Please check our wiki for help on navigating the form.

Horizon 2020

Call: H2020-MSCA-ITN-2019

(Marie Skłodowska-Curie Innovative Training Networks)

Topic: MSCA-ITN-2019

Type of action: MSCA-ITN-ETN

Proposal number: 861023

Proposal acronym: CODA

Deadline Id: H2020-MSCA-ITN-2019

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	MSCA-ITN-2019	Type of Action	MSCA-ITN-ETN
Call Identifier	H2020-MSCA-ITN-2019	Deadline Id	H2020-MSCA-ITN-2019

Acronym	CODA
Proposal title	Coupled Data assimilation for climate prediction and climate change attribution

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

Duration in months	*48*
Panel	ENV - Environmental and Geosciences (ENV)
Descriptor1	Climatology and climate change
Descriptor2	Numerical analysis, simulation, optimisation, modelling tools
Descriptor3	Meteorology, atmospheric physics and dynamics
Descriptor4	Oceanography, marine science, coastal engineering
Descriptor5	Data Analysis
Free keywords	*Data Assimilation, Climate Dynamics, Optimization, Control*

Abstract

Environmental modelling is experiencing major improvements due to a better understanding of natural processes and to increasing computational resources. Earth System Models (ESMs) couple atmosphere, oceans, land surface and cryosphere components, and have become central in environmental prediction on time scales ranging from a few days to decades. The Earth is also observed over a wide range of spatial and temporal scales, with a variety of observation platforms, particularly satellites. Thus, there is now a unique opportunity to combine ESMs with the new generation of observations, and the techniques of Data Assimilation (DA) are the natural framework to do this. Their use with ESM is currently the focus of intense research in coupled DA (CDA) methods able to process all data and propagate the information consistently between model subcomponents. Accordingly, CODA's scientific goal is to study unified CDA strategies to initialize weather- to-decadal climate forecast. The impacts will include the improvement of climate prediction, a robust observation-based identification and understanding of climate variability mechanisms, and a better estimate of the external forcing causing climate change. CODA relies on a team of experts in geosciences and applied mathematics with the mission of training young climate scientists. The network comprises 12 PhDs in 7 countries with 10 Academic Beneficiaries and 6 Industrial Partners, in an original program that includes broad international mobility, schools, workshops as well as training in dissemination, scientific writing and entrepreneurship. CODA is a powerful interdisciplinary initiative designed to train a much-needed new generation of PhDs with both a robust basis in mathematics and a physical understanding of the climate system. The project will increase the awareness and popularity of new DA methodologies by a wider scientific community and will help maintain the EU at the forefront of climate science.

Remaining characters 21

Has this proposal (or a very similar one) been submitted to a previous ITN call in the last two years? (•) Yes ( ) No

Please give the proposal reference or contract number
813317
764984

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	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	NO	
2	INSTITUT ROYAL METEOROLOGIQUE DE BELGIQUE	BE	
3	ECOLE NATIONALE DES PONTS ET CHAUSSEES	FR	
4	INSTITUT NATIONAL DE RECHERCHE ENINFORMATIQUE ET AUTOMATIQUE	FR	
5	THE UNIVERSITY OF READING	UK	
6	CONSEJO NACIONAL DE INVESTIGACIONES CIENTIFICAS Y TECNICAS (CONICET)	AR	
7	UNIVERSITETET I BERGEN	Norway	
8	BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION	ES	
9	CENTRE EUROPEEN DE RECHERCHE ET DE FORMATION AVANCEE EN CALCUL SCIENTIFIQUE	FR	
10	UNIVERSITEIT UTRECHT	NL	

Information on partner organisations

Partner Organisation number	PIC Search PIC	Organisation legal name	Country	Academic Sector	Role of associated		
					Provide training	Host secondmends	
1	999939827	EQUINOR ASA	Norway	No	Yes	Yes	
2	999926829	ELECTRICITE DE FRANCE	France	No	Yes	Yes	
3	933597065	BKK AS	Norway	No	Yes	Yes	
4	948139596	FUTUREWATER SL	Spain	No	Yes	Yes	
5	930584827	BERGEN TEKNOLOGIOVERFORING	Norway	No	Yes	No	
6	969128359	VORTECH BV	Netherlands	No	Yes	Yes	

2 - Administrative data of participating organisations

Coordinator

PIC	***Legal name***
999477913	*STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING*

Short name: NERSC

Address of the organisation

Street THORMOHLENSGATE 47

Town BERGEN

Postcode 5006

Country Norway

Webpage www.nersc.no

Specific Legal Statuses

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

Academic Sector .....yes

Enterprise Data

SME self-declared status.....2007 - yes

SME self-assessment ..... unknown

SME validation sme.....2007 - 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: Data Assimilation Group ☐ not applicable

☒ Same as proposing organisation's address

Street: THORMOHLENSGATE 47

Town: BERGEN

Postcode: 5006

Country: Norway

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Dr.

Sex: (•) Male ( ) Female

First name: **Alberto** Last name: **CARRASSI**

E-Mail: **alberto.carrassi@nersc.no**

Position in org.: Senior Researcher

Department: STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING ☒ Same as organisation name

☒ Same as proposing organisation's address

Street: THORMOHLENSGATE 47

Town: BERGEN Post code: 5006

Country: Norway

Website: www.nersc.no

Phone: +474647817 Phone 2: *+xxx xxxxxxxxx* Fax: *+xxx xxxxxxxxx*

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Laurent	Bertino	laurent.bertino@nersc.no	*+xxx xxxxxxxxx*
Knut	Holba	knut.holba@nersc.no	*+xxx xxxxxxxxx*

Participant

PIC	***Legal name***
996699154	*INSTITUT ROYAL METEOROLOGIQUE DE BELGIQUE*

Short name: IRM/ KMI

Address of the organisation

Street AVENUE CIRCULAIRE 3

Town BRUXELLES

Postcode 1180

Country Belgium

Webpage www.meteo.be

Specific Legal Statuses

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

Academic Sector .....yes

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: Research and Development Department ☐ not applicable

☒ Same as proposing organisation's address

Street: AVENUE CIRCULAIRE 3

Town: BRUXELLES

Postcode: 1180

Country: Belgium

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Dr.

Sex: (•) Male ( ) Female

First name: **Stephane**

Last name: **Vannitsem**

E-Mail: **svn@meteo.be**

Position in org.: Senior Scientist (SW3)

Department: Research and Development Department ☐ Same as organisation name

☒ Same as proposing organisation's address

Street: AVENUE CIRCULAIRE 3

Town: BRUXELLES

Post code: 1180

Country: Belgium

Website: climdyn.meteo.be

Phone: +3223730552

Phone 2: *+xxx xxxxxxxxx*

Fax: *+xxx xxxxxxxxx*

Participant

PIC	***Legal name***
997637629	*ECOLE NATIONALE DES PONTS ET CHAUSSEES*

Short name: ENPC

Address of the organisation

Street AVENUE BLAISE PASCAL-CITE DESCARTES

Town MARNE LA VALLEE CEDEX 2

Postcode 77455

Country France

Webpage http://www.enpc.fr

Specific Legal Statuses

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

Academic Sector .....yes

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: CEREA ☐ not applicable

☒ Same as proposing organisation's address

Street: AVENUE BLAISE PASCAL-CITE DESCARTES-CHAM

Town: MARNE LA VALLEE CEDEX 2

Postcode: 77455

Country: France

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Prof. Sex: (•) Male ( ) Female

First name: **Marc** Last name: **Bocquet**

E-Mail: **bocquet@cerea.enpc.fr**

Position in org.: Deputy director of CEREA / Researcher

Department: ECOLE NATIONALE DES PONTS ET CHAUSSEES ☒ Same as organisation name

☒ Same as proposing organisation's address

Street: AVENUE BLAISE PASCAL-CITE DESCARTES-CHAMPS-SUR-MARNE 6-8

Town: MARNE LA VALLEE CEDEX 2 Post code: 77455

Country: France

Website: cerea.enpc.fr/HomePages/bocquet/

Phone: +33164152151 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Carolina	Olmedo-Garcia	carolina.garcia-olmedo@enpc.fr	+xxx xxxxxxxxx

Participant

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

Specific Legal Statuses

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

Academic Sector .....yes

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: Centre de Recherche Inria Grenoble Rhone-Alpes ☐ not applicable

☐ Same as proposing organisation's address

Street: 655 Avenue de l'Europe - Zirst Inovallee

Town: Saint Ismier

Postcode: 38334

Country: France

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Dr. Sex: (•) Male ( ) Female

First name: **Arthur** Last name: **Vidard**

E-Mail: **arthur.vidard@inria.fr**

Position in org.: Researcher

Department: Inria Grenoble Rhone-Alpes - AIRSEA ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: LJK - 51 rue de Mathematiques, BP 53

Town: Grenoble cedex 9 Post code: 38041

Country: France

Website: https://team.inria.fr/airsea/en/

Phone: +33476514256 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Laurent	Debreu	laurent.debreu@inria.fr	+xxx xxxxxxxxx
Béatrice	Pouchot-Camoz	recettes-grenoble@inria.fr	+xxx xxxxxxxxx

Participant

PIC	***Legal name***
999984156	*THE UNIVERSITY OF READING*

Short name: UREAD

Address of the organisation

Street WHITEKNIGHTS CAMPUS WHITEKNIGHTS H

Town READING

Postcode RG6 6AH

Country United Kingdom

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

Specific Legal Statuses

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

Academic Sector .....yes

Enterprise Data

SME self-declared status.....2011 - no

SME self-assessment ..... unknown

SME validation sme.....2011 - 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: School of mathematical, physical and computational science ☐ not applicable

☐ Same as proposing organisation's address

Street: Whiteknights, PO Box 220

Town: Reading

Postcode: RG6 6AX

Country: United Kingdom

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Prof. Sex: (•) Male ( ) Female

First name: **Amos Stephen** Last name: **Lawless**

E-Mail: **a.s.lawless@reading.ac.uk**

Position in org.: Associated professor in data assimilation and inverse problems

Department: School of mathematical, physical and computational science ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Whiteknights, PO Box 220

Town: Reading Post code: RG6 6AX

Country: United Kingdom

Website: http://www.personal.reading.ac.uk/~sms00asl/

Phone: +441183785018 Phone 2: +xxx xxxxxxxxx Fax: +441189313423

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Alison	Fowler	a.m.fowler@reading.ac.uk	+xxx xxxxxxxxx
Mischa	Phillips	m.phillips@reading.ac.uk	+xxx xxxxxxxxx
EU-unit	Reading	eu-unit@reading.ac.uk	+xxx xxxxxxxxx

Participant

PIC	***Legal name***
998619754	*CONSEJO NACIONAL DE INVESTIGACIONES CIENTIFICAS Y TECNICAS (CONICET)*

Short name: CONICET

Address of the organisation

Street GODOY CRUZ 2290

Town BUENOS AIRES

Postcode C1425FQB

Country Argentina

Webpage www.conicet.gov.ar

Specific Legal Statuses

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

Academic Sector .....yes

Enterprise Data

SME self-declared status.....2007 - no

SME self-assessment ..... unknown

SME validation sme.....2007 - 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: IFAECI ☐ not applicable

☐ Same as proposing organisation's address

Street: Intendente Guiraides, 2160

Town: Buenos Aires

Postcode: 1428EGA

Country: Argentina

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Dr.

Sex: (•) Male ( ) Female

First name: **Juan**

Last name: **Ruiz**

E-Mail: **jruiz@cima.fcen.uba.ar**

Position in org.: Researcher

Department: CONSEJO NACIONAL DE INVESTIGACIONES CIENTIFICAS Y TECNICAS ☒ Same as organisation name

☐ Same as proposing organisation's address

Street: Intendente Guirades 2160

Town: Buenos Aires

Post code: 1428EGA

Country: Argentina

Website:

Phone: +5491158947666

Phone 2: *+xxx xxxxxxxxx*

Fax: *+xxx xxxxxxxxx*

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Jorge	Tezon	jtezon@conicet.gov.ar	*+xxx xxxxxxxxx*

Participant

PIC	***Legal name***
999974456	*UNIVERSITETET I BERGEN*

Short name: UiB

Address of the organisation

Street MUSEPLASSEN 1

Town BERGEN

Postcode 5020

Country Norway

Webpage www.uib.no

Specific Legal Statuses

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 ..... no

Legal person .....yes

Academic Sector .....yes

Enterprise Data

SME self-declared status.....2015 - 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: Geophysical Institute ☐ not applicable

☐ Same as proposing organisation's address

Street: Allegt 70, PO Box 7803

Town: Bergen

Postcode: 5020

Country: Norway

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Prof. Sex: (•) Male ( ) Female

First name: **Noel** Last name: **Keenlyside**

E-Mail: **noel.keenlyside@gfi.uib.no**

Position in org.: Professor

Department: Geophysical Institute ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Allegt 70, PO Box 7803

Town: Bergen Post code: 5020

Country: Norway

Website: http://www.uib.no/gfi/

Phone: +47 55 58 20 32 Phone 2: *+xxx xxxxxxxxx* Fax: *+xxx xxxxxxxxx*

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Francois	Counillon	francois.counillon@nersc.no	*+xxx xxxxxxxxx*
Liv-Grethe	Gudmundsen	post@fa.uib.no	*+4755584965*

Participant

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

Specific Legal Statuses

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

Academic Sector .....yes

Enterprise Data

SME self-declared status.....2011 - 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 building, Jordi Girona 29

Town: Barcelona

Postcode: 08034

Country: Spain

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Prof. Sex: (•) Male ( ) Female

First name: **Francisco** Last name: **Doblas-Reyes**

E-Mail: **francisco.doblas-reyes@bsc.es**

Position in org.: Director of the Earth Science Department

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: ww.bsc.es

Phone: +34934137719 Phone 2: *+xxx xxxxxxxxx* Fax: *+xxx xxxxxxxxx*

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Mar	Rodriguez Rodrigo	mar.rodriguez@bsc.es	*+xxx xxxxxxxxx*
Virginie	Guemas	virginie.guemas@bsc.es	*+xxx xxxxxxxxx*

Participant

PIC	***Legal name***
999940118	*CENTRE EUROPEEN DE RECHERCHE ET DE FORMATION AVANCEE EN CALCUL SCIENTIFIQU*

Short name: CERFACS

Address of the organisation

Street Avenue Gaspard Coriolis 42

Town TOULOUSE

Postcode 31057

Country France

Webpage www.cerfacs.fr

Specific Legal Statuses

Research and Innovation legal statuses

Public body .....no

Non-profit .....no

International organisation .....no

International organisation of European interest .....no

Secondary or Higher education establishment .....no

Research organisation .....no

Legal person .....yes

Academic Sector .....no

Enterprise Data

SME self-declared status.....2015 - no

SME self-assessment ..... unknown

SME validation sme.....2007 - 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: Climate Environment Coupling and Uncertainty (CECI) ☐ not applicable

☒ Same as proposing organisation's address

Street: Avenue Gaspard Coriolis 42

Town: TOULOUSE

Postcode: 31057

Country: France

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Dr.

Sex: ○ Male ◉ Female

First name: **Sophie**

Last name: **Ricci**

E-Mail: **sophie.ricci@cerfacs.fr**

Position in org.: Researcher in the CECI team

Department: CECI ☐ Same as organisation name

☒ Same as proposing organisation's address

Street: Avenue Gaspard Coriolis 42

Town: TOULOUSE Post code: 31057

Country: France

Website: www.cerfacs.fr

Phone: +33561193128 Phone 2: *+xxx xxxxxxxxx* Fax: *+xxx xxxxxxxxx*

Participant

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

Specific Legal Statuses

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

Academic Sector .....yes

Enterprise Data

SME self-declared status.....2007 - no

SME self-assessment ..... unknown

SME validation sme.....2007 - 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: Mathematical Institute ☐ not applicable

☐ Same as proposing organisation's address

Street: P.O. Box 80010

Town: Utrecht

Postcode: 3508TA

Country: Netherlands

Dependencies with other proposal participants

Character of dependence	***Participant***	

Person in charge of the proposal

Title: Prof.

Sex: (•) Male ( ) Female

First name: **Jason**

Last name: **Frank**

E-Mail: **j.e.frank@uu.nl**

Position in org.: Head of Department Mathematics

Department: Mathematical Institute

[ ] Same as organisation name

[ ] Same as proposing organisation's address

Street: P.O. Box 80010

Town: Utrecht

Post code: 3508 TA

Country: Netherlands

Website: https://www.uu.nl/staff/J.E.Frank

Phone: +31 352532549

Phone 2: 31 624407181

Fax: *+xxx xxxxxxxxx*

3 - Budget

Researcher Number	Recruiting Participant (short name)	Planned start month	Duration (months)
1	NERSC	6	36
2	IRM/ KMI	6	36
3	ENPC	6	36
4	INRIA	6	36
5	THE UNIVERSITY OF READING	6	36
6	CONICET	6	36
7	NERSC	6	36
8	UiB	6	36
9	BSC	6	36
10	BSC	6	36
11	CERFACS	6	36
12	UU	6	36

Researcher Number	Recruiting Participant (short name)	Planned start month	Duration (months)
Total			432

Participant Number	Organisation Short Name	Country	IOEI	No of researchers	Number of person.months	Researcher Unit Cost			Institutional Unit Cost		TOTAL
						Living allowance	Mobility Allowance	Family Allowance	Research, training and networking costs	Management and overheads	
1	NERSC	Norway	no	2	72	307484,64	43200,00	18000,00	129600,00	86400,00	584684,64
2	IRM/ KMI	Belgium	no	1	36	117720,00	21600,00	9000,00	64800,00	43200,00	256320,00
3	ENPC	France	no	1	36	136202,04	21600,00	9000,00	64800,00	43200,00	274802,04
4	INRIA	France	no	1	36	136202,04	21600,00	9000,00	64800,00	43200,00	274802,04
5	UREAD	United Kingd	no	0	0	164572,56	0,00	0,00	0,00	0,00	164572,56
6	CONICET	Argentina	no	1	36	77224,32	21600,00	9000,00	64800,00	43200,00	215824,32
7	UiB	Norway	no	1	36	153742,32	21600,00	9000,00	64800,00	43200,00	292342,32
8	BSC	Spain	no	2	72	224609,76	43200,00	18000,00	129600,00	86400,00	501809,76
9	CERFACS	France	no	1	36	136202,04	21600,00	9000,00	64800,00	43200,00	274802,04
10	UU	Netherlands	no	1	36	127019,88	21600,00	9000,00	64800,00	43200,00	265619,88

Participant Number	Organisation Short Name	Country	IOEI	No of researchers	Number of person.months	Researcher Unit Cost			Institutional Unit Cost		TOTAL
						Living allowance	Mobility Allowance	Family Allowance	Research, training and networking costs	Management and overheads	
Total				11	396	1580979,60	237600,00	99000,00	712800,00	475200,00	3105579,60

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.*

START PAGE

MARIE SKŁODOWSKA-CURIE ACTIONS

Innovative Training Networks (ITN)
Call: H2020-MSCA-ITN-2019

PART B

CODA

Coupled data assimilation for climate prediction and climate change attribution

This proposal is to be evaluated as:

ETN

Table of contents

LIST OF PARTICIPANTS

Consortium Member	Legal Entity Short Name	Academic	Non-academic	Awards Doctoral Degrees	Country	Dept./ Division /Laboratory	Scientist-in-Charge	Role of Partner Organisation
Beneficiaries								
1) Nansen Environmental and Remote Sensing Centre	NERSC	X			Norway	Data Assimilation Group	Alberto CARRASSI Laurent BERTINO Geir EVENSEN	Project Coordination Leader of WP3 Hosting and Supervision of ESR 1 and 7 Hosting Secondments
2) Royal Meteorological Institute of Belgium	RMI	X			Belgium	Dynamical Meteorology and Climatology Unit	Stéphane VANNITSEM	Hosting and Supervision of ESR 2 Hosting Secondments
3) École des Ponts Paris Tech	ENPC	X		X	France	Environment Research Center (CEREA)	Marc BOCQUET	Leader WP1 Hosting and Supervision of ESR 3 Hosting Secondments
4) Institut National de Recherche en Informatique et en Automatique	INRIA	X			France		Laurent DEBREU Arthur VIDARD	Co-Leader WP1 Hosting and Supervision of ESR 4 Hosting Secondments
5) University of Reading	UR	X		X	United Kingdom	School of Mathematical, Physical and Computational Sciences	Amos LAWLESS Alison FOWLER	Hosting and Supervision of ESR 5
6) Consejo Nacional de Investigaciones Científicas y Técnicas	CONICET	X			Argentina	IFAECI	Juan RUIZ Alexis HANNART	Hosting and Supervision of ESR 6
7) University of Bergen	UiB	X		X	Norway	Geophysical Institute	Noel KEENLYSIDE Francois COUNILLON	Leader of WP4 Hosting and Supervision of ESR 8 Hosting Secondments
8) Barcelona Super-Computing Center	BSC	X			Spain	Earth Sciences Department	Virginie GUEMAS Francisco DOBLAS-REYES François MASSONNET	Leader of WP2 Co-Leader WP4 Hosting and Supervision of ESR 9 and 10 Hosting Secondments
9) Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique	CERFACS		X		France	Global Change and Climate Modelling team (GLOBC)	Sophie RICCI	Co-Leader WP2 Supervision of ESR 11 Hosting Secondments
10) University of Utrecht	UU	X		X	Holland	Department of Mathematics	Jason Frank	Hosting and Supervision of ESR 12
Partner Organisations								
EQUINOR	EQUINOR		X		Norway	TPD RDI	Remus HANEA	Hosting Secondments & Supervision
Électricité de France	EDF		X		France	Research and Development	Nicole GOUTAL	Hosting Secondments & Supervision
BKK	BKK		X		Norway	Production and Energy Optimization	Ina T. KINDEM	Hosting Secondments & Supervision
Future Water	FutureWater		X		Spain		Johannes HUNINK	Hosting Secondments & Supervision
Bergen Teknologioverføring AS	BTO		X		Norway		Nils-Eivind HOLMEDAL	Training on transferrable skill
VORtech BV	VORtech		X		Holland		Mark Roest	Hosting Secondments, Supervision and Training on software development

Data for non-academic beneficiaries:

Name	Location of research premises (city / country)	Type of R&D activities	No. of full-time employees	No. of employees in R&D	Web site	Annual turnover (in Euro)	Enterprise status (Yes/No)	SME status (Yes/No)
EQUINOR	Bergen, Norway	**Petroleum, gas, renewable energy,** ensemble applications	23000	650	www.equinor.com	90 billion (2012)	YES	NO
EDF *Electricité de France*	Clamart, France	**Electricity** production	158 467	2125	www.edf.fr	75.6 billion	YES	NO
BKK	Bergen, Norway	New technology and **renewable energy**	1100	_	www.bkk.no	3.9 billion (2015)	YES	NO
FutureWater	Cartagena, SPAIN	Consultancy and **research for water resources and agricolture** management	11	11	www.futurewater.eu	1,150,000	YES	YES
BTO	Bergen, Norway	N/A*	45	0*	www.bergento.no	13,000,000	YES	YES
VORtech BV	Delft, the Netherlands	Applied mathematics	20	4	www.vortech.nl	2 million	YES	YES

* BTO's owners and partners are 10 research institutions and organize 4000 researchers with an annual turnover of 500M€. The technology transfer office is organized as a separate entity and has for that reason no employees dedicated to R&D.

1. EXCELLENCE

1.1 Quality, innovative aspects and credibility of the research programme

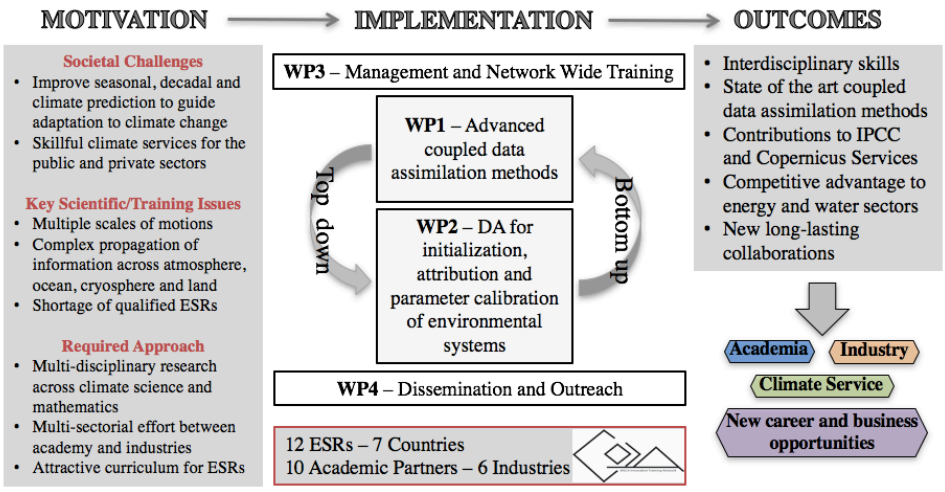
1.1.1 Introduction, objectives and overview of the research programme

Weather forecasting is a well-established scientific practice serving society, which success in the past 40 years has been enabled also by **Data Assimilation**, **DA** [19, 52]. More generally known as state estimation theory, DA combines the observations of a system with dynamical information (*e.g.* the model) to provide the best possible estimate of its state. Beyond the meteorological time horizon of two weeks, predictions over longer seasonal-to-decadal time scales potentially bear even higher societal relevance: they can guide adaptation to near-term climate change and related risks. Such long-term predictability arises from the interactions between the atmosphere and the more slowly varying components of the climate system, like the ocean, land surface and cryosphere. Understanding their coupling mechanisms is therefore of paramount importance to improve climate prediction beyond a couple of weeks. Earth System Models (ESMs) have thus become widespread tools because they enable the exchange of information between these model components. Still numerical climate prediction is in its infancy in contrast to weather predictions. Current DA procedures used in weather, ocean or land prediction are mostly designed to deal with a single dominant scale of variability and their use with coupled ESM is hampered by the lack of qualified young researchers. In addition, the whole Earth is now observed over a wide range of spatial and temporal scales, thanks to an increasingly wider variety of sustained observing systems particularly from satellites. **The times are thus mature for questioning to which degree the combined use of non-linear coupled ESMs with new Earth Observations can improve climate forecasts skill and our understanding of their driving mechanisms.** While DA appears as the natural methodological framework to optimally merge both sources of information, this also opens challenging questions on how to best adapt, extend and develop DA strategies for this new class of problems.

CODA's **scientific objective is to develop advanced Coupled DA (CDA) methods suitable for coupled ESMs**. The ultimate goal is to initialize *seamless* predictions across all time scales from days to decades, and **CODA´s key impacts will be (1) the improvement of the climate prediction and reconstruction** toward skilful **climate services** for the private and public sector, **(2)** a robust **observation-based identification and understanding of climate variability mechanisms**, and **(3)** a **better estimate of the external forcing causing climate change**. These problems are mathematically complex and require a double level of research, reflected in the two research Work Packages (WP) of CODA, one theoretical and one application-oriented**: WP1 –** Advanced methods for CDA and **WP2 –** Exploitation of DA for initialization, attribution and parameter calibration of environmental systems. The team supports CODA's goals with expertise in applied mathematics, dynamical systems, statistics, climate dynamics and climate prediction with state-of-the-art ESMs, all leading worldwide experts gathered by an appealing scientific problem and with the mission to train a new generation of young researchers with a robust theoretical and practical background. The relation and interplay between WP1 and WP2 makes CODA a naturally interdisciplinary project joining expertise in mathematical and Earth System sciences.

CODA proposes a European Training Network of **12 PhDs students** across **7 countries.** The network comprises **10 academic beneficiaries**, including universities and research institutes, along with **6 industrial partners**, brought together in an original research and training program which includes co-supervision, secondments, schools and workshops as well as additional trainings in dissemination, scientific writing and entrepreneurship. Students will also be trained in numerical and visualization tools to handle the huge datasets that make environmental science an exemplary case of the Big Data problem. CODA will collaboratively train the ESR fellows in a framework of strong interdisciplinary, mutual exchanges, and complementarity. CODA is a powerful interdisciplinary PhD training platform with a key position in training a much-needed new generation of European PhDs. The project will not only provide valuable outputs to society, but also contribute to the awareness and endorsement of new DA methodologies by the wider scientific community and will help to give the EU a leading edge for climate adaptation and resilience to related risks. The ESRs will use the private partners to build their post-CODA career strategy.

Figure 1 - CODA at glance



1.1.2 Research methodology and approach

CODA is organized in 4 Work Packages: WP1 and 2 are related with the research activities described in the PhD research sub-projects (see Section 1.2.1), WP3 and 4 concern *Management & Training* and *Dissemination* activities respectively. Details about their execution plan, subdivision, partner's involvement, deliverables and milestones are given in Sect. 3.

Table 1.1a: Work Package (WP) List and ESR involvement

WP #	WP Title	Lead (Co) Benef. No.	Start Month	End Month	Activity Type	Lead (Co) Participant(s) Short Name	ESR involvement
1	Advanced methods for CDA	3 and (4)	1	48	Research	Leader: *ENPC (M. Bocquet)* Co-Leader: *INRIA (A. Vidard)*	ESR 1 to 6
2	Exploitation of DA for initialization, attribution and parameter calibration of environmental systems	8 and (9)	1	48	Research	Leader: *BSC (V. Guemas)* Co-Leader: *CERFACS (S. Ricci)*	ESR 7 to 11
3	Management & network-wide Training	1	1	48	Management and Training	Leader: *NERSC (L. Bertino)* Co-Leader: *NERSC (A. Carrassi)*	None & All
4	Dissemination & Outreach	7 and (8)	6	48	Dissemination	Leader: *UiB (N. Keenlyside)* Co-Leader: *BSC (F. Doblas-Reyes)*	All

An overall description is provided in Table 1.1a. CODA's numerical test-ground is based on an extensive use of a hierarchy of models from low-order to intermediate complexity all way up to state-of-art ESMs (see Table 1.1c), shared among partners. A new intermediate complex coupled model will be developed as part of the Sub-Project 1.2 (see Sect. 3.1.4 for details). The participants to CODA will benefit from a number of existing utilities for numerical integration and DA. These include for instance, the open-source *educational data assimilation platforms* DAPPER (Python) developed at NERSC and OpenDA (C++/Java) at VORTech that both include different DA methods interfaced to several models coded in Fortran or C++ with high computational performance. Two ESMs are available in CODA: the Norwegian Earth System Model (NorESM) and the EC-Earth ESM. These are two out of ~20 climate models contributing to the CMIP6 (pcmdi.llnl.gov/?cmip6) IPCC assessment report. NorESM is developed in Norway based on the Community Earth System Model (CESM) while EC-Earth is developed and used by a European consortium of about 15 institutes. Both models couple atmosphere, ocean, sea-ice and land models using advanced couplers (CPL7 and OASIS) but remain original due to different choices of ocean models (Lagrangian or Eulerian vertical coordinates). The main version of NorESM1-ME has a horizontal resolution of approximately 2° for the atmosphere and land components and 1° for the ocean and sea ice components. NorESM is also available at lower resolution version (NorESM1-L), and with high-top version with specified and full chemistry. The low-resolution configuration of EC-Earth3 will be used in CODA with a horizontal resolution of about 1° in the ocean and 75 levels and a T255L91 grid for the atmosphere. Codes and data will be all shared among the partners in appropriate common-utility drop-boxes. The third state-of-the-art model at disposal is the Lagrangian sea-ice model neXtSIM in an adaptive mesh.

Table 1.1c – Models available to the CODA partners

Complexity	Model Name	Dim	Coupled	Ref
Low	L63	3	NO	[61]
	GJ98	5	YES	[36]
	PK04	3 -- 9	YES	[74]
	MFPV	6	YES	[69]
Low/Medium	L96	N (large scale) x M (small scale)	YES / NO	[62]
	VDDG15	24 -- 56	YES	[100]
Medium/High	SCM	400	YES	[87]
	L95-GRS	$O(10^3)$	YES	[43]
	SPEEDO	$O(10^5)$	YES	[85]
State-of-the-Art	neXtSIM	$O(10^6)$	NO	[11]
	NorESM	$O(10^8)$	YES	[8]
	EC-Earth 3.2	$O(10^8)$	YES	[44]

Observation System Simulation Experiments (OSSE) will be extensively performed to benchmark the new methods on synthetic observations before assimilating real observations. The OSSE framework provides high flexibility: sampling characteristics of observations can be easily modified and degraded to study the robustness of the CDA algorithms, and model errors can be introduced by, for instance, using different model parameters in a "nature run" and a forecast model, or by running the nature run at a higher resolution.

1.1.3 Originality and innovative aspects of the research programme

1.1.3.1 Data assimilation methods: Background & State-of-the-art

Formally, weather and climate predictions are both an initial value and a forced boundary problem, though the latter is more important with longer predictions [68]. DA is meant to treat such initial and/or boundary conditions, and DA techniques were originally designed to deal with high-dimensional systems - such as those from numerical weather and ocean predictions – using observations that are incomplete, diverse, unevenly distributed and contaminated by errors [see *e.g.* 52]. The geosciences have thus been a challenging terrain of application for DA and have stimulated an intense stream of research, making DA a key contributor to the continuous improvement of NWP over the past three decades. DA is also regularly used to evaluate the cost-efficiency of a heterogeneous monitoring network.

Different DA approaches are conveniently labelled variational (smoother) or sequential (filter). Both aim at estimating the posterior *probability density function* (PDF) of the system state, conditioned on observations and using prior information. The posterior PDF fully characterizes the problem and can be formally obtained using Bayes' rule at the updating steps and the Liouville equation (or the stochastic Kolmogorov equation) at any other time. Nevertheless, such a straightforward Bayesian approach is unsuited for geophysical applications in high dimension. The Gaussian approximation has thus been employed in most practical DA algorithms: the estimation problem is then reduced to that of computing only the first two moments of the PDF, the mean and covariance. The four-dimensional variational assimilation, *4DVar* [94], and the ensemble Kalman filter, *EnKF*, [32] are the two most popular and successful Gaussian DA methods, exemplar of smoothers and filters respectively. In 4DVar the initial condition is optimized so that the model trajectory follows the observations. The DA problem then minimises the misfits between model output and observations. This optimization is hampered by the indirect and non-linear relationship between the initial conditions and the observations. The second difficulty is the sheer size of the problem (up to several billions of unknowns) that makes the minimization extremely expensive and requires good convergence properties: both issues are exacerbated in a coupled model when compared to stand-alone models. In order to deal with nonlinearities, operational 4DVar implementations use the incremental strategy where the full non-linear problem is approximated by successive linear and lower resolution problems [104] and are routinely used in weather centres worldwide, including the ECMWF, UK MetOffice and Météo-France [see *e.g.* 34, 78, 79]. However, [38] showed that such scheme does not converge toward the right minimum, so a proper use of multigrid methods has been recently proposed in [71] to solve the non-linear case. Furthermore, [25] proposed a more robust algorithm using a multigrid iteration as a preconditioner for a Krylov optimization method, but so far it has only been applied to very simple models.

A version of the EnKF is nowadays operational in the atmospheric model at the Canadian Meteorological Centre, CMC [48] and in the ocean system TOPAZ developed at NERSC [22] and exploited operationally by MET Norway as the Arctic Ocean, sea ice and ecosystem forecasts of the European Copernicus Marine Services (marine.copernicus.eu). Recent promising efforts toward hybrid EnKF-4DVar methods are endowing the 4DVar with a flow-dependent estimate of the error covariance [see *e.g.* 13, 53, 60]. Ensemble-variational methods that truly account for nonlinear dynamics have recently been developed [9, 10] for tracking chaotic geophysical systems. One of them, the *Iterative Ensemble Kalman Smoother* (IEnKS) [10] solves a full nonlinear variational analysis over an extended temporal DA window while keeping track of the uncertainties between successive DA windows. The IEnKS significantly outperforms standard EnKF and 4DVar on low-order models and makes an efficient tool for estimating model error [9]. However, its high accuracy as well as some upper bounds on the DA window length are not fully understood [10], probably related to the interplay of the dynamics with variational assimilation.

A major cause of errors in climate predictions are model deficiencies [24]. The two main difficulties in estimating model errors are the huge size of the models and the wide range of possible sources (incorrect parameters, numerical discretization, unresolved scales, etc.). The former implies the need to estimate large error covariance matrices based on limited available observations, while the diversity of sources of model error makes it difficult to outline a general and unified approach. In long-term predictions with coupled models, model errors feed back between coupled components and accumulate into large long-term forecast biases. In 4DVar, different solutions have been proposed to account for model error [96, 109]. They have also been investigated in KF-like schemes, for bias correction in atmospheric [26] and ocean prediction [6]. In the EnKF, a model error is included in the ensemble design via the artificial inflation of its variance [1]. In a new deterministic approach model error evolution is described using a short-time approximation, suitable for high-dimensional applications, in sequential [15, 69], variational [16] as well as for parameter estimation [17]. DA allows the inference of model parameters that are not directly connected to the observables, a key feature for applications to coupled dynamics where the coupling parameters should be optimized (see Sub-Project 2.2). Parameter of prototypical nonlinear dynamics have been estimated with various variants of the EnKF [3, 4, 9, 110]; see [81] for a review.

1.1.3.2 Coupled data assimilation: *The Challenge*

DA algorithms have been conceived mainly for NWP applications and have been designed for systems with a single dominant dynamical scale and/or for an observational network with a dominant spatiotemporal density. The sustained increase of model resolutions, the deployment of more and more observation facilities and the use of coupled ESMs, altogether bind to a deep re-thinking of the DA procedures. As model and observational resolution increase, new phenomena are resolved, on a broader range of scales, including for instance convection and turbulence [106]. Models are continuously improved by a more profound understanding of small scales processes and thanks to larger computational resources that allow increasing their resolution. Modern coupling softwares (*e.g.* CPL7 used in NorESM or OASIS developed at CERFACS and used in EC-Earth) are flexible enough to connect a fixed (finite differences) grid to an adaptive (finite element) mesh or to run ensembles of one component of the ESM with a single – deterministic – instance of another. This latter capability can be exploited by targeted DA methods in each compartment of the ESM, but it opens new questions about the probabilistic consistency of the information passed across by the coupler. For

instance, should it pass the ensemble mean to the deterministic components? Such questions become relevant as new models use an adaptive mesh (*e.g.* neXtSIM sea ice model in Lagrangian grid [11]). They also become more arduous as couplers handle arbitrary spatial grids and time stepping for the different components, adding a statistical problem of change of support (Sub-Project 2.1). This on-going transition to high-resolution and coupled modelling capabilities must be accompanied by a similar transformation and adaptation of the DA procedures [see *e.g.* 93]. In the aftermath of the implementation of high-resolution coupled ESMs it is urgent to design efficient Coupled DA (CDA) methods, able to keep simultaneously control of all resolved scales and propagate adequately information between and across the climate system components. CDA is the primary way to add value to new Earth Observations that are relevant for two or more components such as the European Space Agency missions like Soil Moisture and Ocean Salinity (SMOS, esa.int). By producing reanalyses for coupled systems, CDA will improve climate reconstructions in poorly observed areas.

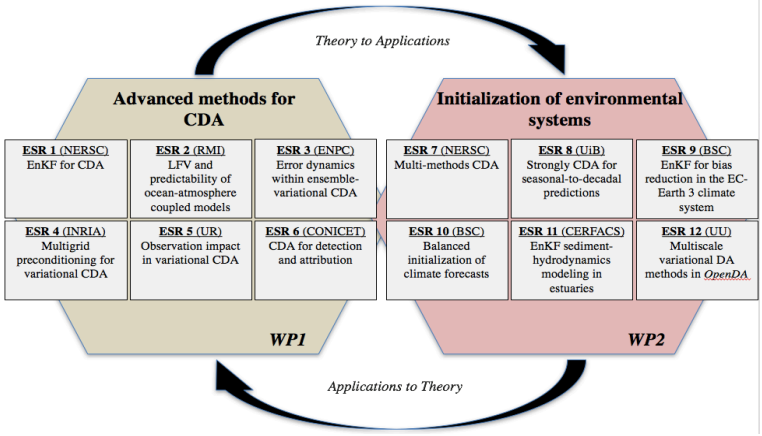
1.1.3.3 Coupled data assimilation: *The state-of-the-art*

Several research groups and institutions, including weather and climate services, are currently studying and developing CDA methods. Early attempts include the case of sparsely observed flows possessing a wide range of scales with a KF-like procedure [42], or a study of the performance of the EnKF in a two-scales system [5]. A modification of the 4DVar for coupled dynamics was described by [60], although practical issues in operational mode were acknowledged. Seasonal predictions are issued using coupled atmosphere-ocean models, but the sources of initial data from the various model components are usually not consistent. This "decoupled" initialization induces imbalances at the ocean-atmosphere boundaries that dissipate as shock waves that degrade the skills of the forecast. An intermediate solution has shown some success: *weakly coupled data assimilation* (wCDA). In wCDA, a coupled model is used to run predictions but the observations of the model compartments (atmosphere, ocean, land and sea-ice) are used independently; each component is subject to a separate analysis. A first attempt to produce a wCDA reanalysis has been done in the USA at the National Centre for Environmental Prediction (NCEP) [82] and at the Japanese Agency for Marine-Earth Science and Technology (JAMSTEC) [92], with a global ESMs and using 3DVar and 4DVar respectively. The wCDA reanalysis showed a marked improvement over the standard uncoupled formulation. At JAMSTEC the control variable includes the ocean initial conditions plus a set of parameters related to the air-sea fluxes. The approach acted as a proof-of-concept for producing successfully balanced initial conditions for the coupled system and optimal coupling parameters, and enhancing the skills of seasonal to decadal predictions. The UK MetOffice designed wCDA with incremental 4DVar [28] and the ECMWF is producing a 20-th century reanalysis based on wCDA [56].
Atmosphere and ocean are constrained independently using an EnKF-like approach at the Geophysical Fluid Dynamics Laboratory (GFDL) [107]. Using the same framework, [64] has achieved some success in a controlled simulated scenario using strongly CDA (sCDA), but relying on very idealised hypotheses about the coupled mechanism: it reconstructs successfully relevant climate fields over the period of interest and, being based on an ensemble of trajectories, provides automatically the initial conditions to run an ensemble of forecasts. The EnKF in a wCDA setting has been recently used to assimilate ocean observations for seasonal-to-decadal predictions with NorESM, [22]. NorESM uses an isopycnal coordinate ocean model that enhances the efficiency of the assimilation of surface observations [23] and has delivered promising results. One of the first attempts of sCDA for a coupled ocean and sea-ice model has been used operationally in TOPAZ, demonstrating that successful assimilation of sea-ice concentrations requires a coupled, multivariate and time-dependent assimilation method [66, 84]. A recent interesting result using sCDA is due to [88] that shows improvements over wCDA using atmospheric-only observations. A review on the state-of-the-art in CDA can be found in [27, 39, 76]; see also the material of a conference organised by Météo France in 2016 (meteo.fr/cic/meetings/2016/CDAW2016/).

1.1.3.4 *Innovation & Main Research Ideas in CODA*

Despite the positive impact of using wCDA and the promising preliminary results with sCDA, the solutions proposed so far only mitigate the imbalances between model components. The analysis is still based on separate assimilations or accounts only partially for the physical and dynamical correlations across atmosphere, ocean, land and sea-ice. A marked step toward full sCDA is thus urgent in view of societal needs for seasonal-to-decadal forecasts. CODA research is thus consistent with the objective of the Intergovernmental Panel on Climate Change 5th Assessment Report (IPCC-AR5) on initialised prediction in the scope of CMIP6 [68], and with the World Climate Research Programme (WCRP) that identified "near-term climate prediction" (seasonal-to-decadal) as one of the "Grand Challenges".

Figure 1.1 Scientific working packages 1-2 and associated subprojects



CODA research activity is carried out in WP1 and WP2 (Fig.1.1). The focus in **WP1** is on understanding the fundamental, theoretical, issues hampering the use of standard DA procedures in climate models, provide proof-of-concepts for novel methods and favour a renewal of the discipline. Low-order models will be central research tools, shared by students, and allowing extensive statistical and numerical computation. A distinctive feature of the research approach in WP1 is the use of concepts and tools from dynamical system theory, statistics and optimal control theory that will guide new developments adapted to climate modelling. This cross-fertilization among nonlinear science and climate science is already one of the key assets of climate research in Europe, as reflected in the Nonlinear Processes division of the European Geophysical Union (EGU) that has climate dynamics as a key focus. The use of state-of-the-art ESMs and operational geophysical datasets will characterise **WP2**, where practical CDA and initialization approaches, suitable for large nonlinear numerical systems, will be investigated. WP1 and 2 integrate and complement each other: a natural platform to exchange ideas between scientists with diverse expertise and backgrounds. WP1 and 2 are further subdivided in 6 and 5 Sub-Projects, respectively (see Fig.1.1).

WP1 – Advanced coupled data assimilation methods

WP1 is the theoretical hub of CODA research, includes 6 Subprojects, and focuses on four scientific problems:

1. *Coupled system dynamics.*
2. *Ensemble-based CDA.*
3. *Variational CDA.*
4. *DA for detection and attribution of climate change.*

Subproject 1.1 aims at designing new strategies for ensemble-based CDA, and at understanding the fundamental dynamical reasons hampering the use of standard procedures. A cornerstone idea in **Subprojects 1.1, 1.2** and **1.3** will be the use of the unstable manifold of chaotic dynamics. Its importance in controlling the error evolution in nonlinear systems has been investigated recently in connection with DA. Algorithms referred to as Assimilation in the Unstable Subspace (AUS) exploit the unstable subspace, the span of the leading Lyapunov vectors, in the analysis update [74]. The successful applications of AUS with atmospheric and oceanic models [14, 97, 98] demonstrate the robustness of its fundamental paradigm. Can the same paradigm be useful in coupled dynamics? Addressing this question requires a deep study of the error dynamics, correlations and interaction in coupled systems. Suitable unstable manifold estimation methods for this class of systems have to be introduced. The assimilation can then be done using the AUS philosophy: the analysis update is confined in the unstable subspaces of each of the model components, and represents a natural way to target the relevant instabilities associated to each model subcomponent. Much of the understanding of coupled system dynamics required for Subproject 1.1 (and 1.3 below) is provided by **Subproject 1.2** which studies the low frequency variability and predictability in low-order coupled systems. Weather forecasting has reached a mature stage whose usefulness extends up to 15 days. Beyond that period, the dynamics of the atmosphere (within the extra-tropical troposphere) is predominantly determined by the boundary forcing associated with the other climate components, displaying longer time scales. The evolution of these components is expected to provide information determining the statistical characteristics of the short-time scale atmospheric dynamics. In view of the difficulty in providing definitive conclusions using complex ESMs, simpler description of the climate dynamics based on low-order modelling is explored. This is the focus of subproject 1.2 and is articulated around three different themes about extended-range forecasting (see Section 3.1.4). The research strategy will be based on the use of tools developed in the context of nonlinear dynamics and chaos theory [72, 73, 102]. The coupled model studied in Subproject 1.2 will be used in Subprojects 1.1, 1.3 and 1.5, creating a natural interchange of expertise. **Subproject 1.3** will analyse the advantages and drawbacks of the IEnKS using tools of dynamical systems such as covariant Lyapunov vectors [55]. It will further confront the findings by devising and testing, in relation with Subproject 1.1, an AUS variant of the IEnKS. Although the issue is largely unexplored yet, we believe that the use of the IEnKS may also be an efficient tool to perform CDA. In particular, as an ensemble-variational method, it does not require the need of an adjoint model, which is usually difficult to compute: the computational issues related to the adjoint model are expected to grow commensurately with the increase of complexity of the Earth system simulators. **Subproject 1.3** is the natural bridge between ensemble and variational methods, the latter being the subject of the Subprojects 1.4 and 1.5. Extension of the multigrid 4DVar

methods to more realistic applications is challenging and constitutes the focus of **Subproject 1.4**. When switching to coupled models, strong non-trivial multi-physics and multi-scales interactions will arise that may be difficult to approximate at lower resolution. Still using a variational framework, **Subproject 1.5** aims to develop methods for quantifying observation impact in wCDA. With the development of new CDA and forecast systems it is necessary to understand which observations are needed to initialize these systems correctly. Impact measures indicate which of these observations are most likely to be of benefit to future coupled forecasting and can also aid the development of CDA. However, current measures of observation impact on the analysis (*e.g.* sensitivity of the analysis to observations, degrees of freedom for signal and entropy measures [20]) are mainly based on a linear approximation to the assimilation system. This means that they are unable to give a true measure of impact in wCDA systems, where the tangent linear model used in the inner loop is uncoupled. In particular they do not correctly quantify the information that is passed across the atmosphere-ocean interface. The objectives of Subproject 1.5 are (i) extend measures of the analysis sensitivity to observations to wCDA; (ii) develop new forecast impact measures for wCDA, by using ensemble sensitivities to approximate the adjoint [59]; (iii) use these new measures to understand the likely effect of different observation types on CDA. A different theoretical challenge is at the core of **Subproject 1.6** which investigates the potential of DA for a new type of application: Detection and Attribution (D&A) of observed climate changes. D&A investigates causal relationships between human activity and climate changes. Conventional D&A methods are based on linear regression of observations on space-time patterns extracted from climate models [46]. They are successful in a variety of situations, yet they show key limitations for a number of variables and scales [91]. Causal counterfactual theory, as recently introduced in climate science [40], shows that causal evidence can be obtained by deriving the likelihood of the sequence of climatic observations under causal scrutiny in two models successively: (i) the factual one representing the world as it is, and (ii) the counterfactual one which represents the world as it would be without the forcing of interest. The ratio of these two likelihoods can next be interpreted in terms of causal attribution. DA is thus relevant to tackle D&A in so far as it is able to yield the likelihood of assimilated observations [41]. In practice, an immediate computational difficulty consists in assimilating observations over the entire instrumental period. One way to circumvent this issue is to focus on the assimilation of time-averaged observations – a general problem that has recently raised interest for distinct climatic applications [30]. The objectives of Subproject 1.6 are therefore to: (i) contribute to methodological research on the assimilation of time-averaged observations; (ii) establish a proof-of-concept of the relevance of a DA treatment for the attribution of long term observed changes.

WP2 – Exploitation of DA for initialization, attribution, and calibration of environmental systems

WP2 aims at enhancing climate prediction capability and at improving estuaries modelling through two main angles:

1. *Improving the quality and consistency of initial conditions provided to climate forecast systems.*
2. *Reducing climate model errors in capturing physical processes by observation-based calibration of the parameters.*

WP2 is organised in 5 Subprojects (see Fig.1.1). **Subproject 2.1** focuses on multi-method coupled assimilation. The work takes as focal point the hypothetical coupling of a fixed-grid model to another using an adaptive grid and assume that the former uses an EnKF while the latter a range of methods from simple nudging to an efficient version of the particle filter. **Subproject 2.2** addresses the problem of sCDA in an ESM. Development of sCDA between ocean and sea ice are progressing, taking advantage of the years of experiences with the TOPAZ system [83]. Subproject 2.2 focuses on enhancing sCDA between ocean, sea-ice, and atmosphere, using NorCPM. In a first stage, the leading averaged coupled covariance (LACC) [64] that shows potential for sCDA between the ocean and atmosphere will be implemented and tested with NorCPM and compared against wCDA for different forecast ranges. This will set a benchmark for the method to be tested in the second stage, based on the outcomes from WP1. In particular, Subproject 2.2 will explore how to relax the hypothesis made with the LACC method, by testing AUS and the IEnKS framework developed in Subproject 1.3. **Subproject 2.3** addresses the problem of model bias in ESMs that results in a change of their climatological mean and strong forecast drift. In this context, WP2 builds on the ideas explored in FP7 projects like SPECS (specs-fp7.eu) and PREFACE (preface.b.uib.no) where the drift and systematic error [33] of operational climate forecast systems have been thoroughly documented. Climate model biases, for a large part, originate from unresolved processes occurring at the sub-grid scale level and that are represented by parameterizations, with a large associated uncertainty, but the number of parameters increases with its complexity and the calibration process is challenging. DA has been widely applied in geosciences for state estimation [52] and for parameter estimation and calibration. A significant bulk of research and knowledge on parameter estimation techniques exist [19], but their use in climate models is still at an early stage and rarely reported [65]. Subproject 2.3 will tackle from end-to-end the issue of minimizing the model biases originating from parameters in the EC-Earth coupled general circulation model, with an original and highly innovative approach relying on DA techniques. Sophisticated parameter calibration techniques alone might not be sufficient to remove completely the climate prediction drift and one needs to also rely on robust, DA based, initialization techniques. Indeed, an alternative approach to reduce the climate prediction drift rely on initializing climate forecast systems closer to their attractor, but still holding as much observed climate information as possible. An

initialization of this sort is currently being implemented in EC-Earth, and includes an EnKF of sea-ice observations and a nudging towards reanalyses in the atmosphere and the ocean. The DA phase provides ensembles of initial conditions that can be used to perform climate predictions. **Subproject 2.4** aims at testing initialization approaches finding a compromise between the best estimate of the state of the system, which will be obtained with the current tools of DA applied to each model component, and an initial condition that eliminates the initial shock and controls the impact of the drift on the model dynamics [108]. The optimal choice of DA coefficients that reduce the drift and, potentially, could improve different aspects of the forecast quality, will be investigated. In **Subproject 2.5**, WP2 moves to small-scale coastal oceanographic applications (central to land-ocean coupling), and merge the complementary state and parameter estimation problems, addressed in Subproject 2.1 to 2.4, into their simultaneous treatment. Dynamics in estuaries are complex as various interactions occur between water masses that are driven by different physics. A model with the TELEMAC software was developed for the Gironde estuary area where the nuclear power plant of Blayais is located. Over this area the bathymetry has a temporal variability induced by the presence of a mud plug resulting from the merging of fluvial and oceanic waters. Subproject 2.5 aims at correcting the TELEMAC model using water level in-situ DA to correct both the model state and the model parameters, especially the bathymetry input field. This work will be extended to coupled physics using SISYPHE-TELEMAC that allow for the coupled evolution of the sediment field in coherence with the hydrodynamics fields. Finally, **Subproject 2.6** will study new applications of multiscale variational assimilation within the quasi-operational platform OpenDA developed and maintained at VORtech. Subproject 3.6 will thus relate to the other partners and subprojects in CODA working on variational methods (see Subprojects 1.5).

1.2 Quality, innovative aspects and credibility of the training programme

1.2.1 Overview and content structure of the training

CODA is a multidisciplinary educational platform characterised by an inter-sectorial crossover among universities, research institute and industries. The training program is organised along two main axes: **(1) scientific** and **(2) transferable skill**. Both axes cover a diverse and wide spectrum of training whose objectives are scientific methodological rigours combined with upfront skills in outreach, dissemination, academies-to-industries transfer of knowledge and entrepreneurship. The training program is detailed in the following.

1.2.1.1 *Axis 1* - Multidisciplinary scientific training

The 4 areas of scientific knowledge along which the ESRs will be trained are: **(1) DA** (including topics of applied mathematics: linear algebra, differential equations and statistics), **(2) Climate Science, (3) Dynamical Systems** and **(4) Scientific Programming**. Table 1.2a lists the Universities where the ESRs will be enrolled, and how the scientific training on those four axes is undergone.

Training offered locally

Each ESR will have Chief supervisor(s) in the hosting team and co-supervisor(s) in another team (see Sect. 3). At least one of the supervisor per ESRs has an academic position at the university entity awarding the PhD. The ESRs will have as working place at the institution of the main supervisor. The supervisor(s) will guide the scientific programme pursued by the ESRs through continuing mentoring and will ensure that the ESR has access to all material and personnel assistance needed for her/his research and training. The co-supervisor(s) will assess progress and give advice on the PhD project through regular e-mail exchanges, Skype meetings and during the network meetings (see Table 1.2b). The universities involved in CODA have locally available postgraduate courses that the ESRs will benefit from (see Sect. 1.4 and Table 1.2a). The training in CODA is ultimately designed to make the ESRs acquire autonomy and maturity in their research field, and the capacity to build a personal project. A characteristic of our approach, whose details are given below, is that the ESRs themselves will play an active role in the decision phase and will be adequately represented in the CODA management structure (see Sect. 3.2). Trainings in scientific programming and on use of High Power Computing are available via the

Table 1.2a - Recruitment per beneficiary, indicative start-dates, durations and composition of the scientific training per ESR.

					Scientific discipline and source of training *L: training available locally* *N: network-wide training events* *S: training through secondment*			
Researcher No.	**Recruiting Participant**	**Start month** (indicative)	**Duration** (months)	**PhD awarding entities**	**DA**	**Climate Predictions**	**Dynamical Systems**	**Scientific Programming**
ESR 1	NERSC	6	36	UiB	L	L	L/S	S
ESR 2	RMI	6	36	UL Bruxelles	L	N	L	S
ESR 3	ENPC	6	36	U Paris Est	L	N	N	S
ESR 4	INRIA	6	36	U Grenoble Alpes	L	N	N	S/L
ESR 5	UR	6	36	UR	L	L	N	S
ESR 6	CONICET	6	36	U Buenos Aires	L	L	N/S	N/S
ESR 7	NERSC	6	36	UiB	L	L	N	S
ESR 8	UiB	6	36	UiB	N	L	N	N
ESR 9	BSC	6	36	UA Barcelona	S	L	N	L
ESR 10	BSC	6	36	UA Barcelona	S	L	N	L
ESR 11	CERFACS	6	36	U P. Sabatier, Toulouse	L	L	N	L
ESR 12	UU	6	36	U of Utrecht	L	N	L	S
Total 12			**432**					

(*): The ESR will either be registered at Universidad Autónoma, Politécnica or at the Universidad de Barcelona.

Norwegian HPC project NOTUR and the EU PrACE partnership (see Sect. 3.3).

Network-wide training The network-wide scientific training will be carried out by:

- Three **progress meetings (PM)** at the end of each of the first 3 years (see Tab 1.2b). The PMs represent the main network-wide monitoring tool on the ESR individual projects and on the inter-network synergies and collaboration. PMs will also be natural training platforms for the ESRs since they will present their research, both orally and under a written report, and will receive feedbacks from all CODA members, including from their peer ESRs.
- **Two international scientific schools.** Built upon the scientific expertise in CODA, the schools will rely on a team of teachers from the academic and industrial partners, and external lectures delivered by internationally recognized experts. The schools will be accessible also from outside the CODA network (under a limit of ~50 participants), and will include a 1-day course in dissemination and writing, although CODA will also offer a dedicated *workshop on dissemination and outreach* as explained under the *Transferable Skill* subsection below.
  1. **School 1 "*Data assimilation school: from theory to state-of-the-art applications in geosciences*".**
     Main Responsible: WP1 members
     Duration: 2 weeks
     Scientific *vs* Transferable skill training: ~80% and ~20% (see Tab 1.2b)
     Examples of previous experiences of the WP1 members:
     - *13 editions of the international EnKF workshop, multiple locations in Norway, 2005 – 2018*
     - *5 editions of the biannual school on data assimilation, multiple locations in Romania, 2009 – 2017*
     - *International school and workshop on data assimilation, Les Houches (France), 2012 and 2015*
     - *International Crash Course on data assimilation, NERSC (Norway), 2017 and 2018*

     The event will rely mainly (but not exclusively) on the expertise brought by the members in WP1. The school will cover the theory of DA: Bayesian inference, Gaussian filters and smoothers, ensemble and variational approaches and nonlinear/non-Gaussian methods. It will include lectures on state-of-the-art DA methods for geoscience: atmosphere, ocean, climate, pollution, chemical transport and solid Earth (from the industrial partner EQUINOR). Complementary topics, finger-prints of CODA, will include dynamical system, computing methods and practical numerical exercises based also on the educational DA Python platform DAPPER (see Sect. 1.1.2) and OpenDA from the industrial partner VORtech. Partners in CODA have a consolidated experience in organizing DA schools and international workshops.
  2. **School 2** "***Climate Prediction: from sub-seasonal to seasonal, inter-annual and decadal.***"
     Main Responsible: WP2 members
     Duration: 2 weeks
     Scientific *vs* Transferable skill training: ~80% and ~20% (see Tab 1.2b)
     Examples of previous experiences of the WP2 members:
     - *Summer school on ocean, climate and marine ecosystems, Cape Town (South Africa), 2014*
     - *SPECS/PREFACE/WCRP Workshop on Initial Shock, Drift, and Bias Adjustment in Climate Prediction, Barcelona (Spain), 2016*
     - *Workshop on uncertainty quantification, EDF (France), 2015 and 2016*

     The school will present an overview of the state-of-the-art seasonal-to-decadal prediction skill, describe the sources and mechanisms of predictability linked to each climate system component, introduce the practical applications of climate prediction and the climate services emergence and provide an extensive review of the initialization methods currently in use in the scientific community. The industrial partners EDF and FutureWater will lecture on climate services for the energy sector, agriculture, and water management while BKK will present how the renewable electricity production depends on seasonal to decadal climate forecasts.
- **Workshop on software development** (months 9-15). Organized by our industrial partner VORtech, the 3-day workshop will teach the ESRs how to conceptualize, develop, maintain, and optimize a scientific code. This training is key to CODA and clearly across both WPs. Importantly, VORtech experts will discuss the commercial dimension of the scientific programming, of major importance for the ESRs professional developments after CODA.

  Main Responsible: VORtech and UU
  Duration: 3 days
  Scientific *vs* Transferable skill training: 0% and 100% (see Tab 1.2b)
  Examples of previous experiences of VORtech:
  - *Many training events for academies and private industries*
- The **final CODA conference** (months 46-48) will summarize the project findings. All network participants, including associated partners, will attend the conference. Worldwide experts on DA and on climate prediction will be invited to give keynote lectures, including the members of the External Advisory Board. The conference will receive international contributions via an appropriate call-for-abstract. All ESRs will present their final PhD thesis work. Flagship users will also be invited. To enhance the international visibility of the project results, the final conference may be organized jointly with other international working groups or programs to which the beneficiaries take part such as the *International Workshop on Ensemble Kalman Filter* (enkf.iris.no) or the *World Climate Research*

Program (WCRP) *Decadal Climate Prediction Panel*. **A special issue**, will be targeted to collect and publish the conference contributions so as to strengthen CODA's scientific impact (see Sect. 2.3.1).

- Another complementary element of the network-wide training in CODA will be the **Scientific Guests** hosted at the members' premises. These will be short stays of about 1 week for leading experts from all around the world. Their seminars will be broadcasted in real-time across the entire network and will later be uploaded to the CODA website. CODA members are also encouraged to broadcast within the network the key seminars or lectures held at their institute, after permission from the speaker.

1.2.1.2 *Axis 2* – Transferable skills training (dissemination, outreach and entrepreneurship)

The CODA training offer is directed here to the transferable skill. Our goal is to provide the ESRs with a wide spectrum of complementary skills so as to enhance the attractiveness of their profile in front-line academies, industries and public employers. We aim at shaping researchers with excellent talent for transforming ideas into practical, and economically valuable, outcomes. To this end CODA offers a structured program on dissemination, outreach, proposal writing, policy-maker oriented dialog and entrepreneurship.

Training offered locally

The ESRs will learn oral and poster presentation techniques, scientific and popular science writing from their local universities (see e.g. the courses offered by the Norwegian Research School in Climate Dynamics RESCLIM/CHESS in Bergen resclim.no/activities/courses/). They will be encouraged to start working groups at their institutes to periodically exercise their oral and writing capabilities among young scientists, but also to improve networking with other researchers, and to assemble a community supporting good science communication. The supervisors will monitor these activities but they will be driven by the ESRs' initiative. Courses for **proposal writing** are also available locally along with information days with funding agencies. CODA must also enable the ESRs to establish as entrepreneurs if such a business opportunity arises during their PhD. To this effect, the ESRs will follow courses in **entrepreneurship** offered by the local Chambers of Commerce in the respective partner's city (e.g. in Barcelona: barcelonactiva.cat/barcelonactiva/en/, Toulouse toulouse.cci.fr/creer-transmettre-construire-votre-projet-les-etapes-recommandees/passer-de-lidee-au-projet or Bergen: bergen-chamber.no/article.php?group_id=8557). CODA's commitment is to act so that all relevant local activities, such as courses or information days, will be made known and accessible to all ESRs in the project, no matter their host institution (see also points 3 and 4 in the bullet list below).

Network-wide training

Table 1.2b provides a complete overview of the network-wide events.

1. **Workshop on dissemination and outreach** (months 9-12) will offer tutorials on scientific writing, presentation (both orally and on poster), on outreach, and on dissemination to general public and policy makers. The ESRs will be trained and exercise on how to expose their work orally for both a scientific and a general audience. They will receive training in writing articles for general press as well as for radio/TV, and special attention will be given to the use of social media (Facebook, LinkedIn, Twitter) for being forms of public engagement, spreading excellence and dissemination.

   Main Responsible: UiB and BSC
   Duration: 1 week
   Scientific *vs* Transferable skill training: 0% and 100% (see Tab 1.2b)
   Examples of previous experiences of the UiB and BSC:
   - *Climate Snacks (climatesnacks.com).*

2. **Workshop on entrepreneurship and technology transfer** (months 3-9). This training event will last 2 days, will be host at NERSC premises but it will be fully organized by our industrial partner BTO. BTO has an extensive track record in commercialization based on research projects and has for over a decade assisted researchers in securing rights and established license agreements. The subjects will be Intellectual Properties Rights, Patenting and Technology Transfer. Due to potential conflicts between publishing research and patenting, it is important to arrange the workshop early, in the first year.

   Main Responsible: BTO and NERSC
   Duration: 2 days
   Scientific *vs* Transferable skill training: 0% and 100% (see Tab 1.2b)
   Examples of previous experiences of BTO:
   - *Many events on patenting and technology transfers in Norway.*
   - *Extensive record in commercialization based on research projects and kick-off of spin-offs*

3. **ESR working groups**: ESRs will learn from each other how to improve their communication skills orally and writing. CODA will task the ESRs to write 2-3 blog posts a year about their research or close topics relevant to CODA. The ESRs will peer-review each other's posts and give constructive feedback. In the absence of local writing groups, CODA will arrange monthly/bi-monthly remote writing groups where the ESRs meet online and give each other feedback on their writing.
4. During each of the three **Progress meetings**, 1 day will be dedicated to transferable skills in communication: one tutorial on oral and writing presentation plus the meeting of the ESR working groups to review each other's posts

and give constructive feedback (see Tab. 1.2b).

5. During the **School 1**, the dissemination of research results will be covered by a course on oral/poster presentation, on writing scientific articles and on the use of multimedia web/video supports.
6. During **School 2**, a course on writing proposals will also be included.
7. **School 3** "***Post-CODA strategy***": intensive training on proposals writing for both public and industrial funding will be offered. The industrial partners will contribute by exposing directions for a fruitful transfer of expertise from academies to industry. The partner BTO will provide lectures on technology transfer, patenting and generally on how to translate scientific research into valuable economical assets, while VORtech on commercial software for mathematical computing. Two lectures, from national and transnational scientific funding agencies will be invited to describe the logic and rationale behind the funding schemes. The ESRs will learn how to identify societal-relevant topics within the scope of her/his PhD and adapt the ideas to the needs of an industrial partner or a public user, define the objectives, plan the activities three years ahead and defend the proposal orally. The ESRs will review each other's proposals according to the guidelines given by the industrial partners and funding agencies. On every school, experts from outside CODA and/or from CODA external Advisory Board (see Sect. 1.4) will be invited to give lectures, contributing to the quality of the training offer and to the prestige of the schools.

   Main Responsible: UiB and NERSC
   Duration: 1 week
   Scientific *vs* Transferable skill training: 20% and 80% (see Tab 1.2b)
   Examples of previous experiences of the UiB and NERSC:
   - *Norwegian Research School in Climate Dynamics (resclim.no).*

8. **Policy makers communication training**: the goal is for the ESRs to gain better understanding on how to communicate at the best with policy makers in order for their scientific work to be better understood and be of greater importance for practical policy making. CODA will have a week training program to give to the ESRs the knowledge and skills on how to dialog with policy makers at local, national and EU level. CODA will organize part one at NERSC office in Bergen, where the program consists of lectures from local and national politicians, bureaucrats and lobby organizations. We have the necessary contacts to provide this. The second part will be arranged in Brussels in cooperation with West Norway Office JCS. CODA has a broad network of contacts for giving enriching lectures about communication to policy makers at EU-level.

   Main Responsible: NERSC
   Duration: 1 week
   Scientific *vs* Transferable skill training: 0% and 80% (see Tab 1.2b)
   Schedule/Structure:
   Day 1 in Bergen – Lectures from local bureaucrats and lobbies
   Day 2 in Bergen – Lectures from local politicians and national parliaments members
   Day 3 – Travel from Bergen to Brussels
   Day 4 in Brussels at Norway House – Lectures organised by West Norway Office JSC from lobbies at EU levels
   Day 5 in Brussels – Visit the EU parliament and lectures with advisors and parliament members on communication to policy makers.

Further details about CODA's activities for dissemination and outreach, in the perspective of promotion of scientific achievements and of the ESRs' training, are given in Sect. 2.3 and 2.4.

1.2.2 Role of the non-academic sector in the training programme

CODA gathers **five companies from four European countries, leaders in the area of renewable energy, oil, water and agriculture resources management, and software development: EQUINOR, EDF, BKK, FutureWater and VORtech**. These industrial partners are accompanied by our partner, **BTO**, a technology-transfer office dedicated to guide scientists to the setup of spin-off companies and patenting. CODA can thus count on a unique complementary ensemble of partners altogether completing the excellence of our scientific and transferable skills training program.

They will contribute to multiple aspects of the training: stimulate the ESRs reflection on the societal needs for their research and provide opportunities to build follow-on projects in niche topics identified to exploit the fruits of their research. EQUINOR, EDF, BKK, FutureWater and VORtech will host secondments and will co-supervise ESRs (see Sect. 3.1). BTO and VORtech will organize the workshops on entrepreneurship and technology transfer, and on software development respectively, and will deliver lectures on such topics to the CODA School 3 (see Sect.1.2.1.2 and Table 1.2b). Details on the activities carried out during the secondments at the industrial partners are provided in Sect. 3.1.4.

The ESRs will share their work experience in a private R&D and consultancy environment with other scientists in CODA, thus fostering the interplay between research and innovation through early demonstration of their work in commercial settings. **EQUINOR** has a consolidated record of research in DA for petroleum applications: its R&D department includes a worldwide expert in EnKF, *Remus Hanea*, who act as the scientists in charge in CODA. EQUINOR has recently dedicated large efforts to the development of EnKF to optimize the deployment of oil extraction to increase in efficiency and perforation costs. EQUINOR will interact in WP1, co-mentoring and advising on the research for ensemble-based methods and will host four secondments.

At **BKK**, *Ina T. Kindem* has worked several years as a climate researcher at the Bjerknes Centre and contributed to the development of the first ESM in Bergen, the *Bergen Climate Model*. In BKK she develops seasonal forecasts based on teleconnections and dynamical states of the atmosphere and ocean. To ensure optimal use and planning of hydro power production reliable weather information on time scales from days to decades is important. Without multi-year reservoirs BKK is particularly vulnerable to seasonal variations in snow reservoirs and precipitation amounts. As a representative of the user sector BKK will co-supervise one ESR and will host two secondments focused on end-user needs from a hydropower perspective.

Table 1.2b *– Main training CODA events. SC: Scientific Courses; TS: Transferable Skills*

		Main Training Events & Conferences	Lead Institution	Month(*)
1	Kick-Off Meeting	SC: Overview talks on CODA scientific objectives	NERSC	1-3
2	Workshop *Entrepreneurship & Technology transfer*	TS: Technology transfer, how to make an idea valuable	BTO	3-9
		TS: Patenting rules, processes and identification	BTO	
		TS: Intellectual Property Rights IPR	BTO	
3	Workshop *Dissemination & Outreach*	TS: Establishing the working groups	UiB	9-12
		TS: Course on scientific and technical oral/poster communication	NERSC	
		TS: Course on general public oral and written communication.	BSC	
		TS: Lecture and tutorial on media communication for science	UiB	
		TS: Tutorial on communicating outcome to policy makers	External	
4	Progress Meeting 1	SC: Scientific talks from all ESRs	INRIA	12-15
		TS: Tutorial on oral and written presentation	UiB	
		TS: Reporting on working groups	BSC	
5	Workshop *Software development*	SC: Software concept design	VORtech	12-15
		SC: Programming languages and use of HPC platform	VORtech	
		SC: Focus on the DA coding platform *OpenDA*	VORtech	
6	School 1 *Data Assimilation*	SC: Lectures on general theory of DA	ENPC	12-15
		SC: Lectures on variational methods	INRIA/UR	
		SC: Lectures on application of DA to geoscience	NERSC/ENPC	
		SC: Lectures on coupled DA	UR/NERSC	
		SC: Lectures on dynamical systems and statistical methods	RMI/CONICET	
		SC: DA application to oil-reservoirs and solid Earth	EQUINOR	
		SC: Tutorial on scientific programming for DA using *OpenDA*	VORtech	
		TS: Tutorial on oral/written presentation and multimedia/video/web support	UiB/NERSC	
7	Progress Meeting 2	SC: Scientific talks from all ESRs	BSC	24-28
		TS: Tutorial on oral and written presentation	UiB	
		TS: Reporting on working groups	NERSC	
8	School 2 *Climate Prediction*	SC: Lectures on climate dynamics & seasonal-to-decadal prediction	UiB/BSC	24-28
		SC: Lectures on high-power computing for climate science	CERFACS/BSC	
		SC: Lectures on climate service for energy management	EDF	
		SC: Lectures on climate service for water management	FutureWater	
		SC: Lectures on climate prediction for the renewable energy sector	BKK	
		TS: Tutorial on proposal conceptual design and writing	BSC/NERSC/UiB	
9	Progress Meeting 3	SC: Scientific talks from all ESRs	RMI	36-39
		TS: Tutorial on oral and written presentation	NERSC	
		TS: Reporting on working groups	BSC	
10	School 3 *Post-CODA strategy*	TS: Tutorial on proposal writing for public and private agencies	UiB	36-39
		TS: Tutorials on valuable transfer of expertise from academies to industry	BTO	
		TS: Tutorials on scientific programming for industries	VORtech	
		TS: Lectures from agents of national and transnational scientific funding agencies	External	
		TS: Career development and networking	NERSC	
		SC: Lectures from the CODA supervisory board and external leading experts	CODA EAB(§)	
11	*Policy makers communication training*	TS: Lectures from local bureaucrats and lobbies in Bergen	External	
		TS: Lectures from local politicians and members of the national parliament	External	
		TS: Lectures from EU lobbies in Brussels	External	
		TS: Visit EU parliament and lectures from EU advisors	External	
12	Final CODA conference	SC: Talks from all ESRs	ALL	46-48
		SC: Keynote talks form leading experts		
		TS: Training on the organisation of conferences and scientific events		
		TS: Training on the setup and organisation of the special issue		

(*) Indicative. (§) EAB: External Advisory Board (see Sect. 3.2.2)

Scientific Courses | Transferable Skill | Private Partners | Externals

EDF is involved in CODA via *Dr. N. Goutal*, the co-supervisor of ESR11, and will host 3 secondments. In connection with the electricity production, EDF has a strong expertise in hydro-environmental modelling and will provide its own suite of software *Télémac-Mascaret*. Environmental data being increasingly accessible, EDF envisages the development of DA techniques to estimate model parameters and predict electricity production.

EU water policy is designed to promote sustainable water use based on long-term protection of available resources and to contribute to the provision of sufficient supply for sustainable, balanced and equitable water use. **FutureWater** is a research and consulting organization working throughout the world to combine scientific research with practical solutions for water management. FutureWater brings in CODA another element of complementarity, adding water management and agriculture among represented stakeholder of seasonal to decadal predictions. Its focus topics are water for food, irrigation, water excess, water shortage, climate change, and river basin management, and its key expertise is in the field of quantitative methods, based on simulation models, geographic information systems and satellite observations. FutureWater will co-supervise ESR10, and will host two secondments.

VORtech is a company of scientific software engineers, working in projects for companies and institutes on their software for prediction and analysis. The core expertise is in data-assimilation, HPC and machine learning. VORtech brings into CODA the rigor of the industrial programming, reflected also in the specific workshop on software development it will organize. VORtech will co-supervise one ESR and host one secondment.

BTO contribution to CODA is the expertise in technology transfer, patenting and entrepreneurship and in organizing a specific training workshop on these themes.

All partners will contribute actively to the three CODA schools and in the final conference as detailed in Tab.1.2b,c, by delivering lectures, and scientific contributions. Remarkably, they all have a consolidated experience in running and participating to training events, workshop and conferences. For instance, EQUINOR is the main sponsor of the international workshop on EnKF (co-organized with NERSC; Sect. 1.2.1), where top researchers from academies and industries are gathered (enkf.iris.no), or the bi-annual *Summer School on DA and its applications - Oceanography, Hydrology, Risk & Safety and Reservoir Engineering*. The possibility exists to coordinate/merge the CODA DA School (School 1) with some of these events.

***Table 1.2c** – Summary of partner participation*

EQUINOR	*1 – Participate in the Recruitment of ESR 1*
	2 – External mentoring on ESR 1, 2, 3 and 6
	3 – Hosting Secondments for ESR 1, 2, 3and 6
	4 – Lecturing in school 1
EDF	*1 – Participate in the recruitment of ESR 11*
	2 – Supervision on ESR 11
	3 – Hosting secondments for ESR 4, 5 and 11
	4 – Lecturing in schools 2
BKK	*1 – Participate in the recruitment of ESR 8*
	2 – Supervision on ESR 8
	3 – Hosting secondments for ESR 7 and 8
	4 – Lecturing in school 2
FutureWater	*1 – Participate in the recruitment of ESR 10*
	2 – External mentoring on ESR 9 and 10
	3 – Hosting secondments for ESR 9 and 10
	4 – Participation in school 2
BTO	*1 – Organize and lecturing at workshop on "Technology transfer and Entrepreneurship"*
	2 – Lecturing in School 3
VORtech	*1 – Participate in the recruitment of ESR 12*
	2 – Supervision on ESR 12
	3 – Hosting secondment for ESR 12
	4 – Organize and lecturing at workshop on "Software development"
	5 – Lecturing in school 1 and 3

1.3 Quality of the supervision

1.3.1 Qualifications and supervision experience of supervisors

The ESRs will be enrolled in Doctoral Program at their respective host Universities (see Tab1.2a): all supervisors in CODA are renowned experts and the ESRs will all have one co-supervisor from another beneficiary and will spend one secondment at a private partner. The overall synergy of the program, and the interplay among beneficiaries, is overseen by the Supervisory Board (see Sect. 3.2.2). The areas of expertise, the previous teaching and supervision experience and the time involvement in CODA per beneficiary are summarized below.

Beneficiary and Main supervisor	ESR	Expertise, Teaching and Supervision experience, %Time
NERSC	1, 7	Hosts PhD students since the early 1990s, with an average of 3 successful PhD dissertations each year ever since. It organizes summer schools on climate research and participates to similar short-term schools, teaching DA, on a yearly basis
Alberto Carrassi		Co-leader of the DA group. Expert in mathematics of DA and application to geosciences. PI in several national and international projects and authors of over 30 pubs. Associate professor of DA at University of Bergen. He is currently coordinating 3 international projects, supervising 2 PhD students and 3 postdocs. Involvement: 55%
Laurent Bertino		Research director at NERSC. Expert of DA, stochastic modelling and oceanography. Key contributor to the migration of theory into operational applications, mainly with the TOPAZ system. Experience with industry projects. He presently leads the Arctic Marine Forecasting Centre of the Copernicus (marine.copernicus.eu, Arctic MFC) project and has supervised 5 PhD students and mentoring 8 postdocs. Involvement: 20%
Geir Evensen		Worldwide expert of ensemble-based DA methods and pioneer inventor of the Ensemble Kalman filter. He has supervised and mentored more than 20 PhD students and postdocs. Experience with industry projects. Professor of DA at University of Bergen. Involvement: 8%
RMI	2	Scientific federal institution of Belgium, responsible for providing weather forecasts and early warnings to the public and the Belgian authorities. RMI delivers official certificates for assurance companies, climatological information to the disaster fund, researchers, universities, companies. RMI has developed important research activities in atmospheric and climate sciences. About 200 persons are working at the RMI, with 1/3 of scientists.
Stéphane Vannitsem		Expert in dynamical system application to the geoscience. Professor of dynamical meteorology at the Université Libre de Bruxelles for about 10 years. President of the *Nonlinear Processes* division of the *European Geoscience Union*. Supervision and co-supervision of 7 master theses, 2 PhD theses and mentor of 5 postdocs. Involvement: 20%
ENPC	3	The student will be enrolled to the Science Engineering and Environment doctoral School of University Paris-Est of whose ENPC is a founding member. The ESR will be hosted at CEREA, a joint ENPC-EDF laboratory, with more than 10 PhD students. There is an average of 4 PhDs per year on topics related to atmospheric environment, including DA with applications to atmospheric chemistry. CEREA is a member of the Institute Pierre-Simon Laplace (IPSL, ipsl.fr), which is a significant contributor to the IPCC reports.
Marc Bocquet		Expert in theory and application of DA to many different areas. Leader in the methodological development of advanced DA methods. Supervise and co-supervised 12 PhD and about 10 master students as well as mentored about 10 postdocs. Coordinator of the SAMA group (Statistics for Analysis, Modelling and Assimilation) of IPSL. Involvement: 20%
INRIA	4	The only French public research body fully dedicated to computational sciences. The AIRSEA project team is dedicated to numerical modeling, DA and uncertainty quantification applied to the Earth system. The AIRSEA team regularly hosts 2-3 new PhD students per year.
Arthur Vidard		Expert in variational DA for ocean applications and he has supervised 5 PhD students so far. Involvement: 20%
Laurent Debreu		Leading expert of multi-scale numerical ocean modeling, coupling methods and variational DA; he has supervised 4 PhDs. Involvement: 20%
UR	5	Home to the DA Research Centre, an academic group in the School of Mathematical, Physical and Computational Sciences involving 9 academic staff and over 20 research staff and students. The group works on all aspects of DA, from developing theoretical ideas in simplified models, to practical applications using satellite data in large complex systems.

	Amos Lawless		Over 20 years' experience in DA, in the operational and academic environments. He was recently involved in a ESA project on CDA, in which he interacted regularly with ECMWF. He was PI on a recent UK-funded project in the area of CDA and is now PI on another such project. He has supervised 8 PhD students and currently supervises a further 5. Involvement: 20%
	Alison Fowler		Research fellow of the National Centre for Earth Observation, based at the University of Reading. She has recently been working with Dr Lawless on coupled atmosphere-ocean DA. Involvement: 10%
CONICET		6	Currently hosts 21 PhD students, two of them on DA. Organization of several international events on DA and two regional intensive courses on DA over the past few years. A. Hannart and J. Ruiz have co-organized two international workshops on DA.
	Juan Ruiz		Several years of expertise in the field of numerical weather prediction and DA application with state-of-the-art numerical weather prediction models. He coordinates the field "mathematical methods for weather and climate studies" at IFAECI. Involvement: 20%
	Alexis Hannart		Several years of expertise in the development of statistical methods with several applications in climate science, in particular in the field of detection and attribution, as well as in DA's statistical aspects. Co-supervision of two PhD students working on the development of statistical methods. Involvement: 20%
UiB		8	The primary academic marine research organization in Norway with internationally acknowledged expertise in physical oceanography, climate research, and meteorology. The ESRs 1, 7 and 8 will take PhD degrees at the Geophysical Institute (GFI), UiB. The GFI provides sound and stimulating teaching environments for PhD students, with currently more than 40 active PhD students.
	Noel Keenlyside		Extensive experience in climate variability, modeling and prediction, and currently coordinates several national and international projects on climate prediction and the development of the Norwegian Climate Prediction Model (NorCPM). Awarded with an ERC Consolidator grant. Supervised 12 PhD students. Five postdocs in his group will help in the training and supervision of the ESR. Involvement: 15%
	François Counillon		He has a dual position at UiB and NERSC. He is involved in the development of several prediction systems, namely: the NorCPM and the TOPAZ system. Experience with industry projects. Keenlyside and Counillon are the contact point in Norway for the decadal prediction project in CMIP6. Involvement: 20%
BSC		9,10	One of the four hosting members of the *Partnership for Advanced Computing in Europe* (PrACE) research Infrastructure. Active in many EU projects and contracts with the private sector. Most of BSC group leaders are university professors, with broad experience in teaching. Participation in 4 ITNs from FP7 and 1 from H2020.
	Francisco Doblas-Reyes		Director of the Earth Science Dept, he is an active member of the climate prediction research community, where he plays a leading role in the connection between global climate modeling and climate services. He has supervised 5 PhD students, and he has mentored several postdocs. Involvement: 15%
	Virginie Guemas		Head of the climate prediction group. She has so far supervised 3 PhD students. Involvement: 25%
CERFACS		11	Hosted a large number of PhD students since 1988 working in computer sciences applied in the field of computational fluid dynamics. The main research axes are climate modeling, combustion, aerodynamics and algorithmic. CERFACS has a leading position in climate modeling and coupling software development. It also has a strong expertise in DA applied to geosciences from oceanography to hydrology.
	Sophie Ricci		Expert in hydrology and DA. Supervised and co-supervised about 10 PhDs. Involvement: 30%
UU		12	The student will be enrolled within the Graduate School of Natural Sciences at Utrecht University as a member of the Mathematical Institute and will have close collaboration with the Centre for Complex Systems Studies, the UU Focus Area on Applied Data Sciences, and interact with the national mathematics cluster Nonlinear Dynamics of Natural Systems (NDNS+) and the Dutch-Flemish Scientific Computing Society.
	Jason Frank		Professor of numerical analysis and head of the Department of Mathematics at Utrecht University, expert in mathematical modelling and computation, numerical analysis and data assimilation methods. Supervision and co-supervision of 12 Ph.D. students. Involvement: 15%

1.4 Quality of the proposed interaction between the participating organisations

1.4.1 Contribution of all participants to the research and training programme

A strength of CODA is the interdisciplinary and complementary composition of the network. The training program is organized along 4 axes reflecting the spectrum of expertise brought in by all CODA partners. The scientific training of the ESRs will address the following skills (see also Table 1.2a), using the measures (seminars, workshops, schools and visiting scientists) described in Sect. 1.2, and the regular courses offered at members institutes described in Sect. 1.4.2 and 1.4.3. These are summarised below, along with the distribution of duties and responsibilities:

1) **DA**. Leading Partners: **NERSC**, **ENPC**, **INRIA, CERFACS**, **UR**, **EQUINOR**, **EDF** and **VORTech**
   The ESRs will be trained on the foundation of the DA theory, filtering and optimal control. This encompasses knowledge of probability and statistics, linear algebra and differential calculus. The partners have strong expertise in DA and will provide the ESRs on-site and on-line training and guidance. ESRs will share bibliography and numerical tools such as the DAPPER educational DA toolbox developed at NERSC.
2) **Climate Prediction**. Leading Partners: **UiB**, **BSC, BKK and FutureWater**
   The ESRs will be trained on climate dynamics with emphasis on the initialization of seasonal-to-decadal forecast. Advanced methodologies will be considered using knowledge of oceanography, climate system dynamics and thermodynamics.
3) **Dynamical System**. Leading Partners: **RMI, UU and NERSC**

The ESRs will learn the fundamental of dynamical systems theory and nonlinear analysis, including Lyapunov stability, chaos theory and numerical methods therein. The ESRs hosted at RMI and UU will attend courses on nonlinear sciences at the local premises, while lectures to all ESRs will be given in CODA School 1.

4) **Scientific Programming**. Leading Partners: **All, notably BSC, VORTech and CERFACS**
All ESRs will be trained to program using *Fortran-90* on parallel high-performance computing facilities (HPC), *Matlab* and *Python*. They will learn the use of *R* for statistical analysis and graphical visualization of geophysical fields, and on how to prepare, monitor and post-process simulations using advanced computing platforms.

1.4.2 Synergies between participants

The partners have different levels of expertise in the four disciplines aforementioned. Synergy is warranted by the natural complementarity of the participants and by the fact that most of them are already involved, or have been involved, in a number of common research projects, co-authoring papers and sharing PhD students. CODA will exploit further these synergies by enhancing the exchange of knowledge between large climate modelling communities (*e.g.*, EC-Earth and NorESM), providing an opportunity to share parts of their DA and coupled modelling tools and in turn facilitating future collaborative research. **CODA members have a supervisorial arrangement for non-university based ESR** (see Sect. 1.2.1): there are established agreements between the academic partners that are not entitled to issue doctoral degrees and local close universities (Tab.1.2a). The agreements, that pre-exist CODA, are based on a consolidated collaboration between the research institute and the local university. **These Universities offer a wide spectrum of courses**, some of them given by the scientists involved in CODA: 4 of them on DA, 1 on climate dynamics, 2 dynamical systems (see Part B2, for the details and Table 1.2a for an overview). **These courses are open to all ESRs in CODA**, no matter the University where they are appointed, and CODA management will assist to reduce practical/formal obstacles so that ESRs could have full access. ESRs will be involved in a dense intersection of secondments to other institutes of the network and to the industrial/private partners (see Sect. 3.1). The secondment plan is planned to expose the ESRs to the widest possible spectrum of training offer within the network and to the diverse areas of expertise of the members in a natural multidisciplinary, multi-sectorial and multinational platform.

1.4.3 Exposure of recruited researchers to different (research) environments, and the complementarity thereof

Not a single country alone could program training with all complementary skills that CODA incorporates. Such an effort requires funding schemes explicitly designed to support international collaboration such as the ITN. Three different types of **work environments** will be made available to each ESR: (partners counted between parentheses)

1. **Universities** (4) offer the full depth of long academic traditions with focus on fundamental research questions and teaching. They can offer academic careers to ESRs.
2. **Research institutes** (6) have a more applied focus than universities, more pressure from external projects with concrete deliverables, although research and writing publications remains a central objective. They can offer research positions to ESRs if these can be funded by research projects of societal relevance.
3. **Non-academic partners** (6) do not have any obligation to write scientific publications but rather need to address concrete questions, with results that they can provide to their users within a time horizon of weeks/months rather than years. They will react rapidly if an opportunity for profit arises and can provide jobs to the ESRs. The diversity of the non-academic partners, from big player in the energy sector, to consultancy office in water management and technology transfer is a key asset in CODA and a natural multi-platform for career development.

All three perspectives should be experienced within the time of a PhD in order to take maximum benefits of the strengths of each environment: the most precise definitions of mathematical concepts and natural processes they will find among academic partners and the most precise definition of a practical societal need will be given by the non-academic ones. ESRs have the option to reflect on their research from either a top-down (from fundamental ideas to applications) or a bottom-up perspective (new ideas inspired by practical problems). Being exposed to a variety of working environments and countries will also help the ESRs projecting themselves to their future career, including the possibility to gather funding for their post-CODA project.
Specific network-wide training on complementary skills will be organized (see Sect. 1.2.1), taking also advantage of the knowledge brought in by the private partners in software development, entrepreneurship, project management, outreach, training in Ethics, IPR and environmental issues. To minimize travels, when possible, these events will take place at the same time as the progress meetings, but CODA will also make use of Facebook, LinkedIn groups, web-seminars or Adobe Connect when necessary. We will work with doctoral schools to make sure that CODA training events on complementary skills are fully recognized (in term of credits) for the student's PhDs.

2. IMPACT

2.1 Enhancing the career perspective and employability of researchers and contribution to their skills development

The ESRs will benefit from top-level training and outstanding mobility opportunities across leading laboratories and universities in 7 countries and at 6 private companies, world leaders in energy, water management, technology transfer and software development. The international mobility will expose the young ESRs to different cultures and countries, and they will develop language and communication skills as well as personal abilities much faster than it would be possible at a single institute/country. Internships and visits to private partners will help them be at ease in the non-academic sector. ESRs will gain maturity, openness, and practical transferable skills to become key actors in the future of European research in climate.

Specific Actions:

CODA fellows will learn to use each other's expertise to set themselves ambitious goals, by performing model and/or DA method inter-comparisons or coordinated sensitivity experiments. They will broaden their scientific perspective by making links between different disciplines.

- The ESRs will participate to develop their own research project, carrying out their mobility plan within the network and assessing their need for complementary skills, thus gaining experience in project management. Research in climate science needs a strong collaborative network to address the multi-facets character of the scientific questions: CODA will naturally train its ESR to establish, maintain and benefit from collaborative work.
- The ESRs will prepare their own career plan at the end of the 1st year. The plan will be then continuously updated by the ESR and submitted to supervisors and to the whole network for monitoring every 6 months, and discussed during the PM meetings. The final career plan will be discussed during the CODA School 3 "*Post-CODA strategy*" (see Tab.1.2b) and later submitted with the PhD thesis (see *Milestones & Deliverables* in Sect. 3).

After CODA:

- The career plan will be oriented to academic institutions, climate services (a fast-growing sector with new job opportunities, ec.europa.eu/research/environment/index.cfm?pg=climate_services), regular calls for service enhancement proposals, and the private sector. The ESR training as climate system forecasters and their understanding of key processes will be valuable in all these sectors.
- The CODA team will assist the ESRs who wish to pursue a career in the academic sector to apply for prestigious post-doctoral programs such as Marie Curie individual fellowships.
- Gaining skills in the use of complex climate models, prestigious tools within the EU High Power Computer network (ec.europa.eu/programmes/horizon2020/en/h2020-section/high-performance-computing-hpc), will also undoubtedly enhance the ESR future job opportunities well beyond the academic arena.
- CODA ultimate ambition is to shape outstanding young researchers who may become strong candidates for ERC Starting Grants within 7 years from the completion of the project. The multidisciplinary and inter-sectorial CODA fingerprint is a key asset in this perspective.

2.2 Contribution to structuring doctoral/early-stage research training at the European level and to strengthening European innovation capacity

An immediate impact of CODA will be to strengthen cooperation across Europe among key institutions and centers working on DA and climate prediction, and with industrial partners. CODA will demonstrate the need for such network to train much-needed researchers with the key expertise to advance the skill of climate predictions for their increased use in climate services for society. In the EU, "[…] *there is increasing demand for translating the existing wealth of climate data and information into customised tools, products and information ('climate services').* ***Climate services*** *have the potential to become the intelligence behind the transition to a climate-resilient and low-carbon society. They can help decision-makers take informed decisions in order to boost resilience and adaptation capacity by addressing existing or emerging risks.*" (bookshop.europa.eu/en/a-european-research-and-innovation-roadmap-for-climate-services-pbKI0614177/). The main impact of CODA in the EU capacity for early-stage research training will be to force the restructuring of PhD programs in climate science to have the required interdisciplinary competence and links to industry/climate services. Similar to the concept of the ECMWF for the weather forecast, there is interest in centralizing climate prediction activities in Europe: CODA training and network could be important also in this initiative. In particular the network in CODA will give rise to future consortia for upcoming funding opportunities.

The EU has launched the ambitious **Copernicus Services** covering all aspects of our planet's global environment (copernicus.eu/pages-principales/services/). These services represent an enormous opportunity for European businesses that will first be able to harness these powerful sources of information to propose innovative services to society and reduce anthropogenic environmental and climate footprint (for example reducing electricity consumption, reducing environmental footprint of fossil fuel exploitation), but they are unlikely to reach their potential without an ambitious training programme for students. The vision of CODA is that the exchange of knowledge is the key of a successful

integration of Copernicus services to the private sector and that knowledge needs to be at the state-of-the-art. The Copernicus services primarily targets are the *Climate Change Services* and the *Marine Services*, in which the partners already hold (Arctic MFC of CMEMS at NERSC) or participate significantly to precursor projects (MyOcean, SWARP, MAIRES, EUPORIAS, SPECS, CLIM-RUN).
The involvement of the private sector is central in CODA and in structuring the future EU training platform for PhD in climate science. The six industrial partners are examples of economic sectors needing updated climate information and using this information according to their own needs (*i.e.* water management, reservoir capacity etc.), but also on how to turn a scientific idea into a valuable economical asset. This is the key contribution of the private partner in CODA: proving the strategic importance of climate information and training the ESR to manage these data in a cost-effective way. The ESRs will take advantage of CODA cutting-edge expertise and create their own opportunities either in the private sector or in academia by submitting targeted proposals for research grants.
CODA will help both the scientific community and policy makers in targeting and achieving some of the UN Sustainable Development goals that the EU has signed up to - including Climate action, clean water and sanitation, life on land, responsible consumption and production, industry, innovation and infrastructure, affordable and clean energy etc. Importantly CODA will contribute to bring EU climate prediction capacity at forefront worldwide.

2.3.1 Dissemination of the research results

2.3 Quality of the proposed measures to exploit and disseminate the project results

The dissemination strategy is organised along three axes: 1. Academies, 2. General Public and 3. Media. This section describes CODA plan in regard to the first axis, Academies, and is thus intended for a qualified arena. We refer to Sect. 2.4.1 and 3.1.1 for the communication approach to the broader audience (axes 2 and 3). A key characteristic of CODA is that it involves two close but distinct disciplines, DA and Climate Prediction (linked here via the mathematical dimension of the research strategy) that have their own scientific communities, meetings and agendas. Dissemination of research results will thus be confronted with this aspect.

JOURNALS – A representative, non-exhaustive, list of relevant journals includes *Quarterly Journal of the Royal Meteorological Society, Tellus, Monthly Weather Review, Atmospheric Science Letters, Climate Dynamics, Journal of Climate, Journal of Geophysical Research, Geophysical Research Letters*. When possible, CODA will encourage submission to journals that are open access, and will use web-based archive such as *ArXiv* (arxiv.org) to enhance visibility vie e-print publications already during the review process and to the extent of which this does not conflict with the copyright policy of the journal where the article is reviewed. CODA is committed to apply for a Special Issue in the aftermath of the final conference. An EU-based publisher will be chosen for the scope such as the EGU-Publisher that offers several open access journals of large impact factors.

CONFERENCES – Large conferences, such as the *General Assembly of the EGU* (egu2019.eu), where some CODA members are conveners in sessions on DA and Climate Science, offer the advantage of a large audience with mixed expertise in line with the expected outcomes of CODA. The American counterpart of the EGU, the fall meeting of the *American Geoscience Union*, represents a similar large conference hub to be considered, as well as the *DA International Symposium*, or the *International Union of Geodesy and Geophysics* (IUGG). CODA will also be present on targeted conferences of the Copernicus community, such as the European Space Solutions week (european-space-solutions.eu). ESRs will be encouraged to submit contributions to relevant sectorial meetings and conferences. CODA will rely on the online list of DA-related conferences (met.reading.ac.uk/~darc/conferences/) maintained by UR (member 5 in CODA) and that will be linked via the CODA website.
SOFTWARE – New versions of the open-source education softwares DAPPER and OpenDA will be made freely available on Github github.com/nansencenter/DAPPER and github.com/OpenDA-Association/OpenDA.
CODA website will be setup in the first 3 months by the partners leading WP4. UiB will take responsibility of the website maintenance and update. It will be updated by the PhD results explained in *layman's terms*, and will include the list of publications/talks and be complemented by newsletters once a year. A Wiki-Page on *CDA* will be set up (the Wikipedia page does not exist as of today). The website will address the three axes of dissemination mentioned above, will contain online examples of CDA in the spirit of the Monash Simple Climate Model (monash.edu/research/simple-climate-model/mscm/overview_i18n.html) where DA can switch from strongly to weakly coupled and uncoupled.

2.3.2 Exploitation of the results and intellectual property

Results from WP1 will help producing free educational open-source codes useful for other graduate students and researchers world-wide, such as *NERSC's Python platform DAPPER*, *VORTech's OpenDA software*, *EQUINOR's Ensemble Reservoir Tool* (ERT - ert.nr.no/wiki/index.php/Main_Page) or NERSC's operational EnKF code (svn.nersc.no/enkf); the codes property rights are protected by adapted licenses. Results from WP2 will contribute to existing complex climate modeling and DA systems such as EC-Earth, NorCPM, TELEMAC and TOPAZ, which are part of high-profile projects like those underlying the IPCC or the Copernicus services. These complex codes already

follow their own dissemination strategies and IPR rules and the ESRs will obtain fair citations for their contributions to their developments. The CODA project will eventually strengthen the commonalities of some of these codes but each partner institute will remain sole owner of its background.
The common points between the codes adopted in CODA will strength the liaisons among the members, both academic and non-academic, making natural the future career prosecution of the ESRs to other members. The shoulder-shoulder work on coding will fortify the member's collaboration seeding the basis for teaming up for future relevant EU calls. The developed codes may have commercial value, as it has been for the TOPAZ in different Joint Industry Projects (SeaFINE, ART JIP). In general, the commercial value lies in the licensing of output products (data files) rather than in the source code, which can remain an open-source freeware. The CODA industrial partners can be involved in their commercial use without reducing the level of distribution of the source codes, but we do not foresee that patents will come out from this project. CODA will contribute significantly to the awareness and to the setup of the Copernicus *climate services* for society by training a new generation of scientists ready to become key actors in this new framework: *transforming of the climate-related data and other information into customised products such as projections, trends, economic analysis, advice on best practices, development and evaluation of solutions, and any other climate-related service liable to benefit that may be of use for the society*.
Specific training on IPR will be provided by our partner BTO in the workshop on *Technology transfer and entrepreneurship* and during the *Post-CODA School* (see Sect.1.2.1.2 and Tab.1.2b).

2.4 Quality of the proposed measures to communicate the project activities to different target audiences

2.4.1 Communication and public engagement of the project

CODA strategy combines targeted communication to *"flagship users"* and broad public dissemination to society at large. "Flagship users" will provide concrete examples of returns on investment in DA research. These examples will motivate other potential users to follow the same path, proving in turn that research leads to valuable returns on investment and (invaluable) evolutions of a knowledge-based society. They will participate in the CODA conference, further contributing to the international visibility of the project. The ESRs will take the opportunity of their stays at the private partners to present their works and to initiate follow-up projects, either within the industry or supported by public funding if appropriate. The ESRs will contribute in communicating the project activities using skills they have achieved during CODA training programs (Sect 1.2.2.). Each ESR should become able to explain his PhD to the first passer-by in the street. This ability will be trained in addressing a younger generation, with the goal to motivate more of them for higher education and research. The ESRs will be *Marie Curie Ambassadors* by holding a presentation in a high school/college or organizing a visit to her/his own host institution. They will be enrolled in public outreach happenings, like the *European Researcher's Nights* (ec.europa.eu/research/mariecurieactions/actions/european-researchers-night_en) or the *Research Days* in Bergen (forskningsdagenebergen.com).
As part of the **CODA communication approach to media**, the ESRs will describe their work in an article aimed for a broad public (*e.g. La Recherche* magazine in France, Bertino and Wackernagel, 2004 or a local newspaper). Their activity in both online and live debates will be evaluated as part of their progress. They can contribute to related blogs (*e.g.* Arctic climate neven1.typepad.com) or happenings bringing together scientists and non-experts (*e.g.* the Climate Snacks scisnack.com/event-where-the-science-story-burns). The objective is to confront the students to the societal expectations for their research, and to train them at communicating in written and oral forms to a non-specialized audience. Each ESR will be encouraged to take part in at least one event aimed at the general public, either at her/his institution or in collaboration with other partners, showing the two facets of DA (theoretical and applied), and will be announced on the CODA web site. **Social media**, namely Facebook, LinkedIn and Twitter, will also be actively used in CODA to strength the public engagement and dissemination. CODA workshop on transferable skills, the Post-CODA school, and the event dialog with policy makers will train them to communicate to general public and policy makers the scientific insights, so important in climate science (see Sect.1.2.1.2).

3. QUALITY and EFFICIENCY of the IMPLEMENTATION

3.1 Coherence and effectiveness of the work plan

3.1.1 Work Packages Description

The content and organization of the work packages is given in the four Tables that follow, one for each WP.

Table 3.1a – Description of Work Packages (4 tables)

WP Number: **1**	Start month **1** – End Month **48**
WP Title: **Advanced DA methods for coupled dynamics**	
Lead/Co-Lead Beneficiary	**ENPC/INRIA – Marc Bocquet/Arthur Vidard**
Objectives: **Development of CDA Methods**	
Distribution of Work and Role of Partners	

1. **NERSC**
   Supervise ESR 1 working on PhD Subproject 1.1: *Ensemble based DA methods for coupled systems*
   Secondment and Co-Supervision for ESR 2 and 3. Co-Supervision for ESR 6.
2. **RMI**
   Supervise ESR 2 working on PhD Subproject 1.2: *Low-frequency variability and predictability of ocean-atmosphere coupled systems*
   Secondment for ESR 1, 6 and 8. Co-Supervision ESR 8.
3. **ENPC** (WP1 Leader)
   Supervise ESR 3 working on PhD Subproject 1.3: *Error dynamics characterization within an ensemble-variational DA system*
   Secondment for ESR 1, 5, 8 and 11. Co-Supervision for ESR 1, 5 and 6.
4. **INRIA** (WP1 Co-Leader)
   Supervise ESR 4 working on PhD Subproject 1.4: *Multigrid preconditioning for variational DA*
   Secondment for ESR 5, 9 and 11.
5. **UR**
   Supervise ESR 5 working on PhD Subproject 1.5*: Observation impact in coupled variational DA.*
6. **CONICET**
   Supervise ESR 6 working on PhD Subproject 1.6: *Assimilation of time-averaged observations with application to detection and attribution of climate change*.

Description of Deliverables

Deliverables of WP1 SubProj 1.1: **Ensemble based DA methods in coupled systems**

D1.1.1 *Comparison of standard EnKF in different regime of scale separation – Article submitted to DA journal (month 16 of PhD thesis)*

D1.1.2 *Adaptive EnKF for coupled system – Articles submitted to a DA journal (PhD thesis submission + 3 months)*

Deliverables of WP1 SubProj 1.2: **Low-frequency variability and predictability of ocean-atmosphere coupled systems**

D1.2.1. *Dynamics of instabilities in coupled dynamics - Article submitted to a nonlinear/geoscience journal (Month 15 of the PhD)*

D1.2.2 *Dynamics of error beyond the linearized regime - Article submitted to a nonlinear/geoscience journal (Month 24 of the PhD thesis)*

D1.2.3 *Impact of DA on the error dynamics - Article submitted to a nonlinear/geoscience journal. (PhD thesis Submission + 2 months)*

Deliverables of WP1 SubProj 1.3: Error dynamics characterization within an ensemble-variational DA system

D1.3.1 *Numerical dynamical analysis of the iterative ensemble Kalman smoother (IEnKS) - Article submitted to a DA journal (month 15 of PhD thesis)*

D1.3.2 *IEnKS in the unstable subspace; tests on low-order Lorenz models - Article submitted to a DA journal (month 24 of PhD thesis)*

D1.3.3 *Applications with a coupled low-order air quality model - Article submitted to a DA or atmospheric chemistry journal (PhD thesis submission + 3 months)*

Deliverables of WP1 SubProj 1.4: Multigrid preconditioning for variational DA

D1.4.1 *Theoretical design of the new multigrid-based preconditioning techniques and application to an intermediate complexity uncoupled system – Article submitted to a DA journal (month 18 of PhD thesis)*

D1.4.2 *Theory and applications with a coupled low-order model - Article submitted to a DA journal (PhD thesis submission + 2 months)*

Deliverables of WP1 SubProj 1.5: Observation impact in coupled variational DA

D1.5.1 *Development of new measures for analysis sensitivity to observations – Article submitted to a DA journal (month 12 of thesis).*

D1.5.2 *Development of new measures of observation impact on a forecast – Article submitted to a DA journal (month 22 of thesis).*

D1.5.3 *Observing system design experiments with new sensitivity measures in a single-column model – Article submitted to a geosciences journal (PhD thesis submission + 2 months).*

Deliverables of WP1 SubProj 1.6: Assimilation of time-averaged observations with application to the detection and attribution of climate change

D1.6.1 *Evaluation of recent methods for assimilating time-averaged observations on low-order coupled models (month 12 of PhD thesis)*

D1.6.2 *Design of a new method for assimilating time-averaged observations - Article submitted to a DA journal (month 24 of PhD thesis)*

D1.6.3 *Application to Detection and Attribution of climate change within a forced low-order climate model - Article submitted to a DA or climate journal (PhD thesis submission + 3 months)*

WP Number: **2**	Start month **1** – End Month **48**
WP Title: **Exploitation of DA methods for initialization, attribution and parameter calibration of environmental systems**	
Lead/Co-Lead Beneficiary	**BSC/CERFACS – Virginie Guemas/ Sophie Ricci**
Objectives: **Exploitation of DA methods for applications with coupled environmental models**	

Distribution of Work and Role of Partners

1. **NERSC**
   Supervise ESR 7 working on PhD Subproject 2.1: *Multi-methods CDA*
   Secondment for ESR 10 and 12. Co-Supervision for ESR 12.
2. **UiB**
   Supervise ESR 8 working on PhD Subproject 2.2: *Strongly CDA for seasonal-to-decadal prediction*
   Secondment and Co-Supervision for ESR 9 and 10.
3. **BSC** (WP2 Leader)

Supervise ESR 9 working on PhD Subproject 2.3: *Toward reduced surface biases in EC-Earth 3 climate forecast system through parameter calibration based on the Ensemble Kalman Filter*

Supervise ESR 10 working on PhD Subproject 2.4: *Impact of the balanced initialization of dynamical climate forecasts on forecast quality*

Secondment for ESR 1, 3, 4 and 6.

Co-Supervision and Secondment for ESR 7.

4. **CERFACS** (WP2 Co-Leader)

Supervise ESR 11 working on PhD Sub-Project 2.5: *Ensemble DA for coupled sediment-hydrodynamics modelling in estuaries*

Secondment for ESR 4 and 7.

5. **UU**

Supervise ESR 12 working on PhD Sub-Project 2.6: *Implementation of multiscale variational DA methods in OpenDA*.

Description of Deliverables

Deliverables of WP2 SubProj 2.1: Multi methods coupled DA

D2.1.1 *A new idealized coupled adaptive-fixed grid system (month 12 of PhD thesis, paper I)*

D2.1.2 *Multi-methods DA experiments in the new idealized system (month 24 of PhD thesis, paper II)*

D2.1.3 Good practices for multi-method DA (*month 36 of PhD thesis, paper III*).

Deliverables of WP2 SubProj 2.2: Strongly coupled DA for seasonal-to-decadal prediction

D2.2.1 *Implementation of the leading averaged coupled covariance in NorCPM (month 12 of PhD thesis; paper I)*

D2.2.2 *Exploring improved coupled covariance and variational framework (month 30 of PhD thesis; Paper II)*

D2.2.3 *Demonstration of strongly coupled DA in real framework (month 36 of PhD thesis; Paper III and PhD thesis submission)*

Deliverables of WP2 SubProj 2.3: Toward reduced surface biases in EC-Earth 3 climate forecast system through parameter calibration based on the Ensemble Kalman Filter

D2.3.1. *Mechanisms controlling the development of surface biases in EC-Earth3.1 - Article submitted to a climate dynamics journal (Month 15 of the PhD)*

D2.3.2 *Validation of the parameter estimation in EC-Earth - Article submitted to an applied science journal (PhD thesis + 2 months)*

D2.3.3 *Correction of General Circulation Model biases using DA - Article in an oceanography journal. (PhD thesis + 3 months)*

Deliverables of WP2 SubProj 2.4: Impact of a balanced initialization of dynamical climate forecasts on forecast quality

D2.4.1. *Illustration of the links between the drift and the forecast quality in S2S climate predictions (Month 18 of PhD thesis)*

D2.4.2. *Recommendations for operational climate forecast institutions concerning the relevance of implementing balanced initialization of climate forecasts (Month 36 of PhD thesis)*

Deliverables of WP2 SubProj 2.5: ***Ensemble DA for coupled sediment-hydrodynamics modelling in estuaries***

D2.5.1 *Validation of the TELEMAC2D model for the Gironde estuary with and without SISYPHE coupling. - Article in a hydrodynamics journal (Month 18 of the PhD Thesis)*

D2.5.2 *Gathering available in-situ data* completed *(Month 18 of the PhD Thesis)*

D2.5.3 *Implementation of the ensemble based DA for TELEMAC2D achieved. (Month 24 of the PhD Thesis)*

D2.5.4 *Coupled TELEMAC2D and SISYPHE with DA- Article in a hydrodynamics journal (Month 36 of the PhD Thesis)*

Deliverables of WP2 SubProj 2.6: ***Implementation of multiscale variational methods in OpenDA***

D2.6.1 *Weak-constraint 4DVar with method of successive approximations in OpenDA (Month 12 of the PhD Thesis)*

D2.6.2 *Multivariate variational integrators in OpenDA (Month 24 of the PhD Thesis)*

D2.6.3 *Implementation of low-to-high complexity models from CODA in OpenDA (Month 33 of the PhD Thesis)*

WP Number: **3**	Start month **1** – End Month **48**
WP Title: **Management & Network-Wide Training**	
Lead/Co-Lead Beneficiary	**NERSC – Laurent Bertino/Alberto Carrassi** + Project Manager
Objectives: **Management of the Project and Supervision of the Training**	

Distribution of Work and Role of Partners

- **NERSC –** WP3 Leader

Managing the Project:

1. Network management structure: management team, supervisory board, training and recruitment committees (see Sect. 3.2);
2. Oversee the recruitment of ESRs;
3. Organize progress meetings and reporting;
4. Financial management.

Organizing the Network-Wide Training (based on Section 1.2):

1. Organize and oversee the progress meetings and reporting
2. Organize and supervise the three CODA schools and the training events
3. Organize the writing groups for ESR in the progress meeting
4. Coordinate the training offered locally with those at the network level
5. Compile and make available information regarding skills audits, needs and available training in complementary skills;
6. Ensure the flow of information in the network, including job/career opportunities;

- **UiB, ENPC and BSC**

Organizing the Network-Wide Training:

1. Organize workshop in dissemination and outreach and coordinate the training in climate prediction **(UiB)**
2. Coordinate the CODA school 1 in DA (**ENPC**)
3. Coordinate the CODA school 2 in Climate Prediction (**BSC**)
4. Coordinate the CODA school 3 on the CODA exit strategy (**UiB**)

Description of Deliverables

- **D3.1** – Selection of the Supervisory Board and Training and Recruitment Committees (Month 1)
- **D3.2** – 1st Financial Status Report and 1 Year Projection (Month 1)
- **D3.3** – Kick-Off Meeting Organization (Month 1)

- **D3.4** – Recruitment Start (Month 3)
- **D3.5** – ESR mobility plan (Month 4)
- **D3.6** – Network-wide Training & Secondment Plan (Month 6; see also Section 1.2.2 for secondment to the industrial partners)
- **D3.7** –Workshop on Dissemination & Outreach (Month 3 – 12; see Section 1.2.1)
- **D3.8** – CODA School 1 on DA (Month 12 - 15; see Section 1.2.1)
- **D3.9** – 2nd Financial Status Report and 1 Year Projection (Month 13)
- **D3.10** – Progress Meeting 1: ESR project status and career plan monitoring (Month 12-15)
- **D3.11** – 3rd Financial Status Report and 1 Year Projection (Month 25)
- **D3.12** – Progress Meeting 2: ESR project status and career plan monitoring (Month 24-28)
- **D3.13** – CODA School 2 on Climate Prediction (Month 24-28; see Section 1.2.1)
- **D3.14** – Progress Meeting 3: ESR project status and career plan monitoring (Month 36-39)
- **D3.15** – Submit the ESR career plan (Month 38)
- **D3.16** – CODA School 3 on the post-CODA strategy (Month 36-39; see Section 1.2.1)
- **D3.17** – Final Conference (Month 46-48)
- **D3.18** – Final Management Meeting (Month 48)

WP Number: **4**	Start month **6** – End Month **48**
WP Title: **Dissemination and Outreach**	
Lead/Co-Lead Beneficiary	**UiB – Noel Keenlyside / BSC – Francisco Doblas-Reyes** + Project Manager

Objectives: **Dissemination of Scientific Results to Experts and Broad Public**

- Setup and maintain the CODA website, which will be hosted by UiB. The website will include the list of publications and presentations and it will be complemented by newsletters disseminated once a year to the partners and their networks.
- Setup and maintain the WikiPage on CDA.
- Update the list of relevant conferences and publish them on the CODA website.
- Update the list of relevant journals and keep informed on the CODA Special Issue
- Coordinate the ESR direct involvement in the dissemination activity for the general public (see Section 2.4.1): EU research nights, articles in journals for general public and outreach seminars.
- Prepare a series of outreach talks given by the ESR to the public and relevant stakeholder organizations (see Section 2.4.1). These talks will be broadcasted and recorded whenever possible.
- Facebook and twitter accounts setup; nowadays many young scientists use these as a means of communication.
- Brochures summarizing results and disseminate to potential future employers (*e.g.*, ECMWF, stakeholders in climate prediction and services) and international organizations (e.g., Copernicus Services, WMO, ESA) interested in the CODA training program; a list will be drawn up with the help of all partners and the web site, among other vehicles, will be used to spread this information.
- Link to UiB, BSC and Bjerknes Centre divisions of communication. They have skilled scientific journalists who will help the researchers to disseminate project results to national and international media by preparing press releases, articles and also videos.
- Announce project activities, summer schools, targeting the main mailing lists and announcement channels, such as specialized magazines and newsletters of other projects

Description of Deliverables

D4.1 CODA Webpage (month 3)
D4.2 First project brochure for dissemination to prospective employers and relevant organisations (month 24)
D4.3 Final project brochure for dissemination to prospective employers and relevant organisations (month 48)
D4.4 Special issue in a high-impact journal (month 48)

3.1.2 List of Major Deliverables

Table 3.1b describes major deliverables, separated into scientific and management/training/dissemination. Note that the estimated due date is given in months from the beginning of the project and that only the major deliverables are reported in Table 3.1b; the full list is found in the WP description tables in Sect. 3.1.1.

Table 3.1b – List of major deliverable

Scientific Deliverables						
Deliverable Number	**Deliverable Title**	**WP No.**	**Lead Beneficiary Short Name**	**Type**	**Dissemination Level**	**Due Date** (estimate)
D1.2.3	Impact of DA on the error dynamics.	**1**	**RMI**	**PDE**	**PU**	**38**
D1.4.2	Multigrid-based preconditioning techniques for coupled systems	**1**	**INRIA**	**PDE**	**PU**	**38**
D1.1.2	EnKF for coupled system.	**1**	**NERSC**	**PDE**	**PU**	**39**
D1.3.3	Applications with a coupled low-order air quality model.	**1**	**ENPC**	**PDE**	**PU**	**39**
D1.5.3	Observing system design experiments with new sensitivity in a single-column model.	**1**	**UR**	**PDE**	**PU**	**38**
D1.6.3	Detection and Attribution of	**1**	**CONICET**	**PDE**	**PU**	**39**

	climate change within a forced low-order climate model.					
D2.1.3	Practices multi-methods DA	**2**	**NERSC**	**PDE**	**PU**	39
D2.2.3	Advanced method for sCDA	**2**	**UiB**	**PDE**	**PU**	**39**
D2.3.3	Correcting model biases with DA	**2**	**BSC**	**PDE**	**PU**	**39**
D2.4.2	Recommendations for operational climate forecast institutions for implementing balanced initialization of climate forecasts	**2**	**BSC**	**PDE**	**PU**	**39**
D2.5.4	Coupled TELEMAC2D and SISYPHE with DA	**2**	**CERFACS**	**PDE**	**PU**	**39**
D2.6.3	Implementation of CODA models within OpenDA	**2**	**UU**	**PDE**	**PU**	**39**
Management, Training, Recruitment and Dissemination Deliverables						
Deliverable Number	**Deliverable Title**	**WP No.**	**Lead Beneficiary Short Name**	**Type**	**Dissemination Level**	**Due Date** (estimate)
D3.1	Selection of the SB and Training and Recruitment Committees	**3**	**NERSC**	**AMD**	**CO**	**1**
D3.3	Kick-Off Meeting Organization	**3**	**NERSC**	**ADM**	**CO**	**1**
D3.4	Recruitment Completion	**3**	**NERSC**	**OTHER**	**PU**	**3**
D4.1	Setup and maintain project website and blog	**4**	**UiB**	**OTHER**	**PU**	**3**
D3.5	ESR mobility plan	**3**	**NERSC**	**OTHER**	**CO**	**4**
D3.6	Network-wide Training Plan	**3**	**NERSC**	**OTHER**	**CO**	**6**
D3.8	Organization School 1	**3**	**ENPC**	**OTHER**	**PU**	**12**
D4.2	First project brochure	**4**	**UiB**	**OTHER**	**PU**	**24**
D3.13	Organization of School 2	**3**	**BSC**	**OTHER**	**PU**	**27**
D3.14	ESR career development plan	**3**	**NERSC**	**OTHER**	**CO**	**38**
D3.17	Organize Final Conference	**3**	**NERSC**	**OTHER**	**PU**	**47**
D4.4	Special issue	**4**	**BSC**	**OTHER**	**PU**	**48**
D3.18	Final Management Meeting	**3**	**NERSC**	**ADM**	**CO**	**48**

3.1.3 List of Major Milestones

Table 3.1c – List of Major Milestones

No.#	Title	Related WP	Lead Beneficiary	Due Date (estimate)	Means of Verification
M1	Kick-Off Meeting and ESR project and mobility plan	All	NERSC	1	Minutes of meeting
M2	ESR recruitment and audit	All	All	1	Minutes of meeting
M3	Summer School on DA	1	ENPC / INRIA NERSC	12	Minutes of meeting
M4	1st Review of Individual Subprojects status	1 and 2	ENPC / BSC	15	Minutes of Supervisor Committee meeting
M5	Summer School on Climate Prediction	2	BSC	24	Minutes of meeting
M6	2nd Review of Individual Subprojects status	1 and 2	ENPC / BSC	27	Minutes of Supervisor Committee meeting
M7	PhD Theses Submission	1 and 2	All	34	Minutes of Supervisor Committee meeting
M8	Summer School on Post-CODA strategy	All	UiB	36	Minutes of meeting
M9	3rd Review of Individual Subprojects status	1 and 2	ENPC / BSC	38	Minutes of Supervisor Committee meeting
M10	ESR Career Plan	3	NERSC	38	Minutes of meeting

3.1.4 Fellow´s individual projects

Fellow	**Host institution**	**PhD enrolment (University of Bergen)**	**Start date**	**Duration**	**Deliverables**
ESR 1	**NERSC**		**3**	**36**	**D1.1.1 and D1.1.2**

Project Title and Work Package	**Ensemble DA methods in Coupled Systems (WP1)**
Objectives	***Supervisor: Alberto Carrassi and Laurent Bertino (NERSC)*** ***Co-Supervisor: Marc Bocquet (ENPC)*** ***Phase 1: Error Dynamics Characterization in Coupled Systems (months 1 – 9 of the PhD thesis)*** A deep study of the error dynamics as a function of the coupling type and strength will be carried out. Lyapunov stability analysis will be used to characterize the system's stability properties. Two estimation methods will be used. First the classical approach from [7] that allows for computing the time-dependent unstable subspaces, but the information about the specific directions is lost. Second the new algorithm developed by [29] that allows for estimating the individual Lyapunov vectors and so precisely identify the coupling effect on the direction of instabilities. ***Phase 2: Comparison of standard EnKF in different regime of scale separation (months 9 – 16 of the PhD thesis)*** Stochastic and Deterministic EnKFs will be implemented in low order coupled systems. The objective is to identify the regime of scale separation causing the collapse of the fully CDA approach. The weakly- and strongly-coupled EnKF will be compared in relation with the type and strength of the coupling and in a range of different observational and model error scenarios to understand under which circumstances and why the strongly-coupled formulation fails. This will guide the exploration of novel strongly-coupled EnKF formulations. ***Phase 3: Coupled DA using unstable subspace information (months 16 – 33 of the PhD thesis)*** Research focus to adapt standard methods to propagate information across all compartments. Attention will be driven toward the design of the error covariance to cross-infer the different model compartment using all available observations simultaneously. Target observations strategies based on unstable modes will be tested: the phase-space location of the observations is chosen in the maximum of the unstable modes. A systematic study will be done to assess the impact on prediction error at different time-horizons/model-compartment as a function of the target observations type and location. The unstable modes themselves will then be used in the assimilation step following the AUS approach. ***Phase 4: PhD Dissertation writing (months 33-36 of the PhD thesis)***
Expected Results	**New Methods for Ensemble based DA in Coupled Systems**
Planned secondments	1. **Secondment Host**: ENPC (Marc Bocquet) months 3-7 of the PhD thesis **Purpose**: Ensemble-based methods. The IEnKS applied to low-order models. 2. **Secondment Host**: EQUINOR (Remus Hanea) months15-16 of the PhD thesis **Purpose**: Practical applications of EnKF to petroleum sector. 3. **Secondment Host:** BSC (Virginie Guemas) months 28-29 of the PhD thesis **Purpose**: Initialisation and prediction with state-of-the-art ESMs: Low frequency variability and Predictability in comparison with low-order systems used in the PhD work.

Fellow	**Host institution**	**PhD enrolment**	**Start date**	**Duration**	**Deliverables**
ESR 2	**RMI**	**(Université Libre de Bruxelles)**	**3**	**36**	**D1.2.1, D1.2.2 and D1.2.3**

Project Title and Work Package	**Low-frequency variability and predictability of coupled ocean-atmosphere coupled systems (WP1)**
Objectives	***Supervisor: Stephane Vannitsem (RMI)*** ***Co-Supervisor: Alberto Carrassi (NERSC)*** ***Phase 1: Dynamical instability of coupled systems (months 1 – 12 of the PhD thesis)*** Different approaches exist for the evaluation of the dynamical instabilities namely singular vectors (SV), bred vectors (BV), and Lyapunov vectors (LV) [52]. Recently new tools have been developed known as covariant Lyapunov Vectors (CLV) whose main property is to be invariant through the action of the flow [55]. This interesting property makes these vectors natural instability structures of the flow. The purpose is therefore to investigate the properties of these vectors when a slow dynamic (long term variability) is coexisting with fast variability, in the perspective of ensemble DAs developed in WP1 learned by the ESR 2 during the stays at NERSC and EQUINOR. ***Phase 2: Dynamics of the error beyond the linearized regime (months 12 – 24 of the PhD thesis)*** Beyond the linearized regime well described by LVs and BVs, the error is growing nonlinearly, and saturates after a typical time scale associated with the inverse of the dominant Lyapunov exponent [72]. In multiscale systems, the picture is more complicate with the error rapidly saturating at the shorter time scales, but continuing to grow for longer time scales. This feature opens the question on the actual dynamics of the error at these long-time scales. It will be addressed in the context of idealized slow-fast dynamics and low-order coupled ocean-atmosphere models. This question will also be addressed in state-of-the-art climate models during the stay at BSC. ***Phase 3: Impact of DA on the error dynamics (months 24 – 33 of the PhD thesis)*** The behaviour of the forecast error after is strongly conditioned by the quality/quantity of information gathered during the DA. This will be evaluated in the light of the recent theories on the short-term error dynamics [73]. The analysis will be performed with reduced-order coupled ocean-atmosphere models in which the DA schemes of the other Sub-Projects of WP1 have been implemented. ***Phase 4 - PhD Dissertation writing (months 33-36 of the PhD thesis)***
Expected Results	**The development of a theory for the error dynamics in slow-fast systems and the impact of DA**
Planned secondments	1. **Secondment Host**: NERSC (Alberto Carrassi) months 11-14 of the PhD thesis **Purpose**: AUS and ensemble methods. Implementation of EnKF methods (including IEnKS) to the 36-variables coupled model from [102], and study of the choice of the unstable vectors for AUS. 2. **Secondment Host**: EQUINOR (Remus Hanea) months 15-16 of the PhD thesis **Purpose**: Study of the applications of DA to petroleum sector, in particular parameter estimation 3. **Secondment Host**: UiB (Francois Counillon and Noel Keenlyside) months 27-28 of the PhD thesis **Purpose**: Initialisation and prediction with state-of-the-art ESMs: Low frequency variability and Predictability in comparison with the properties found in [102]

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR 3	**ENPC**	**(Université Paris-Est)**	**3**	**36**	**D1.3.1, D1.3.2 and D1.3.3**
Project Title and Work Package		**Error dynamics characterization within an ensemble-variational DA system (WP1)**			

Objectives

Supervisor: Marc Bocquet (ENPC)
Co-Supervisor: Laurent Bertino and Alberto Carrassi (NERSC)

Phase 1: Numerical dynamical analysis of the iterative ensemble Kalman smoother (months 1 – 12 of the PhD thesis)
We plan to study the dynamical propagations of errors within the DA temporal window of the IEnKS [9, 10] on several key low-order models. Focusing on its analysis within a DA temporal window but also in between analysis steps, we will use Lyapunov vectors to study this dynamic. We also plan to study this propagation of errors in between two coupled systems.
Phase 2: *IEnKS in the unstable subspace; tests on low-order Lorenz models* (months 12 –20 of the PhD thesis)
Building on the results of phase 1, we plan to define and implement an AUS variant of the IEnKS. This will be carried out on low-order Lorenz systems. This potentially powerful numerical tool should help validate the results of phase 1. Expertise on AUS systems will be acquired during a stay at NERSC.
Phase 3: Applications with a coupled low-order air quality model (months 20 – 33 of the PhD thesis)
One typical application is that of an online air quality model, which is composed of a meteorological model, whose meteorological fields drive a chemical transport model (CTM), with possible feedback from the CTM to the weather forecast model. We have recently developed a low-order model (L95-GRS) with these dynamical features that will be used in this study. This application is typical of a coupled DA system where one of the system is chaotic (meteorology) but accurate and relatively well controlled and of a non-chaotic though highly nonlinear and uncertain system (constituents transport and chemistry). The results of phase 3 will be confronted to larger online CTM systems during a stay at the BSC.
Phase 4: PhD Dissertation writing (months 33-36 of the PhD thesis)

Expected Results	**Better understanding of new ensemble variational methods, and evaluation of their potential for DA in coupled systems. Application to online CTMs.**
Planned secondments	**1. Secondment Host**: NERSC (Alberto Carrassi) months 12-14 of the PhD thesis **Purpose**: AUS and ensemble methods. Implementation of EnKF methods (including IEnKS) to the VDDG model [102] **2. Secondment Host**: EQUINOR (Remus Hanea) months 15-16 of the PhD thesis **Purpose**: Practical Applications of EnKF to petroleum sector. **3. Secondment Host**: BSC (Francisco Doblas-Reyes) months 28-29 of the PhD thesis **Purpose**: Complementary/Related Skill: Learning on the EnKF in the coupled transport-chemical model of BSC

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR 4	**INRIA**	**(Université Grenoble-Alpes)**	**3**	**36**	**D1.4.1, and D1.4.2**
Project Title and Work Package		***Multigrid preconditioning for variational DA* (WP1)**			

Objectives

Supervisor: Arthur Vidard and Laurent Debreu (INRIA)
Co-Supervisor: Francisco Doblas-Reyes (BSC)

Phase 1: Bibliography and theoretical study of multigrid techniques and preconditioning (months 1 – 12 of the PhD thesis)
Only very simple multigrid techniques have been used in the optimization part of variational DA while more advanced and robust methods exist in the literature. The first phase of this will be to browse through these techniques and select the ones relevant to our large-scale problem. Some adaptations are likely to be necessary and the convergence properties will be carefully studied and some novel preconditioning techniques will be proposed.
***Phase 2: Application to an uncoupled academic model* (months 12 –20)**
The methods proposed in phase one will be tested on academic uncoupled models of intermediate complexity and compared with classical approaches. Both the quality of the results and the computing efficiency will be evaluated.
Phase 3: Theoretical extension to coupled models - Applications to a coupled academic model (months 20 – 33)
The extension of the proposed methods to coupled models will be studied with a particular focus on the validity of the necessary hypotheses for the convergence result. The case where models are coupled through a bulk formula (like in ocean-atmosphere) will be especially investigated. Once the relevant theory designed, we will test the methods on an academic coupled model from table 1.1c
Phase 4: PhD Dissertation writing (months 33-36 of the PhD thesis)

Expected Results	**New efficient preconditioning methods for variational DA**
Planned secondments	**1. Secondment Host**: CERFACS (Sophie Ricci) months 10-12 of the PhD thesis (phase 1) **Purpose**: Optimization techniques play a key role in DA but are most of the time seen as back box. This ESR requires a deep knowledge of such methods and CERFACS is a major player in the field **2. Secondment Host**: BSC (Francisco Doblas-Reyes) months 16-20 of the PhD thesis (phase 2) **Purpose**: Aiming at realistic applications requires to design methods fit for HPCs today and futures paradigms. BSC is an obvious place to learn about these issues. **3. Secondment Host**: EDF (Nicole Goutal) months 26-28 of the PhD thesis (phase 3-4) **Purpose:** Operational applications induce additional constraints: what is at stakes, scale interactions, strong and weak hypotheses, and numerical challenges. EDF will train the ESR4 on these aspects.

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR 5	**UR**	**(University of Reading)**	**3**	**36**	**D1.5.1, D1.5.2 and D1.5.3**
Project Title and Work Package		***Observation impact in coupled variational DA* (WP1)**			

Objectives	***Supervisor: Amos Lawless and Alison Fowler (UR)*** ***Co-Supervisor: Marc Bocquet (ENPC)*** The objective of the project is to develop new methods for assessing observation impact in coupled atmosphere-ocean DA. ***Phase 1: Development of analysis impact measures (months 1-12)*** A theoretical derivation of the analysis sensitivity to observations in weakly variational DA will be carried out. We expect the full expression intractable in practice, so approximations will be sought retaining the essential information of observation across the air-sea interface. Methods will be tested numerically using the low order coupled ODE model MFPV and compared with standard measures. ***Phase 2. Development of forecast impact measures (months 13-22)*** Standard measures for quantifying forecast impact of observations often rely on adjoint sensitivities. In wCDA the adjoint of the full coupled model is not available. Here we will develop approximations to these sensitivities based on ensemble methods, to allow assessment of forecast impact in the coupled system. In particular measures will be developed to assess the impact of ocean observations on the atmospheric forecast and *vice versa*. Methods will again be tested in a low order ODE model. ***Phase 3. Observing system design coupled atmosphere-ocean models (months 24-32)*** In this phase the measures developed in phases 1 and 2 will be implemented on a single-column atmosphere-ocean model (SCM) assimilation system already available at UR. Results from assimilation experiments will be compared with predictions from the new measures. By considering different observation types we will study the likely effects of different observations on the analysis and forecast from coupled assimilation systems. ***Phase 4: PhD Dissertation writing (months 33-36)***
Expected Results	**Methods for quantifying the impact of different observation types on the analysis and forecast from weakly-CDA. An understanding of the effect of different observation types in CDA.**
Planned secondments	**1. Secondment Host**: ENPC (Marc Bocquet) months 10-12 of the PhD thesis **Purpose**: Understand mathematical methods for optimal design of observing systems. **2. Secondment Host**: EDF (Nicole Goutal) months 18 – 20 of the PhD thesis **Purpose**: Develop practical measures of forecast impact for the electricity generation industry. **3. Secondment Host**: INRIA (Arthur Vidard) months 30 – 32 of the PhD thesis **Purpose**: Learn about practical aspects of ocean DA.

Fellow	**Host institution**	**PhD enrolment**	**Start date**	**Duration**	**Deliverables**
ESR 6	**CONICET-IFAECI**	**(Universidad de Buenos Aires)**	**3**	**36**	**D1.6.1, D1.6.2 and D1.6.3**
Project Title and Work Package		***Assimilation of time-averaged observations with application to detection and attribution of climate change*. (WP1)**			

Objectives	***Supervisor: Juan Ruiz (CONICET-IFAECI) and Alexis Hannart (CONICET-IFAECI)*** ***Co-Supervisor: Alberto Carrassi (NERSC) and Marc Bocquet (ENPC)*** ***Phase 1: Evaluation of methods for assimilating time-averaged observations (months 1-12 of the PhD thesis)*** We will tackle the problem of assimilating observations that are time-averaged over a time window which is long respective to the fast-atmospheric timescale of a coupled climate model (i.e. year to decade). This problem can be viewed as the most critical issue in order to unlock the use of DA for D&A. We will start by implementing within the VC13 and L96 models the relatively few existing methods developed for this purpose [91], and adapt them to D&A by deriving the associated likelihood. ***Phase 2: Design of methods for assimilating time-averaged observations (months 13-24 of the PhD thesis)*** We will design theoretical improvements attempting to address the most obvious weaknesses identified in Phase 1. For this purpose, we will revisit the EnKF formulation which is underpinning all the existing methods and release some fundamental assumptions which are inherent to the latter and may be considered too restrictive, in an attempt to obtain a more general, improved class of estimators for the update equations. We will then assess the potential benefit of the resulting improved DA method. ***Phase 3: Application to Detection and Attribution (months 25-33 of the PhD thesis)*** The most relevant time-averaged DA method resulting from Phase 1 and 2 will be implemented and tested by using an ad-hoc D&A testbed consisting of a double factual-counterfactual assimilation into a forced version of the coupled climate-model of VDDG [102], using a twin experiment set-up. The results obtained will be analysed and compared with those obtained from conventional D&A methods (i.e. optimal fingerprinting) applied to the above experimental set-up. ***Phase 4: PhD Dissertation writing (months 33-36 of the PhD thesis)***
Expected Results	**Method for assimilating time-averaged observations to attribute climate changes**
Planned secondments	**1. Secondment Host**: RMI (Stéphane Vannitsem) months 6-8 of the PhD thesis **Purpose**: EnKF methods to the nonlinear coupled model from [102]. **2. Secondment Host**: BSC (Francisco Doblas-Reyes) months 22-26 of the PhD thesis **Purpose**: Interaction with the team running the global climate model in order to precisely assess the benefits and requirements of a potential implementation of the time-averaged DA method in an ESM model. **3. Secondment Host**: EQUINOR (Remus Hanea) months 26-27 of the PhD thesis **Purpose**: Learning about the real-user requirement for energy management and exploitation of climate prediction.

Fellow	**Host institution**	**PhD enrolment**	**Start date**	**Duration**	**Deliverables**
ESR 7	**NERSC**	**(University of Bergen)**	**1**	**36**	**D2.1.1, D2.1.2 and D2.1.3**
Project Title and Work Package		**Multi methods CDA (WP2)**			

Objectives	***Supervisor: Laurent Bertino and Alberto Carrassi (NERSC)*** ***Co-Supervisor: Francisco Doblas-Reyes (BSC)*** ***Phase 1: Implementation and set up of an idealized test case (months 1-12 of PhD)*** Set up a 1-dimensional idealized coupled model that justifies the exploration of multi-method coupled DA: a toy model in Lagrangian coordinates (inelastic shocks of pinballs, as an analogy of sea ice floes) is coupled to a fixed-grid model (a static ocean as a heat reservoir, which exchanges are modulated by the opening and closing of sea ice leads). Testing the numerical stability and the dynamical properties of the idealized system. ***Phase 2: Testing of multi-methods coupled DA, their probabilistic consistency. (months 13-24 of the PhD)*** The DA methods EnKF, nudging and EWPF are implemented in the "sea ice" component and the EnKF is applied to the "ocean" of the system developed in Phase 1. All combinations are tested with variable ensemble sizes and assimilation window lengths. Various options are also tested for the communication between its "sea ice" and "ocean" compartments: passing the mean state or the most likely member, bootstrapping. The performances are evaluated both in terms of accuracy and consistency of the coupled solution: statistical properties of the fields exchanged (smoothness, temporal variability) and preservation of equilibrium properties. ***Phase 3: Synthesis of best practices for multi-method assimilation (months 25 – 36 of the PhD)*** Practical aspects of the assimilation are tested: localization, interpolation of the adaptive grid to a fixed grid. A synthesis paper is written targeted to users in climate modeling. If the neXtSIM model is coupled to the TOPAZ system at the beginning of Phase 3, a realistic coupled ice-ocean application in the Arctic Ocean will be tested in collaboration with the TOPAZ development team at NERSC.
Expected Results	**Improved understanding of the probabilistic content of multi-method CDA methods and best practices for their applications in coupled climate forecasting models.**
Planned secondments	**1. Secondment Host**: BSC (Francisco Doblas-Reyes) months 6-8 of the PhD. **Purpose**: Improved design of an idealized system analogous to an ice-ocean system. **2. Secondment Host**: CERFACS (Sophie Ricci) months 21-23 of the PhD **Purpose**: Better understanding of the design of a coupling software. Initiation of Phase 3. **3. Secondment Host**: BKK (Ina K. Kindem) month 28 of the PhD **Purpose**: Understand requirements of end user in real framework.

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR 8	**UiB**	**(University of Bergen)**	**1**	**36**	**D2.2.1, D2.2.2 and D2.2.3**
Project Title and Work Package	**Strongly coupled DA for seasonal-to-decadal prediction (WP2)**				

Objectives	***Supervisor: Noel Keenlyside (UiB) and Francois Counillon (UiB)*** ***Co-Supervisor: Stephane Vannitsem (RMI) and Ina K. Kindem (BKK)*** ***Phase 1: Implementation of the leading averaged coupled covariance in NorCPM (months 1-12 of the PhD thesis)*** During the first 6 months, the student will get familiar with the EnKF, first with toy models from the enkf-matlab educational toolbox and within NorCPM. Twin experiments (with synthetic observation) will be used to test leading averaged coupled covariance for strongly coupled DA between the ocean and the atmosphere. The observation network will mimic todays observation network of ocean and atmosphere. ***Phase 2: Exploring improved coupled covariance and variational framework (months 13-27 of the PhD thesis)*** In phase 1, a strong assumption is made in the expression of the coupled covariance between the ocean and the atmosphere. The student will visit RMI to explore how this assumption can be relaxed, taking advantage of the progress of ESR2. The advantages of using a variational framework with the IEnKS for handling the highly chaotic behaviour of the atmosphere would be also evaluated during a visit at ENPC; strengthening the link with ESR3. ***Phase 3: Demonstration of strongly coupled DA in real framework (months 28-36 of the PhD thesis)*** The student will pay regular visits to BKK over a period of 4 months in order to fully understand the requirement of the end-user and set up a real scenario to assess the skill of NorCPM for temperature and precipitation in the west coast of Norway. The system will be validated in hindcast mode and depending of the skill obtained, a prediction will be attempted and delivered to the end-user.
Expected Results	**Consistent initialization of the Earth system for enhanced seasonal-to-decadal prediction skills**
Planned secondments	**1. Secondment Host**: RMI (Stephane Vannitsem) months 13-14 of the PhD thesis **Purpose:** Exploring the formulation of coupled covariance in low-order coupled ocean-atmosphere models. **2. Secondment Host**: ENPC (Marc Bocquet) months 15-16 of the PhD thesis **Purpose**: Investigate the benefit of the IEnKS for couple assimilation between atmosphere and ocean **3. Secondment Host**: BKK (Ina K. Kindem) months 28 - 31 of the PhD thesis **Purpose**: Setting up of a real framework to test NorCPM with strongly couple assimilation

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR 9	**BSC**	**(Universitat Autònoma de Barcelona)**	**3**	**36**	**D2.3.1, D2.3.2 and D2.3.3**
Project Title and Work Package	**Toward reduced surface biases in EC-Earth 3 climate forecast system through parameter calibration based on the Ensemble Kalman Filter (WP2)**				

Objectives	***Supervisors: Virginie Guemas (BSC)*** ***Co-Supervisor: François Counillon (UiB)*** ***Phase 1: Identification of biases in EC-Earth and their relation to parameters (months 1-12 of the PhD thesis)*** Several observational datasets and metrics will be exploited to identify robustly the surface biases of the EC-Earth model in an ensemble of historical simulations and their development in a set of retrospective decadal climate predictions covering the satellite period. A list of 3-4 parameters susceptible to affect the surface biases will be identified by doing sensitivity tests. A stay at INRIA is planned during this period to ensure a deep knowledge of DA and prepare phase 2. ***Phase 2: Implementation of a global parameter estimation DA method using the ensemble Kalman filter (months 13-34 of the PhD thesis)*** The PhD student will spend months 13-14 at NERSC where the EnKF is used for *state* and *parameter* estimation, and get the training to understand how the EnKF is implemented in large scale climate models. The aim is to return to BSC's premises with a modified version of the EnKF that allows parameter estimation. From there, two steps will be undertaken at BSC: **a. Twin experiments (months 13-18)** An integration of the EC-Earth model using the default values for the 3-4 parameters identified in Phase 1 to obtain a reference considered as the "truth". The ESR will attempt to estimate one of the parameters only, using the modified-EnKF version developed. The focus will be put on specific regions where large model biases were identified (North Atlantic, Tropical Pacific, Southern Ocean, depending on the outcome from Phase 1). He/she will then attempt to estimate more parameters simultaneously. **b. Realistic experiments (months 19-34)** The ESR will apply the method to realistic cases, estimating one, and then several parameters using real observations. The ESR will assess whether the parameter values returned by the filter are more appropriate than the original, default values in two steps. First, he/she will run the model with these new values and assess the performance of this new simulation against observations. Second, he/she will investigate how model biases are affected by the new choice of parameters for another time period and discuss the results. A stay at FutureWater is planned during this period to estimate the potential outcome for water management. ***Phase 3: PhD Dissertation writing (months 34-36 of the PhD thesis)***
Expected Results	**Original and innovative methods/Strategies to efficiently reduce surface biases in coupled general circulation models**
Planned secondments	**1. Secondment Host**: INRIA (Arthur Vidard) months 6 - 8 of the PhD thesis **Purpose**: Training on the theory of DA **2. Secondment Host**: UiB (Francois Counillon) months 13 - 15 of the PhD thesis **Purpose**: Training on the Ensemble Kalman Filter **3. Secondment Host**: FutureWater (Johannes Hunink) months 25 - 27 of the PhD thesis **Purpose**: Assessment of the benefits of improved parameter estimation on the forecast quality for water management

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR 10	**BSC**	**(Universitat de Barcelona)**	**3**	**36**	**D2.4.1 and D2.4.2**

Project Title and Work Package	**Impact of a balanced initialization of dynamical climate forecasts on forecast quality (WP2)**
Objectives	***Supervisor: Francisco Doblas-Reyes (BSC)*** ***Co-Supervisor: Noel Keenlyside (UiB)*** The objective of this ESR consists in exploring the links between the reductions of the drift of dynamical climate forecasts, in particular in sub-seasonal-to-seasonal (S2S) predictions. The EC-Earth3 global model will be used for the exercise. ***Phase 1: Drift and forecast quality in the standard initialization approaches used in EC-Earth3 (months 1-12 of the PhD thesis)*** Full-field and anomaly initialization have been explored in EC-Earth to perform climate predictions. The drift of these predictions will be estimated for a range of variables in the atmosphere, land surface, sea ice and ocean components. The forecast quality, including measures of reliability and accuracy, will be estimated as well as the characteristics of the drift. A stay is planned at UiB to compare the behaviors of EC-Earth3 and NorCPM models. ***Phase 2: Impact of the drift reduction using EnKF of sea-ice observations on the forecast quality (months 13-34 of the PhD thesis)*** An initialization methodology is being implemented in EC-Earth that includes an EnKF of sea-ice observations and a nudging towards reanalyses in the atmosphere and the ocean. The DA phase provides ensembles of initial conditions that can be used to perform climate predictions. This phase will begin by a stay at NERSC to ensure sufficient training on the EnKF to conduct the subsequent two stages: **a. Experimental set up for the generation of the initial conditions and the climate forecasts (months 13-18)** The standard set of coefficients will be used in a reference DA experiment to provide initial conditions and generate subsequent reference predictions. The affordable set up, in particular in terms of ensemble size, forecast length and period of study needs to be assessed during this stage. Given the interest in S2S prediction, special attention will be paid to how the Madden Julian Oscillation, El Niño-Southern Oscillation and the Arctic sea ice are predicted at those time scales. **b. Sensitivity tests to the coefficients to optimize the forecast quality (months 19-29)** The experiment set up of stage a will be repeated as many times as both computing resources and time allow to investigate the sensitivity of the forecast quality (both reliability and accuracy) to changes in the DA coefficient that reduce the drift in the forecasts. The stay at FutureWater is planned during this stage to assess the benefits from the forecast quality improvement on renewable energy and water resource management sectors respectively. ***Phase 3: PhD dissertation writing (months 30-36 of the PhD thesis)***
Expected Results	**Illustration of the links between the drift and the forecast quality in S2S climate predictions** **Recommendations for operational climate institutions on the balanced initialization of climate forecasts**
Planned secondments	**1. Secondment Host**: UiB (Noel Keenlyside) months 6-8 of the PhD thesis **Purpose**: Training on the relationship between drift and forecast quality **2. Secondment Host**: NERSC (Laurent Bertino) months 13 - 15 of the PhD thesis **Purpose**: Training on DA, the Ensemble Kalman Filter and its application in global models **3. Secondment Host**: FutureWater (Johannes Hunink) months 25-27 of the PhD thesis

	Purpose: Assessment of the benefits of improved initial conditions and forecast quality for water management

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR 11	**CERFACS**	**(Université Paul Sabatier)**	**3**	**36**	**D2.5.1, D2.5.2, D2.5.3 and D2.5.4**

Project Title and Work Package	**Ensemble DA for coupled sediment-hydrodynamics modelling in estuaries (WP2)**
Objectives	***Supervisor: Sophie Ricci (CERFACS)*** ***Co-Supervisor: Nicole Goutal (EDF)*** The objective of the project is to demonstrate the benefits of DA for modelling the hydrodynamics of estuarine areas such as the Gironde estuary. On the Gironde estuary, a TELEMAC 2D model (developed by EDF-CEREMA) is used for real-time operation of the Blayais nuclear power plant that is cooled by the estuary waters. Over this area the bathymetry has a temporal variability induced by the presence of a mud plug resulting from the merging of fluvial and oceanic waters. ***Phase 1: Implement the DA (DA) method for the hydrodynamics model TELEMAC2D***. The scope is to correct both the model state and the model parameters, especially the bathymetry input field. An ensemble-based approach will be favoured (Ensemble Kalman Filter) in order to partially take into account the nonlinearities in the relationship that maps the model parameters onto the observation space. Particular care will be addressed to the description of spatial and multivariate covariances within the ensemble, and an hybrid En-Var approach will be tested if needed. A re-analysis study will be carried out over several decades with in-situ observation and will improve knowledge on the estuarine dynamics. ***Phase 2: Extending to the coupled hydrodynamics-sediment model SISYPHE-TELEMAC2D.*** Assimilation of water level data will first constrain the hydrodynamics model, then the coupled model. This work will first be carried out in the framework of an Observing System Experiments using synthetic data with arbitrary spatio-temporal distribution. The benefits from assimilating real in-situ data will finally be shown. ***Phase 3: PhD Dissertation writing (months 33-36 of the PhD thesis)***
Expected Results	**Method for assimilating in-situ water level observations in 2D hydrodynamics model in order to correct bathymetry variability. Method to implement DA in a hydrodynamics-sediment estuary model.**
Planned secondments	**1. Secondment Host**: EDF (Nicole Goutal) months 2-4 of the PhD thesis **Purpose**: Training in hydraulic modeling with the TELEMAC-SISYHE model developed at EDF. **2. Secondment Host**: ENPC (Marc Bocquet) months 18 – 20 of the PhD thesis **Purpose**: Training in Stochastic and Deterministic EnKF **3. Secondment Host**: INRIA (Arthur Vidard) months 30 – 32 of the PhD thesis **Purpose**: Training in model coupling

Fellow	Host institution	PhD enrollment	Start date	Duration	Deliverables
ESR 12	**UU**	**(Utrecht University)**	**1**	**36**	**D2.6.1, D2.6.2 and D2.6.3**

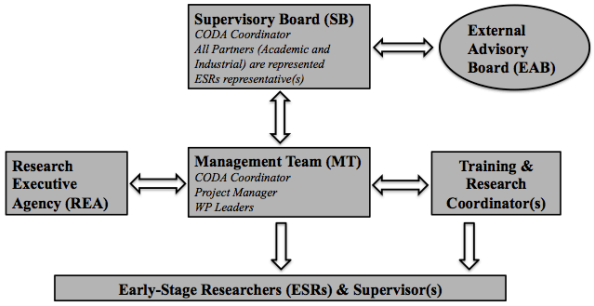
Project Title and Work Package	***Implementation of multiscale variational DA methods in OpenDA*. (WP2)**
Objectives	***Supervisor: Jason Frank (UU) and Alberto Carrassi (NERSC)*** ***Co-Supervisor: Alison Fowler and Amos Lawless (UR) and Nils van Velzen (VORtech)*** ***Phase 1: Development of the method of successive approximations for variational DA (months 1-12 of the PhD thesis)*** The weak-constrained 4DVar framework possesses a natural variational structure that makes it amenable to recent progress in efficient numerical implementation of optimal control problems. In [58] a modification of the method of successive approximations is proposed, related to the method of augmented Lagrangians, that ensures convergence of optimal control problems under very mild assumptions. The analysis in [58] is presented for the continuous case, but an analogous numerical implementation is straightforward in the setting of variational integrators [85]. The approach is also suitable to large scale problems, when the adjoint system is available. In Phase 1 we will adapt this approach in a weak-constrained 4DVar setting and implement it in OpenDA. ***Phase 2: Multirate variational discretizations for multiscale problems (months 13-24 of the PhD thesis)*** In Phase 2 we extend the above approach to multiscale systems by introducing multirate time integration, which can be naturally handled within the setting of variational integrators [57]. We apply the method of successive approximations to minimize the 4DVar objective function along the whole-time window, as opposed to optimizing the initial condition. This makes the scheme robust on time intervals that are long compared to the time scale of fast dynamics. We initially validate the method using the L96 and VDDG15 models. ***Phase 3: Validation on medium- and high-complexity models (months 25-33 of the PhD thesis)*** In Phase 3 we will port the medium/high complexity models from CODA (i.e. SCM, L95-GRS and SPEEDO) into OpenDA and validate them there. ***Phase 4: PhD Dissertation writing (months 33-36 of the PhD thesis)***
Expected Results	**Variational method for assimilating data for fast-slow dynamics and operational implementation in OpenDA**
Planned secondments	**1. Secondment Host**: VORtech (Nils van Velzen) 1 day/week during entire project **Purpose**: Gaining experience with OpenDA and implementing the 4DVar with the modified method of successive approximations and low/middle/high complexity models in OpenDA. **2. Secondment Host**: RU (Alison Fowler) months 7-9 of the PhD thesis **Purpose**: Interaction with scientists at University of Reading who have experience with weak-constrained 4DVar. **3. Secondment Host**: NERSC (Alberto Carrassi) months 19-21 of the PhD thesis **Purpose**: Collaboration with Alberto Carrassi on multiscale variational DA.

3.2 Appropriateness of the management structure and procedures

3.2.1 Network organisation and management structure

The management strategy aims at achieving the scientific and training program goals, and at fostering interactions among partners in the most flexible and efficient way. The **Management Team (MT),** comprises the Coordinator and a **professional Project Manager (PrM)** that will be hired for the entire duration of CODA; MT holds the responsibility for the execution of the project. Each year the MT will nominate the **Research and Training Coordinator** that will help executing the action planned by the Supervisory Board (SB, see Sect.3.2.2) and the MT to ensure their implementation. The PrM, for which the CODA members have agreed in sharing the cost, will assist the coordinator with financial, administrative, practical and logistical issues. The entire structure of the management is illustrated in Fig. 3. The coordinator will ensure regular contacts with the **Research Executive Agency**, coordinate the Consortium Agreement procedures, chair and organize progress meetings (PM), supervise the preparation of progress reports, and organize the audit certification. The PrM will prepare the agenda of the annual meetings, the SB meetings and the reporting, aid on the organization of the schools, workshops and advertising out of the network and monitor the financial. The Research and Training Coordinators will be in charge of the elaboration and implementation of the scientific training and secondment program, reviews ESR's project during the PMs and supervises their career development plan. They will also be contact points for the ESRs who have possible problems or conflicts.

Figure 3 – CODA management structure



3.2.2 Supervisory Board

The Supervisory Board (SB) will be composed by the Coordinator and representative(s) from all partners, both Academic and non-Academic, as well as from the ESR(s) fellow. The SB will coordinate the actions of the committees and approve the general plan of the project research and training directions as well as for allocation of costs. It will meet every year in conjunction with school(s)/PMs. The SB is the organ where important strategic decisions are taken. In particular in relation to recruitment (Sect. 3.2.3), risk management (Sect. 3.2.5), training coordination and project monitoring (Sect. 3.2.4). The SB will be supported by the **External Advisory Board (EAB)** composed of six members (see Table): four outstanding scientists in climate science, DA and applied mathematics, one expert from the private-industrial sector and one representing stakeholders from climate prediction services. The EAB will attend the CODA annual meetings, giving guidance, comments and suggestions on the research and training program.

CODA - External Advisory Board EAB		
Name	***Affiliation***	***Sector***
Prof M. Ghil	Ecole Normale Supérieure de Paris & University of California in Los Angeles	Academic
Prof C. K.R.T. Jones	University of North Carolina	Academic
Prof E. Kalnay	University of Maryland	Academic
Prof O. Talagrand	Ecole Normale Supérieure de Paris	Academic
Dr B. Å. Hjøllo	NAVTOR AS www.navtor.com	Industrial
Dr L. Iversen	Manager Expert for city development and response policies to climate change	Stakeholder from Climate Services

3.2.3 Recruitment Strategy

The recruitment process will be implemented within the first six months of the project so as to have enough time to ensure a good selection procedure. ESRs will be recruited for a period of 36 months. We will try to lure promising young scientists, those appearing to have potential to become leaders in the field. The vacancies will be advertised via:

- Personal follow-up and motivation of local Master students with a strong potential for research, with particular focus on female students in view of gender parity.
- In the scientific community, by postings at the partners and university web sites, announcements at international conferences and workshops, advertisements in newsletters.
- At the European level on websites: Euraxess.eu, Cordis, Nature jobs, jobs.ac.uk web portal, or mailing-list like met-jobs, math-jobs, ResearchGate.

The SB will oversee the recruitment process which will be based on three main principles: the ESR best working conditions, the transparency of recruitment and the ESR career development, in respect of the *EU Charter for Researchers* and of the *Code of Conduct for the Recruitment of Researchers* (*Brussels*, 11/03/2005). To the maximum extent the recruitment will take place in a single cohort so as to ease integration in the training courses and welcoming activities of the host Universities. The local supervisors will base the selection on network-wide guidelines to ensure transparency and equality of the process. They will take into accounts the Marie Curie mobility rules and research experience tailored to the vacancies. The SB will interview the candidates by videoconference or in person, so as to check the candidate skills, knowledge and relevant research experience, and the capacity and enthusiasm to be part of an ETN network. The impact of the participation to an ETN on their future career will also be carefully evaluated. Everyone is treated equally based on competence, however to mitigate the fact that only few women are found in the

DA scientific community, priority will be given to female candidature when equal to all other selection criteria.

3.2.4 Progress monitoring and evaluation of individual projects

The monitoring of the progress and of the management quality will be done mainly during the progress meetings and summer schools. The **Kick-Off meeting (KM)** will be organized at the coordinator premises within the first 3 months (see Tab.1.2b), it will last 2-3 days and will be opened to the whole network, including personnel from the associated partners. The first day will be dedicated to scientific talks and will provide the context and overview of the research objectives. In the next day, the training and the start-up of individual PhD projects, their liaisons with other participants, the involvement of the private sector partners and the synergy for secondments will be discussed. Bi-, or three-lateral, discussions between partners will be setup first, followed by a (plenary) network-wide session to approve the overall strategy. Three **Progress Meetings (PM)** will be organized every 12 months, starting between month 12 and 15, at which the ESRs will present their report on the status of research and discuss the collaboration between partners. PMs will be opened to the CODA ESRs and senior scientists only and will take place at the premises of 3 different partners (Tab.1.2b). The ESR will submit a PhD project plan during the first year (~10 pages), and status-reports (~5 pages) every 12 months before the PMs. During the PMs, the ESRs will present the scientific objectives within the network's overall goals, the methodology and the expected outcomes (with a timeline), and identify the necessary collaborations and stays at other institutes and private partners. The PhD project plans will be first evaluated and amended by the (co)-supervisor(s) and then circulate among all partners who will judge the overall consistency with the network broad objectives. The process will be overseen by the MT in light of the research and training objectives. WP leaders will organize phone/videoconferences with the ESRs, in-between the network-wide PM and schools. This will ensure that progress is monitored on a regular basis (typically every 3 months). For each of these phone/video meetings, one ESR will volunteer to report the conclusions in writing to the management team.

3.2.5 Risk Management

Table 3.2a. Summary of the potential risks and proposed measures for mitigation.

Risk #	Description of Risk	WP #	Proposed mitigation measures
R1	Difficulty in recruitment of PhD candidates	1, 2	Delay the start of the corresponding PhD project
R2	New DA method does not converge / perform well	1, 2	Find alternative DA method within the consortium
R3	Insufficient access to supercomputers	2	Revert to cheaper algorithms
R4	Coupled model system unstable / does not perform	2	Use alternative model within the consortium
R5	Secondment plan problematic for ESRs with family	1, 2	Find alternatives including reducing the length/number of secondments

R1: A collective announcement of 12 positions is more attractive than a single one. A centralized application allows the redirection of candidates from one partner to another. The recruitment campaign will be repeated if is not successful at once. This is possible since the project duration is 12 months longer than the PhD grants (36 months). ESRs starting later may miss the first workshop on dissemination and outreach. If the second round is still unsuccessful, the supervisor will decide whether a candidate with a lower level can be hired or if plans must be changed. Reasons for changes in the start-month are related to delay in the recruitment process considering also that the peak of request of PhD positions coincides with summers. This makes the project start-date in slight delay with respect to when most EU Master courses have completed and students start looking for PhD positions (see Sect. 3.2.3 for details of the recruitment process and counteractions).

R2/R4: The DA methods and climate models proposed are novel and the risks of algorithmic failure exist and can be severe for an ESR. These risks are mitigated by the expertise of the consortium, of the larger community developing the climate models used in CODA, and the frequency of contacts between the PIs within and outside CODA.

R3: WP2 depends on highly reliable access to state-of-art supercomputing facilities (including storage facilities). The risk of failure of such facilities or insufficient availability can be severe for an ESR but is mitigated by the access to different and diverse facilities within CODA and the applications to PrACE infrastructure. We did not consider any risk on the availability of data because climate data are widely available and quality checked independently of CODA.

R5: ESRs with family may have troubles in undertaking the full secondment plan. In this case the MT, in conjunction with the SB and the research and training coordinators, will propose alternative with shorter and/or less secondments. The alternative plan will be discussed with the supposed secondment hosts in order to foster the interaction with the ESR even tough she/he could not move there.

3.2.6 Intellectual Property Rights

The ESRs hosted in the partners' infrastructures will respect the local rules and will commit themselves with confidentiality and intellectual property clauses when needed. As mentioned in Sect. 2.3.2, the IPR of the ESRs will be protected by their respective work contract with the partner institute. The issue of IPR will be on the program of the two workshops *Entrepreneurship and Technology Transfer* and *Dissemination and Outreach*, the School 3 (*Post-CODA strategy*). The practices that protect both the ESRs and their institute will be then shared between the partners.

3.2.7 Gender Aspects

CODA already has five women in the network, three from the academic sector and two from the private one, making the female representation in CODA at 25%. Two female scientists are the leaders of the scientific WP2. The scientists in charge of half of the CODA private partners are females. The EAB includes two women: *Prof Eugenia Kalnay*, an outstanding female scientist, among the most important geoscientist in the last 3 decades, who has been also very much committed in her career to facilitate woman inclusion in the academic world, and *Lisbeth Iversen*, an international expert working on many projects related to city development and policies in response to climate change. Special emphasis will be put on the gender balance in the recruitment of ESRs within CODA (for candidates with the same qualifications, preference will be given to women). We are therefore confident that the gender parity in the project is likely to improve during its lifetime.

The gender dimension of CODA is that of climate research in general: women are more often exposed to adverse effects of climate change in poorer countries[1] and CODA will bring a contribution towards gender equality by providing more reliable climate projections to the broader public, with better described uncertainties.

3.2.8 Data management plan

Data and model codes will be stored at local HPC facilities and made publicly available. NERSC has experience as the data node for the *Norwegian Marine Data Centre* that provides data freely to the consortium of marine science institutions, and is in the process to have its own *DOI* as data provider. CODA will join the *Open Research Data Pilot* initiative to improve and maximise access to and re-use of data generated by projects.

3.3 Appropriateness of the infrastructure of the participating organisations

All hosts can satisfactorily fulfil this need since all infrastructures and research premises belong to the host and all have sufficient space and facilities to appropriately accommodate the ESRs. These include: office space, PCs, software, libraries and top equipment and facilities. The ESRs will also have access to state-of the-art national HPC:

- *Norway*: via NOTUR (notur.no) for CPU and NorStore (norstore.no) for data-storage available to UiB and NERSC.
- *Spain*: BSC hosts MareNostrum III, a Tier-0 PrACE system with 1.1Pflop/s capacity and other HPC resources, which will be used by the ESRs to performe climate simulations. BSC is responsible for granting and managing computing resources at national level. The ESRs will apply to these computing time grants if considered necessary.
- *France*: ESRs will have access to several of EDF supercomputers through the secured CEREA access at ENPC. Computational resources are also available at CERFACS.

CODA applications will be sent to other HPC facilities in EU via PrACE calls, for which experience of successful proposals is in the CODA network. CDA in ESMs requires large computing time, so ESRs will interact with VORtech to optimize their codes. BSC developed tools to quantify the time spent in all parts of a program, providing powerful computer performance metrics. CODA will make wiki pages available for the ESRs to share their know-how.

3.4 Competences, experience and complementarity of the participating organisations and their commitment to the programme

3.4.1 Consortium composition and exploitation of participating organisations' complementarities

CODA counts 10 beneficiaries and 5 partners from private sector in technological/economic areas related to climate science such as renewable energy production, water and agriculture management, software development, and in the science-to-patent transfer (BTO), and covers 6 European and 1 South American countries, favouring the mobility across all latitudes. CODA needs this diversity to gather top expertise in its four scientific disciplines (Sect. 1.4.1), and to target the multidisciplinary of its scientific problem. The bottom-up/top-down exchange of knowledge is across the WPs and the ESRs will have access to a diverse training in transferable skills (Sect. 1.2.1). To maximize the chances of post-CODA employment of the ESRs, CODA embeds applications in water, energy and software development, and link to the Copernicus services. The ESRs will learn on applications from small to global scales, and on entrepreneurship and technology transfer.

3.4.2 Commitment of beneficiaries and partner organisations to the programme

The beneficiaries are committed to provide the best available training, supervision and facilities. They will provide supervision time, access to external research projects (see the PIs CVs) and dissemination infrastructures. The non-academic partners are committed to co-supervise and host the ESRs, to participate to project meetings and to several training activities, some of them as leader or main contributors (see Tab.1.2b).

[1] See the related United Nations factsheet www.un.org/womenwatch/feature/climate_change/downloads/Women_and_Climate_Change_Factsheet.pdf

5. Participating Organisations

For **Beneficiaries**:

Beneficiary Legal Name	**Nansen Environmental and Remote Sensing Center (NERSC)**
General Description	NERSC is a non-profit research centre affiliated with the University of Bergen since 1986, with core expertise in remote sensing, data assimilation, ocean, sea ice and climate modelling. It is a project-based centre receiving funding from EU research programmes, the Research Council of Norway, the European Space Agency, the Nordic Council NordForsk, and the industry. Currently NERSC participates in 10 EU funded projects, and coordinates 2 of them. The staff counts 74 employees from 24 countries and includes scientific personnel, 5 Ph.D. candidates, and 10 administrative/technical positions. Within NERSC, the modelling and data assimilation department counts 10 scientists. It has initially introduced the EnKF (Evensen 1994) and kept applying that method in real-time ocean forecasting systems. NERSC is the main developer of the operational TOPAZ system, presently the Arctic Marine Forecasting Center in the European Copernicus Marine Environment Monitoring Services (http://marine.copernicus.eu) and it has more recently introduced the EnKF in the coupled NorCPM climate model.
Role and Commitment of key persons (including supervisors)	Dr. Alberto Carrassi (55%) will coordinate CODA, and co-lead WP3. He will supervise ESR 1 and 7 and co-supervise ESR 2, 3 and 6. Dr. Laurent Bertino (15%) will lead WP3, will supervise ESR 7 and co-supervise ESR 1 and 3.
Key Research Facilities, Infrastructure and Equipment	NERSC has access to Norwegian supercomputing facilities (computer time, storage, visualization software and technical support), including a 1.1Pflop/s Lenovo NeXtScale nx360.
Independent Research premises	NERSC facilities (servers, library, software licenses) are available for use in CODA. NERSC maintains an EnKF Python package (https://github.com/nansencenter/DAPPER).
Previous Involvement in Research and Training Programmes	Each year, about 3-4 PhD students complete their education at NERSC (since 1992). NERSC has organized summer schools on ocean and climate dynamics in China, India, and Norway and participated to about 7 similar schools with contributions on data assimilation. These includes recently: ▪ Les Houches 2015 one-week workshop, *Theoretical aspects of ensemble DA for the Earth system, in April 2015* (lgge.osug.fr/meom/pages-perso/cosme/LesHouches2015/index.php), which has welcomed about 50 students. ▪ *DA Crash Course* in 2017 + 2018 at NERSC with ~35 students ▪ *Winter School in Operational Oceanography at the Indian National Centre for Ocean Information Services,* Hyderabad, India, 10th – 14th October, 2016. www.incois.gov.in/ITCOocean/iocslv.jsp ▪ A. Carrassi, L. Bertino and G. Evensen teach data assimilation at the Dept. of Mathematics of the University of Bergen ▪ A. Carrassi teaches a short course on DA at EGU 2018 + 2019 with M. Bocquet (ENPC, beneficiary #3)
Current Involvement in Research and Training Programmes	NERSC leads the Nordic Center of Excellence EmblA (2014-2018), which aims at applying data assimilation across different environmental forecasting problems. EmblA funds 4 ESRs in 3 Nordic countries. 5 externally-funded ESRs are associated to EmblA. NERSC participated to the EU FP7 projects SANGOMA, GROOM, MyOcean, CarboChange, GeoCarbon, EUCISE, national projects EPOCASA, EVA with contributions on data assimilation. NERSC has taken the initiative to establish five independent Nansen Centers in Russia, P.R. China, India, South Africa and Bangladesh, where doctoral training in climate research is a central focus.
Relevant Publications and/or Research / Innovation Product	1. **Carrassi A**, Bocquet M, **Bertino L, Evensen G**. Data assimilation in the geosciences: An overview of methods, issues, and perspectives. *WIREs Clim Change*. 2018;e535. 2. **Carrassi, A.,** M. Bocquet, A. Hannart and M. Ghil (2017), Estimating model evidence using data assimilation. In Print on Q. Roy. Met. Soc. 143, 866-880 3. Raanes P., **A. Carrassi** and **L. Bertino** (2015), Extending the Square Root method to account for additive forecast noise in ensemble methods. Mon. Wea. Rev., 143, 3857–3873 4. Xie, J., **Bertino, L**., Counillon, F., Lisæter, K. A., & Sakov, P. (2017). Quality assessment of the TOPAZ4 reanalysis in the Arctic over the period 1991–2013. *Oc. Science*, 13(1), 123–144. 5. **Bertino L.** and M. M. Holland (2017): Coupled ice-ocean modeling and predictions. In *The Sea*: The Science of Ocean Prediction, special issue. *J. Marine Res*. 75(6), pp. 839-875.

Beneficiary Legal Name	**Institut Royal Météorologique de Belgique (RMI)**
General Description	The Institut Royal Météorologique de Belgique is a Scientific federal institution of Belgium, depending from the State Secretary in charge of Science Policy. The RMI is responsible for providing weather forecasts and early warnings to the public and the Belgian authorities. RMI delivers official certificates for assurance companies, climatological information to the disaster fund, researchers, universities, companies. To reach these goals and support the government policy, RMI has developed important research activities in atmospheric and climate sciences. About 200 persons are working at the RMI, with 1/3 of scientists. Strong links exist with many Universities of the different Communities of Belgium for both teaching and research activities.
Role and Commitment of key persons (including supervisors)	Dr Stéphane Vannitsem (20%), senior scientist: Supervisor ESR 2 and co-supervise ESR 8. Dr Lesley De Cruz, Researcher (10%): support in the supervision of ESRs involved in the training.
Key Research Facilities, Infrastructure and Equipment	The training activities will be mostly organised in the context of the "Meteorological and Climatological Research and Development" Department of the RMI, located in one of the main buildings of RMI. About 25 scientists and PhD students are currently working in the Department. The computational facilities of RMI consist of four Intel 64-bit compute servers, all of which have shared memory. A 192-core 1.66 GHz IA-64 machine with 580GB of RAM is used for research purposes as well as for running the operational forecasts for Belgium. A second server has 144 Xeon cores (2.67 GHz) and 396GB of RAM. Furthermore, there are two scientific application servers with 64 Xeon cores (2.70GHz and 2.27 GHz, respectively) with 132GB RAM each. A tender for a new supercomputer has been made, which will be used by RMI, ROB (Royal Observatory of Belgium) and BIRA-IASB (Belgian Institute for Space Aeronomy) (due 2015).
Independent Research premises	The beneficiary has own facilities, which are not shared with any other beneficiary.
Previous Involvement in Research and Training Programmes	The beneficiary has been involved in several research projects at national and international levels as coordinator, principal investigator or contributor. These are: **National project** - *Approche nouvelle de l'assimilation de données intégrant les propriétés dynamiques et statistiques de l'erreur de modélisation*. SPP project: MO/34/017. Coordinator : Prof. C. Rouvas-Nicolis. 2007-2010. Role of the Beneficiary: Responsible of the project from February 1st 2010. - *Dynamique de l'erreur de modélisation et correction des prévisions dans des modèles atmosphériques réalistes*. SPP project: MO/34/020. Coordinator : Dr S. Vannitsem, 2009-2010. - *Understanding and predicting Antarctic Sea Ice variability at the decadal timescale*. Projet SPP: SD/CA/04A. 2011-2014. Coordinator of RMI node : Dr. S. Vannitsem, 1 ETP/year over 4 years. - Projet SPP « Additional Researcher » : *Model error dynamics and forecast correction in realistic atmospheric models*. Coordinator : Dr S. Vannitsem, 2013. - Projet BRAIN-BE, *Improving the representation and prediction of climate processes through stochastic parameterization schemes* (STOCHCLIM), 2013-2017. Coordinator : Dr S. Vannitsem. **International project** E*xtreme events : causes and consequences*. European project E2C2, du programme FP6-2003-NEST-PATH. Coordinator of RMI node: Prof. C. Rouvas-Nicolis. 2005-2008. Site internet : http://e2c2.ipsl.jussieu.fr/. Role of the beneficiary: participant in the research activities. At the Université Libre de Bruxelles, different courses related to the core aspects of CODA are delivered: *Dynamical Meteorology*, in which basics of predictability and dynamics of instabilities within the atmosphere are provided (Dr Vannitsem).
Relevant Publications and/or Research / Innovation Product	1. Nicolis, C., R. Perdigao and **S. Vannitsem**. 2009. *Dynamics of prediction errors under the combined effect of initial condition and model errors*. J. Atmos. Sci., 66, 766-778. 2. Carrassi A and **S. Vannitsem**. 2011. *State and parameter estimation with extended Kalman Filter. An alternative formulation of the model error dynamics*. Q.J.Roy.Meteor.Soc., 137, 435-451. 3. **Vannitsem, S.** 2014. Stochastic modelling and predictability: Analysis of a low-order coupled ocean-atmosphere model. Phil Trans Roy Soc, A372, 20130282. 4. **Vannitsem, S.**, J. Demaeyer, L. De Cruz, M Ghil: Low-frequency variability and heat transport in a low-order nonlinear coupled ocean-atmosphere model. *Physica D*, 309, 71-85, 2015. 5. **Vannitsem, S.**, The role of the ocean mixed layer on the development of the North Atlantic Oscillation: A dynamical system's perspective, *Geophys. Res. Lett.*, 42, doi:10.1002/2015GL065974, 2015

Beneficiary Legal Name	**École nationale des ponts et chausses ENPC**
General Description	École nationale des ponts et chaussées (legal name), or École des Ponts ParisTech, abbreviated ENPC. École des Ponts ParisTech, created in 1747 under the name École Royale des Ponts et Chaussées, is a higher education establishment that trains engineers to a high level of scientific, technical and general competency (www.enpc.fr).
Role and Commitment of key persons (including supervisors)	**Professor Marc Bocquet** (20%): WP1 Leader, Supervisor ESR 3. Co-Supervision ESR 1, 5 and 6. Youngseob Kim research engineer (5%)
Key Research Facilities, Infrastructure and Equipment	ENPC (and in particular its laboratory CEREA) whose primary goals are the training of future engineers, as well as research has its own facility and infrastructure, perfectly suited to support the training of PhD students and the research of this project.
Independent Research premises	Research facilities are owned by ENPC and available for use in CODA.
Previous Involvement in Research and Training Programmes	Focusing on ENPC/CEREA laboratory: Les Houches 2012 summer school, a three-week international summer school on *Advanced DA for Geosciences* in Les Houches, France, May-June 2012, (http://houches2012.gforge.inria.fr) with 53 students.
Current Involvement in Research and Training Programmes	Focusing on ENPC/CEREA laboratory: Les Houches 2015 Data Assimilation Workshop Les Houches 2015 one-week workshop, *Theoretical aspects of ensemble DA for the Earth system, in April 2015* (http://lgge.osug.fr/meom/pages-perso/cosme/LesHouches2015/index.php), which has welcomed about 15 students, ANR DADA project, INSU/LEFE DAVE project, IPSL/AVES project Prof Bocquet teaches a graduate class on *Introduction to DA* in the Master of Sciences program *OACOS/WAPE* (ocean, atmosphere, climate) of the leading universities and institutes in Paris.
Relevant Publications and/or Research / Innovation Product	1. **Bocquet, M**., Pires, C. A. and L. Wu, 2010: *Beyond Gaussian statistical modeling in geophysical data assimilation*. Mon. Wea. Rev. **138**, 2997-3023. 2. **Bocquet, M**. and Sakov, P., 2014: *An iterative ensemble Kalman smoother*. Q. J. R. Meteorol. Soc. **140**, 1521-1535. 3. **Bocquet, M.** and Sakov, P., 2013*: Joint state and parameter estimation with an iterative ensemble Kalman smoother*, Nonlin. Processes Geophys. **20**, 803-818. 4. **Bocquet, M**., 2012: *Parameter field estimation for atmospheric dispersion: Application to the Chernobyl accident using 4D-Var*, Q. J. R. Meteorol. Soc. **138**, 664-681. 5. **Bocquet, M**., Elbern, H., Eskes, H., Hirtl, M., Žabkar, R., Carmichael, G. R., Flemming, J., Inness, A., Pagowski, M., Pérez Camaco, J. L., Saide, P. E., San Jose, R., Sofiev, M., Vira, J., Baklanov, A., Carnevale, C., Grell, G. and Seigneur, C. , 2014: *Data Assimilation in Atmospheric Chemistry Models: Current Status and Future Prospects for Coupled Chemistry Meteorology Models*, Atmos. Chem. Phys., 15, 5325--5358.

Beneficiary Legal Name	**Institut National de Recherche en Informatique et Automatique - Inria**
General Description	Established in 1967, INRIA is the only French public research body fully dedicated to computational sciences. It is a national operator in research in digital sciences and is a primary contact point for the French Government on digital matters. Under its founding decree as a public science and technology institution, jointly supervised by the French ministries for research and industry, Inria's missions are to produce outstanding research in the computing and mathematical fields of digital sciences and to ensure the impact of this research on the economy and society in particular. Inria covers the entire spectrum of research at the heart of these activity fields and works on digitally-related issues raised by other sciences and by actors in the economy and society at large. Beyond its structures, Inria's identity and strength are forged by its ability to develop a culture of scientific innovation, to stimulate creativity in digital research. Throughout its 8 research centres and its 180 project teams, Inria has a workforce of 3 400 scientists with an annual budget of 265 million euros, 29% of which coming from its own resources. In 2013, INRIA hosted a total of 1 219 doctorates and 258 postdoctorates.
Role and Commitment of key persons (including supervisors)	Arthur Vidard (20%): WP1 co-leader, Supervisor ESR 4. Laurent Debreu (20%), supervisor ESR 4
Key Research Facilities, Infrastructure and Equipment	Inria gives access to its PhD student to numerous lectures and to national-grade computing facilities whose primary goals are the training of future engineers, as well as research has its own facility and infrastructure, perfectly suited to support the training of PhD students and the research of this project.
Independent Research premises	In addition to national facilities, ESR4 will have access to our local cluster: BullX DLC supercomputer (Bull Newsca) made of 190 nodes, 2 processors per node, 8 cores per processor of Intel Sandy Bridge EP E5-2670, 8c/2.6 GHz/20M/8 GT/s (45.8 TFlops) as well as a few lesser clusters.
Previous Involvement in Research and Training Programmes	Inria (A. Vidard) was coordinator of the French-funded VODA project whose aim was to produce a variational data assimilation system for the ocean model NEMO
Current Involvement in Research and Training Programmes	Inria (A. Vidard) is a partner in FP7 project ERACLIM2 (2014-2016) which will produce a coupled (ocean-atmosphere-ice–land) reanalysis of the 20th century. Contribution to a yearly 1-week course *Introduction to DA* (http://lgge.osug.fr/meom/pages-perso/cosme/info_cours_AD2015.html) at the University of Grenoble Alpes.
Relevant Publications and/or Research / Innovation Product	1. Chabot V., M. Nodet, N. Papadakis and **A. Vidard** (2015). *Accounting for observation errors in image data assimilation*. Tellus A, **67**. doi:10.3402/tellusa.v67.23629 2. **Debreu L.**, E. Neveu, E. Simon, F.X. Le Dimet and A. Vidard (2015), Multigrid solvers and multigrid preconditioners for the solution of variational data assimilation problems. Q.J.R. Meteorol. Soc.. Accepted Author Manuscript. doi:10.1002/qj.2676 3. **Debreu L.**, E. Neveu, E. Simon, F.-X. Le Dimet. Multigrid algorithms and local mesh refinement methods in the context of variational data assimilation. *In: E. Blayo et al. (eds): Advanced Data Assimilation for Geosciences. Lecture notes of Les Houches summer school 2012*. Oxford University Press, 395-412, 2014. 4. Simon, E., **Debreu, L.** and Blayo, E., 2011. 4D variational data assimilation for locally nested models: Complementary theoretical aspects and application to a 2D shallow water model. *Int. J. Numer. Meth. Fluids*, 66: 135–161. doi: 10.1002/fld.2244 5. **Vidard A.**, M. Balmaseda and D. Anderson, 2009. *Assimilation of altimeter data in the ECMWF ocean analysis system 3*. Mon.Wea.Rev. 137 (4), pp.1393-1408

Beneficiary Legal Name	**University of Reading (UR)**
General Description	**UR** was established in 1892, and is now ranked in the top 1% of universities worldwide (QS University World Rankings 2015/16), with a world-class reputation for the quality of teaching, research and links to business. Research at UR is split into five major themes, of which one is Environment. The **School of Mathematical, Physical and Computational Sciences** includes the Department of Mathematics and Statistics and the Department of Meteorology. The Department of Meteorology is internationally renowned for its research in weather, climate and ocean sciences. It is home to over 200 research scientists, working in all aspects of weather, climate and Earth observation, including many scientists of the NERC National Centre for Earth Observation and of the NERC National Centre for Atmospheric Science. The Department of Mathematics and Statistics is home to a strong numerical analysis group and strong and productive links with industry are maintained. The **Data Assimilation Research Centre** (DARC), was founded in 2001, incorporates scientists throughout the School working in data assimilation theory and applications. DARC involves 9 academic staff and over 20 research staff and students working on all aspects of data assimilation, from developing theoretical ideas in simplified models, to practical applications using satellite data in large complex systems.
Role and Commitment of key persons (including supervisors)	Dr Amos Lawless (20%), supervisor ESR 5 Dr Alison Fowler (10%), supervisor ESR 5
Key Research Facilities, Infrastructure and Equipment	The School of Mathematical, Physical and Computational Sciences has a very large PhD programme with appropriate facilities for a project of this kind, including personal computing and a computing cluster.
Independent Research premises	Facilities are owned by UR and are available for use in CODA.
Previous Involvement in Research and Training Programmes	DARC has organised national courses on data assimilation in 2010, 2011, 21012, 2014. As part of this a suite of training tools for teaching data assimilation has been developed and made available on the Web. Support for use of these tools at the ESA summer school on Earth observation has been given since 2002.
Current Involvement in Research and Training Programmes	In 2016 DARC delivered courses linked to the ECMWF data assimilation course, with an introduction for the 2 days before and a computing "hands-on" course for 2 days after. A similar course will be offered in March 2017. A further week-long course in data assimilation is being planned for February 2017, aimed at early career researchers. Dr Lawless teaches an *Introductory course on DA* at UR and organizes UK-wide training courses in DA. In 2016 he gave lectures in DA at the ESA Earth Observation summer school.
Relevant Publications and/or Research / Innovation Product	1. **Fowler, A.M**. and **Lawless, A.S.** (2016), An idealized study of coupled atmosphere-ocean 4D-Var in the presence of model error, Monthly Weather Review, 144, 4007-4030. 2. Smith, P.J., **Fowler, A.M.** and **Lawless, A.S.** (2015), Exploring strategies for coupled 4D-Var data assimilation using an idealised atmosphere-ocean model. Tellus A, 67, 27025 3. **Fowler, A. M.** and van Leeuwen, P. J. (2013), Measures of observation impact in Data assimilation: the effect of a non-Gaussian measurement error, Tellus A, 65, 20035. 4. **Fowler, A. M.** and van Leeuwen, P. J. (2012), Measures of observation impact in non-Gaussian data assimilation, Tellus A, 64, 17192. 5. Haben, S., **Lawless, A.S.** and Nichols, N.K. (2011), Conditioning of incremental variational data assimilation, with application to the Met Office system. Tellus A, 63, 782-792.

Beneficiary Legal Name	Consejo Nacional de Investigaciones Científicas y Técnicas **(CONICET),** Instituto Franco-Argentino sobre Estudios de Clima y sus Impactos (**IFAECI**)
General Description	The National Scientific and Technical Research Council (CONICET) is a large public research organization founded in 1958. As the largest fundamental research organization in Argentina, CONICET is active in all disciplines, from mathematics to human sciences, as well as environmental and climate sciences. CONICET laboratories employ a large body of tenured researchers, engineers and support staff and are located throughout Argentina. CONICET also maintains a strong international collaboration through partnership agreements with more than thirty countries as well as several international associated laboratories and research centres in Argentina and in Europe.The French research organization CNRS (Centre National de la Recherche Scientifique) is one of the main international partners of CONICET. The IFAECI (French-Argentinean Institute for the Study of Climate and its Impacts) is one of the aforementioned international units. The IFAECI has been created in 2010 and renewed in 2014 as a joint laboratory between CONICET, its French counterpart CNRS and the UBA (University of Buenos Aires). Its mission is to develop a large and multidisciplinary array of scientific interactions between Argentina and France on climate related issues. The broad blend of research expertises present throughout the lab's three facilities provide an excellent synergetic framework to tackle its scientific agenda which is organized under nine main research themes: Climate variability and change in southern South America; Mathematical methods for studies of Weather and Climate; Weather and Climate Prediction; Regional climate modeling and sensitivity studies; Impact studies; Ground-based remote sensing of the atmosphere and its applications; South Atlantic Studies; Physical atmospheric processes at meso and synoptic scales; Physical processes in coastal areas and the Rio de la Plata Estuary.
Role and Commitment of key persons (including supervisors)	Dr. Juan Ruiz (20%) coordinates the field "Mathematical methods for studies of Weather and Climate" at IFAECI- Supervisor of ESR6. Dr. Alexis Hannart (20%) – Supervisor of ESR6.
Key Research Facilities, Infrastructure and Equipment	IFAECI research facility consists of a computing and data storage system based on a network of 33 servers, a cluster of 284 processors, 2 mass data storage systems with a capacity of 45 terabytes together with an internet service allowing high-speed transfers and connections. The whole system is protected by a central UPS system maintaining energy supply in the event of power outages. IFAECI has 90 personal workstations (PCs) connected in network with structured cabling. ESR6 will have access to IFAECI's facility, which is adapted to support the research planned in the context of this subproject.
Independent Research premises	The research facility is owned by the University of Buenos Aires and is attributed to IFAECI for its research and training activities, and as such will be available for CODA activities.
Previous Involvement in Research and Training Programmes	WWRP/THORPEX workshop on 4D-VAR and Ensemble Kalman Filters intercomparisons (2008), Intensive Course on Data Assimilation (2008, 2011)
Current Involvement in Research and Training Programmes	DADA project, leaded by Alexis Hannart and funded by ANR (2014-2017). Dr. Juan Ruiz teaches Numerical Weather Prediction course at UBA and leads a local project on radar data assimilation.
Relevant Publications and/or Research / Innovation Product	1. **Ruiz, J. J.** and M. Pulido, 2015: Parameter estimation using ensemble-based data assimilation in the presence of model error. Monthly Weather Review. http://dx.doi.org/10.1175/MWR-D-14-00017.1 2. **Ruiz, J. J.**, M. Pulido, and T. Miyoshi, 2013: Estimating model parameters with ensemble-based data assimilation: A review. J. Meteorol. Soc. Japan, 91, 79-99. doi:10.2151/jmsj.2013-201 3. **Hannart A**., J. Pearl, F. E. L. Otto, P. Naveau, M. Ghil (2015) *Counterfactual causal theory for the attribution of weather and climate-related events*, Bull. Am. Met. Soc., accepted. 4. **Hannart A**., A. Carrassi, M. Bocquet, M. Ghil, M. Pulido, **J. Ruiz**, P. Tandéo (2015) *DADA : Data Assimilation for the Detection and Attribution of weather and climate related events,* Clim. Change, submitted. 5. **Hannart A**., A. Ribes, P. Naveau (2014) *Optimal fingerprinting under multiple sources of uncertainty*, Geophys. Res. Lett., 41, 1261-1268, doi:10.1002/2013GL058653.

Beneficiary Legal Name	University of Bergen **UiB**
General Description	**UiB** is a young, modern university with about 14 000 students and 3,400 faculty and staff. Six faculties cover most of the traditional university disciplines, and include 60 different specialized departments, multi-disciplinary research centers and institutes. UiB is engaged in the European Union's Framework programmes for research and technological development and has been designated as a European Research Infrastructure and a Research Training Site in several scientific fields. Since 1997 more than 500 European researchers (professors, senior researchers, post docs and PhD candidates) have visited Bergen on EU grants, making Bergen one of the most international universities, setting out to attract both established and junior scientists to contribute to research teams and work in multidisciplinary research groups. UiB is currently involved in 104 FP7 projects, 39 of which it coordinates. The **Geophysical Institute** (GFI) at UiB is the primary academic marine research organisation in Norway with internationally acknowledged expertise in physical oceanography, climate research, and meteorology. The GFI, with a total of more than 40 active PhD students, provides sound and stimulating teaching environments for PhD students. The institute's research strategy rests upon use of own cutting edge measurement techniques developed in collaboration with technology partners in combination with theoretical studies and modelling in geophysics. GFI is partner in the **Bjerknes Centre for Climate Research**, and has a leading role in the development of the Norwegian Earth System Model (**NorESM**) and climate prediction system (**NorCPM**).
Role and Commitment of key persons (including supervisors)	Prof. Noel Keenlyside (15%) will supervise ESR 8 and co-supervise ESR 10. Dr. François Counillon (20%) will supervise ESR 8 and co-supervise ESR 9.
Key Research Facilities, Infrastructure and Equipment	GFI is the largest such institute in Norway (and likely in the Nordic countries) in climate research and has in its strategic plan to continue to lead in both observational, modeling and prediction oriented studies. The institute provides an excellent environment for the CODA in terms of a competent staff, and provides access to key research infrastructure. In particular, CODA will have access to the necessary super computing facilities and technical support available to UiB through the national NOTUR (www.notur.no) and NorStore (www.norstore.no) projects. Climate model experiments will be performed on the Hexagon (205 TFlop) and Vilje (467 Tflop) and the new Lenovo supercomputer in Tromsø (1.1 PFlops). GFI will provide assistance in application of NorESM and NorCPM, through numerous project staff.
Independent Research premises	Research facilities are owned by UiB and available for use in CODA.
Previous Involvement in Research and Training Programmes	GFI coordinated MARECLIM, joint Nordic Master Program in Marine Ecosystems and Climate (2007-2010); GFI coordinated NOMA Sudan, Development of Master programmes in physical and chemical oceanography at Red Sea University (2008-2013); GFI hosted several Marie Curie, ERASMUS, DAAD grant fellows GFI has coordinated a series of EU projects in the field of climate research, among others TRACTOR, PACLIVA, CYCLOPS, CARBOOCEAN, and been a partner in many others
Current Involvement in Research and Training Programmes	GFI is coordinating **(1)** the EU Marie Curie IRSES project SOCCLI, an international exchange scheme for early stage and experienced researchers between Europe and South Africa; **(2)** RESCLIM, The Norwegian Research School in Climate Dynamics which is a national training environment for PhD candidates in climate dynamics. GFI coordinates projects related to climate prediction that include development of the NorCPM: EU-PREFACE, NordForsk-GREENICE, and NFR-EPOCASA UiB gives graduate level courses in climate dynamics, and in particular Prof Keenlyside teaches *Physical Climatology* and *General Atmospheric Circulation* courses.
Relevant Publications and/or Research / Innovation Product	1. Shen, M.-L., **N. Keenlyside**, F. Selten, W. Wiegerinck, G. Duane, Dynamically combining climate models to "supermodel" the tropical Pacific, Geophys. Res. Lett., 43, 359–366 2. **Counillon, F**., I. Bethke, **N. Keenlyside**, M. Bentsen, L. Bertino, and F. Zheng, 2014: *Seasonal-decadal prediction with the EnKF and NorESM: a twin experiment*. Tellus A, 66. 3. **F. Counillon, N. Keenlyside**, I. Bethke, Y. Wang, S. Billeau, M.-L. Shen, et al. Flow dependent assimilation of sea surface temperature in isopycnal coordinates with the Norwegian Climate Prediction Model. Tellus A. 2016 4. Gulev, S.K., M. Latif, **N. Keenlyside**, W. Park, and K. P. Koltermann, 2013: *North Atlantic Ocean Control on Surface Heat Flux at Multidecadal Timescales*, Nature, 499, 464-467 5. Kimmritz M., **F. Counillon**, C.M. Bitz, F. Massonnet, I. Bethke & Y. Gao (2018) Optimising assimilation of sea ice concentration in an Earth system model with a multicategory sea ice model, Tellus A: Dynamic Meteorology and Oceanography, 70:1, 1435945,

Beneficiary Legal Name	**Barcelona Supercomputing Center – Centro Nacional de Supercomputación (BSC)**
General Description	The Barcelona Supercomputing Center - Centro Nacional de Supercomputación (BSC), created in 2005, has the mission to research, develop and manage information technology in order to facilitate scientific progress. At the BSC, more than 450 people from 40 different countries perform and facilitate research into Computer Sciences, Life Sciences, Earth Sciences and Computational Applications in Science and Engineering. The BSC is one of the four hosting members of the European PRACE Research Infrastructure as well as one of the first eight Spanish "Severo Ochoa Centre of Excellence" awarded by the Spanish Government. The Earth Sciences Department of the BSC (BSC-ES) was established with the objective of carrying out research in Earth system modelling. The BSC-ES conducts research on emissions, air quality, mineral dust and global and regional climate modelling and prediction. The department operates the high-resolution air quality forecasting system CALIOPE for Europe and Spain; it also maintains the BSC-DREAM8b model for daily operational mineral dust forecasts for the Euro-Mediterranean region, collaborates with the WMO and the Spanish Meteorological Agency (AEMET) to host the Regional Centre for Sand and Dust Warning System (SDS-WAS) covering Europe, Northern Africa and the Middle East and is an active member of the EC-Earth consortium, whose global climate model is widely used at ES-BSC at very high resolution for research and teaching purposes.
Role and Commitment of key persons (including supervisors)	**Prof. Francisco Doblas-Reyes** (15%) will supervise ESR 10, co-supervise ESR 4 and co-lead WP4. **Dr Virginie Guemas** (25%) will supervise ESR9 and lead WP2. **Dr Francois Massonnet** (10%) will supervise ESR9.
Key Research Facilities, Infrastructure and Equipment	The BSC hosts MareNostrum III, a Tier-0 PRACE system with 1.1 Pflop/s capacity as well as other High-Performance Computing (HPC) resources, which will be used by ESRs during their training in climate modelling to conduct their experiments. The BSC also coordinates the Spanish Supercomputing Network, which is the main instrument to grant competitive computing time to Spanish research institutions. The BSC is located within a university campus, and has special agreements to use the university residence and other university facilities (libraries, EDUROAM network, etc.). In fact, most of BSC's group leaders are also university professors, with broad experience in teaching and proved training skills. As a consequence, the BSC profits from an important educational environment.
Independent Research premises	The BSC is a consortium of recent creation. As a consequence, the research premises are all rented. This has never been a problem to provide the space required by all engineers and scientists who either work at or visit the Center. The BSC is located within a university campus, but keeping a complete administrative, financial and research independence. It is worth mentioning that the BSC will have its own building in 2016, which will host all BSC researchers under the same roof.
Previous Involvement in Research and Training Programmes	Over the years, the department has been active in numerous European Projects, including MEDSPA-91, INCO, EUREKA, EARLINET, DEISA, EARLINET-ASOS, ACTRIS, IS-ENES, FIELD_AC, SPECS, EUPORIAS, PREFACE, PRIMAVERA, EUCLEIA, IMPREX and CMUG2. The BSC has participated in 4 ITNs from FP7 and one from H2020, and is continuously involved in the organization of summer schools, workshops and other training events related to the use of high-performance computing in climate modeling and atmospheric sciences.
Current Involvement in Research and Training Programmes	The BSC has around 80 PhD students and 30 postdoctoral researchers. In addition, the BSC is currently involved in several Marie Curie Actions, namely NEMOH and COPA-GT FP7 ITNs, MDRAF, EEPPIBM and MatComPhys FP7 Individual Fellowships, and GEAGAM H2020 RISE.
Relevant Publications and/or Research / Innovation Product	1. **F. Massonnet**, H. Goosse, T. Fichefet, F. Counillon, 2014 *Calibration of sea ice dynamic parameters in an ocean-sea ice model using an ensemble Kalman filter*, Journal of Geophysical Research, **119**, doi:10.1002/2013JC009705. 2. **F. Massonnet,** P. Mathiot, T. Fichefet, H. Goosse, C. König Beatty, M. Vancoppenolle, T. Lavergne, 2013, *A model reconstruction of the Antarctic sea ice thickness and volume changes over 1980-2008 using data assimilation*, Ocean Modelling, **64** 67-75, doi:10.1016/j.ocemod.2013.01.003 3. **Guemas V,** Doblas-Reyes F J, Mogensen K, Keeley S. , Tang Y., 2014, Ensemble of sea ice initial conditions for interannual climate predictions. Climate Dynamics, in press, doi:10.1007/s00382-014-2095-7 4. **Doblas-Reyes, F.J.**, J. García-Serrano, F. Lienert, A. Pintó Biescas and L.R.L. Rodrigues (2013). *Seasonal climate predictability and forecasting: status and prospects*. WIREs Climate Change, doi:10.1002/WCC.217. 5. **Doblas-Reyes, F.J.**, I. Andreu-Burillo, Y. Chikamoto, J. García-Serrano, V. Guemas, M. Kimoto, T. Mochizuki, L.R.L. Rodrigues and G.J. van Oldenborgh (2013). *Initialized near-term regional climate change prediction*. Nature Communications, 4, 1715, doi:10.1038/ncomms2704.

Beneficiary Legal Name	Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique **CERFACS**
General Description	CERFACS is a research organization that aims to develop advanced methods for the numerical simulation and the algorithmic solution of large scientific and technological problems of interest for research as well as industry, and that requires access to the most powerful computers presently available. CERFACS hosts interdisciplinary teams, both for research and advanced training that are comprised of: physicists, applied mathematicians, numerical analysts, and software engineers. Approximately 150 people work at CERFACS, including more than 130 researchers and engineers, coming from 10 different countries. They work on specific projects in nine main research areas: parallel algorithms, code coupling, aerodynamics, gas turbines, combustion, climate, environmental impact and data assimilation. CERFACS is interested in "Global Change and Climate modelling". For more than 10 years, one of the axes of the team is the development and use of data assimilation techniques for geosciences, mostly in ocean and more recently in atmospheric chemistry and hydraulics. Studies on data assimilation for hydraulics and hydrology are currently on going at CERFACS in the framework of several thesis in collaboration with EDF, CNES and several academic labs.
Role and Commitment of key persons (including supervisors)	Sophie Ricci (30%) will supervise ESR 11 in the field of ensemble -based data assimilation for hydrodynamics. ESR will have access to CERFACS training courses (advanced data assimilation).
Key Research Facilities, Infrastructure and Equipment	Technical and scientific high performance supercomputing is becoming more and more important. Realistic combustion computation using complex geometries, chemical kinetics, aircrafts aerodynamics, climate variability ... for each of these CERFACS' research domains high performance computing is a prerequisite to stay competitive. Indoors CERFACS' computing servers deliver 75 Tflop/s with BULL, HP and IBM super computers along with external resources.
Independent Research premises	Research facilities are owned by CERFACS and available for use in CODA.
Previous Involvement in Research and Training Programmes	Data assimilation training program at CERFACS (3 day)
Current Involvement in Research and Training Programmes	There are DA training courses at CERFACS where CODA ESRs can enrol (http://cerfacs.fr/en/event/?category=formation). These courses will provide an overview of the theory and practical methods of DA and its application in geosciences. The lectures will also cover more specialized topics including covariance modelling and estimation, advanced minimization algorithms, preconditioning, and hybrid ensemble-variational methods.
Relevant Publications and/or Research / Innovation Product	1. M. Durand, C. J. Gleason, P. A. Garambois, D. Bjerklie, L. C. Smith, H. Roux, E. Rodriguez, P. D. Bates, T. M. Pavelsky, J. Monnier, X. Chen, G. Di Baldassarre, J.-M. Fiset, N. Flipo, R. P. M. Frasson, J. Fulton, N. Goutal, F. Hossain, E. Humphries, J. T. Minear, M. M. Mukolwe, J. C. Neal, **S. Ricci**, B. F. Sanders, G. Schumann, J. E. Schubert, and L. Vilmin. An intercomparison of remote sensing river discharge 1 estimation algorithms from measurements of river height, width, and slope. Water Resour. Res., 52, doi:10.1002/2015WR018434 2. J. Habert, **S. Ricci**, O. Thual, E. Le Pape, A. Piacentini, N. Goutal, M. Rochoux, G. Jonville, Reduction of the uncertainties in the water level-discharge relation of a 1D hydraulic model in the context of operational flood forecasting. Journal of Hydrology, HYDROL20865, DOI : 10.1016/j.jhydrol.2015.11.023, , vo. 532, p52--64, 2016. 3. O. Pannekoucke, **S. Ricci**, S.Barthelemy, R. Ménard, O. Thual. Parametric Kalman Filter for Chemical Transport Models, Tellus A, 31547. Accepted in Tellus, 2016 4. Rochoux, M. C., Emery, C., **Ricci, S**., Cuenot, B., and Trouvé, A.: Towards predictive data-driven simulations of wildfire spread – Part II: Ensemble Kalman Filter for the state estimation of a front-tracking simulator of wildfire spread, Nat. Hazards Earth Syst. Sci., 15, 1721-1739, doi:10.5194/nhess-15-1721-2015, 2015. 5. **Ricci S**., Piacentini A., Thual O., Pape E. L., Jonville G., 2011. *Correction of upstream flow and hydraulics state with a data assimilation in the context of flood forecasting*. Hydrol. Earth Syst. Sci 15, 1-21.

Beneficiary Legal Name	Utrecht University **UU**
General Description	Established in 1636, Utrecht University is one of the largest general research universities in Europe. It hosts more than 30,000 students, and 6700 employees and has an annual budget of 810 million euro. On the 2018 Shanghai Academic Ranking of World Universities, Utrecht University ranks first in the Netherlands, 14th in Europe and 51st in the world. Utrecht University is a member of the League of European Research Universities (LERU) consisting of 21 prestigious European Universities. UU's multidisciplinary research is organised in four strategic themes and seven focus areas including Sustainability, Applied Data Science and Foundation of Complex Systems. The Mathematical Instituut (MI) of the Faculy of Science of UU accommodates the researchers in Mathematical Sciences. Virtually every core area of mathematics is represented by members of the Institute and the MI provides a stimulating research environment with ample opportunity for interaction between different fields. The MI employs about 25 tenured staff, about 25 PhD students and 10 post doctoral researchers.
Role and Commitment of key persons (including supervisors)	Prof. Jason Frank (15%) will supervise ESR 12.
Key Research Facilities, Infrastructure and Equipment	Utrecht University and the Mathematical Institute provide an excellent environment for the CODA team. With its open discussion areas, coffee facilities and in-house library, the MI stimulates interaction and discussion between researchers in different fields. On the Utrecht campus, the MI works closely with the Institute for Marine and Atmospheric Research Utrecht (IMAU) and the Centre for Complex Systems Studies. The MI also engages regularly in exchanges with The Royal Netherlands Meteorological Institute KNMI in nearby De Bilt. The ESR will be fully integrated in the institute and will have their own work space, and have access to excellent ICT infrastructure, as well as to the outstanding library and on-line journals, also remotely.
Independent Research premises	Research facilities are owned by UU and available for use in CODA. The facilities are wholly independent from other beneficiaries and partner organisations in the consortium.
Previous Involvement in Research and Training Programmes	In the seventh framework programme the UU Faculty of Science participated in 14 Marie Curie Initial Training Networks, of which is coordinated 5 and participated in many other EU programmes. The Mathematical Institute hosted amongst others Marie Curie fellows Cavalcanti, Reynolds, Ros Camacho, Kool and Caspers. and participated in a range of national and international research programmes including the National Research School Mathematical Research Institute (MRI) and ERC Starting Grant 'New Poetry'.
Current Involvement in Research and Training Programmes	In Horizon2020, the UU Faculty of Science participates in 17 Marie Curie Initial Training Networks, of which is coordinates 4, and participates in many other EU programmes. The Mathematical Institute participates in research and training programmes such as the NWO Mathematics for Planet Earth project "Vertical Mixing and Internal Wave Attractors", the National research school in mathematics (WONDER), National mathematics cluster Nonlinear Dynamics of Natural Systems (NDNS+).
Relevant Publications and/or Research / Innovation Product	1. J. Frank & S. Zhuk, A detectability criterion and data assimilation for non-linear differential equations, *Nonlinearity* **31** (2018) 5235. 2. B. M. de Leeuw, S. Dubinkina, J. Frank, A. Steyer, X. Tu & E.S. van Vleck, "Projected Shadowing-based Data Assimilation", *SIAM Journal on Applied Dynamical Systems* **17**(2018) 2446–2477. 3. S. Zhuk, J. Frank, I. Herlin & R. Shorten, "State estimation for linear parabolic equations: minimax projection method", *SIAM J. Sci. Comput.*, **37** (2015) A1174–A1196. 4. J. Frank, & S. Zhuk, "Symplectic Möbius integrators for LQ optimal control problems", IEEE 53rd Annual Conference on Decision and Control (CDC), 15–17 Dec 2014, pp. 6377–6382. 5. J. Frank, B. E. Moore & S. Reich, "Linear PDEs and numerical methods that preserve a multi-symplectic conservation law", SIAM J. Sci. Comput., 28 (2006) 260–277.

For **partner organisations**

Partner Organisation Legal Name	**Equinor ASA**
General description	Oil and Energy company (Aka. Statoil ASA).
Key Persons and Expertise	Remus Hanea, expert in ensemble data assimilation.
Key Research Facilities, Infrastructure and Equipment	Equinor Research department co-supervises and hosts approximately 5-8 PhD and master students a year. Statoil provide proper equipment and facilities for the adequate hosting and guidance of the four students. Open-source data assimilation software: Ensemble Reservoir Tool (ERT - ert.nr.no/wiki/index.php/Main_Page)
Previous and Current Involvement in Research and Training Programmes	Data assimilation schools, bi-annual in Romania co-ordinated by Remus Hanea. 6 editions. Sibiu 2009, Iasi 2011, Cluj Napoca 2013, Brasov 2015, Sibiu 2017, Timisoara 2019, Romania (40 participants each). See http://www.data-assimilation.com
Relevant Publications and/or Research / Innovation Product	1. **Hanea, R.**, **G. Evensen**, L. Hustoft, T. Ek, A. Chitu and F. Wilschut: Reservoir Management under geological uncertainty using Fast Model Update. SPE-173305-MS, 2015 2. **Evensen G.**, Data Assimilation: The Ensemble Kalman Filter, 2nd ed., Springer, 2009a 3. Sebacher, B., **Hanea, R.G.** and Heemink, A.W. A probabilistic parametrization for geological uncertainty estimation using the ensemble Kalman filter (EnKF), Computational Geosciences, Volume 17, Issue 5, pp 813-832. (2013)

Partner Organisation Legal Name	**Électricité de France**
General description	Energy Production and Distribution.
Key Persons and Expertise	Dr Nicole Goutal, EDF-R&D, has a strong expertise in hydraulic modelling for the purpose of water resource management and operation of electricity generating facilities. During 10 years, she has been the main developer of an open channel finite element and finite-volume modelling suite. More recently, she was rewarded through the successful academic accreditation to supervise PhD students, for which uncertainty quantification in environmental sciences was one of the main subjects. Nicole leads research projects and cross-field engineering and environmental studies for which uncertainty quantification and data assimilation are critical.
Key Research Facilities, Infrastructure and Equipment	EDF-R&D (Laboratoire National d'Hydraulique et Environnement de Électricité de France Recherche et Développement). EDF-R&D develops and implements modelling tools (TELEMAC-MASCARET system) and analytical methods (numeric and experimental) in response to EDF requirements, and conducts research and development activities and studies mainly for the benefit of nuclear, hydraulic and, to a lesser extent, thermal power plants. Some of its activities are also focused on marine renewable energies
Previous and Current Involvement in Research and Training Programmes	CERFACS and EDF-R&D are participating in the so-called "Hydrassim" project in collaboration with the UPMC (Pierre and Marie Curie University), LHSV (Saint-Venant Laboratory for Hydraulics) and SCHAPI (Service Central d'Hydrométéorologie et d'Appui à la Prévision des Inondations). This project aims at promoting use of uncertainty quantification and data assimilation for modelling of rivers, lakes and estuaries. CERFACS and EDF-R&D participate in TOSCA project led by CNES and purpose as the use of satellite data for data assimilation. A thesis is in progress on this topic. EDF-R&D conducted in Stresa (Italy) in 2012 a workshop on quantifying uncertainties in hydraulic modeling.
Relevant Publications and/or Research / Innovation Product	1. Ricci S., A. Piacentini, A. Weaver A., **N. Goutal** and R. Ata. 2013: *A Variational Data Assimilation Algorithm to Estimate Salinity in the Berre Lagoon with Telemac3D*. Proceedings of the Telemac User Conference, Karlsruhe, (2013). 2. Bozzi S., G. Passoni, P. Bernardara, **N. Goutal,** and A. Arnaud. 2011. *Roughness and discharge uncertainty in 1D water level computations*. Environ. Model Assess DOI 10.1007/s10666-014-9430-6 3. Audusse, E., S. Boyaval, **N. Goutal** and M. Jodeau. 2014. *Numerical simulation of the dynamics of sedimentary river beds with stochastic exner equation*., Ph. Ung ESAIM Proceedings 2014

Partner Organisation Legal Name	**BKK Produksjon AS**
General description	Hydro Power Company
Key Persons and Expertise	Ina K. Thorstensen Kindem, Ph. D Meteorology. Areas of expertise: Seasonal predictability and teleconnections, weather forecasting for the energy sector, future climate hydrology. Investigating the potential for solar energy in Bergen.
Key Research Facilities, Infrastructure and Equipment	Each year students are offered summer jobs or write their master thesis by cooperating with BKK. With 1100 employees, BKK cover several disciplines, the biggest within hydro power production and transmission of electricity, but we also have employees working with trading, human resources, hydrology and meteorology.
Previous and Current Involvement in Research and Training Programmes	Participating in GREENICE (NordForsk, Top-level Research Initiative; Project n. 6184, Feb. 2014 – Dec. 2017) BKK goal: Improve forecasts of regional climate in the near future, hence improving hydro power planning. Participation in several research projects related to hydro power planning, production and environmental consequences.
Relevant Publications and/or Research / Innovation Product	1. Neu et al., (2013) IMILAST – a community effort to intercompare extratropical cyclone detection and tracking algorithms: assessing method-related uncertainties. Bull. Am. Met. Soc., 94, 529-547 2. Orsolini et al., (2011) On the potential impact of the stratosphere upon seasonal dynamical hindcasts of the North Atlantic Oscillation: A Pilot study. Climate Dynamics 36, 579-588 3. Orsolini et al., (2008) Influence of the Aleutian-Icelandic low seesaw and ENSO onto the Stratosphere in ensemble winter hindcasts. J. Met. Soc. Japan 86, 817-825

Partner Organisation Legal Name	**FutureWater**
General description	FutureWater is a research and consulting organization that works throughout the world to combine scientific research with practical solutions for water management. FutureWater works with partners at both global, national and local levels. Important topics are: water for food, irrigation, water excess, water shortage, climate change, and river basin management. FutureWater has offices in Wageningen (Netherlands) and in Cartagena (Spain).
Key Persons and Expertise	Dr. Peter Droogers is an expert on integrated water resources management at different spatial scales with emphasize on water for food issues, climate change, decision support systems, simulation 14ompanies in combination with data mining and remote sensing. Peter has about 20 years of experience working in The Netherlands and overseas He is Editor in Chief of the scientific journal Agricultural Water Management. Peter is external advisor to various projects and institutions including: World Bank, European Commission, FAO and National Science Foundations. Dr. Johannes Hunink is a hydrologist with more than 10 years of experience in decision support studies and tools for water resources management. Since 2012 he is Managing Director of the FutureWater base in Cartagena, Spain. Dr. Sergio Contreras is a dryland ecohydrologist, and drought and remote sensing expert with more than 10 years of career as researcher and consultant in water resources assessment, hydrological and water allocation modelling, and geomatic technologies. He has actively participated in in many international and Spanish research projects and contracts.
Key Research Facilities, Infrastructure and Equipment	ESRs will be offered all necessary equipment, desktop space, fast internet connections and all required facilities. FutureWater has tradition to host MsC and PhD student at its premises and offer high standard environment.
Previous and Current Involvement in Research and Training Programmes	ASSET (2014 – 2015) –Water Accounting using UN-SEEAW framework in the Segura basin, Spain. Pilot innovation project DG-Environment (European Commission), supporting Guidance document on the application of water balances for implementation of the Water Framework Directive IMPREX (2015 – 2019) – Research and leader of agriculture-drought work package in European Union-funded (H2020) project IMPREX (http://imprex.eu/) on developing climate services and improving predictions of hydrological extremes (budget 8M€, 23 partners). BRIGAID (2016 – 2020) – European research and innovation project BRIGAID (Horizon 2020 programme) on market transfer of technologies for water resources management. Using drones and satellite imagery for drought management TWIGA (2018 – 2022) – H2020 project on citizen science, water resources management and earth observation, focusing on applications in Africa
Relevant Publications and/or Research / Innovation Product	- InfoSequia (www.infosequia.eu) is a satellite-based Drought Monitoring and Impact Assessment Toolbox to support decision making during water scarcity situations. InfoSequia provides end-users with timely and reliable access to information on the drought state and recommendations on actions to be taken - The Spatial Processes in Hydrology (SPHY) model is a hydrological modelling tool suitable for a wide range of water resource management applications. The SPHY modelling package is available in the public domain and only uses open source software. SPHY is developed by FutureWater in cooperation with national and international clients and partners.

Partner Organisation Legal Name	**Bergen Teknologioverforing AS**
General description	BTO – Bergen Technology Transfer Office
Key Persons and Expertise	Technology Transfer from research to industry and business development within a broad range of areas: Medical technology, marine science, life science, energy and petroleum, materials/chemistry, information and communication technologies etc.
Key Research Facilities, Infrastructure and Equipment	Incubator for start-up companies
Previous and Current Involvement in Research and Training Programmes	BTO has a long merit list of commercialization of research projects and securing Intellectual Property Rights in terms of patents and licensing agreements.
Relevant Publications and/or Research / Innovation Product	- Technology transfer from research to industry, funding, intellectual property rights (IPR), legal advice - Clinical trials, icensing and establishment of new companies, consulting services, communication and marketing - Lectures, key note speakers and seminars, projects facilitating innovation, innovative products and processes in the public sector

Partner Organisation Legal Name	**VORtech bv**
General description	VORtech is a company of scientific software engineers. We work in projects for companies and institutes on their software for prediction and analysis. Expertise in data-assimilation, High Performance Computing and machine learning are the most important topics that make our customers choose us.
Key Persons and Expertise	Nils van Velzen, PhD in data-assimilation. Expertise: development and application of data-assimilation techniques in water management and environmental management.
Key Research Facilities, Infrastructure and Equipment	Most of our work is related to our clients' R&D and client employees typically spend time at VORtech to work on research questions. Besides, we maintain close ties to various universities in the Netherlands and particularly Delft University of Technology. Some of our employees hold part-time positions at Delft university.
Previous and Current Involvement in Research and Training Programmes	VORtech has been part of the LINC ITN (Learning about Interacting Networks in Climate, project ID 289447). We were involved in the EID project WAKEUPCALL (grant 643045). Through our collaboration with Delft University of Technology we were involved in the SANGOMA project (Stochastic Assimilation for the Next Generation Ocean Model Applications, grant 283580). VORtech is involved in the preparation of an EID proposal (MENTAL NET).
Relevant Publications and/or Research / Innovation Product	• VORtech is a lead developer of OpenDA, an open source software toolbox for data assimilation which is used by many researchers world wide (www.openda.org). • Velzen, N. & Altaf, M. & Verlaan, M. (2016). OpenDA-NEMO framework for ocean data assimilation. Ocean Dynamics. 66. 10.1007/s10236-016-0945-z. • Ridler, ME. & Hummel, S. & Velzen, N. & Falk, AK. & Madsen, H. (2013). Open source data assimilation framework for hydrological modeling.7844-. • Velzen, N. (2010). A Generic Software Framework for Data Assimilation and Model Calibration. 10.13140/2.1.4607.2008.

6. Ethics Issues

It is expected that the project participants will adopt and conform to all EU policies and changes in these policies. The research topics addressed by the proposed consortium do not raise any sensitive ethical issues related to human beings, human biological samples, personal data, genetic information or animals. At this stage, no potential ethical and/or safety aspects of the research topic [objectives, methodology and possible implications of the results] have been identified.

7. Letters of Commitment

Our date	RT representative	Administrative officer
7 January 2019	Remus Gabriel Hanea	Ingunn Brenne

Nansen Environmental and Remote Sensing Center
Thormøehlensgt 47
N-5006 Bergen

Attn. Alberto Carrassi

Letter of Intent

Project: Coupled Data Assimilation for Climate Prediction and Climate Change Attribution

Dear Sir,

Equinor Energy AS ("Equinor") hereby has the pleasure of informing Nansen Environmental and Remote Sensing Centre (the "Applicant") of its intention to support the project "Coupled Data Assimilation for Climate Prediction and Climate Change Attribution" ("the Project") by the following maximum in-kind contribution during a 3 months period, in the total time framework of the project (Sept 2019 – Sept 23).

Equinor's maximum contribution will be as follows:

- In-kind contribution under the form of internal manpower (supervision and hosting of 4 PhDs during 3 months in the total timeframe of the Project.)

.

Equinor's support and any future contract shall be based on the Project application entitled "CODA Coupled Data Assimilation for climate prediction and climate change attribution" (CODA_B1.pdf) dated 07/01/2019.

Such contract shall contain provisions that reflect the following principles/requirements:

- Equinor giving input to/having influence on the technical content of the research activities, including Equinor's consent required for changes to the scope of work.

Until such time as a formal contract is entered into Equinor reserves the right to cancel, at its discretion, this Letter of Intent by immediate notice. Similar cancellation right shall be included in all the Applicant subcontracts.

Any costs incurred in connection with the Project are at the Applicant's own risk and, in case of cancellation of this Letter of Intent, Equinor will not cover any such costs.

This Letter of Intent shall automatically be cancelled if the Applicant does not obtain support from/enters into contract with other industry or institutional partners as described in the Project application.

The Applicant shall not publish information concerning this Letter of Intent without Equinor's prior approval.

This Letter of Intent shall be governed by the laws of Norway, with Stavanger District Court as legal venue.

Please confirm the receipt of this Letter of Intent by e-mail to the attention of Ingunn Brenne – ibr@equinor.com within 24 (twenty-four) hours from receipt of this Letter of Intent.

Company	Office address:	Telephone:	Internet:
Equinor Energy AS	Arkitekt Ebbells veg 10	+47 559 95 000	www.equinor.com
Registered Number	7053 Ranheim	Telefax:	
NO 990 888 213	Norway	+47 559 96 600	

Our date	RT representative	Administrative officer
7 January 2019	Remus Gabriel Hanea	Ingunn Brenne

Yours faithfully,
for Equinor Energy AS

Digitally signed by
Ingunn Brenne
Date: 2019.01.07
12:46:04 +01'00'

Ingunn Brenne
PRINCIPAL CONSULTANT SUPPLY CHAIN MANAGEMENT

Electricité de France
Recherche & Développement
Département Laboratoire National
d'Hydraulique et Environnement

Site de Chatou
6, quai Watier
78400 - CHATOU

T +33 1 30 87 82 37

Your references :

Our references : HP-70/2018/12

Nicole.goutal@edf.fr

Subject : LETTER OF COMMITMENT

Chatou, November 7th, 2018

LETTER OF COMMITMENT

With this letter I, Pellet Laure, in my capacity as legal representative of Electricity of France – Research and Development (EDF R&D) hereby declares that EDF R&D commits itself to participate in and contribute as partner organisation to the Innovative Trainings Networks (ITN) "CODA", more precisely to host up 3 ESRs for periods of 1 – 3 months (max), to co-supervise their theses and to contribute to the training.

Done at Chatou the 7th of November 2018,

For the organisation,

The legal representative

Laure PELLET

Director Department National Laboratory
of Hydraulics and Environment,

Morgendagen er her | bkk.no

BKK

Alberto Carrassi
NERSC – Nansen Environmental and Remote Sensing Center
Thormøhlensgt 47
N-5006 Bergen – Norway
www.nersc.no

Your ref.:
Our ref.: 12120805 Date: 04.12.2018

Letter of Commitment CODA

This is a letter to confirm our participation as a partner in the proposal for a Marie Curie Innovative Training Network called "COupled DAta assimilation for climate prediction and climate change attribution" (CODA).

CODA offers a unique opportunity to improve forecast skill by combining highly non-linear coupled Earth System Models with new generations of Earth observations.

Reliable weather information on timescales from days to seasons to decades is of vital importance to ensure optimal use and planning of hydro power. Vestlandet is a core area for hydropower generation in Norway. BKK owns and pursues 28 hydropower stations along the west coast of Norway with a yearly mean production of 6,9 TWh.

Our contribution will be to participate in the recruitment and co-supervision of a PhD student (ESR 8). In addition ESR 7 and ESR 8 will spend a short period on secondment to BKK. We will also contribute in the organization of a school on climate prediction. The expected outcome for BKK will be to evaluate the benefits of using seasonal-to-decadal climate prediction in planning and also the provision of a real-time forecast.

Yours sincerely
BKK PRODUKSJON AS

Ina T. Kindem
Ina T. Kindem
PhD, Energy Meteorologist

BKK PRODUKSJON AS

Erik Spildo,
Head of Hydropower Production Department

FutureWater

A research and consulting organization that works throughout the world to combine scientific research with practical solutions for water management.

To whom it may concern

With this support letter, I, Johannes Hunink, as legal representative and Managing Director of FutureWater, declare that we are very much interested in participating in the Innovative Trainings Networks (ITN) project called “Coupled data assimilation for climate prediction and climate change attribution” (CODA).

We are an SME based in Spain and the Netherlands, providing research and consultancy on water resources management and climate change risk assessments. We offer climate services in different parts of the world and are eager to be involved in this project to contribute and guide the activities where possible.

We´d be happy to host 2 ESRs for periods of 1-3 months in our facilities, co-supervise them and contribute to their training and development. FutureWater recognizes the value of the CODA proposal and fully recommends its implementation.

Sincerely,

Dr. Johannes Hunink
Managing Director FutureWater

Date
November 11, 2018

Subject
Support letter CODA

Address
Calle San Diego 17, 4a
30202 Cartagena
SPAIN

Telephone
+34 968 209 834

E-mail
j.hunink@futurewater.es

Website
www.futurewater.eu

Nansen Environmental and Remote Sensing Center
Thormøhlensgate 47
5006 Bergen
Norway

Attn: Dr. Alberto Carrasi

Our ref.: Nils-Eivind Holmedal Your ref.: A. Carrassi *Bergen, 06. November 2018*

Letter of support - CODA

This letter confirms our participation in the proposal for a Marie Curie Innovative Training Network – "Coupled Data assimilation for climate prediction and climate change attribution" (CODA).

BTO's is planned to host an innovation workshop for PhD candidates where important issues such as intellectual property rights, patents and technology transfer will be discussed.

BTO is the Technology Transfer Office for the Bergen region. BTO's owners and partners, organize 4000 researchers and has an annual turnover of 5.000 MNOK (appr €500M).

Yours sincerely

DocuSigned by:
Anders Haugland
166C10BA8C7C450...
Anders Haugland
CEO

BTO AS
Thormøhlensgate 51
5006 Bergen, Norge
Org.nr.: 987 753 153
post@bergento.no
P (+47) 55 58 30 50
F (+47) 55 58 30 56
www.bergento.no

VORTECH

VORtech
Postbus 260
2600 AG Delft
tel. 015 - 285 01 25
info@vortech.nl

BIC: RABONL2U
IBAN: NL96RABO0138839956
KvK Haaglanden: 272.39.958

scientific
software
engineers

your reference

our reference
MR/U18.098

date
December 13, 2018

subject
LETTER OF COMMITMENT

LETTER OF COMMITMENT

With this letter I, Mark Roest, in my capacity as general manager and legal representative of VORtech, hereby declare that VORtech commits itself to participate in and contribute as partner organization to the Innovative Training Network (ITN) "CODA", more precisely to help select and host 1 ESR for a period of 3 months and to co-supervise his/her thesis.

In addition we can provide training on professional scientific software development to all ESRs if the ITN decides that this is indeed an important training activity. This would not only help the ESRs in any future career in industry but will also contribute to the quality and sustainability of any software that will be created in this ITN.

Delft, December 13th, 2018

Mark Roest
General Manager

References

[1] Anderson, J.L., and S.L. Anderson, 1999. *Mon. Wea. Rev.*, **127**, 2741-2758
[2] Anderson, D.L.T., et al., 2007. ECMWF Technical Memorandum 503.
[3] Anderson, J.L., 2001. *Mon. Wea. Rev.* **129**, 2884-2903
[4] Aksoy A., *et al.*, 2006. *Mon. Wea. Rev.* **134**, 2951–2970.
[5] Ballabrera-Poy, et al., 2009. *Tellus*, **61A**, 539-549
[6] Bell, M.J., *et al.*, 2004. *Q. J. R. Meteorol. Soc.*, **130**, 873-893.
[7] Benettin et al., 1980. *Meccanica*, 15, 9
[8] Bentsen, M., et al, 2012. *Geosci. Model Dev. Discuss.*, **5,** 2843–2931.
[9] Bocquet, M. and Sakov, P., 2013. *Nonlin. Processes Geophys.* **20**, 803-818
[10] Bocquet, M. and Sakov, P., 2014. *Q.J.R. Meteorol. Soc.,* **140**: 1521–1535.
[11] Bouillon, S. & Rampal, P., *Ocean Mod.* doi: 10.1016/j.ocemod.2015.04.005, 2015
[12] Brasseur, P. 2006. *Ocean Weather Forecasting*, 271-316
[13] Buehner M, and Co-authors, 2015. *Mon. Wea. Rev.*, **143**, 2532-2559
[14] Carrassi, A., et al., 2008. *Nonlin. Proc. Geophys*, **15**, 503-521
[15] Carrassi, A., *et al.*, 2008. *Q.J.R. Meteorol. Soc.*, **134**, 1297-1313
[16] Carrassi, A. and S. Vannitsem, 2010. *Mon. Wea. Rev.,* **138**, 3369-3386
[17] Carrassi, A. and S. Vannitsem, 2011. *Q. J. R . Meteorol. Soc.,* **137**, 435-451
[18] Carrassi, A. and S. Vannitsem, 2016. INDAM Springer Volume
[19] Carrassi et al., 2018. WIREs Climate Change, DOI: 10.1002/wcc.535
[20] Cardiali, C. et al. 2004. *Q.J.R. Meteorol.Soc.*, **130**, 2767-2786
[21] Cohn and Dee, 1988. *SIAM J. Numer. Anal.*, **25**(3), 586–617
[22] Counillon et al., 2014. *Tellus*, **66**, 21974
[23] Counillon F et al, 2016. *Tellus*
[24] Dalcher A. and E. Kalnay, 1987. *Tellus*, **39A**, 474-491
[25] Debreu L., et al, 2015. Q.J.Roy.Meteor.Soc., in Press
[26] Dee D., 2005. *Quart. J. Roy. Meteorol. Soc.*, **131**, 3323-3343
[27] Dee, 2013. "Coupled DA". Talk at the WMO Symp.on DA (http://das6.umd.edu/program/das6_program.html)
[28] Dharssi, I. et al., 2011. *Hydrol.Earth Syst.Sci.*, **15**, 2729-2746
[29] Dieci et al., 2011. J. of Comp. and Nonlin. Dyn., 6, 011003-1
[30] Dirren S. and G. J. Hakim, 2005. *Geophys. Res. Lett.*, **32**, L04804
[31] Evensen G., 1994. *J. Geophys. Res.*, 99(C5), 10143-10162
[32] Evensen, G., 2009. Springer Verlag (307pp)
[33] García-Serrano, J. and F.J. Doblas-Reyes, 2012. *Clim. Dyn.*, **39**, 2025-2040, doi:10.1007/s00382-012-1413-1
[34] Gauthier, P. and J.-N.Thepaut, 2001. *Mon.Wea.Rev.*, **129**, 2089-2102
[35] Ghil, M. and P. Malanotte-Rizzoli, 1991. *Adv. Geophys.*, **33**, 141–266.
[36] Ghil and Jiang, 1998. *Geophys. Res.*, 25, 171-174
[37] Goose et al., 2012 *Clim. Dyn.* 39, 2847-2866
[38] Gratton, S., et al. 2007. *SIAM Journal on Optimization, **18*(1)**, 106–132. doi:10.1137/050624935
[39] Haines, K. in ECMWF Annual Seminar Series 2011
[40] Hannart A., *et al.*, 2016. *Bull. Am. Met. Soc.*, **97**, 99-110.
[41] Hannart A., *et al.*, 2016. *Clim. Change*, **136**, 155-174.
[42] Harlim, J. and A.J. Majda, 2010. *Mon. Wea. Rev.*, **138**, 1050-1083
[43] Haussaire, J.-M. and Bocquet, M., 2016. Geosci. Model Dev. **8**, 393--412.
[44] Hazeleger W, et al. 2012. *Clim Dyn* DOI 10.1007/s00382-011-1228-5
[45] Hegerl, G.C., et al., 2007. Cambridge University Press, Cambridge, UK
[46] Hegerl, G., and F. Zwiers, 2011. Wiley Interdiscip. Rev. Clim. Change, 2, 570-591, doi:10.1002/wcc.121
[47] Hourdin F., et al., 2006. Clim Dyn (2006) 27:787–813. DOI 10.1007/s00382-006-0158-0
[48] Houtekamer, P.L., et al., 2005. Mon. Wea. Rev., 133, 604-620
[49] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 1535 pp.
[50] Jazwinski A.H. 1970. Academic Press, New York. (376pp)
[51] Kalman R., 1960. Trans. ASME, J. Basic Eng., 82, 35-45
[52] Kalnay, E., 2003. Cambridge University Press. Cambridge (341pp)
[53] Kleist, D.T. and K. Ide, 2015. *Mon.Wea.Rev.*, **143**, 433-451
[54] Lea, D.J., *et al.*, 2015. *Mon. Wea. Rev.*, **11**, 4678-4694
[55] Legras, B., and Vautard, R., 1996. ECMWF Seminar, UK, pp. 135-146, 1996.
[56] Laloyaux, P. et al., 2016. *Q.J.R.Meteorol.Soc.,* 142, 65-78
[57] Lew A, J.E. Marsden, M. Ortiz and M. West, *Arch. Rational Mech. Anal.* **167** (2003) 85—146.
[58] Li Q., L. Chen, C. Tai and Weinan , *J. Machine Learning Res.* **18** (2018) 1—29.
[59] Liu, C. et al., 2008, *Mon. Wea. Rev,* **136**, 3363-3373
[60] Lorenc, A.C. and T. Payne, 2007. Q. J. R. Meteorol. Soc., 133, 607-614
[61] Lorenc, A.C. et al., 2015. *Mon.Wea.Rev.*, **143**, 2012-2229
[62] Lorenz, E.N., 1963. J. Atmos. Sci., 20: 130-141
[63] Lorenz EN. 1996. ECMWF, Reading, pp. 1–18
[64] Lu F 2015 et al, *Mon Wea Rev* 143, 3823-3837.
[65] Magnusson, L., et al., 2013. *Clim. Dyn.*, **41**, 2393-2409.
[66] Massonnet F, et al., 2014 J. G. R. - Oceans; 119.
[67] Mauritsen, T.et al., 2012. *J. Adv. Model. Earth Syst.,* **4**, M00A01
[68] Meehl et al., 2014 *Eos*, 95, 9
[69] Mitchell, L. and A. Carrassi, 2015**.** *Q. J. Roy. Meteor. Soc.* **141**, 1417-1428
[70] Molteni, F. et al., 1993, *J. Clim.,* **6**, 777-795
[71] Neveu, É. (2011, March 31). *Application des méthodes multigrilles à l'assimilation variationnelle de données en géophysique*. (dir F.-X. Le Dimet & L. Debreu). Université de Grenoble.
[72] Nicolis. C., 1992. *Q. J. Roy. Meteor. Soc.*, **118**, 553-568.
[73] Nicolis, C., et al., 2009. *J. Atmos. Sci.*, **66**, 766-778.
[74] Palatella, L., et al., 2013. JPhysA, 46, 254020
[75] Pena, M., and E. Kalnay, 2004. *Nonlin. Proc. Geophys.* **11**, 319–327
[76] Penny S. and T. Hamill, 2017. *BAMS* doi: 101175/BAMS-D-17-0036.1
[77] Pires, C. et al., 1996. *Tellus A* **48**, 96-121

[78] Rabier F., et al., 2000. *Q.J.R. Meteorol. Soc.*, **126**, 1143-1170
[79] Rawlins, F. et al., 2007. *Q.J.R.Meteorol.Soc.*, **133**, 347-362
[80] Ricci, S., et al., 2014. 11th International Conference on Hydroinformatics, HIC 2014, New York City, USA
[81] Ruiz, J., *et al.*, 2013. *JMSJ*, **91**(2): 79-99
[82] Saha, S. et al., 2010. *Bull Amer Met Soc* **91**,1015- 1057.
[83] Sakov P. et al., 2012, *Ocean Sci.*, **8**, 633-656, 2012
[84] Sakov, P. et al., 2012. *Mon. Wea. Rev.* **140**, 1988-2004.
[85] Sanz-Serna JM., *SIAM Review* **58** (2016) 3—33.
[86] Sasaki Y., 1970. *Mon. Wea. Rev.*, **98**, 875-883
[87] Severijns C. A. and W. Hazeleger, 2010 G*eosci. Model Dev.,* **3**, 105–122.
[88] Sluka, T.C. et al., 2016. Geophy. Res. Letter. **43**, 752-759
[89] Smith, P.J. et al., 2015, *Tellus A,* **67**, 27025.
[90] Snyder, C., et al., 2008. *Mon. Wea. Rev.*, **136**, 4629-4640
[91] Stott P. A., et al., 2013. G. R. Asrar and J. W. Hurrell (Eds.), Springer, in press.
[92] Sugiura et al., 2008. *J. Geophys. Res.*,**113**, C10017.
[93] Sun et al., 2014. *Bull.Amer.Meteor.Soc.*, **95**, 409-426
[94] Talagrand O., and P. Courtier, 1987. *Q.J.R.Meteorol.Soc.*, **113**, 1311-1328
[95] Tardif R., et al. 2014. *Clim. Dyn.*, **43**, 1631-1643
[96] Trémolet Y., 2006. *Q.J.R. Meteorol.Soc.*, **132**, 2483-2504
[97] Trevisan A, et al., 2010. *Q. J. R. Meteorol. Soc.* **136** 487–96
[98] Trevisan, A. and L. Palatella, 2011. *Nonlin. Proc. Geophys.* **18**, 243–250.
[99] Uboldi, F. and A. Trevisan, 2006 *Nonlin. Process. Geophys.* **16** 67–81
[100] Van Leeuwen, P.J., 2010. *Q.J.R. Meteorol.Soc.*, **136**, 1991-1999.
[101] Vannitsem, S., and Nicolis, C, 1997. *J. Atmos. Sci.*, **54**, 347-361.
[102] Vannitsem, S. et al., 2015 *Physica D*, 309, 71-85.
[103] Veersé, F., & Thépaut, J.-N. 1998. Q. J. Roy. Meteor. Soc., **124**, 1889–1908.
[104] Winiarek V., et al., 2011. *Atmos. Env.*, **45**, 2944-2955
[105] Yang, S.C., et al., 2009. *Mon. Wea. Rev.* **137**, 693-709
[106] Yano, J-I. et al., 2017. *BAMS* doi: 10.1175/BAMS-D-17-0125.1
[107] Zhang, S., et al., 2007. *Mon. Wea. Rev.,* **135**, 3541-3564
[108] Zhao, M., et al., 2014. *Clim. Dyn.*, **42**, 2565-2583. DOI: 10.1007/s00382-014-2081-0.
[109] Zupanski D. 1997. *Mon. Wea. Rev.,* **125**, 2274 – 2292.
[110] Zupanski D and M. Zupanski, 2006. *Mon. Wea. Rev.* **134**, 1337 – 1354

Digitally sealed by the European Commission
Date: 2019.01.16 18:41:42 CET
Reason: Acknowledgement of Receipt

This electronic receipt is a digitally signed version of the document submitted by your organisation. Both the content of the document and a set of metadata have been digitally sealed.

This digital signature mechanism, using a public-private key pair mechanism, uniquely binds this eReceipt to the modules of the Participant Portal of the European Commission, to the transaction for which it was generated and ensures its full integrity. Therefore a complete digitally signed trail of the transaction is available both for your organisation and for the issuer of the eReceipt.

Any attempt to modify the content will lead to a break of the integrity of the electronic signature, which can be verified at any time by clicking on the eReceipt validation symbol.

More info about eReceipts can be found in the FAQ page of the Participant Portal. (http://ec.europa.eu/research/participants/portal/page/faq)