Please check our wiki for help on navigating the form.

Horizon 2020

Call: H2020-SPACE-2018-2020
(Space 2018-2020)

Topic: LC-SPACE-03-EO-2018
Type of action: RIA

Proposal number: SEP-210497321

Proposal acronym: IMMERSE

Deadline Id: H2020-SPACE-2018

Table of contents

How to fill in the forms

The administrative forms must be filled in for each proposal using the templates available in the submission system. Some data fields in the administrative forms are pre-filled based on the steps in the submission wizard.

1 - General information

Topic	LC-SPACE-03-EO-2018	Type of Action	RIA
Call Identifier	H2020-SPACE-2018-2020	Deadline Id	H2020-SPACE-2018

Acronym	IMMERSE
Proposal title	Improving Models for Marine EnviRonment SErvices

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Duration in months	*48*
Fixed keyword 1	Ocean observing systems and operational forecasting
Free keywords	*ocean modelling, physical oceanography, numerical modelling*

Abstract

The overarching goal of IMMERSE project is to ensure that the Copernicus Marine Environment Monitoring Service (CMEMS) will have continuing access to world-class marine modelling tools for its next generation systems while leveraging advances in space and information technologies, therefore allowing it to address the ever-increasing and evolving demands for marine monitoring and prediction in the 2020s and beyond. In response to the future priorities for CMEMS, IMMERSE will develop new capabilities to: - enable the production of ocean forecasts and analyses that exploit upcoming high resolution satellite datasets, - deliver ocean analyses and forecasts with the higher spatial resolution and additional process complexity demanded by users, - exploit the opportunities of new high performance computing (HPC) technology - allow easy interfacing of CMEMS products with detailed local coastal models. These developments will be delivered in the NEMO ocean model, an established, world-class ocean modelling system that already forms the basis of the majority of CMEMS analysis and forecast products. Hence the pathway from the research in IMMERSE to implementation in CMEMS will be simple and seamless, as the model code developed will be directly applicable in CMEMS models. NEMO has a long track record of producing and maintaining a stable, robustly engineered code base of the type that is needed for operational applications, including CMEMS. The IMMERSE consortium combines world-class expertise in ocean modelling, applied mathematics and HPC, established software engineering processes and infrastructure, and in-depth knowledge of the CMEMS systems and downstream CMEMS systems. Thus IMMERSE is exceptionally well placed to deliver the operational-quality model code required to meet the emerging needs of CMEMS, and maintain it into the future.

Remaining characters 128

Has this proposal (or a very similar one) been submitted in the past 2 years in response to a call for proposals under Horizon 2020 or any other EU programme(s)? ◉ Yes ○ No

Please give the proposal reference or contract number.
730070

Declarations

1) The coordinator declares to have the explicit consent of all applicants on their participation and on the content of this proposal.	☒
2) The information contained in this proposal is correct and complete.	☒
3) This proposal complies with ethical principles (including the highest standards of research integrity — as set out, for instance, in the European Code of Conduct for Research Integrity — and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct).	☒

4) The coordinator confirms:

- to have carried out the self-check of the financial capacity of the organisation on http://ec.europa.eu/research/participants/portal/desktop/en/organisations/lfv.html or to be covered by a financial viability check in an EU project for the last closed financial year. Where the result was "weak" or "insufficient", the coordinator confirms being aware of the measures that may be imposed in accordance with the H2020 Grants Manual (Chapter on Financial capacity check); or	○
- is exempt from the financial capacity check being a public body including international organisations, higher or secondary education establishment or a legal entity, whose viability is guaranteed by a Member State or associated country, as defined in the H2020 Grants Manual (Chapter on Financial capacity check); or	◉
- as sole participant in the proposal is exempt from the financial capacity check.	○

5) The coordinator hereby declares that each applicant has confirmed:

- they are fully eligible in accordance with the criteria set out in the specific call for proposals; and	☒
- they have the financial and operational capacity to carry out the proposed action.	☒

The coordinator is only responsible for the correctness of the information relating to his/her own organisation. Each applicant remains responsible for the correctness of the information related to him and declared above. Where the proposal to be retained for EU funding, the coordinator and each beneficiary applicant will be required to present a formal declaration in this respect.

According to Article 131 of the Financial Regulation of 25 October 2012 on the financial rules applicable to the general budget of the Union (Official Journal L 298 of 26.10.2012, p. 1) and Article 145 of its Rules of Application (Official Journal L 362, 31.12.2012, p.1) applicants found guilty of misrepresentation may be subject to administrative and financial penalties under certain conditions.

Personal data protection

The assessment of your grant application will involve the collection and processing of personal data (such as your name, address and CV), which will be performed pursuant to Regulation (EC) No 45/2001 on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data. Unless indicated otherwise, your replies to the questions in this form and any personal data requested are required to assess your grant application in accordance with the specifications of the call for proposals and will be processed solely for that purpose. Details concerning the purposes and means of the processing of your personal data as well as information on how to exercise your rights are available in the privacy statement. Applicants may lodge a complaint about the processing of their personal data with the European Data Protection Supervisor at any time.

Your personal data may be registered in the Early Detection and Exclusion system of the European Commission (EDES), the new system established by the Commission to reinforce the protection of the Union's financial interests and to ensure sound financial management, in accordance with the provisions of articles 105a and 108 of the revised EU Financial Regulation (FR) (Regulation (EU, EURATOM) 2015/1929 of the European Parliament and of the Council of 28 October 2015 amending Regulation (EU, EURATOM) No 966/2012) and articles 143 - 144 of the corresponding Rules of Application (RAP) (COMMISSION DELEGATED REGULATION (EU) 2015/2462 of 30 October 2015 amending Delegated Regulation (EU) No 1268/2012) for more information see the Privacy statement for the EDES Database.

2 - Participants & contacts

#	Participant Legal Name	Country	Action
1	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	France	
2	FONDAZIONE CENTRO EURO-MEDITERRANEO SUI CAMBIAMENTI CLIMATICI	IT	
3	NATURAL ENVIRONMENT RESEARCH COUNCIL	United Kingdom	
4	MERCATOR OCEAN	FR	
5	MET OFFICE	UK	
6	BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION	ES	
7	INSTITUT NATIONAL DE RECHERCHE ENINFORMATIQUE ET AUTOMATIQUE	France	
8	Puertos del Estado	Spain	
9	Ocean Next	France	
10	HELMHOLTZ ZENTRUM FUR OZEANFORSCHUNG KIEL	Germany	
11	ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA	Italy	
12	HELMHOLTZ-ZENTRUM GEESTHACHT ZENTRUM FUR MATERIAL- UND KUSTENFORSCHUNG GMBH	Germany	
13	UNIVERSITEIT UTRECHT	Netherlands	
14	PLYMOUTH MARINE LABORATORY	United Kingdom	

2 - Administrative data of participating organisations

PIC	***Legal name***
999997930	*CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS*

Short name: CNRS

Address of the organisation

Street RUE MICHEL ANGE 3

Town PARIS

Postcode 75794

Country France

Webpage www.cnrs.fr

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status...18/11/2008 - no

SME self-assessment .... unknown

SME validation sme..18/11/2008 - no

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

No department involved

Department name: *Name of the department/institute carrying out the work.* ☒ not applicable

☐ Same as proposing organisation's address

Street: *Please enter street name and number.*

Town: *Please enter the name of the town.*

Postcode: *Area code.*

Country: *Please select a country*

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (•) Male ( ) Female

First name **Julien** Last name **Le Sommer**

E-Mail **julien.lesommer@univ-grenoble-alpes.fr**

Position in org.: Research Scientist

Department: Institut des Geosciences de l'Environnement ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: 1025 rue de la Piscine

Town: St Martin d’Hères Post code: 38400

Country: France

Website: http://lesommer.github.io

Phone: +33476825065 Phone 2: +33610732744 Fax: +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Camille	LAMBERT	camille.lambert@cnrs.fr	+xxx xxxxxxxxx
Isabelle	Raynaud	a.spv-europe@dr11.cnrs.fr	+xxx xxxxxxxxx

PIC	***Legal name***
999419422	*FONDAZIONE CENTRO EURO-MEDITERRANEO SUI CAMBIAMENTI CLIMATICI*

Short name: FONDAZIONE CENTRO EURO-MEDITERRANEO SUI CAMBIAMENTI CLIMATICI

Address of the organisation

Street VIA A IMPERATORE 16

Town LECCE

Postcode 73100

Country Italy

Webpage www.cmcc.it

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....no

Legal person ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Industry (private for profit)..................no

Secondary or Higher education establishment ....no

Research organisation ....yes

Enterprise Data

SME self-declared status..11/05/2005 - no

SME self-assessment .... unknown

SME validation sme... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name	ODA - Ocean modeling and Data Assimilation	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Viale Carlo Berti Pichat 6/2	
Town	Bologna	
Postcode	40127	
Country	Italy	

Department 2

Department name	ASC - Advanced Scientific Computing Division	☐ not applicable
	☒ Same as proposing organisation's address	
Street	VIA A IMPERATORE 16	
Town	LECCE	
Postcode	73100	
Country	Italy	

Department 3

Department name: OPA - Ocean Predictions and Applications

☐ not applicable

☒ Same as proposing organisation's address

Street: VIA A IMPERATORE 16

Town: LECCE

Postcode: 73100

Country: Italy

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: ○ Male ◉ Female

First name: **Dorotea** Last name: **Iovino**

E-Mail: **dorotea.iovino@cmcc.it**

Position in org.: Scientist, leader of Ocean and Sea Ice Modeling group

Department: ODA - Ocean modeling and Data Assimilation ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Viale Carlo Berti Pichat 6/2

Town: Bologna Post code: 40127

Country: Italy

Website: www.cmcc.it

Phone: +393478350435 Phone 2: +xxx xxxxxxxxx Fax: +390510301699

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Giulia	Galluccio	giulia.galluccio@cmcc.it	*+390283623433*
Silvia	Mocavero	silvia.mocavero@cmcc.it	*+390832297304*

PIC	***Legal name***
999989200	*NATURAL ENVIRONMENT RESEARCH COUNCIL*

Short name: NERC

Address of the organisation

Street Polaris House, North Star Avenue

Town SWINDON WILTSHIRE

Postcode SN2 1EU

Country United Kingdom

Webpage http://www.nerc.ac.uk

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status..25/02/2016 - no

SME self-assessment ....25/02/2016 - no

SME validation sme... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name	National Oceanography Centre	☐ not applicable
	☐ Same as proposing organisation's address	
Street	European Way	
Town	Southampton	
Postcode	SO14 3ZH	
Country	United Kingdom	

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Prof.

Sex: (•) Male ( ) Female

First name: **Adrian Laurence** Last name: **New**

E-Mail: **anw@noc.ac.uk**

Position in org.: Senior scientist

Department: National Oceanography Centre ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: European Way

Town: Southampton Post code: SO14 3ZH

Country: United Kingdom

Website: www.noc.ac.uk

Phone: +44 (0)2380 596173 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Holly	Pelling	hpell@noc.ac.uk	+xxx xxxxxxxxx
Phil	Worrall	pgwo@noc.ac.uk	+xxx xxxxxxxxx

PIC	***Legal name***
974300496	*MERCATOR OCEAN*

Short name: MERCATOR OCEAN

Address of the organisation

Street RUE HERMES 8-10 PARC TECHNOLOGIQUE

Town RAMONVILLE SAINT AGNE

Postcode 31520

Country France

Webpage www.mercator-ocean.fr

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....no

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status..04/06/2010 - no

SME self-assessment .... unknown

SME validation sme.. unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name: Research & Development

☐ not applicable

☒ Same as proposing organisation's address

Street: RUE HERMES 8-10 PARC TECHNOLOGIQUE DU CA

Town: RAMONVILLE SAINT AGNE

Postcode: 31520

Country: France

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Mr.

Sex: (•) Male ( ) Female

First name: **Romain**

Last name: **Bourdallé-Badie**

E-Mail: **rbourdal@mercator-ocean.fr**

Position in org.: Engineer

Department: Research & Development

☐ Same as organisation name

☒ Same as proposing organisation's address

Street: RUE HERMES 8-10 PARC TECHNOLOGIQUE DU CANAL

Town: RAMONVILLE SAINT AGNE

Post code: 31520

Country: France

Website: https://www.mercator-ocean.fr/

Phone: +33561393823

Phone 2: *+xxx xxxxxxxxx*

Fax: +33561393899

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Laura	Cherdel	laura.cherdel@mercator-ocean.fr	*+xxx xxxxxxxxx*

PIC	***Legal name***
999892685	*MET OFFICE*

Short name: MET OFFICE

Address of the organisation

Street FitzRoy Road

Town EXETER

Postcode EX1 3PB

Country United Kingdom

Webpage www.metoffice.gov.uk

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....no

International organisation ....unknown

International organisation of European interest ....unknown

Secondary or Higher education establishment ....unknown

Research organisation ....no

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status... unknown

SME self-assessment .... unknown

SME validation sme.. unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name: Met Office ☐ not applicable

☒ Same as proposing organisation's address

Street: FitzRoy Road

Town: EXETER

Postcode: EX1 3PB

Country: United Kingdom

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (●) Male ( ) Female

First name: **Mike** Last name: **Bell**

E-Mail: **mike.bell@metoffice.gov.uk**

Position in org.: Fellow in Ocean Dynamics

Department: Met Office Hadley Centre ☐ Same as organisation name

☒ Same as proposing organisation's address

Street: FitzRoy Road

Town: EXETER Post code: EX1 3PB

Country: United Kingdom

Website: www.metoffice.gov.uk

Phone: +44 1392 886434 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Paula	Newton	paula.newton@metoffice.gov.uk	+xxx xxxxxxxxx

PIC	***Legal name***
999655520	*BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION*

Short name: BSC

Address of the organisation

Street Calle Jordi Girona 31

Town BARCELONA

Postcode 08034

Country Spain

Webpage www.bsc.es

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status..01/03/2005 - no

SME self-assessment .... unknown

SME validation sme... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name: Earth Science Department ☐ not applicable

☐ Same as proposing organisation's address

Street: NEXUS II buidling, Jordi Girona 29

Town: Barcelona

Postcode: 08034

Country: Spain

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Mr.

Sex: (•) Male ( ) Female

First name **Miguel** Last name **Castrillo**

E-Mail **miguel.castrillo@bsc.es**

Position in org.: Research Support Engineer

Department: Earth Science Department ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: NEXUS II building, Jordi Girona 29

Town: Barcelona Post code: 08034

Country: Spain

Website: www.bsc.es

Phone: +34 934134051 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Mar	Rodriguez	mar.rodriguez@bsc.es	+340934137566

PIC	***Legal name***
999547074	*INSTITUT NATIONAL DE RECHERCHE ENINFORMATIQUE ET AUTOMATIQUE*

Short name: INRIA

Address of the organisation

Street DOMAINE DE VOLUCEAU ROCQUENCOURT

Town LE CHESNAY CEDEX

Postcode 78153

Country France

Webpage www.inria.fr

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status.. unknown

SME self-assessment .... unknown

SME validation sme... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name: Inria Grenoble Rhône-Alpes – EPI AIRSEA ☐ not applicable

☐ Same as proposing organisation's address

Street: 700 avenue de la centrale-bâtiment IMAG

Town: Saint Martin d'Hères

Postcode: 38400

Country: France

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Mr.

Sex: (●) Male ( ) Female

First name: **Florian**

Last name: **Lemarié**

E-Mail: **florian.lemarie@inria.fr**

Position in org.: Researcher

Department: Inria Grenoble Rhône-Alpes – EPI AIRSEA

☐ Same as organisation name

☐ Same as proposing organisation's address

Street: 700 avenue de la centrale-bâtiment IMAG

Town: Saint Martin d'Hères

Post code: 38400

Country: France

Website: https://www.inria.fr/equipes/airsea

Phone: +33 4 57 42 17 57

Phone 2: +xxx xxxxxxxxx

Fax: +xxx xxxxxxxxx

Other contact persons

First Name	*Last Name*	*E-mail*	*Phone*
Béatrice	Pouchot-Camoz	recettes-grenoble@inria.fr	+33476615412

PIC	***Legal name***
998357563	*Puertos del Estado*

Short name: EPPE

Address of the organisation

Street AVENIDA DEL PARTENON 10

Town Madrid

Postcode 28042

Country Spain

Webpage http://www.puertos.es

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....unknown

International organisation of European interest ....unknown

Secondary or Higher education establishment ....unknown

Research organisation ....unknown

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status.. unknown

SME self-assessment .... unknown

SME validation sme... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name	Physical Oceanography Division	☐ not applicable
	☒ Same as proposing organisation's address	
Street	AVENIDA DEL PARTENON 10	
Town	Madrid	
Postcode	28042	
Country	Spain	

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (●) Male ( ) Female

First name: **Marcos** Last name: **Garcia Sotillo**

E-Mail: **marcos@puertos.es**

Position in org.: Head of the Port and Coastal Dynamics Division

Department: Physical Oceanography Division ☐ Same as organisation name

☒ Same as proposing organisation's address

Street: AVENIDA DEL PARTENON 10

Town: Madrid Post code: 28042

Country: Spain

Website: www.puertos.es

Phone: +34915245548 Phone 2: +xxx xxxxxxxxx Fax: +34915245500

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Enrique	Alvarez Fanjul	enrique@puertos.es	+xxx xxxxxxxxx

PIC	***Legal name***
908203047	*Ocean Next*

Short name: Ocean Next

Address of the organisation

Street 90 Chemin du Moulin

Town La Terrasse

Postcode 38660

Country France

Webpage www.ocean-next.fr

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....unknown

Non-profit ....unknown

International organisation ....unknown

International organisation of European interest ....unknown

Secondary or Higher education establishment ....unknown

Research organisation ....unknown

Legal person ....yes

Industry (private for profit)..................unknown

Enterprise Data

SME self-declared status.. unknown

SME self-assessment .... unknown

SME validation sme... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name: Ocean Next / R&D ☐ not applicable

☒ Same as proposing organisation's address

Street: 90 Chemin du Moulin

Town: La Terrasse

Postcode: 38660

Country: France

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title	Dr.	Sex	(•) Male ( ) Female
First name	**Laurent**	Last name	**Brodeau**
E-Mail	**laurent.brodeau@ocean-next.fr**		
Position in org.	Research Scientist		
Department	Ocean Next / R&D	☐	Same as organisation name

☒ Same as proposing organisation's address

Street	90 Chemin du Moulin		
Town	La Terrasse	Post code	38660
Country	France		
Website	http://www.ocean-next.fr/		

Phone	+33 4 76 82 70 76	Phone 2	+xxx xxxxxxxxx	Fax	+xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Sylvie	Sahuc	sylvie.sahuc@ocean-next.fr	+xxx xxxxxxxxx

PIC	***Legal name***
986090458	*HELMHOLTZ ZENTRUM FUR OZEANFORSCHUNG KIEL*

Short name: GEOMAR

Address of the organisation

Street WISCHHOFSTRASSE 1-3

Town KIEL

Postcode 24148

Country Germany

Webpage www.geomar.de

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status..01/01/2012 - no

SME self-assessment .... unknown

SME validation sme... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name: Ocean Circulation and Climate Dynamics ☐ not applicable

☐ Same as proposing organisation's address

Street: Düsternbrooker Weg 20

Town: Kiel

Postcode: 24105

Country: Germany

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (•) Male ( ) Female

First name: **Markus** Last name: **Scheinert**

E-Mail: **mscheinert@geomar.de**

Position in org.: Scientific Programmer, Data Steward

Department: Ocean Circulation and Climate Dynamics / Theory and Modelling ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Düsternbrooker Weg 20

Town: Kiel Post code: 24105

Country: Germany

Website: https://www.geomar.de/en/research/fb1/fb1-tm/topics/

Phone: +49 4316004014 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Alexandra	Drossou-Berendes	adrossou-berendes@geomar.de	+494316002808

PIC	***Legal name***
999993953	*ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA*

Short name: UNIBO

Address of the organisation

Street VIA ZAMBONI 33

Town BOLOGNA

Postcode 40126

Country Italy

Webpage www.unibo.it

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....yes

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status.. unknown

SME self-assessment .... unknown

SME validation sme... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name: Department of Physics and Astronomy

☐ not applicable

☐ Same as proposing organisation's address

Street: viale Berti Pichat 6/2

Town: Bologna

Postcode: 40127

Country: Italy

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr. Sex: (•) Male ( ) Female

First name **Francesco** Last name **Trotta**

E-Mail **francesco.trotta4@unibo.it**

Position in org.: Research fellow (RTD-A)

Department: Department of Physics and Astronomy ☐ Same as organisation name

☐ Same as proposing organisation's address

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Country: Italy

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Other contact persons

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PIC	***Legal name***
999507401	*HELMHOLTZ-ZENTRUM GEESTHACHT ZENTRUM FUR MATERIAL- UND KUSTENFORSCHUNG G*

Short name: HZG

Address of the organisation

Street MAX PLANCK STRASSE 1

Town GEESTHACHT

Postcode 21502

Country Germany

Webpage www.hzg.de

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....no

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status..07/07/2008 - no

SME self-assessment .... unknown

SME validation sme...07/07/2008 - no

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name: Hydrodynamics and Data Assimilation ☐ not applicable

☒ Same as proposing organisation's address

Street: MAX PLANCK STRASSE 1

Town: GEESTHACHT

Postcode: 21502

Country: Germany

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: ○ Male ◉ Female

First name: **Joanna** Last name: **Staneva**

E-Mail: **joanna.staneva@hzg.de**

Position in org.: Head of Department

Department: Hydrodynamics and Data Assimilation ☐ Same as organisation name

☒ Same as proposing organisation's address

Street: MAX PLANCK STRASSE 1

Town: GEESTHACHT Post code: 21502

Country: Germany

Website: https://www.hzg.de/data_analysis_assimilation

Phone: +494152871804 Phone 2: +xxx xxxxxxxxx Fax: +4941528741804

Other contact persons

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PIC	***Legal name***
999985805	*UNIVERSITEIT UTRECHT*

Short name: UU

Address of the organisation

Street HEIDELBERGLAAN 8

Town UTRECHT

Postcode 3584 CS

Country Netherlands

Webpage www.uu.nl

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....yes

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status..01/01/2008 - no

SME self-assessment .... unknown

SME validation sme...26/05/2008 - no

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name	Institute for Marine and Atmospheric research Utrecht	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Princetonplein 5	
Town	Utrecht	
Postcode	3584 CC	
Country	Netherlands	

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (•) Male ( ) Female

First name **Erik** Last name **Van Sebille**

E-Mail **e.vansebille@uu.nl**

Position in org.: Associate Professor

Department: Institute for Marine and Atmospheric research Utrecht ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Princetonplein 5

Town: Utrecht Post code: 3584 CC

Country: Netherlands

Website: www.uu.nl

Phone: +31-30-2535441 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

Other contact persons

First Name	*Last Name*	*E-mail*	*Phone*
Pieter	Thijssen	p.m.a.thijssen@uu.nl	+31 30 2533065

PIC	***Legal name***
999484024	*PLYMOUTH MARINE LABORATORY*

Short name: PML

Address of the organisation

Street Prospect Place, The Hoe

Town PLYMOUTH

Postcode PL1 3DH

Country United Kingdom

Webpage http://www.pml.ac.uk/

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....no

Non-profit ....yes

International organisation ....unknown

International organisation of European interest ....unknown

Secondary or Higher education establishment ....unknown

Research organisation ....yes

Legal person ....yes

Industry (private for profit)..................no

Enterprise Data

SME self-declared status..31/03/2014 - yes

SME self-assessment ....31/03/2014 - yes

SME validation sme.. unknown

Based on the above details of the Beneficiary Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name: Marine Ecosystems Models & Predictions ☐ not applicable

☒ Same as proposing organisation's address

Street: Prospect Place, The Hoe

Town: PLYMOUTH

Postcode: PL1 3DH

Country: United Kingdom

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr. Sex: (●) Male ( ) Female

First name **Ricardo** Last name **Torres**

E-Mail **rito@pml.ac.uk**

Position in org.: Senior Scientist, Head of fine-scale modelling at PML

Department: Marine Ecosystems Models & Predictions ☐ Same as organisation name

☒ Same as proposing organisation's address

Street: Prospect Place, The Hoe

Town: PLYMOUTH Post code: PL1 3DH

Country: United Kingdom

Website: www.pml.ac.uk

Phone: +441752633100 Phone 2: +xxx xxxxxxxxx Fax: +441752633101

Other contact persons

First Name	*Last Name*	*E-mail*	*Phone*
Christopher	Taysom	cajt@pml.ac.uk	+xxx xxxxxxxxx

3 - Budget

No	Participant	Country	(A) Direct personnel costs/€	(B) Other direct costs/€	(C) Direct costs of sub-contracting/€	(D) Direct costs of providing financial support to third parties/€	(E) Costs of inkind contributions not used on the beneficiary's premises/€	(F) Indirect Costs / € (=0.25(A+B-E))	(G) Special unit costs covering direct & indirect costs / €	(H) Total estimated eligible costs / € (=A+B+C+D+F +G)	(I) Reimburse-ment rate (%)	(J) Max.EU Contribution / € (=H*I)	(K) Requested EU Contribution/ €
1	Centre National De La Recherche	FR	616424	67751	0	0	0	171043,75	0	855218,75	100	855218,75	855218,75
2	Fondazione Centro Euro-mediterraneo	IT	558000	39301	37000	0	0	149325,25	0	783626,25	100	783626,25	783626,25
3	Natural Environment Research	UK	566439	38688	0	0	0	151281,75	0	756408,75	100	756408,75	756408,75
4	Mercator Ocean	FR	405431	35300	0	0	0	110182,75	0	550913,75	100	550913,75	550913,75
5	Met Office	UK	423507	37249	0	0	0	115189,00	0	575945,00	100	575945,00	575945,00
6	Barcelona Supercomputi ng Center -	ES	63000	9300	0	0	0	18075,00	0	90375,00	100	90375,00	90375,00
7	Institut National De Recherche	FR	306922	19000	0	0	0	81480,50	0	407402,50	100	407402,50	407402,50
8	Puertos Del Estado	ES	102000	9150	4500	0	0	27787,50	0	143437,50	100	143437,50	143437,50
9	Ocean Next	FR	224640	14926	0	0	0	59891,50	0	299457,50	100	299457,50	299457,50
10	Helmholtz Zentrum Fur Ozeanforschu	DE	74400	4860	0	0	0	19815,00	0	99075,00	100	99075,00	99075,00

11	Alma Mater Studiorum - Universita Di	IT	79160	12900	0	0	0	23015,00	0	115075,00	100	115075,00	115075,00
12	Helmholtz-zentrum Geesthacht	DE	90000	8000	0	0	0	24500,00	0	122500,00	100	122500,00	122500,00
13	Universiteit Utrecht	NL	70452	5000	0	0	0	18863,00	0	94315,00	100	94315,00	94315,00
14	Plymouth Marine Laboratory	UK	76212	8000	0	0	0	21053,00	0	105265,00	100	105265,00	105265,00
	Total		3656587	309425	41500	0	0	991503,00	0	4999015,00		4999015,00	4999015,00

4 - Ethics

1. HUMAN EMBRYOS/FOETUSES		Page
Does your research involve Human Embryonic Stem Cells (hESCs)?	◯Yes ◉No	
Does your research involve the use of human embryos?	◯Yes ◉No	
Does your research involve the use of human foetal tissues / cells?	◯Yes ◉No	
2. HUMANS		**Page**
Does your research involve human participants?	◯Yes ◉No	
Does your research involve physical interventions on the study participants?	◯Yes ◉No	
3. HUMAN CELLS / TISSUES		**Page**
Does your research involve human cells or tissues (other than from Human Embryos/ Foetuses, i.e. section 1)?	◯Yes ◉No	
4. PERSONAL DATA		**Page**
Does your research involve personal data collection and/or processing?	◯Yes ◉No	
Does your research involve further processing of previously collected personal data (secondary use)?	◯Yes ◉No	
5. ANIMALS		**Page**
Does your research involve animals?	◯Yes ◉No	
6. THIRD COUNTRIES		**Page**
In case non-EU countries are involved, do the research related activities undertaken in these countries raise potential ethics issues?	◯Yes ◉No	
Do you plan to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?	◯Yes ◉No	
Do you plan to import any material - including personal data - from non-EU countries into the EU?	◯Yes ◉No	
Do you plan to export any material - including personal data - from the EU to non-EU countries?	◯Yes ◉No	
In case your research involves low and/or lower middle income countries, are any benefits-sharing actions planned?	◯Yes ◉No	
Could the situation in the country put the individuals taking part in the research at risk?	◯Yes ◉No	

7. ENVIRONMENT & HEALTH and SAFETY		Page
Does your research involve the use of elements that may cause harm to the environment, to animals or plants?	◯ Yes ◉ No	
Does your research deal with endangered fauna and/or flora and/or protected areas?	◯ Yes ◉ No	
Does your research involve the use of elements that may cause harm to humans, including research staff?	◯ Yes ◉ No	
8. DUAL USE		**Page**
Does your research involve dual-use items in the sense of Regulation 428/2009, or other items for which an authorisation is required?	◯ Yes ◉ No	
9. EXCLUSIVE FOCUS ON CIVIL APPLICATIONS		**Page**
Could your research raise concerns regarding the exclusive focus on civil applications?	◯ Yes ◉ No	
10. MISUSE		**Page**
Does your research have the potential for misuse of research results?	◯ Yes ◉ No	
11. OTHER ETHICS ISSUES		**Page**
Are there any other ethics issues that should be taken into consideration? Please specify	◯ Yes ◉ No	

I confirm that I have taken into account all ethics issues described above and that, if any ethics issues apply, I will complete the ethics self-assessment and attach the required documents. ☒

[How to Complete your Ethics Self-Assessment]

5 - Call-specific questions

Extended Open Research Data Pilot in Horizon 2020

If selected, applicants will by default participate in the Pilot on Open Research Data in Horizon 2020[1] , which aims to improve and maximise access to and re-use of research data generated by actions.

However, participation in the Pilot is flexible in the sense that it does not mean that all research data needs to be open. After the action has started, participants will formulate a Data Management Plan (DMP), which should address the relevant aspects of making data FAIR – findable, accessible, interoperable and re-usable, including what data the project will generate, whether and how it will be made accessible for verification and re-use, and how it will be curated and preserved. Through this DMP projects can define certain datasets to remain closed according to the principle "as open as possible, as closed as necessary". A Data Management Plan does not have to be submitted at the proposal stage.

Furthermore, applicants also have the possibility to opt out of this Pilot completely at any stage (before or after the grant signature). In this case, applicants must indicate a reason for this choice (see options below).

Please note that participation in this Pilot does not constitute part of the evaluation process. Proposals will not be penalised for opting out.

We wish to opt out of the Pilot on Open Research Data in Horizon 2020.	○ Yes	◉ No

Further guidance on open access and research data management is available on the participant portal: http://ec.europa.eu/research/participants/docs/h2020-funding-guide/cross-cutting-issues/open-access-dissemination_en.htm and in general annex L of the Work Programme.

[1] *According to article 43.2 of Regulation (EU) No 1290/2013 of the European Parliament and of the Council, of 11 December 2013, laying down the rules for participation and dissemination in "Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)" and repealing Regulation (EC) No 1906/2006.*

Title of Proposal : Improving Models for Marine EnviRonment SErvices (IMMERSE)

LIST OF PARTICIPANTS

Participant No	Participant organisation name	Country
1	Centre National de la Recherche Scientifique (CNRS)	FR
2	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)	IT
3	Natural Environment Research Council (NERC)	UK
4	Mercator Ocean (Mercator Ocean)	FR
5	Met Office (Met Office)	UK
6	Barcelona Supercomputing Center - Centro Nacional de la Supercomputación (BSC)	SP
7	Institut National de Recherche en Informatique et en Automatique (INRIA)	FR
8	Puertos del Estado (PdE)	SP
9	Ocean Next (Ocean Next)	FR
10	Helmholtz-Zentrum für Ozeanforschung Kiel (GEOMAR)	GE
11	Università di Bologna (UNIBO)	IT
12	Helmholtz-Zentrum für Material und Küstenforschung Geesthacht (HZG)	GE
13	Universiteit Utrecht (Univ. Utrecht)	NE
14	Plymouth Marine Laboratory (PML)	UK

TABLE OF CONTENTS

1. EXCELLENCE

1.1 Objectives of IMMERSE

The overarching goal of IMMERSE is ensure that the Copernicus Marine Environment Monitoring Service will have continuing access to world-class marine modelling tools for its next generation systems while leveraging advances in space and information technologies, therefore allowing it to address the ever-increasing and evolving demands for marine monitoring and prediction in the 2020s and beyond.

The Copernicus Marine Environment Monitoring Service (CMEMS) provides a suite of observation- and model-based products to support monitoring and sustainable management of the marine environment across multiple user sectors. CMEMS products are delivered through three Thematic Assembly Centres (TACs) and seven Monitoring and Forecasting Centres (MFCs). The MFCs, covering the global ocean and six regional partitions of European waters, each provide (i) near-real-time analyses of the current state of the ocean; (ii) reanalyses, i.e. consistent, observation-constrained estimates of the ocean's evolution over recent decades; and (iii) forecasts of ocean evolution a few days ahead. For (i) and (ii) observations from multiple sources are assimilated into an ocean model, providing a synthesis of the different observations and a dynamically consistent estimate of the ocean state where there are no observations. To produce (iii) models are run forwards in time from the current analysis state. Thus ocean models are at the centre of CMEMS MFC products.

NEMO (Nucleus for European Modelling of the Ocean) is a flagship European modelling framework, developed by five European partners, all of whom contribute to this proposal. NEMO has more than 1600 registered users in all continents except Antarctica, and the latest user version of the NEMO code has been downloaded around 1300 times per year since its last release. NEMO underpins the CMEMS services and is used in six of the seven CMEMS MFCs.

NEMO is internationally recognised as a state-of-the-art ocean modelling framework, providing high quality analysis and forecast products. However, user demands for marine monitoring do not stand still, and analysis by CMEMS identified a number of future requirements for development of the CMEMS service. The goal of IMMERSE is to address the requirements for long term (Tier 3) ocean modelling research identified in the call LC-SPACE-03-EO-2018, and to deliver the results of this research as thoroughly proven and assessed code in the NEMO reference code repository, ready for rapid implementation by the CMEMS MFCs in future versions of their modelling and data assimilation systems.

Specifically, IMMERSE will address the following objectives:

Objective 1: Develop a new, efficient, stable and scalable NEMO reference code with improved performances adapted to exploit future HPC technologies in the context of CMEMS systems.

This objective addresses the requirements "*Exploit the opportunities of new high performance computing (HPC) technology*" and "*Develop advanced numerical schemes with improved accuracy and stability*". The need to address user demands for high resolution information, and to exploit new, high resolution satellite and in situ observations, cannot be achieved simply by running NEMO at higher resolution with current numerical schemes and HPC algorithms. IMMERSE will perform the research and development needed to allow CMEMS to take full advantage of future HPC resources with a more efficient, more scalable, and more stable NEMO reference code. The research proposed in WP3[1] will increase the stability of NEMO numerical schemes and reduce the time-to-return of numerical integration. The research proposed in WP4 will allow NEMO to exploit more effectively future architectures through : an improved use of memory hierarchies and hardware peak performance, an improved macro-task parallelism, and an improved NEMO I/O management in operational systems. The research proposed in WP6 will demonstrate how the above developments will

[1] A detailed description of IMMERSE work-packages is available in section 3.1 (page 30-31).

allow CMEMS to deploy ambitious high resolution systems in order to meet users needs in a cost effective way.

Objective 2: Develop NEMO for the challenges of delivering ocean state estimates and forecasts describing ocean dynamics and biogeochemistry at kilometric scale with improved accuracy

This objective addresses the requirement "*Deliver global ocean analyses and forecasts at a kilometric scale with additional process complexity*". Addressing users demand for higher resolution information not only require improved NEMO code performance to exploit upcoming HPC resources. Forecast accuracy at fine scale should also be improved with (i) numerical schemes adapted to the very energetic dynamical regimes of fine scale oceanic flows (WP3), with (ii) ocean models describing explicitly key physical and biogeochemical processes impacting oceanic flows at kilometric scale (WP5). IMMERSE will specifically focus on improving the accuracy of NEMO time-stepping scheme and improving the ability of NEMO vertical coordinate to account for high frequency processes (including tidal physics and internal waves) (WP3). IMMERSE will also improve the representation of physical processes at key interfaces (WP5) : the feedbacks of ocean properties on surface winds and the impact of surface waves on oceanic mixing will be represented; the rheology of NEMO sea-ice model will be adapted to kilometer scale flows; the coupling with biogeochemical models will also be improved. Because global forecasts of oceanic currents at kilometric scale will still remain difficult to reach at global scale for the next 15 years, IMMERSE will also improve NEMO local grid refinement capability (AGRIF) in order to allow CMEMS systems to reach kilometric resolution in key areas (WP3). The impact of the above development will be demonstrated in systems prefiguring future CMEMS applications (WP6).

Objective 3: Prepare the exploitation of the next generation of high resolution observing networks within CMEMS systems and in detailed, downstream modelling systems.

This objective addresses the requirements "*Production of ocean forecasts and analyses that exploit upcoming HR satellite datasets*" and "*Assess the adequacy and quality of satellite-derived ocean data into the coastal models, thus providing an opportunity for validation and integration with local ocean conditions*." Copernicus Marine Environment Monitoring Service combine information from observing networks with numerical models within products that are used by downstream services in order to address users and market needs. The development of new high resolution EO datasets from the Sentinel series and contributing missions (e.g. Meteosat Third Generation), the advent of wide-swath altimetry (NASA/CNES SWOT mission) and the availability of localized high resolution in-situ observations (e.g. sub-surface profile data from gliders, HF radars) pose challenges for the optimal exploitation of high resolution data into CMEMS and downstream services. IMMERSE will study the predictability horizon of ocean dynamics at kilometric scale and quantify the impact of resolution on forecast errors in order to guide the design of future CMEMS data assimilation components at high resolution (WP7). IMMERSE will also help foster the use of the highest resolution EO datasets in more detailed, downstream modelling system by prototyping a downstream model assessment toolbox based on a series of downstream cases studies (WP8). The outcomes will be software tools for CMEMS users, recommendations to CMEMS for data assimilation in future systems, and advice for future EO programmes to optimise the beneficial impact on CMEMS products.

Objective 4: Develop a flexible and generic software tools series for interfacing CMEMS observation and model-based products and detailed, downstream modelling systems

This objective addresses the requirement "*Allow easy interfacing of the Copernicus service with local coastal models, allowing for two-way data exchange between coastal systems and the Copernicus Marine System*". A key challenge for the future evolution of CMEMS is the articulation of CMEMS systems and products with detailed, downstream modelling systems, the question of the two-way data exchanges being essential to this articulation. IMMERSE will develop a prototype generic interface system between CMEMS products and coastal modelling systems (WP7), and trial this with a number of potential users (WP8). The outcome will be a tested prototype interface code, suitable to be packaged and delivered as a user utility alongside future CMEMS products or within the upcoming Copernicus Data and Information Access Services. The benefit of two-way data exchange through local grid refinements within CMEMS systems will also be demonstrated in prototype configurations in WP6.

Objective 5: Provide proven model code and software tools with assessments suitable for rapid deployment in CMEMS
The IMMERSE output will be code and scientific assessments that are designed and tested to allow rapid assessment and uptake by the CMEMS services as part of their system evolution roadmap. Code will be developed according to the rigorous NEMO software engineering standards in order to assure easy transition to operational use. A detailed roadmap to deployment will be developed as a deliverable of IMMERSE (WP2). Additionally, IMMERSE will use a range of engagement mechanisms with downstream users of the CMEMS services (WP2, 7, 8) to capture their requirements, to inform them of upcoming capabilities and to build user skills in exploitation of future CMEMS products (WP8).

1.2 Relation to the work programme

IMMERSE relates to work programme topic **LC-SPACE-03-EO-2018 Copernicus evolution - Preparing for the next generation of Copernicus Marine Service ocean models**. Specifically, IMMERSE will deliver the key developments in ocean modelling capability identified in the call and in the accompanying Guidance Document by the Copernicus Marine Environment Monitoring Service (CMEMS) as critical for the future evolution of CMEMS model-synthesised products of the future (near-real-time ocean analyses and forecasts, and delayed mode reanalyses of the evolving ocean state over recent decades).

In this section we summarize how the proposed research and development relates to the Specific Challenge and Scope of the work programme topic.

1.2a) Relation to the overarching Specific Challenge of the Call

"***The overarching challenge is to prepare the next generation of the Copernicus Marine Service in line with the evolution of requirements, policies and national expectations"***
IMMERSE will deliver a package of developments to the NEMO ocean modelling framework, which is widely used by the CMEMS Monitoring and Forecasting Centres (MFCs) in the production of CMEMS products, and specific prototype software toolboxes that can be used within future CMEMS services. The proposed code developments have been identified on the basis of CMEMS service evolution strategy that builds upon the evolution of requirements, policies and national expectations. Most developments will be implemented in the NEMO reference code, which is the code repository, centrally maintained by the NEMO System Team, that forms the source of all NEMO applications. Hence the codes will have been tested and demonstrated to a high level of robustness and in a context that is close to operational CMEMS configurations and therefore suitable for preparing the next generation Copernicus Marine Service.

"(...) and also benefiting from advances in space, IT technologies and modelling"
IMMERSE proposed research and development is aimed at guaranteeing the best possible synergy between future high resolution CMEMS model-synthesized products and data streams from future Earth Observing (EO) missions. IMMERSE ambition is to prepare NEMO ocean model for CMEMS model-synthesized products to be compliant with the nature and the sampling of future satellite ocean remote sensing data that are planned for "Sentinel expansion" and "Sentinel Next Generation" phases.

IMMERSE code developments are also based on an analysis of the foreseeable evolutions of the HPC context for CMEMS. IMMERSE demonstrations are based on existing and prototype model configurations compliant with this HPC context. IMMERSE will in particular help optimizing the operation of a NEMO global model configuration with 2-3km horizontal resolution (ORCA36, WP6) that is both compliant with the mesoscale resolution capacity of future high resolution EO datasets and with the HPC context in terms of time-to-solution in an operational context. IMMERSE project will also contribute to prepare NEMO ocean model to the challenges of exascale computing with specific activities aimed at increasing the modularity and the scalability of NEMO ocean model (WP4).

IMMERSE code developments are based on the most recent established scientific knowledge in the ocean modelling community. Proposed developments are fully consistent with the consensus reached within the NEMO ocean modelling community that is reflected in NEMO Development Strategy document available on NEMO website. IMMERSE will in particular allow to leverage the most recent advances in applied mathematics in designing the new version of NEMO ocean model numerical kernel by engaging new partners in NEMO development process (WP3).

"(...) and in accordance with the Copernicus institutional context."
As mentioned above, proposed research and development activities have been selected on the basis of CMEMS service evolution strategy with the aim of delivering timely developments for CMEMS evolution roadmap. Specific attention has also been paid to the articulation of IMMERSE Tier-3 research and development with on-going Tier-1 and Tier-2 CMEMS service evolution projects (in particular in WP5). Recognising the boundary between the generic (European core) Copernicus Marine Service and downstream uses such as high resolution coastal modelling for marine planning and services, and the need for easy interfacing of CMEMS products with these downstream systems, IMMERSE project will also undertake specific developments at the interface between CMEMS and downstream systems (WPs 7, 8). These developments also take into consideration the context of the upcoming Copernicus Data and Information Access Services.

1.2 b) Relation to the Scope of the Call and other Specific Challenges

Development of high resolution models
The scope requires that "**Numerical codes shall be prepared to achieve smallest target effective resolution in the kilometric range …"** and its third & fourth bullets require activities to ***"develop advanced numerical schemes with improved accuracy and stability"*** and ***"exploit the opportunities of new high performance computing (HPC) technology".***
WP3 is devoted to developing advanced numerical schemes with improved accuracy and stability. The new time-stepping scheme (T3.1) will be more efficient, stable and accurate and the pressure forces scheme will be stable and more accurate. WP4 is devoted to exploiting new HPC technology (see details in section 1.4). T3.2 and T4.4 will enable the model grids to be refined in selected regions within the CMEMS models through a local grid refinement algorithm allowing two way data-exchanges. T6.1 will demonstrate this capability in one of the CMEMS regional systems achieving kilometre grid spacing within selected parts of the domain. T6.3 will demonstrate these capabilities in a prototype 1/36º global model (see next paragraph).

Exploitation of satellite data
The second bullet of the scope requires: "**Production of ocean forecasts and analyses that exploit upcoming HR satellite datasets**". The last paragraph of the specific challenge describes the ***"need for numerical models to develop a resolution capacity compliant with the spatial (and time) scales from present (Sentinels) and future EO satellites (e.g. wide-swath altimetry, geostationary sensors, surface currents)."***
IMMERSE will prepare the ocean modelling component of CMEMS systems to be operated at space and time resolution compliant with future EO satellites. Recognizing that satellite altimetry is a key control of model-synthesized operational products, IMMERSE will in particular prepare NEMO ocean model configurations to the challenge of exploiting the full range of space and time scales sampled by future altimetric constellations. The effective spatial resolution capability of Sentinel-3-A along-track altimeter data is close to 30km; the spatial resolution capability of the upcoming SWOT wide-swath altimeter data to be launched in 2021 is expected to be close to 15 km on two-dimensional swaths (Dufau et al. 2016). For the *effective resolution* of an ocean model to be close to 15km, its grid resolution should be about 5 to 8 times smaller, and therefore about 2-3 km (Soufflet et al. 2016). With its 1/36° horizontal resolution, the proposed prototype model configuration eORCA36 to be prepared for CMEMS Global MFC will meet this requirement (WP6). IMMERSE also proposes to further improve NEMO local grid refinement capacity (AGRIF) in order to allow its deployment in key areas, allowing CMEMS systems to reach kilometric effective resolution (WP6) compliant with sea surface temperature and ocean color satellite observations.

WP7 will explore the predictability horizontal of ocean flows at kilometric resolution to inform the design of future observation networks (as for instance the new altimetry architecture S3-NG TOP proposed in the context of the Long Term Scenario of the Copernicus Satellite Component). It will also assimilate the current HR SST and altimeter data into models with 1/12° and 1.5km grids and produce the quantitative information on the forecast error statistics required to improve future assimilation of satellite data into high resolution models.

Improved representation of physical processes

The fifth paragraph of the specific challenge states that ***"mesoscale to sub-mesoscale features, … , as well as turbulent mixing are of fundamental importance … The representation of tidal physics and wave-current interaction is also needed for a more complete representation of dynamical processes."*** The first bullet of the scope requires ***"global ocean analyses and forecasts … with additional process complexity".***

Accurate representation of small-scale variations in the air-sea fluxes and of the turbulent mixing in the upper ocean are of particular relevance to CMEMS forecasts so WP5 focuses on their improvement. T5.1 will improve the representation of the feedback mechanisms between small-scale ocean surface properties and surface winds. T5.2 will improve the air-sea coupling through surface waves and start to pull through into the CMEMS systems fundamental improvements to the representation of mixing by Langmuir turbulence developed within the PRIMAVERA project. Task 5.3 will improve the formulation of sea-ice rheology in NEMO and provide advice as to the formulation that should be used in high resolution CMEMS systems covering arctic regions (which are explicitly mentioned in the guidance document on page 13).

Data exchange with coastal systems

The fifth bullet of the scope requires activities to ***"Allow easy interfacing of the Copernicus service with local coastal models, allowing for two-way data exchange between coastal systems and the Copernicus Marine System".*** The last bullet point of the scope demands ***"Assess the adequacy and quality of satellite-derived ocean data into the coastal models, thus providing an opportunity for validation and integration with local ocean conditions."*** The fourth paragraph of the specific challenge states that ***"a high priority is (..) to better describe ocean phenomenon with high dynamics at fine spatial scales to provide enhanced boundary conditions to coastal models ".***

Task 7.3 will design and implement a flexible suite of tools to give coastal modellers and other downstream users ready access to the CMEMS forecast and observational data products. The coastal modellers system leaders and other downstream system leaders involved in the design of this system will exploit it in WP8 and provide feedback on the quality of the CMEMS products and their impact on the downstream systems. This work will be done in coordination with the CEASELESS project through links with HZG and advice from the External Experts Advisory Board (EEAB).

Impact of resolution on the role of oceans in climate models

The sixth bullet in the scope demands ***"Assess the impact of solving the ocean dynamics at kilometric scales on the role of ocean on climate (e.g. vertical exchange of heat, representation of overflows)."*** The penultimate paragraph of the specific challenge states that ***"Development of high-resolution global ocean models would also ultimately benefit to the development of higher resolution climate models needed for more skilful climate predictions."***

Tasks T3.2, T3.3 and T3.4 are devoted to improvements to the vertical coordinates required to improve the representation of overflows and to reduce the spurious diapycnal mixing in the NEMO model, both of which are major limitations on the fidelity of climate simulations using NEMO. Task T6.2 is devoted to a demonstration of the improvements in a global NEMO configuration designed for climate simulation and reanalyses. Task T6.3 will develop a a new ambitious 1/36° global configuration (ORCA36) in-line with the needs of a proposed Flagship European Programme on Extreme Computing and Climate.

Impact of resolution on biogeochemical modelling

The penultimate bullet of the scope is to ***"Assess the impact of solving the ocean dynamics at kilometric scales on the coupling with biogeochemistry and on the carbon, oxygen and nutrient cycles"***

Task 6.1 is devoted to demonstrating the impact of solving ocean dynamics at kilometric scale in a prototype CMEMS regional systems achieving kilometre grid spacing within selected parts of the domain. The prototype system of task 6.1 will include a fully coupled biogeochemical model. Task 6.1 will use an improved interface to biogeochemical models in NEMO that will be implemented in task 5.3. Specific activities are devoted in task 6.1 to assessing the impact of increased resolution on vertical exchanges of tracers that are key for biogeochemical cycles of carbon, oxygen and nutrients.

1.3 Concept and methodology

1.3a) Overall concept

The concept of IMMERSE is to use the internationally recognised NEMO ocean model, already used for the majority of CMEMS model-based products as the basis for developing new capabilities for CMEMS, facilitating rapid and seamless transition from research to operation.

To realise the full value of the new Earth Observation (EO) capabilities implemented under Copernicus, the EO data will need to be integrated with other observation types and synthesized into spatially and temporally complete products using ocean models. The NEMO model is well-established, with around 1600 registered users around the world. NEMO is used in the production of CMEMS products in six of the seven CMEMS regional Monitoring and Forecasting Centres (MFCs), and is under consideration for use in a sixth. NEMO is also well-established in global climate modelling, forming the ocean component of eight of the climate models assessed in the IPCC 5th Assessment Report (expected to increase to twelve in the 6th Assessment).

The NEMO model is well designed to deliver CMEMS products that are state-of-the-art given the current observing system and computational capabilities. However, to derive the value from new EO capabilities, and to deliver higher-resolution products based on the next generation of supercomputers, further development of the capability of NEMO is needed.

NEMO is developed and maintained by a consortium comprising six European partners. The most active ongoing members are partners of IMMERSE projects (Partners 1-5). NEMO is underpinned by core funding from the six partners, which supports a small NEMO System Team to develop and maintain the code functionality and configuration tools at a baseline rate. The formal consortium process allows the pooling of the different expertise and resources of the partners, while maintaining the ability to set and follow clear strategic priorities. Since 2013, the NEMO consortium has maintained a development strategy, which was agreed following a structured workshop and drafting process involving both NEMO consortium scientists and other ocean modelling experts. The NEMO consortium has recently released openly the updated NEMO Development Strategy 2018-2022. Many of the NEMO development goals contribute to the requirements identified by CMEMS to serve its future service requirements (reflecting the fact that MyOcean/CMEMS scientists were involved in the development of the NEMO strategy), and the work proposed in IMMERSE focuses on these areas, enabling development to take place on a timescale that will deliver the required functionality improvements on the timeframe when the computational resources available to CMEMS are expected to have reached a level where it is viable to implement them operationally, and when new satellite instruments are expected to become operational. In other words, IMMERSE will deliver the ocean modelling developments needed for CMEMS to exploit the next generation of satellite instruments and High Performance Computers (HPC).

IMMERSE development of NEMO reference code will in particular focus on allowing easy deployment in CMEMS at kilometric scale resolution with improved accuracy in order to meet user requirements and ensure compatibility with future EO observation. This is achieved through : innovative numerical schemes (WP3), and algorithms (WP4), improved representation of key processes (WP5). All NEMO developments will be fed into NEMO reference code (WP2) and tested in systems prefiguring future CMEMS systems (WP6), with a careful evaluation with high resolution EO datasets (WP6). Besides developments of NEMO baseline code, IMMERSE will also prepare the integration of model information with high resolution EO datasets (WP7). This is achieved through specific studies that will guide the development of DA systems an inform the design of high resolution EO networks. The transition of NEMO developments to CMEMS systems will be prepared through the definition of a roadmap for dissemination to CMEMS (D2.4)

Recognising the need to leverage stakeholder knowledge for preparing the future evolution of CMEMS, IMMERSE will build upon the expertise of downtreams users of CMEMS for prototyping a new interface for downstream users involved in high resolution coastal modelling to use CMEMS products (WPs 7,8). A two way exchange mechanism will also increase community uptake by allowing downstream users to share softwares implementing model assessment metrics based on high resolution EO datasets. The above prototype software will be prepared within the perspective of a possible deployment within Copernicus Data and Information Access Service.

Positioning of the project

In terms of the EC's definitions of Technology Readiness Levels, the starting point for IMMERSE will mainly be concepts and theoretical developments (TRL 1-2), in some cases demonstrated in simple proof-of-concept tests (TRL 3). IMMERSE will move these ideas beyond proof-of-concept, to a point where they have been demonstrated in an operationally-relevant environment (TRL 6), in some cases with early testing in operational environments (TRL 7). This is the appropriate endpoint for targeted Tier 3 research, to be followed by operational implementation by CMEMS MFCs through Tier 1 activities.

According to CMEMS service evolution roadmap, the expected time to return of Tier-3 R&D activities is expected to be 3-10 years, so 2022 to 2029. Most activities of IMMERSE project will consist in mid-term development which results/code can be transferred to the existing Copernicus Service by the end of the project in 2022 (TRL6). A small fraction of the proposed activities will consist in proof of concept development (TRL3) which result can serve for defining future Copernicus Services beyond 2025. An explicit roadmap to operational implementation of IMMERSE deliverables in CMEMS, developed in consultation with the CMEMS MFCs, will be delivered (D2.4).

Links to other national and international activities.

The groups involved in the current proposal obtain considerable gearing from their position in other international research projects. Some specific projects include:

- National (France, Italy, UK) programmes providing baseline support for the NEMO System Team;
- CMEMS MFCs, several of which are based at the home institutions of IMMERSE scientists, so providing easy access to operational oceanography expertise;
- Horizon 2020 PRIMAVERA which includes developments of NEMO parameterisations relevant for high resolution climate modelling (and complementary to the developments in IMMERSE);
- Horizon 2020 AtlantOS which delivers data impact studies to understand the impact of assimilating different in situ data types into operational systems;
- Horizon 2020 CEASELESS which uses Sentinel data combined with in-situ coastal observations to develop a coastal dimension in Copernicus;
- ESI-Wace Centre of excellence in High Performance Computing;
- IS-ENES3 (Infrastructure for the European Network for Earth System Modelling) which will deliver further development of modelling systems and will deploy technologies that will enable fast and robust analysis of IMMERSE results.

Additionally, IMMERSE scientists are active members of several important international panels, providing links to the global ocean modelling and operational oceanography communities, e.g.:

- CLIVAR Ocean Model Development Panel (CLIVAR-OMDP);
- DRAKKAR coordination (a European group sharing expertise on development and tuning of global NEMO configurations, primarily as a research tool);
- GOV Data Assimilation Task Team (GOV-DA-TT) whose co-chair contributes to IMMERSE project;

- GOV Coastal Ocean and Shelf Seas Task Team (GOV-COSST-TT) (provides links to coastal modelling internationally);
- GOV Observing System Evaluation Task Team (GOV-OSEval-TT) (provides links between modellers and Earth Observation Mission Planners);
- GOV Intercomparison and Validation Task Team (GOV-IV-TT).

Several IMMERSE scientists also contribute to on-going CMEMS service evolution R&D projects.

1.3b) Methodology

IMMERSE WPs 3-6 provide and demonstrate developments to the NEMO code. WP7 prepares the articulation of CMEMS models with EO datasets. WP8 demonstrate the impact of CMEMS service evolution on downstream cases studies.

All the activities proposed in WP 3-7 are based on NEMO Development Strategy 2018-2022. NEMO consortium institutions being tightly linked to CMEMS and CMEMS MFCs, NEMO Development Strategy 2018-2022 largely transcribed the requirements of evolution for CMEMS. The IMMERSE project team has carefully selected from NEMO Development Strategy 2018-2022 NEMO code development that would most effectively benefit CMEMS. Specific attention has been paid to the articulation of proposed activities with CMEMS Service Evolution R&D projects. **IMMERSE project will therefore accelerate the implementation of NEMO Development Strategy to the benefit of CMEMS in accordance to CMEMS service Evolution Strategy priorities**.

Experience in many operational modelling centres has shown that to **develop model code that is suitable for use in a range of operational configurations requires substantially more effort** than to develop working code that is to be used in 'research mode' by a single researcher or team. The development of NEMO follows a carefully defined process which has been steadily refined over the 10 years since the NEMO consortium was initiated. Developments are supported by the NEMO System Team funded by the consortium members, whose job is to incorporate new scientific developments into the NEMO reference code and ensure that the code and its documentation are of robust quality. The NEMO software development process is described on NEMO forge project wiki pages, it consists of:

- ***Implementation plan***: explaining the scientific scientific rationale of the development (with references to relevant literature), list of code modifications with modules/files/variables and documentation changes, definition of a means of verification (academic demonstration case.)
- ***Preview and feedbacks***: review of the implementation plan by science and software experts, with feedbacks and discussion to reach full agreement on the implementation plan
- ***Implementation of demonstration case***: to be used as a mean of verification of the development; demonstration cases are eventually collected in the testing suite for each NEMO release;
- ***Development in NEMO code***: in a separate branch of NEMO repository including documentation by the developer (in NEMO code and in NEMO reference manual);
- ***Evaluation and validation***: iterative process including functional validation and scientific validation with the demonstration case;
- ***Developer report***: developer to write a short report to demonstrate success of development;
- ***Expert review***: the code and its documentation is reviewed and tested by an external expert not involved in the development phase;
- ***Full-scale demonstration***: the code branch is further tested in a full-scale NEMO configuration
- ***Integration in NEMO reference code:*** the branch is merged in NEMO reference code with its associated demonstration case included in the testing suite.

NEMO reference code is distributed under an open source software licence (CECILL licence). Information on the development process is open to registered users through NEMO website. **IMMERSE will also contribute to further improving NEMO dissemination strategy and foster engagement of intermediate users**. IMMERSE will produce outreach material that will be made available on NEMO website (D2.2).

IMMERSE will also help the open and robust dissemination of NEMO code with a specific deliverable (D2.3) aiming at providing a methodology for NEMO users to reproducibly reference NEMO configuration information in scientific articles and documentation of operational systems.

A key feature of IMMERSE's methodology is to establish **effective channels of communication with the key stakeholders**, so that developments can rapidly be brought into operational use in CMEMS and exploited by end users. These channels exploit the existing close links between IMMERSE consortium institutions, the NEMO System Team, and CMEMS personnel. Figure 1.3.1 and the text following it summarise data and information flows between IMMERSE, the NEMO System Team, various bodies of CMEMS, and downstream CMEMS users. The detailed methods of dissemination and exploitation are described in more detail in Section 2.2.

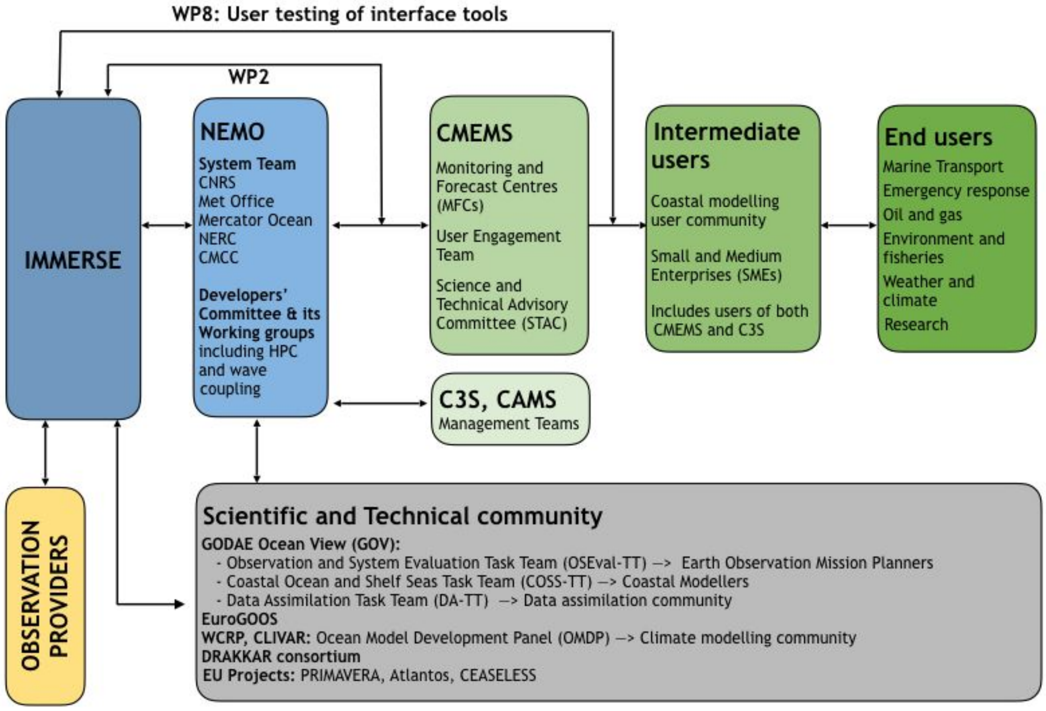

Figure 1.3.1 *: Links between IMMERSE and key impact areas*

Explanation of acronyms

NEMO System Team: the core team supporting and implementing developments into the NEMO reference code. Recipients of IMMERSE code developments.

NEMO Developers' Committee: an expert group consisting of NEMO consortium members and external experts, advising on strategy for NEMO development. Provide feedback on IMMERSE developments.

CMEMS Monitoring and Forecast Centre: CMEMS centre producing analyses, reanalyses and forecasts for one of seven regions (including global). Potential implementor of IMMERSE developments (via NEMO reference code).

CMEMS User Engagement Team: the team in CMEMS responsible for developing downstream use of the CMEMS services. IMMERSE interaction with downstream users will be in close collaboration with this team.

CMEMS Science and Technical Advisory Committee: external expert committee advising Mercator Ocean (as the EU delegated entity for the operational implementation of CMEMS) on overall science and technical development strategy (potentially including IMMERSE developments).

***C3S**:* Copernicus Climate Change Service. Potential user of IMMERSE developments via the NEMO reference code.

Intermediate Users: Individuals/bodies who translate the generic Copernicus products to user scales to inform end users, for example by downscaling or integrating with socio-economic models. Benefit from IMMERSE developments primarily indirectly through improvements to CMEMS products. Coastal Interface (IMMERSE WP7 Task 7.3) feeds directly to intermediate users.

End Users: decision makers who are dependent on knowledge of the state of the marine (or climate) environment. Benefit from IMMERSE developments primarily indirectly through improvements to CMEMS products.

GOV-OSEVal-TT: International committee bringing together experts on marine observations with experts on their use in operational oceanographic systems. Provides established pathway for insights on observing system design from IMMERSE WP7 Task 7.1 to feed into EO mission planning.

GOV-COSS-TT: International committee promoting and guiding the development of operational oceanography for coastal and shelf waters. Provides established pathway for two-way communication with coastal users.

GOV-DA-TT: International committee promoting and guiding the development of data assimilation methods for operational oceanography. Provides established pathway for two-way communication with the international data assimilation community (WP7).

EuroGOOS: European body promoting the science and practice of operational oceanography in Europe. Provides established pathway for two-way communication with intermediate and end users.

WCRP/CLIVAR OMDP: International committee promoting and guiding the development of ocean models, particularly for climate. Provides established pathway for two-way communication with the international ocean modelling community.

DRAKKAR: Collaborative European grouping developing high resolution global ocean models based on NEMO, primarily for research purposes. Provides established pathway for two-way communication with the wider European ocean modelling community.

EU projects: PRIMAVERA delivers complementary ocean modelling developments focusing on physical parameterizations for climate modelling. AtlantOS provides complementary observing system impact studies focusing on in situ observations. CEASELESS provides recommendations on how Sentinel measurements can be used for assessing downstream coastal models.

Sex and gender analysis.

SPACE-03-EO-2018 does not have a gender dimension explicitly integrated into it, however careful thought has been given to how gender considerations are applicable to the project content, communications and dissemination. The nature of the work done by the project is considered to be gender neutral. The consortium does recognise however, that gender considerations can be highly relevant when communicating with users, and when designing information and services that it is hoped will have a societal impact. The project will consider how these activities can be designed such that there is no gender (or other bias) within them, so that the project both gathers information effectively from the full range of potentially impacted areas, as well as disseminates and communicates in ways that do not discriminate against any potentially interested areas (or people within them).

A Gender Strategy and Action Plan (MS1.2) will be produced by M3 of the project, and will act as a living document, detailing how gender considerations and gender balance will be managed within the project. The Coordinator will maintain awareness of sex and gender dimension research within areas relevant to IMMERSE, to ensure that it organises any activities (in particular those involving groups external to the project), in line with the best knowledge on sex and/or gender analysis. Further information on this can be found in Section 3.2.10.

1.4 Ambition

The ambition of IMMERSE is **to deliver innovative developments to NEMO and at its interfaces, to enable CMEMS to take advantage of future Earth Observations and computing platforms.** The activities are organised in IMMERSE into seven work-packages (WP 2-8). We describe below the advances to be made by each work package.

Delivering an open NEMO reference code with the highest standard quality control procedures for a timely dissemination in CMEMS systems (WP2)

The overall ambition of this work-package is to guarantee that CMEMS and end users will benefit optimally IMMERSE outcome and specifically developments to NEMO code carried out during the project. This will be achieved by articulating adequately IMMERSE activities with NEMO development process (Task 2.1), further improving NEMO development process and testing suite (Task 2.2), facilitating the uptake of IMMERSE developments by end-users (Task 2.3), coordinating the transfer of IMMERSE outcome to CMEMS and CMEMS MFCs (Task 2.4).

(i) Articulating IMMERSE activities with NEMO development process
NEMO development process follows state-of-the-art protocols in software engineering and geoscientific model development. This development process includes a multi-year planification of new development through NEMO Development Strategy and a development workflow aiming at delivering robust code suitable for operational applications with appropriate software version control and documentation. The NEMO project manager (Claire Levy, CNRS) is in charge of the day-to-day scientific and technical management of NEMO System Team. Task 2.1 will ensure that IMMERSE developers benefit from this environment. IMMERSE developers will participate in NEMO System Team activity and follow NEMO development process (described in section 1.3 b). NEMO System Team will provide the necessary support and formation. This will ensure that IMMERSE development to NEMO are integrated in NEMO official release cycle and maintained in the future.

(ii) Further improving NEMO development process and testing suite
IMMERSE will improve NEMO development process beyond state-of-the-art through the extension of NEMO testing suite with a *continuous integration service* based on a collection of demonstration cases. Currently, NEMO testing suite for is based on a (i) a functional testing layer (SETTE) that allows to check whether new development are functionally compatible with other NEMO components and (ii) a series of scripts that deploy a small collection of full-size NEMO reference configurations on a series of supercomputer across the centers. Following most recent best practices in software development, Task 2.2 will harmonise this process through the deployment of a *continuous integration service* (ci) that will be triggered after each commit to NEMO reference repository. This service will run an extensive series of lightweight academic demonstration cases that will allow a functional and scientific verification of code results after each commit. Results of this service will be used during code review (see section 1.3b). The demonstration case will be defined in IMMERSE WP3-5 and integrated in the continuous integration service. Task 2.2 will therefore allow NEMO to switch to a test-driven development process.

(iii) Facilitating the uptake of IMMERSE developments by end-users
NEMO reference code is used in CMEMS MFCs and in several downstream systems by intermediate users (some of which contributing to IMMERSE WP8). The liaison with these stakeholders is usually established through NEMO code release cycle, and through NEMO users meeting. Information on NEMO reference code is available openly through NEMO website but currently NEMO System Team does not provide support to sharing NEMO configuration information beyond NEMO reference configurations distributed with NEMO reference code. The ambition of task 2.3 is to improve the communication pathways from NEMO to end-users and foster the exchange of information among end-users. To this purpose, IMMERSE will build and use software tools allowing to easily document NEMO configuration information through open source repositories with appropriate *digital object identifiers*. This will improve the reproducibility of results obtained with NEMO and foster exchange of information among end-users. Task 2.3 will also provide

outreach material based on IMMERSE demonstration case for showcasing new NEMO developments to end-users.

(iv) Coordinating the transfer of IMMERSE outcome to CMEMS and CMEMS MFCs

The main pathway from IMMERSE to CMEMS MFCs is through NEMO reference code, which release cycle will be coordinated through Task 2.1. In addition, in order to guaranteeing the impact of IMMERSE development on CMEMS and CMEMS MFCs, IMMERSE will establish a roadmap for dissemination of IMMERSE outcome to CMEMS (D2.4). The roadmap will allow to phase Tier 1 and Tier 2 activities that will help the transition IMMERSE developments to CMEMS systems and scope necessary additional steps in particular in terms of data-assimilation and EO data processing. The roadmap will be update annually.

Building the next generation numerical kernel for NEMO ocean model to improve forecast accuracy (WP3)

The numerical kernel (also known as the dynamical core) of ocean (and atmosphere) models has a key impact on the efficiency and the fidelity of their simulations. The time-stepping algorithm and the vertical coordinate are two of the most fundamental choices in an ocean model. Small inconsistencies in the kernel typically generate noise within the simulations and/or restrict the length of the time-step. Improving the consistency and quality of the kernel is an ambitious task because all the other aspects of the code are dependent on it.

(i) Two-level time-step (2LTS) scheme

It is proposed to implement a new time-stepping scheme within NEMO. The new scheme is expected to reduce the computational cost of the model, make its integration more robust and stable, reduce spurious dissipation and improve the accuracy of the simulations particularly in fine-scale models. NEMO currently uses a three-level time-step (3LTS) scheme called the leapfrog scheme. Three main options for two-level time-step (2LTS) schemes have been proposed (Lemarié et al. 2015): (a) a forward-backward step (FBS) scheme (useful for 1^{o} climate modelling) ; (b) a 3^{rd} order Runge-Kutta (RK3) scheme; (c) a compensated time-space scheme (CTS). These schemes have the following advantages over the current scheme:

- there is no computational mode
- longer time-steps can be used (see next paragraph)
- regional grid refinement (or coarsening) is simplified
- the calculation of flux limiters is simplified
- top and bottom friction can be calculated implicitly

In order to take longer time-steps one needs to use (Shchepetkin 2015, Lemarié et al. 2015) an adaptive, Courant number dependent, implicit vertical advection of momentum (u and v) and the active tracers (T and S). Computational costs can also be reduced by evaluating some of the more costly terms only once per time-step. The schemes are then 2-3 times more computationally efficient than the current leapfrog scheme. This is a major improvement to the efficiency of the code. Avoiding noise in numerical simulations at the grid-scale or between time-steps is particularly important in ocean simulations as spurious dissipation needs to be minimized. The elimination of the computational mode (which changes sign between time-steps) will help to avoid such noise. Also with the leap-frog scheme, fluxes which should be calculated from one set of inputs have to be split into terms evaluated on different time-steps, complicating the calculation of flux limiters.

Implementation of such a fundamental change to a multi-purpose community ocean model is an ambitious undertaking. It will involve a considerable amount of re-organisation of the code and requires expertise in numerical methods, code design and testing. A considerable amount of effort has already been spent preparing for the task and its execution will require a significant amount of coordination.

(ii)Improved treatment of vertical coordinates

The ocean bathymetry has an extremely important role in steering the paths of the major ocean currents through the bottom pressure torque and the associated vortex stretching (see e.g. Greatbatch et al. 1991 and

Yeager 2015). The bathymetry is crudely represented by "Lego" blocks in z-coordinate models. In terrain-following coordinates the pressure forces over steep slopes are difficult to represent accurately. A finite volume representation of the pressure forces (Adcroft et al. 2008, Engwirda et al. 2017) is attractive and such a formulation which conserves total energy and does not generate spurious circulations around level bathymetry has recently been derived. With appropriate choices for interpolation of the densities and integration of the pressures on the faces of the cells this scheme is hydrostatically consistent even for steep bathymetry. Suitable interpolation choices will be explored (in collaboration with Engwirda) and a suitable one coded and tested within NEMO.

The numerical errors in regions with steep slopes can also be reduced by increasing the horizontal resolution in these regions using the AGRIF system. Valuable improvements in the flexibility of deployment of AGRIF will be obtained by allowing the finer and coarser resolution regions to use different vertical coordinates. It is planned to use the two-way nesting capability provided by AGRIF to resolve the flow in a fairly large number of critical regions, such as downstream of sills and where the accurate representation of the path of the currents requires improved resolution (see for instance WP6, Task 6.2). In order to realise its full capability AGRIF will be adapted to the 2LTS scheme and the AGRIF code itself will be developed so that the nested grids can be efficiently deployed across processors.

Implicit diapycnal transport, associated with numerical dispersion and dissipation in the advection of tracers, can result in significant, unphysical, transport of heat through the main thermocline. This is particularly problematic in eddy permitting models driven by high frequency winds (Lee et al. 2002, Megann 2018). It is important for climate simulations and CMEMS reanalyses to have access to suitable algorithms to improve the control of these numerical errors. NEMO has an option for an Arbitrary Lagrangian Eulerian (ALE) algorithm in which the target grid is the vertical coordinate (Leclair and Madec 2011). This coordinate was novel when it was developed for NEMO but it has not been fully exploited within NEMO. A greater choice of target grids and suitable vertical re-mapping or advection schemes need to be implemented. The NEMO consortium has significant theoretical and practical expertise in these issues (Debreu, Madec, Nurser, Megann, Chanut). Using the 2LTS code and code for improved horizontal transport of thickness which are expected to improve the robustness of z-tilde, we will minimise diapycnal mixing in a 1/12^{o} z-tilde NEMO configuration with suitable high-frequency forcing and recommend how to further develop ALE algorithms within NEMO.

Preparing the NEMO ocean model for the next generation HPC infrastructures accessible to CMEMS services (WP4)

The main ambition of WP4 is to ensure that the NEMO code is well designed for very efficient deployment on current and future hardware architectures, taking into account current technology trends. This is the aim of the NEMO HPC Working Group (HPC WG) which brings together the experts in the major HPC manufacturers, computer scientists & ocean modelling scientists who work on NEMO. The main members of the HPC WG are the partners in this WP. The main goal is the design of the future developments of the NEMO code in such a way as to ensure the full exploitation of the features of the emerging HPC architectures.

NEMO scientific developments are aimed at increasing the model resolution with a target ~2-3 km resolution for global simulations which require a speed-up in model execution in order to preserve a high number of simulated years per day (SYPD), even in operational mode. This goal will be reached by relying on four computational activities. First of all, the code execution will be speeded up through an efficient use of the hardware peak performance. The current version of the NEMO code only reaches a low percentage of the core peak performance, since it requires a lot of memory intensive tasks. Usually, working on a parallel code means improving its parallel efficiency. Here the focus is on increasing the capacity of each parallel process to use the computational power of the hardware unit. New coding approaches to improve the bandwidth requirements (e.g. with algorithms that are aware of the memory architecture) will be investigated and integrated into the NEMO code. Secondly, the task parallelism approach combined with the traditional domain parallelism, currently developed in NEMO, will be proposed to increase the code parallelism level. Some components of the NEMO framework can actually be decoupled by the ocean dynamical core, which means that a different parallel approach as well as a different pool of resources can be used for each component. This approach has already been tested on the sea-ice component and can be extended to the biogeochemical model during the project. Another key factor is to address issues related to I/O management, which is one of the main bottlenecks when the resolution and the number of parallel processes increase. NEMO interfaces the XIOS package for overlapping model computation and diagnostics. Its use will be extended to all reading/writing operations performed by the NEMO code thanks to the existing XIOS support for both reading/writing operations. The big challenge will be to run NEMO and XIOS on thousands of cores by limiting the I/O overhead as much as possible. Moreover, new approaches for online diagnostics will be investigated to speed up the diagnostics process by using emerging technologies, (e.g. GPUs, fat nodes to support data analytics approaches). Finally, some important work is planned to improve the load balance among the parallel processors when the AGRIF tool is used to perform high-resolution zooms in specified regions. The AGRIF library will be developed to allow the compute cores to be distributed across models at the same level of nesting. This will enable a much more efficient use of resources.

The objective is ambitious but it is based on the analysis carried out by the HPC WG, which has outlined the suggested development strategy in the medium term, also reported in a dedicated chapter of the NEMO Development Strategy document.

The analysis of the code behaviour, before and after the implementation of the proposed optimization strategies, will be carried out on a representative set of HPC systems. The access of the partners and their collaborators to a variety of machines will assure performance portability.

Improving the representation of key interaction processes at the ocean surface boundary layer for high resolution systems (WP5)

Our ambition with WP5 is to adapt the representation of the interactions between the ocean and the atmosphere to high resolution regimes in order to improve the realism of predicted ocean physical and biogeochemical properties in next generation CMEMS systems. Our target is to improve the physical consistency of the representation of processes from the atmospheric boundary layer, through to the ocean via waves, sea-ice and the biogeochemistry. This WP is divided in 4 tasks presented here from the lower atmosphere toward the ocean.

Recent studies have shown the strong impact of thermal and dynamical air-sea coupling, at the characteristic scales of the oceanic mesoscale, on the Eddy Kinetic Energy (Renault et al 2016, 2017). The quality of high-resolution simulations is therefore requiring to complete traditional bulk formulae with an innovative and more explicit coupling with the Atmospheric Boundary Layer (ABL). Our first task will be to incorporate the 1-dimension ABL model that has recently been developed in ALBATROS project (Lemarié et al, 2017) in the NEMO reference version, ensuring compatibility with AGRIF and multi-category sea-ice. The methodology of this unique approach in the ocean modelling community, is based on a dynamical downscaling of atmospheric data to the oceanic resolution via a simplified ABL model guided by operational weather forecasts or reanalysis. In order to fully benefit from this coupling with ABL, we next propose to add new physical processes in the bulk formulae used in NEMO with (1) a cool-skin/warm-layer parameterization and (2) specific closures and parameterizations for extremely stable atmosphere over sea-ice. The ABL model will then be further improved in order to account for 3D physics. This innovative and challenging task will start with a demonstrator based on a first version, which does not handle land points. Then we will evaluate which strategy is the most appropriate to deal with coastlines which act as open boundaries for the ABL model.

The second task of this WP5 is dedicated to improvement of the representation of the interactions between surface waves and atmospheric/oceanic layers. Our work on this topic will start with the integration of lower atmosphere-wave coupling through effects of waves on wind stress. We will, for instance, add this new coupling into the bulk formulae by using waves height and steepness in drag coefficient computation. We also plan to upgrade the ocean-wave coupling representation by including recent works on enhanced ocean mixing due to breaking waves (Janssen et al 2014, Alari et al. 2016, and outcomes from WAVE2NEMO and OWAIRS CMEMS service evolution projects). A new source term in the vertical mixing will be added as an energy flux explicitly evaluated by a wave model. Having improved waves-air-sea interactions and the surface energy input into the ocean, the next step, to fully benefit from this work, is to go further down into ocean boundary layer physics and ensure a full compliance with NEMO vertical mixing scheme. We propose to tackle this challenge through the development and the finalisation of the OSMOSIS parameterisation of oceanic boundary layer mixing that has been recently initiated within PRIMAVERA project. This work will first ensure the complete inclusion of all ocean-waves processes, and then deal with specific but critical issues such as mixing under sea-ice, in presence of the strong shear (e.g. equatorial undercurrent in the tropics) or in shallow shelf seas (interaction with bottom boundary layer). The physical robustness of these developments will be constrained through diagnostics on energetic consistency and validated in a Mediterranean Sea configuration at 1/24°.

The evolution of NEMO interface with biogeochemical models (TOP) must also follow the evolution of the code toward the high resolution. Our work will first cover the development of a general scheme for the vertical sinking of tracers in the pelagic environment. We will develop most up-to-date scheme to be included in TOP, coherent with new ocean vertical mixing schemes described in the preceding task, and ensuring an adequate balance between accuracy and computational efficiency. Specific care will be taken to manage the treatment of very thin layers occurring when the model is used in sigma levels on the continental shelf. We also propose to improve the vertical penetration of visible light and its dependence on the content in pigments, coloured dissolved substances and particles. A new stand-alone module will be developed including more elaborate optics (backscattering, ...) and a larger number of wavelengths chosen to be compliant with those used by satellite sensors. This will allow direct comparison between the reflectance simulated by the model and obtained from satellites. These new components will be integrated into the NEMO modelling framework to facilitate the transition into the Copernicus operational environment, thus contributing to the enhancement of analysis and forecast products.

The last task of the WP is dedicated to the sea ice in order to improve CMEMS products in the Arctic. Ice dynamics are of fundamental importance for high-resolution sea ice forecasting applications such as accurate prediction of the ice edge or lead formation. The internal ice stress, resolved by the sea ice rheology, is the dominant factor governing the ice dynamics. Recent development of the Elastic-Anisotropic-Plastic (EAP) rheology (Tsamados et al., 2013), and evaluation of the Viscous-Plastic (VP) rheology, suggest a more realistic representation of small-scale processes than is possible with the Elastic-Viscous-Plastic (EVP) rheology currently used by mainstream sea ice models. To aid decision making for forecast and climate model applications, the three different rheologies (VP, EVP & EAP) will be assessed in terms of: (1) drift and deformation statistics; and (2) impacts on sea ice state and ice-ocean heat exchanges. The VP and EAP rheologies will be implemented into the NEMO sea ice model, and simulations using VP, EVP and EAP will be compared across a broad range of horizontal resolutions (1/4°, 1/16° and 1/36°). The performance of the three rheologies will be evaluated against observations, allowing recommendations to be made for future rheology use within NEMO and for high-resolution CMEMS forecasting.

Demonstrating the impact of NEMO developments on CMEMS model based systems (WP6)

The overall ambition of this work package is to demonstrate the impact of the NEMO code developments undertaken in IMMERSE on prototype NEMO-based model configurations prefiguring future CMEMS systems. None of the prototype systems listed below will use a full data-assimilation component but close liaison with CMEMS MFCs teams will be established to anticipate this transition. This work-package will specifically focus on three challenges for the next generation of CMEMS system :

(i) Increasing effective resolution in CMEMS Regional MFC
In the framework of IBI-MFC component, a specific area covering the Atlantic European coast is routinely delivered at high temporal resolution (hourly) to end-users. This product aims to meet specific users demand.

IMMERSE will highlight the benefit of new physics and of increasing resolution in this particular region with a 1/36° IBI configuration including an AGRIF zoom reaching the kilometric resolution and covering most of the sub areas of interest for downstream users delivered by IBI-MFC (see figure A1.1 in appendix). The demonstrator will include physical and biogeochemical model component and also benefit from the results of WP4 and WP5 delivered at M24. The impact of improved physics and resolution, will be quantified based on three one-year-long simulations: standard IBI model, IBI model including IMMERSE developments and an "IBI IMMERSE" including the kilometric resolution area. A dedicated subtask will use high resolution observational products (in-situ, wide-swath altimeter data, HF Radar, gliders) for assessing how IMMERSE developments improved the representation of oceanic properties at fine scales (inc. sub-mesoscale activity, vertical velocities and frontogenesis).

(ii) Improving the representation of key processes for reanalyses with multiple high resolution nests
One of the major weakness of model used for reanalysis applications is their difficulty to represent dense waters overflow. The data assimilation methods have strong difficulties to correct this bias. The ambition of this task is to demonstrate how the representation of dense water overflows can be notably improved in NEMO global configurations with high resolution local nests. This demonstration will leverage IMMERSE AGRIF developments (efficiency of grid refinement, different types of vertical grids and a good load balancing between zooms). Two zooms will be implemented in the CMEMS global configuration at 1/12°, respectively in the Denmark and Gibraltar Straits. These will improve the representation of North Atlantic Deep Water, and Mediterranean Overflow Water in the model, two key water masses for climate. The work will be coordinated jointly by four institutions involved in the DRAKKAR coordination. The outcome of this task will benefit not only the systems used for CMEMS global reanalyses but also the systems used for Copernicus Climate Change Service (C3S) and in Earth System Models. .

(iii) Reducing the time to solution in next generation global configuration.
Currently, CMEMS global ocean forecast products are delivered at 1/12° resolution. Evolution of CMEMS global ocean forecast products toward finer grid resolution are sought to better address users needs. However, addressing this challenge in a cost-effective way requires improvements in NEMO code performance. IMMERSE WP4 will investigate systematically different approaches to improve further NEMO performance. In WP6, these approaches will be integrated into a prototype global model at 1/36° (3 km at the equator and 2 km along European coasts, see figure A1.2 in appendix). This new prototype model configuration will also use the new two-level time stepping scheme from WP3 and the developments at the air-sea interface from WP5. Short simulations showing the performances of the prototype global model at 1/36° will be performed and analyzed. The task will quantify how IMMERSE development will improve the ability of future CMEMS models to deliver cost-effective global ocean forecasts products at higher resolution with a higher level of process complexity.

The demonstrations (i) and (ii) listed above will be based on IMMERSE developments and will include extensive analysis. Relevant NEMO developments to NEMO will be collected in a NEMO beta-release at M30 (see section 3.1). Analysis of system performance in demonstrator (iii), will be based on NEMO beta-release.

Preparing the integration of model based products and high resolution EO datasets (WP7)

The overall ambition of this work package is to enhance the synergy between future high resolution CMEMS model based products and Earth Observing (EO) datasets for the benefit of downstream applications. This is achieved through three tasks aiming at (i) studying the dynamics of model uncertainty in high resolution ocean models; (ii) studying the resolution dependence of short-range forecast accuracy in data assimilation systems; (iii) designing tools that facilitate the uptake of CMEMS observation and model-based products. The specific ambition regarding those three aspects is detailed in what follows.

(i) Quantifying the short term predictability horizon in high resolution systems
Our ambition with this task is to better articulate high resolution EO datasets within model based products. CMEMS model based products indeed combine information from EO datasets and ocean models through Data Assimilation (DA). A fundamental question is whether the model component is able to retain and

propagate information derived from the observations. This question is particularly acute for ocean dynamics at scales of 1-10 km, where submesoscale dynamics generate a very fast evolution of ocean properties. Relatively little is known about the ability of high resolution ocean models to retain such information derived from EO sampling patterns. Several factors influence the rate at which model simulations diverge. The spread of simulations can however now be explicitly quantified through stochastic and ensemble techniques. The ambition is two-fold (i) to prototype a systematic procedure for quantifying the growth rate and propagation of model errors and (ii) to understand the predictability horizon of fine-scale (1-10 km) dynamics. The information provided by this activity will be important for designing future EO datasets (in particular its altimetry component) and for designing DA component of CMEMS forecasting system. This activity will in particular be key for the optimal use of Sentinel data in CMEMS systems, including biogeochemical information that its essential for downstream applications.

(ii) Quantifying how forecast accuracy depends on model resolution in Data Assimilation systems

Our ambition with this task is to improve the use of EO data in CMEMS systems and foster the use of CMEMS products in downstream systems. Indeed the forecast temperatures, salinities, surface heights and velocities produced by the CMEMS systems are not perfect. The differences between the model values and “true” values are known as the forecast errors. The size of these errors and the scales over which they are correlated are described by the forecast error covariances. Exploitation of satellite observations through data assimilation is crucially dependent on how well these forecast error covariances are specified. Better use of the forecasts could also be made by downstream users if a summary of the forecast covariances were made available with the CMEMS products. We will use short-range forecasts together with the historical record of satellite observations, including those from Sentinel-3, to estimate the forecast error covariances. These estimates are complementary to the ensemble-based estimates described above (the best assimilation schemes use both sorts of estimates). We will calculate the covariances of model minus observation values in geographical boxes as a function of depth. It will find a small number of horizontal scales that best describe the forecast error and determine the amplitude of the error in these scales. The techniques will be used with forecasts from a 1/12° global forecast system and a 1.5 km model of the north-east Atlantic that assimilate swathes of satellite SST data, along-track altimeter data and in situ data (including Argo data). A comparison of the forecast error covariances from the two resolution models in the common region will be made. Similar calculations have been performed for coarser resolution models, but have not been performed for forecast systems of these resolutions. Some adjustment of the techniques will be required to optimize the results. Less than a handful of groups in the world are able to do the calculations proposed. The python tools used and the results will be made available to the NEMO Assimilation community.

(iii) Facilitating the uptake of CMEMS observation and model-based products in downstream systems

Our ambition with this task is to better connect CMEMS to downstream systems in order to increase the impact of CMEMS products on society and business. Specifically we aim at reducing the time needed for prototyping a downstream application of CMEMS remote sensing and forecasts products products. Downstream systems are indeed key in the transformation of CMEMS information into bespoke information tailored to specific end-users applications. We will here develop a python coupling tool that translates CMEMS data to a generic data structure needed by the downstream systems, that is easy to configure for specific transformation options and data requirements. This toolbox will be highly flexible rather than model-specific because different downstream systems employ different numerical codes (e.g. finite difference, volume and element approaches in two and three dimensions). The novelty is in the ability of the toolbox to flexibly link to any coastal model and to support real time operational systems and unstructured meshes.

The outcome of this activity will substantially reduce the set-up time (from months to weeks) of the interface between CMEMS and downstream systems, improving robustness and traceability of the downstream system, and facilitating access to Earth Observation data. The new prototype service from CMEMS to users will enable them to extract initial conditions, boundary forcing, and observations for validation or assimilation from the CMEMS catalogue and to use them for developing new configurations of their systems, for long-term simulations, and for real-time forecast demonstrations.

Fostering intermediate-user driven assessment of the impact of NEMO evolution on downstream systems (WP8)

CMEMS by design focuses on activities that are best delivered at a global to regional scale by a pan-European effort. This naturally leads to generic products that are widely applicable across a diverse range of sectors. End users, however, generally require bespoke information tailored to the particular question at hand, often crossing disciplinary boundaries, at finer (national to local) scale, and/or requiring more in-depth analysis or processing. This gap is closed by Downstream Services, which take the form of either nested model systems or ancillary tools that take a different view of the system (e.g. Lagrangian models) or add different components (e.g. more detailed ecosystem representation). It is often through these services that the real societal benefit of CMEMS is realised. Hence, benefits arising from developments of CMEMS (e.g. of the NEMO model and its configurations) can best be assessed by their impact on potential downstream services. Here, this will be achieved through a set of case studies. These are selected to span a range of societal challenges and scientific approaches, to gauge the benefits of the system evolution in real world cases. Specifically we consider: **i. Coastal processes in the German Bight** (T8.2), comparing high resolution NEMO-WAM (Staneva et al 2017) and unstructured mesh (SCHISM; Zhang et al 2016) approaches. The focus here is on near-coastal circulation for sediment transport, search and rescue, and oil-spill response. **ii. Marine plastic litter transport from NW Europe to the Arctic** (T8.3), introducing wave physics to Lagrangian particle tracking approaches (Parcels; Lange and van Sebille; 2017). This investigates the transport and fate of plastic litter from NW Europe to the Barents Sea (Cózar et al 2017). **iii. Water quality modelling of the Tamar Estuary and adjacent coast** (T8.4), investigating sensitivity of near coastal ecosystem modelling (FVCOM-ERSEM; Cazenave et al 2016; Butenschon et al 2016) to the spatio-temporal resolution of larger scale driving information. This investigates the benefits of this information for local ecosystem services. **iv. Pollution transport by submesoscales in the open ocean** (T8.5)**,** exploring oil-spill dispersion with sub-km resolution NEMO applications (Trotta et al 2017). This investigates how modelling the sub-mesoscale can improve the accuracy of pollutant transport predictions in deep ocean regions using MEDSLIK-II (De Dominicis et al 2013).

The case studies each follow a common structure. A baseline simulation case is established, along with an observationally derived assessment approach. This draws specifically on the new generation of satellite based Earth Observations (e.g. Sentinel-3 and -6, from c2020), but also includes the full range of *in-situ* observations. The assessment process will use a combination of well-established and bespoke metrics of model skill, and where appropriate we will share approaches between case studies at an early stage. Next, a set of code and configuration developments are implemented and assessed for each case study. These are taken, in the first instance, from Tier 1 CMEMS developments, notably the planned refinement in resolution (e.g. NWS MFC moving from 7 km to 1.5km), introduction of features such as wetting/drying, and the inclusion of surface wave products. Case studies T8.2 and T8.5 directly use the NEMO code and so will test the beta release of NEMO from WP2, concentrating on improved advection, horizontal pressure terms, wave coupling, and HPC scalability. The developments for the case studies are systematically tested through incrementally modifying components (e.g. forcing resolution), individually and in combination to attribute the process response, in the context of the observational based assessment. Each case study will also evaluate the tool kit for improving access to CMEMS information for downstream systems (T7.3).

The outcomes of the development-assessment process will be collated to provide advice on the future evolution of the CMEMS service. The assessment approaches will be gathered into a set of harmonised downstream assessment tools (as scripts on an open-source server, e.g. gitlab) so that best practice in validating downstream services with CMEMS information can be shared with the wider community, as a legacy of this work.

Innovation potential of IMMERSE

The primary route to innovation for IMMERSE is through enhancements to the capability and quality of the CMEMS services. This innovation is an integral part of the IMMERSE programme, described in detail elsewhere in this document, so we do not discuss it further here. We have identified two other specific areas of innovation potential, which are described briefly below.

First, the experiments on model predictability and forecast errors in WP7 (Task 7.1 and Task 7.2) will help to define optimal configurations of future satellite instruments and constellations, and will show how to derive optimal value for ocean state estimates from high resolution satellite data. These outcomes therefore support the development of space-based environmental monitoring technology and the associated industries. The appropriate dissemination and interaction with mission planners and industry will be achieved through international fora such as the GODAE Ocean View Observing System Evaluation Task Team.

Secondly, innovation impact will be delivered by IMMERSE through the wealth of opportunities opened up to the downstream CMEMS user community through the improvements in the quality, resolution and capabilities of CMEMS products. These will allow downstream users such as marine consultancies, many in the SME sector, to propose new and cost-efficient approaches to environmental monitoring and prediction, in support of EU, government and industrial users. Interaction with these downstream users will be delivered in collaboration with the existing CMEMS User Engagement activities. See Section 2.2 for more detail.

2. IMPACT

2.1 Expected impacts

IMMERSE aims to provide the scientific and technical basis for CMEMS to address the ever-increasing and evolving demands for marine monitoring and prediction in the 2020s and beyond.The impact of IMMERSE will therefore primarily be measured to the extent that it would allow CMEMS model component to better meet users demand. As stated in *CMEMS requirements for the evolution of Copernicus satellite component*, "***major evolutions are required to monitor and forecast the ocean at fine scale and to improve the monitoring of the coastal zone"***[2]. The key driver for evolution of CMEMS model component relate to the evolving demands in key impact areas : marine safety, maritime transport, search and rescue, fish egg and larvae drift monitoring, pollution monitoring and offshore operations. All the above applications require CMEMS ocean models to better describe upper ocean dynamics at fine scale in order to improve ***"our capabilities to describe and forecast the ocean currents and provide better boundary conditions for very high resolution coastal models (a few hundred of meters)***". This is why it is sought that "***in the post 2025 time period, CMEMS model resolutions will be increased by a factor of at least 3 (e.g. global 1/36°, regional 1/108°)***". IMMERSE will provide the scientific and technical basis for this major evolution of global and regional CMEMS service towards higher resolution by 2025.

We summarise below how IMMERSE will address the expected impacts from the call LC-SPACE-03-EO-3018 topic description. In what follows, bold italicised quotes are from the call's topic description expected impacts.

"Provide a significant contribution from the Science community to address the precedent list of unsolved issues related to a higher resolution of the ocean description"
IMMERSE project team gathers a multidisciplinary group of researchers and engineers from the fields of open ocean modelling, coastal ocean modelling, applied mathematics, computer sciences and operational applications in order to address the unsolved issues related to a higher resolution of the ocean description. Building upon the NEMO Consortium institutions (described above in section 1.3a), IMMERSE project team also involves new partners that will allow IMMERSE to leverage innovative applied mathematics (eg. INRIA) for a more stable and efficient NEMO kernel (WP3), and expertise in computer science (eg. BSC) for a more efficient and scalable NEMO code (WP4). **IMMERSE therefore leverages innovative science**

[2] quotes in this paragraph are from "*CMEMS requirements for the evolution of Copernicus satellite component" (2017)*

in order to transition CMEMS models to higher resolution in a cost-effective way to the benefit of CMEMS users. IMMERSE will also engage key stakeholders in its activities : operating institutions of several CMEMS MFCs are involved in WP6; the coastal modelling community is closely involved in the design and evaluation of interface tools between CMEMS and CMEMS intermediate users in WP7 and WP8.

"Deliver developments based on the NEMO ocean model to easily transition to the Copernicus operational environment as this world-class ocean model already forms the basis of the majority of analysis and forecast products"
As described above in section 1.3a, NEMO in an open source software which is developed and maintained by a consortium comprising six European institutions, the most active ongoing members of which are partners of IMMERSE project (Partners 1-5). The partners from NEMO Consortium have more than 10 years of working experience in developing and delivering model code that is suitable for use in a range of operational configurations. IMMERSE project will build upon this experience in software engineering and leverage expertise from partners external to NEMO Consortium in order to deliver code suitable for CMEMS service evolutions. The coordination and dissemination activities proposed in WP2 will further guarantee that **IMMERSE developments are adequately articulated with NEMO System Team activity and will be smoothly integrated in NEMO reference code** (see for instance D2.5).

"Prepare the necessary steps for further validation and integration into Copernicus and transition to operations"
As described below in section 2.2, a primary pathway to impact of IMMERSE is through delivering improved modelling and monitoring tools to the CMEMS Monitoring and Forecasting Centres (MFCs). To this purpose IMMERSE will demonstrate the impact of the developments into NEMO code in a series of prototype configurations prefiguring future CMEMS systems (WP6). These model configurations will be documented in order to guarantee the reproducibility of model results, in particular through a specific software tool that will be developed in WP2 (D2.3). As stated above, several CMEMS MFCs are actual members of IMMERSE consortium, which provides a natural pathway from research to operation. In order to further guarantee a smooth transition of IMMERSE results to CMEMS systems, IMMERSE will also deliver a roadmap to implementation of IMMERSE development into CMEMS (D2.4). This roadmap will identify the necessary additional steps to the transition of IMMERSE results to operation (in particular in terms of data assimilation).

"Identify priorities for next developments both in EO processing, in-situ contribution (additional data sources), assimilation and modelling capacities"
IMMERSE WP7 will prepare the integration of CMEMS model based products and high resolution datasets to the benefit of downstream applications through the quantification of the predictability horizon of ocean dynamics at fine scales (T7.1) and the assessments of the impact of model resolution on short-term forecast errors in data assimilation systems (T7.2). IMMERSE WP8 will also gather recommendations for CMEMS service evolution and new observations from downstream users (D8.2). Relevant outcome from IMMERSE will be communicated to CMEMS through IMMERSE WP2. IMMERSE WP2 will ensure that the project outcome are adequately disseminated to CMEMS MFCs by presenting annually project results to Mercator Ocean (as the EU delegated entity in charge of the implementation of CMEMS) and CMEMS MFCs and by maintaining a roadmap for the integration of IMMERSE results into CMEMS operational modelling and data assimilation systems (D2.4). This roadmap will allow to **identify next development priorities** to be supported through Tier 1 and Tier 2 activities.

"Identify required coordination with other Copernicus services related to land, atmosphere or climate if so required"
Liaison with other Copernicus services will be the responsibility of the Scientific Coordinator through IMMERSE WP1. WP1 will in particular deliver a dissemination plan that will identify the main communication pathways to other Copernicus services (D1.3). A key priority will be to ensure that NEMO and its interface are in-line with the needs of other Copernicus services. Copernicus Climate Change Services (C3S) will naturally benefit from the development of the NEMO reference code as NEMO is already a

component of the C3S modelling systems (see below). Connection to Copernicus Land Monitoring Service will mostly focus on the exchange of information at the interface between riverine and marine environments, which is already covered by two service evolution R&D projects selected for the second call in February 2018. An other area of substantial impact concerns the Copernicus Atmosphere Monitoring Service as NEMO could be used for coupled weather prediction in future years (see Nils Wedi support letter).

Other substantial impact:
The developments in IMMERSE are targeted at the needs of CMEMS, but they will also deliver major advances to climate modelling and prediction, including the Copernicus Climate Change Service (C3S), as outlined below.

The NEMO ocean model is widely used as a component of global climate models. For example the EC-Earth, French, Italian and UK contributions to the next Coupled Model Intercomparison (CMIP6), feeding into the next IPCC Assessment report will be based on NEMO. A number of leading seasonal forecasting systems around the world are also based on NEMO. This includes contributions to the C3S from ECMWF, the Met Office and CMCC as well as systems based outside Europe such as the Canadian and Australian systems. It is also used for oceanographic research worldwide, with several hundred projects (including very large projects such as EC Earth), and 1600 registered users, all accessing NEMO.

Sustainable improvements to the NEMO model (WP3-5) will substantially benefit the above range of climate modelling activities, including the seasonal forecasting component of C3S and European contributions to the CMIP6 and IPCC processes. A particular advance will be provided by the reduction of spurious energy dissipation and mixing with improved vertical coordinate and time-stepping (WP3), which will enhance the representation of overflows and water masses. This will allow climate scientists to better assess the role of the deep and abyssal waters on carbon sequestration and earth climate.

End users with interests in marine planning frequently have a requirement for long term outlooks that take into account climate change (for example for planning of coastal defences or lifetime planning for offshore renewables and aquaculture infrastructure). The generic interfacing tools developed in WP7 will be equally applicable for downscaling of climate change scenarios and seasonal forecasts, allowing marine planning decisions to be informed by consistent information across timescales from days to decades.

A current focus of international ocean-climate research is how atmosphere-ocean interactions at small scales can impact on variability in large scale weather patterns. Current climate models are thought to underestimate the signal-to-noise ratio of predictable climate variability (e.g. Eade et al 2014). By enabling resolution (WP3-4) and better representation (WP5) of these interactions, IMMERSE is likely to facilitate the development of the next generation of more reliable probabilistic seasonal predictions (including for C3S). As mentioned above, the new ambitious 1/36° global configuration (ORCA36) is also in-line with the needs of a proposed Flagship European Programme on Extreme Computing and Climate.

Barriers to implementation
Because IMMERSE is explicitly designed with ease of implementation in CMEMS in mind, we do not anticipate major barriers. The IMMERSE science coordination team will work closely with the CMEMS MFC System Evolution leads over the course of the project to facilitate this transition and anticipate and mitigate any issues.
A generic barrier to quick uptake is the broad shortage of expertise around Europe (and globally) in quantitative modelling and high level IT skills. This generic shortage cannot be addressed at the level of IMMERSE, but by contributing to the CMEMS User Training Workshops, we will contribute to the development of understanding and skills in the specifics of marine modelling and services.

2.2 Measures to maximise impact

2.2a) Dissemination and exploitation of results

Draft plan for dissemination and exploitation of results

This draft plan will be used by WP1 as the basis on which to develop the Dissemination and Communication Plan (D1.3) and Roadmap for transfers to CMEMS (D2.4), which will be living documents in the project. The approach of this draft has been to identify the five areas which are expected to be key for dissemination and exploitation, in order for IMMERSE to achieve its stated impacts. Each of these is described in turn, with information on the results that will be relevant to them and how they will be made available for dissemination and exploitation by these varied areas. Some other areas/audiences are also identified in Section 2.2, which will also be considered for inclusion in D2.2 and D2.3. As the project progresses, dissemination and exploitation to these areas may become more and more relevant, and will therefore be reviewed and planned for accordingly.

IMMERSE plans to use existing methods of dissemination and channels for user engagement as effectively as possible, to avoid duplication and potential confusion, and to ensure that all the relevant existing audiences will be reached. Existing workshops that will be utilised are shown in table 2.2.1.

WORKSHOP TITLE	FREQUENCY	TARGET AUDIENCE
CMEMS User Uptake and Service Evolution workshop	Occasional	CMEMS STAC CMEMS MFCs Intermediate users
CMEMS Service Evolution meeting	Annual	CMEMS MFCs
CMEMS User Training Workshops	~6-monthly	Intermediate users
EGU NEMO Users Session	Annual	CMEMS MFCs Wider scientific community
NEMO Users Workshop	Every 2-years	CMEMS MFCs Wider scientific community
NEMO Developers' Committee	6 monthly	Nemo system team CMEMS (Mercator)
Extended Developers Committee	Next meeting 2019	Nemo System Team CMEMS (Mercator)
NEMO System Team meeting	3-weekly	Nemo System Team

Table 2.2.1: Workshops identified for IMMERSE dissemination, exploitation and engagement.

The key impact areas and audiences to be considered have been introduced in Section 1.3 (Figure 1.3.1). This figure helps to identify the key areas relevant to IMMERSE; we have identified five primary ***impact areas*** from the research performed in IMMERSE:

a. CMEMS (in particular Monitoring and Forecasting Centres (MFCs)). These are the primary direct recipient of IMMERSE developments, and end user value will often be delivered indirectly via improvements to the CMEMS services produced by the MFCs
b. Intermediate users of CMEMS services, who add value to the CMEMS products to deliver information and advice relevant to end-user decision-making
c. End-users, using CMEMS data to inform decisions that are sensitive to or impact on the marine environment
d. Earth Observation mission planners, who need information on the best configurations of instruments and satellite constellations to deliver value to ocean state estimates
e. The wider Scientific and Technical Community, who will benefit from the developments in IMMERSE – particularly climate change and oceanographic researchers, as well as a number of providers of the Copernicus Climate Change Service.

The plans for each of these impact areas are treated separately in more detail below. Most dissemination, exploitation and communication activities cross several IMMERSE WPs, and these activities are therefore managed by WP2. WP 7, 8 produce a set of software tools targeted at the Coastal Modelling User Community (a specific case of intermediate users), and so dissemination and exploitation activities for these are included these WPs. IMMERSE will also develop links with any relevant areas that are not already adequately provided for.

An IMMERSE project website will be set up. Aims of the website will be to:

- Provide visibility of the project for specialists such as CMEMS MFC staff and all intermediate users, through project overview, technical overviews and science contacts for each WP, and periodic research highlights;
- Provide visibility of the project for end users, and the wider scientific and technical community, as well as other audiences through descriptions of the IMMERSE objectives, contacts to the IMMERSE Science Leadership team, project highlights, and links to the detailed technical WP pages which will include detailed technical highlights. Links will also be included to CMEMS web pages.
- Enable internal communication within the project, including meeting planning and minutes, technical details of code configurations, model runs and shared datasets, and project documents.

a. CMEMS

The Specific Challenge of this call is to perform long term R&D that will inform the future development of the Copernicus services. Therefore ensuring that IMMERSE R&D can feed through effectively to CMEMS service evolution is a key task. *The **specific recipients** here are system developers at the CMEMS MFCs, who will evaluate and implement system evolutions through Tier 1 R&D activities.*

Many of the deliverables of IMMERSE will be in the form of proven, quality assured, NEMO code, accompanied by a scientific assessment of their impact in realistic model configurations (often based on current operational CMEMS configurations). Because the NEMO model is already widely used in the CMEMS MFCs, the deliverables will therefore be in the ideal form to be assessed and incorporated quickly into the MFC modelling products. Code developed will be incorporated into the NEMO code repository through a robust and well-established software engineering process that has been operated successfully by the NEMO Systems Team for a number of years[3]. Key members of the NEMO System Team are named experts (research and IT) in the IMMERSE consortium. Hence the code delivered can be guaranteed to be of high quality, suitable for rapid implementation in the operational systems of CMEMS.

Results of the development and evaluation activities of IMMERSE will be published in the open-access peer-reviewed literature (e.g. in a special issue of Geoscientific Model Development) and presented at international conferences, providing quality assurance to the CMEMS developers that our developments and assessments are scientifically robust.

A particular attention will be paid to providing a reproducible framework for facilitating the uptake of NEMO developments by NEMO users and CMEMS MFCs in particular. This will be achieved through the definition and implementation of the protocol for reproducible exchange of NEMO configurations (D2.3) that will extend further the range of information that is currently shared distributed by NEMO to its users by providing a reproducible framework for users to exchange information as to which particular configuration of NEMO is used in a specific system.

Close communication will be maintained with system developers at the CMEMS MFCs throughout IMMERSE by building on working relationships that have been well established over many years through the MyOcean and Mersea projects, which were the forerunners of CMEMS. This will give the MFC developers early sight of the results, allowing them to work with IMMERSE to identify and address potential issues with operational implementation, so that the IMMERSE deliverables are as close as possible to 'operations-ready'. This two-way communication will be achieved through:

[3] The NEMO software development method is described in Section 1.3b

- Participation in the NEMO Users' Workshop and NEMO Developers Committee meetings; established fora for exchange of information between developers and users of NEMO;
- IMMERSE Scientific Coordination team (WP1) establishing direct links with the Service Evolution lead for each of the MFCs, ensuring that MFC Service Evolution plans are fully informed of upcoming IMMERSE developments. This will be through individual contact ahead of the annual CMEMS Service Evolution Meeting, followed by possible attendance at the meeting;
- Close institutional links which will allow day-to-day contact with several of the MFCs (the IMMERSE consortium includes institutions that are contributing to five of the seven MFCs, and IMMERSE partner Mercator-Ocean is the Trusted Entity for overall CMEMS delivery);
- The IMMERSE website which will include overview technical descriptions of the individual work packages, science contacts for each work package, and periodic research highlights.

b. Intermediate users of CMEMS services

These users are a key bridge between the generic Copernicus services and end users. They perform their role, for example, by interpretation of the CMEMS data to produce value-added products, by downscaling the CMEMS products using high resolution coastal models, or by feeding CMEMS data into broader, application-specific models (e.g. socio-economics, energy production-supply-demand). ***Specific recipients*** *here could include downstream modellers and decision analysts in private consultancies, research institutions/universities, and public sector marine policy and management organisations.* As well as targeted information on the IMMERSE website, the following will be undertaken.

For the output of IMMERSE, which deliver value through improvements to the CMEMS services (WP 2-6), the role of IMMERSE will be to enhance and complement the existing user engagement activities of CMEMS in this area, rather than setting up a separate process. IMMERSE will work with the CMEMS User Engagement team[4] to provide intermediate users with a forward look at the capabilities they can expect when IMMERSE developments have reached operational implementation, seeking early user feedback to help refine development plans. IMMERSE partner institutions are active contributors to the GODAE Ocean View Coastal Ocean and Shelf Seas Task Team (GOV COSSTT) and this forum will be used to disseminate IMMERSE research on a wider international stage and to ensure that we are remaining at the forefront of international ocean prediction. Some intermediate users also attend the NEMO Users' Workshop, and IMMERSE intends to present results at these, providing further opportunities for interaction.

IMMERSE WP7,8 are special cases, as their output are software tools (i) to facilitate the interfacing of CMEMS products with the downstream models (WP7) and to facilitate the evaluation of downstream modelling systems with high resolution EO datasets (WP8). Intermediate users are thus a key target user group for WP7,8. This is why our consortium includes institutions involved in downstream activities in addition to institutions involved in developing NEMO. The engagement of CMEMS intermediate users with the development of the interface will be assured by a dedicated user workshop/webinar early in the project (MS7.1), engagement of users in the expert review of the interface tool design, and open dissemination of the prototype interface code towards the end of the project. The interface tool is of particular relevance to GOV-COSS-TT and the help of non-European experts will be sought in the reviewing of its design.

The WP7 interface code and the WP8 assessment toolboxes will be stand-alone software libraries that is not part of the main NEMO code, but will also be available under open licence. It is envisaged that the interface tool would eventually be made accessible as a CMEMS user utility downloaded from the CMEMS website or possibly deployed through the Copernicus Data and Information access service. IMMERSE will liaise with the CMEMS User Engagement team regarding this. WP7, 8 will also provide documentation for tools,

[4] The CMEMS User Engagement team, based at Mercator-Océan, coordinates dissemination, exploitation and training for downstream users of CMEMS services. It builds on long-standing experience through the MyOcean projects which were the fore-runners to CMEMS. Their activities include organising CMEMS User Uptake workshops and regional User Training workshops, providing use cases via the CMEMS website, and promotion of CMEMS products at conferences and industry events.

worked examples and training sessions to enhance the dissemination and exploitation to the Coastal Modelling Community in particular.

c. End users of CMEMS services

In addition to those in Figure 1.3.1, ***specific recipients*** *here could be decision makers in marine management and operations, regulatory compliance and infrastructure planning, in private and public sector organisations.*

Most of the value of IMMERSE for end users will be delivered through improvements to the CMEMS services, in many cases via intermediate users. In this way they will benefit from IMMERSE's model and data assimilation improvements.

The needs of end users who are direct users of CMEMS products are similar to those of Intermediate Users, and for these we will adopt the same approach as in (b) above, in particular the provision of a forward look on possible future CMEMS capabilities through the CMEMS User Engagement and Training Workshops. IMMERSE partner institutions are active contributors to GOV COSSTT and this forum will be used to disseminate IMMERSE research on a wider international stage. Interfacing tools and assessments of the developments published in the peer-reviewed literature as described in (a) and (b) above, and will be accessible to end users.

The IMMERSE website is envisaged to be an important source of dissemination to end users. It will include descriptions of the IMMERSE objectives, targeted at these users, with links to detailed technical WP pages which will include progress highlights and information on results. Links will also be included to CMEMS web pages. Newsletters and other communication material produced by the project will also be used to disseminate information to this audience.

d. Earth Observation mission planners

Specific recipients *are EO mission planners and industrial partners who wish to deliver optimal cost-effective remote sensing systems for marine monitoring.*

Insights into the potential impact of different satellite constellation design, as well as constraints on how observational data can be assimilated into ocean models, will be delivered by WP7 and are essential information for EO mission planners. The appropriate lines of communication exist through the GODAE Ocean View Observing System Evaluation Task Team. The team members are well-known in the ocean data assimilation community and will exploit a number of other formal and informal channels, including with the CMEMS Thematic Assembly Centres, to ensure a wide dissemination of IMMERSE results to this audience.

e. Wider scientific community

In addition to those in Figure 1.3.1, ***specific recipients*** *here are ocean modelling scientists beyond the community of CMEMS providers and users, including climate modellers and specifically providers of the modelling elements of the Copernicus Climate Change Service.*

While the developments in IMMERSE WPs 2-6 are primarily motivated by the future requirements of the CMEMS services, many of them will benefit a wider scientific community.

Developments to enable higher resolution modelling (WPs 2-6) will also contribute to the requirement of the Copernicus Climate Change Service (C3S), since many of the C3S services are based on the NEMO ocean model. The generic model interface developed in IMMERSE WP7 will facilitate downscaling of climate model outputs by C3S Intermediate Users.

There is already strong engagement from the climate modelling community (including C3S partners) with the NEMO consortium, through attendance at the NEMO Users' Workshops and membership of the NEMO Extended Developers' Committee. IMMERSE partners are also prominent members of these fora. IMMERSE will exploit these well-established channels to inform users in this category of upcoming developments, and obtain feedback. IMMERSE will in particular communicate results to CLIVAR Ocean Model Development Panel on a regular basis as the Scientific Coordinator is a member of this group.

Further communication with the climate modelling community will be through presentations at scientific conferences and publications in peer reviewed journals and newsletters. The IMMERSE website will include overview technical descriptions of the individual work packages, science contacts for each work package, and periodic research highlights. Newsletters and other communication material produced by the project will also be used to disseminate information to this audience.

The IMMERSE Scientific Coordination team will establish direct links with the Service Evolution lead for C3S, ensuring that C3S Service Evolution plans are fully informed of upcoming IMMERSE developments. Initial contact between IMMERSE and the C3S Management team has been established.

Actual delivery will be largely via the provision of robust model improvements, and interfacing tools, to the CMEMS services, as described in (a) and (b) above. Thus the wider scientific community will benefit from the same quality assurance standards for IMMERSE outputs as are applied for CMEMS developers.

Follow-up of IMMERSE advances beyond the end of the project
The long term legacy of IMMERSE will be realised through implementation of NEMO developments from IMMERSE into CMEMS products. This is likely to require an element of Tier 1 R&D work, to apply the developments both to individual MFC model configurations, and to the associated data assimilation systems. Implementation work will be informed by the IMMERSE Implementation Roadmap (D2.4). The adoption by IMMERSE of the rigorous NEMO software engineering process is designed to ensure that costs of the Tier 1 implementation work are kept to a minimum.

IMMERSE developments to the NEMO code will be consolidated into the NEMO code shared reference in collaboration with the NEMO System Team, which is well represented in the IMMERSE consortium. Maintenance and further developments after this point will be the responsibility of the NEMO System Team rather than CMEMS. The NEMO System Team has a long-established track record in this work.

Project web pages will be hosted after the end of the project by CNRS, and will include links to project reports and published papers, all of which will have been deposited in long term archives.

<u>Outline strategy for knowledge management and protection</u>

IMMERSE partners agree to participate in the Open Research Data pilot. A Data Management Plan (DMP, D1.4) will be setup, using the online data management tool developed by the CNRS, DMP OPIDoR, and will specify what data will be open, and which efforts will be made to make the data FAIR: detailing what data the project will generate, whether and how it will be exploited or made accessible for verification and re-use, and how it will be curated and preserved. A first version of the DMP will be provided as an early deliverable within six months of the project and will be updated during the project as appropriate.

Background management and protection
In preparation for an effective knowledge management and protection strategy, at the proposal phase the consortium have identified the background that they will each bring to the project. This is particularly relevant for data sources that will be used. Data from sources other than partners in the consortium have also been considered.

Background of the partners will be protected as per the DESCA Consortium Agreement. As well as the background register in the CA, an internal catalogue of all data sources will be created following the project start date. Details will include what access rights apply to each of these data sources, and a statement as to any restrictions of its use and subsequent dissemination or incorporation within any knowledge generated by IMMERSE. This will ensure that any restrictions are accounted for and are correctly adhered to.

The consortium have already started to gather a list of the datasets that are external inputs to the project, typically to be used for model evaluation. Data sets owned by Oil and Gas producers will not be used within the project, because they are not freely available.

Results management and protection
The most valuable outcomes are embodied in the NEMO code, in order to improve its functionality. The NEMO code is open source and freely downloadable from the NEMO website www.nemo-ocean.eu under a

CeCILL Free Software Licence. The software and the source code are therefore freely and openly available to any interested party who wishes to use it.

Code developments will be incorporated into the NEMO reference code, where they will be maintained by the NEMO System Team, which is resourced by NEMO consortium partners. The NEMO consortium has operated under a formal consortium agreement since 2008 and provides a stable and proven mechanism to support this open access modelling capability.

WP7,8 will produce separate codes and capabilities for a flexible downstream interface. As above, this will be made available under an open access licence and will be freely available for all who wish to use it.

Other outputs of IMMERSE will be in the form of scientific assessments and reports. These will be published in the peer-reviewed scientific literature, ideally under the 'gold' open access model, but always under the 'green' model. In parallel we will make use of the IMMERSE website, and institutional and subject based repositories available through the partners, to provide further access to publications. Authors will avoid entering into any copyright agreements with publishers that will not allow them to fulfil the EC Open Access requirement. These publications will be advertised and logged through the project website. All published material will contain an acknowledgement to the research funding from the European Union and Horizon 2020 which has led to the results and outcomes.

2.2b) Communication activities

In order to successfully promote IMMERSE, its progress, results and achievements, key messages will be communicated at suitable times, to the appropriate target audiences. There will be agreement on who will carry out the communicating, and on how the successful communication will be measured, monitored and evaluated. All of these elements will be included in the communications plan (D1.3) The impact areas identified in Section 2.1 and shown in Figure 1.3.1 are included in the communication plan. Additional audiences have also been identified as those who will benefit from communication by IMMERSE.

The communication matrix below (Table 2.2.2) details some of the already identified measures for communication by the project.

Target audience	**Objective**	**Material/content (and responsibility)**	**Method/communication measures**	**Frequency**
IMMERSE partners	Ensure an effective and integrated project	Progress and results (WP1) Risks/benefits/issues (WP1) Queries/questions (WP1)	Internal project website General Assemblies Email, Web and teleconferencing	Regular updates Four General Assemblies Frequent
EC Project Officer	Ensure EC is fully informed of project progress	Overall project progress (WP1) Issues (WP1) Deliverable progress (WP1)	One page progress reports Deliverable and periodic reports IMMERSE website	Quarterly As per deliverable dates As per reporting periods
NEMO System Team	Effective development and validation of new code	Code design & reviews (WP2, WPLs) Code documentation (WP2, WPLs) Demonstration cases results (WP2, WPLs)	On NEMO internal website In GMD NEMO special issue	As per deliverable dates

CMEMS MFC Leads	Exploitation of developments	Roadmap, concept documentation, summaries of results, presentations, reports & papers (WP1, WP2, WPLs)	Teleconferencing CMEMS STAC	As required Annual
C3S management team	Exploitation of developments	Roadmap, concept documentation, summaries of results, presentations, reports & papers (WP1)	Teleconferencing workshops	As required Annual
Intermediate users (and end users)	Awareness of capabilities and discussion of needs	Presentations (WP1) Workshop discussions (WP7)	CMEMS user workshops GOV COSS-TT meetings	as they occur As required
Observation providers	clarify needs for and impacts of observations	Presentations and reports (WP7)	GOV OSEval workshops	as they occur
Wider scientific and technical community	Advertise progress and obtain expert advice	Deliverables and other reports (WPLs) Presentations at conferences (WPLs) Papers (WPLs)	Project web-site Project & task team meetings Conferences & discussions Publication in open literature	As per timetable As they occur As opportunities arise When ready
Other EU bodies	Mutual awareness	Discussion of needs (WP1) Plans and results (WP1)	Project website EC or project meetings	Regular updates As required
Policy and decision makers	Exploitation of new capabilities	Presentations (WP1) Summary information (WP1)	Meetings organised by EC IMMERSE website	As they occur Updated annually
Wider public	Project visibility and raise public awareness	Relevant results and their implications (WP1)	IMMERSE website	As opportunity arises

Table 2.2.2: IMMERSE communication measures

3. IMPLEMENTATION

3.1 Work plan — Work packages, deliverables

IMMERSE has a relatively simple project work package structure, summarised in Figure 3.1.1 below. There are six science WPs, supported by WPs on Management and coordination (WP1) and Software quality control and dissemination (WP2). The WP structure has been chosen to minimise inter-dependencies between WPs. The Gantt chart (Figure 3.1.2) and detailed WP tables below show that tasks within WPs have strong inter-dependencies that will be managed by the WP leaders. The tasks within WPs have been designed to provide clear critical paths within the WPs.

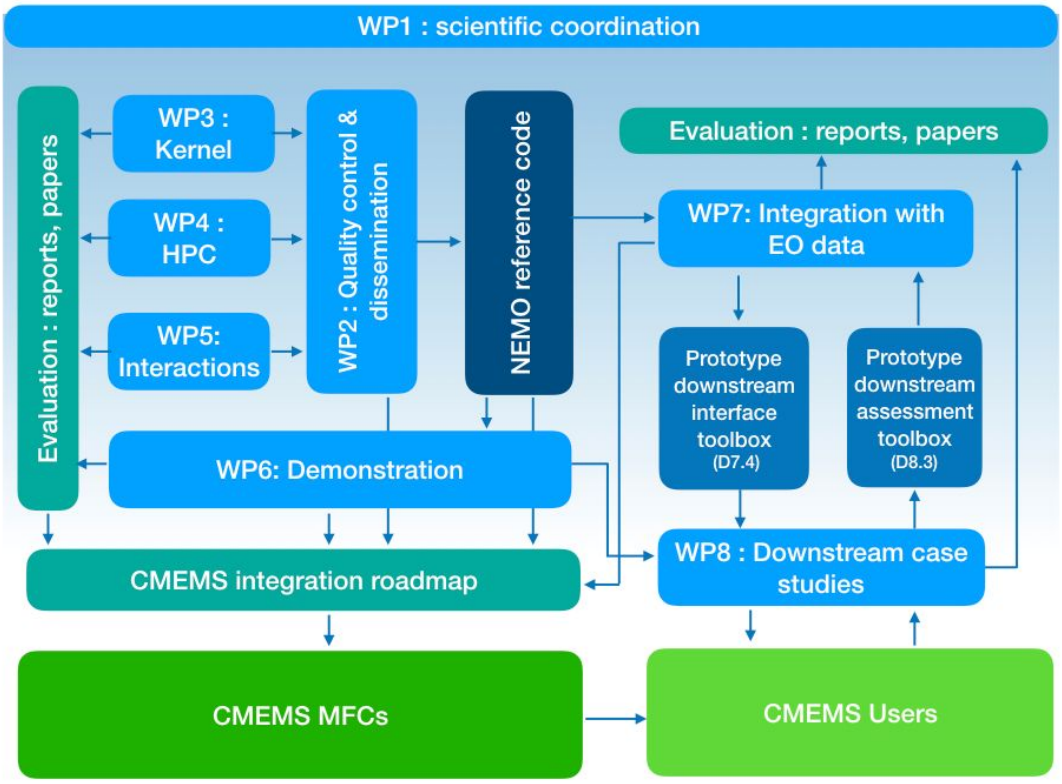

Figure 3.1.1: IMMERSE Structure and flow of output

WPs 3, 4, 5 will develop NEMO ocean model code. The developments will proceed in parallel using code branches from the main NEMO reference code, and will be integrated into the reference code through the regular NEMO software merge/test/release cycle (described in Section 1.3b). IMMERSE will deliver a specific code release NEMO v4.2 (D2.5). Key developments for NEMO v4.2 beta-release from WP3-5 and listed in the work-package descriptions below. There will be inter-dependencies between tasks aiming to submit code to the NEMO trunk, and these will be managed through the standard NEMO merging process (Section 1.3b). Close liaison will be maintained with the NEMO System Team (through Task 2.1), to ensure that IMMERSE developments are delivered on time for specific reference code releases during the course of the project (including NEMO v4.2 beta-release, D2.5). Additionally the Coordinator will facilitate and ensure regular communication between the IMMERSE WPs, for example through the code design review process, to ensure early identification of possible points of code interaction. The NEMO Systems Team and the IMMERSE partners have a long track record of successfully integrating parallel code developments in this way. **WP6** will demonstrate the impact of NEMO ocean model code development undertaken in WPs 3, 4, 5. Demonstration will be based on a NEMO v4.2 beta release (D2.5) and on NEMO code branches internally distributed to IMMERSE project team. WP6 delivers its output to CMEMS through reports and papers which will serve as a basis for updating CMEMS integration roadmap (D2.4) . **WPs 7, 8** which focus on better connecting CMEMS intermediate users to CMEMS, are largely independent from NEMO development WPs. WPs 7 and 8 deliver their output through software, reports and papers. The *downstream interface toolbox* (WP7, D7.4) and the *downstream assessment toolbox* (WP8, D8.3) will be delivered as separate code library through an open code repository.

A detailed list of the work packages and their tasks follows:

WP1 ***Management and coordination***

Task 1.1 Strategic and technical coordination
Task 1.2 Day-to-day management and internal communication
Task 1.3 Communication with the European Commission
Task 1.4 Scientific quality control and risk management

Task 1.5 External Experts Advisory Board (EEAB) management

WP2 ***Software quality control and dissemination***

Task 2.1 Coordination of NEMO developments

Task 2.2 Software verification and distribution

Task 2.3 Outreach and reproducible dissemination to NEMO users

Task 2.4 Coordination of project transfers to CMEMS

WP3 ***Building the next generation numerical kernel for NEMO ocean model***

Task 3.1 Implement two-level time-step (2LTS) scheme in NEMO

Task 3.2 Developments to nesting

Task 3.3 Develop improved algorithms for vertical coordinates

Task 3.4 Assess adequacy of z-tilde vertical coordinates

WP4 ***Preparing CMEMS to future HPC infrastructures***

Task 4.1 Efficient exploitation of memory hierarchies and hardware peak performance

Task 4.2 Increase modularity of NEMO components - macro-task parallelism

Task 4.3 Efficient IOs and diagnostics for operational systems

Task 4.4 Load balancing for AGRIF massive multigrid capability

WP5 ***Modelling key interaction processes at the interfaces at kilometric resolution***

Task 5.1 Integration of an Atmospheric Boundary Layer model in NEMO

Task 5.2 Interactions between waves and O/A boundary layers processes

Task 5.3 Efficient and flexible interface with biogeochemical models

Task 5.4 Sea-Ice Rheology for high-resolution

WP6 ***Demonstrating impact of NEMO developments on CMEMS model based systems***

Task 6.1 Impact of NEMO developments on a regional forecasts framework

Task 6.2 Impact of NEMO developments for reanalyses and climate modelling

Task 6.3 Impact of NEMO developments on the global forecasts framework

WP7 ***Integrating model based products and high resolution EO datasets***

Task 7.1 Ensemble quantification of short term predictability of ocean fine scale dynamics

Task 7.2 Statistical description of forecast accuracy in DA systems for downstream applications

Task 7.3 Toolbox for seamless uptake of CMEMS products in downstream monitoring systems

WP8 ***Assessing impact of NEMO and CMEMS evolutions on downstream systems***

Task 8.1 Case study coordination

Task 8.2 Coastal processes in the German Bight

Task 8.3 Marine plastic litter transport from NW Europe to the Arctic

Task 8.4 Water quality modelling of the Tamar Estuary and adjacent coast

Task 8.5 Pollution transport by submesoscales in the open ocean

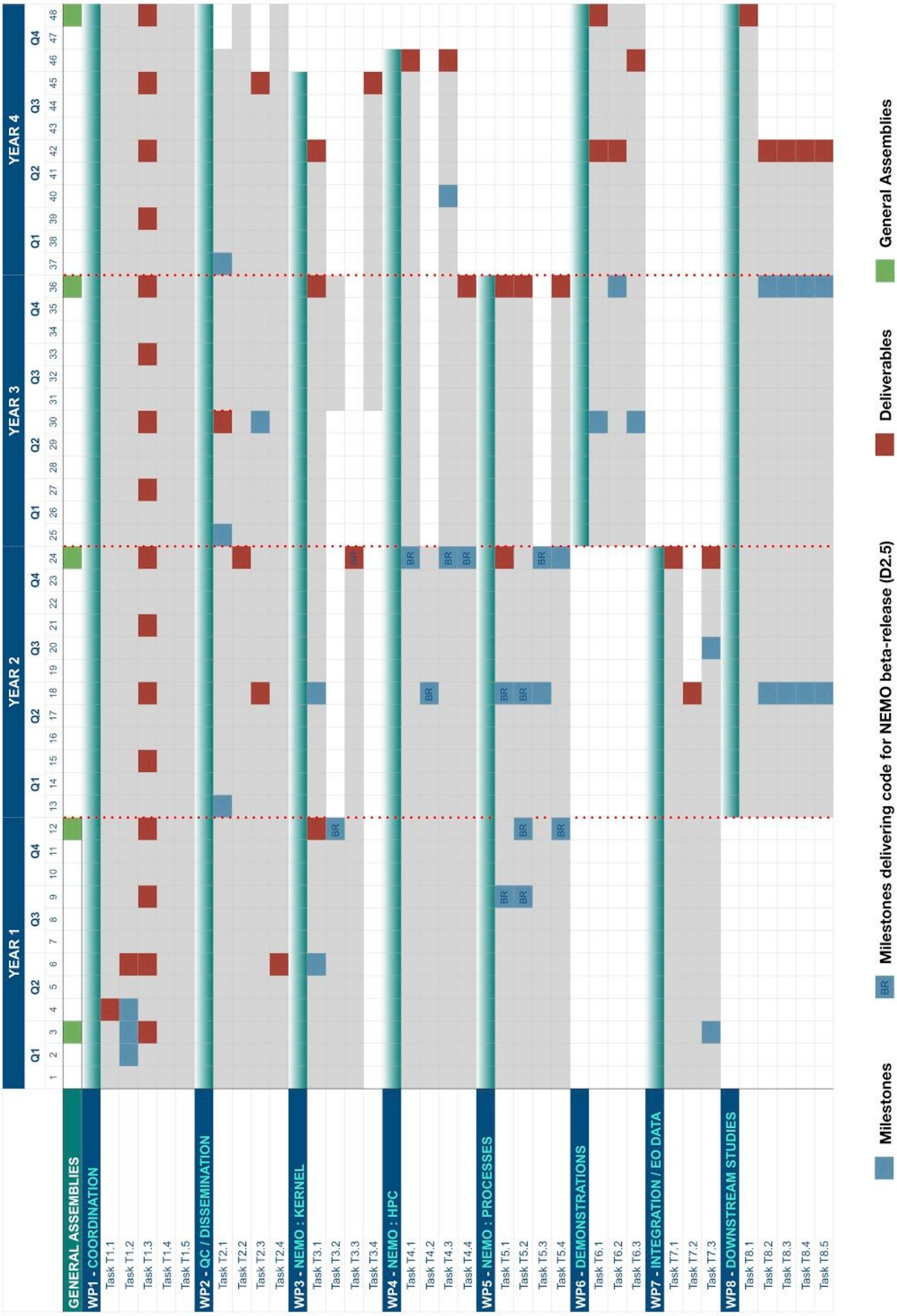

Figure 3.1.2: Timings of the work packages and their components.

IMMERSE Work Package descriptions

Work package number	1		**Lead beneficiary**			CNRS		
Work package title	Management and coordination							
Participant number	1							
Short name of participant	CNRS							
Person/months per participant:	36							
Start month	M1			**End month**	M48			

Objectives

- Establish and maintain top-level project management and scientific coordination of IMMERSE to ensure that the objectives and impacts are efficiently and effectively achieved, on time and within the resources budgeted.
- Establish and maintain an effective working relationship between IMMERSE and the European Commission (EC), which includes regular reporting on project progress.
- Coordinate and facilitate effective relationships, collaboration and coordination between partners within IMMERSE, including sharing of information associated with all project management aspects.
- Effectively manage the Intellectual Property (IP) and innovation within IMMERSE to ensure maximum exploitation potential and continuing impact.
- Ensure that the advice of the External Expert Advisory Board (EEAB) is integrated into the project.
- Formulate high-level synthesis of progress and results, using this and other information to represent IMMERSE at relevant external events and meetings.

This work package is led by: Julien Le Sommer, CNRS

Description of work

There are 5 tasks within this work package. These will primarily be the responsibility of the IMMERSE Scientific Coordinator who provides the scientific leadership for the project.

Tasks

T1.1 [M1-M48] Strategic and technical coordination (Lead: CNRS)

Maintain a holistic view of ongoing work, and provide direction. Carry out the scientific coordination and monitoring of work packages, work package leaders and project milestones.

The Science Coordinator will also provide overall coordination (including information exchange) and linkages with the associated projects and programmes which IMMERSE will need to work in close conjunction with in order to ensure success (e.g. EC, CMEMS, NEMO Consortium Science Committee [NCSC] and some of the activities listed in Section 1.3). The project partners will use their knowledge and connections with other projects to assist with this task. The Scientific Coordination board described in section 3.2.1 will assist the Science Coordinator in this task.

T1.2 [M1-M48] Day-to-day management and internal communication (Lead: CNRS)

Manage the project using effective management procedures based on PRINCE2 (Projects IN Controlled Environments) formal methodology. These will primarily be the responsibility of CNRS.

Managing the project includes the following, non-exhaustive activities:
(i) Implementation and maintenance of the Grant Agreement and the preceding Consortium Agreement;
(ii) Overall legal, financial, administrative management and reporting, including:

- Designing and maintaining partner specific templates for collecting inputs to the required EC documents;
- Implementing and maintaining a project-specific process for reporting;
- Preparing for periodic reviews by the EC and supporting the implementation of recommendations;
- Handling of project correspondence and day-to-day requests from partners and external bodies;
- Adaptation of project and management structure after changes in the work plan and the consortium;
- Organisation of meetings relating to the management of the project; then executing, and post-processing, of major project meetings (i.e., agendas, invitations, locations, preparation, distribution and archiving of material, minutes and action lists);
- Financial management – including transfer of project funds to partners (in compliance with directives from EC), providing clarification on any budget/financial issues, monitoring and controlling the budget.

(iii) Appropriate management of ethics issues (MS1.1); gender aspects and equality (MS1.2); and risks/benefits on behalf of the General Assembly (including the production and monitoring of the Gender Strategy and Action Plan (MS1.2));
(iv) Handling of/facilitating the resolution of any ethics issues, and any disputes/complaints in accordance with the Consortium Agreement;
(v) Implementation of competitive calls by the consortium for the participation of new beneficiaries.

Internal communication will be key to IMMERSE project implementation. The Project Office will ensure optimal internal information exchange through regular and routine communications. For example, an information sharing platform in the form of a dedicated internal password-protected application, will be provided and managed (MS1.3). This will also host links to milestones and deliverables, as well as templates, documents and tools that the project office will develop to aid the management and reporting of the project. There will be space for each partner and work package in order to encourage continual conversations, dialogue and knowledge exchange amongst the partners. This task will also ensure the implementing and maintenance of mailing lists for scientific contacts and administrative contacts.

T1.3 [M1-M48] Communication with the European Commission (Lead: CNRS)

Provide regular and comprehensive communication with the European Commission in Brussels. The conduit for this will be the IMMERSE Coordinator and the Project Manager. This will be partly fulfilled through the provision of regular summary reports outlining the project's progress and developments (D1.1).

This task will ensure the appropriate follow-up of project obligations from the Grant Agreement (formal reporting – of science results and finances, project reviews, communication, and management). The IMMERSE Coordinator will ensure that the appropriate EC representative is invited to the General Assembly meetings.
If there are any major problems within the project that cannot be resolved through the appropriate management structure, the Coordinator will liaise with the EC in order to seek advice and a solution.

T1.4 [M1-M48] Scientific quality control and risk management (Lead: CNRS)

This task includes verifying the quality, consistency and timeliness of the work and deliverables, and synthesising the results of the project. It includes reviewing the scientific element of the reports and deliverables to be submitted to the European Commission (EC).

This will also include resolving any conflict relating to technical issues. It will mean acting on unforeseen events and adapting work packages as required. It will also mean monitoring foreseen risks (see risk register in Section 3.2), and highlighting any unforeseen risks as early as possible, then considering the necessary mitigation.

T1.5 [M1-M48] External Experts Advisory Board (EEAB) management (Lead: CNRS)

Ensure the appropriate level of consultation with the scientific EEAB. It is essential that the project receives independent advice and feedback from the EEAB, especially in relation to the direction of the scientific research and application. This task will be led by the IMMERSE Science Coordinator to ensure that the consultations with the EEAB are organised and co-ordinated in an efficient and effective manner, that the appropriate level of information is provided to the EEAB, and that advice given is reviewed and acted on appropriately.

Deliverables (Summary)

D1.1: Summary reports on project progress: Short summary reports to be provided to the EC every quarter, starting from M3 **(M 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, resp. CNRS**)

D1.2: Public website **(M4, resp. CNRS)**

D1.3 : Updated dissemination and communication plan (with annual updates) **(M6, resp. CNRS)**

D1.4 : Data Management Plan **(M6, resp. CNRS)**

Work package number	2		**Lead beneficiary**		CNRS	
Work package title	Software quality control and dissemination					
Participant number	1	10	4			
Short name of participant	CNRS	GEOMAR	Mercator Ocean			
Person/months per participant:	24	12	2			
Start month	M1		**End month**	M48		

Objectives

- Establish and maintain an effective working relationship between IMMERSE project team and NEMO System Team in order to guarantee the robustness and the quality of NEMO development process in IMMERSE project
- Ensure that relevant software developments from IMMERSE, including NEMO developments, are integrated, tested and distributed according to the state-of-the-art software development practice
- Raise awareness of NEMO users regarding NEMO development process and help disseminate most recent developments of NEMO reference code to NEMO users
- Establish and coordinate the communication and dissemination processes for IMMERSE, in particular toward CMEMS and CMEMS MFCs

This work package is led by: Julien Le Sommer, CNRS

Description of work

There are 4 tasks within this work package. These activities will be primarily the responsibility of the CNRS partner but will also engage key stakeholders (CMEMS and the broader community of NEMO users) .

Tasks

T2.1 [M1-M48] Coordination of NEMO developments (Lead: CNRS)

This tasks aims at guaranteeing that the development and results from IMMERSE project will be integrated in NEMO reference code with the appropriate level of validation and documentation so that it can be maintained in NEMO reference code by NEMO System Team. This task will in particular ensure that IMMERSE developments to NEMO code delivered before M24 are integrated in an official, public beta-release of NEMO v4.2 at M30 in-time for WP6 (D2.5).

Developers from IMMERSE team will participate in NEMO System Team activity under the responsibility of NEMO project manager (Claire Levy, CNRS). NEMO project manager will coordinate the scientific and technical activity of NEMO System Team and IMMERSE developers through regular meeting (every 3 weeks).

This task will also include the initial formation of new IMMERSE developers to NEMO development process.

T2.2 [M1-M48] Software verification and distribution (Lead: CNRS, Participants: All**)**

This task aims at further improving the robustness of NEMO development and testing process to the benefit of CMEMS and the wider community of end users.

Implement and maintain a continuous integration service in the current NEMO software repository in order to support activities of the NEMO System Team and IMMERSE contributors (resp. CNRS) (D2.1). The continuous integration service will be triggered after each commit to the code repository and include code verification based on demonstration cases. The service will allow to perform tests routinely on various selected configurations (code branch, testing scope, compiler, compilation options, HPC centers, ...).

Maintain and further develop the generic interface used for setting up and distributing demonstration cases in NEMO reference code, testing suite and website.

Inform IMMERSE developers on how demonstration cases should be implemented and maintained in NEMO (MS2.1), providing advice on the implementation strategy if so required.

Collect demonstration cases from WP3-5 and integrate NEMO testing suite and continuous integration service (delivered in NEMO v4.2 beta-release D2.5).

T2.3 [M1-M45] Outreach and reproducible dissemination to NEMO users (Lead: CNRS, Participant: GEOMAR**)**

This task aims at increasing the visibility of NEMO development process and the reproducibility of experiments performed with NEMO, to the benefit of CMEMS and the wider community of end users.

Develop outreach material for dissemination to NEMO users (through summer schools, NEMO user meeting). This material will be based on results from a subset of demonstration cases from IMMERSE project and will be delivered on NEMO website (resp. CNRS) (D2.2).

Define and implement a standard protocol and software toolbox for sharing configuration information for NEMO simulations operated on heterogeneous systems in a citable way (resp. GEOMAR) (D2.3). The protocol will leverage existing services and techniques and will be fully compatible with the existing NEMO reference code distribution process. The protocol will be tested for documenting NEMO model configurations developed in WP6-8.

T2.4 [M1-M48] Coordination of project transfers to CMEMS (Lead: Mercator Ocean, Participant: CNRS**)**

This task will ensure that the project delivers to CMEMS a roadmap for the dissemination of project outcome to CMEMS MFCs.

Present annually project results to Mercator Ocean (as the EU delegated entity in charge of the implementation of CMEMS) and CMEMS MFCs and discuss on the transfer of these R&D results towards operational systems (planning and deliverables from the project, uptake by CMEMS incl. HPC and data assimilation issues) (resp. CNRS).

Based on these discussions, initiate and maintain/update a roadmap for the integration of IMMERSE project results into CMEMS operational modelling and data assimilation systems (resp. Mercator Ocean) (D2.4).

Interactions with other work packages
Overall coordination between WPs of code implementation in the NEMO reference code will be managed by Task T2.1. The collection of demonstration cases from WP3-5 will be done in Task T2.2. NEMO v4.2 beta-release will (D2.5) will be used in WP6.

Deliverables (Summary)

D2.1: Continuous integration service NEMO deployed on NEMO repository. **(M24, Task 2.1, resp. CNRS)**

D2.2: A series of demonstration cases from IMMERSE project on NEMO website for outreach. **(M45, Task 2.2, resp. CNRS)**

D2.3: Definition and implementation of the protocol for reproducible exchange of NEMO configurations. **(M18, Task 2.3, resp. GEOMAR)**

D2.4: Roadmap for implementation of IMMERSE outcomes within the CMEMS systems with annual updates. **(M6, Task 2.4, resp. Mercator-Ocean)**

D2.5: NEMO v4.2 beta release collecting IMMERSE developments to NEMO delivered before M24 **(M30, Task 2.1, resp. CNRS)**

Work package number	3	**Lead beneficiary**			Met Office
Work package title	Building the next generation numerical kernel for the NEMO ocean model				
Participant number	5	1	4	3	7
Short name of participant	Met Office	CNRS	Mercator Ocean	NERC	INRIA
Person/months per participant:	30	4	26	30	36
Start month	M1	**End month**	M45		

Objectives

- Specify first Runge-Kutta (RK) version of two-level time-step (2LTS) schemes in detail
- Design, implement and test first version of RK scheme in NEMO
- Explore and make recommendations on options for more advanced 2LTS schemes
- Adapt AGRIF (two-way nesting code) for first RK 2LTS scheme

- Enable AGRIF to use different vertical coordinates in the finer and coarser resolution regions
- Develop mixed explicit/implicit vertical advection schemes that allow longer time-steps
- Develop finite-volume representations of pressure forces suitable for steeply sloping coordinates
- Assess the performance of z-tilde coordinate in 1/12º NEMO models
- Assess and make recommendations on options for ALE (Arbitrary Lagrangian Eulerian) algorithms

This work package is led by: Met Office

Description of work

The main aim of this work package is to implement a two-level time-step (2LTS) scheme within NEMO. The second aim is to improve the flexibility and performance of the vertical coordinates used by NEMO. The specification, design, coding, testing and exploration of future options for schemes are covered in this WP. Demonstrations of capability will be made in WP6.

Tasks

T3.1 [M1-M42] Implement two-level time-step (2LTS) scheme (Lead: Met Office, Participants: CNRS, INRIA, Mercator-Ocean, NERC**)**

The detailed specification of the algorithm to implement the 2LTS will be completed in the first year of the project. The design of the code is independent of the details. It will start before the project commences and include consideration of HPC efficiency issues. A final code design and mid-term algorithm review at T+6 will ensure consistency. Two stages of code implementation and testing will be executed in years 2 and 3. The options for future enhancements will be analysed in years 2 and 3 of the project. The WP management will ensure proper review of the code design, establishing a realistic plan for the coding, then monitoring of progress.

INRIA will specify the 2LTS scheme to be implemented. CNRS will design the code. The Met Office and NERC will implement the code design and perform testing. Mercator-Ocean will implement the barotropic sub-stepping. INRIA will analyse options for future development. Each team will review the others work.

T3.2 [M1-M12 and M31-M36] Developments to nesting (Lead Mercator-Ocean, Participants: NERC**)**

The two-way nesting AGRIF capability will be developed in year 1 to allow each inner nest to use a different vertical coordinate from the model in which it is nested. The AGRIF and one-way nesting (BDY) capabilities will be adapted to the 2LTS scheme in the second half of year 3.

T3.3 [M1-M24] Develop improved algorithms for vertical coordinates (Lead: Met Office, Participants: INRIA, Mercator-Ocean**)**

Two developments will be made to support more general vertical coordinates. First a piecewise parabolic method (PPM) for horizontal advection of thickness will be implemented. Second representations of the pressure forces on very steeply sloping cells in generalised vertical coordinates using finite volume methods will be developed and compared with existing density Jacobian methods in standard test configurations (e.g. Beckmann and Haidvogel 1993)

Mercator-Ocean will implement the horizontal advection scheme with advice from INRIA. The Met Office will develop the scheme for pressure forces.

T3.4 [M31-M45] Assess adequacy of z-tilde vertical coordinates (Lead: NERC, Participants: INRIA, Mercator-Ocean**)**

The performance of the z-tilde coordinate will be assessed in 1/12º configurations using code from T3.3 and T3.1 (from M36). Its control of diapycnal mixing will be optimised and the need for, options for, and issues with deployment of ALE algorithms will be explored. A report will summarise results and recommendations for further work.

NERC will perform investigations of z-tilde in ORCA simulations and assist INRIA in the assessment of options and issues for ALE algorithms.

Interactions with other work packages

Coordination with WP4 and WP5 and the manager of NEMO System Team will minimise conflicts with other code developments. Coordination with WP4 (HPC optimization) will help to ensure the new code will work efficiently. Liaison with WP6 will help resolve issues with the demonstrations, especially for scheduling the work in WP6.1 and solving problems in WP6.1 with the code developed in this WP. In liaison with WP2, WP3 will assist exploitation of the code by the CMEMS systems.

Key milestones (for NEMO v4.2 beta release in D2.5) :

MS3.2: Code for AGRIF change in vertical coordinates. **(M12, Task 3.2, resp. Mercator-Ocean)**

MS3.4: Codes on pressure forces and vertical advection scheme **(M24, Task 3.3, resp. Met Office)**

Deliverables (Summary)

D3.1: Algorithm specification and code design for 2LTS scheme. **(M12, Task 3.1, resp. Met Office)**

D3.2: Reports on pressure forces and vertical advection scheme . **(M24, Task 3.3, resp. Met Office)**

D3.3: First version of 2LTS code available. **(M36, Task 3.1, resp. Met Office)**

D3.4: Recommendations on options for refinement of 2LTS schemes. **(M42, Task 3.1, resp. INRIA)**

D3.5: Report on z-tilde performance and recommendations on ALE algorithms. **(M45, Task 3.4, resp. NERC)**

Work package number	4	**Lead beneficiary**			CMCC
Work package title	Preparing CMEMS for future HPC infrastructures				
Participant number	2	5	6	4	1	7
Short name of participant	CMCC	Met Office	BSC	Mercator Ocean	CNRS	INRIA
Person months per participant:	34	27	14	3	9	6
Start month	1		**End month**	46	

Objectives

- Improve the computational performance of NEMO by reducing the data transfers in and out of low-level memory and increasing the vectorisation
- Introduce spatial and temporal coarsening and parallel execution of the biogeochemical sub-model
- Speed up data management operations during either the processing and post-processing phases
- Implement an efficient distribution of sub-domains with refined grids on massive parallel architectures

This work package is led by: Silvia Mocavero, CMCC

Description of work

The new massively parallel architectures and their increasing diversity present significant challenges to teams seeking to efficiently use current and future High Performance Computers (HPCs). The main goal is the efficient exploitation of the computing power for speeding up the time-to-solution in order to match the requirements in the CMEMS context.

This WP investigates: (i) technical solutions to fully exploit the hardware peak performance, (ii) the adoption of macro-scale task parallelism for sub-models (iii) the improvement of I/O management (iv) innovative solutions for online diagnostics and (v) load balancing mechanisms among parallel processes when using the AGRIF mesh refinement package.

Tasks

T4.1 [M1-M46] Efficient exploitation of memory hierarchies and hardware peak performance (Lead: CMCC, Participants: Met Office, BSC**)**

One of the key issues of model performance is its ability to fully exploit the computational power of modern HPC architectures, usually characterized by many-core nodes with a limited amount of memory/core and steeper memory hierarchies. Memory intensive codes, such as NEMO, suffers from this change in the technology trend and may require a deep revision to better handle the concurrency among the processes allocated within the same computational node when they access shared resources (e.g. some levels of the memory hierarchy). On the other side, the increasing of vector registers size on future systems encourages to revisit the code to fully exploit their capabilities.

Some work on this direction has been already started by the NEMO HPC Working Group. A benchmark suite has been configured and used to analyse the “single-core” performance at routine level. Here we refer to “single-core”, even though the code is executed in parallel, to focus our attention on the efficient use of the individual core peak performance.

A set of metrics needed to analyse the code behaviour have been identified and automatically extracted due to the integration of a portable library for automatically profiling a configurable set of hardware performance counters.

There is clear evidence that execution of some of the most time-consuming routines within NEMO on current CPUs is determined by the bandwidth of the low-level cache memory. The memory usage in similar codes in atmosphere models has been re-organised using tiling methods so as to greatly reduce the transfers in and out of cache and release the computational potential of the CPUs. Techniques to increase the data locality in NEMO will be investigated in this task. The main challenge will be the design of a portable solution able to improve the memory hierarchy reuse on different architectures. To this aim, it will be needed to implement the optimization taking into account the variability of the memory hierarchy on the different machines as well as the memory access pattern, which characterises the different routines.

The peak performance can be better exploited also working on the vectorisation level of the code. Many compilers usually are able to perform automatic vectorisation but the code needs to be written in such a way as to drive the compiler to increase the vectorisation level. A screening of the code will be needed in order to limit the dependency issues. Moreover, directives can also be used to increase the execution of SIMD instructions and to get closer to modern core peak performance.

Planned optimisations will be designed taking care to ensure that scientific quality of the code is not compromised.

The performance impact of these optimizations will be assessed using cutting-edge performance tools, to validate the outcome obtained from this action and double check the results coming from the profiling library used to carry out this action.

CMCC and Met Office will design, implement and test the optimisation strategies. BSC will contribute to the test of the proposed optimisations.

T4.2 [M1-M18] Increase modularity of NEMO components - macro-task parallelism (Lead: CNRS, Participant: Mercator-Ocean**)**
The evolution of supercomputing technology strongly drives us to increase in all possible directions the parallelism of our models. Different NEMO components (ocean dynamics, white ocean, green ocean) can, under some conditions, be split in independent executable, discretized at various resolutions and performed concurrently. Modules can be mapped to different computing cores and inter-module communications/interpolations be ensured by a coupling library. The NEMO surface module (including the sea ice model) was already modularised following this procedure and the implementation included in the reference version (Maisonnave and Masson, 2015).

We propose to shape the existing ocean/sea-ice interface to an ocean/biogeochemistry coupling, to make possible the computing of tracer advection and biogeochemical equations in a separate executable and its coupling to the rest of the NEMO model. This modularity is supposed to enhance the overall computing performances by allowing (i) to reduce the biogeochemical module horizontal resolution and (ii) to choose the best suited parallel decomposition for both components. Regardless to result modifications that have to be evaluated, computation of the two modules can be performed concurrently, reducing time to solution even more. The OASIS coupling library (Craig at al., 2017), basis of the existing ocean/sea-ice interface, will ensure the efficient (parallel) communication of 3D fields, the easy switch between sequential and concurrent modes and, possibly, the coupling field interpolation.

CNRS will design and implement the NEMO/biogeochemical modular solution. Mercator-Ocean will contribute to the design of the modular solution.

T4.3 [M1-M46] Efficient IOs and diagnostics for operational systems (Lead: Met Office, Participants: CMCC, BSC**)**
The explosion in both the amount and the complexity of the data being generated into operational environments by high-resolution NEMO simulations poses very strong challenges from both I/O and data management perspectives, in terms of hardware and software architecture.

The first goal of this task is the improvement of NEMO I/O management in an operational system, taking into account that I/O operations can be a relevant bottleneck when the number of parallel processes increases. NEMO uses XIOS (http://forge.ipsl.jussieu.fr/ioserver) for the output diagnostics: I/O and computation can be overlapped through a dedicated parallel and asynchronous I/O server and a post-processing workflow can be easily defined and performed 'in-situ'.
The increasing in the model resolution and the need to efficiently run it in an operational system suggest extending the use of XIOS to read and write inputs/restarts. The main goal is to avoid inefficiency when thousands of cores access the same forcing file, as well as to write thousands of restart files (one for each parallel process). Some work on restart file has been to implement restart read/write using XIOS for a limited set of prognostic variables and this task will extend and improve the work already done.
XIOS is not currently used in the NEMO OBS code which handles the input of observations and the output of model-observation differences. In current configurations (ORCA025, ORCA12) with current processor counts (e.g. one to two thousand cores) observations I/O is not found to be a significant bottleneck however in future architectures as processor / core counts rise significantly the file system load from concurrent read / write will increase. The effect of increased processor counts on any I/O bottleneck in the OBS code will be profiled to evaluate whether the OBS code should be updated to use XIOS I/O.
A deep analysis of the optimal distribution of resources between the model and XIOS is also needed. Diagnostics parameters (i.e. the number of output and the writing frequency) will play a key role in order to reduce the idle time of the system component.
Preliminary tests on current high-resolution global (e.g. ORCA12) configurations will be done to assess I/O developments.

Looking forward large-scale operational scenarios, and in addition to I/O approaches like XIOS, high performance data analytics solutions aiming at tackling the online diagnostics of the NEMO model will be also explored as complementary components in the model diagnostics software eco-system. In this respect, solution to offload model diagnostics from NEMO will be considered in two complementary directions. In particular, online techniques leveraging fast (low latency and real-time) data analytics approaches (e.g. on fat nodes) as well as other ones relying on accelerators (e.g. GPUs on heterogeneous HPC computing clusters) will be evaluated in real cluster environments. Mixed approaches will be also considered depending on the preliminary assessments on the single solutions. The proposed activity will mainly focus on coupling with NEMO, benchmarking and providing assessments of such solutions in operational scenarios.

Met Office will work for extending the use of XIOS to read and write input/restarts. CMCC will contribute on testing the development on current high-resolution global configurations. BSC and CMCC will design and implement online diagnostics solutions on fat nodes and GPUs.

T4.4 [M1-M36] Load balancing for AGRIF massive multigrid capability (Lead: INRIA, Participants: Met Office, BSC**)**
The NEMO model has the ability to use the AGRIF library to perform high-resolution zooms in specified regions. These zooms can be implemented passively but also actively, with a feedback of the high-resolution solutions to the coarse solution. Even if NEMO users have a long history of using this library, current applications involve only the implementation of a few zooms (typically between 1 and 3).
The developments proposed here are intended to greatly increase this number of zooms while maintaining a good parallel efficiency. *These developments are a major necessary step towards NEMO as a fully multiresolution model.* At present, when several high-resolution grids are present in the hierarchy, these grids are integrated sequentially using all the computing cores. That is, all the cores integrate the root grid (which covers the entire compute domain), then the first high-resolution grid, the second grid, and so on.

The main drawback here is that, when the hierarchy contains small grids, these grids very strongly limit the overall efficiency of the code because of a very low computation/communications ratio. The purpose of this task is to allow greater flexibility in the cores to grids assignment algorithm. The compute cores will be distributed over all the high-resolution grids. High-resolution grids are in this case integrate simultaneously and not sequentially. The assignment of the computation cores must be carried out in order to obtain the best possible load balancing. Previous developments of the AGRIF library now offer this possibility. However, this has only been tested in idealized settings and optimizations will be required for realistic applications with the NEMO model.

The tests will notably be undertaken in global configurations, with zooms in the overflow regions within the demonstrator developed in task 6.2. Within WP4, preliminary tests will be carried out in smaller configurations in order to measure the efficiency and to proceed to the necessary improvements.

The developments are here divided into two subtasks:

1) allow NEMO to use the advanced features of the latest AGRIF library version with a more efficient cores to grids assignment. This mainly requires the NEMO model to provide an estimation of the computational cost of each grid and some changes to the AGRIF interpolation/update calls
2) perform efficiency tests in high resolution regional configurations. These applications will be performed with high-resolution grids of very distinct sizes in order to check the efficiency of the algorithm.

INRIA in collaboration with Met Office will integrate the AGRIF distributed-memory feature into NEMO. BSC will perform efficiency test on high-resolution configuration.

Interactions with other work packages
The activities carried out within this WP will support the development of computational efficient NEMO demonstrators developed in WP6. In particular, new coding approaches to exploit peak performance, XIOS reading and writing and high-performance online diagnostics will be tested on the global high-resolution configuration of task 6.3. The macro-task parallelism will be tested on regional and global configurations,

respectively of task 6.1 and 6.3. The AGRIF advanced features for load balancing will be tested on the global configuration with zooms provided by task 6.2.

Key milestones (for NEMO v4.2 beta release in D2.5) :

MS4.1: Implementation and validation of a coupling interface between ocean and biogeochemistry separate executables. **(M18, Task 4.2, resp. CNRS)**

MS4.2: Integration of new coding approaches in core NEMO routines to improve the computational performance at node level **(M24, Task 4.1, resp. CMCC)**

MS4.3: Extension of the use of XIOS for reading/writing operations in NEMO. **(M24, Task 4.3, resp. Met Office)**

MS4.4: First setup of online diagnostics operational scenarios for NEMO, based on high performance solutions for high memory nodes and heterogeneous architectures **(M24, Task 4.3, resp. BSC)**

MS4.5 : Integration in NEMO of the AGRIF advanced features for load balancing **(M24, Task 4.4, resp. INRIA)**

Deliverables (Summary)

D4.1: Report on performance improvement and portability. The document will describe the new coding approaches and analyse the impacts on global demonstrator of WP6. It will also provide recommendations for the maintenance of the new coding rules. **(M46, Task 4.1, resp. CMCC)**

D4.2: Report on high performance solutions for online diagnostics on heterogeneous cluster architectures. The document will describe the solutions developed to offload model diagnostics and will provide an assessment of their applicability to operational scenarios. **(M46, Task 4.3, resp. BSC)**

D4.3: Report on performance improvement. Integration of the developments with optimizations according to the first results of the global demonstrator of WP6. **(M36, Task 4.4, resp. INRIA)**

Work package number	5	**Lead beneficiary**			CNRS	
Work package title	Modelling key interaction processes at the interfaces at kilometric resolution					
Participant number	1	4	2	5	9	3	7
Short name of participant	CNRS	Mercator Ocean	CMCC	Met Office	Ocean Next	NERC	INRIA
Person/months per participant:	29	9	27	6	18	23	9
Start month	M1		**End month**	M36		

Objectives

- Atmospheric Boundary Layer (ABL) model 1D, and ocean-only 3D in NEMO reference version. Recommendation for coastline compatible 3D.
- Advanced bulks fully compliant with ABL, sea-ice and waves in NEMO reference version
- Revised Ocean boundary layer and its integrations with waves in NEMO reference version

- Up-to-date coupling with waves in NEMO reference version
- Test and choice recommendation between three different sea-ice rheologies
- New TOP developments on vertical sinking and vertical penetration of visible light

This work package is led by: Sebastien Masson, CNRS

Description of work

This WP aims at improving the representation of the interactions between the ocean and the atmosphere that are key to for the quality of ocean simulations at high resolution. Our target is to improve the consistency of the processes taken into account from the atmospheric boundary layer to waves to the ocean, including the sea-ice and the biogeochemistry. This WP is divided in 4 tasks going schematically from the lower atmosphere toward the ocean.

Tasks

T5.1 [M1-M36] Integration of an Atmospheric Boundary Layer model in NEMO (Lead: INRIA, Participants: Mercator Ocean, Ocean-Next, CNRS**)**

In this task, we will work to improve the representation of the Atmospheric Boundary Layer (ABL) interacting with the ocean through the use of a simplified ABL model coupled to advanced atmospheric bulks.

1. Complete ABL-1D integration: the proof of concept of a one dimensional (vertical) ABL model has been done in NEMO. We will first insure its full compatibility with the different functionalities of NEMO (AGRIF, fractions of open water and sea-ice categories) before implementing it into the reference version of NEMO. [Lead: CNRS, Participant: Mercator Ocean]
2. Improvement of Atmospheric Bulks: We first propose to implement advanced cool-skin/warm-layer parameterization in NEMO, to take into account the skin temperature required by ECMWF and COARE bulk algorithms. Next our efforts will focus on the implementation and validation of more advanced bulk closures and parameterizations to estimate exchange coefficients over sea-ice (extremely stable conditions). [Lead: Ocean-Next]
3. Toward a 3D-ABL model: we will develop a first version of a 3D ABL model that will not be compatible with the presence of land points. Next we will evaluate the different methods and decide which strategy is the most appropriated to deal with coastlines which act as open boundaries for the ABL model. [Lead: INRIA, Participant: Mercator Ocean]

T5.2 [M1-M36] Interactions between waves and O/A boundary layers processes (Lead: CMCC, Participants: Ocean-Next, NERC**)**

This second task is dedicated to the improvements of the representation of the interactions between the waves and atmospheric/oceanic layers.

1. Waves and bulk interactions: Improvement of bulk closures and parameterizations for the estimate bulk exchange coefficients over sea, and wave-wind stress coupling, through the use of the relevant surface wave information (height, steepness, …). [Lead: Ocean-Next]
2. Include an additional wave coupling development, which consists in modified vertical mixing due to breaking waves: the energy flux explicitly evaluated by a wave model (through the dissipation term in the wave energy balance equation) is used as a new source of vertical mixing scheme. [Lead: CMCC]
3. Wave and oceanic boundary layer mixing: insure a full compliance between waves and vertical mixing schemes (wave-to-ocean stress, wave breaking, Langmuir, Stokes drift, …). Improve OSMOSIS scheme under sea-ice, in the tropics (shear with equatorial undercurrent) and in shallow shelf seas (interaction with bottom boundary layer). Develop diagnostics energy budget to assure energetic consistency. [Lead: NERC]
4. After the implementation phase, the impact of waves on the ocean will be tested using the CMEMS Med-MFC physical analysis and forecast operational system (Med-Currents) which is composed by a

coupled hydrodynamic-wave modeling system, NEMO-WW3, implemented in the Mediterranean Sea at 1/24 horizontal resolution and 141 vertical levels. [Lead: CMCC]

T5.3 [M1-M24] Efficient and flexible interface with biogeochemical models (Lead: CNRS, Participant: CMCC**)**

This task will address the development of a new, generalized set of parameterizations to enhance NEMO-TOP interface, by performing the subsequent steps:

1. Analyse the capabilities of different vertical sinking schemes and evaluate their performance/compatibility within NEMO standard configurations. [Lead: CNRS]
2. Develop a generalized scheme to represent the vertical penetration of visible light and assess its impacts on both ocean physics and biogeochemistry. [Lead: CMCC]
3. Implement the most suitable vertical sinking and visible light penetration schemes in the NEMO-TOP interface. [Lead: CNRS, Participant: CMCC]
4. Evaluate the robustness and portability of the proposed parameterizations within the appropriate test cases of the project. [Lead: CMCC, Participant: CNRS]
5. Deliver the new components to the NEMO modelling framework and provide the related documentation. [Lead: CNRS, Participant: CMCC]

T5.4 [M1-M36] Sea-Ice Rheology for high-resolution (Lead: Met Office, Participants: NERC, CNRS, CMCC**)**

In this task the three different rheologies (VP, EVP & EAP) will be assessed in terms of: (1) drift and deformation statistics; and (2) impacts on sea ice state and ice-ocean heat exchanges.

1. The VP and EAP rheologies will be implemented into the NEMO sea ice model - alongside the existing EVP scheme. [Lead: NERC, Participant: CNRS]
2. Model simulations will be performed at 1/4° (ORCA025), 1/16° (GLOB16) and 1/36° (ARC36) resolution with each rheology. [Lead: Met Office, Participants: NERC, CMCC]
3. The performance of the three rheologies will be evaluated by comparing model simulations with observations, and with each other, across a range of different horizontal resolutions allowing recommendations to be made for future rheology use within NEMO and for high-resolution forecasting systems. [Lead: CNRS, Participants: Met Office, NERC, CMCC]

<u>Interactions with other work packages</u>

Most of the developments achieved in this WP will be demonstrated in full-scale simulations in WP6. New bulk parameterisations (skin temperature, over sea-ice) are particularly adapted to the global configuration of task 6.2. ABL-1D, the improvement of ocean-waves (wave-wind stress coupling, wave breaking, OSMOSIS) and biochemistry will mostly benefit to the regional configuration of task 6.2 that uses the highest configuration.

<u>Key milestones (for NEMO v4.2 beta release in D2.5) :</u>

MS5.1: Optimized OBL mixing scheme in NEMO reference version (using wave model output and adapted to under ice and tropical conditions) **(M9, Task 5.2, resp. NERC)**
MS5.2: ABL-1D in NEMO reference version **(M9, Task 5.1, resp. CNRS)**
MS5.3: Gathering all developments done in the ocean-wave community **(M12, Task 5.2, resp. CMCC)**
MS5.4: EAP and VP rheologies into the NEMO sea ice model **(M12, Task 5.4, resp. NERC)**
MS5.5: Advanced bulk (skin temperature and over sea-iced) in NEMO reference version **(M18, Task 5.1, resp. Ocean-Next)**
MS5.6: Wave compliant with bulks and OBL mixing in NEMO reference version. **(M18, Task 5.2, resp. CMCC)**
MS5.9: Biogeochemical developments into the reference version of NEMO **(M24, Task 5.3, resp. CNRS)**

<u>Deliverables (Summary)</u>

D5.1: ocean-only ABL-3D model in NEMO reference version **(M24, Task 5.1, resp. Mercator-Ocean)**
D5.2: report on rheologies evaluation, recommendations for future rheology use **(M36, Task 5.4, resp. Met Office)**

D5.3: report on the tested strategies and presentation of the best choice to deal with costal open boundary conditions in ABL-3D **(M36, Task 5.2, resp. INRIA)**
D5.4: Code to allow NEMO with OSMOSIS-OBL to model surface OBL over shelf areas **(M36, Task 5.2, resp. NERC)**
D5.5: Assessment of wave-current effects on the circulation in the Med-MFC system **(M36, Task 5.2, resp. CMCC)**

Work package number	6		**Lead beneficiary**		Mercator Ocean		
Work package title	Demonstrating impact of NEMO developments on CMEMS model based systems						
Participant number	4	8	3	1	5	2	9
Short name of participant	Mercator Ocean	PdE	NERC	CNRS	Met Office	CMCC	Ocean Next
Person/months per participant:	32	24	20	2	2	12	6
Start month	M24		**End month**	M48			

Objectives

- Deliver examples of ocean and biogeochemistry models at a kilometric scale with additional process complexity.
- Assess the impact of improving deep ocean overflows due to a new vertical coordinate system in a global eddy resolving model.
- Assess HPC capability of a global demonstration configuration at very high resolution including additional process complexity.

This work package is led by: Romain Bourdallé-Badie, Mercator-Ocean

Description of work

This WP is dedicated to building global and regional configuration sat frontier- resolution for the next generation of Copernicus Marine Service ocean models, which will include a suite of developments provided in this project. These configurations will show the impacts of model improvements and will ensure an easy transition to the Copernicus operational environment.

Tasks

T6.1 [M24-M48] Impact of NEMO developments on a regional forecast framework (Lead: Puertos Del Estado , Participants: Mercator-Ocean, Ocean-Next, CMCC **)**

Subtask: T6.1.1 [M24-M42] Development of the demonstrator: *IBI36zoom* (Lead: Puertos Del Estado, Participant: Mercator-Ocean**)**

A Regional configuration at 1/36° resolution, covering the coasts and shelf seas of Ireland, France, Spain and Portugal coasts is currently operated by the CMEMS IBI-MFC. Based on this CMEMS IBI model application, Puertos Del Estado and Mercator-Ocean propose to develop conjointly a demonstration configuration including a 2-way nested area, based on the AGRIF library, reaching the kilometric resolution. This prototype will include both ocean and biogeochemical component, and this new configuration will benefit from the advances done in WP3 (numerical improvements on vertical coordinates), the advances done in WP4 (high performance computing) and the advances done in WP5 (interaction ocean/atmosphere and BGC component). This configuration could be used later by the CMEMS IBI MFC as element for its NRT forecast product evolution. To highlight the possible impact on the regional forecast, we will simulate, starting from an operational IBI near-real-time analysis, 1 year with standard IBI model, 1 year with IBI configuration including new physical development of WP3 and 1 year with this new IBI high-resolution demonstrator model including the zoom area. In order to assess the added value of this prototype with respect to the IBI MFC model available at that time, a comparison of three solutions will be performed through the IBI MFC NARVAL operational multi-platform validation tool, operated by PdE. First, changes due to the new physic will assessed through the twin experiments on same IBI36 grid. Then, an assessment of the increase of resolution will be done by intercomparing the new IBI36 and the new IBI36 with zoom.

Subtask: T6.1.2 [M42-M48] Assessment of IBI36zoom to represent submeso and mesoscale based on high resolution observations (Lead: Ocean-Next, Participants: Mercator-Ocean, Puertos Del Estado, CMCC**)**

The main objective of this sub-task is to compare the new very high model solution with high resolution observations such as the swath altimetry product available at the time in the IBI region, Radar HF data, mooring data, gliders data. The study will be performed along several directions depending on the data used: i) Comparisons of this new very high resolution IBI model solution with altimeter data (inc. S-3A, S-3B and SWOT) will be performed by Mercator-Ocean and Ocean-Next (resp. Ocean Next). These comparisons will combine conventional and wide-swath altimetry data and investigate how the new high resolution IBI model and wide-swath altimetry capture oceanic features and fronts in the IBI region. Analogous comparisons will be performed with the 1/36° IBI without zoom solution, in order to assess the potential added value of the new high resolution 1km IBI solution with respect to the currently operational IBI product. After analysing results from this model-swath comparison, Puerto Del estado will evaluate the possibility to transfer the metrics designed into an operational validation tool. To this aim, it will be organized with the CMEMS IBI MFC Product Quality experts some actions to ease the inclusion of swath altimetry and the metrics designed as part of the multi-platform Operational Validation Tool of the IBI-MFC (the NARVAL Tool). ii) Evaluation of the impact of new sub-kilometric scale model simulations on vertical velocities will be performed with a focus on intense fronts where vertical velocities are associated with enhanced subduction as shown in multi-platform experiments (Pascual et al., 2017) (resp. CMCC). iii) An assessment of the IBI prototype modeling system will be performed by means of velocity validation with in-situ data will be done (resp. CMCC). Mean and variability of surface currents will be compared to in situ coastal moorings, drifters, radar HF and gliders in the area of interest aiming at highlighting the benefit of the increased resolution on the small-scale ocean dynamics. An additional assessment of velocity derived variables will be provided in terms of transports through the Gibraltar strait and specific transects with respect to observations, if available, and climatologies through the use of Glider missions.

T6.2 [M24-M42]: Impact of NEMO developments for NEMO configurations used for reanalyses and climate modelling (Lead: NERC, Participants: CNRS, Met Office, Mercator-Ocean**)**

In this task, two AGRIF nests will be implemented in a global eORCA12 NEMO model configuration, in the Denmark Strait and Gibraltar overflow region, respectively. Tests will be undertaken to assess how the local adjustment of the horizontal and vertical grid may lead to a substantial improvement of the representation of dense water overflows (including the possibility of terrain-following coordinates in the nested regions). Model solutions will be assessed with respect to hydrographic data and current meter arrays in the target regions. The performance of the grid refinement capability will be documented and recommendations will be formulated as to how to improve the representation of dense water overflows in eORCA12 for reanalysis and climate modelling.

The work will be carried out by NERC, Met Office, Mercator-Ocean and CNRS in the framework of DRAKKAR coordination. WP2 will ensure that the outcome of this work will be smoothly transitioned to relevant bodies.

T6.3 [M24-M48]: Impact of NEMO developments on the global forecasts framework (Lead: Mercator-Ocean, Participants: Ocean-Next , CMCC**)**
The principal mission of CMEMS is delivering ocean forecasts at high resolution also for the global ocean. In this task, Mercator-Ocean and CMCC propose to test i) the HPC efficiency of the developed code to performed short simulations for a global configuration at 1/36° (3 km at the Equator) and ii) highlighting the integration of new numerical schemes and physical processes developed in WP3 and WP5. Besides new numerical schemes (e.g. new time stepping, improved vertical coordinates), we aim to address the effect of HPC upgrades and online coupling with other geophysical components, in particular with a biogeochemistry model and an atmospheric boundary layer. At the end of this task, Ocean-Next will propose a model, based on the future NEMO beta release, integrating all previous tests. The main goal is to highlight the additional physics capability and the progress of the HPC aspects in order to prepare for the next generation of CMEMS global systems.

Interactions with other work packages

This WP will follow on from the developments elsewhere in this project, and implies the need for a very strong coordination with those WPs which will develop the NEMO new capability (WP3: next generation numerical kernel; WP4: HPC improvement; WP5: interaction processes at the interfaces).

Deliverables (Summary)

D6.1: Report/paper on impact for forecasting of new IBI regional demonstrator. **(M42, Task 6.1.1, resp. PdE)**

D6.2: Report/paper on assessment of new IBIzoom comparisons to high resolution data. **(M48, Task 6.1.2, resp. Ocean-Next)**

D6.3: Report/paper on impact of solving the overflow dynamics in a global model. **(M42, Task 6.2, resp. NERC)**

D6.4: Report on performances of global 1/36° demonstrator. **(M46, Task 6.3, resp. Mercator-Ocean)**

Work package number	7	**Lead beneficiary**	CMCC		
Work package title	Integrating model based products and high resolution EO datasets for downstream applications				
Participant number	2	1	5	3	9
Short name of participant	CMCC	CNRS	Met Office	NERC	Ocean Next
Person/months per participant:	17	2	12	11	12
Start month	M1	**End month**	M24		

Objectives

- Recommendations to the observational community for the design of future CMEMS system
- Diagnosis of error in short-term forecast systems
- Develop a seamless approach to interfacing the ocean model and remote sensed observed information, global and regional, available from the CMEMS systems with the modelling component of coastal monitoring systems. This will take the form of a flexible Python-based code tool kit, with code development following NEMO quality control and documentation standards.
- To disseminate this system to the coastal modelling community and accept feedback from that community to assist the development of the CMEMS services and their use.

This work package is led by: Doroteaciro Iovino (CMCC)

Work-package description: The main aim of this work package is to prepare the articulation of future high resolution CMEMS model based products with EO datasets for the benefit of downstream applications. Work will be dedicated to describe the predictability and accuracy of high resolution forecasting systems and to design a seamless interface for CMEMS downstream users to access model based products and EO datasets. Prototype toolbox will be delivered. Demonstration of capability will be made in WP8.

T.7.1 [M1-M24] Ensemble quantification of short term predictability of ocean fine scale dynamics (Lead: CNRS, participant: Ocean Next**)**
In this task, ensemble forecast experiments will be carried out with a high-resolution NEMO configuration in order to quantify the predictability of ocean dynamics at scale 1-10 km over short time periods (1-20 days). Key sources of uncertainty will be explicitly simulated using stochastic forcings in the model. Statistical techniques will be used for describing the structure, growth and propagation of uncertainties. This information will be combined in order to assess the predictability horizon of ocean properties at scale 1-10 km. This task will deliver results relevant to the design of future CMEMS systems including the space component of the associated observing systems (in particular altimetry). Software tools will be made openly available. The work will be carried out by CNRS and Ocean Next. Mercator-Ocean will participate to scientific discussions when needed and ensure the transfer of results to the design of CMEMS systems.

T7.2: [M1-M18] Statistical description of forecast accuracy in DA systems for downstream applications (Lead: Met Office)
In this task, analysis of short range forecasts error in existing CMEMS systems will be carried out. The proposed work will involve, in the first year, the production of a 2-year integration of the global ORCA12 and the regional AMM15 configurations, including assimilation of swath satellite SST data, along-track altimeter SLA data, in situ temperature and salinity profiles and surface measurements. NEMO observation operator code (OBS) will be used for calculating the model equivalent of the observations collocated in time and space. Statistical methods based on the work of Roberts-Jones et al. (2016) will be improved in order to estimate short-range forecast errors at different spatial scales. During the second year, the new methods will be applied to the output of both configurations in order to assess the nature of forecast errors at different model resolutions. This task will deliver python software tools that will be made openly available, and a report/draft paper describing methods and results.

T7.3: [M1-M24] Prototype toolbox for seamless uptake of CMEMS products in downstream monitoring systems (Lead: CMCC, participant: NERC)
The objective of this task is to develop a flexible coupler tool between CMEMS and Coastal Community that will combine NEMO-based tools and custom CMEMS-oriented processing tools for interfacing coastal models with CMEMS (to be possibly used through DIAS). An online workshop (webinar) will be organized to strength the link with the coastal modelling community, and take advice on the systems design and its applications within the constraints of the CMEMS service. The activities are articulated in 3 items:

- NEMO-Lab Interface: developing the Python-based suite for preparing data package to use as input for new model configurations (resp. NERC);
- Research-to-Operations Interface: preparing interface with CMEMS Model/Obs products, and with Coastal and Estuarine Models (resp. CMCC);
- Generic Interface: connecting to DIAS for accessing operational CMEMS data, and for CMEMS Operations and for Downstream Services (resp. CMCC).

To exchange information, custom procedures will be developed for accessing data through the Copernicus Data and Information Access Services. Results will be shown with a set of examples of applications based on existing coastal models available within the consortium, these will be implemented and tested in case studies in WP8.

Interactions with other work packages
This work package provides the coupling tools for the applications in WP8.

Deliverables (Summary)

D7.1: Report/paper on the predictability of oceanic fine scales. **(M24, Task 7.1, resp. Ocean-Next)**

D7.2: Python tool to estimate forecast errors from outputs of the OBS code in NEMO made available in an open repository. **(M18, Task 7.2, resp. Met Office)**
D7.3: Report/paper to describe the methods and results of estimating forecast errors from high resolution models using high resolution observations. **(M24, Task 7.2, resp. Met Office)**
D7.4: Python coupling tool kit and documentation. **(M24, Task 7.3, resp. CMCC)**

Work package number	8	**Lead beneficiary**			UNIBO	
Work package title	Demonstrating impact of NEMO and CMEMS evolutions on downstream case studies					
Participant number	3	12	13	14	11	
Short name of participant	NERC	HZG	Univ. Utrecht	PML	UNIBO	
Person/months per participant:	9	12	12	12	15	
Start month	12		**End month**	48		

Objectives

- To demonstrate that the continuous evolution of the CMEMS system has specific, quantifiable benefits to selected Downstream Services
- To demonstrate that the improvements to the interface capability in WP7 leads to an improved ability of Downstream Services to take up new CMEMS developments, and so effectively realises these benefits.
- To feedback how the CMEMS system could be improved to the benefit of downstream systems and inform the CMEMS evolution strategy.
- To assess the benefits of improved observational products to support downstream systems

- To collate and make available a set of harmonised downstream assessment tools, which provide a legacy of this work to assess future CMEMS developments and other systems

This work package is led by: Jason Holt, NERC and involves Stavena (HZG), van Stebille (Uni Utrecht), Torres (PML) and Trotta (UniBo)

Description of work

This work package focuses around four case studies of Downstream Services. Each will follow a common cycle:
i. A baseline version of the downstream system is established;
ii. This is developed using improved CMEMS and NEMO code (WP2), and the coupling interface (T7.3)
iii. An observational based assessment protocol is developed to establish how the improvements feed through to benefit the specific applications
iv. Outcomes are fed-back to CMEMS and observational service evolution.

Tasks

T8.1 [12-48] Case study coordination (NERC)

The common approach to the case studies will be refined and an implementation plan developed. The results of the case studies will be evaluated to assess the combined benefits of CMEMS and NEMO developments and new observations, and also identify the gaps in the assessments process. This information will aid the development of the CMEMS evolution strategy. The assessment tools used in T8.2-5 will be collated into a prototype assessment software suite, made available on an open source code repository (e.g. gitlab) to aid the wider community.

T8.2 [12-42] Coastal processes in the German Bight (HZG)

Focusing on sediment transport, search and rescue, and oil spill response, this task will test the coupled hydrodynamic-wave model NEMO-WAM (1-3.5km) and the unstructured mesh model, SCHISM (20-200m), applications in the German Bight. Comparing the two systems, this will test the impact on near coastal circulation and estuarine frontal structures of using refined resolution CMEMS boundary conditions (NWS 1.5 km cf 7km). It will also test wave-current interaction, wetting/drying and the WP2 beta release NEMO version. Data sources include altimetry (sentinel-3 and -6) and drifter observations, using a Lagrangian analysis. Recommendations to improve near coastal circulation will be fed back to the Tier 1 evolution of the NWS MFC.

T8.3 [12-42] Marine plastic litter transport from NW Europe to the Arctic (Uni Utrecht)

This task will investigate the fate of plastic litter released into the sea from NW Europe, hypothesized to be transported to the Arctic. A large number (>100M) of particles will be tracked using the new Parcels Lagrangian code specifically designed for the simulation of plastic in the ocean (ERC StG project TOPIOS). This will be driven by the new global CMEMS products (1/12º) to establish the importance of using wave data to provide a Stokes drift term and other wave effects, usually omitted from such studies. Smaller area studies using NWS (1.5km) forcing will demonstrate the importance of fine scale and tidal currents. *In situ* observation will provide the distribution of plastic litter, and drifter and altimetry (sentinel-3 and -6) data will validate the transport pathways.

T8.4 [12-42] Water quality modelling of the Tamar Estuary and adjacent coast (PML)

Estuarine and coastal water quality will be investigated here using the coupled FVCOM-ERSEM unstructured mesh hydrodynamic-ecosystem model in the Tamar estuary (~200m). We will investigate sensitivity to refined resolution (NWS 1.5 km cf 7km) and higher frequency (daily to hourly) CMEMS boundary conditions in terms of a range of ecosystem parameters: nutrients, oxygen and plankton. We focus on the balance of oceanic and riverine processes pertaining to the regions conservation status as a Special Area of Conservation and Estuarine Marine Site (part of the Natura 2000 network) and its sustainable growth. Model assessment will be provided by the PML Western Channel Observatory and Sentinel-3 (SST and chl-a), and contrasted with CMEMS products.

T8.5 [12-42] Pollution transport by submesoscales in the open ocean (UniBo)
Here we will explore the impact of submesoscale processes on the transport of oil-spills and their environmental impacts using MEDSLIK-II. The expectation is that resolving the submesoscale leads to more accurate predictions of pollutant advection-diffusion and, therefore, their impacts on the coastal environment. The SURF platform will provide velocity fields from submesoscale-permitting NEMO models, using multiple model nests to 2-300m, focusing in the CMEMS IBI region to provide the outer nest. This will investigate the current CMEMS system compared with the kilometric AGRIF nest (WP6) and the WP2 beta release NEMO version, and also consider the treatment of viscosity/diffusivity parameterisation at these resolutions. Data sources used will be Sentinel-3, SST and ocean color.

Interactions with other work packages
Each task in this WP will draw on, test and feedback to, the toolkit development in T7.3. Case studies using NEMO code (8.2 and 8.5) will test the beta NEMO release from WP2.

Deliverables (Summary)

D8.1: Report summarising outcomes of the case studies **(M42, Tasks 8.2, 8.3, 8.4, 8.5, NERC)**

D8.2: Report providing recommendations for CMEMS service evolution and new observations **(M48, Task 8.1, NERC)**

D8.3: Prototype suite of open source scripts for downstream service assessment **(M48, Task 8.1, NERC)**

List of work packages

Work package No.	Work Package Title	Lead Participant No.	Lead Participant Short Name	Person-Months	Start Month	End Month
1	Management and coordination	1	CNRS	36	1	48
2	Software quality control and dissemination	1	CNRS	38	1	48
3	Building the next generation numerical kernel for the NEMO ocean model	5	Met Office	126	1	45
4	Preparing CMEMS for future HPC infrastructures	2	CMCC	93	1	46
5	Modelling key interaction processes at the interfaces at kilometric resolution	1	CNRS	121	1	36
6	Demonstrating impact of NEMO developments on CMEMS model based systems	4	Mercator Ocean	98	24	48
7	Integrating model based products and high resolution EO datasets	2	CMCC	54	1	24
8	Assessing impact of NEMO and CMEMS evolutions on downstream systems	3	NERC	60	12	48

Total person-months				626		

Table 3.1.1: List of work packages

List of Deliverables

Table 3.1.2 details the project's deliverables. Importantly, IMMERSE will deliver a package of developments to NEMO reference code within a publically available **NEMO v4.2 beta release to be distributed at M30 (D2.5).** The associated individual developments to NEMO will be monitored through dedicated milestones (see Table 3.2.1 below). Other developments to NEMO that will be delivered before M24 have been assigned a specific deliverable in Table 3.1.2.

Deliver. number	**Deliverable name**	**WP nber**	**Short name of lead participant**	**Type**	**Diss. level**	**Delivery date (in months)**
D1.1	Summary reports on project progress	1	CNRS	R	CO	M 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48
D1.2	Public website	1	CNRS	DEC	PU	M4
D1.3	Updated dissemination and communication plan (with annual updates)	1	CNRS	R	CO	M6
D1.4	Data Management Plan	1	CNRS	R	PU	M6
D2.4	Roadmap for implementation of IMMERSE outcomes within the CMEMS systems with annual updates	2	Mercator Ocean	R	CO	M6
D3.1	Algorithm specification and code design for 2LTS scheme	3	Met Office	OTHER	CO	M12
D2.3	Definition and implementation of the protocol for reproducible exchange of NEMO configurations	2	GEOMAR	OTHER	PU	M18

D7.2	Python tool to estimate forecast errors from outputs of the OBS code in NEMO made available in an open repository	7	Met Office	OTHER	PU	M18
D2.1	Continuous integration service NEMO deployed on NEMO repository	2	CNRS	OTHER	CO	M24
D3.2	Reports on pressure forces and vertical advection scheme (cf MS3.4)	3	Met Office	R/OTH ER	PU	M24
D5.1	ocean-only ABL-3D model in NEMO reference version	5	Mercator Ocean	OTHER	CO	M24
D7.1	Report/paper on the predictability of oceanic fine scales	7	Ocean Next	R	PU	M24
D7.3	Report/paper to describe the methods and results of estimating forecast errors from high resolution models using high resolution observations	7	Met Office	R	PU	M24
D7.4	Python coupling tool kit and documentation	7	CMCC	R	PU	M24
D2.5	NEMO v4.2 beta-release collecting IMMERSE developments delivered before M24	2	CNRS	OTHER	PU	M30
D3.3	First version of 2LTS code available	3	Met Office	OTHER	CO	M36
D4.3	Report on performance improvement. Integration of the developments with optimizations according to the first results of the global demonstrator of WP6	4	INRIA	OTHER /R	PU	M36
D5.2	report on rheologies evaluation, recommendations for future rheology use	5	Met Office	R	PU	M36

D5.3	report on the tested strategies and presentation of the best choice to deal with costal open boundary conditions in ABL-3D	5	INRIA	R	PU	M36
D5.4	Code to allow NEMO with OSMOSIS-OBL to model surface OBL over shelf areas	5	NERC	OTHER	CO	M36
D5.5	Assessment of wave-current effects on the circulation in the Med-MFC system	5	CMCC	R	PU	M36
D3.4	Recommendations on options for refinement of 2LTS schemes	3	INRIA	R	PU	M42
D6.1	Report/paper on impact over forecast of new IBI regional demonstrator	6	PdE	R	PU	M42
D6.3	Report/paper on impact of solving the overflow dynamics in a global model	6	NERC	R	PU	M42
D8.1	Report summarising outcomes of the case studies	8	NERC	R	PU	M42
D3.5	Report on z-tilde performance and recommendations on ALE algorithms	3	NERC	R	PU	M45
D2.2	A series of demonstration cases from IMMERSE project on NEMO website for outreach	2	CNRS	R	PU	M45
D4.1	Report on performance improvement and portability. The document will describe the new coding approaches and analyse the impacts on global demonstrator of WP6. It will also provide recommendations for the maintenance of the new coding rules	4	CMCC	R	PU	M46

D4.2	Report on high performance solutions for online diagnostics on heterogeneous cluster architectures. The document will describe the solutions developed to offload model diagnostics and will provide an assessment of their applicability to operational scenarios	4	BSC	R	PU	M46
D6.4	Report on performances of global 1/36° demonstrator	6	Mercator Ocean	R	PU	M46
D6.2	Report/paper on assessment of new IBIzoom comparisons to high resolution data	6	Ocean Next	R	PU	M48
D8.2	Report providing recommendations for CMEMS service evolution and new observations	8	NERC	R	PU	M48
D8.3	Prototype suite of open source scripts for downstream service assessment	8	NERC	Others	PU	M48

Table 3.1.2: List of Deliverables

3.2 Management structure, milestones and procedures

IMMERSE brings together fourteen partners and is considered to be a medium sized project. We have devised a management structure and decision making processes appropriate for the nature of the project and the size of the consortium, that can ensure that the project is well managed and that all objectives are achieved. A distinct Work Package (WP) – WP1: Management and Coordination, will ensure that this management structure is established. The project will be led and coordinated by Dr Julien Le Sommer, who has had experience in leading projects in ocean modelling research at the national level including several coordination projects. A project manager will be appointed at CNRS for the full duration of the project to assist Julien Le Sommer with the day-to-day management (24PM).

3.2.1 Overview of structure and decision-making bodies/mechanisms

The structure that has been adopted for IMMERSE follows the DESCA Model Consortium Agreement for Horizon 2020 projects (the model favoured by the Coordinating Institution), and specific roles and decision making responsibilities have been assigned accordingly. These are illustrated in Figure 3.2.1, and further detail is given below.

In summary:

- The **General Assembly** is the ultimate decision making body for IMMERSE and will be the supervisory body ensuring successful execution of the project. This will be chaired by the Coordinator and will consist of representatives from all of the partner organisations.

- The **Coordinator** is responsible for the overall coordination of the project and will act as the point of contact for the European Commission (EC). The Scientific Coordinator has ultimate responsibility for ensuring the scientific and technical integrity of the project and that it delivers what is expected.
- The **Scientific Coordination Board** is an advisory group comprising Mike Bell (Met Office), Doroteaciro Iovino (CMCC) and Claire Levy (CNRS, NEMO project manager) that will assist the Scientific Coordinator in supervising on-going activity and in preparing the General Assembly.
- The **Project Office** will conduct the routine management of IMMERSE and assist the coordinator.
- The **Work Package Leaders** (**and their co-leaders**) have a responsibility to ensure delivery of their Work Package objectives and deliverables, working closely with the Coordinator to support the outcomes of IMMERSE as a whole.
- The **External Expert Advisory Board** is a group of independent experts, whose role is to provide advice on project progress and plans.
- The **Stakeholder Groups** that IMMERSE will interact with were defined in Section 1.3 and 2.1. They will be represented on the General Assembly by the Scientific Coordinator.

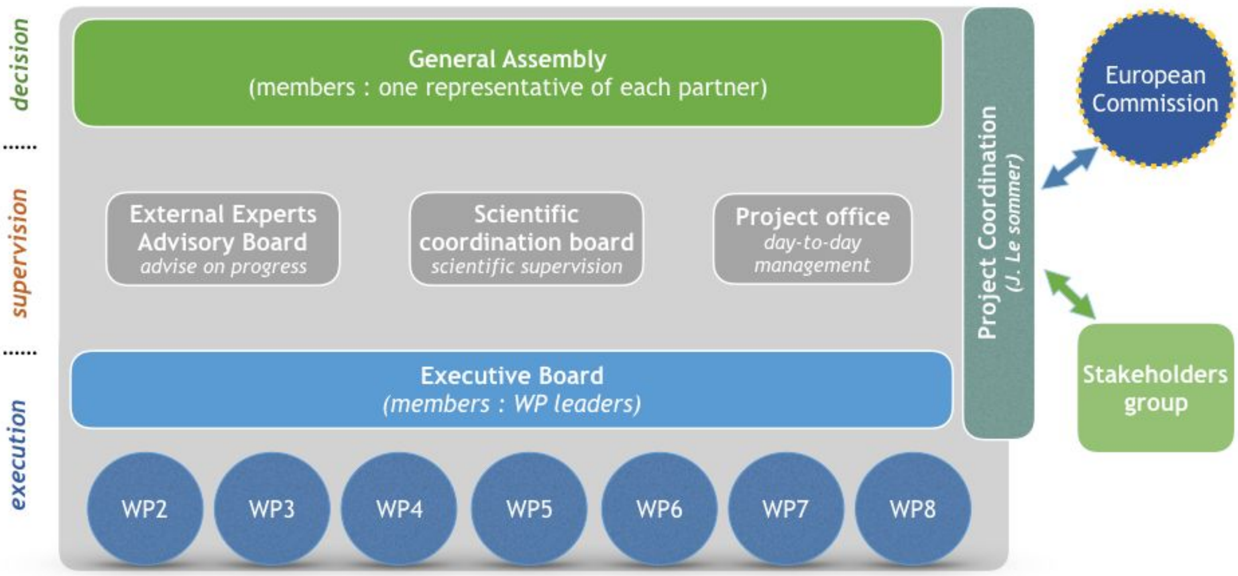

Figure 3.2.2: IMMERSE Management Structure

3.2.2 General Assembly (GA)

The GA will have oversight of the entire project and its purpose will be to:

- Act as the overall decision-making body for the project and be responsible for agreeing on how to implement these decisions;
- Deliver the aims, deliverables and milestones of the project;
- Oversee political and strategic orientation of the project;
- Share and disseminate knowledge as widely as possible across and beyond the project;
- Agree the work plan, and any changes to the plan;
- Ensure the proper operation of the consortium, including financial management, reporting and communication;
- Make and approve recommendations in the event of changes to the consortium composition or budget allocations;
- Act on any necessary alterations to the Consortium Agreement;
- Responsible for overseeing and resolving risks; any ethical issues that may arise; disputes and complaints; and intellectual property;
- Oversee the cross-cutting theme of gender balance.

There will be five General Assembly meetings; the first at project inception and then annually thereafter until project end. Additional meetings can be called at any time as required by any member of the General Assembly. These can be conducted via video-conferencing/Skype/Webex if appropriate. In principle, approval by the General Assembly to any decisions taken outside of the five core meetings; shall be given by e-mail vote. The framework for these voting procedures will be laid down in the Consortium Agreement.

3.2.3 IMMERSE Coordinator
IMMERSE will be coordinated in all the administrative, financial and management aspects by CNRS. This is at the delegation of the General Assembly. Day-to-day management tasks are listed in the WP1 table under Section 3.1.

IMMERSE Scientific Coordinator (Dr Julien Le Sommer)
Responsible for the overall coordination of the project; coordination with other EU funded and international projects; intermediary between the European Commission and the project, including communicating any agreements and proposed deviations from agreed plans; acting as the project point of contact for the independent advisory board. Responsible for monitoring scientific progress of the work packages; provides science leadership and quality assurance or the project; identifying any gaps; manages the scientific risks within IMMERSE, oversees effective innovation management for the project; and reports to the General Assembly. Coordinates and monitor the projects' gender balance strategy, plan and activities; and the knowledge management strategy. Has overall responsibility for the communications plan. Provides formal reports to the European Commission and is assisted by the project manager.

Project Manager
Responsible for facilitating internal communication within the project; providing support and planning tools for work package management; scheduling and organising meetings of the project; providing regular communications to the EC and IMMERSE; managing, monitoring and reporting of project finances and budget; management of the risks, benefits and issues registers; production of Gender Strategy and Action Plan; providing administrative support to the IMMERSE coordinator. The project manager reports to the General Assembly.

The Project Manager will be appointed at CNRS to work close to the coordinator. Specialist support (e.g. finance, legal and communications) will be provided to the project office by the appropriate CNRS departments (who also have extensive experience of European research programmes); and other partners' institutes when necessary.

3.2.4 IMMERSE executive board
Work Package Leaders (and any co-leaders) have been appointed. They form IMMERSE executive board. They will have the autonomous responsibility for coordinating the tasks within their work package to contribute to the delivery of the project goals and deliverables. The Executive Board will therefore provide the necessary support to the project's scientific coordination. They will ensure that the progress of their work package is tracked, monitored and reported on; including highlighting and discussing any departure from the proposed work and any problems with the Scientific Coordinator as early as possible. The executive board will assist with exchanges with other projects and the scientific community. To achieve these aims, the WPLs will meet face-to-face at the annual General Assemblies, and take advantage of other meetings that they will be attending outside of the project (e.g. various NEMO meetings). They will arrange other more regular teleconference meetings between those involved in their WP, and will communicate regularly with the Scientific Coordinator.

3.2.5 Stakeholder Groups
WP2 in IMMERSE will promote, coordinate and facilitate the exploitation of progress within IMMERSE by each of the regional Monitoring and Forecasting Centres contributing to the CMEMS, using the mechanisms outlined in Section 2.2. They will be represented at the IMMERSE General Assembly by the Scientific Coordinator.

For engagement with downstream users of CMEMS, IMMERSE will exploit primarily suitable existing user forums and other channels. It will coordinate with the CMEMS User Engagement Team in order to make appropriate inputs to the CMEMS Regional User Workshops. It will coordinate user workshops for its down-scaling tool (WP7) with the GOV COSS-TT and take advantage of other GOV Task Team meetings (such as joint meetings of the biogeochemistry and data assimilation Task Teams). It will also present its work to scientists who are well placed to exploit it at the Operational Oceanography sessions at EGU assemblies, and the annual Drakkar workshops and NEMO user workshops.

3.2.6 External Expert Advisory Board (EEAB)

This small independent group will be created by the IMMERSE Scientific Coordinator and will be made up of distinguished experts whose specialist subject matter is specifically relevant to this project. The EEAB members will provide independent evaluation and recommendations about improvements to the project's work plans, progress, tools and techniques. Consulting with the advisory board will ensure that the deliverables, milestones and associated prototypes of IMMERSE, support the overall aims of IMMERSE (e.g. respond to the needs of independent CMEMS service providers and national service suppliers downstream of CMEMS) and parallel European and international policies and activities. The EEAB will receive information detailing the project status and results. The advisory board has currently received formal commitment from: Sergey Danilov (scientific leader and main developer of FESOM ocean model), Alistair Adcroft (scientific leader and main developer of MOM6 ocean model), Agustín Sánchez-Arcilla (PI of H2020 CEASELESS, marine engineering expert), Pierre Brasseur (co-chair of the Scientific and Technical Advisory Committee of the Copernicus Marine Service, and ocean data assimilation expert), Pierre de Mey (Joint Chair of GOV COSS-TT and ocean data assimilation expert). The intention is to recruit another member to the EEAB, which IMMERSE will ensure will be female. Potential candidates have been identified.

The EEAB will be invited to attend each of the General Assembly meetings (arrangements will be made for those who cannot attend to participate via, for example, video-conferencing). The Scientific Co-ordinator will also hold telephone conferences with the EEAB at six monthly intervals. The advisory board will receive information detailing the project status and results from the Co-ordinator.

3.2.7 How the organisational structure is appropriate to IMMERSE

It is essential that the project management and decision making procedures are rigorous enough to manage all the complex technical developments and information exchange within the IMMERSE project environment (i.e., between partners, users, CMEMS and the European Commission) and the 'outside world' (i.e., adjoining projects, advisory board, wider user community) in as rapid and efficient a manner as possible. At the same time, since IMMERSE is a medium sized consortium, the management structure will be kept simple in order to optimise important interactions between all parties and to reflect the number of project partners. So IMMERSE only has one management body, which is its General Assembly; thus all partners will be involved in major decisions that need to be made. It is also worth remembering that IMMERSE is going to exploit the quality control around the technical developments of the NEMO code and system that exists within the NEMO consortium. This is another reason for the simple IMMERSE management structure. The representation of the stakeholder groups in the General Assembly means that they too have a voice in the decision making of IMMERSE.

The General Assembly will delegate some responsibilities and decisions to specific subsets of the General Assembly. For example, the management of specific areas of importance such as gender, ethics and IPR is expected to be carried out centrally through the Scientific Coordinator and Project Manager.

3.2.8 List of milestones

Table 3.2.1 details the project's milestones. These milestones will ensure that the project's progress is continually monitored. All the developments to NEMO code made available on NEMO development branches before M24 are associated with a dedicated milestone which means of verification will ensure that the expert review described in section 1.3.b. has been passed successfully. The associated development will then be integrated in NEMO 4.2 beta release to be distributed at M30 (D2.5).

Milestone number	Milestone name	Related WPs	Due date (month)	Means of verification
MS1.1	Description of process and procedures for treatment of personal data	WP1	M2	Procedures will be implemented for the collection, storage, protection, access, retention and destruction of any personal data. These procedures will be documented through this milestone report
MS1.2	Gender Strategy and Action Plan for IMMERSE defined and adopted by the consortium	WP1	M3	Plan written and agreed by consortium
MS7.1	User Remote Workshop (webinar)	WP7	M3	Assessed by attendance of feedback
MS1.3	Design and implement internal communication platform and tools	WP1	M4	Internal communication platform ready for use
MS2.1	Procedure for definition of academic demonstration cases available for WP3-5 developers	WP2	M6	Procedures described on NEMO information platform (internal use) and communicated to NEMO System Team
MS3.1	First specification of algorithm and outline design of code for the 2LTS to be implemented	WP3	M6	Documents available for scientific and technical review.
MS5.1	Optimized OBL mixing scheme in NEMO reference version (using wave model output and adapted to under ice and tropical conditions)	WP5	M9	Expert review (see section 1.3.b) available on NEMO information platform (internal use).
MS5.2	ABL-1D in NEMO reference version	WP5	M9	Expert review (see section 1.3.b) available on NEMO information platform (internal use).
MS5.3	Gathering all developments done in the ocean-wave community	WP5	M12	New ocean-wave code on a development branch on NEMO repository
MS3.2	Code for AGRIF change in vertical coordinates	WP3	M12	Expert review (see section 1.3.b) available on NEMO information platform (internal use).
MS5.4	EAP and VP rheologies into the NEMO sea ice model	WP5	M12	Expert review (see section 1.3.b) available on NEMO information platform (internal use).

MS2.2	Annual reports on the progress of NEMO development from IMMERSE to NEMO Steering committee	WP2	M13, M25, M37	Presentation made available internally on NEMO website
MS3.3	Delivery of first half of 2LTS code	WP3	M18	Expert review (see section 1.3.b) available on NEMO information platform (internal use).
MS4.1	Implementation and validation of a coupling interface between ocean and biogeochemistry separate executables	WP4	M18	Expert review (see section 1.3.b) available on NEMO information platform (internal use).
MS5.5	Advanced bulk (skin temperature and over sea-iced) in NEMO reference version	WP5	M18	Expert review (see section 1.3.b) available on NEMO information platform (internal use).
MS5.6	Wave compliant with bulks and OBL mixing in NEMO reference version	WP5	M18	Expert review (see section 1.3.b) available on NEMO information platform (internal use).
MS5.7	ABL-3D test simulations starting	WP5	M18	ABL-3D code on a development branch on NEMO repository
MS5.8	Biogeochemical developments in testing phase	WP5	M18	New biogeochemical code on a development branch on NEMO depository
MS8.1	Baseline scenario and assessment process established	WP8	M18	Relevant sections of D8.1 and 8.2 reports completed
MS7.2	Coupler tool released for community testing	WP7	M20	Assessed by Project Coordinator and WP8 group
MS3.4	Codes on pressure forces and vertical advection scheme (cf D3.2)	WP3	M24	Expert review (see section 1.3.b) available on NEMO information platform (internal use).
MS4.2	Integration of new coding approaches in core NEMO routines to improve the computational performance at node level	WP4	M24	Computational performance gain on high-resolution configurations, preserving the output accuracy
MS4.3	Extension of the use of XIOS for reading/writing operations in NEMO	WP4	M24	Expert review (see section 1.3.b) available on NEMO information platform (internal use).

MS5.9	Biogeochemical developments into the reference version of NEMO	WP5	M24	Expert review (see section 1.3.b) available on NEMO information platform (internal use).
MS4.4	First setup of online diagnostics operational scenarios for NEMO, based on high performance solutions for high memory nodes and heterogeneous architectures	WP4	M24	First prototype related to MS4.5 running on high memory nodes and heterogeneous clusters
MS5.10	Simulations with the 3 rheologies (VP, EVP & EAP) running in the 3 targeted resolution	WP5	M24	New rheologies code on a development branch on NEMO depository
MS8.2	Coupling toolkit received and implemented from WP7.3	WP8	M24	Relevant sections of D8.1 and 8.2 reports completed
MS4.5	Integration in NEMO of the AGRIF advanced features for load balancing	WP4	M24	The code should give the exactly same results but with a much better computational efficiency in the case of the presence of grids with low computational cost in the grid hierarchy
MS2.3	First demonstration cases documented on NEMO website for outreach	WP2	M30	Available on NEMO public website
MS6.1	Final specification of nested domains and parameterizations to be implemented	WP6	M30	Documents available for technical review
MS6.2	Configuration available for final HPC tests in WP4	WP6	M30	Code available
MS6.3	Final configuration design and specification of experiments to be performed for the overflow study	WP6	M36	Code and documents available for technical review
MS8.3	Case study improvement scenarios completed	WP8	M36	Relevant sections of D8.1 and 8.2 reports completed
MS4.6	Final setup of online diagnostics operational scenarios for NEMO, based on high performance solutions for high memory	WP4	M40	Final prototype related to MS4.5 running on high memory nodes and heterogeneous clusters

	nodes and heterogeneous architectures			

Table 3.2.1: List of milestones

3.2.9 Innovation Management

Effective innovation management within this project will require an overview of the project in its entirety and for this reason the Scientific Coordinator will be responsible for the process. Due to the nature of the project deliverables, both the technical and operational aspects of innovation are considered together. There is scientific expertise, technical and system expertise, and user engagement expertise within the consortium. Through the Scientific Coordinator, these elements will be brought together and will ensure that IMMERSE achieves its aim of CMEMS having access to the best marine modelling tools, which can be exploited by them and all users. This is the primary innovation impact of IMMERSE, and our approach to achieve the impact is discussed in Section 2.2.

Two further innovation areas were identified in Section 1.4, namely supporting the technical development of environmental monitoring from space, and supporting the technical development of the 'Intermediate User' sector. The pathways to achieve impact in those areas are described in Section 2.2.

3.2.10 Further Management Considerations

Gender Balance within IMMERSE
By signing the Grant Agreement, the IMMERSE consortium will commit to promoting equal opportunities during the implementation of the project, and makes a commitment to aim to achieve gender balance at all levels of personnel assigned to the project, including at supervisory, management and decision-making levels, as well as in the research team (Article 33.1 Grant Agreement). IMMERSE will ensure that where possible it works to satisfy the three primary Horizon 2020 gender balance objectives.

In IMMERSE, there is a 10:49 ratio of females to males as named individuals to work on the project and two of the work package leaders are female. The named EEAB members are currently male, however IMMERSE will ensure that the final member is female. Suitable candidates have been identified. All partners will be encouraged to stay up to date with gender training, and if necessary the Project Office will facilitate this training.

Gender Strategy
The promotion and monitoring of gender equality throughout the project will be the responsibility of the Scientific Coordinator, with support from the Project Manager. A Gender Strategy and Action Plan (MS1.2) will be produced by month three of the project, and will be monitored and updated during the project. The Scientific Coordinator will ensure that the Strategy is applied throughout the project, and that a process is followed for monitoring gender equality. The strategy will encompass both internal and external participants, and all partners are obliged to aim for gender equality. The strategy and plan will detail specific activities under each of the Horizon 2020 gender equality objectives, and associated measures. Links will be made with initiatives and commitments within each partner organisation to promote gender equality and advance women's careers in science, thus IMMERSE will benefit from existing efforts and expertise in this area and pull through lessons learnt to this project and to the wider ocean modelling community within Europe.
A section of the Project Progress Reports, produced by the project manager, will be dedicated to reporting on the Gender Strategy and will contain information on the Specific Performance Indicators for Horizon 2020 needed by the European Commission for monitoring the gender equality in this programme.

Ethics
The Ethics criteria have been considered. However, the nature of the activities proposed under IMMERSE means that there are very few ethical issues and it is not anticipated that the criteria will need to be invoked. Consideration has been given to the external groups and organisations who will be involved in the project.

Mainly organisational data will be collected. On occasions where any personal data is collected, procedures will be followed for the collection, storage, protection, retention and destruction of such data. Where commercially sensitive data is concerned, this will be identified and the relevant information will be withheld accordingly. All information will be gathered in accordance with guidelines laid down by the European Commission, and national legal requirements.

Knowledge Management

The partners have a collective responsibility to ensure that any knowledge collected, generated and disseminated by this Action, is appropriately protected and shared (intellectual property). However, the Scientific Coordinator is responsible for the action's knowledge management strategy and processes, ensuring they are kept up to date and that the associated protocols are adhered to. More detail on this is given in Section 2.2.

3.2.11 Critical risks for implementation

The General Assembly will be responsible for dealing with the risks, issues and benefits realisation of this project. The scientific coordinator will be responsible for management of these risks, including mitigation the risks, and proposing preventative and corrective solution in case of their occurrence. Day-to-day maintenance of the risk register will be undertaken by the project manager.

Critical risks to the project's implementation, which have the potential to impact the objectives being achieved, have been identified and described in Table 3.2.2 below. These risks will be actively managed and monitored throughout the period of the project, as will any new risks that arise. Where there are risks that exist specifically within individual WPs, these have been identified already and the design of the WPs has taken account of preventative measures for each.

Description of risk (indicate level of likelihood: Low/Medium/High)	**Work packages involved**	**Proposed risk-mitigation measures**
Model developments are too computationally expensive for operational use (L)	5	Careful review at code design stage (see section 1.3b)
Some developments do not initially increase the model skill (M)	3-6	Preparatory selection of developments has been informed by expert discussion in NEMO development strategy process. WP plans include a substantial evaluation phase which will allow tuning/modification.
Code developments from different WPs are difficult to integrate (M)	3-5	Task 2.1 maintains regular communication between IMMERSE NEMO developers. Consortium members have strong experience and track record in integrating parallel developments through NEMO annual merge process.
The coastal interface system is not taken up by coastal modelling user community (L)	7	Proactive, early, constructive engagement with key groups to establish user requirements, including WP7 webinar. Responsive and open systems development.
Difficulty in recruiting/deploying appropriately skilled staff for some of the technical tasks, resulting in delays (L)	3-8	Established staff numbers with NEMO expertise in partner institutions mitigates this risk. Reduce reliance on single points of expertise by making sure that multiple team members are able to work on project

Table 3.2.2: Critical Risks for Implementation

3.3 Consortium as a whole

The IMMERSE consortium brings together academic institutions and operational service providers that together can make transformational changes to the NEMO reference code that are needed to satisfy the CMEMS user community. The IMMERSE consortium relies on the existing NEMO Consortium, and includes nine additional institutions as described below.

The NEMO Consortium was formed in 2008 through a formal Agreement. Its purpose was "to set up appropriate arrangements for the successful and sustainable development of the NEMO System as a well-organised, state-of-the-art ocean model code system suitable for both research and operational work." The Consortium now contains five European research and operational institutions all of whom are participating in IMMERSE (CMCC, CNRS, Mercator-Ocean, NERC and the Met Office). The evolution and maintenance of NEMO relies on a team of expert developers from within these organisations, the NEMO System Team. This team is responsible for the validation, documentation and distribution of the open source NEMO code repository (also called the "NEMO reference code"). Since 2008, this Team and the Consortium as a whole has proven its effectiveness, both for the development of NEMO itself and in gathering, enhancing and increasing the NEMO community involved in research and operational applications.

Complementarity of the partners and coverage of the value chain
The operational institutes involved in IMMERSE have strong links with the teams providing the CMEMS and with the intermediate users downstream of CMEMS. They also have experience and skills in the assessment of the suitability of developments for CMEMS, some skills in the development of new schemes, and strong links with ocean research institutes. All but one of the research institutes in IMMERSE have a track record of working with these operational institutes, and have very strong links with the international research community. They have in depth expertise in many aspects of the science and technology of ocean modelling.

Expertise matched to objectives
The consortium as a whole has the expertise needed to deliver the five main objectives described in Section 1.1. Each WP team combines members with the scientific, technical and planning expertise needed to achieve the identified tasks. For the first objective we have chosen experts in adapting codes for modern HPCs, experts in numerical analysis, the lead developer of the AGRIF nesting tool and several expert members of the NEMO System Team (NST). The involvement of NST members, particularly in objectives 1, 2 and 5, will ensure that the project's developments feed through into new versions of the NEMO reference code. The IMMERSE team also comprises internationally recognised experts in air-sea interaction, parameterisation of turbulence, sea-ice modelling and ocean data assimilation, who are very well placed to perform the proposed work towards Objectives 2 and 3. The team working on the flexible external interface (Objective 4), has considerable experience in coastal modelling, and skills in developing flexible python tools for NEMO inputs and outputs. For objective 5, the NST members have expertise in improving code reliability and the operational institutes are very experienced in engaging with users and planning operational implementation of developments.

Roles and contributions of individual members
CNRS is very experienced in leading EC proposals. The coordinator has strong expertise in ocean model numerics and led the writing of the NEMO Development Strategy 2018-2022. He has a strong experience in coordinating research projects involving code developments. The WP5 leader is a renowned expert in high resolution ocean modelling and air-sea interactions at fine scales, with experience in leading research projects and EU project work-packages. The CNRS team also includes the leader of the NST since 2008 and the original author and lead developer of NEMO (Gurvan Madec).

The WP4 leader from **CMCC** is an expert in the development of NEMO for modern HPCs and joint leader of the NEMO HPC working group. She leads the High End Computing research group of the Advanced Scientific Computing at CMCC. The WP7 leader is an expert in high resolution ocean modelling. She coordinates the research activities of Ocean and Sea-Ice Modelling group within the Ocean Modeling and Data Assimilation Division at CMCC. CMCC is the CMEMS MFC for the Mediterranean.

The WP8 leader from **NERC** has considerable expertise in shelf-seas modelling and is joint leader of the UK's National Partnership for Ocean Prediction (NPOP). The team includes experts in the NEMO system (WP3), spurious numerical mixing (WP3), the parameterisation of turbulent mixing (WP5) and the development of flexible python tools for NEMO outputs (WP7).

The WP6 leader from **Mercator-Ocean** has a wide-ranging expertise in operational oceanography. He is a member of Mercator-Ocean R&D division, where he is in charge of developing, tuning and validating the high-resolution oceanic and ice model of the future Mercator Ocean prototype. The Mercator-Ocean team includes Mercator Ocean NEMO officer, an expert in the application of AGRIF to NEMO and in the numerics involved in time-stepping and vertical coordinates and an expert in air-sea interaction. Mercator-Ocean is the entrusted entity which defines, implements and operates CMEMS.

The WP3 leader from the **Met Office** is a very experienced WP leader with expertise in the numerics of ocean models and a long-term involvement in NEMO, CMEMS and ocean data assimilation. The team includes an experienced NST member with expertise in ocean numerics (in WP3), experts in adapting code for HPCs (WP4), the joint leader of the new European sea-ice model (in WP5) and the leader of the GODAE-OceanView Data Assimilation Task-Team (WP7). The Met Office is the CMEMS MFC for the north-west European shelf.

The **BSC** team members have made valuable improvements to the performance of NEMO on modern HPCs and are key members of WP4.

The **INRIA** team brings outstanding expertise in applied mathematics and ocean numerics to the IMMERSE consortium and includes the lead developers of the AGRIF code. Their contribution is vital to WP3, WP4 and WP5.

PdE has been chosen to demonstrate high resolution nesting capabilities (WP6) because of its long standing contribution to the Iberian-Irish (IBI) CMEMS system. The **Ocean Next** team member in WP5 is a NEMO Developer Committee member with renowned expertise on air-sea interaction.

For the demonstration of two-way exchange with downstream services in WP8, **UNIBO** and **HZG** have been selected for their expertise in coastal prediction, **Univ Utrecht** for its leading expertise and innovation in Lagrangian tracking and **PML** for its expertise in shelf seas and coastal biogeochemistry.

3.4 Resources to be committed

The total requested European Commission contribution for IMMERSE is 4 999 015€. The fourteen partners have offered 626 person.months to the project.

3.4.1 Financial planning approach

The largest percentage of the funding for IMMERSE is required for personnel costs, as the project will rely on the skills and many years of expertise of the partner organisations and key personnel involved. Therefore it was key that the budget was calculated using an estimation of the costs associated with these experts that have been identified to deliver the project's objectives. As tasks and the scope and description of IMMERSE developed; the associated estimate of personnel resources developed. This iterative approach to calculating the required budget will ensure a good estimate of the resources required; and associated funding required.

A simple travel and meeting plan for the project was drafted, and as a result, the partners' travel budgets were calculated. It is assumed that many of the IMMERSE meetings, including General Assemblies, will utilise existing NEMO community meetings, thus keeping the budget incurred by IMMERSE to a minimum.

All unnecessary travel will be avoided, and alternative forms of communication will be used if possible (i.e., teleconference/Skype); certainly in the case of internal meetings and discussions.

3.4.2 Distribution and breakdown of resources

3.4.2.1 Personnel costs

Personnel costs represent 92% of the direct cost budget. Table 3.4.1 shows the amount of staff effort broken down by beneficiary and by work package. The time that work-package leaders will commit to coordinating their work package activity and liaising with IMMERSE coordinator is included in the budget for their work-package (4PM per work-package).

Management activities – The coordinator will allocate 12 PM to the project management and the coordination (WP1) and a part-time project manager will be recruited at CNRS for the duration of the project, corresponding to 24 PM.

Others – In order to harmonize the average personnel costs across the consortium, CNRS has chosen to request only 75% of the direct cost associated with permanent staff personnel costs, the extra 25% will be covered as an in-kind contribution by CNRS and its third parties. This excludes the cost for the project manager (24PM) and the CERFACS third party (9PM).

	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	Total PMs per Participant
1/CNRS	36	24	4	9	29	2	2	0	106
2/CMCC	0	0	0	34	27	12	17	0	90
3/NERC	0	0	30	0	23	20	11	9	93
4/Mercator Ocean	0	2	26	3	9	32	0	0	72
5/Met Office	0	0	30	27	6	2	12	0	77
6/BSC	0	0	0	14	0	0	0	0	14
7/INRIA	0	0	36	6	0	0	0	0	51
8/PdE	0	0	0	0	0	24	0	0	24
9/Ocean Next	0	0	0	0	18	6	12	0	36
10/GEOMAR	0	12	0	0	0	0	0	0	12
11/UNIBO	0	0	0	0	0	0	0	15	15
12/HZG	0	0	0	0	0	0	0	12	12
13/U. Utrecht	0	0	0	0	0	0	0	12	12
14/PML	0	0	0	0	0	0	0	12	12
Total PMs	**36**	**38**	**126**	**93**	**121**	**98**	**54**	**60**	**626**

Table 3.4.1: Summary of staff effort

3.4.2.2 Other direct costs

About 5% of the direct costs budget has been put aside for travel. This includes small allocations for the Advisory Board to attend the IMMERSE General Assemblies. Other direct costs will also cover publication fees in open access peer-reviewed literature.

One of the partners has other direct costs budgets that are greater than 15% of their personnel costs. Table 3.4.2 provides the breakdown in detail of these other direct costs.

11/UNIBO	Cost (€)	Justification
Travel	**7400**	**Project/WP meetings, conferences etc**

Equipment		
Other goods and services	**5500**	**Open access (3500), conference fees (2000)**
Total	**12900**	

Table 3.4.2: Summary of other direct costs for participants UNIBO

Appendix 1 : Illustration of demonstrators

This appendix shows illustrations of two IMMERSE demonstrators that will be deployed in WP6.

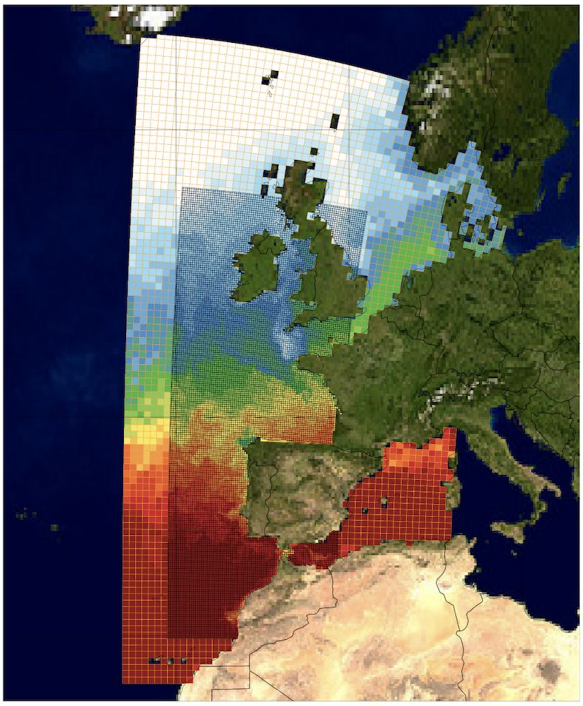

Figure A1.1 : Illustration of the prototype IBI-MFC demonstrator (WP6, Task 6.1). The domain covers the whole IBI region at a resolution of 1/36° with a 2-way nested area at higher resolution which covers a fraction of the western Europe coastal areas. Sea surface temperature is shown in background. For both grids, only one grid cell every 400 grid cells is plotted.

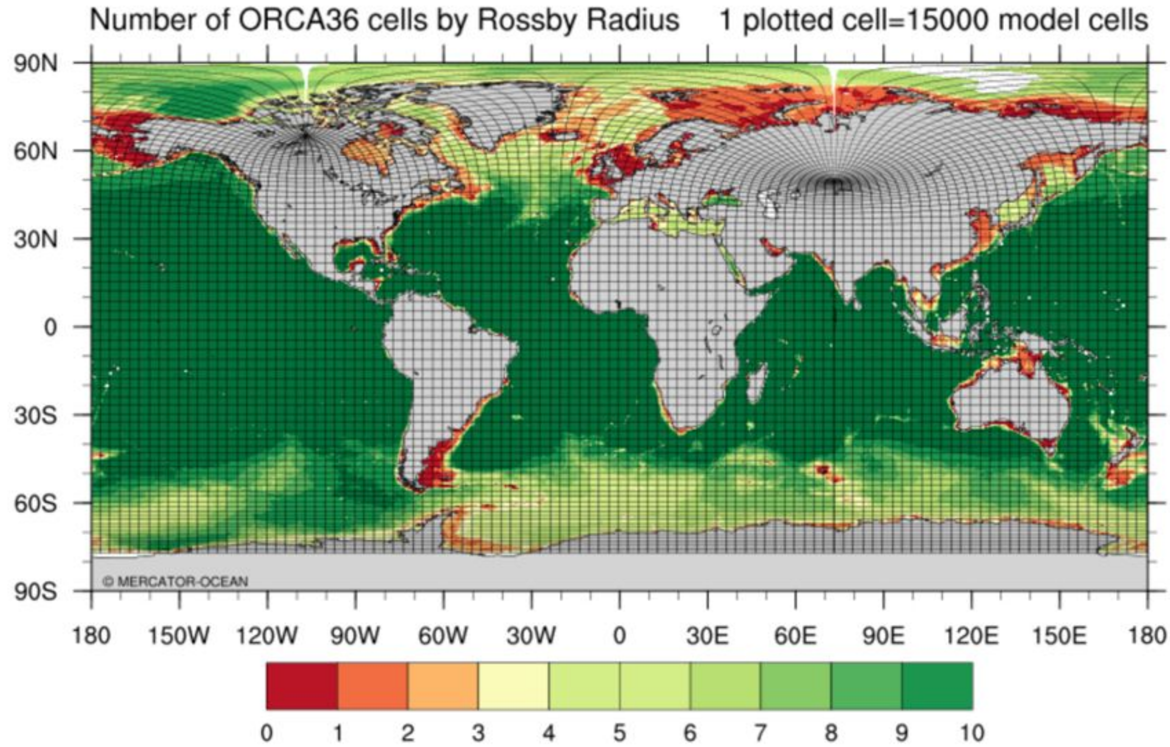

Figure A1.2 : Illustration of the prototype global demonstrator at 1/36° (WP6, Task 6.3). This shows the number of grid cells per first baroclinic Rossby radius. This new NEMO configuration will allow to describe oceanic flows with more than 4 grid cells per Rossby radius over most of the global ocean (grid resolution of 2-3 km). The climatological Rossby radius (2000-2014) is computed from a new 1/12° CMEMS ocean reanalysis. Lines indicate the model grid with one cell every 15 000 grid points.

Appendix 2 : Letters of support

The IMMERSE team has received support letters for IMMERSE proposal from :

- **Pierre Bahurel,** CEO of Mercator Ocean, entrusted entity for the implementation of CMEMS
- **Glenn Nolan**, secretary general of EuroGOOS AISBL
- **Eric Chassignet**, co-chair of GODAE OceanView
- **Nils Wedi**, Head of the Earth System Modelling division at ECMWF
- **Baylor Fox-Kemper**, co-chair of CLIVAR Ocean Model Development Panel

These letters are included in part B section 6.

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Section 4: Members of the consortium

4.1. Participants (applicants)

Participant 1: Centre National de la Recherche Scientifique (CNRS)

The **Centre National de la Recherche Scientifique** (CNRS) is a government-funded research organisation under the administrative authority of France's Ministry of Research. With about 33 000 staff, CNRS is the main fundamental research organisation in Europe and is largely involved in national, European, and international projects covering all fields of knowledge. CNRS is organised in different types of laboratories in partnership with universities, other research organisations or industry, corresponding to joint research units. CNRS has developed the first versions of NEMO dynamical core (OPA). Since the creation of the NEMO consortium, CNRS has been involved in the development and in the coordination of the NEMO consortium. The Alpes Delegation of CNRS will manage IMMERSE project, and is fully experienced in this field with dedicated staff in legal, financial and administrative issues.

CNRS will contribute to IMMERSE project through 3 research laboratories. The "Institute for Geosciences and Environmental research" (IGE) is a public research laboratory in Earth and Environmental Sciences. IGE conducts research on climate, the water cycle, cryosphere and natural and anthropized environments. The "Laboratoire d'Océanographie et du Climat : Expérimentations et Approches Numériques" (LOCEAN) is a public research laboratory in Earth and Environmental Sciences. LOCEAN conducts research on the physical and biogeochemical processes controlling oceanic variability at various scales. "Climat, Environnement, Couplages et Incertitudes" (CECI) is a public research laboratory in Earth and Environmental Sciences. CECI conducts research in climate variability and on geoscientific modelling.

Short profile of key personnel involved:
IMMERSE CNRS team involves in alphabetical order :

Dr. Olivier Aumont (Male), PhD, is a IRD research scientist. He is an expert in ocean biogeochemical modelling and the lead developer of PISCES model. He is a member of NEMO System Team where he contributes to the design and implementation of NEMO interface with biogeochemical models (NEMO-TOP). He will contribute to WP5.

Dr. Bernard Barnier (Male) PhD, is a CNRS research Scientist at Institut de Geosciences de l'Environnement. His research is on the role of the ocean in the climate variability, ocean forecasting and physical understanding of the dynamical processes that generate variability in the ocean over a wide range of space and time scales. He was the President of the Ocean Sciences Division of the European Geosciences Union (2010-2013) and has been leading DRAKKAR coordination since its foundation. He is involved in WP6.

Dr. Jean-Michel Brankart (Male) PhD is Research Engineer at CNRS. He has about 20 years experience in the development and application of ocean data assimilation, with various interests including ensemble simulations, quantification of modelling uncertainties, parameterization of forecast and observation errors. He has over 50 research publications in peer-reviewed journals and participated to several EU-funded ocean modelling and data assimilation projects (MODB, MATER, DIADEM, TOPAZ, MERSEA, MyOcean, Sangoma, AtlantOS). He is involved in WP7 to contribute to the predictability studies.

Simona Flavoni (Female) holds her degree in mathematics at Rome University. She is engineer at CNRS since 2009, she is the CNRS NEMO Officer i.e. she represents CNRS in NEMO consortium and she's responsible of the CNRS Annual Workplan. She executed various climate model experiment for CMIP5 exercise, she was involved in IS-ENES1 and IS-ENES2 European Projects and she took part in

COMODO ANR project. She leads the Robustness & Test Cases working group. She is interested in numerical analysis, she is strongly involved in development of idealized configurations in NEMO. She will contribute to WP2.

Dr. Julien Le Sommer (Male) PhD, is a CNRS research Scientist at Institut de Geosciences de l'Environnement where he co-leads the MEOM research group. With his background in applied mathematics and physical oceanography, his main field of expertise is on the modelling and understanding of oceanic fine scale processes. He has been involved in high resolution ocean modelling with NEMO since 2004 as a member of DRAKKAR coordination. Since 2013, he is in charge of the scientific coordination of NEMO research activities for CNRS and Mercator-Ocean. He was a lead author of NEMO Development Strategy 2018-2022. He is also an active member of CLIVAR Ocean Model Development Panel and of SWOT mission Science Team, where he uses submesoscale permitting NEMO simulations for preparing the upcoming SWOT altimeter mission. Website : http://lesommer.github.io

Dr. Claire Lévy (Female), PhD in numerical ocean modelling, is software engineer at CNRS. She has been working on NEMO (previously OPA) development since the 1990s. She has been a major contributor to building of the NEMO Consortium and is NEMO Project Manager since 2008. She will contribute to WP2 on the quality control procedures for NEMO developments.

Dr. Gurvan Madec (Male), PhD, has been a CNRS research scientist in physical oceanography and ocean modeling since 1990. Gurvan Madec is a NEMO expert and a member of the NEMO System Team. He is the main developer of NEMO and the scientific leader of the NEMO consortium. He is a funding member of DRAKKAR coordination and a former member of CLIVAR Ocean Model Development Panel. He has contributed to more than 200 research papers covering a range of topics in the field of ocean modeling and numerical methods, small scale ocean processes, ocean biogeochemistry, air-sea interaction, high latitude processes and climate studies. He will contribute to WP3.

Eric Maisonnave (Male) started working as research engineer at CERFACS in 1999. He has developed abilities to configure and use several OASIS-based coupled models. He was involved in the European projects IS-ENES1&2, to facilitate Earth System Model assembling and provide dedicated support in link with OASIS coupling to several European laboratories. He has a broad experience in HPC and code parallelisation. His main current interests are code coupling, set up and technical validation of sustainable climate models. In WP4, he will introduce a new OASIS-based coupling in NEMO (biogeochemistry), to increase modularity and performances of the ocean model.

Nicolas Martin (Male), Engineer in Programming and Information Technology. Within the NEMO System Team, Nicolas oversees the web presence of the project and rolls out the collaborative environment for the NEMO community (users and developers). He is in charge of the institutional website (www.nemo-ocean.eu), the distribution/development platform of the source code (http://forge.ipsl.jussieu.fr/nemo) and the mailing lists for internal/external communications. He has build by full refactoring a simple and flexible verification tool (https://pagesperso.locean-ipsl.upmc.fr/ntmlod/trusting) which will serve as a building block for the implementation of a continuous integration service for WP2.

Dr. Sébastien Masson (Male), PhD, has a permanent position at LOCEAN-IPSL. With more than 20-year experience on NEMO, he is member of the NEMO system team since 2005. His specific fields of expertise encompass air-sea interactions from basin-scale to eddy-scales, frontier ocean-atmosphere coupled simulations and high performance computing. His is the leader of WP5.

Dr. Clément Rousset (Male), PhD is a research engineer employed by CNRS with a PhD in physical oceanography obtained in 2008 at the University Pierre et Marie Curie (UPMC). He is working as a sea-ice modeler in the NEMO system team at LOCEAN (Paris, France) and is one of the main developers of LIM3. His current interests cover sea-ice and ocean physics from small scale O(1 km) to global scale O(100 km). He will be involved in WP5.

Dr. Martin Vancoppenolle (Male), PhD, is a CNRS research scientist. He wants to understand the role of sea ice in the Earth System. To do that, he studies sea ice physical, biological and chemical processes from observations and numerical models. He has contributed to the development of LIM, the sea ice model of NEMO, the European ocean modelling system, used in several Earth System Models used as a basis for IPCC reports and co-leads the sea ice working group. He also (within the international team BEPSII) has gathered and analyzed databases of Antarctic sea ice biogeochemical parameters and taken part to several missions on the field. He will be involved in WP5.

Relevant publications, and/or products, services, or other achievements :

- **Brankart J.-M.**, Candille G., Garnier F., Calone C., Melet A., Bouttier P.-A., Brasseur P. and Verron, J. (2015). A generic approach to explicit simulation of uncertainty in the NEMO ocean model. Geoscientific Model Development, 8, 1285-1297.

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- **C. Rousset**, M. Vancoppenolle, **G. Madec**, T. Fichefet, **S Flavoni**, A. Barthélemy, R. Benshila, **J. Chanut**, **C. Levy**, **S Masson**, and F. Vivier (2015). The Louvain-la-Neuve sea ice model LIM3.6: global and regional capabilities. Geoscientific Model Development, 8:2991–3005.

Relevant previous projects or activities:

- **CMEMS MFC GLO-HR Scientific Evolutions of production systems** (22-GLO-HR tender) (2016-2019) : R&D project aiming at providing the science basis for guiding the evolution of CMEMS global MFC high resolution component by 2020.
- **NASA/CNES SWOT Science Team project** (2016-2019): Research project aiming at preparing SWOT mission by through submesoscale permitting NEMO simulations and observation system simulation experiments.
- **EU FP7 IS-ENES2** (2013-2017), follow on of EU FP7 IS-ENES (2009-2013). European projects aiming at developing and consolidating a common climate and Earth system modelling distributed research infrastructure in Europe and stimulating common developments of software for models and their environments. The IS-ENES3 infrastructure project is now being submitted.

- **EU H2020 ATLANTOS** (2015-2019), is aiming at optimising and enhancing the integration of Atlantic Ocean Observing systems to the benefit of Copernicus Marine Environment Monitoring Service. The CNRS team contributes to this project by leveraging NEMO ocean model for conducting Observing System Simulation Experiments in WP5.

- **ANR COCOA** (2016-2019): Project funded by the Agence Nationale de la Recherche aiming at revisiting the mathematical, numerical and algorithmic formulations of ocean atmosphere coupling in Climate Models and to propose a mathematically justified coupling algorithm reducing the spatial and/or temporal inconsistencies associated to present-day coupling methods

Relevant significant infrastructure and/or any major items of technical equipment:

GENCI is a french HPC infrastructure funded by the french ministry of research in partnership with french universities, CNRS and INRIA in 2007. GENCI provides high-performance computing resources and promote the use of supercomputing to the benefit of French scientific communities. GENCI provides access to Tier-0 and Tier-1 HPC resources distributed in 3 centers across France on a call for project basis. Through GENCI, the IMMERSE CNRS team leverage about 5M cpu hours every year on Tier-0 and Tier-1 supercomputing facilities. GENCI ressources will provide the computing resources for CNRS partner within IMMERSE.

Participant 2 : Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)

The **Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)** is a non-profit research institution (www.cmcc.it). CMCC's mission is to investigate and model our climate system and its interactions with society to provide reliable, rigorous, and timely scientific results, which will in turn stimulate sustainable growth, protect the environment, and develop science driven adaptation and mitigation policies in a changing climate. CMCC collaborates with experienced scientists, economists, and technicians, which work together in order to provide full analyses of climate impacts on various systems such as agriculture, ecosystems, coasts, water resources, health, and economics. CMCC also supports policymakers in setting and assessing costs, mitigation, and adaptation policies. CMCC benefits from the extensive applied research experience of its members and institutional partners: Istituto Nazionale di Geofisica e Vulcanologia (INGV); Università del Salento; Centro Italiano di Ricerche Aerospaziali (CIRA S.c.p.a.); Università Ca' Foscari Venezia; Università di Sassari, Università della Tuscia, Politecnico di Milano.

CMCC research activities are distributed among eight research divisions that share different knowledge and skills in the field of climate science: Advanced Scientific Computing (ASC) Division; Climate Simulation and Prediction (CSP) Division; Economic analysis of Climate Impacts and Policy (ECIP) Division; Impacts on Agriculture, Forests and Ecosystem Services (IAFES) Division; Ocean modeling and Data Assimilation (ODA) Division; Ocean Predictions and Applications (OPA) Division; Risk Assessment and Adaptation Strategies (RAAS) Division; Regional Models and geo-Hydrological Impacts (REHMI) Division.

CMCC acquired portfolio of research projects includes 250 funded projects: 37 funded projects in FP6 and FP7, 37 funded projects in H2020 and 176 funded projects under other EU and international research grants. In about a half of the implemented projects, CMCC acted as the coordinator.

For further information on CMCC please see Annual Report 2016 and CMCC Strategic Plan (www.cmcc.it/publications-type/annual-report)

Short profile of key personnel involved:

Dr. Doroteaciro Iovino (Female), PhD., holds a Ph.D. in physical oceanography from the Geophysical Institute, University of Bergen (Norway). She expanded her knowledge and experience in oceanography and numerical modelling during the post-doctorate at the Laboratoire d'Océanographie et du Climat: Expérimentations et Approches Numériques (LOCEAN) in Paris (France), and is currently a scientist at the Euro-Mediterranean Centre on Climate Change (CMCC), in Bologna, where she coordinates the research activities of Ocean and Sea-Ice Modelling group within the Ocean Modeling and Data Assimilation Division since 2015. She has been involved into several national and international projects, with more than 10 years of experience working on ocean and sea ice modelling, both on the technical and scientific aspects, with particular interest in the high-resolution ocean/sea ice modelling. She was involved in high-resolution ocean modelling within ENS4OCEAN, PRACE funded project, and now coordinates the PRACE project ROMEO. Since 2017, she is member of the CLIVAR/CliC Northern Oceans Regional Panel (NORP). As NEMO Officer, she leads the CMCC effort within the NEMO System Team in developing the model system, member of the NEMO sea ice Working Group since 2016. Since 2012, she teaches in Ph.D. programme in Science and Management of Climate Change at Ca' Foscari University in Venice. She will lead WP7 and will contribute to activities in WP5 and WP6.

Dr. Silvia Mocavero (Female), PhD, is scientist at the "Advanced Scientific Computing" (ASC) Division of the "Euro-Mediterranean Center on Climate Change" (CMCC), where she leads the "High End Computing" research group. Her skills include parallel programming on hybrid architectures, distributed environments, and a long experience in several parallel programming models: message passing, shared memory, many-threads programming with accelerators. She is currently exploring new computing issues, such as exascale computing. She works on the performance analysis and optimisation of climate models with a particular focus on the NEMO ocean framework. She has been Visiting Scientist at Barcelona Supercomputing Center (BSC) and at Argonne National Laboratory (ANL) working on NEMO benchmarking on large HPC systems. Since 2012, she has been a member of the NEMO System Team and, since 2014, member of the HPC group of the NEMO Consortium. She has been strongly involved in several EU projects such as GridLab, CoreGRID, IS-ENES1, IS-ENES2 and national projects like FIRB Grid.it and TESSA. She is currently involved in the ESIWACE CoE, working on models scalability. She is co-author of more than 25 papers in journals/proceedings on high-performance, distributed and grid computing. In IMMERSE, she will lead and contribute to activities in WP4.

Dr. Sandro Fiore (Male), Ph.D., Director of the Advanced Scientific Computing (ASC) Division of the Euro-Mediterranean Centre on Climate Change Foundation. His research activities focus on parallel and distributed computing, in particular on scientific data management, big data, data analysis, mining and high-performance data analytics. He has been Visiting Scientist at Lawrence Livermore National Laboratory (LLNL) working at PCMDI in the context of the Earth System Grid Federation (ESGF). Since 2004, he has been involved in several national and international projects, such as: EGI-InSPIRE, IS-ENES, EUBRAZILCC, ExArch, ORIENTGATE, TESSA, OFIDIA, CLIP-C, INDIGO-DataCloud, EUBra-BIGSEA and ESIWACE, working on data management topics. Since 2010, he has been the Principal Investigator of the Ophidia project, a research project on high performance data analytics, mining, and diagnostics for eScience. He is the author and co-author of more than 60 papers in refereed books/journals/proceedings on parallel and distributed computing and holds a patent on data management. He is the editor of the book "Grid and Cloud Database Management" (Springer, 2011). He is an ACM Member. He will be involved in WP4.

Dr. Tomas Lovato (Male), PhD, is a scientist at the Ocean modeling and Data Assimilation division of Fondazione CMCC, working in the marine ecosystem modelling group. He obtained his Ph.D. in 2009 at the Ca' Foscari University of Venice in close collaboration with the University of Hamburg, studying the hydrodynamic circulation and biogeochemical cycles of the composite system Adriatic Sea/Lagoon of Venice. In 2011, he joined the Ocean Modeling and Data Applications Division of CMCC to develop the Biogeochemical Flux Model (www.bfm-community.eu) and its applications to the Mediterranean Sea, within the EU framework 7 projects MedSEA and PERSEUS, and the high-resolution global configuration during MyOcean2. At present, he is the technical responsible for the development of the marine biogeochemical component of the CMEMS Black Sea MFC and of the CMCC Earth System Model in the EU H2020 project CRESCENDO. His expertise mainly includes the modelling of coupled physical and biogeochemical marine systems, analysis of low trophic level ecosystem dynamics, and climate dynamics interaction with the marine ecosystems. He will be involved in WP5.

Dr. Emanuela Clementi (Female), PhD, presently researcher at INGV (National Institution for Geophysics and Volcanology), Italy, degree in Environmental Engineering, Ph.D. in Hydraulic and Maritime Engineering. She has experience in coastal wave circulation and wave-structure interactions achieved through numerical and physical experiments; she has performed numerical modelling of the marine ecosystem dynamics and production of marine environmental forecasting in the Adriatic Sea. During last years she focused her research activity on ocean and wave numerical modelling in the Mediterranean Sea and on the study of wave-current interaction processes and their numerical development and implementation. In the frame of the Copernicus Marine Service, she is leading the numerical developments of the analysis and forecasting physical system of the Med-MFC and she is Product Quality responsible of the Med-MFC consortium. She is representative in the EuroGOOS network (pan-European network operating within the Global Ocean Observing System of the Intergovernmental Oceanographic Commission of UNESCO), member of the GODAE Intercomparison and Validation Task Team, Officer for the NEMO consortium and she has been responsible of the NEMO-WAVE working group. She participated in several European and National projects related to ocean modelling and operational oceanography, recently: EMODnet MedSea Checkpoint, MyOcean2, MyOcean FO, CMEMS Med-MFC. She will be involved in WP5 and WP6.

Dr. Eng. Stefania A. Ciliberti (Female), PhD, is a Researcher at CMCC Ocean Predictions and Applications Division. She is Research Leader of the Numerical Modelling Group since 2015, leading the numerical developments and design of novel operational procedures for regional configurations in the Central Mediterranean and in the Black Sea. In the frame of Copernicus Marine Service, she is BS-MFC Leader Deputy and Responsible for the BS-Physics PU, guaranteeing service evolution and continuous production and delivery of data for the Black Sea ocean state. She is also Task Leader within JERICO-NEXT Project, related to optimal OSE/OSSE systems in coastal areas. In the frame of the NEMO Community Model, she is Scientist of the System Team and Leader of the Configuration Manager Working Group. Since 2016, she is Permanent Representative of Italy within World Meteorological Organization (WMO) for the Global Data Processing and Forecasting Systems Group and Member of its Steering Group. She collaborates and supports CMCC OPA Division national and international projects in the framework of ocean modelling, operational oceanography and research-to-operations activities. She holds a Ph.D. in Hydraulic Environmental Engineering in 2012 from the University of Calabria (Italy) and a M.Sc. Degree in Environmental Engineering cum laude in 2007 from the same University. She will contribute to WP7 activities.

Massimiliano Drudi (Male) holds a Master degree in Scientific Computing and a Master degree in Computer Engineering from Rome "La Sapienza" University. He is member of NEMO System team in NEMO Consortium and participated in EU projects, as MyOcean and CMEMS Med MFC, related to the implementation of the European Marine Service, with special focus on Mediterranean Sea. His expertise is on HPC performance analysis and on delivery operational oceanography system. He will contribute to WP4.

Relevant publications, and/or products, services, or other achievements :

- **Iovino, D.**, S. Masina, A. Storto, A. Cipollone, and V. N. Stepanov (2016) A 1/16 eddying simulation of the global NEMO sea ice-ocean system. Geosci. Model Dev., 9, 2665-2684. doi:10.5194/gmd-9-2665-2016.

- Epicoco I., **Mocavero S.**, Porter A. R., Pickles S. M., Ashworth M., Aloisio G. (2017). Hybridisation strategies and data structures for the NEMO ocean model, International Journal of High Performance Computing Applications, SAGE Publications, ISSN 1094-3420, Online ISSN: 1741-2846, DOI: 10.1177/1094342016684930

- Galli, G., Solidoro, C., and **Lovato, T.** (2017). Marine heat waves hazard 3D maps and the risk for low motility organisms in a warming Mediterranean Sea. *Frontiers in Marine Science*, *4*, 136.

- **Clementi E.**, Oddo P., **Drudi M.**, **Pinardi N.**, Korres G., Grandi A. (2017). Coupling hydrodynamic and wave models: first step and sensitivity experiments in the Mediterranean Sea. Ocean Dynamics, Volume 67 (10), pp.1293-1312. Doi: https://doi.org/10.1007/s10236-017- 1087-7.

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Relevant previous projects or activities:

- **EU H2020 Project PRIMAVERA** (PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment; 2015-2019). The goal of PRIMAVERA is to deliver novel, advanced and well-evaluated high-resolution global climate models (GCMs), capable of simulating and predicting regional climate with unprecedented fidelity, out to 2050. The ASC division of the CMCC Foundation works in WP9 addressing HPC and Data management challenges. The ODA division contributes to WP2 and WP3, assessing the effect of model resolution on the performances of global climate models, and developing physical parameterisations specifically designed for use in combination with high-resolution.

- **EU H2020 Project ESIWACE** (Centre of Excellence in Simulation of Weather and Climate in Europe; 2015-2019). ESIWACE is a user-driven Centre of Excellence in Simulation of Climate and Weather in Europe. In particular, CMCC Foundation participates to several activities including: enhancing community capacity in HPC; scheduling and workflow capabilities; implementation of new storage layouts for Earth System Data to be evaluated on fast (in-memory) data analytics frameworks for scientific data management.

- **EU FP7 Project IS-ENES** (2009-2013) and its follow on IS-ENES2 (2013-2017). The goal of IS-ENES has been the development of a common climate and Earth system modelling distributed research infrastructure in Europe. IS-ENES2 further integrated the European climate modelling community, stimulated common developments of software for models and their environments, fostered the execution and exploitation of high-end simulations and supported the dissemination of model results to the climate research and impact communities. CMCC worked on the use of exascale to develop next generation climate models and on the data node monitoring infrastructure.

- **CMEMS Med-MFC**: the Mediterranean Monitoring and Forecasting Center coordinated by CMCC in the framework of the Copernicus Marine Service, operationally produces numerical analysis, short-term forecasts, specific and targeted products and reanalysis in the Mediterranean Sea. http://marine.copernicus.eu/mediterranean-monitoring-forecasting-centre-med-mfc/

- **CMEMS BS-MFC**: the Black Sea Monitoring and Forecasting Center coordinated by IOBAS in the framework of the Copernicus Marine Service, operationally produces numerical analysis, short-term forecasts, specific and targeted products and reanalysis in the Mediterranean Sea. http://marine.copernicus.eu/black-sea-monitoring-forecasting-centre-bs-mfc/

Relevant significant infrastructure and/or any major items of technical equipment:

The CMCC's Supercomputing Center provides the technological infrastructure and the computational capabilities needed in order to develop simulations and models able to provide more accurate, detailed and better defined results. The main facility of the Supercomputing Center is the Athena system based on 482 IBM iDataPlex compute nodes. Each node is a dual Intel E5-2670 processor working at 2,6 GHz. Athena has a computing capability of 160TFlops (160,000 billions operations per second). The design of the computing architecture, comprised of the IBM dx360M4 server cluster, the InfiniBand interconnection network and the storage subsystem, accelerates research activities and improves the quality of the scientific research for the development of future climate change scenarios and impacts. The huge amount of data produced by CMCC researchers is managed by a DLM system based on a hierarchical storage management solution (HSM). HSM allows data storage on different tiers based on specific policies, enabling administrators to migrate and store data on the most appropriate tier and enabling transparent data access. The CMCC Supercomputing Center is the only computational facility in Italy specializing in Climate Change research.

Participant 3 : Natural Environment Research Council (NERC)

The Natural Environment Research Council (NERC) is the UK's largest funder of independent environmental science, training and innovation, delivered through universities and research centres. It invests in excellent, peer-reviewed science, often designed and delivered in partnership with the academic community, businesses and other organisations. The research meets society's needs through discovery science - driven by curiosity - and strategic research that addresses major challenges of the 21st century: how we can benefit from finite natural resources, build resilience to environmental hazards and manage environmental change. The National Oceanography Centre (NOC) is a component centre of NERC with expertise in ocean physics, biology, and geosciences, and undertakes both modelling and observations at sea, both from ships and with autonomous vehicles. NERC is a member of the NEMO consortium and the NOC provides effort to the NEMO system team.

Short profile of key personnel involved:

Prof. Adrian New (Male), PhD, is Associate Head of the Marine Systems Modelling group at the National Oceanography Centre in the UK. He has over 35 years experience of scientific research and management, with wide ranging interests in most aspects of physical oceanography and modelling. He has over 60 research publications, 2150 citations, and an h-factor of 29. His interests cover both numerical ocean models and direct observations at sea, with applications to ocean circulation, climate dynamics and internal waves. He is the NERC representative on the NEMO Steering Committee and has a long history of involvement with NEMO. He is also the NOC PI on the H2020 project PRIMAVERA leading the development of new schemes for upper ocean mixing, and leads WP 3.6 of the ACSIS programme (for collaborative climate science in the UK) investigating modes of variability in the natural climate system..

Prof. Jason Holt (Male), PhD, is head of MSM. With 20+ years' experience of physical oceanography, particular areas of interest include the impact of climate change/variability on shelf-seas and ocean margins, and coastal-ocean model development. He has acted as PI or NOC/group lead for 25 NERC, EC and Contract Research projects, including the ReCICLE project on climate change impacts in shelf seas, leading the modelling component in the NERC Ocean-shelf exchange and Land Ocean Carbon Transfer programs and is NOC lead on Shelf Sea Biogeochemistry. He led the NERC Next Generation Ocean Dynamical Core Road Map Project and is NOC lead for the CMEMS NW Shelf MFC project, NOWMAPS. He co-chairs the National Partnership for Ocean Forecasting and, until 2017, a member of the NEMO Developers committee. He is an expert on the hydrodynamics of shelf seas and has published 60+ peer reviewed papers, with an h-factor of 29 and 2017 citations. He was the architect of the POLCOMS hydrodynamic model and the translation of these capabilities into the NEMO model. These have underpinned UK research and operational shelf sea modelling over the last 16 years.

Dr. George Nurser (Male), PhD, is a principal scientist in the Marine Systems Modelling group at the National Oceanography Centre in the UK. He has over 65 research publications, 1632 citations, and an h-factor of 24. His interests are wide-ranging and lie both in theory and numerical modelling. He is on the System Team of the NEMO model and actively develops that model. He has worked on thermocline theory, subduction processes, mixed layers, watermass transformation, and eddy fluxes and their parameterisation into ocean models. Recently he has been working on surface mixing in the ocean surface boundary layer. He is currently leading the modelling effort of the NERC ORCHESTRA programme that is studying heat uptake in the Southern Ocean.

Dr. Yevgeny Aksenov (Male), PhD, is a Senior Research Fellow at the National Oceanography Centre and has 27 years of experience in sea ice and ocean research. He has published 36 papers in ISI peer-reviewed journals and two book chapters (over 900 citations and h-index 18 to date). His research includes global modelling of ocean circulation and sea ice dynamics, implications for climate and impacts on sea ice and the ocean in the Marginal Ice Zone and collaborations in bio-geochemical modelling. He has participated in four high-latitude Arctic field campaigns. Dr Aksenov represents NOC in the NEMO Sea Ice Working Group and contributes to the NEMO Wave-currents Working Group. He led the UK contribution in the EU FP7 Project 'Ships and waves reaching Polar Regions (SWARP)'. The project was focused on new developed modelling and satellite products for ship safety for the Copernicus services.

Dr. Andrew C. Coward (Male), PhD, is a member of the Marine Systems Modelling group at the National Oceanography Centre in the UK. He has 30 years experience of scientific research and ocean model development, with wide ranging interests in most aspects of physical oceanography, High Performance Computing and modelling. He has over 100 research publications, 2500 citations, and an h-factor of 32. His interests cover both ocean models and coupled ocean-atmosphere-biogeochemical models, with applications to ocean circulation and climate dynamics. He is the NERC officer on the NEMO system team, a position he has held since the formation of the NEMO consortium.

Dr. Alex Megann (Male), PhD, is an ocean and climate modeller in the Marine Systems Modelling group at the National Oceanography Centre in the UK, with over 28 years of experience developing and running ocean models. He is a core member of the JMMP collaboration between NERC and the Met Office, and a major contributor to the GO5, GO6 and GO8 ocean configurations of NEMO which are used in UK predictive systems. He leads WP2.3 of the NERC ACSIS project (to produce ocean/sea ice integrations), and is overall PI on the CMEMS RENUMERATE project for reducing numerical mixing. His interests include diagnosing and ameliorating numerical mixing in NEMO, and he has expertise unrivalled in the UK with isopycnic (density-coordinate) models, in particular HYCOM.

Dr. James Harle (Male), PhD, is a physical oceanographer whose research interests include numerical modelling of ocean basins and shelf seas, model development and analysis techniques. He is also part of the NEMO Systems Team and their Configuration Manager Working Group, and was PI of the pyNEMO project (ARCHER eCSE02-17) to develop a python based regional configuration toolbox for the NEMO framework. He is currently involved in developing a framework for relocatable regional NEMO simulations, hybrid vertical coordinate schemes in a Southern Ocean regional model and the Resolving Climate Impacts on shelf and CoastaL sea Ecosystems (ReCICLE) NERC funded project.

Dr. Stefanie Rynders (Female), PhD, is a Researcher with extensive expertise in coupled sea ice, ocean and wave modelling in the Arctic. Stefanie received her PhD in sea ice-ocean modelling from the University of Southampton (UK) as a tied student on the EU FP7 Project 'Ships and waves reaching Polar Regions (SWARP)'. Since then she has been working as a postdoctoral researcher at the NOC. She carried out Arctic analysis for CMIP5 scenarios in the EU H2020 project CRESCENDO. Stefanie contributes to NEMO model development and is a member of the NEMO Wave-currents Working Group.

Dr. Ashley Brereton (Male), PhD, has been a member of the Marine Systems Modelling group at the National Oceanography Centre in the UK for 5 years. He has over 10 years of experience in applied mathematics and physical oceanography, primarily in the areas of ocean modelling and computational fluid dynamics. Dr Brereton has been involved in a number of published works concerning a broad range of topics including; regional ocean model development in NEMO, ecosystem modelling and turbulence modelling. As well as ocean science, he is an expert in scientific computing, specializing in HPC and parallel computing techniques and is a representative for the scientific computing advisory group in the National Oceanography Centre.

Dr Jeff Polton (Male), PhD, leads the High Resolution Coastal-Ocean Modelling activity at the National Oceanography Centre (NOC) and coordinates NOC's role in the Joint Marine Modelling Programme (JMMP) with the Met Office in terms of shelf sea modelling. With 30+ peer reviewed publications, he is an expert in ocean dynamics across a range of scales, with extensive experience in multidisciplinary applications (e.g. turbulence modelling; regional modelling; habitat connectivity; tidal data products). He is the PI on a NERC Standard Grant, ‘Pycnocline Mixing is Shelf Seas (PycNMIX)’, which integrates models with observations to better understand shallow sea mixing in order to better parameterise the effect in forecast models. This has applications to the NEMO-shelf models used in the NWS Copernicus system. He is also the IP lead on a tidal prediction product, anyTide, which delivers tidal height and current predictions on smart phones for the Northwest European Shelf coastal waters.

Chris Wood (Male) has worked in the technical groups at the National Oceanography Centre for many years and is a skilled programmer with a high level of python expertise.

Relevant publications, and/or products, services, or other achievements :

- Marzocchi, A., **Hirschi, J. J. M.**, Holliday, N. P., Cunningham, S. A., Blaker, A. T. and **Coward, A. C.**, 2015. The North Atlantic subpolar circulation in an eddy-resolving global ocean model. J. Mar. Sys., 142, 126-143. 10.1016/j.jmarsys.2014.10.007.

- Hewitt, H. T, M. J. Roberts, P. Hyder, T. Graham, J. Rae, S. E. Belcher, R. Bourdallé-Badie, D. Copsey, A. Coward, C. Guiavarch, C. Harris, R. Hill, **J.-M. Hirschi***,* G. Madec, M. S. Mizielinski, E. Neininger, **A. L. New**, J.-C. Rioual, B. Sinha, D. Storkey, A. Shelly*,* L. Thorpe, and R. A. Wood, 2016. The impact of resolving the Rossby radius at mid-latitudes in the ocean: results from a high-resolution version of the Met Office GC2 coupled model. Geoscientific Model Development, 9 (10), 3655–3670, 2016.

- **Aksenov, Yevgeny**; Popova, Ekaterina; Yool, Andrew; Nurser, A.J. George, 2017. On the future navigability of Arctic sea routes: high resolution projections of the Arctic Ocean and sea ice decline. Marine Policy, 75, 300-317.

- Guihou, K., **Polton, J., Harle, J.**, Wakelin, S., O'Dea, E., & **Holt, J.**, 2018. Kilometric scale modeling of the North West European Shelf Seas: Exploring the spatial and temporal variability of internal tides. Journal of Geophysical Research: Oceans, 123, 688–707.

- Co-production of global and coastal/shelf sea model configurations (with the UK Met Office) GO5, GO6, and CO6, CO7 (for UK operational systems).

Relevant previous projects or activities:

- **H2020 project *PRIMAVERA*** *PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment* (GA 641727-2). The goal of PRIMAVERA is to deliver novel, advanced and well-evaluated high-resolution global climate models (GCMs), capable of simulating and predicting regional climate with unprecedented fidelity, out to 2050. This capability will deliver innovative climate science and a new generation of advanced Earth System Models. Sector-specific end-users in policy and business will be identified and engaged individually, with iterative feedback, to ensure that new climate information is tailored, actionable and strengthening societal risk management decisions.

- **CMEMS**: NERC are involved in the CMEMS NW Shelf MFC project, NOWMAPS and contribute to the development of shelf sea models working with the The Met Office.

- **NEMO consortium**: NERC is one of the members of the NEMO consortium with representatives on the steering committee and developers’ committee as well as contributing at least 1 person equivalent of effort to the maintenance and development of NEMO via the systems team.

- **JMMP**: The Joint Marine Modelling Programme (JMMP) coordinates work at the Met Office and NERC on the development and evaluation of configurations of the global ocean, sea ice and north-west shelf using the NEMO model.

- **EU FP7 Project** ‘Ships and waves reaching Polar Regions (SWARP)

- **CMEMS RENUMERATE** project

- **pyNEMO project** (ARCHER eCSE02-17) – an Archer project

- **PycNMIX**: a NERC project for pycnocline mixing in shelf seas.

- **ReCICLE** : Resolving Climate Impacts on shelf and CoastaL sea Ecosystems - a NERC funded project

Relevant significant infrastructure and/or any major items of technical equipment:

The ARCHER HPC facility in the UK.

Participant 4 : Mercator Ocean (Mercator Ocean)

Between observation infrastructures and users, Mercator Ocean is a non profit company employing a team of 60 persons which ensures the continuity from research to oceanographic operational services. Mercator Ocean has nine research and operational governmental shareholders (Centre National de la Recherche Scientifique (CNRS), Institut pour la Recherche et le Développement (IRD), Météo-France (the French Meteorological office), Naval Hydrographic and Oceanographic Service (SHOM), Institut Français de Recherche pour l'Exploitation de la MER (IFREMER), the Euro-Mediterranean Center on Climate Change (CMCC s.r.l.), Met-Office (the UK Meteorological office), National Energy Research Scientific Computing Center (NERSC), and Puerto Del Estado. Over the last 15 years, Mercator Ocean has been playing a leading role in operational oceanography at international level and European level. After having successfully coordinated the European MyOcean projects since 2009, Mercator Ocean was officially appointed by the European Commission on November, 2014 to define, manage, implement and operate the "Copernicus Marine Environment Monitoring Service" (CMEMS) (as part of the European Earth observation program, Copernicus) on its current multi-annual financial framework 2014-2020. Mercator Ocean also defines and manages the service evolution and user uptake of the CMEMS activities.

Short profile of key personnel involved:

Dr. Mounir Benkiran (Male), Ph.D., is a Mercator Ocean researcher with more 20 years of experience. He was in charge implementing data assimilation in Mercator Ocean operational system and in the IBI-MFC system. He works currently on OSSE experiments based on high resolution data as next generations of atlimetric data (swat products) and Sea Surface Temperature at High resolution.

Romain Bourdallé-Badie (Male) has been engineer at Mercator Ocean since the year 2000. Within the R&D team, he is in charge of developing, tuning and validating the high-resolution oceanic and ice model of the future Mercator Ocean prototype. In this context, he has developed the global 1/12° model. He participates to the NEMO developments. He is the scientific contact point of the IMMERSE project and leads WP6.

Clément Bricaud (Male) has been Ocean engineer at Mercator Ocean since 2006. He is the Mercator Ocean NEMO officer i.e. he represents Mercator Ocean inside the NEMO consortium. As such he is deeply involved in the development and testing of the code. He works also on Mercator's ocean model development and he is the main developer of the online coarsening for Biogeochemistry model.

Dr. Jérôme Chanut (Male), Ph.D., is a Mercator Ocean research engineer since 2004, soon after his PhD in physical oceanography. During his 12 years' experience in ocean modelling, he has been involved in the development of many numerical aspects of the NEMO code. He has strongly participated to the development of coastal modelling capacities of NEMO during Mersea and MyOcean projects. During the latter, he coordinated the "Iberian Biscay Irish" Marine Forecasting Center.

Yann Drillet (Male) is the head of R&D department and scientific director deputy at Mercator Océan, the French global scale operational oceanography center. He is a member of DRAKKAR and NEMO consortiums and leader of the global monitoring and forecasting centre in Copernicus Marine Services. He is an expert on ocean modelling and operational forecasting design.

Dr. Guillaume Reffray (Male), Ph.D., has been Ocean engineer at Mercator Ocean since 2005. He works on the development of NEMO and on the development of High resolution configurations with a high level of complexity. As such he was ones of main developer of the first version of IBI model operate by IBI-MFC and he has been in charged to perform the new release of this CMEMS system. He is also the scientific referent at Mercator Ocean of the INDESO project lead by CLS.

Dr. Guillaume Samson (Male), Ph.D., is Mercator Ocean engineer specialist in ocean/atmosphere interactions. He has been working on this theme for more than 10 years, especially during his PhD, then in the PULSATION project. At Mercator Ocean, he is in charge of improving the bulk formulae and developing a simplified Atmospheric Boundary Layer to force the next generation of global CMEMS forecast systems. In this framework, he is involved in SimBAD and ALBATROSS project.

Relevant publications, and/or products, services, or other achievements :

- Chanut, J., **B. Barnier**, W. Large, **L. Debreu**, T. Penduff, J. M. Molines, and **P. Mathiot** (2008): Mesoscale Eddies in the Labrador Sea and Their Contribution to Convection and Restratification. J. Phys. Oceanogr., 38, 1617–1643.

- Lellouche, J.M., O. Le Galloudec, M. Drévillon, C. Régnier, E. Greiner, G. Garric, N. Ferry, C. Desportes, C.-E. Testut, **C. Bricaud**, **R. Bourdallé-Badie**, B. Tranchant, **M. Benkiran**, **Y. Drillet**, A. Daudin, C. de Nicola (2013): Evaluation of real time and future global monitoring and forecasting systems at Mercator Océan, Ocean Science Discussions ; 9(2):1123-1185..

- Hewitt, H. T., Roberts, M. J., Hyder, P., Graham, T., Rae, J., Belcher, S. E., **Bourdallé-Badie, R.**, Copsey, D., **Coward, A.**, Guiavarch, C., Harris, C., Hill, R., Hirschi, J. J.-M., **Madec, G.**, Mizielinski, M. S., Neininger, E., New, A. L., Rioual, J.-C., Sinha, B., **Storkey, D.**, Shelly, A., Thorpe, L., and Wood, R. A. (2016): The impact of resolving the Rossby radius at mid-latitudes in the ocean: results from a high-resolution version of the Met Office GC2 coupled model, Geosci. Model Dev., 9, 3655-3670, https://doi.org/10.5194/gmd-9-3655-2016.

- Maraldi, C., **Chanut, J.**, Levier, B., Ayoub, N., De Mey, P., **Reffray, G.**, Lyard, F., Cailleau, S., Drévillon, M., Fanjul, E. A., **Sotillo, M. G.**, Marsaleix, P., and the Mercator Research and Development Team (2013): NEMO on the shelf: assessment of the Iberia–Biscay–Ireland configuration, Ocean Sci., 9, 745-771, doi:10.5194/os-9-745-2013.

- Reffray, G., **Bourdalle-Badie, R.**, and Calone, C. (2015): Modelling turbulent vertical mixing sensitivity using a 1-D version of NEMO, Geosci. Model Dev., 8, 69-86, https://doi.org/10.5194/gmd-8-69-2015.

Relevant previous projects or activities:

- Mercator Ocean was the coordinator of the **EC/FP7 MyOcean**, **MyOcean2** and **MyOcean FO** projects (**Copernicus Marine Service**).

- Mercator Ocean is a member of the **NEMO consortium**. Mercator Ocean participates of the road map elaboration (parameterizations, technical choices,…), of the developments and of the supports of NEMO. The participation of is up to one man/year.

- Participation to the **ERA-CLIM2** (FP7): a collaborative research project funded by the European Union, with the goal of preparing input data and assimilation systems for a new global coupled reanalysis of the 20th century. Mercator Ocean will contribute on sea-ice assimilation and Physical Ocean and bio-geo-chemical model coupling.

- Participation in **ANR COMODO**: COMODO (COmmunauté de Modélisation Océanique) is a research project supported by the French national research agency (ANR), which regroups the whole French ocean modeling community. This common effort will be directed towards two main objectives: improvement of existing models and numerical methods, guidelines for the development of future generation ocean models.

- Mercator Ocean is involved in **ALBATROS** project, on of objectives is to derive a simplified model of the marine atmospheric boundary layer which would have the ability to represent key processes associated to air/sea interactions at the characteristic scales of the oceanic mesoscale. This model called SIMBAD (SIMplified Boundary Atmospheric layer moDel) is of intermediate complexity between a bulk parameterization and a full three-dimensional atmospheric model. The goal is improving the CMEMS forecast by improving the interactions ocean/atmosphere

Relevant significant infrastructure and/or any major items of technical equipment:

Access to High Performance Computers at Meteo-France and ECMWF and internal computing facilities.

Participant 5 : Met Office (Met Office)

The Met Office, founded in 1854, is the National Meteorological Service (NMS) for the United Kingdom. It employs around 1,800 staff including meteorologists, hydrologists, oceanographers, climate scientists, IT and support staff. A world renowned centre of excellence for research and operational services in meteorology, oceanography, forecasting and climate prediction, the Met Office supports a large number of customers globally, including governments, civil aviation, defence, commerce and industry. The Met Office is a Trading Fund within the UK Government's Department for Business, Innovation and Skills (BIS), and this status engenders a business approach in addition to the R&D activities, resulting in successful products and service delivery. There are over 500 people actively involved in strong research and development programmes in the areas of ocean and atmospheric modelling, observational research, data assimilation and reanalysis, ensemble forecasting and forecast verification on all timescales from days to centuries, as well as climate impacts and consultancy services. This global reputation in these areas requires an infrastructure that not only includes a high performance computing environment, but also the processes and the people and software to manage those processes.

Ocean modelling activities have taken place at the Met Office since the 1980s both for climate applications and later for ocean forecasting applications. Over 60 staff are directly involved in the ocean modelling effort supporting ocean and coupled prediction on timescales ranging from days to centuries. The Met Office was one of the founding members of the NEMO consortium which has now expanded to six members. The NEMO consortium provides significant ocean modelling infrastructure across Europe, notably beyond the countries represented by the consortium (France, UK and Italy). The Met Office was one of the leading partners in the EU MyOcean project and makes a significant contribution to the Copernicus Marine Environmental Management System (leading delivery of the North-West European Shelf Seas Monitoring and Forecasting Centre (NWS-MFC), providing the coupled model component of the Global MFC and the global component of Ocean and Sea Ice Thematic Assembly Centre (OSI TAC) and working towards provision of the global component of the in-situ TAC). The Met Office leads the UK National Partnership for Ocean Prediction and, as part of the Met Office-NERC Joint Weather and Climate Research Programme, co-leads Ocean Modelling programmes on both global and shelf seas modelling.

Mike Bell of the Met Office will lead WP3. He is a very experienced manager and WP leader. Ed Blockley will lead WP5.4 and Matt Martin will lead WP7.2. Both are experienced managers and leaders in international collaborations. The team members contributing to the work of WP3, WP4, WP5 and WP6 are all very capable scientists with experience and expertise in the tasks to which they will contribute.

Short profile of key personnel involved:

Dr Miroslaw Andrejczuk (Male) : has more than 15 years of experience in numerical model development in HPC environment and numerical modelling of the atmosphere and ocean. His early work was with numerical models of the atmosphere. He worked on development and validation of the Lagrangian microphysics for Large Eddy Simulation models. This work started at the Los Alamos National Laboratory and continued at the University of Leeds. His work with ocean models started at the University of Oxford, where he implemented stochastic parameterizations in NEMO and investigated the impact of these parameterizations on seasonal forecast using ECMWF seasonal prediction system. Currently he works at the MetOffice as a senior scientific software engineer. His expertise is in I/O servers in NEMO and UM, coupling models using coupler, and coupled models performance tuning. He is co-author of 12 peer-reviewed publications.

Dr. Mike Bell (Male), Ph.D., Fellow in Ocean Dynamics, Mike led the operational implementation of daily global ocean forecasts at the Met Office in 1997. He was the leader of the Implementation and Production WP in MERSEA Integrated Project (for 4 years) and a member of the MyOcean Board (for 6 years). He also played a key role in initiating the NEMO consortium. He was joint chair of the Global Ocean Data Assimilation Experiment (GODAE) International Science Team for 5 years, and Head of the

National Centre for Ocean Forecasting for 10 years. He is now in a research (rather than managerial position) and is working on the detailed numerics of the NEMO model.

Dr Ed Blockley (Male): [WP 5.4 leader] manages the Polar Climate Group of the Met Office Hadley Centre – a group with considerable experience of developing and evaluating sea ice climate models and understanding climate change in polar regions.Within the UK, under the auspices of the UK's Joint Weather and Climate Research Programme, Ed leads development of the Global Sea Ice (GSI) configurations that are used within all Met Office/Hadley Centre physical models and the UK Earth System Model. These sea ice configurations are used for forecasting and prediction across all time-scales from hours to seasons as well as for climate projections. Ed is also co-chair of the NEMO Sea Ice Working Group and co-leads development of the NEMO sea ice model – a newly agreed collaborative venture bringing together all existing NEMO sea ice model developers within the NEMO framework. Ed has 10 years' experience developing and evaluating ocean-sea ice systems based upon NEMO within the framework of the Met Office's operational short-range and seasonal forecasting systems and global climate models. Prior to taking on the leadership of the Polar Climate Group in 2014, Ed worked in the Ocean Forecasting Research and Development team where he led development and evaluation of the Met Office's near-real-time operational ocean-sea ice forecasting system FOAM. During this time he was heavily involved with the (EU) MyOcean series of projects - including as work package leader.

Ann Keen (Female): [WP5.4 Scientist] is a Senior Research Scientist at the Met Office Hadley Centre (MOHC). Since 2002 she has specialised in the development and assessment of the representation of sea ice within climate models, with the aim of increasing confidence in projections of polar climate change. She contributed to the development and evaluation of the models HadGEM1 and HadGEM2, and spent 18 months managing the Polar Climate Group at the MOHC, including leading the development of the CICE sea ice component of HadGEM3, which forms the basis of the MOHC's contribution to CMIP6. She is currently working to understand the processes driving variability and decline in modelled Arctic sea ice via changes in the sea ice volume budget, and also to evaluate the impact of an anisotropic rheology on the sea ice simulation in HadGEM3.

Dr. Rob King (Male), Ph.D., Rob is a Senior Scientist in the Marine Data Assimilation group within the Ocean Forecasting R&D team of the Met Office. He is involved in the development of the ocean data assimilation system used in the FOAM ocean forecasting system, and in implementing various operational upgrades to the system. Specifically, he is currently working on the implementation of assimilation of sea surface height, sea surface temperature and in situ profile observations in a 1.5km resolution forecasting system of the north-east Atlantic. He has over 5 years of experience developing, tuning and implementing ocean data assimilation systems, and has been involved in various EU projects including E-AIMS, ERA-CLIM2, and is currently contributing to the AtlantOS project.

Dr. Matt Martin (Male), Ph.D., Manager of the Marine Data Assimilation group and Met Office Science Fellow. Matt has over 17 years of experience developing ocean data assimilation systems for operational ocean forecasting and reanalysis applications, as well as contributing to the development of the OSTIA SST and sea-ice analysis system. He leads the group which develops the data assimilation system, NEMOVAR, used to initialise the FOAM operational ocean forecasting system in various deep-ocean configurations and in shelf-seas. The data assimilation system is also used for reanalysis and operational forecasting in the GloSea seasonal forecasting system. He has about 10 years of experience successfully managing teams and projects, and has just finished leading a work package within the ERA-CLIM2 EU project as well as contributing to the AtlantOS project. He has over 60 peer-reviewed publications and co-chairs the GODAE OceanView (GOV) Data Assimilation Task Team as well as being the UK representative on the GOV Science Team, and is a member of the NEMOVAR Steering Group.

Dr. Pierre Mathiot (Male), Ph.D., He has 10 years experience in developing and evaluating coupled ocean/sea-ice model NEMO. He worked on investigating deficiency into the atmospheric forcing in Antarctic shelf seas (LGGE, France), assimilating sea-ice data into NEMO (UCL, Belgium). He led the implementation of under ice shelf seas capability into NEMO (BAS, UK). He participated in about 20 peer-reviewed publications in various domains (paleoclimate, sea-ice, polar ocean, ice/ocean interaction, data assimilation and atmospheric forcing). In his role at the Met Office, he is responsible of the eddy resolving global configuration eORCA12 developed for ocean forecasting and high resolution climate modelling.

Dr. David Storkey (Male), Ph.D., He has 20 years experience working on ocean model development at the Met Office, first on the Unified Model ocean component and then on NEMO. Major contributions to code development have including implementing new advection schemes in the UM ocean model and rewriting the module to implement open boundary conditions in NEMO. He is currently the Met Office lead for the maintenance and development of the medium-resolution global configuration used for a range of applications from climate research to ocean forecasting.

Dr Jennie Waters (Female): [WP7.2 Scientist] – Jennie is a Senior Scientist working in the Marine Data Assimilation group at the Met Office. She has more than 10 years experience in implementation and development of marine data assimilation in both wave and deep ocean models. Jennie was responsible for the first implementation of the NEMOVAR data assimilation system in the FOAM global ocean forecasting system. She has recently worked on improving ocean data assimilation in the equatorial region and was a member of the Modelling and Data Assimilation task team for TPOS 2020. She also worked on the investigation of coupled ocean-atmosphere error covariances for the ERA-CLIM2 project. Her current work focuses on the development and tuning of the data assimilation in a 1/12th degree global ocean configuration.

Relevant publications, and/or products, services, or other achievements :

- **Bell, M. J.**, P S. Peixoto, and J. Thuburn (2017): Numerical instabilities of vector invariant momentum equations on rectangular C-grids. Q. J. R. Meteorol. Soc., 143, 702A, 563-581, DOI:10.1002/qj.2950

- **Blockley, E. W.**, Martin, M. J., McLaren, A. J., Ryan, A. G., Waters, J., Lea, D. J., Mirouze, I., Peterson, K. A., Sellar, A., and Storkey, D.: Recent development of the Met Office operational ocean forecasting system: an overview and assessment of the new Global FOAM forecasts, Geosci. Model Dev., 7, 2613-2638, doi:10.5194/gmd-7-2613-2014, 2014

- **Martin, M.J.**, M. Balmaseda, L. Bertino, P. Brasseur, G. Brassington, J. Cummings, Y. Fujii, D.J. Lea, J.-M. Lellouche, K. Mogensen, P.R. Oke, G.C. Smith, C.-E. Testut, G.A. Waagbo, J. Waters and A.T. Weaver (2015) Status and future of data assimilation in operational oceanography, Journal of Operational Oceanography, 8:sup1, s28-s48.

- **Storkey, D.**, Blaker, A. T., **Mathiot, P.**, **Megann, A.**, **Aksenov, Y.**, Blockley, E. W., Calvert, D., Graham, T., Hewitt, H. T., Hyder, P., Kuhlbrodt, T., Rae, J. G. L., and Sinha, B. (2018): UK Global Ocean GO6 and GO7: a traceable hierarchy of model resolutions, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2017-263, in review.

- **Waters J**, Lea D, Martin M, Mirouze I, Weaver A, While J. 2014. Implementing a variational data assimilation systemin an operational 1/4 degree global ocean model. Quarterly Journal of the Royal Meteorological Society 141: 333–349.

Relevant previous projects or activities:

- **CMEMS**: The Met Office leads the North-West European Shelf-Seas monitoring and forecasting centre (MFC), contributes to the Global MFC and produces the global SST analysis product, OSTIA.

- **MyOcean**: The EC FP7 MyOcean and MyOcean2 projects developed a coordinated pre-operational European ocean monitoring and prediction system which was the prototype for the CMEMS.

- **NEMO consortium**: Met Office is one of the members of the NEMO consortium with representatives on the steering committee and developers' committee as well as contributing at least 1 person equivalent of effort to the maintenance and development of NEMO via the system team.

- **FOAM**: The Forecasting Ocean Assimilation Model system has produced global daily operational ocean forecasts since 1997 and regional higher resolution forecasts since 1999. It is based on the NEMO ocean model and the NEMOVAR data assimilation system.

- **JMMP**: The Joint Marine Modelling Programme (JMMP) coordinates work at the Met Office and NERC on the development and evaluation of configurations of the global ocean, sea ice and north-west shelf using the NEMO model.

Relevant significant infrastructure and/or any major items of technical equipment:

The Met operates a powerful High Performance Computing facility based on a CRAY XC40 supercomputer system able to perform more than 16,000 trillion calculations per second. The computing engine is supported by the Met Office's MASS-R storage system, which uses the IBM HPSS (High Performance Storage System: http://www.hpss-collaboration.org/) to provide hierarchical storage management of IBM disk and tape hardware, and services for very large storage requirements. It enables high data transfer rates to move large files between storage devices and computers, and an environment that can scale to multiple petabytes (10^{15} bytes). Access to these facilities will allow the Met Office to test model developments and carry out the work of T7.2.

Participant 6 : Barcelona Supercomputing Center - Centro Nacional de la Supercomputación (BSC)

The Barcelona Supercomputing Center (BSC) was established in 2005 and is a key element of and coordinates the Spanish Supercomputing Network, which is the main framework for granting competitive HPC time to Spanish research institutions. Furthermore, BSC is one of six hosting nodes in France, Germany, Italy and Spain that form the core of the Partnership for Advanced Computing in Europe (PRACE) network. PRACE provides competitive computing time on world-class supercomputers to researchers in the 25 European member countries. The Center houses MareNostrum, one of the most powerful supercomputers in Europe with 48,128 cores and 1.1 Pflops capacity.

The mission of BSC is to research, develop and manage information technologies in order to facilitate scientific progress. BSC combines HPC service provision, and R&D into both computer and computational science (life, earth and engineering sciences) under one roof and currently has over 450 staff from 44 countries. BSC has collaborated with industry since its creation, and participates in various bilateral joint research centers with companies such as IBM, Microsoft, Intel, NVIDIA and Spanish oil company Repsol.

The centre has been extremely active in the EC Framework Programmes and has participated in over 100 projects funded by it. BSC is a founding member of HiPEAC, the ETP4HPC and other international fora. The Earth Science department at BSC (ES-BSC) is the one involved in this proposal, its activities with the focus on global climate modelling and prediction are based on research, development and predictions with the EC-Earth climate forecast system. EC-Earth is the state-of-the art coupled climate model that is being developed and used for climate predictions and projections by the European consortium of more than 20 research and operational institutions from European Centre for Mid-range weather Forecasts (ECMWF is provider of the atmospheric and land components) to ES-BSC. Beside contributing to the 5th phase of the Coupled Model Intercomparison Project (CIMP5) critical for the UN IPCC Fifth Assessment Report (AR5), global climate research activities at ES-BSC enable provision of various historical reconstructions and initial conditions to the EC-Earth community for analysis of climate dynamics and for seasonal to decadal climate predictions. The ES-BSC is a contributor to the IS- ENES and IS-ENES2 FP7 European projects fostering the integration of the European climate modelling community and the development of Earth System Models (ESM) for advancing the understanding and predictions of climate variability and change. The ES-BSC is already active in the planning and design of the future coupled climate model intercomparison project, CIMP6, and is preparing to make key contributions including the groundbreaking high-resolution climate simulations with EC-Earth.

Short profile of key personnel involved:

Miguel Castrillo (Male), Computer Scientist in the Computational Earth Sciences group [WP8 Scientist]: Miguel holds an MSc in computer science from the University of León. Having more than five years of experience as software analyst and developer for different companies in the private sector, he joined the Computational Earth Sciences group at the Earth Sciences department of the Barcelona Supercomputing Center (BSC) in 2012, where he has been specializing in HPC and Earth Sciences modelling. His extensive expertise in the sector ranges from HPC data management and visualization tools, to parallel applications performance. He developed the CALIOPE air quality system mobile application, winner of the European Commission MYGEOSS project (2015-2016) for innovative applications using open data. In the last five years he has been intensely focused on HPC performance and model workflows, being involved in the IS-ENES2 and ESiWACE European projects and collaborating with the EC-Earth and NEMO models development teams. Currently he is head of the Models and Workflows Team in the Earth Sciences Department, as well as permanent member of the NEMO HPC working group and EC-Earth technical group.

Dr. Mario Acosta (Male), Ph.D., Mario C. Acosta is a post-Doctoral fellow in the Computational Group of the Earth Sciences Department at the Barcelona Supercomputing Center. He received his PhD in Computer Science (related to High Performance Computing applied to Earth System Modelling) from University of Granada in 2015. His research interests and expertise include wide knowledge in numerical models (governing equation, numerical algorithms and computational implementation), performance analysis to highlight the main bottlenecks of the models and how to adapt and optimize them efficiently to actual and new High Performance Platforms.

Mr. Javier Vegas (Male), Ph.D., Javier Vegas-Regidor is a Physics and Computer Sciences graduated from the University of Salamanca. He joined BSC Earth Sciences Department in 2015 and he is currently the person in charge of the climate diagnostics for the Earth Sciences Department. He is also part of the core development team of ESMValTool in behalf of BSC-ES and the PRIMAVERA H2020 project.
His main responsibilities include the enhancement and maintenance of the current tools as well as exploring new tools and technologies that can be applied to diagnostics. In particular, he has ported diagnostics to GPUs with very promising results that are expected to arrive to production in the coming months.

Relevant publications, and/or products, services, or other achievements :

- Tinto, O., **M. Castrillo**, **M.C. Acosta**, A. Cortes, A. Sanchez, K. Serradell, F.J. Doblas-Reyes (2017). Finding, analyzing and optimizing MPI communication bottlenecks in Earth System models. Journal of Computational Sciences. (in press)

- Tinto, O., **M.C. Acosta., M. Castrillo,** A. Cortes, A. Sanchez, K. Serradell, F.J. Doblas-Reyes (2017). Optimizing domain decomposition in an ocean model: the case of NEMO. Procedia of Computer Sciences. http://www.sciencedirect.com/science/article/pii/S1877050917308888

- Tintó Prims, O., **M. Castrillo**, K. Serradell, O. Mula-Valls and F.J. Doblas-Reyes (2015). Optimization of an ocean model using performance tools.BSC-CES Technical Memorandum 2015-002, 16 pp.

- Yepes-Arbós, X., **M. C. Acosta,** K. Serradell, A. Sanchez Lorente, F.J. Doblas-Reyes (2017). Simulation-based performance analysis of EC-Earth 3.2.0 using Dimemas. BSC-CES Technical Memorandum 2017-001, 30 pp.

- **Acosta, M.C.**, X. Yepes-Arbós, S. Valcke, **E. Maisonnave,** K. Serradell, O. Mula-Valls and F.J. Doblas-Reyes (2016). Performance analysis of EC-Earth 3.2: Coupling BSC-CES Technical Memorandum 2016-006, 38 pp.

Relevant previous projects or activities:

- **FP7 project** *Infrastructure for the European Network for Earth System modelling phase 2* (IS-ENES2-312979) IS-ENES2 is the second phase project of the distributed e-infrastructure of models, model data and metadata of the European Network for Earth System Modelling (ENES). This network gathers together the European modelling community working on understanding and predicting climate variability and change. ENES organizes and supports European contributions to international experiments used in assessments of the Intergovernmental Panel on Climate Change. This activity provides the predictions on which EU mitigation and adaptation policies are built.

- **H2020 project *ESiWACE*** *Excellence in SImulation of Weather and Climate in Europe* (GA 675191): will substantially improve efficiency and productivity of numerical weather and climate simulation on high performance computing platforms by supporting the end-to-end workflow of global Earth system modelling in HPC environment. This will be obtained by improving and supporting (1) scalability of models, tools and data management on state-of-the-art supercomputer systems (2) Usability of models and tools throughout the European HPC eco-system, and (3) the Exploitability of the huge amount of resulting data.

- H2020 project *ESCAPE-2* *Energy-efficient SCalable Algorithms for weather and climate Prediction at Exascale* (GA 800897). ESCAPE-2 will develop world-class, extreme-scale computing capabilities for European operational numerical weather and climate prediction, and provide the key components for weather and climate domain benchmarks to be deployed on extreme-scale demonstrators and beyond.

- H2020 project *PRIMAVERA* *PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment* (GA 641727-2). The goal of PRIMAVERA is to deliver novel, advanced and well-evaluated high-resolution global climate models (GCMs), capable of simulating and predicting regional climate with unprecedented fidelity, out to 2050. This capability will deliver innovative climate science and a new generation of advanced Earth System Models. Sector-specific end-users in policy and business will be identified and engaged individually, with iterative feedback, to ensure that new climate information is tailored, actionable and strengthening societal risk management decisions.

- H2020 project *APPLICATE* *Advanced Prediction in Polar regions and beyond: modelling, observing system design and LInkages associated with a Changing Arctic climate* (GA 727862). APPLICATE brings together an international and multidisciplinary team of experts in weather and climate prediction in order to improve climate and weather forecasting models as well as prediction tools while expanding and improving observational capabilities in the Arctic. The project members are working towards not only to enhance weather and climate prediction capabilities in the Arctic, but also in Europe, Asia, and North America. A focus on the Arctic is important for improved predictions of weather and climate in the mid-latitudes because the changes taking place in the Arctic due to climate change—the retreat of sea ice, warming seas and a warming atmosphere—have the potential to influence weather and climate in the mid-latitudes

Relevant significant infrastructure and/or any major items of technical equipment:

BSC is the National Supercomputing Facility of Spain and hosts a range of high-performance computing (HPC) systems including MareNostrum IV the new supercomputer, will be 12.4 times more powerful than the current MareNostrum 3 that will have a performance capacity of 13, 7 Petaflop/s. The general purpose element, will have 48 racks with more than 3,400 nodes with next generation Intel Xeon processors and a central memory of 390 Terabytes. The second element of MareNostrum 4 will be formed of clusters of three different technologies that will be added and updated as they become available. These are technologies currently being developed in the US and Japan to accelerate the arrival of the new generation of pre-exascale supercomputers.
The BSC is a key element of and coordinates the Spanish Supercomputing Network, which is the main framework for granting competitive HPC time to Spanish research institutions. Furthermore, BSC is one of six hosting nodes in France, Germany, Italy and Spain that form the core of the Partnership for Advanced Computing in Europe (PRACE) network. PRACE provides competitive computing time on world-class supercomputers to researchers in the 25 European member countries.

Participant 7 : Institut National de Recherche en Informatique et en Automatique (INRIA)

Established in 1967, Inria is the only French public research body fully dedicated to computational sciences. Under its founding decree as a public science and technology institution, jointly supervised by the French ministries for research and industry, Inria's mission is to pursue excellent research in computer science and applied mathematics in order to play a major role in resolving scientific, societal and industrial challenges. Throughout its 8 research centers and its 178 project teams, Inria has a workforce of 2 600 scientists with an annual budget of 230 million euros, 27% of which coming from its own resources. Inria has been very active in the previous European framework programmes (in FP7: 231 projects).
The institute is strongly involved in programmes aimed at fostering scientific excellence, such as the European Research Council: 32 Grants in FP7 and 17 Grants in Horizon 2020. Inria makes a firm commitment to Horizon 2020, with which the institute's strategic plan is aligned. The objective is to combine scientific excellence with a more focused consideration of major European and global societal challenges to which Inria can bring a key contribution. Inria is currently involved in more than 75 H2020 funded projects). **More information:** http://www.inria.fr.
In this Project, Inria represents the Team AIRSEA. The general scope of the AIRSEA project-team is to develop mathematical and computational methods for the modelling of oceanic and atmospheric flows. The used mathematical tools involve both deterministic and statistical approaches. The domains of applications range from climate modelling to the prediction of extreme events.

Short profile of key personnel involved:

Dr. Florian Lemarié (Male), Ph.D., is an Inria researcher in applied mathematics since January 2013. He has contributed to several topics including mesh-refinement methods for structured grids, numerical methods for multi-physics coupling, discrete algorithms for ocean models, and air-sea interactions. During his PhD in applied mathematics, he has worked on ocean-atmosphere coupling methods. Then, during his 4 years at the UCLA Department of Atmospheric and Oceanic Sciences he has gained a truly multi-disciplinary vision with strong knowledge of the numerical and physical aspects of oceanic and atmospheric models. Over the last four years he has authored or co-authored 12 international publications and has been PI or co-PI of 4 research projects.
http://www-ljk.imag.fr/membres/Florian.Lemarie/

Dr. Laurent Debreu (Male), Ph.D., is an Inria researcher in applied mathematics with primary interests in numerical methods for ocean and atmosphere modeling. L. Debreu successively worked on nesting implementation (NEMO, ROMS, HYCOM and MARS models), advection schemes (NEMO and MARS), spurious diapycnal mixing (ROMS and MARS), vertical coordinate systems (HYCOM). In the last four years, L. Debreu has been PI or co-PI of 8 contracts with research or industrial organisms and has authored or co-authored 11 international publications. He is the coordinator of COMODO a research project which brings together the whole French ocean mod- eling community. He is the main developer of the AGRIF software, a library for the integration of local mesh refinement features, internationally recognized and currently included in several ocean models of the international community. Since January 2015, he is the head of the INRIA Project-Team AIRSEA.
https://sites.google.com/site/laurentdebreu1/

Relevant publications, and/or products, services, or other achievements :

- **L. Debreu**, P. Marchesiello, P. Penven, G. Cambon (2012): *Two-way nesting in split-explicit ocean models: algorithms, implementation and validation.* Ocean Modelling, 49-50, pp 1-21.

- **F. Lemarié**, **L. Debreu**, **G. Madec**, J. Demange, J.-M. Molines, M. Honnorat (2015): *Stability constraints for oceanic numerical models: implications for the formulation of time and space discretizations.* Ocean Modelling, 92, pp 124-148.

- K. Klingbeil, **F. Lemarié**, **L. Debreu** , H. Burchard (2018): *The numerics of hydrostatic structured-grid coastal ocean models : state of the art and future perspectives,* Ocean Modelling, doi :10.1016/j.ocemod.2018.01.007.

- **F. Lemarié**, **G. Samson**, J.-L. Redelsperger, H. Giordani, **G. Madec** (2017): *Toward an improved representation of air-sea interactions in high-resolution global ocean forecasting systems*. *EGU 2017 - European Geosciences Union General Assembly*, Apr 2017, Vienna, Austria
https://hal.inria.fr/hal-01660799

- AGRIF : Adaptive Grid Refinement In Fortran : **L. Debreu** is the main developer of the AGRIF software. AGRIF is a sofware for the integration of *full adaptive mesh refinement (AMR)* features within a *multidimensional finite difference/finite volume numerical model* written in the Fortran language. AGRIF is routinely used in several state of the art ocean models. http://www-ljk.imag.fr/MOISE/AGRIF/

Relevant previous projects or activities:

- **ANR** (French National Research Agency) **COMODO** (2011-2015): French numerical Ocean Modeling Community (PI Laurent Debreu). Other institutes involved : IRD, CNRS, SHOM, IFREMER (Total grant: 1,3 million euros). The aim of this project was to conduct research in numerical methods for ocean modeling and also to produce a benchmark suite of idealized test cases.

- **ANR** (French National Research Agency) **HEAT** (2014-2018): Highly Efficient Atmospheric modeling (Co-PI Laurent Debreu). Other institutes involved: CEA, CERFACS, CNRS, Ecole Polytechnique (PI T. Dubos), CNRM. This research project focus on the development on a latest generation atmospheric model, based on a icosahedral dynamical core (DYNAMICO), for climate and weather modeling.

- **LEFE-GMMC** (Groupe Mission Mercator Coriolis) **CHRONOS** (2013-2015) : the CHRONOS project (PI Florian Lemarié) was dedicated to the study of time-stepping algorithms in primitive equations oceanic models. The aim is first to study the constraints on the numerics in terms of stability and accuracy for a given application, and then to propose alternatives to existing time-stepping schemes used in global models.

- **LEFE-GMMC** (Groupe Mission Mercator Coriolis) **SIMBAD** (2015-2018) : the objective of the SIMBAD project (PI : Florian Lemarié) in collaboration with Mercator-Ocean is to derive a simplified model of the marine atmospheric boundary layer which would have the ability to represent key processes associated to air/sea interactions at the characteristic scales of the oceanic mesoscale. This simplified model is of intermediate complexity between a bulk parameterization and a full three-dimensional atmospheric model.

Relevant significant infrastructure and/or any major items of technical equipment:
GENCI HPC infrastructure (as for participant 1/ CNRS)

Participant 8 : Puertos del Estado (PdE)

Puertos del Estado (http://www.puertos.es) is the Spanish government agency, dependent of the Ministry of Public Works, responsible for the coordination and efficiency control of State-owned Spanish Port System, including 46 ports managed by 28 Port Authorities. The PdE Physical Oceanography Division, by means of the own-managed operational monitoring and forecasting oceanography services, provides to the Spanish port system, to other institutions and to the society with met-ocean data essential to increase efficiency (reducing the costs and ensuring safety) in routine port operations as well as to support a sustained coastal and port management.

With respect to the monitoring and model forecasting of the environment in coastal area, PdE has worked in the last years on the following working lines related to operational oceanography:

- Control and management of the measuring networks of Puertos del Estado (deep water and coastal buoys, HF radars and tide gauges).
- Support and development of an oceanographic database containing information from measuring networks, numerical models and statistical analysis.
- Activitities and developments in numerical wave and ocean circulation modelling. Supporting operational forecasts of wave, sea level and ocean circulation with applications that goes from basin and regional scale model systems up to very high resolution local application (in the Spanish harbours).
- Climatic characterization. Use of models in Hindcast mode to generate climatology.

Puertos del Estado has long experience in numerical modeling, having established operational wave forecast systems since 1995, storm surge systems since 1998 and circulation forecasts since 2006.

Furthermore, Puertos del Estado has developed and operated, together with Mercator Ocean, the present IBI-MFC forecast applications during the MyOcean series of projects and the first phase of CMEMS Service.

PdE is leading the IBI-MFC since 2012, ensuring thus the links and potential transfers from the project outcomes (specifically on the IBI high resolution model demonstrator) with the CMEMS IBI MFC operational services.

Puertos employs more than 143 skilled people, 2016 turnover around 34,9 M€.

Short profile of key personnel involved:

Dr. Marcos García Sotillo (Male), PhD, is head of the Port and Coastal Dinamics Division in Puertos del Estado. Senior physical oceanographer scientist, working at Puertos del Estado since 2002. After a PhD in physics, focused on regional climate modelling in the Mediterranean, he has contributed to the progress of Spanish operational oceanography, mainly involved in activities related to regional ocean modelling. He was the main developer of the Spanish ESEOO Regional Ocean Forecast Service (later the MyOcean IBI V0 system). Within the MyOcean IBI-MFC infrastructure, he has been responsible for the Nominal IBI-MFC operational suite, service and R&D activities. Author of more than 40 peer-reviewed papers, he has been deeply involved in several projects at national and European level. He is a founding member, and currently coordinator, of the CMEMS IBI Monitoring Forecasting Centre (IBI-MFC), the regional oceanographic forecasting service for the Atlantic Europe (IBI area -Iberian-Biscay-Ireland) with extensive experience in ocean modelling and operational oceanographic services at regional and coastal scales.

Researcher (post-doc position) to be recruited specifically for the Project. The person selected will develop those activities related to the implementation and running of the new NEMO model set-ups in the IBI demonstrator. This person should have expertise not only in ocean modelling with NEMO but also a good knowledge of physical oceanography and coastal processes to carried out tasks related to the validation with observational data from HF radar, swath altimetry, etc…

Relevant publications, and/or products, services, or other achievements :

- **Sotillo M G**, A Amo-Baladrón, E Padorno, E Garcia-Ladona, A Orfila, P Rodríguez-Rubio, D Conti, JA Jiménez Madrid, F J de los Santos, E Alvarez Fanjul. (2016) How is the surface Atlantic water inflow through the Gibraltar Strait forecasted? A lagrangian validation of operational oceanographic services in the Alboran Sea and the Western Mediterranean. Deep Sea Research II. Vol 133. pp 100-117

- Aznar R., **Sotillo M.G.**, Cailleau S., Lorente P., Levier B., Amo-Baladrón A., Reffray G., Álvarez-Fanjul E. (2016): Strengths and weaknesses of the Copernicus forecasted and reanalyzed solutions for the Iberia-Biscay-Ireland (IBI) waters. Journal of Marine Systems, 159, pp. 1-14.

- **Sotillo MG**, S Cailleau, P Lorente, B Levier, R Aznar, G Reffray, A Amo-Baladrón, J Chanut, M Benkiran & E Alvarez-Fanjul (2015): The MyOcean IBI Ocean Forecast and Reanalysis Systems: operational products and roadmap to the future Copernicus Service. DOI:10.1080/1755876X.2015.1014663 Journal of Operational Oceanography. V 8 issue 1 63-79.

- Lorente P., Piedracoba S., **Sotillo M.G.**, Aznar R., Amo-Balandron, A., **Pascual, A.**, Soto-Navarro J., Alvarez-Fanjul E (2016): Characterizing the surface circulation in Ebro Delta (NW Mediterranean) with HF radar and modeled current data. Journal of Marine Systems 163:61-79.

- Sánchez-Garrido J.C., J. García Lafuente, E. Álvaréz-Fanjul, **M. García Sotillo**, F.J de los Santos (2013). What does cause the collapse of the western Alboran Gyre? Results of an operational ocean model. Progress in Oceanography 2013 116 142-153

Relevant previous projects or activities:

- **Copernicus IBI-MFC** – CMEMS-Phase1 Call for Tender Iberian-Biscay-Irish Monitoring and Forecasting Centre.

- **Myocean Series of Projects**: MyOcean (EU-FP7) Myocean2 (EU-FP7) & Myocean-FollowOn (H2020).

- **MyCoast** - A Coordinated Atlantic Coastal Operational Oceanographical Observatory. (EU-FEDER Interreg, Atlantic Program).

Relevant significant infrastructure and/or any major items of technical equipment:

Participant 9 : Ocean Next (Ocean Next)

Ocean Next is a non profit small-sized enterprise specialized in the development and prototyping of numerical technologies and services in the field of operational oceanography and space-borne observation, including:

- high-resolution ocean numerical model experiments and their execution on HPC systems.
- scientific software (GCMs, analysis/assessment of numerical experiments, etc).
- modeling of air-sea interactions and marine atmospheric boundary layer.
- probabilistic approaches based on large-ensemble eddy-permitting ocean simulations.
- Observing System Simulation Experiments (OSSEs), satellite and in-situ data.
- Construction of high-standard spatial-observation-based products.

Ocean Next was founded in 2017 by Jacques Verron (CNRS Research Director Emeritus), an internationally-renowned expert and pioneer in spatial oceanography and ocean data assimilation. Ocean Next strongly benefits from interactions with researchers from the MEOM group at the Institut des Géosciences de l'Environnement (IGE) in Grenoble, for which it carries out several contractual activities.

Currently, Ocean Next is in charge of the execution of several contracts in relation to the Copernicus Marine Environment Monitoring Service (CMEMS) and in preparation for SWOT altimeter mission.

Despite being a relatively young company, Ocean Next gathers employees with a long-standing and recognized expertise in using and developing NEMO, as highlighted in the upcoming sections.

Short profile of key personnel involved:

Dr. Laurent Brodeau (Male), Ph.D., research scientist at Ocean Next, is in charge of the activities related to high-resolution modeling of the ocean, HPC issues, coupling of GCM components, simulation design and model configurations. He is an expert in GCM modeling on supercomputers (in particular with NEMO), air-sea interactions, atmospheric forcing of ocean GCMs, inter-coupling of GCM components, and spatial interpolation of geophysical data. He has 15 years of experience in working with NEM and contributing to the development of NEMO. He is part of the NEMO developper Committee since 2014.

Prior to joining Ocean Next, he was employed one year as a Senior Scientist at the Barcelona Supercomputing Center (BSC) in Spain. There, he developed and made the global ultrahigh horizontal resolution (~15 km) version of the EC-Earth climate model (NEMO-ORCA12 coupled to IFS-T1279) come to life in the context of PRIMAVERA WP4 (H2020).

Between 2008 and 2016 he was employed as a climate modeler at Stockholm University. There, he designed and executed various coupled climate experiments with EC-Earth, such as the Swedish CMIP5 historical/scenario simulations. He authored scientific publications with a focus on high-latitude ocean circulation changes in the context of climate change. He holds a PhD from Université Joseph Fourier of Grenoble (2007), which focused on air-sea interactions and the atmospheric forcing of ocean models (mainly NEMO).

Laurent Brodeau will be involved in IMMERSE WP5 and WP6.

Dr. Stephanie Leroux (Female), Ph.D., research scientist at Ocean Next, is in charge of the activities related to ensemble approaches in ocean numerical modeling and data analysis. She has a background in Geophysics, Earth and Environmental sciences from Ecole Normale Supérieure de Lyon and from Université de Grenoble, France. She graduated in 2009 with a PhD in atmospheric dynamics from Université de Grenoble.

Before joining Ocean Next, she has been working as a postdoctoral fellow and a research assistant in several research institutes, including three years in the USA, at NOAA, Colorado, and SUNY, New York, and four years in France at CNRM/Météo-France, Toulouse, and MEOM/IGE, Grenoble.

Her research experience covers a wide range of topics in ocean, atmosphere and climate sciences, including eddy-permitting ocean GCMs and ensemble simulations, ocean low-frequency intrinsic variability, atmospheric GCMs and atmospheric tropical variability, monsoon, teleconnexions.
She gained a strong technical expertise in designing and running ocean and atmosphere numerical experiments with various types of GCMs, e.g. full-physics, idealized, data-driven; in developing appropriate numerical tools and metrics; and in performing statistical analyses on numerical model outputs and observational datasets.
In particular, she recently took part with the MEOM group in the OCCIPUT project and gained a strong expertise in running large ensemble simulations with the newly developed ensemble-configuration of NEMO (see Bessières et al., 2017). She is now involved in the production, distribution, and analysis of the ensemble simulation dataset based on NEMO.
Stephanie Leroux will be involved in IMMERSE WP7.

Relevant publications, and/or products, services, or other achievements :

Publications:

- Bessières L., **Leroux S.**, **Brankart J.-M.**, Molines J.-M., Bouttier P.-A., Penduff T., Terray L., **Barnier B.**, Serazin G. (2017): Development of a probabilistic ocean modelling system based on NEMO 3.5: application at eddying resolution. *Geosci. Model Dev.*, 10, 1091–1106, doi:10.5194/gmd-10-1091-2017.
- **Leroux S.**, T. Penduff, L. Bessières, J-M. Molines, **J-M. Brankart**, G. Sérazin, **B. Barnier** and L. Terray (2018): Intrinsic and Atmospherically Forced Variability of the AMOC: Insights from a Large-Ensemble Ocean Hindcast. *J. Clim.*, 31 (3), 1183–1203, doi:10.1175/JCLI-D-17-0168.1.
- **Brodeau, L., B. Barnier**, S. Gulev, and C. Woods (2017): Climatologically significant effects of some approximations in the bulk parameterizations of turbulent air-sea fluxes. *J. Phys. Oceanogr.*, 47 (1), 5–28, doi:10.1175/JPO-D-16-0169.1.
- **Brodeau, L.**, **B. Barnier,** A.-M. Treguier, T. Penduff, and S. Gulev (2010): An ERA40-based atmospheric forcing for global ocean circulation models. *Ocean Modelling*, 31, 88–104, doi:10.1016/j.ocemod.2009.10.005. *[207 citations, Scopus, feb. 2018]* and the associated DRAKKAR (atmospheric) Forcing Sets (DFS4 & DFS5) used to force NEMO simulations.

Software:

The **AeroBulk** (software) project (https://github.com/brodeau/aerobulk ; Brodeau *et al.,* 2017) on which the NEMO code relies (since version 4) to computes air-sea fluxes was initiated and is led by Laurent Brodeau (AeroBulk will be one of the main tools to be used and further developed during the execution of WP5).

Relevant previous projects or activities:

- contractor for CNRS in the execution of the **CMEMS 22-GLO-HR R&D project**.
- contractor with CNES in the context of the **SWOT Science Team** for the validation and dissemination of NATL60 (1/60° North Atlantic submesoscale permitting NEMO simulation with 300 vertical levels)
- Project **ReSuMPTiOn**: ongoing PRACE project (40 million cpu hours) aiming at performing next generation ultra-high resolution NEMO simulations with NATL60.

Participant 10 : Helmholtz-Zentrum für Ozeanforschung Kiel (GEOMAR)

GEOMAR is among the largest non-university research institutions in the field of marine sciences in Germany (1000 staff, incl. 450 experienced scientists and about 200 doctoral candidates), and a member of the Helmholtz Association, Germany’s largest non-university scientific organisation. The centre’s mandate is the inter- and multidisciplinary investigation of all relevant aspects of modern marine sciences, from seafloor geology through physical, chemical and biological oceanography to marine meteorology. Research is conducted worldwide in all oceans. The main research topics are grouped in four divisions: Ocean Circulation and Climate Dynamics, Marine Biogeochemistry, Marine Ecology, and Dynamics of the Ocean Floor. GEOMAR cooperates closely with national and international research institutions and with a number of SMEs active in marine technology and science. The scientific breadth and the state-of-the-art infrastructure, particularly adapted for deployments in the open ocean and the deep sea, gives GEOMAR a unique profile and a central collaborative role within the German and international marine science community.
The department “Theory and Modeling” has a 15-year long experience with the NEMO modeling framework and is an experienced partner in joint simulation efforts in European and international collaborations.

Short profile of key personnel involved:
Dr. Markus Scheinert (Male), PhD, is a scientific programmer and data steward at GEOMAR. During his studies in physical oceanography at GEOMAR, Dr. Markus Scheinert worked as a student helper for different working groups: observational oceanography, ocean modeling and for the computer department. During this time he gained a broad range of experience with different aspects of scientific programming and software development. During his PhD studies of the variability of the subpolar freshwater budget in the North Atlantic, he already undertook the task of implementing collaboration software for the department "Theory and Modeling" at GEOMAR. He received his PhD in physical oceanography at Kiel University, Germany in 2008. As a PostDoc in the same department he worked as a scientific programmer and took on responsibility for the management of the model code and the programming environment for the whole working group. Since 2016, he has a permanent position as scientific programmer and data steward. Together with other developers and the data-management department at GEOMAR he develops and helps to establish modern strategies and services in support of other scientists in the modeling department. He is also in collaboration with international working groups in the field of ocean modeling (inc. the DRAKKAR coordination) and is responsible for the contributions of the working group to ocean model intercomparison projects. In IMMERSE WP2 he will design the conceptual framework for sharing configuration information for NEMO simulations. Together with a programmer-to-be-hired, he will be responsible for the implementation and the final delivery of the solution.

Relevant publications, and/or products, services, or other achievements :

- **Scheinert, M.**, Biastoch, A. and Böning, C. W. (2009) The Agulhas System as a Prime Example for the Use of Nesting Capabilities in Ocean Modelling. In: High Performance Computing on Vector Systems 2009. , ed. by Resch, M., Roller, S., Benkert, K., Galle, M., Bez, W. and Kobayashi, H.. Springer, Berlin, pp. 191-198. ISBN 978-3642039126

- Danabasoglu, (...) **Scheinert** (...) et al. (2016) North Atlantic simulations in Coordinated Ocean-ice Reference Experiments phase II (CORE-II). Part II: Inter-annual to decadal variability. Ocean Modelling, 97 . pp. 65-90. DOI 10.1016/j.ocemod.2015.11.007.

Relevant previous projects or activities:
simreg.geomar.de - A test server for a git-based simulation registry (2017); for internal use only.

Relevant significant infrastructure and/or any major items of technical equipment:
The following infrastructure will be involved:
* Disk storage for input data and diagnostic output fields.
* A public git-server for a central repository holding the configuration files
* A central SQL database for collecting the simulation's meta data
* A web server hosting static pages for simulation summaries and providing an interface for the database.

Participant 11 : Università di Bologna (UNIBO)

UNIBO is one of the most important institutions of higher education across Europe and the second largest university in Italy with 11 Schools, 33 Departments and more than 84.000 students. UNIBO is the second Italian University in access to EU funding. UNIBO is now part of the Copernicus Academy and it works on several Blue Growth projects in the Mediterranean and the Atlantic. It is involved in the BLUEMED initiative and coordinates the EU STRATEGY FOR THE ADRIATIC-IONIAN REGION (EUSAIR) initiative.
The Oceanography group of the Department of Physics and Astronomy at UNIBO is actively working in the field of numerical modelling of the coupled physical-biogeochemical dynamics of the Marine Environment. Furthermore is a leading group in Copernicus Marine Environment Monitoring Service for the development of satellite and in situ data assimilation. Furthermore it develops applications for security and management of pollution emergencies by developing oil transport and transformation models. The group has been active (with coordination and Workpackage coordination duties) in several EU funded FP5, FP6, FP7 and H2020 research programmes.

Short profile of key personnel involved:

Nadia Pinardi (Female), Ph.D., she is Associate Professor at the Physics and Astronomy Department and she holds a doctorate in Applied Physics at Harvard University, USA. She holds research positions at the EuroMediterranean Center for Climate Change (CMCC, IT), at the Cooperative Institute for Research in Environmental Sciences of the University of Colorado (USA) and she is the co-president of the Joint Committee for Oceanography and Marine Meteorology of the World Meterological Organization and the International Oceanographic Commission of Unesco. She has written more than 150 papers and her H index is 38 (ISI) and 39 (SCOPUS).

Francesco Trotta (Male), Ph.D., he currently holds the position of research fellow (RTD-A) at the Physics and Astronomy Department of the University of Bologna. During the last five years he has worked on high resolution ocean modeling and in particular he has developed an innovative relocatable ocean modelling framework to generate high resolution oceanic forecasts. Since November 2016 he is a consortium expert for the NEMO Developer's Committee.

Relevant publications, and/or products, services, or other achievements :

- **Pinardi, N.;** Cavaleri, L.; Coppini, G.; De Mey, P.; Fratianni, C.; Huthnance, J.; Lermusiaux, P. F. J.; Navarra, A.; Preller, R.; Tibaldi, S. (2017): *From weather to ocean predictions: An historical viewpoint, Journal of Marine Research*, 2017, 75, pp. 103 – 159, doi: 10.1357/002224017821836789

- **Pinardi, N.**, M. Zavatarelli, M. Adani, G. Coppini, C. Fratianni, P. Oddo, S. Simoncelli, M.Tonani, V. Lyubartsev, S. Dobricic (2015). The Mediterranean Sea large scale low frequency ocean variability from 1987 to 2007: a retrospective analysis, Progress in Oceanography, doi: 10.1016/j.pocean.2013.11.003.

- **Pinardi, N.**; Lyubartsev, V.; Cardellicchio, N.; Caporale, C.; Ciliberti, S.; Coppini, G.; De Pascalis, F.; Dialti, L.; Federico, I.; Filippone, M.; Grandi, A.; Guideri, M.; Lecci, R.; Lamberti, L.; Lorenzetti, G.; Lusiani, P.; Damiano Macripo, C.; Maicu, F.; Mossa, M.; Tartarini, D.; **Trotta, F.**; Umgiesser, G.; Zaggia, L.; (2016). Marine rapid environmental assessment in the gulf of Taranto: A multiscale approach, NATURAL HAZARDS AND EARTH SYSTEM SCIENCES, 2016, 16, pp. 2623 – 2639

-**Trotta, F.**; Fenu E.; Pinardi, N.; Bruciaferri, D.; Giacomelli, L.; Federico, I; Coppini, G.; 2016. A Structured and Unstructured grid Relocatable ocean platform for Forecasting (SURF), Deep Sea Research Part II: Topical Studies in Oceanography, 133, pp. 54 – 75

- **Trotta, F.**; Pinardi, N.; Fenu, E.; Grandi, A.; Lyubartsev, V. ; 2017. Multi-nest high-resolution model of submesoscale circulation features in the Gulf of Taranto, Ocean Dynamics, 67, pp. 1609 – 1625

Relevant previous projects or activities:

- EU-FP7 "**PERSEUS**" project (Policy Oriented Research in the Southern European Seas). The FP7 project develops and implements innovative tools for the sustainable management of large marine ecosystems.

- EU-FP7 "**MEECE**" project (Marine Ecosystem Evolution in a Changing Environment). The FP7 project explores the impacts of both climate drivers and human induced drivers like fishing, invasive species and pollution on marine ecosystems.

- EU-H2020 "**AtlantOS**" project (Optimising and Enhancing the Integrated Atlantic Ocean Observing Systems, https://www.atlantos-h2020.eu/): a large scale research and innovation project contributing to the Trans-Atlantic Research Alliance and GEO.

- EU-H2020 "**SeaDataCloud**" project (2016-2020), aims at considerably advancing SeaDataNet Services and increasing their usage, adopting cloud and High Performance Computing technology for better performance.

- EU-H2020 "**MARISA**" project (Maritime Integrated Surveillance Awareness, http://www.marisaproject.eu/): the project develops a data fusion kit enabling maritime security forces to effectively share information, identify potential risk situations, and improve reaction and decision-making capabilities.

Relevant significant infrastructure and/or any major items of technical equipment:

The oceanography laboratory at the University of Bologna is equipped with several Linux-based multi-processors workstations and it has available the High Performance Computing resources from the Italian Supercomputing Centre (CINECA) located in Bologna.

Participant 12 : Helmholtz-Zentrum für Material und Küstenforschung Geesthacht (HZG)

HZG is one of 16 national research centres belonging to the Hermann von Helmholtz Association (HGF). One of the main research areas of HZG covers environmental research focusing on weather and climate in the coastal zone. In HZG new instruments and automatic monitoring systems have been prepared and numerical models have been used for the development of new monitoring strategies, ocean state estimates and forecasting. HZG coordinates COSYNA (Coastal Observation System for Northern and Arctic Seas), which aims at increasing synergy between observations and numerical modelling with the aim to improve the performance of ocean forecasting systems. HZG expertise includes data fusion, numerical modelling and data assimilation, as well as skill assessment and metrics. One of the main research areas of HZG covers environmental research focusing on weather and climate in the coastal zone. HZG will participate in WP8.

Short profile of key personnel involved:

Dr. Joanna Staneva (Female), Ph.D., is a senior researcher and head of the Department of hHydrodynamics and Data Assimilation in the Institute for Coastal Research, HZG, Germany Her field of experience is circulation and wave modelling, coastal ocean predictions, coupled model systems, modelling of marine environment, wave dynamics, coastal and regional oceanography. She received her PhD in Physical Oceanography (1998). She published more than 60 peer review papers, participated (in many as a PI) in numerous national and international projects and is member of different editorial and scientific boards and reviewer of scientific programmers, projects and journals.

Dr. Sebastian Grayek (Male), Ph.D., field of experience is in NEMO modelling for the regional scales, synergy between the newly available observational data and models, data assimilation.

Dr. Johannes Pein (Male), Ph.D., is experienced in unstructured-grid modelling with focus on German Bight and tidal estuaries.

Relevant publications, and/or products, services, or other achievements :

- **Staneva, J.**, K. Wahle, H. Günther and E. Stanev (2016): Coupling of wave and circulation models in coastal-ocean predicting systems: a case study for the German Bight. Ocean Science, 12, 797–806,

- **Staneva J.**, Alari V., Breivik O, Bidlot J.-R. and Mogensen K., (2017). Effects of wave-induced forcing on a circulation model of the North Sea. Ocean Dynamics, DOI 10.1007/s10236-016-1009-0,

- **Staneva J**, Wahle K, Koch W, Behrens A, Fenoglio-Marc L., and Stanev E., (2016). Coastal flooding: impact of waves on storm surge during extremes – a case study for the German Bight, Nat. Hazards Earth Syst. Sci., 16, 2373-2389, doi:10.5194/nhess-16-2373-2016;

- **Staneva J.**, A. Behrens and K. Wahle (2015): Wave modelling for the German Bight, J. Phys. 633 012117

- Stanev, E. V., Schulz-Stellenfleth, J., **Staneva, J.**, **Grayek, S.**, Grashorn, S., Behrens, A., Koch, W., and **Pein, J.** (2016): Ocean forecasting for the German Bight: from regional to coastal scales, Ocean Sci., 12, 1105-1136.

Relevant previous projects or activities:

HZG has cultivated a successful year-long tradition in both the co-ordination of and participation in different types of EU projects. Since the year 2000, researchers at HZG have coordinated some 40, and have participated in more than 120 EU projects co-financed mainly through FP5, FP6, FP7 and H2020 framework programmes. In the following latest projects the Department and the PI are involved (incl. as leader or WP leader):

- **H2020-EO-2016, EO-3-2016**: Copernicus Evolution and Applications with Sentinel Enhancements and Land Effluents for Shores and Seas (CEASELESS)
- **CMEMS BS-MFC**: Black Sea – Monitoring Forecasting Centre
- **COPERNICUS Marine Environment Monitoring Service** (CMEMS) - Coupled ocean-wave model development in forecast environment
- **Helmholz Initiative**: Advanced Earth System Modelling Capacity (ESM): A contribution to solving Grand Challenges
- **H2020: JERICO-NEXT**
- **FONA**: Future Ems: The future of the Ems-Dollart estuary – tackling environmental degradation
- **FP7**: **myOcean-FO, myOcean-2, myWave, FieldAC**

Relevant significant infrastructure and/or any major items of technical equipment:

Well-equipped computational facilities and scientific laboratories, high sophisticated analytical instruments and other facilities such as coastal radars, research vessels, stations and buoys for testing new sensors under operational conditions are available. Numerical modelling at HZG comprises, among others, regional wave, circulation and atmosphere modelling with focus on multi-decadal reconstruction and scenarios on global and regional scales. Access to supercomputing facilities).

Participant 13 : Universiteit Utrecht (Univ. Utrecht)

Established in 1636, **Utrecht University** has evolved into a leading modern comprehensive research university with a growing international reputation. On the 2017 Shanghai Academic Ranking of World Universities, Utrecht University ranks first in the Netherlands, 14th in Europe and 47th in the world. UU has an annual turnover of over 750 million euro, 34% of which from external funding.
Within Utrecht University, the Institute of Marine and Atmospheric Research is The Netherland's leading centre for academic research into meteorology, oceanography and climate. Recently celebrating its 50th anniversary, the Institute has strong ties within the University and the wider research community in Europe.

Short profile of key personnel involved:

Dr Erik van Sebille (Male), Ph.D., is associate professor in oceanography and climate change at Utrecht University. He investigates the pathways and time scales of ocean circulation, and how currents transport tracers and particulates such as plastic and plankton around.

Relevant publications, and/or products, services, or other achievements :

- Lange, M, **E van Sebille** (2017), Parcels v0.9: prototyping a Lagrangian Ocean Analysis framework for the petascale age. *Geoscientific Model Development*, *10,* 4175-4186

- van Sebille, E, C Wilcox, L Lebreton, N Maximenko, BD Hardesty, J Van Franeker, M Eriksen, D Siegel, F Galgani, KL Law (2015). A global inventory of small floating plastic debris. *Environmental Research Letters*, *10*, 124006

- Cózar, A, E Martí, CM Duarte, J García-de-Lomas, **E van Sebille**, TJ Ballatore, VM Eguíluz, JI González-Gordillo, ML Pedrotti, F Echevarría, R Troublè, X Irigoien (2017): The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation. *Science Advances*, *3*, e1600582

- Hardesty, BD, J Harari, A Isobe, L Lebreton, N Maximenko, J Potemra, **E van Sebille**, D Vethaak, C Wilcox (2017) Using numerical model simulations to improve the understanding of microplastic distribution and pathways in the marine environment. *Frontiers in Marine Science*, *4*, 30

- van Sebille, E, et al. (2018) Lagrangian ocean analysis: fundamentals and practices. *Ocean Modelling*, *121*, 49-75

Relevant previous projects or activities:

- **European Research Council H2020** Starting Grant "Tracking Of Plastic In Our Oceans"
- **EPSRC** Institutional Sponsorship Award "Extracting Lagrangian information from numerical ocean models in the petascale age"
Development of website plasticadrift.org

Relevant significant infrastructure and/or any major items of technical equipment:

Development of the open-source oceanparcels.org code for tracking virtual Lagrangian particles in ocean hydrodynamic fields.

Participant 14 : Plymouth Marine Laboratory (PML)

Plymouth Marine Laboratory is a NERC Collaborative Centre and An International Centre of Excellence in Marine Science & Technology. PML research focuses on understanding biodiversity and ecosystem function, which is critical to providing solutions in terms of measures of ecological sensitivity, biogeochemical cycling, scaling biodiversity and forecasting the role of the oceans in the Earth System. PML provides the biogeochemical model system (ERSEM) for the operational Copernicus Marine Core Service for the NW European Shelf through the UK Met Office and leads the UK wide development of ERSEM through the NERC SSB, MERP and UKESM programs.

Short profile of key personnel involved:

Dr Ricardo Torres (Male), Ph.D., is a senior Physical Oceanographer, a member of the Marine Ecosystem Models and Predictions and head of the fine-scale modelling team. Torres has over 17 years' experience on shelf-seas and coastal oceanography with a broad interest in mesoscale dynamics, bio-physical interactions and modelling. He has considerable experience with unstructured grid coupled hydrodynamic-ecosystem models, led the development of FVCOM-ERSEM model system and collaborates closely with the FVCOM development team (Dr Chen's group, UMASSD). He has participated on 8 EU projects (3 as Co-I), and 7 NERC projects (4 PI/ 3 Co-I) and has published 38 peer-review articles (679 citations, H-index 15; Researchgate February. 2018). He will lead the modelling work in the Water Quality case study in WP8.

Dr Pierre Cazenave (Male), Ph.D., is a numerical modeller specialising in unstructured grid modelling. His work has focused on a range of coastal and shelf sea problems, including: modelling impacts from large scale marine renewable device installations and the consequences for marine ecosystems; the impacts of aquaculture on ecosystems; the fate of microplastics released from land; and the impacts of potential leaks of carbon capture and storage. He has 14 peer-reviewed articles with 109 citations (h-index 6).

Dr Michael Bedington (Male), Ph.D., is a hydrodynamic modeller working with high resolution unstructured grid coastal models in estuarine and coastal settings. He is currently participating in the NERC LOCATE project, and the Interreg MyCOAST and PRIMROSE projects. His PhD from the University of Aberdeen (2016) was titled 'Drift of marine mammal carcases in coastal waters' and focused on lagrangian modelling of carcases to inform monitoring programmes of marine mammal strandings.

Relevant publications, and/or products, services, or other achievements :

- **R. Torres** and R. Uncles (2011). Modelling of Estuarine and Coastal Waters. In Treatise on Estuarine and Coastal Sciences. Ed. E. Wolanski and D.S. McLusky, Waltham: Ac. Press. V. 2, 395-427.

- **P. W. Cazenave**, **R. Torres**, J. I. Allen (2016), Unstructured grid modelling of offshore wind farm impacts on seasonally stratified shelf seas, Progress in Oceanography, Volume 145, Pages 25-41

- M., Butenschön, Clark, J., Aldridge, J. N., Allen, J. I., Artioli, Y., Blackford, J., Bruggeman, J., **Cazenave, P**., Ciavatta, S., Kay, S., Lessin, G., van Leeuwen, S., van der Molen, J., de Mora, L., Polimene, L., Sailley, S., Stephens, N., and **Torres, R.** (2015) ERSEM 15.06: a generic model for marine biogeochemistry and the ecosystem dynamics of the lower trophic levels, Geoscientific Model Development 9 (4):1293–1339.

- Gilcoto, M., J. Largier, E. D. Barton, S. Piedracoba, **R. Torres**, R. Graña, F. Alonso-Pérez, N. Villacieros-Robineau, and F. de la Granda (2017). Rapid Response to Coastal Upwelling in a Semienclosed Bay. Geophys. Res. Letters, 2016GL072416. doi:10.1002/2016GL072416.

- Skákala, J., **P. W. Cazenave**, T. J. Smyth, and **R. Torres**. (2016). Using Multifractals to Evaluate Oceanographic Model Skill. Journal of Geophysical Research: Oceans 121 (8): 5487–5500. https://doi.org/10.1002/2016JC011741.

Relevant previous projects or activities:

PML has extensive experience in EU and international projects and hosts two international offices from KMIST and POGO. Since 2010 we have been involved in more than 15 EU programs leading three of them. These have involved modelling (e.g. EU-MEECE, VECTORS, OPEC), EO (MEDINA, MyCOAST) and coastal Observatories (Marinexus, Medon, Charm).
Of particular relevance to this proposal are the current H2020 EU projects **CMEMS-NOWMAPS (2)**, **CMEMS-TOSCA** (Towards Operational Size-class Assimilation), Interreg project **MyCOAST** and the FP6 project Marine Environment and security for the European Area (**MERSEA**) and FP7 Operational Ecology Marine Ecosystem Forecasting (**OPEC**) project.

Relevant significant infrastructure and/or any major items of technical equipment:

PML provides all infrastructures required to work on computer modelling of complex systems such as access to Linux workstations, High Performance Computing and associated software. In addition PML have a range of field work facilities such as our coastal boat and infrastructure associated with our Western Channel Observatory (from permanent moorings and marine sensors to research laboratories).

If operational capacity cannot be demonstrated at the time of submitting the proposal, describe the concrete measures that will be taken to obtain it by the time of the implementation of the task:

Our involvement in WP8 does not require the use of our modelling systems in operational mode although the capability is being developed under Interreg projects MyCoast and PRIMROSE. In the past we have setup an operational system of the Western English Channel through the MERSEA project. That system was based on models POLCOMS and ERSEM and was nested directly onto the MetOffice UK operational system at the time (2007).

4.2. Third parties involved in the project (including use of third party resources)

There are NO third parties involved for :

MERCATOR OCEAN, MET OFFICE, BSC, PdE, OCEAN NEXT, UNIBO, HZG, Univ. Utrecht, PML

CNRS:

Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)	N
Does the participant envisage that part of its work is performed by linked third parties[15]	Y
CNRS' third parties involved in IMMERSE are : - Institut de Recherche pour le Développement (IRD) - Centre européen de recherche et de formation avancée en calcul scientifique (CERFACS) - Sorbonne Universités (SU) The laboratories "LOCEAN" (Laboratoire d'océanographie et du climat : expérimentations et approches numériques, UMR7159), and "ECCE TERRA" (Observatoire des sciences de l'Univers Paris-Centre Ecce Terra, UMS3455) are Joint Research Units (JRU) between CNRS, IRD and SU. Therefore, IRD and SU staff members (respectively Olivier Aumont and Sébastien Masson, Nicolas Martin) will participate to the different tasks of the project. The laboratory "CECI" (Climat, Environnement, Couplages et Incertitudes, UMR5318) is a JRU between CNRS and CERFACS. Therefore, a CERFACS staff member (Eric Maisonnave) will participate to the different tasks of the project.	
Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)	N
Does the participant envisage that part of the work is performed by International Partners[16] (Article 14a of the General Model Grant Agreement)?	N

CMCC:

Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)	Y
CMCC will subcontract some technical aspects of the evaluation of vertical velocities in the sub-kilometric scale model simulations of the Iberia-Biscay-Irish MFC demonstrator. The contractor will contribute to the software engineering tasks for the validation of the regional kilometric demonstrator in WP6. A competitive tender will allow to select a contractor with the appropriate expertise on the quantification of vertical velocities at submesoscale from ocean model simulations.	
Does the participant envisage that part of its work is performed by linked third parties[19]	N
Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)	N
Does the participant envisage that part of the work is performed by International Partners[20] (Article 14a of the General Model Grant Agreement)?	N

NERC:

Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)	N
Does the participant envisage that part of its work is performed by linked third parties[17]	N
Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)	Y
Dr Alan Grant at the University of Reading (UoR) in the UK will work with Dr George Nurser (NERC) on the development of the OSMOSIS scheme in Work Package 5. Dr Grant is funded separately at the UoR whereas Dr Nurser will receive funding from WP5. The value of Dr Grant's work in kind work would be approximately 100k Euros.	
Does the participant envisage that part of the work is performed by International Partners[18] (Article 14a of the General Model Grant Agreement)?	N

INRIA:

Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)	N
Does the participant envisage that part of its work is performed by linked third parties[21]	Y
In this Project, Inria represents the Team AIRSEA AIRSEA Team is a Joint Research Unit for which Inria will represent University of Grenoble Alpes (UGA), a **Third Party linked to Inria** in future Grant Agreement and Consortium Agreement: UGA as a **Third Party linked to Inria**, will carry out part of the work attributed by the future Grant Agreement. They will fill Third Party's Financial Reports with their own costs. AIRSEA is a "Joint Project Team" of both UGA and Inria, with contributions from UGA and Inria. At Inria, a Joint Project Team is an administrative entity created by the signature of a contract between one or some research laboratories of a higher education and research establishment (such as a University) with Inria, in order to optimise the research infrastructures in the same domain. AIRSEA is located inside UGA buildings, and in this Joint Project Team, some people are paid by Inria and other people are paid by UGA. Inria pays for the "rooms" and contributes, together with UGA, to buy machines, to pay researchers travels, chemical products and other consumables. An agreement among parties, called "Accord Cadre", describes all details and is actualised every 4 years.	
Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)	N
Does the participant envisage that part of the work is performed by International Partners[22] (Article 14a of the General Model Grant Agreement)?	N

GEOMAR:

Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)	N
Does the participant envisage that part of its work is performed by linked third parties[23]	N
Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)	Y

The final solution or parts of it, as developed in T2.3, may rely on free services provided by gitlab.com and/or github.com as well as zenodo.org.	
Does the participant envisage that part of the work is performed by International Partners[24] (Article 14a of the General Model Grant Agreement)?	N

Section 5: Ethics and Security

5.1 Ethics

There are no ethics issues to declare. However, we will only collect personal information that is necessary for the project, and use it exclusively for the relevant objectives of IMMERSE. All beneficiaries will ensure that they adhere to EC legislation and their own national legislation with regard to data protection (including EU Directive 95/46/EC and any subsequent updates to this directive).

Procedures will be implemented for data collection, storage, protection, access, retention and destruction. This includes an informed consent procedure, thus ensuring that all interviewees, workshop attendees etc will understand and agree to how the data they provide will be handled. These procedures will be developed by the end of the second month of the project. No personal data will be collected until these procedures are in place.

5.2 Security

IMMERSE project will NOT involve :

- activities or results raising security issues, nor
- 'EU-classified information' as background or results

Section 6 : Letters of Support

This section includes letters of support for IMMERSE proposal from :

- **Pierre Bahurel**, CEO of Mercator Ocean, entrusted entity for the implementation of CMEMS
- **Glenn Nolan**, secretary general of EuroGOOS AISBL
- **Eric Chassignet**, co-chair of GODAE OceanView
- **Nils Wedi**, Head of the Earth System Modelling division at ECMWF
- **Baylor Fox-Kemper**, co-chair of CLIVAR Ocean Model Development Panel

Ramonville Saint-Agne, 1st March 2018

MERCATOR OCEAN
OCEAN FORECASTERS

Pierre Bahurel
CEO Mercator Ocean
Entrusted Entity for the implementation of the
EU Copernicus Marine Environment Monitoring Service

Dr. Julien Le Sommer
IMMERSE Proposal leader
CNRS
Institute for Geosciences and
Environmental research (IGE/MEOM)
CS 40700 –
38 058 Grenoble Cedex 9
France

Re: PB-LM - 2018-028

Subject: Letter of support to the H2020 "IMMERSE" project

Dear Dr Le Sommer,

Mercator Ocean is entrusted by the European Union for implementing the Copernicus Marine Environment Monitoring Service (CMEMS). The operational phase of the service has started early 2015, following 10 years of scientific and technical development resulting in a cutting-edge and worldwide capacity in ocean monitoring and forecasting. With more than 12000 subscribers so far and a constantly growing uptake, this unique EU Marine Service outreaches on all continents ocean state information from the best European experts. Cooperation between advanced science and operational services has always been amongst CMEMS core principles and key factors of success.

Mercator Ocean has set up accompanying measures to stimulate constant innovation in the CMEMS operational service performance at short-term (Tier 1) and mid-term (Tier2): this takes the form of innovation contracts with expert teams committed to transition mature tools and methods into the operational chains. This ensures a smooth transition from research to operation, but is however based on the assumption that a sound and long-term (Tier3) effort is maintained by the research community in such areas to feed the overall know-how. The H2020 programme is of course pivotal in this matter, and initiatives such as the IMMERSE proposal can be exemplary by their contributions to feed the long value chain bringing innovations from upstream research to downstream uses.

The proposal *Improving Models for Marine EnviRonment SErvices* (IMMERSE) aims at "ensuring that the Copernicus Marine Environment Monitoring Service will have continuing access to world-class marine modelling tools for its next generation systems while leveraging advances in space and information technologies, therefore allowing it to address the ever-increasing and evolving demands for marine monitoring and prediction in the 2020s and beyond". Ocean modelling is indeed at the heart of the CMEMS ocean monitoring capacity and NEMO – which is central in the IMMERSE proposal – is by far the most widely used modelling framework in our Monitoring and Forecasting Centres. The quality of our ocean products is consequently highly dependent upon the NEMO overall performance, and I see in IMMERSE a great potential to meet our requirements for long-term improvements.

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MERCATOR OCEAN
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IMMERSE gathers highly-qualified partners forming a unique consortium by the complementarity of their skills ranging from research, operations and high-performance computing. Having carefully read the five objectives and the overall description of the IMMERSE proposal, I see how the proposed workplan could strengthen the current modelling foundation of CMEMS with an improved NEMO, more efficient, more performant, and more prepared to address the next generation modelling challenges. This is critically needed to support the competitivity of the EU Marine Service, for blue growth and ocean knowledge.

I therefore support the IMMERSE proposal.

Yours sincerely,

Pierre BAHUREL

EuroGOOS
European Global Ocean Observing System

EG18.03
2 March 2018

Julien Le Sommer
Research Scientist
IGE/MEOM group

Letter of Support for the IMMERSE Proposal

Dear Dr Le Sommer,

As you know, EuroGOOS identifies priorities, enhances cooperation and promotes the benefits of operational oceanography to ensure sustained observations are made in Europe's seas underpinning a suite of fit-for-purpose products and services for marine and maritime end-users. EuroGOOS has played a key role in supporting and guiding the development of the Copernicus Marine Environment Monitoring Service (CMEMS) in line with the interests of its members for many years.

IMMERSE proposes to make important improvements to the NEMO model which underpins CMEMS. These improvements are also of direct interest to many of our members who use NEMO within their own systems. The development and demonstrations of a tool to simplify access to the CMEMS products for downstream services will also be of very great interest to many of our members.

The IMMERSE team includes on the one hand groups leading the development of NEMO and of operational oceanography in Europe who have a long history of successful collaboration within European projects and on the other world-class researchers in relevant topics (e.g. model numerics, adaptation of models for modern HPCs, parametrization of physical processes). We believe that the IMMERSE project has every chance of meeting its ambitious objectives.

In summary, we strongly support the IMMERSE proposal which we are confident will make important contributions to the improvement of the CMEMS service and the services provided by our members.

Yours sincerely,

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Glenn Nolan

Secretary General EuroGOOS AISBL

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GODAE OceanView

February 28, 2018

RE: GODAE-OceanView support for the IMMERSE proposal to LC-SPACE-03-EO-2018

Dear Dr. Le Sommer,

The mission of the GODAE OceanView Science Team (GOVST) is to define, monitor and promote actions aimed at coordinating and integrating research associated with multi-scale and multi-disciplinary ocean analysis and forecasting systems. GOVST since its inception has always been proactive in supporting the development of global- and basin-scale ocean models with high horizontal resolutions that are designed to exploit the satellite and in situ observing systems. IMMERSE, by modernizing the ocean model code NEMO to be able to deliver ocean state forecasts and ocean state estimates on scales of the order of the kilometer, will make a substantial contribution to this effort. IMMERSE will also provide the next generation modeling tool that will ensure that CMEMS and Europe is able to address the demands for marine monitoring and prediction past 2020. This is especially important to GODAE OceanView since its Coastal Ocean and Shelf Seas multi-disciplinary task team specifically focuses on the use of products from the high resolution forecast systems to monitor and predict the shelf seas and coastal transition zones. The new and flexible software tools that will be developed as part of IMMERSE will also improve significantly the delivery of information between CMEMS and coastal systems. Finally, the investigations of forecast errors and predictability horizon at fine scale, as proposed in one of the work package, will also make valuable contributions to the GODAE OceanView Data Assimilation task team.

Sincerely,

Eric P. Chassignet

Co-Chair GODAE OceanView

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ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

Europäisches Zentrum für mittelfristige Wettervorhersage | Centre européen pour les prévisions météorologiques à moyen terme

Dr Julien Le Sommer
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Ref.: Letter of support for IMMERSE project in response to the H2020 call LC-SPACE-03-EO-2018

20/02/2018

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0044/118/9499657

Dear Dr Le Sommer,

ECMWF wishes to express very strong and enthusiastic support for the project proposal IMMERSE regarding the development of the leading European ocean model NEMO under your leadership.

ECMWF is an intergovernmental organisation based in the UK supported by 34 member and co-operating states. Its foundation principle was the implementation of a centre of excellence for weather forecasting and supercomputing including the largest meteorological data archive in the world, and the notion of economy of scale provided by strengthening and broadening of capability created by scientists from across Europe and beyond through ECMWF.

The proposed activities have a direct impact on ECMWF's future strategy aimed towards an ocean-atmosphere coupled ensemble forecasting and assimilation system, of which the NEMO model is a central component. The proposed activities towards preparing the NEMO model for higher horizontal resolutions, more effective time-stepping schemes, mesh-refinement capabilities in key areas impacting global atmospheric predictability, improvements to the representation of physical processes at the interface between atmospheric and oceanic boundary layers, together with its adaptability on emerging computing architectures are all essential components of this proposal as well as essential contributions to ECMWF's future operational analysis and forecasting system.

ECMWF will provide constructive feedback that allows to align the ongoing research interests of this project with its own research in this area. I encourage seminar talks at ECMWF and could provide access to ECMWF's computing facilities on emerging architectures through collaboration with ECMWF scientists. The ongoing work in the H2020 funded projects ESCAPE and ESCAPE-2 and the centre of Excellence network ESiWACE will provide and stimulate important collaborative interactions with the proposed project IMMERSE.

Yours sincerely,

Dr Nils Wedi
Head of Earth System Modelling
Scientific coordinator of ESCAPE & ESCAPE-2

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March 2, 2018

Re: IMMERSE H2020
Julien Le Sommer Research Scientist
IGE/MEOM group

Dear Julien,

On behalf of the CLIVAR Ocean Model Development Panel, we are happy to hear the news of your IMMERSE H2020 proposal in response to H2020 LC-SPACE-03-EO-2018. As you state, "The overarching goal of IMMERSE is to ensure that the Copernicus Marine Environment Monitoring Service will have continuing access to world-class marine modelling tools for its next generation systems while leveraging advances in space and information technologies, therefore allowing it to address the ever-increasing and evolving demands for marine monitoring and prediction in the 2020s and beyond."

It is clear that our panel has much to offer in collaborations around these topics. Our panel's terms of reference are: 1) To stimulate the development of ocean models for research in climate and related fields. 2) To encourage investigations of the effects of model formulation on the results of ocean models, making use of sensitivity studies and intercomparisons. 3) To promote interaction amongst the ocean modelling community and between this and other communities through workshops and other activities. 4) To stimulate the validation of ocean models when used in stand alone mode and as part of a coupled ocean-atmosphere model, using oceanographic data and other methods, and to advise on the observational requirements of such studies. 5) To publicise developments in ocean models amongst the climate modelling community. 6) To collaborate with other activities in areas of overlapping responsibility. 7) To advise on ocean modelling and related issues and to report on its activities to the CLIVAR Scientific Steering Group and the CLIVAR co-chair of WGCM. It is clear that your proposal synergizes with terms of reference 1, 2, 4, 6, and 7. We can help you with collecting international input on those tasks, as well as help promote your successes and discoveries through terms of reference 3 and 5. I think in particular that the systematic use of demonstration cases in code testing and validation that you propose in WP2 is a very important step to increase further the robustness of the ocean model development process. Our panel focuses on just such approaches that allow for objective comparisons of ocean model capabilities.

The NEMO and CMEMS teams have been participating in OMDP since its inception. NEMO is one of the most advanced ocean modeling systems in the world, and your project to prepare it for an even grander future through improved high-performance computing capabilities, operational state estimation and forecast features, synthesis with CMEMS observations, and software tools and documentation is a welcome step. The OMDP will aid as it can in communicating your advances, as well as inviting NEMO to participate in many international model comparisons over the course of your project. It is through these comparisons that new technologies, such as those you plan to develop, are built, vetted, and exchanged, and CLIVAR OMDP will do what it can to aid in this process.

Please do not hesitate to contact me if needed.

Sincerely,

Baylor Fox-Kemper

Baylor Fox-Kemper, co-chair of
CLIVAR OMDP, on behalf of co-chair
Simon Marsland and the OMDP