each new simulation. We will also take advantage of the simulations already available. Numerical experiments will be carried out with the AC and FCs chain. On the other hand, a set of 10 simulations will be performed with the RC modelling chain and a set of 100-1000 simulations with the EC chain for the MEDNOW demonstrator (in collaboration with Task 1.5) to apply these concepts to explore at best the multi-stressor uncertainty space.

2.2.3 WP3: Representation of physical and biogeochemical processes and scale interactions. WP leaders: F. Dumas, P. Marchesiello. Fluminance, MEOM, AirSea, ATOS, IRD, Shom, MIO

T3.1: Multiresolution capability: refinement and coarsening. PD8. Multi-resolution methods allow to locally refine the grid resolution for a better representation of morphological features (coastline, topography) or local phenomena (fronts, river plumes) at low cost. It will also be an asset for some of the questions on the appropriate level (local or regional) of decision making. Mesh refinement methods are now widely used and MEDIATION partners have a long history of developing and applying structured methods (Debreu et al., 2012). However, a new step will be taken by moving from nesting to fully multi-resolution methods that can involve several hundred computational grids. The work here will focus on the technical challenges of realistic configurations, i.e., parallelization and I/O strategies. These will be tested in WP1 for MANGA. The AGRIF software used in CROCO and NEMO allows the grid resolution to be coarsened and thus gives the possibility to integrate the computationally intensive parts of the codes at a lower resolution. Here we plan to use this feature for the transport of biogeochemical variables.

T3.2: Subgrid-scale parametrization. PD9. PD10. Parametrizations are still needed despite the significant increase in computing power and the improved accuracy of numerical models - removing balance approximations (Auclair et al. 2018) and reducing spurious numerical diffusion/dispersion (Marchesiello et al., 2009, Menesguen et al., 2018). This is mainly due to requirements of long-term ensemble simulations for which four research tracks will be considered. (i) Parametrizations of turbulence first require constraining numerical errors below the unresolved turbulence activity (Penney et al. 2020). We will use CROCO to investigate advection schemes that satisfy this constraint, especially 7th-order monotone schemes (e.g., WENO7). (ii) Next, we will evaluate the available parametrizations for submesoscale processes such as mixed layer instabilities (Fox-Kemper et al., 2008) or symmetric instabilities (Dong et al., 2021). (iii) Following the recent work of Giordani et al. (2020), we will then address the parametrization of oceanic convection by targeting the main events of the Mediterranean Sea (WP1). We will use CROCO in a Large Eddy Simulation approach to test the parametrization that will later be implemented in NEMO. (iv) The last track is more prospective and relies on a stochastic approach to represent unresolved scales (ULU of WP2) this time in a nonhydrostatic framework.

T3.3: Building surrogate models. PD11. The task's objective is to find a methodology to obtain a low-cost representation of coupled Ocean-Atmosphere-Wave (OAW) processes in ocean-only simulations. We will study two approaches: ***(i)*** defining a simplified equation system to mimic the underlying physical mechanisms; ***(ii)*** building a surrogate model for the response of the atmospheric boundary layer to sea state and large-scale conditions via learning strategies. The first approach, already initiated within the Inria Airsea team (Lemarié et al., 2021), falls into the class of low-fidelity

physical surrogates, which are built on a simplified version of the original equation system (**ABL1d**), while the second approach amounts to building an empirical model based on data emulating the responses of the original model. ABL1d is already implemented in **NEMO** and **CROCO** and will be compared to the standard approach (bulk formulations) for surface boundary conditions. The training data will be built from high-resolution OAW simulations and the supervised learning strategy will be carried out in close collaboration with the WP4 experts.

T3.4: Simplification of biological models. PhD3. Despite the large body of work deployed since the first Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD) models, the biological compartment remains the one with the greatest room for improvement in end-to-end ocean models. The effort will focus on complexification (for increased realism) before simplification (for acceleration). Complexification will concern: (i) low trophic levels (LTL) in order to develop a size-structured version of **BLOOM** dealing with the full planktonic spectrum, with emphasis on metazoans (copepods) and the mixotrophy process; (ii) high trophic levels (HTL) in order to include individual variability in the sardine and anchovy **DEB-IBM** for MANGA and genetic and trait variability for a larger number of fish species so as to describe their ecological and Darwinian evolutionary dynamics in **EV-OSMOSE** for MEDNOW. Simplification will next be a key objective, consisting (i) in the elimination of variables and processes from **Eco3M-MED** with dedicated methods (Lawrie and Hearne, 2007) and (ii) in the redesign of the advection of non-independent state variables (with flexible-stoichiometry models) to avoid inconsistency and waste of computing resources.

T3.5: Coupling of plankton and fish models. PD12, PD13, E1. Two-way coupling between the plankton and fish models is another aspect of complexification that will be addressed to explicitly represent the effect of fish predation on plankton and to avoid the use of empirical closure terms that are known to oversimplify the zooplankton mortality term (Daewel et al., 2014), to account for the resulting feedback loop on HTL dynamics (de Roos and Persson, 2013), and to introduce uncertainty (Minter et al., 2011). We will investigate how the inclusion of this feedback affects the dynamics of plankton groups and their variability (top-down effect) and alters the predicted HTL food web structure, dynamics and abundance supported by plankton (bottom-up effect). Darwinian evolutionary consequences for HTL will also be considered. These simulations and comparisons with data will help in defining the required model architecture to predict the effects of fishing and climate change on marine ecosystems.

2.2.4 WP4: Leveraging AI and HPC for Digital Twins of the Ocean. WP leaders: B. Raffin, J. Le Sommer. DataMove, MEOM, AI4SIM, IRIT/APO, IMT Atlantique

T.4.1 Software Infrastructure for hybrid digital twins of the ocean. T.4.1 focuses on rationalizing the underlying software infrastructure for efficiently deploying hybrid ML/HPC models with support for training from large databases, on-line coupling and data processing, for single and ensemble runs. T4.1 will leverage work done on Melissa (on-line data processing/analysis), Dask (parallel data processing/analysis), SmartSim (interface between HPC and ML), as well as the AI4SIM suite developed by ATOS.

T4.1.1 Scalable solutions for learning models from large databases. E3. This task will define multi-GPU solutions for training ML models encoded in Pytorch/TensorFlow from large databases of netCDF files. Solutions will leverage Dask (parallel loads), Horovod (parallel training) and will allow the generation of training batches from Xarray objects.

T4.1.2 Online coupling of ocean models and AI-native libraries. E2. This task will develop the tools for deploying ML models encoded in Pytorch/TensorFlow in ocean modelling chains. This entails (i) the definition of parallel data extraction/injection protocols from/to the ocean model (reusing HPC solutions like OASIS, XIOS, ADIOS, and interfaces like SmartSim), and (ii) the exploration of on-line training strategies where epoch-based strategies are not adapted.

T4.1.3 Production and data processing for large ensembles. E3. This task will define the tools for ensemble simulations to be used in WP1-3 (in particular T2.3). This includes the orchestration/data handling for the production of large ensembles on HPC, the computation of ensemble statistics, and the orchestration of online-training. Solutions will leverage Melissa, SmartSim and Radical-EnTK.

T4.2 Applications of AI in the modelling chains. T.4.2 focuses on deploying ML models for specific key applications relevant to MEDIATION modelling chains and demonstrators. The proposed activities will use datasets produced in WP1-3 and software solutions from T4.1. For each application, teams will involve AI-experts and process-oriented modelers. The proposed activities will also provide quantifications of the uncertainties of ML-based predictions.

T4.2.1 Learning sub-grid closures for unresolved processes at the air-sea interface. (funded by French recovery plan AIRSEA/ATOS). This task will design a sub-grid closure (see Zanna & Bolton, 2021, for a review) for improving the representation of coupled ocean-atmosphere-waves (OAW) processes at the air-sea interface. High resolution OAW simulations from T3.3 will be used for formulating a supervised learning problem to relate the response of the atmospheric boundary layer processes to large scale conditions. Investigations will be carried out in close collaboration with ATOS. A posteriori tests will be performed in the academic chain (AC).

T4.2.2 Learning representations of model errors in downscaled scenarios. PD14. This task will demonstrate how ML can be used to account for systematic biases in high-resolution downscaling approaches (e.g., Bonavita & Laloyaux (2020)). A representation of the systematic errors of physical models will be learned from historical simulations of T1.5 and observations (in particular ARGO floats). Representations of model errors will then be used to correct future projections (seasonal cycle, tendencies). Tests will first be performed in the MEDNOW demonstrator.

T4.2.3 Designing fast emulators of RC modelling chains. PD15. This task will use ML-based statistical emulation techniques for designing lightweight versions of entire E2E complex regional modelling chains (RC) (the so-called Emulated Chain, EC). See Gadat et al (2021) for preliminary work. As emulating the whole 4D complexity of the RC is currently out of reach, the task will focus on emulating 2D maps of key relevant indicators identified in T1.2 (spatially-integrated indicators, probability distribution functions of key parameters, ...). Emulators will be trained on the basis of ensemble simulations of MANGA and MEDNOW demonstrators and used in T2.3.

2.2.5 WP5: Science and society. WP leader: E. Blayo. Airsea and all partners

T5.1: Actions towards the general public. E4. In addition to conferences for the general public, we are going to develop specific mediation supports, usable in an autonomous way (in order to reach a large public, without depending on the availability of a scientific mediator) and pleasant, even playful. They will be elaborated within our project, but in interaction with scientific culture structures, in particular related to the ocean (for example CCSTI of Grenoble, Océanopolis, Oceanographic Museum of Monaco...). Two main supports are considered: video sequences and interactive software demonstrator. Videos will be developed, which will aim to: (i) explain what a modeling chain

is and how it is built; (ii) illustrate the dependency relationships through a cascade of phenomena; (iii) explain the notion of uncertainty propagation along a modeling chain, and the provision of results in the form of probability distributions; (iv) explain and illustrate the principle of scenarios (energy, inputs...) for projections. The production (video capture and editing) will be done by the communication department of one of our institutes (Inria, CNRS, UGA - to be defined), based on a scenario written in the project. An interactive software demonstrator will be developed from the emulated chain, in the spirit of a serious game. The users will try to solve a problem that is posed to them, such as finding a resilient scenario in a given context. They will thus be able to appropriate the notion of socio-economic and climate scenarios, and directly experiment the effect on ocean physics and food chains of modifying such or such parameter of a scenario. Different secondary products can be imagined, such as a booklet and a video for teachers, which would contain scientific information and pedagogical suggestions, in order to help a teacher to propose a class project around this game. The software will be designed for real-time use. It will be usable alone but also with several people, in order to stimulate discussions and arguments. The actual computer implementation will be subcontracted to a specialized company.

T5.2: Improved synthesis of simulation results for decision-makers. E5. A numerical simulation performed by a system such as the WP1 demonstrators produces for each physical or biological variable represented in the model 4D fields (its temporal evolution at each point of a 3-dimensional ocean area). We also wish to associate an estimation of uncertainty to each of these values. Processing the huge amount of data from these systems to provide a decision-maker or manager with relevant information is far from immediate. This difficulty is accentuated by the significant differences in culture and point of view between model developers and end-users. However, these large digital systems are obviously valuable tools for addressing important issues for public policies, such as scenarios, indicators and scales of action. In this project, we therefore envisage a long-term collaboration with the OFB (French Biodiversity Agency), in order to work together on these issues from the concrete cases of the systems operated in the project. A first phase will be devoted to a mutual dialogue in order to share knowledge, to formulate questions of interest for each one, to make a state of the art of the current practices for certain applications, and to identify managers/decision makers willing to participate in case studies. To facilitate the dialogue, it will be possible for example to co-construct a "tailor-made" training adapted to the end-users on modeling and observations, in particular by adapting the available material for the general public (conferences, demonstrator...). The second phase will then be devoted to these case studies, with the aim of developing indicators and forms of presentation (in particular thanks to scientific visualization) that are as relevant as possible.

2.2.6 TA1: Cross-cutting Activities: Data for Digital Twin Developments (CAD). TA leader: P. Brasseur. All

Cross-cutting activities identified in the initial roadmap (to be revised on an annual basis)

Data Management Plan: MEDIATION will follow the FAIR (Findable, Accessible, Interoperable, Re-usable) data paradigm and will adhere to principles of accessibility and interoperability. This will be reflected in the data management plan (DMP) to be delivered at T0+6. The DMP will cover aspects such as (i) what data will be generated; (ii) how data will be handled during and after the project (including data curation); (iii) how sharing of data within and outside the project is organized (relying on existing infrastructures such as GRICAD or ESGF depending on purpose), and (iv) what formats, metadata and standards will be adopted.

Observation data catalogue: During the first year, the Task Team will establish a catalogue of *in situ* + satellite data sets available / required /useful to support cal/val of modeling chains (WP1), ensembles (WP2), developments in hindcast mode (WP3), learning schemes (WP4) and science-society engagements (WP5). The objective will be the provision of a common data access for all partners, with a focus on satellite (ocean color, SST, altimetry), in situ (Argo BGC leveraging from new Argo France projects, MOOSE) and dedicated coastal data sets (e.g., COAST-HF), in line with the strategy set up for the validation of the RC chains during the historical period. The catalogue will be fed and updated regularly by harvesting data bases accessible through IR ILICO, ODATIS/Data Terra, Copernicus CMEMS, as well as opportunity data sets.

Development of advanced data diagnostics and tools: MEDIATION will boost numerical transformation of integrated modeling through new digital paradigms and associated diagnostics such as (i) probabilistic representation of uncertainties requiring new metrics for ensemble verification (CRPS, Entropy, Optimality etc.) (WP2), and (ii) object-oriented methodologies to track and monitor emblematic spatially-defined integrative ecosystem structures, such as eddies, fronts, convective patches, plumes or blooms (WP1). The TT will coordinate the development or upgrades of open libraries (EnsScores) to make sure that all WPs can easily plug these diagnostic tools in their setup. This will be phased at an international level, e.g., in OceanPredict.

Design of future observing systems and recommendations: Ensemble-based quantification of uncertainties is a relatively new way of thinking that will revise the conventional requirements for observational data and associated design of “optimal” observing systems. This might trigger technological innovations (e.g., new remote sensing capabilities or submarine drones slaved at reducing uncertainties) and new specifications for future observation systems (either *in situ* or satellite). A community white paper in the spirit of OceanObs19 will be delivered by the project to make agencies aware of specific observational needs and recommendations for building more robust regional projection systems in global change context. It will also provide input to national surveys such as the space prospective seminar organized every 5 years by CNES.

Watching for opportunities: Along the project’s life, the TT will be watching for opportunities to initiate new actions providing added-value of data production internally an. An example of a possible cross-cutting action could be focused on advanced data visualization software relying on virtual room facilities available at “Maison Climat Planète” (UGA, Grenoble) since 2021 (cf WP5).

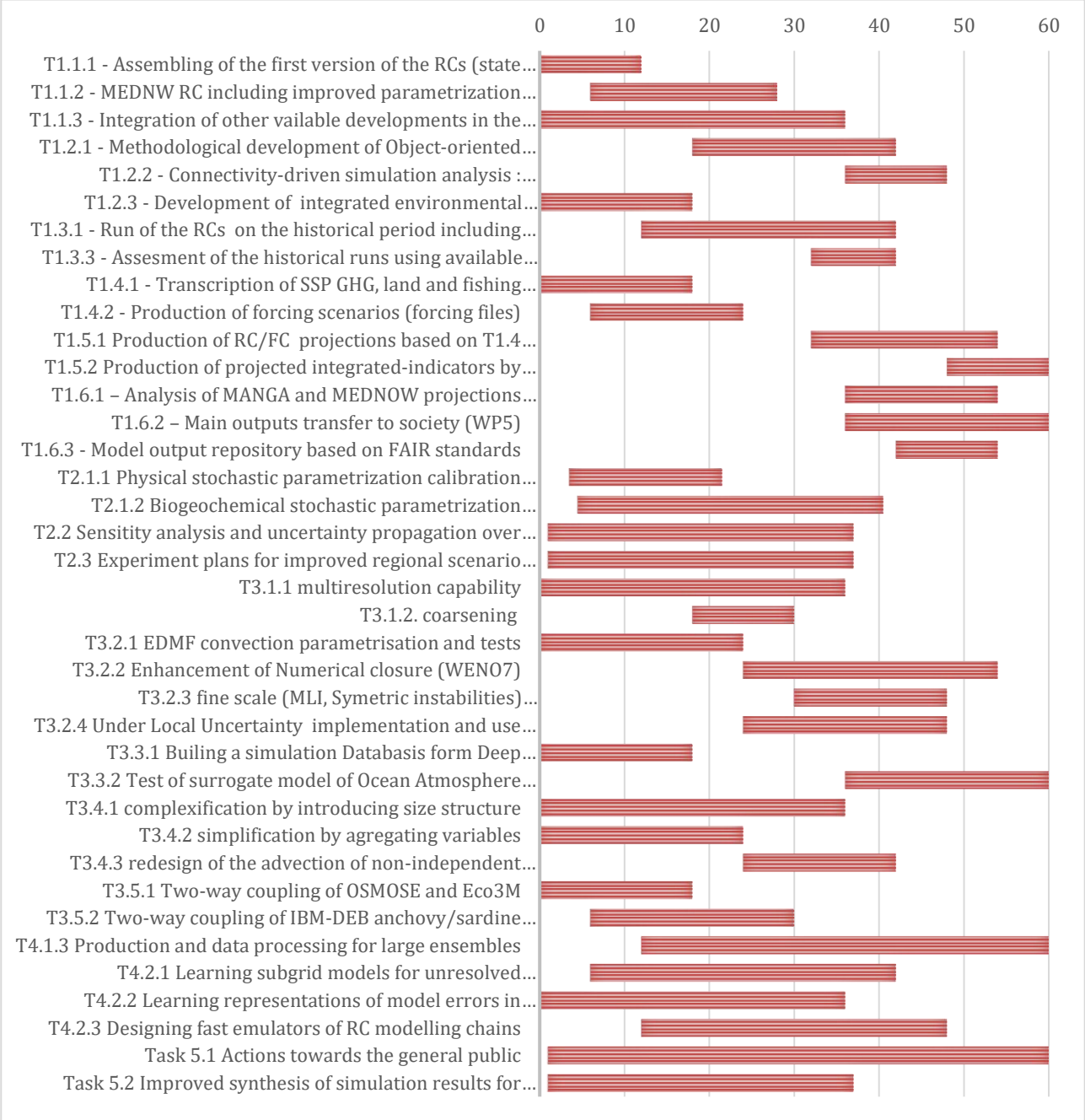
2.2.7 List of deliverables (Code (C), Documentation (DOC), Data (DA), Publication (PUB), Report (REP))

Deliverables and delivery date (T0 + X months)	
D0.1: Project website	3
D1.1a: Updated successive versions of RCs including the available developments (i.e. parametrization for convection, multiresolution, complexified/simplified biological models) **(C/DOC)**	36
D1.1b: Delivery and description of the final updated versions of the MEDNOW and MANGA RCs **(C/DOC)**	36
D1.2.a: Delivery of post-processing original tools providing object-oriented diagnostics for comparison of RC outputs with data an in-depth analysis of RC simulations (**C/DOC**)	42
D1.2.b: A coupled physics/biology connectivity tool providing the coastal population distribution and the effective network of vulnerable marine protected areas **(C/DOC)**	48

D1.2.c: Delivery of integrated environmental indicators for the transformation of projection outputs on an aggregated basis useful for end-users and decision-making and allowing the comparison between several projections. **(C/DOC)**	24
D1.3a: Assessment of the added-value of the methodological developments for RC and FC listed in T1.1 **(REP)**	42
D1.3b: Validated historical simulations over the 2000- 2020 period with the RCs. **(DA)**	46
D1.4a: SSP-consistent multi-stressor forcing regional scenarios for the RCs. **(REP)**	18
D1.4b: Selection of a set of scenarios to be run with the RCs and construction of the corresponding forcing files. **(DA)**	18
D1.5a: RC/FC projections for the 2020-2060 period for MANGA and MEDNOW **(DA)**	54
D1.5b: Provision of projected diagnostics and indicators by the EC over the 2020-2060 period for MANGA and MEDNOW **(DA)**	60
D1.6a: Publications synthetizing the RC/FC and EC projection results **(PUB)**	60
D1.6b: Inputs for the interactive platform (WP5) based on the integrated environmental indicators and object-oriented diagnostics **(DA)**	54
D1.6c: Potential information on resilient scenarios and on the impact of the spatial scale of political decision **(REP)**	60
D2.1.1: Cheap but realistic probabilistic prototype for ensemble generation (Physics part)	22
D2.1.2: Bio-geochemical stochastic model. **(PUB)**	41
D3.1: Updated AGRIF, CROCO and NEMO **(C).** Reference tests and multiresolution simulations for WP1 **(DA)**	36
D3.2: Updated CROCO including convection and submesoscale parametrizations and the stochastic ULU capacity. (**C/PUB)**. Reference simulations for WP1 **(DA).**	48
D3.3: Database simulation for machine or deep learning performed in WP4. Reference simulation with ABL1d. Qualified simulation using the surrogate OAW model **(DA/C/REP).**	54
D3.4: Simplified Eco3M set up for MEDNOW. **(C/PUB)**	48
D3.5a: Mechanistic size-based model of unicellular plankton (mixotrophy) derived from the BLOOM model and coupled to a metazoa model (ontogeny) MANGA. (**PUB)**	36
D3.5 b: Coupling of plankton and fish in MEDNOW and MANGA. **(C/PUB)**	48
D4.1.1: Software infrastructure early prototype **(REP/C).** Identification of the software base needed, test of existing solutions, code base selection, specification of the customization/plugins to develop, and set up of code repository for aggregating code sub-modules, use cases, tests, discussion channels, issue tracking, etc.	24
D4.1.2: Software Infrastructure mid-term release **(REP/C).** Progress report for T4.1.1-3, with code release, including HPC packet manager support (Spack), functional and performance tests (on various HPC architectures), retargeting if necessary, following the fast technological evolution of the domain (ML tools in particular).	42
D4.1.3: Software infrastructure final release **(REP/C).** Code release with documentation for T4.1.1-3, report on scaling experiments, compute hours/energy consumption, report on envisioned actions for sustainability beyond the project end.	58
D4.2.1: Subgrid model for air-sea interactions **(PUB/C).** Available in NEMO and CROCO	42
D4.2.2: Bias correction algorithm for RC (**PUB/C).** Available for WP1.	36
D4.2.3: EC: Emulator of the reference chain (**PUB/C)**. Available for WP1	48
D5.1.1: Series of **videos** for the general public	24

D5.1.2: Interactive **software** and associated pedagogical material	36
D5.2.1: Organization of workshops bringing together researchers and managers	60
D5.2.2: New prototype tools for transferring model results to managers **(C)**	60
D6.1: Data management Plan **(REP)**	6
D6.2: Observation Data Catalogue and access guide **(REP)**	12
D6.3: EnsScore user's guide and library updates **(C/REP)**	18
D6.4: Observation requirements for future in situ / satellite systems **(REP)**	48

2.2.8 Task scheduling table



3. PROJECT ORGANISATION AND MANAGEMENT

3.1. PROJECT MANAGER

The MEDIATION project will be led and coordinated by Laurent Debreu (Inria) and co-led by Franck Dumas (SHOM) and Patrick Marchesiello (IRD). Due to the wide scope of the project which covers a large number of disciplines, the project has two co-leaders to ensure full relevancy of the scientific and technological choices made during the preparation of the proposal and during its development. Most of this section is devoted to the project manager and it ends with a brief biography of the co-leaders.

Laurent Debreu (LD) is a senior scientist ("Directeur de Recherche") at Inria. Inria is the French National Institute for Research in Digital Science and Technology. LD is an applied mathematician who focuses his research on applications related to numerical modeling of the ocean and atmosphere. His main research topics are a) numerical methods b) data assimilation c) coupling methods d) high performance computing. His current research objective is to lower the reducible error (as opposed to irreducible imprecision), which is oriented toward three main axes: i) advanced numerical schemes and their consistency with subgrid-scale parameterizations ii) multiresolution methods iii) new algorithms for high performance computing. Beyond the research aspects, LD is also strongly involved in certain aspects of technological developments such as those to be developed in the framework of MEDIATION. In particular, he coordinates the development of the AGRIF software, an international reference software for mesh refinement. LD has a very strong knowledge of numerical ocean modeling and has interacted with many groups of developers, in France and in the world. He therefore has a very thorough understanding of these complex systems and the main associated issues. Through his research work and his responsibilities, he promotes interdisciplinary work combining different research disciplines and also allowing the transfer of fundamental research results into applications.

3.1.2 Responsibilities in link with MEDIATION

The AIRSEA team

LD is the scientific head of the AIRSEA team, *Mathematic and computing applied to oceanic and atmospheric flows*, a joint team between CNRS, Inria and University Grenoble Alpes. The scope of AIRSEA is to develop *mathematical and computational methods for the modeling of oceanic and atmospheric flows*. The AIRSEA team is composed of 13 permanent members (5 women and 8 men) and the total number is around 35, including PhD and postdoctoral students. The team focuses its research on four axes: (i) modeling of ocean and atmospheric flows, (ii) model reduction and multi-scale algorithms, (iii) uncertainty quantification (iv) high-performance computing. All these research directions are central to the MEDIATION project. Within the framework of the "France relance" plan, the AIRSEA Inria team hosts three additional members from the ATOS private company. Within ATOS' HPC-AI R&D division, the agile AI4Sim (Artificial Intelligence for Simulation) team designs and develops Deep Learning (DL) solutions to make physical modeling and numerical simulation more accurate and efficient.

The LEFE program

LD is a member of the scientific committee of LEFE, a multi-agency (ADEME, CEA, CNES, CNRS, IFREMER, Inria, IRD, Mercator Ocean International, Meteo-France, MTE) national program

dedicated to the study of “Fluid envelopes and the environment”. Within LEFE, he is also the chair of the LEFE-MANU action. The objective of MANU is to promote interdisciplinary research at the intersection between applied mathematics, computer science and ocean-atmosphere sciences. This is achieved by funding one to three years projects. The scientific committee of LEFE-MANU is composed of 11 members, who are strongly involved in the organization of annual training sessions (e.g., Numerical Methods for the Ocean and Atmosphere, Data Science, Data Assimilation Techniques) and more generally in dissemination actions (relations with industry, educational resources). This position gives him a large overview of research carried out by the different French groups, particularly in relation to challenge 6 of the PPR call.

Other current and past responsibilities

LD has been a member of the scientific commission 5 (CCS5) “Data Sciences and Model” of the IRD (French National Research Institute for Sustainable Development). He was also a member of the scientific committee of operational oceanography (Mercator Ocean) and an invited member of the scientific committee of IFREMER. LD is the chair of the Applied Mathematics section of CARI (African Conference on Research in Computer Science and Applied Mathematics), which aims to promote South-North collaborations in the field of applied mathematics and computer science.

3.1.3 Project management

COMODO (“Ocean Modeling Community”)

Laurent Debreu initiated the creation of the French COMODO group based on his knowledge of the different research teams involved. He was the principal investigator of an associated ANR project which involved 7 French laboratories (total cost 4.9M€, 2011-2016). At the end of the ANR project, it was natural to propose an extension to the international level, which gave birth to the COMMODORE workshop series.

CROCO and NEMO

Laurent Debreu is a member of the steering committee of the CROCO ocean model (www.croco-ocean.org). CROCO is a new coastal ocean model developed jointly by members of several institutes: CNRS, Ifremer, Inria, IRD, SHOM, Paul Sabatier University. The steering committee is in charge of institutional links and promotion of CROCO at the national and international level (this includes training sessions, conference presentations and the establishment of new collaborations). LD is also strongly involved in the development of the NEMO ocean model and contributes to its strategic development plan, in particular through the IMMERSE H2020 project and CMEMS contracts.

Other projects

LD has been PI or WP leader for Inria of five ANR projects and two European projects and of several contracts with the IFREMER and SHOM partners. He is currently involved as a WP leader in the ANR project MeLODY (WP: “How to learn physically sound representations of geophysical flows? »), in the ANR project ADOM (Asynchronous Domain Decomposition Methods) and in the CMEMS project on the multiresolution aspects of the NEMO ocean model. On the administrative side, Laurent Debreu has been the researcher responsible for the budget of all the teams of the Inria Grenoble-Alpes center (35 research teams and 10 service teams) for the past 6 years. As such, he has a strong experience in managing a large budget.

Short resume

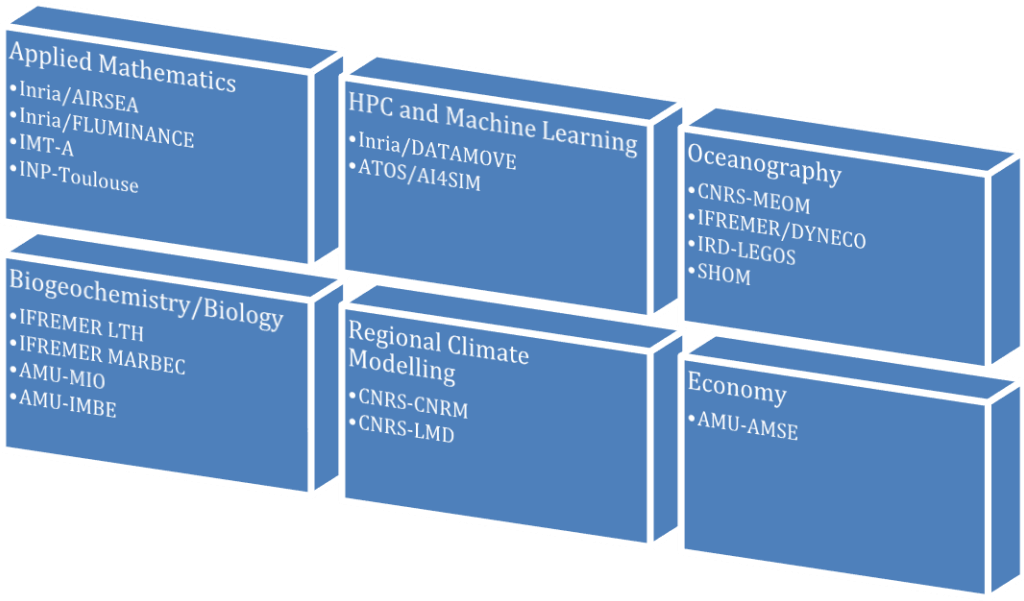
Laurent Debreu, Inria Research Director, Website for additional informations
Date of birth: June 30, 1971 (50 years old).
Education: Engineer in scientific computation, ENSIMAG, 1995 and PhD in applied mathematics, Université Grenoble, 2000 “Local Mesh Refinement Methods – Applications to Ocean Modelling”, Thesis Advisor: Eric Blayo and Francois-Xavier Le Dimet
Visiting positions: University of California at Los Angeles 2000-2001. CSIT, Florida State University, Florida 2002
LD has supervised 10 PhD thesis, 8 postdoctoral students and 11 research engineers.
Number of publications in international journals or book chapters: 39

3.1.4 Co-leaders **Franck Dumas (SHOM).** Franck Dumas is a senior scientist at the French hydrographic and Oceanographic Service for the Navy. His research interests focus on the Mediterranean Sea and more specifically on the dynamics of this semi-enclosed sea. His latest work focuses on long-lived mesoscale structures that can significantly shape the acoustic landscape. To this end, he continues its modeling activities (from the global scale of the Mediterranean Sea to local key areas such as the Strait of Gibraltar) and its data acquisition activities at sea (PI of multi-partner ocean surveys like PERLE-1 or Protevs-SWOT and co-PI for Gibraltar2020). Franck spent the first part of his career at IFREMER (Dyneco team) involved in multidisciplinary research programs and in charge of the development of Ifremer's coastal ocean model (MARS). In 2016, he joined the CROCO group and finally lead the eponymous GdR n°2014 starting in 2018. He was involved in Ifremer’s Scientific Advisory Board and in operational oceanography programs (former PREVIMER demonstrator of a French coastal operational service) and he still is a member of the Scientific Advisory Board of Mercator Ocean International and co-chair of the MONGOOS modeling group. Finally, he is now very involved in the Defense Technology Program "Protevs II" funded by the “Direction Générale de l'Armement” (DGA), which allows him to have many contacts within the French academic community.

Patrick Marchesiello (IRD). Patrick Marchesiello is a senior scientist at IRD with about 80 peer-reviewed publications. His research focuses on the integrated circulation dynamics of coastal and oceanic systems. He spent many years working abroad, in Northern and Southern countries, and was a developer of ROMS in the United States before joining IRD. As part of his involvement in the development of research tools, he has contributed extensively to community numerical models and used them in fundamental and operational applications. He is now in the steering committee of the CROCO model, pursuing an effort to improve numerical methods to give the robustness that coastal modeling needs. Over the last fifteen years, part of his research has been devoted to the issue of sustainable development in the South, for which he has coordinated major projects. His various missions have allowed him a comparative approach of the coastal processes and vulnerability in many regions, as well as the perception and expectations of the populations in this field. In his last assignment in Vietnam, he was the scientific coordinator of a large project (1.2 million €) on erosion and protection measures in the Mekong delta coastal zone, funded by the EU and managed by the French Development Agency (AFD), involving also several Vietnamese research institutes. Finally, his past involvement in New Caledonia (4-year assignment and leadership of several large projects) will put him in a position to interact with colleagues responding to challenge 1 of the PPR call (MaHeWa, Futurisk), concerning the application of new CROCO developments to French overseas territories

3.2. *ORGANIZATION OF THE PARTNERSHIP* / ORGANISATION DU PARTENARIAT

MEDIATION is composed of 16 research entities corresponding to separate research units. These entities cover varied and complementary disciplinary fields that will allow the project to achieve its objectives whether they are related to major challenge 6 or minor challenge 4. Two of them will not be directly funded by MEDIATION because they will have other resources (ATOS/AI4SIM French recovery plan entity, SHOM PDT-DGA entity).



MEDIATION addresses major challenge 6 (6.2, 6.3) and therefore has a strong component oriented towards numerical modeling and digital sciences in general. As is generally the case in these disciplinary fields, the gender parity is far from being reached. Out of ten WP leaders, two are women. Within his own research team, the project coordinator, Laurent Debreu, is very concerned about this parity (60% men, 40% women). In conjunction with the project partners, he will ensure that a major effort is made in terms of recruitment. In particular, the project has set a performance indicator of 30% female recruitment. The project has a fairly good age distribution with an average age of the WP leaders around 50 years and many young permanent researchers are involved.

3.2.1 Entity n°1: Inria-AIRSEA

The AIRSEA team is located in Grenoble, France. It is a joint team between CNRS, Grenoble Alpes University (UGA) and Inria composed of 13 permanent members. The general scope of the AIRSEA project-team is to develop *mathematical and computational methods for the modeling of oceanic and atmospheric flows*. The mathematical tools involve both *deterministic and statistical approaches*. The domains of applications range from climate modeling to the prediction of extreme events.

Outstanding achievements over the past 5 years related to MEDIATION

- Numerical methods (NH solver for CROCO, new time integration scheme for NEMO …)
- Mathematical aspects of OA coupling (ANR COCOA, CMEMS)
- Robust optimization coupled with model reduction.
- Multiresolution methods and development of the AGRIF software

Key AIRSEA staff involved in MEDIATION

- Elise Arnaud, associate professor at UGA. She is an expert in sensitivity analysis and design of experiments. WP2 participant.
- Eric Blayo, professor at UGA. He was leading a large ANR project on mathematical aspects of OA coupling. He is also co-director of the "grange des Maths", an association of scientific mediation whose aim is to "make people love maths". WP2 participant and WP5 leader.
- Laurent Debreu, Inria senior research scientist. He will coordinate the entire MEDIATION project and contribute mainly to the WP3.
- Florian Lemarié, Inria scientist with an expertise in numerical methods and OA coupling. Co-Leader of the NEMO numerical kernel working group. WP3 participant.
- Arthur Vidard, Inria scientist. Expert in data assimilation and robust optimization. WP2 participant.
- Olivier Zahm is scientist at Inria. Expert in dimension and model reduction. WP2 participant.

Key publications in link with the MEDIATION proposal:

1. F. Auclair, L. **Debreu**, E. Duval, M. Hilt, P. Marchesiello, E. **Blayo**, F. Dumas and Y. Morel. Theory and analysis of acoustic-gravity waves in a free-surface compressible and stratified ocean, 2021-10, *Ocean Modelling*
2. V. Trappler, E. **Arnaud**, A. **Vidard**, L. **Debreu**, Robust calibration of numerical models based on relative regret 2021-02, *Journal of Computational Physics* , Vol. 426, p. 109952:1-19
3. F. **Lemarié**, G. Samson, J.-L. Redelsperger, H. Giordani, T. Brivoal, G. **Madec**. A simplified atmospheric boundary layer model for an improved representation of air-sea interactions in eddying oceanic models: implementation and first evaluation in NEMO (4.0) 2020-12. *Geoscientific Model Development* , Vol. 14 European Geosciences Union p. 543 - 572
4. R. Lam, O. **Zahm**, Y. Marzouk, K. Willcox, Multifidelity Dimension Reduction via Active Subspaces 2020-04. *SIAM Journal on Scientific Computing* , Vol. 42, No. 2 Society for Industrial and Applied Mathematics p. A929-A956.
5. K. Klingbeil, F. **Lemarié**, L. **Debreu**, H. Burchard, The numerics of hydrostatic structured-grid coastal ocean models: state of the art and future perspectives, 2018-05 *Ocean Modelling* , Vol. 125 p. 80-105

3.2.2 Entity n°2: Inria-Fluminance

Fluminance is a research group jointly affiliated to Inria and to the mathematical research institute of Rennes I University (IRMAR - UMR 6625). Fluminance is composed of 6 permanent researchers, 3 post-doctoral fellows, 4 PhD students and 1 research engineer. Fluminance is a multidisciplinary group at the crossing of fluid dynamics and applied mathematics. For several years the group is particularly involved in the design of stochastic modeling for geophysical flows to improve model error modeling and quantification. Fluminance has also developed strong skills in data assimilation for fluid flow dynamics. It is both associated with the Labex Henri Lebesgue in Mathematics and with the Labex Cominlabs in computer sciences.

Outstanding achievements over the past 5 years related to MEDIATION

- Conception of a methodological framework for stochastic modeling of fluid flows
- Study and analysis of stochastic reduced order models
- Analysis and development of stochastic oceanic models
- Definition of efficient data assimilation methods with model errors
- Design of data analysis tools to decipher the action of small-scale velocities

Key Fluminance staff involved in MEDIATION

- Etienne Mémin, Inria senior researcher and visiting professor at the Department of Mathematics of Imperial College London, heads the Fluminance group. He is PI of the ERC synergy grant STUOD in collaboration with Ifremer and Imperial College. He is an expert in stochastic modeling for fluid flow dynamics and data assimilation. He will lead WP2 and participate to WP3.

- Gilles Tissot, Inria researcher, is a specialist in data model coupling, and data-driven analysis of fluid flows. He recently developed stochastic linear mode analysis for wave turbulence analysis and simulation.
- Long Li, Inria young scientist, is involved in the development of stochastic ocean codes. He is supported by the ERC STUOD and will contribute to WP2. He is a specialist in uncertainty quantification and stochastic modeling.

STUOD support to MEDIATION: Workshops of the ERC STUOD, as well as the set of a Springer series proceedings devoted to Mathematics of planet Earth, will be opened to the MEDIATION participants.

Key publications in link with the MEDIATION proposal:

1. V. Resseguier, A. Picard, **E. Mémin**, B. Chapron (2021), Quantifying truncation-related uncertainties in unsteady fluid dynamics reduced order models, *SIAM/ASA J. on Uncertainty Quantification,* , 9(3), 1152–1183.
2. **G. Tissot**, A. Cavalieri, **E. Mémin** (2021) Stochastic linear modes in a turbulent channel flow, *J. of Fluid Mechanics*, 912, A51
3. W. Bauer, P. Chandramouli, B. Chapron, **L. Li**, **E. Mémin** (2020), Deciphering the role of small-scale inhomogeneity on geophysical flow structuration: a stochastic approach, *J. of Physical Oceanography,* 50(4), 983-1003.
4. R. Brecht, **Long Li**, Werner Bauer, **E. Mémin** (2021), Rotating shallow water flow under location uncertainty with a structure-preserving discretization, *J. of Advances in Modeling Earth Systems*, In press.
5. V. Resseguier, **E. Mémin**, B. Chapron (2017), Geophysical flows under location uncertainty, Part I, II & III, *Geophysical and Astrophysical Fluid Dynamics.* 111:3, 149-227.

3.2.3 Entity n°3: Inria-Datamove

Datamove (https://team.inria.fr/datamove/) is a join team between INRIA and Laboratoire d'Informatique de Grenoble (LIG – UMR 5217) in the domain of high-performance computing. Datamove gathers 8 permanent researchers, 11 PhD students and 4 engineers. Datamove focuses on data aware large scale computing, investigating approaches to reduce data movements on large scale HPC machines, including optimization of resource allocation, energy reduction strategies, in situ high performance data analysis, large ensemble data processing.

Outstanding achievements over the past 5 years related to MEDIATION:

- Melissa software framework for on-line data processing of very large-scale ensemble runs. Melissa supports large scale sensibility analysis, data assimilation, deep surrogate training (https://gitlab.inria.fr/melissa).
- On-line coupling of MPI simulation code with Dask, a standard Python distributed task programming environment. Enable on-line parallel data analysis and machine learning.
- Deep neural architecture for building a CFD surrogate model for sensibility analysis. Paper accepted at the Neurips 2021 workshop on Machine Learning and the Physical Sciences.

Key Datamove staff involved in MEDIATION:

- Bruno Raffin, INRIA senior researcher and head of the DataMove team. He is expert in high performance data analysis, parallel algorithms, parallel workflows. He leads the INRIA Challenge HPC-BigData on the convergence between HPC, Machine Learning and Big Data. He also co-leads the workgroup Sciences et Usages du Numérique for SP3 of the French Exascale project proposal. WP4 co-leader.
- Christoph Conrads, INRIA engineer, specialist in HPC software, in charge of the Melissa suite development. WP4 participant.

- Sofya Dymchenko, INRIA PhD student (2022-2025), High Performance On-line Deep Neural Network Training from Synthetic Data. WP4 participant.

Key publications in link with the MEDIATION proposal:

1. T. Terraz, A. Ribes, Y. Fournier, B. Iooss, B. Raffin, Melissa: Large Scale In Transit Sensitivity Analysis Avoiding Intermediate Files. *The International Conference for High Performance Computing, Networking, Storage and Analysis (Supercomputing)*, p. 1 – 14, Denver, United States, November 2017, [hal:hal-01607479].
2. A. Ribes, B. Raffin, The Challenges of In Situ Analysis for Multiple Simulations. *ISAV 2020 - In Situ Infrastructures for Enabling Extreme-Scale Analysis and Visualization*, p. 1–6, Atlanta, United States, November 2020, [hal:hal-02968789].
3. Amal Gueroudji, Julien Bigot and Bruno Raffin. DEISA: Dask-Enabled In Situ Analytics. *28th IEEE International Conference on High Performance Computing, Data, and Analytics (HiPC 2021)*, Bangalore, December 2021.
4. C. Mommessin, M. Dreher, T. Peterka, B. Raffin, Automatic Data Filtering for In Situ Workflows, *IEEE International Conference on Cluster Computing*, Hawai, United States, September 2017, [hal:hal-01581032].
5. E. Dirand, L. Colombet, B. Raffin, TINS: A Task-Based Dynamic Helper Core Strategy for In Situ Analytics, *SCA18 - Supercomputing Frontiers Asia 2018*, p. 159–178, Singapore, Singapore, March 2018, [hal:hal-01730910].

Other Datamove Funded Project that will contribute to MEDIATION:

- **EuroHPC H2020 project Regale (2021-2023) (https://regale-project.eu/).** Aim at building an energy efficient software stack for tomorrow's HPC systems, ensemble runs with Melissa being one use case. Results should directly benefit to MEDIATION (WP4).

3.2.4 Entity n°4: ATOS-AI4SIM

The **Atos BDS R&R AI4Sim** Group aims at developing artificial intelligence techniques to make physical modeling and numerical simulation more accurate and efficient on HPC platforms. AI4Sim design solutions to orchestrate coupling strategies between data driven deep learning models and classical numerical solvers. AI4Sim has successful collaborations with industrial and academic partners, in co-designing and co-developing AI-augmented simulation solutions through application of scientific machine learning techniques (surrogate models, deep learning, physics-informed neural network, black-box modeling, meta-optimization, AI-augmented workflow deployment, etc.).

AI4Sim is mainly involved in two Centers of Excellence (CoE) : the Atos Weather and climate modeling CoE in collaboration with ECMWF and NVIDIA, and the RAISE CoE (Research on AI- and Simulation-Based Engineering at Exascale, 11 partners, www.coe-raise.eu) working on the next HPC/AI generation of hybrid solvers on exascale platforms. The AI4Sim Team is also collaborating closely with 3AI institute of Toulouse ANITI, CERFACS, and with CEA.

Furthermore, Atos and Inria have developed a strategic collaboration along with a global partnership agreement signed in April 2021. More specifically related to the topic "modeling the ocean, atmosphere and climate", Atos and Inria have established a joint laboratory combining artificial intelligence methods and HPC related to the oceanography domain. The common laboratory resulting software will be released under open-source license.

Outstanding achievements over the past 5 years related to MEDIATION

- The AI4Sim Library, a Python Library aiming at making physical modeling and numerical simulation more accurate and efficient on HPC platforms. This includes deep surrogate models

(MLP, CNN, GNN, PINN) and the orchestration layer (containerization, coupling, efficient communication between classical and DL solvers).
- Methodological development related to Physics-Informed Machine Learning (Patents pending: FR2005181, EP21305044)
- Research activity in collaboration with ANITI on the combination of machine learning and data assimilation in latent space (Atos-ANITI PhD Student M. Peyron)

Key AI4Sim staff involved in MEDIATION
- Gaël Goret, Atos Distinguished Expert leading the AI4Sim R&D group. Data Scientist holding a PhD in Computational Physics (since 2011) with strong knowledge in AI and HPC.
- Christophe Bovalo, Atos Data Scientist and PhD in Atmospheric Sciences (since 2013)
- Alexis Giorkallos, Atos Lead data scientist, expert on Physics-informed deep learning
- Mathis Peyron, PhD Student (2021-2023) Towards more efficient learning of physical dynamics using machine learning and data assimilation.
- Rémi Druilhe, Atos Data Engineer and PhD in Computer Science (since 2013), in charge of integration and deployment of the deep learning containerized inference engine.

Key publications in link with the MEDIATION proposal
1. Patent Pending FR2005181 Machine learning model surrogating physical models in numerical simulation
2. Patent Pending EP21305044 Hamiltonian Neural Network for Fluid Dynamics
3. Peyron, M., Fillion, A., Gürol, S., Marchais, V., Gratton, S., Boudier, P., et al. (2021) Latent space data assimilation by using deep learning. Q J R Meteorol Soc, 147(740), 3759– 3777. Available from: https://doi.org/10.1002/qj.4153

3.2.5 Entity n°5: CNRS-IGE-MEOM

CNRS MEOM (www.ige-grenoble.fr/meom) is the oceanography research team at IGE (UMR 5001), promoting an integrated data-driven approach to computational oceanography that combines ocean modelling, geophysical fluid dynamics, and satellite/in-situ observations. CNRS MEOM consists of ~25 members including 10 permanent staff. The **main objectives** are the study of the role of the ocean in the variability of the climate system, the development of numerical inversion and data assimilation methods for the analysis and prediction of the marine environment, and the production and analysis of frontier simulations on HPC architectures.

Outstanding achievements over the past 5 years related to MEDIATION:
- ***Development of a generic approach to explicit simulation of uncertainty in NEMO*** for ocean dynamics and coupled applications, based on stochastic perturbations (Brankart *et al*., 2015).
- Use of stochastic NEMO ensemble simulations to study ***intrinsic ocean variability*** and implications for ***climate modelling*** and ***projections*** (Penduff *et al*., 2018; Gehlen *et al*., 2020).
- Production of the ***eNATL60*** ultra-high resolution ocean simulation (github.com/ocean-next/eNATL60) to generate a ***multiscale*** (from km to basin-scale) ***digital twin of the ocean circulation*** (used by ~20 research groups worldwide).
- Transition to **probabilistic/efficient modelling of marine ecosystems**, in support of the new generation operational systems for CMEMS (Garnier *et al*., 2016; Bricaud *et al*., 2020).
- New AI approaches for numerical ocean modelling (e.g. sub-grid parametrizations, Frezat *et al*., 2021) and data-driven inference.

Key CNRS-MEOM staff involved in MEDIATION:

- Thierry Penduff, CNRS senior scientist, is leader of the MEOM group, expert in multi-scale ocean variability and ensemble modelling. *WP2 participant*. PI of the OCCIPUT and MOPGA CONtACTS projects (Prof. W. Dewar).
- Julien Le Sommer, CNRS scientist and co-leader of MEOM, MEDIATION WP4 leader. Scientific coordinator of NEMO at national level and coordinator of the H2020 IMMERSE project (2018-2022, http://immerse-ocean.eu). Co-chair of CLIVAR Ocean Model Development panel (https://www.clivar.org/clivar-panels/omdp), member of the scientific board of the Multidisciplinary Institute in Artificial Intelligence (https://miai.univ-grenoble-alpes.fr).
- Pierre Brasseur, CNRS senior scientist, leader of *MEDIATION Cross-cutting Activities on Data* and *WP3 participant.* Engaged in operational oceanography developments for many years, member of OceanPredict MEAP Task Team (www.oceanpredict.org) and WP leader in H2020 SEAMLESS (www.seamless.org) on ensemble marine ecosystem prediction.
- Jean-Michel Brankart, CNRS research engineer, *WP2 participant*. Pioneer in the development of the stochastic NEMO code. Currently member of the GMMC scientific committee, and actively involved in H2020 SEAMLESS.

Key publications in link with the MEDIATION proposal:

1. **Brankart J.-M.**, Candille G., Garnier F., Calone Ch., Melet A., Bouttier P.-A., **Brasseur P.** and Verron J., 2015: A generic approach to explicit simulation of uncertainty in the NEMO ocean model, Geophysical Model Development, 8, 1285–1297.
2. Bricaud C., **Le Sommer J**., Madec G., Calone Ch., Deshayes J., Ethe Ch., Chanut J., and Levy M., 2020. Multi-grid algorithm for passive tracer transport in the NEMO ocean circulation model: A case study with the NEMO OGCM (version 3.6). Geoscientific Model Development 13(11), pp. 5465-5483.
3. Frezat, H., Balarac, G., **Le Sommer, J**., Fablet, R., Lguensat, R., 2021. Physical invariance in neural networks for subgrid-scale scalar flux modeling. Physical Review Fluids 6(2),024607.
4. Garnier F., **Brankart J.-M., Brasseur P**. and Cosme E., 2016: Stochastic parameterizations of biogeochemical uncertainties in a 1/4° NEMO/PISCES model for probabilistic comparisons with ocean color data, J. Mar. Systems, 155, 59-72
5. **Penduff, T**., Sérazin G., Leroux S., Close S., Molines J.M., Barnier B., Bessières L., Terray L., and Maze G.., 2018. Chaotic variability of ocean heat content: Climate-relevant features and observational implications. Oceanography 31(2).

3.2.6 Entity n°6: CNRM

CNRM (www.umr-cnrm.fr) The Centre National de Recherches Météorologiques is a joint research department (laboratory) of Météo-France (MF-CNRM) and CNRS (CNRS-CNRM). In MEDIATION, CNRM will bring its 20-year long expertise in ocean and coupled regional climate modelling with a primary focus on the Mediterranean area and its wide access to the Meteo-France super-computer facilities. CNRM was part of former projects on similar scientific topics such as GICC MedWater, ANR CICLE, ANR REMEMBER, ANR ASICS-MED, SiMed, HyMeX, FP6 CIRCE, ITN MARmaED.

Outstanding achievements over the past 5 years related to MEDIATION:

- ***Development of the world-class CNRM regional climate system model (CNRM-RCSM6)*** for the study of the Mediterranean climate and sea, including the high-resolution and fully-coupled representation of the regional atmosphere, aerosols, land-surface, land-hydrology and ocean (Darmaraki et al. 2019b), in particular the Mediterranean version (NEMOMED).

- **Production and distribution of ensembles of regional climate scenario simulations** over the 1950-2100 period for the Mediterranean Sea in the framework of Med-CORDEX.
- **Coordination of the international Med-CORDEX initiative** (www.medcordex.eu, Somot et al. 2018b), the Mediterranean domain of the WCRP CORDEX initiative since its start in 2009.
- **Study of the North-Western Mediterranean Deep Water Water Formation** phenomena within the MISTRALS HyMeX framework, including the development and implementation of a **mass-flux based parameterization of the ocean deep convection in NEMO**.

Key CNRS-MEOM staff involved in MEDIATION:

- Samuel Somot, senior scientist, leader of the Regional Climate Modelling team at CNRM, expert in regional climate modelling, scenario and Mediterranean study (*WP1, WP2, WP3)*.
- Robin Waldman, junior scientist, *expert in ocean vertical and meso-scale physics (WP3, WP1)*.
- Hervé Giordani, senior scientist, expert in ocean physics, air-sea interaction (*WP3).*
- Florence Sevault, research engineer, expert in Mediterranean Sea modelling (*WP1, WP3)*.

Key publications in link with the MEDIATION proposal:

1. Darmaraki S., **Somot S., Sevault F.**, et al. (2019a) Future evolution of Marine Heat Waves in the Mediterranean Sea. *Climate Dynamics, doi: 10.1007/s00382-019-04661-z*
2. **Waldman R., Somot S.**, Herrmann M., **Sevault F.**, Isachsen P.E. (2018a) On the chaotic variability of deep convection in the Mediterranean Sea. *GRL, doi: 10.1002/2017GL076319*
3. **Somot S.**, Houpert L., **Sevault F.**, et al. (2018a) Characterizing, modelling and understanding the climate variability of the deep water formation in the North-Western Mediterranean Sea. *Climate Dynamics*, doi: 10.1007/s00382-016-3295-0
4. **Waldman R.**, Herrmann M., **Somot S.**, et al. Arsouze (2017b) Impact of the Mesoscale Dynamics on Ocean Deep Convection: The 2012-2013 Case Study in the Northwestern Mediterranean Sea. *J. Geophys. Res. Oceans,* doi: 10.1002/2016jc012587
5. **Giordani, H.**, Bourdallé-Badie, R., & Madec, G. (2020). An Eddy-Diffusivity Mass-Flux Parameterization for Modeling Oceanic Convection. *Journal of Advances in Modeling Earth Systems*, e2020MS002078.

3.2.7 Entity n°7: LMD

LMD/IPSL INTRO (https://www.lmd.polytechnique.fr/intro/) is the research team at LMD (UMR 8539) studying the physical and chemical properties of the troposphere and its interfaces (land surface and ocean). INTro consists of ~25 members including 11 permanent staff. One of the **main objectives** of the team is the study of the regional climate and water cycle especially in the Mediterranean area using the RegIPSL regional coupled modeling platform, under development in the InTRo team in collaboration with other IPSL teams. The team focuses in particular on the combined impact of climate change and water usage on the Mediterranean basin. Other topics are the atmospheric chemistry transport from urban to hemispheric scales with the development of the CHIMERE model and the impact of climate on renewable energies. Members of the team collaborate also in the development of DYNAMICO a new atmospheric dynamical core.

Outstanding achievements over the past years related to MEDIATION

- ***Development of the RegIPSL regional coupled modeling platform*** and its MedCORDEX configuration, using NEMO-MED12 a NEMO Mediterranean configuration coupled with WRF (atmosphere) and ORCHIDEE (land surface and water routing)
- **Development of AGRIF configurations** for NEMO-MED12 (up to 1/108° resolution)

Key LMD/INTRO staff involved in MEDIATION, associated engagements:

- Romain Pennel, Ecole Polytechnique research engineer, in charge of the RegIPSL development. *WP1 participant* on grid mesh refinement near the coast, convection parametrization and the development of end-user indicators
- Jan Polcher, CNRS senior scientist, RegIPSL scientific leader. Expert in the water cycle of the Mediterranean and main ORCHIDEE developer at IPSL. *WP1 participant.*

Key publications in link with the MEDIATION proposal:

1. D. Keller Jr, Y. Givon, **R. Pennel**, S. Raveh-Rubin, and P. Drobinski : Untangling the mistral and seasonal atmospheric forcing driving deep convection in the gulf of lion: 2012-2013. Ocean Science, Under Review, 2021.
2. Wang F. and **J. Polcher** (2019) Assessing the freshwater flux from the continents to the Mediterranean Sea Nature Science Reports, 9, https://doi.org/10.1038/s41598-019-44293-1
3. Antoine Guion, Solène Turquety, **Jan Polcher**, **Romain Pennel,** Sophie Bastin, Thomas Arsouze: Droughts and heatwaves in the Western Mediterranean : impact on vegetation and wildfires using the coupled WRF-ORCHIDEE regional model (RegIPSL), accepted in Climate Dynamics.
4. **Jan Polcher**, **Romain Pennel**, Thomas Arsouze, Sophie Bastin and Lluis Fita : The water cycle of the Mediterranean sea as represented by IPSL's regional Earth System model. submitted to GMD
5. **Pennel, R.**, Arsouze, T., Akuetevi, C.Q., Waldman, R., 2016. Small-scale processes in the Mediterranean Sea deep convection areas: a numerical study through nesting approach. Rapp. Comm. Int. Mer Médit. 41 (89).

3.2.8 Entity n°8: IFREMER-DYNECO

DYNECO is an IFREMER research unit (22 permanent researchers) investigating the response of coastal ecosystems to natural and anthropogenic pressures. Our approach is structured on the integrated analysis of physical (hydrodynamics and sediment dynamics), biogeochemical and ecological processes, and their complex interactions, based on in situ observations, laboratory experimentations and numerical modeling. DYNECO has developed for 20 years the MARS3D process-based modeling platform, including sediment transport (MUSTANG) and plankton dynamics (ECOMARS3D), and is now fully involved in the GdR CROCO. These models have been applied at shelf and coastal scales, within the Operational Oceanography Previmer project and other research projects (ANR AMORAD), including anthropic pressures such as fishing activity (FP7 BENTHIS) or nutrients inputs and eutrophication risk within the WFD/MSFD context.

Outstanding achievements over the past years related to MEDIATION

- Development of MARS3D, including hydrodynamic core, ecosystem and sediment models. These models are currently being integrated in the new CROCO system.
- Forecast simulation of the French metropolitan coastal dynamics within the Operational Oceanography PREVIMER project.
- Contributor to SNO COAST-HF, with expertise in physical and biogeochemical data analysis.

Key DYNECO staff involved in MEDIATION, associated engagements:

- Romaric Verney, senior researcher in hydro- and sediment dynamics, head of the DYNECO/DHYSED laboratory. Expert in sediment transport modeling and physics/biology interactions. Co-leader of WP1, also contributing to WP4 and WP5.
- Matthieu Caillaud, research engineer expert in hydrodynamics and numerical modeling. Member of the CROCO development team. Contributing to WP1 and WP3 (multiresolution)
- Solène Le Gac, research engineer expert in sediment dynamics modeling. Contributing to WP1.

- Mathilde Cadier, researcher expert in biogeochemical and low trophic level modelling. Contribute to WP1 and WP3 (coupling of low and high trophic levels).
- Martin Plus, senior researcher expert in biogeochemical and low trophic level modeling (eutrophication in the coastal zone). Contribute to WP1 and WP3.
- Philippe Cugier, senior researcher expert in ecological modeling. Contribute to WP1 (connectivity patterns).
- Martin Marzloff, researcher expert in ecological modeling. Contribute to WP1 (connectivity patterns).
- **Sébastien Petton**, research engineer expert in hydrodynamics modeling and numerical techniques. Contribute to WP3 (Surrogate models).

Key publications in link with the MEDIATION proposal:

1. Gangloff, A., **Verney, R.,** Doxaran, D. Ody, A. and Estournel, C. (2017) Investigating Rhône River plume (Gulf of Lions, France) dynamics using metrics analysis from the MERIS 300m Ocean Color archive (2002–2012). Continental Shelf Research, 144, 98-111.
2. Menesguen, A., Dussauze, M., Dumas, F., Thouvenin, B., Garnier, V., Lecornu, F. and Repecaud, M. (2019) Ecological model of the Bay of Biscay and English Channel shelf for environmental status assessment part 1: Nutrients, phytoplankton and oxygen. Ocean Modelling, 133, 56-78.
3. Le Goff C, Lavaud R, **Cugier P**, Jean F, Flye-Sainte-Marie J, Foucher E, Desroy N, Fifas S, Foveau A. 2017. A coupled biophysical model for the distribution of the great scallop Pecten maximus in the English Channel. J Mar Syst 167:55–67.
4. Mengual B., Le Hir P., Cayocca F., Garlan T. (2019). Bottom trawling contribution to the spatio-temporal variability of sediment fluxes on the continental shelf of the Bay of Biscay (France). *Marine Geology* , 414, 77-91.
5. Sourisseau M., Le Guennec V., Le Gland G., **Plus M.,** Chapelle A. (2017). Resource Competition Affects Plankton Community Structure; Evidence from Trait-Based Modeling. Frontiers In Marine Science, 4(52).

3.2.9 Entity n°9: IFREMER-LBH

LBH (Laboratoire de Biologie Halieutique) involve scientists from Ifremer dedicated to research on the assessment of marine fishery resources in France and Southern countries. LBH will be part of the UMR DECOD (Ifremer, Agro Inst., INRAE) from Jan. 2022. LBH has 10-year expertise in the development of Individual-Based Models for larval connectivity patterns and population dynamics. The main focus has been on small pelagics.

Outstanding achievements over the past years related to MEDIATION

- **Hindcast and forecast simulation** of anchovy population based on DEB-IBM within the CERES project aiming at projecting the future of aquatic marine resources in Europe (Bueno-Pardo et al., 2020).
- **Development of a generic IBM framework to describe the eco-evolutionary dynamics of marine fish populations** by accounting for fish genetics, bioenergetics and demography (Marty et al. 2015)

Key LBH staff involved in MEDIATION, associated engagements:

- Martin Huret (LBH-DECOD), Ifremer research scientist has developed for fifteen years ecosystem models with the objective to better understand the response of fish populations to environmental forcing. *WP1 and WP3 participant*, Co-coordinator of an integrated project (France Filière Pêche DEFIPEL) aiming at proposing new management tools and evolution

scenarios for the small pelagic fishery sector in France, that faces new challenges related to the decrease in fish size under climate change,

- Nicolas Barrier (MARBEC): IRD research engineer, expert in scientific computing and marine ecosystem modeling, in charge of of the EV-OSMOSE suite development,
- One new research scientist with modelling skills will be **hired in the team in 2022** and will contribute to the project.

Key publications in link with the MEDIATION proposal:

1. Bueno-Pardo J., Petitgas P., Kay S., **Huret M.** (2020). Integration of bioenergetics in an individual-based model to hindcast anchovy dynamics in the Bay of Biscay . Ices Journal Of Marine Science , 77(2), 655-667.
2. **Huret M**., Tsiaras K., Daewel U., Skogen M., Gatti P., Petitgas P., Somarakis S. (2019). Variation in life-history traits of European anchovy along a latitudinal gradient: a bioenergetics modelling approach . Marine Ecology Progress Series , 617, 95-112.
3. Hufnagl M., Payne M., Lacroix G., Bolle L.J., Daewel U., Dickey-Collas M., Gerkema T., **Huret M.**, Janssen F., Kreus M., Paetsch J., Pohlmann T., Ruardij P., Schrum C., Skogen M.D., Tiessen M.C.H., Petitgas P., Van Beek J.K.L., Van Der Veer H.W., Callies U. (2017). Variation that can be expected when using particle tracking models in connectivity studies . *Journal Of Sea Research* , 127, 133-149.

3.2.10 Entity n°10: MARBEC

UMR **MARBEC** (Marine Biodiversity Exploitation and Conservation) involve scientists from Ifremer and IRD dedicated to research on the assessment of marine fishery resources in France and Southern countries. Fishery scientist from MARBEC will bring their expertise in ecosystem modeling, focusing on fish populations and communities, and their coupling with the environments.

Outstanding achievements over the past years related to MEDIATION

- **Projections of marine fish diversity in the Mediterranean Sea under climate change scenarios** using an end-to-end modelling chain from physics up to the dynamics of 100 fish species (Moullec et al. 2019)
- **Development of a generic IBM framework, EV-OSMOSE, to model the eco-evolutionary dynamics of marine fish communities** under the forcing of abiotic factors and low trophic levels by accounting for fish genetics, bioenergetics, demography, trophic interactions and spatial distribution (ongoing Sombee project, http://sombee.org/)

Key MARBEC staff involved in MEDIATION, associated engagements:

- Bruno Ernande (MARBEC), Ifremer senior scientist has 25 years of experience in marine organism evolutionary ecology with a specific focus on the modelling of the eco-evolutionary response of marine fish to multiple pressures, notably exploitation and climate change. *WP1 participant,* Co-coordinator of the SOMBEE project (sombee.org) on the modeling of the eco-evolutionary response of marine fish communities to fishing and climate change,
  Martin Huret (LBH-DECOD), Ifremer research scientist has developed for fifteen years ecosystem models with the objective to better understand the response of fish populations to environmental forcing. *WP1 and WP3 participant*, Co-coordinator of an integrated project (France Filière Pêche DEFIPEL) aiming at proposing new management tools and evolution scenarios for the small pelagic fishery sector in France, that faces new challenges related to the decrease in fish size under climate change,
- As for LBH, One new research scientists with modelling skills will be **hired in the team in 2022** and will contribute to the project.

Key publications in link with the MEDIATION proposal:

1. Marty, L., Dieckmann, U., & **Ernande, B**. (2015). Fisheries-induced neutral and adaptive evolution in exploited fish populations and consequences for their adaptive potential. *Evolutionary Applications*, *8*(1), 47–63. https://doi.org/10.1111/eva.12220
2. Moullec, F., **Barrier, N.**, Drira, S., Guilhaumon, F., Marsaleix, P., Somot, S., Ulses, C., Velez, L., & Shin, Y.-J. (2019). An End-to-End Model Reveals Losers and Winners in a Warming Mediterranean Sea. *Frontiers in Marine Science*, *6*. https://doi.org/10.3389/fmars.2019.00345

3.2.11 Entity n°11: LEGOS (UMR n°5566)

LEGOS (www.legos.omp.eu) is a joint laboratory under the supervision of CNES, CNRS, IRD and UT3 at the *Midi-Pyrénées Observatory* (OMP) in Toulouse. Its research focuses on oceanography and the water cycle in a broad sense. Several groups developing ocean models and observational services give the laboratory a leading position in realistic, high-resolution modeling of coastal and regional ocean dynamics and of coupled ocean-atmosphere-wave systems. LEGOS is extensively involved in the development of international community models, notably CROCO and NEMO. It is a major contributor to the Research Group (GdR) for the development of CROCO, with a focus on coastal and air-sea applications. In this, LEGOS works in close collaboration with LAERO also at OMP.

Outstanding achievements over the past 5 years related to MEDIATION

- Development of a nonhydrostatic CROCO solver and application to RANS and LES of fine-scale dynamics, including internal waves, stratified turbulence, and nearshore dynamics.
- Introduction of the effective resolution concept in ocean models, in which numerical errors affect the physical solution at scales depending on the order of accuracy of the numerical methods.
- Identification of the key role played by fine-scale air-sea interactions in ocean dynamics. The discovery that about one-third of the mesoscale energy is returned to the atmosphere by friction (top drag) has changed our understanding of the missing ocean energy pathways in models. Development of top drag parametrizations in ocean-only models, now widely used in the international community.

Key LEGOS/OMP staff involved in MEDIATION, associated engagements and publications

- Patrick Marchesiello, IRD senior scientist, expert in coastal ocean modeling and CROCO developer. *WP3 co-leader*. PI of two IRD-SHOM projects, co-PI of GdR CROCO.
- Lionel Renault, IRD scientist, expert in (sub)mesoscale air-sea interaction. *WP3 participant*. PI of solicited ERC grant and of GDRI-South CROCO.
- Francis Auclair, UT3 assistant professor, expert in nonhydrostatic and non-Boussinesq dynamics with focus on large internal waves. *WP3 participant*. PI of LEFE GEPETO project.
- Rachid Benshila, CNRS Research Engineer, one of the leading developers of both CROCO and NEMO. *WP3 participant*. Co-PI of GdR CROCO.
- Guillaume Morvan, IRD, Modeling Engineer, CROCO/NEMO developer. *WP3 participant*.
- Cyril Nguyen, CNRS, Computer Engineer (HPC), CROCO developer. *WP3 participant*.

Key publications in link with the MEDIATION proposal:

1. **Marchesiello** P., F. **Auclair**, L. Debreu, J.C. McWilliams, R. Almar, R. **Benshila**, F. Dumas, 2021: Tridimensional nonhydrostatic transient rip currents in a wave-resolving model. Ocean Modelling, 163, 101816.

2. **Renault** L., P. **Marchesiello**, S. Masson, and J.C. McWilliams, 2019: Remarkable control of Western Boundary Currents by eddy killing, a mechanical air-sea coupling process. Geophysical Research Letters, 46, 2743-2751.
3. **Renault**, L., F. Lemarié, T. Arsouze, 2019: On the implementation and consequences of the oceanic currents feedback in ocean–atmosphere coupled models, Ocean Modelling, 141, 101423.
4. Soufflet Y., P. **Marchesiello**, J. Jouanno, X. Capet, L. Debreu, F. Lemarie, 2016: On effective resolution in ocean models. Ocean Modelling, 98, 36-50.
5. Debreu, L., P. **Marchesiello**, P. Penven, and G. Cambon, 2012: Two-way nesting in split-explicit ocean models: algorithms, implementation and validation. Ocean Modelling, 49-50, 1-21.

3.2.12 Entity n°12: MIO (UMR n°7294)

MIO (https://www.mio.osupytheas.fr/) is a component of the OSU-Pytheas Institute and is under the joint direction of Aix-Marseille University, Toulon University, the CNRS and the IRD. MIO has developed an expertise in marine biology, ecology, biodiversity, microbiology, halieutics, ocean physics, chemistry, biogeochemistry and sedimentology in the world ocean, alongside its continental, atmospheric and sediment interfaces. One of the main objectives is to better understand the oceanic system and its evolution in response to global changes.

Outstanding achievements over the past 5 years related to MEDIATION

- ***Development of a basin-scale version of the Eco3M-Med model for the Mediterranean Sea*** *(forced by physical models provided by the CNRM and the LMD labs)*
- **Production of the projected effects of a RCP scenario on the biogeochemistry of the Med Sea** with Eco3M-Med and the physical ocean model provided by the CNRM lab
- Construction of a **preliminary integrated model** for the Med Sea associating atmosphere-ocean circulation models, Eco3M-Med, the agroecosystem model LPJmL and an economic model.

Key MIO staff involved in MEDIATION, associated engagements and publications

- Melika Baklouti, Professor and leader of the OPLC research team (~50 persons) at MIO, expert in coupled physical-biogeochemical ocean modeling. Co-leader of *WP1 and WP3*. PI of the recently-completed LaSeR-Med project (2016-2020) funded by the OT-MED Labex.
- Camille Mazoyer, IRD research engineer, specialized in the technical support to modeling activities at the MIO. *WP1 and WP3* participant.
- Yann Ourmières, Assistant professor. Expert of high-resolution NEMO-AGRIF configurations over the french mediterranean coasts (GLAZUR64-NIDOR192). Local PI of the recently-completed IMPACT european project (Intereg Marittimo). WP1 participant.

Key publications in link with the MEDIATION proposal:

1. Alekseenko, E., Raybaud, V., Espinasse, B., Carlotti, F., Queguiner, B., Thouvenin, B., Garreau, P. and Baklouti, M. (2014) Seasonal dynamics and stoichiometry of the planktonic community in the NW Mediterranean Sea; a 3D modeling approach, Ocean Dynamics, 64, 79-207
2. Pagès, R., Baklouti, M., Barrier, N., Richon, C., Dutay, J.-C. and Moutin, T. (2020b). Projected effects of climate-induced changes in hydrodynamics on the biogeochemistry of the Mediterranean Sea under the RCP 8.5 regional climate scenario. Frontiers in Marine Science, 7, 563615.
3. Pagès, R., Baklouti, M., Barrier, N., Richon, C., Dutay, J.-C. and Moutin, T. (2020a). Changes in rivers inputs during the last decades significantly impacted the biogeochemistry of the eastern Mediterranean basin: a modelling study. Progress in Oceanography, 181, 102242.

4. Mazoyer, C., Vanneste, H., Dufresne, C., Ourmières, Y., Magaldi, M. G., Molcard, A. (2020) Impact of wind-driven circulation on contaminant dispersion in a semi-enclosed bay, Estuarine, Coastal and Shelf Science, 233, 106529
5. Declerck, A., Ourmières, Y. & Molcard, A. Assessment of the coastal dynamics in a nested zoom and feedback on the boundary current: the North-Western Mediterranean Sea case (2016) *Ocean Dynamics* 66, 1529–1542

3.2.13 Entity n°13: AMU IMBE- AMSE

AMU IMBE (https://www.imbe.fr/l-imbe) The Mediterranean Institute of marine and terrestrial Biodiversity and Ecology develops an integrative approach for the study of biodiversity and socio-ecological systems. It provides fundamental and applied knowledge on the functions, the historical and evolutionary dynamics of all types of Mediterranean ecosystems biodiversity in the context of global change. These contributions also include links with civil societies and human health issues. Through its involvement in research, training and scientific promotion, IMBE actively participates in the environmental transition and sustainable development for the definition of local, national and international environmental policies.

AMU AMSE (https://www.amse-aixmarseille.fr/) is an innovative and original project centered on the fundamental concerns of our societies. Research and teaching are carefully combined to train a new generation of economists capable of dealing with all the challenges of a world in crisis, capable of putting their knowledge of economics to work for citizens and policy makers. AMSE research takes three directions, namely (i) economic crises and the crisis of macroeconomics, (ii) development, democratic transitions, migrations and growth, and (iii) environmental and health crises.

Outstanding achievements over the past 5 years related to MEDIATION

- Implementation of **Mediterranean perennial crops** within the LPJmL agroecosystem model.
- Determination of **adaptation scenarios for Mediterranean agriculture** under increasing temperature and water stress.
- Introduction in LPJmL of **nitrogen and phosphorous cycles** (in addition to the original C cycle)
- Co-edition of the **first Mediterranean Assessment Report on Climate and Environmental Change** (600 scientists from 35 countries)
- Construction of an **economic model providing projected land-uses in the Mediterranean basin** in order to ensure a given level of food for the Mediterranean population

Key IMBE/AMSE staff involved in MEDIATION, associated engagements and publications

- Alberte Bondeau (WP1), CNRS senior scientist, pioneer of agriculture implementation within a global vegetation model (LPJmL), expert in climate adaptation and mitigation of agroecosystems. Leader of the hydro-agricultural task of AFD GEMMES-Morocco. Scientific board member of FRB-CESAB.
- Wolfgang Cramer (WP1), CNRS senior scientist, co-leader of the Mediterranean Experts on Climate and Environmental Change (MedECC) network, IPCC expert, member of “Académie d’Agriculture de France”.
- Dominique AMI (WP1), Assistant Professor. Expert in nonmarket valuation methods, economic valuation of biodiversity and ecosystem services and econometrics and co-PI of LaSer-Med project.

Key publications in link with the MEDIATION proposal:

1. Albert, C.H., Hervé, M., Fader, M., Bondeau, A., Leriche, A., Monnet, A.-C., Cramer, W., (2020). What ecologists should know before using land use/cover change projections for biodiversity and ecosystem service assessments. Regional Environmental Change 20, 106.
2. Ayache, M., Bondeau, A., Barrier, N., Ostberg, S., Baklouti, M., (2020). LPJmL-Med–Modelling the dynamics of the land-sea nutrient transfer over the Mediterranean region–version 1: Model description and evaluation. Geoscientific Model Development Discussions 342, 1–57.
3. Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J.-P., Iglesias, A., Lange, M.A., Lionello, P., Llasat, M.C., Paz, S., Peñuelas, J., Snoussi, M., Toreti, A., Tsimplis, M.N., Xoplaki, E., (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. Nature Climate Change 8, 972–980.
4. Lee H, H., Lautenbach, S., García-Nieto, A.P., Bondeau, A., Cramer, W., Geijzendorffer, I.R., (2019). The impact of conservation farming practices on Mediterranean agro-ecosystem services provisioning—a meta-analysis. Regional Environmental Change 19, 2187–2202.
5. Udumyan N. ,J. Rouchier., D. Ami, «Integration of path-dependency in a simple learning model: the case of marine resources » (2014) Computational Economics, 43, 199-231

3.2.14 Entity n°14: IRIT-APO

IRIT/APO consists of 24 members including 12 permanent staff. Its main activities are at the intersection of Applied Mathematics and Computer Science. Research is conducted in High Performance Computing, Optimal Control, Data Assimilation and Machine Learning. It hosts the ANITI Chair of Serge Gratton on Machine learning under physical constraints, aimed at proposing filtering algorithms that combine Ensemble Kalman filter techniques with Machine learning tool. Currently, 5 PhD student are involved in the chair, that is support by industrial partners including ATOS, NXP, Renault, BRL, Liebherr.

Outstanding achievements over the past 5 years related to MEDIATION

- **A Chair** on machine learning obtained within the 3AI Institute ANITI. Using a variational Bayes approach, and algorithms that outperform the Ensemble Kalman Filter on toy problems.
- **A best paper** Award obtained in 2019 in the international journal COAP (Computational optimisation and Applications).
- **A series of papers** on the behaviour of optimization algorithms in the presence of noise. The application of this work will concern optimization methods in multiprecision.

Key IRIT/APO staff involved in MEDIATION, associated engagements and publications

- Ehouarn Simon, associate professor, responsible for the AI certificate in Toulouse, PI of the MFDA project on multilevel Monte Carlo methods in data assimilation (CNRS 80 | Prime 2019) and *WP4 participant.*
- Serge Gratton, professor, I3A ANITI Chair on Machine learning under physical constraints, WP4 participant.

Key publications in link with the MEDIATION proposal:

1. Complexity and global rates of trust-region methods based on probabilistic models, **S. Gratton**, C.W. Royer, L.N. Vicente, Z. Zhang, *IMA Journal of Numerical Analysis* 38 (3), 1579-1597, 2018
2. Direct search based on probabilistic feasible descent for bound and linearly constrained problems, **S. Gratton**, C. Royer, L. Vicente, Z. Zhang. *Computational Optimization and Applications*, Springer Verlag, Best paper award 2019

3. An Iterative Ensemble Kalman Smoother in Presence of Additive Model Error. A, Fillion, M. Bocquet, **S. Gratton**, S. Gürol, and P. Sakov, *SIAM/ASA J. Uncertainty Quantification*, 8(1), 198–228, 2020
4. Minimizing convex quadratics with variable precision conjugate gradients. **S Gratton**, **E. Simon,** D. Titley-Peloquin and PL Toint, *Numerical Linear Algebra with Applications*, 28:e2337, 2021.
5. An algorithm for the minimization of nonsmooth nonconvex functions using inexact evaluations and its worst-case complexity, **S Gratton**, **E Simon**, PL Toint, *Mathematical Programming* 187 (1), 1-24, 2021

High performance computing infrastructure related to MEDIATION:

- IRIT/APO members benefit already of grants of CPU/GPU time from CALMIP (UMR 3667). Additional HPC resources are expected from CALMIP in support to *MEDIATION.*

3.2.15 Entity n°15: IMT Atlantique

IMT Atlantique (https://www.imt-atlantique.fr) is an engineering school located in Brest. It trains students in digital sciences, with a solid background in mathematics. Various fields of application are treated, including the environment, especially marine sciences. In this context, within the EUR IsBlue, IMT Atlantique works in close collaboration with IFREMER, IUEM, ENSTA Bretagne but also SHOM. Recently a Master 2 program "Data Science for Oceanography", led by IMT Atlantique, has strengthened these academic collaborations.

Outstanding achievements over the past 5 years related to MEDIATION:

Several ANR projects (bridging geophysics and machine learning for the modeling, simulation and reconstruction of ocean dynamics: MeLODy) CMEMS projects (data driven data assimilation), as well as a chair for research and teaching in AI (https://cia-oceanix.github.io/), structure the scientific collaborations, not only within ISBLUE, but also with Inria (Fluminance and Airsea) and CNRS MEOM teams.

Key IMT Atlantique staff involved in MEDIATION and associated engagements:

- Pierre Tandeo (WP1, WP4), associate professor, expert in data-driven approaches. Head of the Master 2 program "Data Science for Oceanography" and head of the "AI & Ocean" department at Lab-STICC (UMR 6285). PI of the 3DA project (CMEMS, 2018-2020).
- Carlos Granero-Belinchón (WP1, WP4), associate professor, expert in physics-driven approaches. WP1 & WP4 participant. PI of the SCALES project (ANR JCJC, 2021-2024).

Key publications in link with the MEDIATION proposal:

1. Le Goff, C., Boussidi, B., Mironov, A., Guichoux, Y., Zhen, Y., **Tandeo, P.**, ... & Chapron, B. (2021). Monitoring the Greater Agulhas Current With AIS Data Information. Journal of Geophysical Research: Oceans, 126(5), e2021JC017228.
2. Zhen, Y., **Tandeo, P.**, Leroux, S., Metref, S., **Penduff, T.**, & **Le Sommer, J.** (2020). An adaptive optimal interpolation based on analog forecasting: application to SSH in the Gulf of Mexico. Journal of Atmospheric and Oceanic Technology, 37(9), 1697-1711.
3. **Tandeo, P.**, Ailliot, P., Bocquet, M., Carrassi, A., Miyoshi, T., Pulido, M., & Zhen, Y. (2020). A review of innovation-based methods to jointly estimate model and observation error covariance matrices in ensemble data assimilation. Monthly Weather Review, 148(10), 3973-3994.
4. **Granero-Belinchón, C.**, Roux, S. G., Abry, P., and Garnier, N. B. (2019). Probing High-Order Dependencies With Information Theory. IEEE Transactions on Signal Processing, 67 (14), 3796-3805.
5. **Granero-Belinchón, C.**, Roux, S. G., & Garnier, N. B. (2018). Kullback-Leibler divergence measure of intermittency: Application to turbulence. Physical Review E, 97(1), 013107.

3.2.16 Entity n°16: SHOM

SHOM is the French hydrographic service which has three departments dedicated to physical oceanography (STM/REC, STM/DTO, STM/Cfud). They consist of 50 members including 45 permanent staff. Shom operates operational information chains dedicated to the support of the French Navy over the Mediterranean Sea, the Bay of Biscay and The English Channel. STM/REC has conducted studies on these French coastal zones for years; they are based on numerical simulation (Hycom and CROCO), experiments at sea and data processing.

Outstanding achievements over the past 5 years related to MEDIATION:

- **Object validation of remanent structure:** a new approach to assess the numerical solution oriented towards particular structures (mesoscales eddies) with original statistics.
- **OSSE on the Med Sea:** in collaboration with the "Laboratoire de Météorologie Dynamique" and the CLS company, OSSE was conducted on altimetry sampling and the bias induced in the detection of Mesoscale eddies.
- **Development of numerical methods**: the team is involved in the development of CROCO, specific expertise has been acquired on numerical schemes for advection.
- Contribution to the development of **high-resolution, nonhydrostatic configurations of the Gibraltar straits**.

Key SHOM staff involved in MEDIATION:

- Lucie Bordois (WP1, WP3), Shom scientist, expert on fine-scale simulation and observation.
- Franck Dumas, (WP3 co-leader), Shom senior scientist, physical oceanographer, PI of CNRS-INSU GdR n°2014 CROCO.
- Stéphane Raynaud (WP2), Shom senior scientist, in charge of data assimilation activity (development of 3DVAR package for CROCO).
- Nicolas Ducousso (WP3), Shom scientist in charge of coastal ocean modeling, expert in numerical analysis and development.

Key publications in link with the MEDIATION proposal:

1. Auclair, F**., Bordois, L**., Dossmann, Y., Duhaut, T., Paci, A., Ulses, C., Nguyen, C. (2018). A non-hydrostatic non-Boussinesq algorithm for free-surface ocean modelling. *Ocean Modelling*, *132*, 12-29.
2. Hilt, M., Auclair, F., Benshila, R., **Bordois, L.,** Capet, X., Debreu, L., **Dumas, F.,** & Roblou, L. (2020). Numerical modelling of hydraulic control, solitary waves and primary instabilities in the Strait of Gibraltar. *Ocean Modelling*, *151*, 101642.
3. Ioannou, A., Stegner, A., **Dumas, F**., & Le Vu, B. (2020). Three-dimensional evolution of mesoscale anticyclones in the lee of Crete. *Frontiers in Marine Science*, *7*, 1019.
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3.3. *MANAGEMENT FRAMEWORK*

Organization between partners and project management, risk management: the management committee (MC) of MEDIATION will be led by the coordinator and composed of all WP/TA leaders meeting every 6 months. The project manager and two co-leaders will organize more monthly meetings, with any of the WP leaders. An important aspect of the coordination will also be through its transverse axis on data. The main activities of the MC will be dedicated to the analysis of the progress of the various WPs and associated tasks. It will ensure that deadlines are met for each task and that the required temporal coordination of tasks is respected. The risks related to exceeding the deadline (for scientific reasons or delay in recruitment) will be managed during these meetings and the timing of each WP will be revised accordingly. A general meeting with all project participants will be held every 18 months, allowing all recruited staff to attend at least one of these meetings. Finally, each WP will organize internal meetings (open to all project participants). The project will use modern communication tools (e.g., Slack channels) to facilitate communication between partners. Special attention will be given to the integration of newly recruited non-permanent staff in order to make their stay in the project fruitful both scientifically and in terms of future career opportunities.
Scientific Steering Committee: At the outset, MEDIATION will form a Scientific Steering Committee (SSC) composed of international experts. We are pleased that Marilaure Grégoire (Director of Research, FNRS, member of the Copernicus STAC) and Baylor Fox-Kemper (Professor at Brown University) have agreed to co-chair this committee. These international experts will be invited to the general meetings of the project (every 18 months). To this end, a progress report will be proposed to the SSC for review. The members of the SSC will also contribute to the promotion of MEDIATION at the international level and foster interactions with other European and international projects.
Key Indicators: A data management plan (DMP) will be proposed 6 months after the project start date and a consortium agreement will be drafted at T0+12 months after.

KPI	Indicator	Target
KPI1	Number of recruited staff before T0+18	14
KPI2	Gender balance of the recruited staff	> 30% of women
KPI3	Number of answers to external calls to increase the funding	5
KPI4	Allocated computing resources through GENCI TGIR calls	10MhCPU, 50khGPU
KPI5	Fraction of the submitted journal articles adopting reproducible practices (code and data)	75%
KPI6	Fraction of the submitted journal articles involving at least 2 entities	90%

Access to shared resources, exploitation of results, intellectual and industrial property
MEDIATION will setup a website with private and public parts. The private side will allow sharing of data (reports, publications) while the public side will allow communication about the project. The agreement with the DMP will be coordinated by AT1 while the dissemination of results in light of their societal impacts will be coordinated by WP5. The consortium agreement at T0+12 will specify the terms of intellectual property.

3.4. *INSTITUTIONAL STRATEGY*

MEDIATION is directly in line with the ESR strategy set up to respond to the SDGs. In the context of the Decade of Ocean Sciences, it will contribute to the digital transition to address more effectively SDG 14 (conservation / sustainable use of oceans), SDG 12 (responsible production) and SDG 2 (food security). By associating applied mathematicians, geophysicists, biologists and socio-economists, the project is built on a strong interdisciplinary basis, as required to provide effective responses to the oceanic challenge at 2030 horizon. More specifically, the project coordinated by Inria will contribute to the national strategy on AI through effective links with two 3IA programs (ANITI, MIAI), as well as with the Grenoble site's priorities on Data Science and environmental modelling in accordance with INRIA's COP. The CNRS, which leads the PPR with Ifremer, has created a "CNRS Agenda 2030" Task Force to translate the United Nations political agenda into scientific questions, with a particular focus on the Ocean. The project will significantly foster co-development of community modeling platforms NEMO and CROCO included in their institutional strategies. By developing a new capacity for multi-decadal projection of resilient marine ecosystems, MEDIATION is at the heart of the Sustainability Science strongly promoted by the IRD. Its achievements will directly benefit Southern Countries by means of the portable and low-resource tools that will result from the project. MEDIATION will provide tools and results on which SHOM will rely for its mission to support naval forces and public policies of the maritime coastline. Finally, the emphasis on integrated modeling and projections guided by space and *in situ* data will feed the long-term planning of observation programs lead by CNES, INSU and Ifremer. Beyond the phasing with the strategic axes of each of the institutions involved, the project also relies on the coordination capacity of the French research institutions in order to provide a collective response built on their respective scientific complementarities, addressing the next strategic goals: (i) The national **research alliance on environment** (ALLENVI): all MEDIATION partners are affiliated with ALLENVI founding or associate institutions, engaged in the **structuration of the research** community on the Ocean theme; (ii) **Operational Oceanography**: the MEDIATION partnership is unique in involving Inria together with the five main French institutions associated with Mercator Ocean International in charge of the EU Marine Copernicus service. (iii) A stronger **escalation capacity** built on the MEDIATION partnership to participate in **future EU research projects** in Horizon Europe, including the main goals of the STARFISH mission. MEDIATION will also rely on infrastructures and services available at FR and EU level: GENCI, Data Terra, ILICO, CMEMS.

The following table summarizes the (approximate) contributions, the number of person-months (permanent staff) and funding requests from each MEDIATION partner institution. Details of the requests, including how to raise additional funds, are provided in Section 5.

Partner	Total cost	Funding request	Contributions	Person-months
Inria	2,84M€	610k€	2,23M€	133
CNRS	1,91M€	580k€	1,33M€	82
IFREMER	1,08M€	300k€	780k€	101
IRD	670k€	170k€	500k€	49
Aix-Marseille University	740k€	330k€	410k€	13
INP-Toulouse	320k€	120k€	200k€	14
IMT-Atlantique	560k€	200k€	360k€	24
SHOM	240k€	0k€	240k€	30
Grenoble Alpes University	630k€	140k€	490k€	28
METEO-FRANCE	710k€	0k€	710k€	48
Total	10M€	2,5M€	7,5M€	522

4. EXPECTED OUTCOMES OF THE PROJECT

4.1. KEY EXPECTED SCIENTIFIC RESULTS

MEDIATION will be a long-term project (five years) with the ambition to have an impact beyond its five-year duration on fundamental research, technological developments and applications and also on the structuring of the French community. The major challenge of the project is challenge 6. As such, and as described in section 1 on the project objectives and in section 2 on its scientific description, significant methodological advances are expected in WP2, 3 and 4. These advances should allow WP1, on demonstrators, to radically transform the existing end-to-end modeling chains. We summarize the main expected scientific results:

1. The MEDIATION project should first open the way to a probabilistic modeling of the chain with the incorporation of stochastic modeling, both in physical and ecosystem models. This probabilistic approach should allow a better quantification of the uncertainties linked to the modeling and thus improve a statistical description of the future state of marine ecosystems. This should also lead to a better evaluation/validation of numerical models against data. In return, important information on future satellite or in situ observation systems will be made available.
2. Considerable achievements are expected on several compartments of the modeling chains. It will lead to the first structured multi-resolution model for efficient treatment of local phenomena that are of primary interest for decision making, while preserving a necessary multi-scale capability. Other capabilities such as non-hydrostatic modeling or mesoscale ocean-atmosphere-wave coupling will not be available for climate projection in the near future. However, MEDIATION proposes significant advances in the representation of the underlying phenomena through subgrid-scale parameterizations and reduced-physics atmospheric models, enhanced by machine learning methods. Finally, the complexity of low and high trophic levels in ecosystem models and their interaction will be revisited, with the objective of optimizing the model chain in terms of realism and computational cost.
3. In recent years, machine learning techniques have brought some revolution in several scientific fields, and remarkable contributions to ocean modeling in particular. However, the transfer of these promising approaches to climate and operational models remains a challenge. MEDIATION will provide the technological building blocks that are currently lacking to transpose these advances to the scale of very complex computational codes written in various computer languages. A prospective part of the project will be devoted to the possibility of building emulators of the complete chain of models (in small spaces), which would be a great asset for public policies.
4. A strong articulation between modeling chains and observational data will allow the construction of a robust and efficient digital twin. The MEDIATION project will initiate research to allow the identification of resilient scenarios. This identification will be based on major themes of MEDIATION: the study of the propagation of uncertainties through a chain of models and the optimal design of experiments, relying on the fast chains (FC) that will be developed during the project.

4.2. DISSEMINATION OF CHALLENGE 6 RESULTS TO THE MODELING COMMUNITY

MEDIATION relies deeply on process-based numerical ocean models, which have been developed by a large community for years: they are named NEMO and CROCO. They are both essential tools for the purposes of WP1 (realistic demonstration), WP2 (theoretical approach to uncertainty management) and WP3 (development of numerical methods and parametrizations). The specifications of these models are listed below:

- **NEMO** (www.nemo-ocean.eu) standing for "Nucleus for European Modelling of the Ocean" is a state-of the-art modeling framework for research activities and forecasting services in ocean and climate sciences, developed in a sustainable way by a European consortium. NEMO has 3 major components: NEMO-OCE for solving the primitive equations of the ocean; NEMO-ICE (SI3: Sea-Ice Integrated Initiative) for sea-ice (thermo)dynamics, brine inclusions and sub-mesh thickness variations; NEMO-TOP (Tracers in the Ocean Paradigm) for on- or off-line oceanic tracers transport and biogeochemical processes (using PISCES). Additional capabilities are a software for embedded zooms (AGRIF); an optimized I/O package (XIOS); a coupling interface to other Earth system components (OASIS). The NEMO Consortium pulling together 5 European institutes (CMCC, CNRS, MOI, MetOffice and NERC) plans the model development to keep a reliable evolving framework since 2008. It defines the multi-year development strategy that is implemented by the System Team on a yearly basis. The model is involved in numerous national and international projects. NEMO is used as the ocean component of 6 Earth System Models, in Copernicus marine services (CMES) and in Copernicus Climate Change Service (C3S) operational chains.
- **CROCO** (www.croco-ocean.org) standing for “Coastal and Regional Ocean Community model” is labeled by the French public organizations involved in ocean sciences (CNRS, Ifremer, IRD and Shom) as the eponymous GdR n°2014 since 2018. The French coastal modeling community has thus started an intensive collaboration by upgrading the former ROMS-AGRIF model with additional features from other codes and new developments. The "trademark" of CROCO is twofold: (i) a focus on the fine oceanic scales; (ii) a multidisciplinary tool that can be implemented in any context (from academic to high realism). A wide range of expertise is brought together for various capabilities (sediments and morphodynamics: MUSTANG or USGS models; ecosystems: PISCES, Bioebus, Bloom, Eco3M, or OSMOSE; air-sea coupling). For fine scales, CROCO has improved the captured physics of the model by relaxing some balance approximations (hydrostatic and Boussinesq), and can thus be used for Large Eddy Simulations. The model is already involved in important projects for the ANR, LEFE (CNRS), TOSCA (CNES), or in the PROTEVS II Technological Defense Program of the DGA (until 2024). It is also involved in NSF-funded US projects, thus maintaining a high level of national and international interaction. For Southern countries, IRD has renewed its commitment to CROCO for 5 years with a GDRI-South (gdri-croco.cnrs.fr).

It is important to note that the groups supporting and developing NEMO and CROCO already have common grounds, i.e., shared software components such as AGRIF (library for mesh refinement), OASIS (facility for model coupling), XIOS (I/O package optimized for HPC). The link between these communities will be reinforced by MEDIATION. A particularly important aspect will be the use of CROCO in realistic LES mode to develop or test parameterizations that can be applied in climate studies with NEMO. LES are a common tool for designing parameterizations, but they are usually limited to idealized configurations. Here, the realism sought in both CROCO and NEMO will improve

the transfer between model communities. The proposed work on stochastic modelling, multi-resolution or machine learning will also involve unprecedented collaboration since the ANR COMODO project (2011-2016) coordinated by the same group.

MEDIATION intends to transfer its methodological innovations to a large community, beyond the code developers. Workshops will be designed to help understand and use the new tools. In particular, these workshops will be aimed at members of other PPR projects responding to this call. A number of submitted projects have been identified as potential MEDIATION partners to help test and validate new developments, in particular in the framework of challenges 1 (Overseas) and 4. The transfer of technology at the international level will also take place naturally via the regular user meetings organized for CROCO and NEMO. At the international level, special sessions (e.g., at AGU, EGU, COMMODORE group, JONSMOD, etc) will also be offered to highlight and exchange around the research conducted within the MEDIATION project.

4.3. INTERACTION BETWEEN SCIENCE AND SOCIETY

MEDIATION dedicates one of its workpackages to science-society interactions (see page (link)). This workpackage is intended to be interactive with the general public and managers in order to develop appropriate tools to 1) promote the collective interest in research to the general public; 2) find, with managers, the right level of complexity of the tools to be proposed to them; 3) fine-tune the indicators provided by the chains. Communication and interaction tools will be developed: videos, interactive platform for testing scenarios, etc. Particular attention will be paid to communication on the uncertainties of modeling. Adapted advanced scientific visualization tools will be developed. Preliminary discussions have taken place with the French Biodiversity Agency (OFB; F. Cayocca), which is willing to play a facilitating role to help us mobilize the relevant managers for the project, and to set up interaction modes adapted to this difficult dialogue between communities with different cultures. Finally, for the first time, MEDIATION will be able to provide user-friendly and user-oriented ensembles of authoritative regional climate change projections, consistent over the whole French metropolitan coast. This will allow the further development of climate research and climate services for the French coastal zone completing what is routinely available for the French continental area.

4.4. IMPROVING FRENCH LEADERSHIP

As explained above, the scientific and technical developments carried out within MEDIATION will be integrated into community tools already widely shared by the international community: physical models (NEMO, CROCO), low tropic level ecosystem models (Eco3M, ECOMARS) and high trophic level models (OSMOSE, BLOOM). They will strengthen these numerical tools by giving them reference assets. The expected advances linked to challenge 6 should provide these models and chains of model with major assets. MEDIATION is interdisciplinary, including several research teams in applied mathematics, computer science, oceanography and climate. The interactions that will take place within the project will pave the way for long-term collaborations, which are important to keep these complex systems closely connected to the current research work of these communities. In addition, MEDIATION will follow the propositions of its scientific committee, composed of international experts, for a better dissemination of the results and to make strong connections with current and future large international projects, in particular with respect to the design of digital twins of the ocean

5. FUNDING JUSTIFICATION

5.1. FUNDING OVERVIEW

The MEDIATION project members have decided to dedicate the majority of their funding requests to the recruitment of non-permanent staff. Additional resources contributing to the project budget will initially be secured from existing budgets. During the course of the project, additional requests will be submitted, including for additional travel costs related to project activities. With respect to the requests made, some general principles have been established:

- Each recruited staff is associated with a request of 4k€ covering the purchase of a small computer equipment as well as an international mission.
- Permanent staff with a high level of involvement in the project (i.e., more than 20%) are also allocated an international mission and, if necessary, a small computer equipment.
- The two categories below also receive, when not supported by their institution, 2k€ to fund the APC of a publication in an open access journal.
- The rest of the travel budget is used to cover participation in general meetings (every 18 months) of the project and internal workpackage meetings. The coordinating establishment (Inria) is making an additional request to cover accommodation for general meetings as well as missions of the scientific committee members.

Almost all the postdoctoral fellowships requested have a duration of 18 months. We consider this to be a minimum duration and additional funding will be requested to try to extend this duration to 24 months. MEDIATION will fund directly only three PhDs positions. Additional PhDs funding, much easier to obtain in France, will also be requested, in particular via the universities hosting the different partner institutions. (Responses to annual calls for proposals). The total budget requested is 2.5M€. This is divided into 2M€ for the recruitment of staff, 260k€ for the functioning (missions, publications, small computer equipment...) and 190k€ of management fees by the partner institutions. The amount of recruitment corresponds to the hiring of 15 post-doctoral students, 3 PhD students and 5 engineers. The total cost of the MEDIATION project is 10M€. This total cost includes 4.1M€ corresponding to the cost of permanent staff wishing to participate in the project. It therefore reflects the strong involvement of the permanent researchers and engineers of the partner teams. Details of the funding requested and contributions made by each partner have been provided in Section 3.4.

The project relies heavily on the already organized groups of developers of the models used, whether for physical, biogeochemical or biological modeling. These groups (NEMO, CROCO, ECO3M, ECOMARS3D, BLOOM, OSMOSE, DEB-IBM, LPJmL ...) are very strongly involved in the MEDIATION response (all the scientific leaders of these groups are present) and are groups that are officially supported by their partners. Not all researchers and engineers of these groups are of course part of the MEDIATION project but many of them will be actively collaborating during the project.

5.2. REQUESTED TEMPORARY POSITIONS

The following table contains the list of requests for non-permanent staff, their duration in months, the associated tasks and the list of entities involved in the supervision. The starting date of these hires must be linked to the starting dates of the corresponding tasks indicated in Subsection 2.1.3.

Task	Pos.	Dur	Objectives	Partner(s)
1.1	PD1	18	Framework for coordinating and validating/exploiting the new parameterization in climate runs.	CNRM
1.2	PD2	18	Methodological developments emblematic objects	IMT/IFREMER/CNRM
1.2	PD3	18	MANGA multi-resolution application, Connectivity development tool and patterns evaluation	IFREMER/AIRSEA
1.3	PD4	18	Simulations with complex physical chain (historical + scenario)	CNRM/LMD
1.3	PD5	18	Simulations with complex organic chain (historical + scenario)	MIO/IMBE/IFREMER
1.4	PD6	18	Collaboration with OFB to define indicators, scenarios	AMSE/MIO/IFREMER
2.1.1	PD7	18	Physical stochastic modeling	MEOM/Fluminance
2.1.2	PhD1	18	Biogeochemical stochastic modeling	Fluminance/MEOM
2.3	PhD2	36	Design of experiments	AIRSEA/CNRM
3.1	PD8	24	Multiresolution technological developments	AIRSEA/LEGOS
3.2	PD9	22	Subgrid scale parameterization	LEGOS/CNRM
3.2	PD10	18	Physical stochastic modeling and non-hydrostatic effects	Fluminance/LEGOS
3.2	PD11	18	Ocean Atmosphere Waves simulations	MEOM/AIRSEA/LEGOS
3.4	PhD3	36	Simplification of biogeochemical models	MIO/MEOM/LEGOS
3.5	PD12	18	LTL-HTL coupling	IFREMER LBH
3.5	PD13	18	LTL-HTL coupling	IFREMER MARBEC
3.5	E1	6	Technological dev for the OSMOSE software	IFREMER MARBEC
4.1.2	E2	18	Core software developments ML	MEOM
4.1.3	E3	24	Core software developments ML	DATAMOVE
4.2.2	PD14	24	Learning representation of model errors	IRIT
4.2.3	PD15	18	Emulator of the complete chain	IMT-A
5.1	E4	12	Development of videos, interactive platform	AIRSEA/ALL
5.2	E5	12	Exchanges with decision-makers in collaboration with OFB	AIRSEA/ALL

5.3. OTHER OPPORTUNITIES FOR THE CO-FUNDING OF THE MEDIATION PROJECT.

5.3.2 Institutional strategy

As described in section 3.4, most of MEDIATION's partners belong to research organizations or universities that are strongly involved in the Ocean-Climate RPP theme. Strong investments are therefore expected in the coming years on these themes and the MEDIATION project will respond to calls for proposals. In particular, attention will be paid to the financing of thesis coming from the Ministry or at the local/regional level via universities.

5.3.3 French calls for proposals

Beyond the partner institutions, some national projects are already identified as potential sources of additional funding. Among these, we can mention the LEFE (Fluid Envelopes and the Environment) multi-agency program, the IMPT (Mathematics for the Planet Earth Institute) or the CNRS interdisciplinary mission. The project is already benefiting very strongly from the PIA and the French stimulus plan (e.g. via the Inria/ATOS agreement) and we can expect further contributions in the course of the project.

5.3.4 Others

Naturally, the members of the MEDIATION project will pursue to answer calls for proposals managed by the ANR as well as at the European level (H2020/ERC), both by leveraging the results of the MEDIATION project (e.g., by contributing to answers on the European digital twins of the oceans) and by trying to be complementary in the objectives, whether they are scientific or technological. MEDIATION will also seek labels to increase its visibility (such as through the Space Climate Observatory).

5.3.5 Funding management between partners

Inria has an in-house support service specialized in the administrative and financial management of contractual resources. This service is notably composed of a legal expert and research contract managers. Under the MEDIATION project, in addition to the consortium agreement that will be signed, payment agreements will be established with each of the partners. These agreements will notably provide a framework for the financial execution of the contracts on the basis of the grant agreement that will be established between Inria and the ANR. For each payment, the Inria research contract manager in charge of the MEDIATION project will gather the partners' expenditure statements, analyze them and send them to the ANR. After acceptance by the ANR, the sums justified and made eligible by the ANR will be paid to each of the partners on the basis of the financial annexes and the payment agreements

6. CITED REFERENCES / REFERENCES BIBLIOGRAPHIQUES CITEES

Due to the page limit of 4 for this section, we list here only the bibliographic references that are cited outside of section 3.2 on entities description. In section 3.2, for each entity, there is a list of 5 publications related to MEDIATION where project participants are co-authors. The total number of references cited in the scientific document (section 6 and section 3.2) excluding duplicates is 95.

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