

**APPLICATE: Advanced Prediction in Polar regions and beyond: Modelling, observing system design and Linkages associated with a Changing Arctic climate**



Technical Annex Sections 1-3 of Proposal for:

Horizon2020 Work Programme 2016-2017, Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research and the Bioeconomy

**Call:** Blue Growth – Demonstrating an ocean of opportunities

**Topic:** BG-10-2016: Impact of Arctic changes on the weather and climate of the Northern Hemisphere

**Proposal acronym:** APPLICATE

**Proposal title:** Advanced prediction in polar regions and beyond: Modelling, observing system design and Linkages associated with a changing Arctic climate

**Type of action:** Research and Innovation Action

**List of participants**

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## 1. Excellence

### 1.1 Objectives

The weather and climate of the Arctic have been changing rapidly in recent years and these profound transformations are projected to continue in the decades to come. These changes provide opportunities, such as the emergence of new, shorter shipping lanes between Europe and parts of East Asia; at the same time they expose society to major risks, such as environmental hazards associated with increased human activities in the Arctic. Climate change also poses major challenges for local communities: indigenous communities, for example, have reported a loss of weather predictive power since the 1990s (Krupnik and Jolly, 2002). This is likely associated with the fact that traditional knowledge is no longer sufficient for weather forecasting in a non-stationary climate. Furthermore, the realization that anthropogenic climate change is amplified in the Arctic has sparked concerns about a possible impact on the weather and climate in mid-latitudes, including extreme events.

Rapid Arctic changes have taken many by surprise, including the scientific and operational forecasting communities. It is therefore no coincidence that our predictive capacity in the Arctic across time scales is still limited; hampering effective decision-making processes (Jung et al. 2016). The fast pace of Arctic change may also explain why our understanding of the impact of Arctic climate change on mid-latitude weather and climate, including high-impact events, is still at a pre-consensus stage (Jung et al. 2015, Overland et al. 2015).

Therefore, the overarching mission of APPLICATE is

**To develop enhanced predictive<sup>1</sup> capacity for weather and climate in the Arctic and beyond, and to determine the influence of Arctic climate change on Northern Hemisphere mid-latitudes, for the benefit of policy makers, businesses and society.**

To achieve its mission, APPLICATE will address the following **7 top-level objectives** (related work packages are given in parentheses):

#### **O1: Observationally constrain models using advanced metrics and diagnostics**

Achieved by: Developing a set of metrics and diagnostics that target key processes in the Arctic atmosphere, sea ice and ocean as well as user-relevant information; Applying these tools to assess, across time scales, the realism of existing models (baseline) as well as improved models developed during the project; Making advanced metrics and diagnostics available in the Earth System Model eValuation Tool (ESMValTool, Eyring et al. 2015); Exploring the concept of emergent constraints in the Arctic for narrowing the uncertainty of regional climate change projections. (WP1, WP2, WP5)

#### **O2: Develop enhanced weather and climate models**

Achieved by: Enhancing formulations of the atmospheric boundary layer, clouds, sea ice (rheology and thermodynamics), snow (multi-layer schemes) and Arctic Ocean (meso-scale features); Improving the representation of fluxes (mass, energy, momentum) at the atmosphere-ocean-sea ice interfaces; Exploring the benefit of horizontal resolution; Making extensive use of a hierarchy of models in conjunction with observational data. (WP2, WP1)

#### **O3: Determine the impact of Arctic climate change on mid latitudes through atmospheric and oceanic linkages**

Achieved by: Carrying out a set of coordinated multi-model experiments with coupled and atmospheric models in which Arctic sea ice decline is imposed; Exploring the sensitivity of the response to the background flow and the regional distribution of ice anomalies; Identifying atmospheric and oceanic pathways for polar-mid latitude linkages; Studying linkages from a prediction perspective. (WP3, WP4, WP5)

#### **O4: Contribute to the design of the future Arctic observing system**

Achieved by: Analysing the impact of existing data from operational model output and reanalyses; Carrying out and analysing atmospheric and coupled observing system ('data denial') experiments; Proposing strategies for enhanced observational capabilities; Providing a tight link to H2020 BG-9-2016 *An integrated Arctic observation system* and the Year of Polar Prediction (YOPP). (WP4, WP5)

#### **O5: Enhance the capacity to predict Northern Hemisphere weather and climate**

Achieved by: Analysing the skill of existing prediction systems; Assessing the impact of enhanced models and initialization strategies developed in APPLICATE in a pre-operational prediction framework; Providing recommendations for the advancements of forecasting systems from an Arctic perspective. (WP5)

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<sup>1</sup> For simplicity, throughout this proposal we will use the term *prediction* to represent both predictions (daily to seasonal and decadal) and projections (decades and longer).

## **O6: Develop and implement APPLICATE's research programme in coordination with external scientific partners to exploit synergies**

Achieved by: Establishing close collaboration with other relevant national, European and international projects (e.g. Research and Innovation Actions under H2020, Belmont); Engaging with relevant external partners institutions (e.g. Environment and Climate Change Canada); Ensuring alignment with and contribution to relevant international activities such as YOPP and the US CLIVAR Working Group on Arctic Change and Possible Influence on Mid-latitude Climate and Weather. (WP8, WP1-7, WP9)

## **O7: Transfer the knowledge generated through APPLICATE to stakeholders including training of early career scientists**

Achieved by: Establishing an effective dialogue with a network of key stakeholders; Disseminating APPLICATE results widely, exploiting means such as project and data portals through international (WMO, ICSU, SAON etc.) data management frameworks; Implementing enhancements in operational prediction systems and transition into Copernicus services (C3S); Involving partners from both weather and climate communities; Developing a training programme in collaboration with the Association of Early Polar Career Scientists (APECS). (WP7, WP1-6)

With APPLICATE, the Alfred Wegener Institute (AWI) is leading an experienced consortium that brings together leading European scientists from universities, research institutes and operational prediction centres. This composition ensures an **effective transfer of scientific knowledge into operations**, thereby reaching a plethora of different stakeholders<sup>2</sup>. Moreover, **APPLICATE unites experts from the weather and climate prediction communities** to tackle challenges faced across time scales and considering climate as a **coupled**, complex system. Finally, **the need for effective knowledge transfer is finally addressed** by bringing together pioneers in the emerging field of climate services, a small and medium-sized enterprise (SME) with strong expertise in knowledge transfer and a network of stakeholders.

### **1.2 Relation to the work programme**

APPLICATE responds to the call BG-10-2016: "Impact of Arctic changes on the weather and climate of the Northern Hemisphere".

The main goal of **APPLICATE is well aligned with the overarching challenge of this call**: *"...to improve the predictability of weather and climate in the Northern Hemisphere, and of related risks"*. Furthermore, **all underpinning elements outlined in the specific scope and challenge of the call will be addressed by APPLICATE** (relevant APPLICATE objectives (O), as provided under section 1.1, are indicated in parentheses):

- APPLICATE will *"develop innovative approaches to improving the descriptions and modelling of the mechanisms, processes and feedbacks affecting Arctic climate change"* (O2). This will be achieved by targeting key processes that are important for the Arctic atmosphere, sea ice and ocean, and that are known to play a pivotal role for atmosphere-sea ice-ocean interactions. Methodologically, APPLICATE will exploit a variety of model configurations – from coupled single column models to state-of-the-art weather and climate prediction models – alongside observational data, including those taken during dedicated intensive observing periods (e.g. YOPP).
- APPLICATE will consider Arctic climate change, with a special focus on *"its impacts on the weather and climate of the Northern Hemisphere"* (O2, O3). More specifically, *"coordinated model experiments"* (coupled and atmosphere-only) will be carried out that target the impact of Arctic sea ice decline on the weather and climate of the Northern Hemisphere, including the North Atlantic Ocean. These activities will be augmented by relaxation experiments that allow Arctic-mid-latitude linkages to be evaluated in models and determine their relevance from a prediction perspective. Through the experimental setup and analysis approach employed, APPLICATE will provide new insight into models' *"ability to represent the links between polar and lower latitudes."*
- APPLICATE will *"assess the performance of models"* (O1, O2). More specifically, APPLICATE will develop a framework for observationally constraining weather and climate models (WP1). This framework will be used to (i) assess the performance of existing models (e.g. CMIP6), especially in the Arctic, (ii) identify shortcomings in existing systems, and (iii) measure the progress resulting from model development efforts made in APPLICATE.

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<sup>2</sup> In terms of knowledge transfer, operational prediction centres can be considered as 'multipliers'. ECMWF, for example, has 20 member states and 10 cooperating states from Europe, and it operates the Copernicus Climate Change Services (C3S) and Atmospheric Monitoring (CAMS) Services on behalf of the European Commission. Any forecasting system improvements therefore, have thus potential to reach multiple ends and enhance decision making capacity across large parts of Europe.

- APPLICATE will “*explore the potential that an improved Arctic observation system would have on the accuracy of weather, and climate forecasts in the Northern Hemisphere, including Europe and North America*” (O4, O3) and “*identify gaps in data and observations*” through observing system experiments (O4). The design of the future Arctic observing system will be carried out in close collaboration with modellers (O2) and the project that will be funded under the topic H2020-BG-09-2016: “Integrated Arctic Observation System” (O6).
- APPLICATE will “*further develop state-of-the-art climate models and predictions*” through the above-mentioned research activities together with a strong synthesis component, resulting in a set of high-level recommendations. These recommendations will not only be beneficial for APPLICATE partners, but also the international scientific community in general.
- APPLICATE activities will “*contribute to the Year of Polar Prediction (YOPP)*” in numerous ways, including substantial contributions to the YOPP Modelling Component (O1-5). This includes the provision of the publicly available YOPP Analysis and Forecast Dataset through ECMWF, which has been proposed as a key element of YOPP in the YOPP Implementation Plan (Jung et al. 2014b). APPLICATE will also contribute to the YOPP Observing Component (O4), the YOPP Outreach and Education Component (O7), as well as the YOPP Data Component (O7). Many of the PIs engaged in APPLICATE play critical roles in the planning and implementation of YOPP, including the coordinator of APPLICATE, Thomas Jung, who leads YOPP in his role as chairman of the steering group of the Polar Prediction Project (PPP) of WMO’s World Weather Research Programme (WWRP).
- APPLICATE will “*provide input to the improvement of short- to medium-term predictions of the Copernicus Climate Change Services (C3S)*” (O4, O5). This will be achieved through the improvement of operational seasonal predictions, climate change projections, and future reanalysis efforts, which will all feed into C3S. Moreover, APPLICATE is destined to improve the quality of initial conditions and hence future reanalysis efforts. It is worth mentioning in this context that ECMWF – one of the APPLICATE partners – has the mandate from the EU to run and implement C3S.
- APPLICATE will implement a dedicated work package (WP8) with the goal to “*cluster with other projects financed under this topic*” and “*also under other parts of Horizon 2020*”, including “*projects funded under earlier calls*” (O6, O7). Furthermore, this work package will establish “*links with projects resulting from the Belmont Forum call on climate predictability and inter-regional linkages*” to ensure synergies will be exploited (O6, O7). The key to success will lie in APPLICATE taking a pro-active approach to collaboration and in exploiting high-level activities such as YOPP that provide an international framework for collaboration.
- APPLICATE will “*develop relevant forms of communication with the EU (and possibly national) services to adequately disseminate results that could be used for policy action*” (O6, O7). Actions include providing input to EU-PolarNet, a coordination and support action that will develop a European polar research agenda, contributions to briefing events for policy makers (e.g. parliamentary events in Brussels and nationally), and providing input to IPCC assessments reports.
- APPLICATE will “*contribute to implementing the Transatlantic Ocean Research Alliance*” through strong collaboration with coordinating bodies and numerous individual collaborators from the US (e.g. **Sea Ice Prediction Network**, NCAR, **US CLIVAR Working Group on Arctic-Mid-latitude Linkages**) and Canada (e.g. **Environment and Climate Change Canada**) as well as intensive research in an area outlined in the Galway scientific report: “*... our common objectives are to have by 2020: ... An enhanced predictive capacity ... for interactions between the Atlantic and Arctic as well as ocean-atmosphere connections.*” APPLICATE is therefore “*in line with the strategy for EU international cooperation in research and innovation*” (O6, O7).
- APPLICATE will “*benefit from the inclusion of partners from the USA and from Canada*” through strong collaboration with Environment and Climate Change Canada, the US Sea Ice Prediction Network (SIPN) and the US CLIVAR Working Group on Arctic Change and Possible Influence on Mid-latitude Climate and Weather. Furthermore, APPLICATE will establish “*international cooperation with partners from other Arctic and non-Arctic third countries*” through the **direct involvement of Russian partners**, through its alignments with other ongoing international activities, mainly in the framework of YOPP, and through cooperation with “*projects resulting from the Belmont Forum call.*” (O6)
- APPLICATE will “*participate in the Pilot of Open Research Data*”. The Data Management is based on a metadata-driven approach where datasets are documented in a standardised manner for data discovery and this information is exposed using machine-to-machine interfaces. APPLICATE data management is linked to WMO data management through the WMO Information System (WIS) Data Collection and Production Centre (DCPC) Arctic Data Centre (ADC) hosted by the Norwegian Meteorological Institute. Through ADC and WIS, APPLICATE data is exposed to the GEOSS Common Infrastructure. ADC is also an active participant in Arctic metadata and data interoperability efforts through the SAON/IASC Arctic Data Committee.

### 1.3 Concept and methodology

#### (a) Concept

##### 1.3.1 Overall concept underpinning APPLICATE

**APPLICATE responds to the challenges outlined in the call by moving the *prediction* problem into the focus.** In doing so, **scientific excellence and innovation can be effectively transferred into socio-economic benefit.** To provide the right framework for enhancing predictive capacity in the Arctic region and beyond, APPLICATE brings together experts from academia, research institutions and operational forecasting centres.

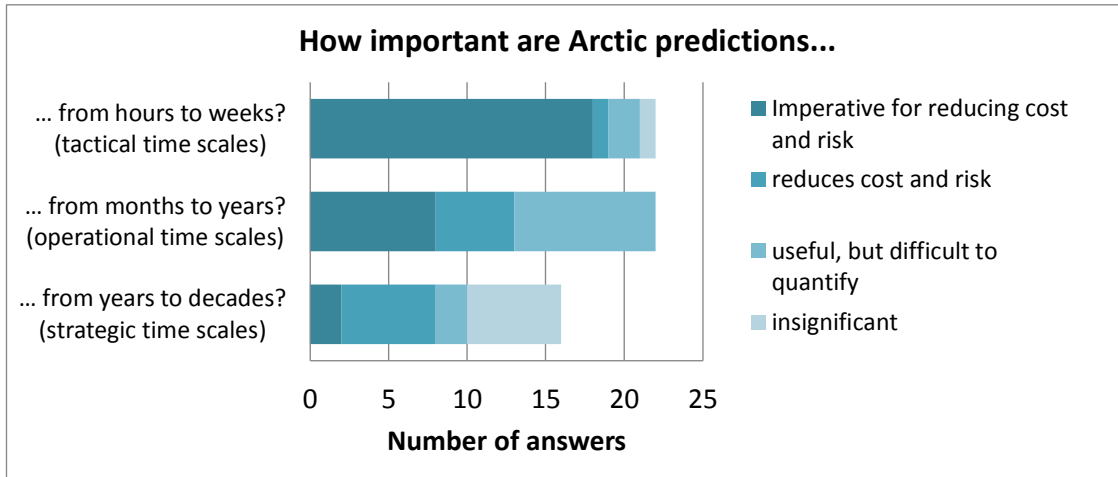


Figure 1: Survey of 22 marine stakeholders, regarding the importance of weather information in the Arctic for different prediction horizons. Data have been kindly provided by the Services Task Team of the WMO Executive Council Panel of Experts on Polar and High Mountain Observations, Research and Services (EC-PHORS).

APPLICATE aims at enhancing predictive capacity from daily to multi-decadal time scales. In doing so, APPLICATE responds to the needs of the majority of stakeholders for enhanced predictions from weather to climate time scales (Fig. 1). APPLICATE addresses this challenge by:

- Focussing research activities on daily to seasonal prediction and on tackling anthropogenic Arctic climate change including its impact on lower latitudes. Significant indirect benefits can be expected for interannual and decadal predictions due to the similarity of the systems used for seasonal and decadal prediction;
- Focussing development efforts limited to a number of key-aspects that are known to be of critical importance, across time scales, for the Arctic. More specifically, APPLICATE will address the Arctic atmospheric boundary layer physics and clouds, snow on land and sea ice, sea ice dynamics and thermodynamics, atmosphere-sea ice-ocean coupling as well as oceanic phenomena that benefit from enhanced horizontal resolution such as exchange processes at the Arctic-Atlantic gateways.

**A central aspect of APPLICATE's concept is to bring together leading experts from the weather and climate prediction communities.** It is based on the premise that the same processes matter across different time scales in the Arctic. In fact, bringing the two communities together will ensure the transfer of relevant expertise for mutual benefit. For example, strong expertise in observing systems design resides within the numerical weather prediction (NWP) community; at the same time, sea ice model development is traditionally being carried out within the climate research community; while limited-area models have been used in both communities for high-resolution predictions. Therefore, bringing the weather and climate prediction communities closer together is very important to ensure progress across time scales and prediction systems.

To achieve its objectives of **advancing predictive capacity in the Arctic and mid-latitudes**, APPLICATE will follow a well-defined strategy (Fig. 2): It will start by developing a model assessment framework that includes existing and novel metrics and diagnostics. These tools will then be provided to all partners and used to establish the status quo (baseline), both in terms of model fidelity and prediction skill. Research efforts in APPLICATE will then lead to proposals for forecasting system enhancements, including improvements to models, initial conditions and the Arctic observing system. The proposed enhancements will be thoroughly tested across time scales, and recommendations will be formulated and disseminated, following careful evaluation and synthesis of the results. At the end of this "value chain", APPLICATE will deliver not only enhanced predictions, but also enhanced knowledge to design more accurate prediction systems.

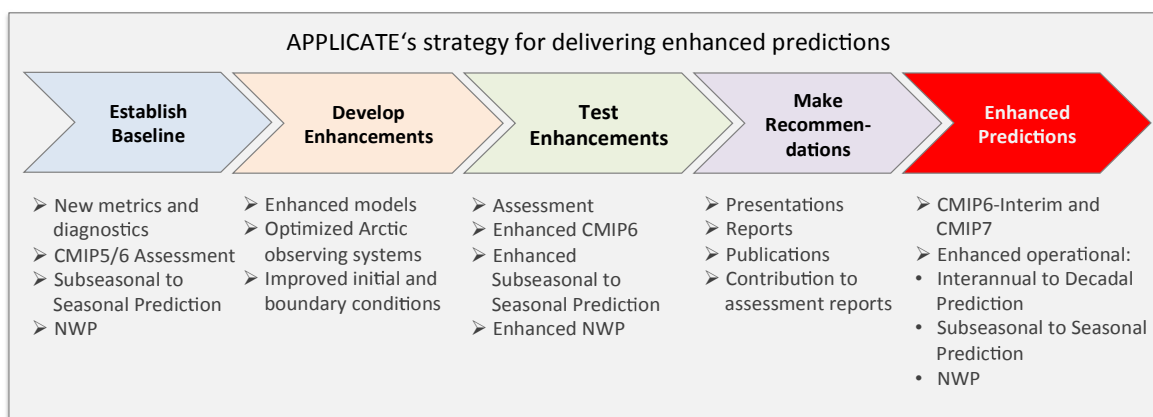


Figure 2: Schematic of APPLICATE's strategy for the enhancement of predictive capacity across time scales.

APPLICATE aims to **narrow the uncertainty of projections that are associated with Arctic climate change**. To this end, two different approaches will be followed. Firstly, the concept of emergent constraints (e.g. Klein and Hall 2015) – find physical relationships between (observable) present-day and projected future climate – will be explored by analysing statistical relationships between future and historical model runs in multi-model ensembles. Secondly, APPLICATE will carry out substantial model development efforts (see O2 above). Given that model error accounts for a substantial share of total uncertainty at multi-decadal time scales (Hawkins and Sutton, 2009), model development can potentially reduce greatly the uncertainty of regional climate change projections in the Northern Hemisphere.

APPLICATE will study the **impact of the Arctic on the weather and climate of the Northern Hemisphere** taking atmospheric and oceanic linkages into account. As pointed out by Barnes and Screen (2015), it is convenient to tackle the issue of an Arctic influence on the mid-latitude circulation by considering three central, but different questions: *Can it? Has it? Will it?* Given the short observational record along with large internal variability of the mid-latitude atmosphere, APPLICATE will *not* address the question whether recent Arctic amplification or internal variability has influenced the mid-latitude circulation; rather, the focus of APPLICATE will be on the “potentially tractable” (Barnes and Screen, 2015) questions *Can it?* and *Will it?*. Central to the concept of APPLICATE will be the use of both uncoupled and coupled models. By using coupled models, it will be possible to account for air-sea interactions and also determine the oceanic response to Arctic sea ice decline. APPLICATE's concept also includes another set of numerical experiments that allow to assess atmospheric teleconnections and to assess their practical relevance from a prediction perspective.

The research carried out in APPLICATE will be **computationally demanding**. However, given that most of the partners have access to dedicated supercomputing facilities and/or have well-established cooperation with different national and international high-performance computing (HPC) providers (e.g. ECMWF special projects), APPLICATE will not strive to carrying out all numerical experimentation at one single HPC centre. The availability of these HPC resources is a major asset of the APPLICATE consortium. In addition, joint proposals for HPC resources at a European level will be pursued (e.g. Partnership for Advanced Computing in Europe, PRACE).

APPLICATE's data strategy involves three main components. Firstly, all partners will be provided access to a common data storage and analysis facility that includes compute nodes and preinstalled software tools. Secondly, part of the model data will be made publicly available and easily accessible following standard formats used by the community. Data will be made available through application servers and metadata describing the data will be searchable and exposed for harvest by relevant data management frameworks. Finally, APPLICATE will maximize the impact of these data through publications in data journals (e.g. Earth System Science Data), provision on operational centre portals, and making the data visible through the YOPP Data Portal.

APPLICATE will be addressing two (related) topics that are very high on the agenda of the international research community, namely the enhancement of predictive capacity in polar regions and the improvement of our understanding of Arctic climate change on the weather and climate in lower-latitudes. Hence, many other activities related to those proposed in APPLICATE can be expected during the coming years. Examples include Belmont Forum projects and research activities related to YOPP. In order to avoid duplication and exploit synergies, APPLICATE includes a work package on clustering. The main element of APPLICATE's clustering concept includes a high-level coordination meeting at the beginning of the funding period. Moreover, international coordination will be envisaged through YOPP, which provides the ideal framework regarding the polar prediction and linkages themes.

### 1.3.2 Positioning of *APPLICATE*

*APPLICATE* covers the whole spectrum from idea to application. In this context, the following value chains will be addressed:

- Development of advanced metrics and diagnostics → thorough assessment of weather and climate models → better understanding of strengths and weaknesses → more trustworthy predictions
- Improved process understanding → improved models → improved weather and climate predictions
- Improved knowledge of the impact of observations → improved reanalyses, initial conditions and predictions
- Enhanced understanding of the impact of Arctic climate change on mid-latitudes → better predictions
- User-engagement → identification of user-relevant parameters → enhanced products

The project aims to develop and test prototype systems for weather and climate prediction, which corresponds to a Technology Readiness Level 6-7. It is possible, however, that for some of the activities, implementation in full operational systems will be achieved towards the end of the project period (Technology Readiness Level 8).

### 1.3.3 National and international research activities related to *APPLICATE*

There are numerous international, European and national projects that are related to *APPLICATE* (many with participation of *APPLICATE* partners – often in leading roles). In the following, a number of high-level projects will be discussed. The focus of the discussion will be on **where these activities provide relevant input to *APPLICATE***, keeping in mind, however, that the relationships are strongly bidirectional in nature. Input provided by *APPLICATE* to other projects will be discussed in section 2 (Impact).

#### **Related international projects include:**

*Coupled Model Intercomparison Project, phase 6 (CMIP6)*: All climate modelling groups participating in *APPLICATE* will be taking part in CMIP6. In this context, CMIP6 provides protocols that will be used by *APPLICATE* partners. For example, the Sea Ice Model Intercomparison Project (SIMIP) defines a list of additional variables that are saved during experiments and can be used to understand the evolution of sea ice in any experiment using the sea ice model as part of CMIP6. Furthermore, *APPLICATE* will exploit efforts made by the Observations for Model Intercomparison Projects (Obs4MIP) through extensive use of its observational data-base. *APPLICATE* will also benefit from the development of ESMValTool, a community diagnostics and performance metrics tool for the evaluation of models.

*World Climate Research Programme (WCRP)*: *APPLICATE* will benefit from activities going on under the auspices of WCRP, especially in the area of research coordination. Examples include the WCRP Polar Climate Predictability Initiative (PCPI) in the area of model development, reanalysis and polar prediction; the Working Group on Seasonal to Interannual Prediction (WGSIP) in seasonal to interannual prediction and the Working Group on Coupled Modelling in model development and CMIP6 related activities.

*Year of Polar Prediction (YOPP)*: YOPP is a high-level international activity that will provide an important mean by which *APPLICATE* will coordinate its research activities with other related initiatives. In this context, close collaboration with the International Coordination Office for Polar Prediction (ICO), which is hosted at AWI, will be exploited. Of particular importance will be the coordination in the framework of the YOPP Modelling Component. YOPP will also play an important role in communicating and disseminating key outcomes of *APPLICATE* through workshops, mailing lists, and news items on the ICO website. Moreover, YOPP will provide a framework to increase the network of stakeholders, and provide resources needed to increase the critical mass behind coordinated education activities. Hence *APPLICATE* is essential for a successful YOPP.

*World Meteorological Organisation (WMO)*: WMO will be one of the key partners for *APPLICATE*, and WWRP in particular as its Polar Prediction Project is one of the flagship activities with YOPP as a key deliverable. The WMO Polar Satellite Task Group (PSTG) will provide advice on Earth Observation data in the Arctic region for use in *APPLICATE*. Furthermore, *APPLICATE* will benefit from activities in the WMO's EC-PHORS, especially in the area of research coordination (Global Integrated Observing System, GIPPS) and services (e.g. evaluation of stakeholder needs, see Fig. 1).

*Belmont Forum*: The Belmont Forum has issued a call on *Climate Predictability and Inter-Regional Linkages*. Some of the funded projects are expected to contribute to the questions addressed by *APPLICATE*. Hence, coordinating activities with these projects will increase the critical mass needed to make progress in addressing the overarching challenge of advancing predictive capacity.

#### **Related European activities include:**

*EU research projects*: *APPLICATE* will develop strong synergies with numerous ongoing and upcoming EU-funded projects. For example, *APPLICATE* will benefit from collaboration with PRIMAVERA in the area of model evaluation, model development and numerical experimentation including Arctic-mid-latitude linkages;



EMBRACE will provide a base line in sea ice and ocean model development; SPECS will be key to prediction and initialization aspects; CRESCENDO will contribute to the provision of CMIP6 experiments; and COST-EOS will provide a database and tools for the evaluation of ocean analyses and reanalyses in the Arctic Ocean. The successful project that will be funded under the topic H2020-BG09-2016 ‘An integrated Arctic observation system’ presents a highly complementary effort.

**Services:** APPLICATE will benefit from EUPORIAS, which provides examples and strategies to develop end-to-end climate-to-impacts-to-decision-making services, including semi-operational prototypes. Furthermore, APPLICATE will have close links to the projects funded in the framework of the climate services (ERA-NET, ERA4CS). An important factor is that many of the APPLICATE partners are eligible for the in-kind call of ERA4CS, which is an additional opportunity to strengthen the links on the impacts of Arctic climate research among them. Along the same lines, the APPLICATE partners involved in the recently started ECOMS2 coordination and support action can ensure that the modelling and services aspects of Arctic climate and its linkages to lower latitudes are taken into account in a broader context, including in the implementation of the "European research and innovation roadmap for climate services" and the European contribution to C3S and the Global Framework for Climate Services (GFCS).

**Coordination and agenda-setting:** Regarding the coordination of Arctic research in Europe, the Arctic Programme of the European Climate Research Alliance (Arctic ECRA, co-chaired by the APPLICATE coordinator) provides an excellent framework that can be exploited by APPLICATE. Furthermore, Arctic ECRA can help to advise policy makers on APPLICATE findings of societal relevance through means such as Parliamentary Lunch Events. Furthermore, EU-PolarNet will provide a platform for communicating high-level recommendations formulated by APPLICATE.

#### **Related national projects include:**

**Met Office Hadley Centre Climate Programme and UK Public Weather Service Programme:** This programme will provide baseline model configurations for prediction on seasonal (GloSea5) to centennial (CMIP6) time scales. Provides guidance on the impact of sea ice model parameters and enhanced resolution.

**Meteorological Co-operation on Operational NWP (MetCoOp):** MetCoOp will provide improved versions of the limited area weather prediction model AROME tailored for Nordic weather and daily surveillance of forecast quality. MetCoOp will also provide daily ensemble predictions on a Nordic domain.

#### **(b) Methodology**

##### *1.3.4 Methodology*

To achieve APPLICATE’s goals, extensive use of models will be made that have been developed by APPLICATE partners. These models can be clustered into four groups: (i) climate models that participate in CMIP6; (ii) those used in operational subseasonal-to-seasonal prediction; (iii) those employed in NWP for short-range and medium-range weather prediction; and (iv) single column models that can be run in coupled mode. While some of the systems are used for specific applications only, the majority of models are used from weather to climate time scales. A more detailed overview of the model systems used in APPLICATE is given in Tab. 1.

*Table 1: Summary of the different model and forecasting systems participating in APPLICATE.*

Climate Models					
Model	AWI-CM	EC-Earth	CNRM-CM	NorESM	HadGEM
Partner	AWI	BSC, UCL, SU	CNRS-GAME, CERFACS	UiB, UR, Met.no	MO, UREAD
Atmosphere	ECHAM6 T127 L95	IFS T255/T511 L91	ARPEGE-Climat T127/T359 L91	CAM-OSLO 1°×1° L32 / L46	MetUM N216/N96 L85
Ocean	FESOM Unstruct. mesh 15-100 km L41 4.5-80 km L41	NEMO 1° , 0.25° L75	NEMO 1° , 0.25° L75	NorESM-O (extended MICOM) 1° , 0.25° L75	NEMO 1°×1° L75 0.25°×0.25° L75
Sea ice	FESIM	LIM3	GELATO	CICE	CICE
Surface	JSBACH	HTESSEL	SURFEX	SURFEX	JULES
CMIP6	Yes	Yes	Yes	Yes	Yes

Subseasonal to Seasonal Prediction Systems				
Model	EC-Earth	CNRM-CM	IFS	HadGEM/GloSea
Partner	BSC, UCL, AWI	CNRS-GAME	ECMWF	MO, UREAD
Atmosphere	IFS T255/T511 L91	ARPEGE Climat T255/T359 L91	IFS T511-T319 L91	MetUM N216 L85
Ocean	NEMO 1°/0.25° L75	NEMO 1°/0.25° , L75	NEMO 1° , L75	NEMO 0.25°×0.25° L75

Sea ice	LIM3	GELATO	LIM2/3	CICE
Land	HTESSEL	SURFEX	HTESSEL	JULES
Data assimilation	Ensemble Kalman filter	Extended Kalman Filter SAM2	4D-Var	4D-Var, NEMOVAR 3D-Var FGAT

Numerical Weather Prediction Systems				
Model	ARPEGE	AROME	IFS	AROME-Arctic
Partner	CNRS-GAME	CNRS-GAME	ECMWF	Met.no
Atmosphere	ARPEGE T1198, stretched HR (7.5km on grid pole), L105	AROME 1.3km / 500m, 90 vertical levels	IFS T1279 L137	AROME 2.5 km L65
Ocean	N/A	N/A	N/A	N/A
Sea ice	GELATO	GELATO	N/A	SICE
Land	SURFEX	SURFEX	HTESSEL	SURFEX
Data assimilation	4D-Var	dynamical adaptation	4D-Var	3D-Var

The fact that APPLICATE will carry out comprehensive numerical experimentation with different model systems across a wide range of time scales requires a strongly coordinated approach. A draft numerical experimentation plan, that summarizes some planned numerical experiments, is presented in Tab. 2. The numerical experimentation plan will be updated throughout the project taking into account input from the WP leaders and following consultation with other related European and international activities as part of the Clustering process.

Table 2: Draft plan for the numerical experimentation carried out in APPLICATE including the level of data dissemination in WP6.

Purpose	Model systems	Experimental design	Data
<b>Determine the impact of model enhancements on process representation and systematic model error (WP2)</b>	<ul style="list-style-type: none"> <li>AWI-CM</li> <li>EC-Earth</li> <li>CNRM-CM</li> <li>NorESM</li> <li>HadGEM</li> </ul>	Baseline data: CMIP6-DECK experiments Implement the model changes suggested in WP2 in coupled models: <ul style="list-style-type: none"> <li>200-yr pre-industrial control experiments</li> <li>CMIP6 historical experiments</li> <li>1% CO<sub>2</sub> increase experiments</li> </ul>	Partial Dissemination
<b>Determine Arctic-lower latitude linkages in atmosphere and ocean (WP3)</b>	Coupled models <ul style="list-style-type: none"> <li>AWI-CM</li> <li>EC-Earth</li> <li>CNRM-CM</li> <li>NorESM</li> <li>HadGEM</li> </ul>	<ul style="list-style-type: none"> <li>Large ensembles (50-100 members) of 12-months experiments starting June 1<sup>st</sup> with sea ice constrained to observed and projected sea ice fields</li> <li>Multi-decadal experiments with and without artificially reduced Arctic sea ice (enhanced downwelling LW radiation over sea ice); use of tracers for the ocean</li> <li>Repeat with enhanced models</li> </ul>	Full Dissemination
	Atmospheric models <ul style="list-style-type: none"> <li>ECHAM6</li> <li>IFS</li> <li>ARPEGE-Climat</li> <li>CAM-OSLO</li> <li>MetUM</li> </ul>	<ul style="list-style-type: none"> <li>Large ensembles (50-100 members) of 12-months experiments starting June 1<sup>st</sup> with sea ice constrained to observed and projected sea ice fields</li> <li>Various corresponding sensitivity experiments to explore the role of the background flow, and the prescribed sea ice pattern</li> <li>Repeat with enhanced models</li> </ul>	Full Dissemination
	Seasonal prediction systems <ul style="list-style-type: none"> <li>EC-Earth</li> <li>CNRM-CM</li> </ul>	Seasonal prediction experiments with and without relaxation of the Arctic atmosphere towards ERA-Interim reanalysis data: 9-member ensemble forecasts with members initialized on Nov 1 <sup>st</sup> , Feb 1 <sup>st</sup> , May 1 <sup>st</sup> and Aug 1 <sup>st</sup> for the years 1979-2016 and 1993-2016 for EC-Earth and CNRM-CM, respectively.	Full Dissemination
<b>Arctic observing system development (WP4)</b>	Atmospheric model <ul style="list-style-type: none"> <li>IFS</li> </ul>	Data denial experiments with the IFS for key observations (snow, surface pressure, wind, moisture) and different seasons.	Partial dissemination
	Seasonal prediction <ul style="list-style-type: none"> <li>EC-Earth</li> <li>HadGEM</li> <li>GloSea</li> </ul>	<ul style="list-style-type: none"> <li>Perfect model experiments to characterize basic sensitivity of forecasts to initial conditions.</li> <li>Different configurations of initial conditions using reanalyses, new observations, ocean reruns forced by atmospheric reanalyses.</li> <li>Experiments focused on sea-ice thickness, snow and spatial data sampling</li> </ul>	Partial dissemination
<b>Determine the impact of APPLICATE model enhancements on weather and climate prediction (WP5)</b>	Atmospheric model <ul style="list-style-type: none"> <li>ARPEGE</li> <li>AROME</li> <li>IFS</li> <li>AROME-Arctic</li> </ul>	Test recommendations for model enhancements made in WP2 in pre-operational configurations  Explore the impact of nesting, driving model and resolution	Partial dissemination

	Seasonal prediction <ul style="list-style-type: none"> <li>• EC-Earth</li> <li>• CNRM-CM</li> <li>• HadGEM</li> </ul>	Test recommendations for model enhancements made in WP2 in pre-operational configurations	Partial dissemination
	Climate change <ul style="list-style-type: none"> <li>• AWI-CM</li> <li>• EC-Earth</li> <li>• NorESM</li> </ul>	Establish the impact of model enhancements developed in WP2 on climate sensitivity by carrying out experiments using the same initial conditions and time period (1950—2050) employed in HiResMIP	Partial dissemination

APPLICATE consists of nine **work packages** that can be clustered into four different groups (Fig. 3). The underlying **scientific core** comprises five strongly interlinked work packages that provide the scientific underpinning (WP1-5). In this context WP5 takes a central role, since this is where synthesis towards prediction systems takes place and key-recommendations will be formulated. The scientific work packages are supported by WP6, which will provide the **infrastructure** in the area of high-performance computing (HPC) as well as data management and dissemination needed to deliver scientific excellence. The **knowledge transfer**, including end-user engagement, dissemination and education will be taking place in WP7. Thus, WP7 is crucial for maximizing the impact of APPLICATE. Through the stakeholder dialogue established in WP7, important feedback will be provided to the scientific core. Finally, WP8 and WP9 will ensure **coordination** with related activities at the European and international level (Clustering) as well as a smooth and efficient **project management** of APPLICATE, respectively.

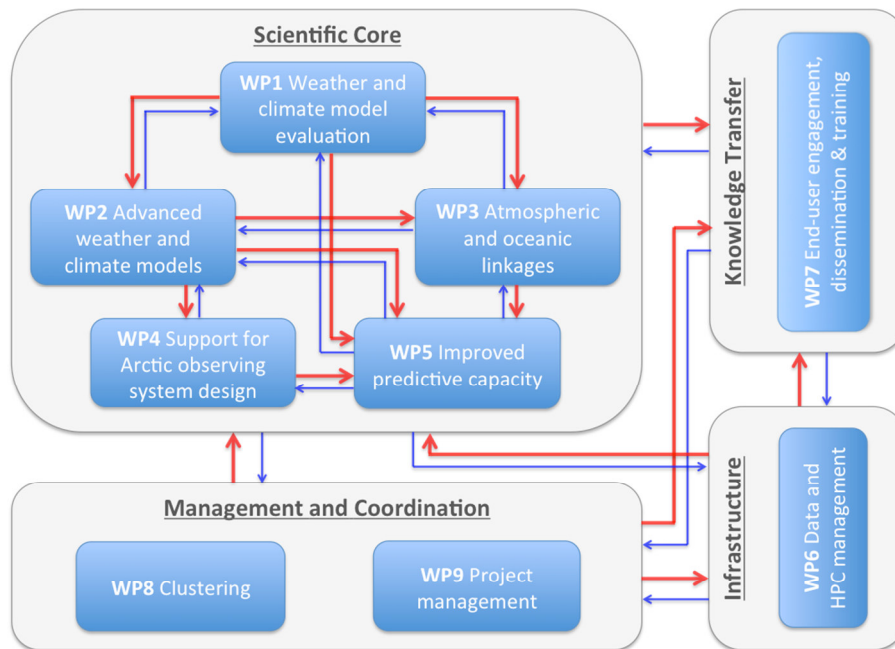


Figure 3: APPLICATE work package structure. Red arrows denote the main direction of dependencies and blue arrows indicate feedbacks.

In the following, the aims and methodology underlying the scientific core and infrastructure work packages are given:

#### WP1: Weather and climate model evaluation

**Aim:** WP1 will develop advanced metrics and diagnostics that will be used to observationally constrain weather and climate models.

**Approach and methodology:** To have confidence in climate projections and weather forecasts, it is essential that the models used to make such predictions are capable of capturing key physical processes in the oceans, atmosphere and cryosphere. WP1 will develop a set of metrics and diagnostics to observationally constrain and evaluate weather and climate models. The initial focus of WP1 will be on metrics, i.e. the quantitative comparison of a quantity within a model to some reference, for example, an observational data set. Several types of metrics will be developed: process-based metrics to evaluate Arctic climate processes and the linkages between the Arctic and the Northern Hemisphere, user-relevant metrics, and novel sea ice metrics based on observations from YOPP. User-relevant metrics will be co-developed with users engaged within WP7. To ensure community and user engagement, the metrics developed during APPLICATE will be made widely available through ESMValTool. The metrics developed in WP1 will be used to assess weather and climate models. This includes the existing CMIP5

data, but also the output from the forthcoming CMIP6 activity that will inform the next IPCC assessment report on climate change. The metrics will also be used to assess the ensemble weather forecasts from NWP models. To encourage the exchange of ideas between the weather and climate modelling communities, a synthesis will be made of how model errors develop across time scales in weather and climate models. A new generation of process-based heat budgets of the Arctic will be used to investigate the feedbacks and processes that lead to uncertainty in Arctic climate model projections. WP1 will also explore the potential of observational emergent constraints to reduce the uncertainty in climate model projections for the Arctic and its linkages to the whole Northern Hemisphere.

## **WP2: Enhanced weather and climate models**

**Aim:** WP2 will improve the representation of Arctic-specific processes in weather and climate prediction models

**Approach and methodology:** The weather and climate research communities rely heavily on the availability of adequate prediction models. However, even the most advanced models still have significant shortcomings in the Arctic. This is particularly true for small-scale processes that need to be parameterised such as the formation of clouds, boundary layer mixing in ocean and atmosphere, sea ice formation/melt and the surface energy exchanges. These processes are also involved in substantial feedback mechanisms in the climate system. APPLICATE will work on improving the representation of the most critical processes for the Arctic climate system as well as on developing methodology that can help constraining model processes by utilizing available observations. An innovative single column framework, extended from the more commonly used atmosphere-only and ocean-only framework to capture the entire system from ocean bottom, through the sea ice and snow, to the top-of-atmosphere will be developed and tested using observational data of the coupled system. The experimental cases developed within APPLICATE will be used in internationally coordinated model inter-comparison projects to continue the successful work in GEWEX Global Atmospheric System Studies (GASS) but extended to examine atmosphere-snow-sea ice-ocean interactions. Enhancement of ocean processes, especially in straits/channels and small-scale sea ice features will be explored using innovative high-resolution grids. At the end of the APPLICATE project, model enhancements will be thoroughly assessed and documented.

## **WP3: Atmospheric and oceanic linkages**

**Aim:** WP3 will advance our understanding of the mechanisms by which the mid-latitude weather and climate could respond to the substantial Arctic climate change that is expected in the coming decades.

**Approach and methodology:** WP3 will perform a thorough assessment of the impact of Arctic climate change on the Northern mid-latitudes. This will be achieved through a suite of novel coordinated multi-model experiments. Fully coupled models will be employed since these are essential in order to properly simulate the linkages, including oceanic and atmospheric pathways and the effects of ocean-atmosphere coupling. Additional atmosphere-only experiments will be performed to further improve our understanding of the physical processes by assessing the relative roles of the ocean and atmosphere, and how the mid-latitude climate response depends on the background model state and the pattern of sea ice changes. Advanced metrics and diagnostics will be used to assess the relevant physical processes. The impact of model improvements (WP2) on atmospheric and oceanic linkages will also be assessed by repeating some key experiments with enhanced models. The improved understanding of the mechanisms linking the Arctic region and Northern mid-latitudes gained in WP3 will lead to improved climate predictions for the coming seasons to decades.

## **WP4: Support for Arctic observing system design**

**Aim:** WP4 will guide the design of the future Arctic observing system in order to improve our capacity to reanalyse the Arctic climate system and enhance the predictive skill in the Arctic and beyond.

**Approach and methodology:** Observations are crucial for a better process understanding, model evaluation, forecast verification and for the initialization of predictions. Enhancing the existing observing system in the Arctic – one of the most undersampled regions of the planet – is a necessity. However, given the high costs associated with taking observations at high latitudes, the future of the Arctic observing system has to be planned thoughtfully. WP4 makes the best use of existing observations, reanalyses, and numerical models to provide guidance to the Arctic observational community regarding the deployment of the observational network in the Arctic. WP4 is designed to identify the most important gaps in the current Arctic observing system and to determine priorities for filling them. An assessment of current polar reanalyses will be conducted, investigating specifically the importance of the assimilation of conventional and satellite observations for capturing the variability of the coupled system, as well as their role for medium-to-seasonal prediction skill. From this, a synoptic analysis providing a consistent view of current shortcomings and requirements for observing system enhancement will be derived. WP4 will employ well-established prediction systems, a variety of model configurations (including atmosphere-only and fully coupled models) and advanced data assimilation methods and diagnostics. These tools will be used to identify

key missing observation types and locations. The proposed experiments will also identify the optimal regional sampling of these observations required to best improve predictions.

## **WP5: Improved predictive capacity**

**Aim:** WP5 will deliver enhanced weather and climate forecast systems with improved predictive skill for the Arctic and beyond on daily to decadal time scales.

**Approach and methodology:** WP5 will synthesize the results from WP 1-4 leading to enhanced weather and climate predictions. A comprehensive assessment of the existing prediction capabilities for the Northern Hemisphere will be carried out to establish a baseline. Sources of predictability will be identified by making extensive use of existing prediction dataset. Empirical forecast systems will be developed to provide a benchmark for dynamical predictions. Advanced forecasting systems will then be tested and delivered building on model enhancements (WP2), improved initialisation strategies (WP4), increased resolution, and novel ensemble generation techniques. The impact of APPLICATE on prediction skill from daily to multi-decadal time scales will be quantified by comparing two streams of experiments: one performed with the prediction systems as available at the start of APPLICATE (stream 1) and another one performed after incorporating the developments produced by APPLICATE (stream 2). Recommendations for operational implementations in weather and climate forecast systems and for further developments will be formulated and widely disseminated.

## **WP6: Data and HPC management**

**Aim:** WP6 will oversee all HPC activities, provide the YOPP Analysis and Forecast Dataset and ensure structured data management, simplifying data sharing, preservation and analysis.

**Approach and methodology:** WP6 will oversee HPC activities of the APPLICATE consortium and provide information about upcoming calls for HPC resources, include those at the Partnership for Advanced Computing in Europe (PRACE). Furthermore, WP6 will produce and disseminate the YOPP Analysis and Forecast Dataset. Data management APPLICATE is based on a metadata driven approach where datasets are documented in a standardised manner for sharing and preservation. This approach is aligned with relevant activities in the context of GEOSS, WMO, SAON, ICSU and EU (INSPIRE). Metadata will be exposed using machine interfaces, enabling visibility in the relevant catalogues. Through integration with the WMO Information System, information will be propagated to the GEOSS Common Infrastructure. Through application of standardised use of metadata and interfaces suitable for process oriented datasets, higher order services and simplified post-processing / analysis in a common post processing environment will be ensured. APPLICATE will use standard formats used in the weather and climate prediction communities (GRIB, NetCDF and CMOR).

### *1.3.5 APPLICATE gender dimension*

While gender aspects are not explicitly mentioned in the call text of BG-10-2016, they are nevertheless an important aspect to be considered. The nature of the work within the core scientific work of APPLICATE is mostly gender neutral. The research carried out in APPLICATE is grounded in math and physics, subjects that generally have a large bias towards male scientists at all levels, although the situation is slowly improving with more females entering the field. APPLICATE can make a difference by employing a recruitment policy and working environment that is welcoming for female candidates. APPLICATE endorses the principles of the *European Charter for Researchers and Code of Conduct for the Recruitment of Researchers*. APPLICATE partners will whenever possible implement actions (such as organising predictable working times and travel, stimulating use of electronic meetings) to support male and female researchers with children or other dependants. The Project Coordinator along with the Management Support Team will gather statistics on and monitor the role of women within APPLICATE and take actions if needed. Attention will be paid to how meeting programs, high profile presentations (keynote talks at conferences) on project results and educational programs are planned from a gender perspective. The impact that APPLICATE will have on prediction tools and predictions, however, does have a gender dimension. When engaging with end-users or other target audiences, and when designing information and services, it is important to keep the gender aspects in the process. Gender aspects must therefore be constantly considered within the context of the end-users and how the project dissemination, exploitation and communication are affected. We will consult the PRIMAVERA Gender Strategy and adopt APPLICATE relevant parts.

## **1.4 Ambition**

### *1.4.1 Advancement beyond the state of the art and ambition*

**APPLICATE will make significant advances in observationally constraining weather and climate models, especially in the Arctic:** Model assessment is an important aspect in the field of weather and climate modelling because it provides insight into the trustworthiness of our prediction systems and it provides guidance for future model development efforts. The increasing importance of this area of research is reflected by numerous recent

community efforts such as the dedicated chapter on evaluation of climate models in the Fifth IPCC Assessment Report (Flato et al. 2013), a move towards the development of community diagnostics and performance metrics tool for the evaluation of Earth System Models (ESMValTool, Eyring et al. 2015), and concerted efforts to run and evaluate climate models in weather prediction mode (Transpose AMIP, Williams et al. 2013). However, it can be argued that previous model evaluation had a bias towards lower latitudes, and that a coordinated approach towards ocean model evaluation is still in its infancy, especially for the Arctic (Wang et al. 2015).

APPLICATE will go beyond the state-of-the-art by developing and applying advanced metrics and diagnostics, targeting physical as well as user-relevant processes that bring the assessment of weather and climate models to a new level, especially in the Arctic. By implementing these tools in ESMValTool, APPLICATE will significantly increase the momentum behind emerging community efforts in model evaluation. Furthermore, the concept of initial tendency and data assimilation increment diagnostics (Rodwell and Palmer, 2007) will be used in an Arctic context for the first time. This approach, which allows to determining errors in the representation of processes before they had time to interact, will provide new insights into the origin of model errors in weather and climate models in the Arctic. Moreover, APPLICATE will explore the concept of emergent constraints with an Arctic focus, which could be an extremely effective way of reducing the uncertainty of regional climate change projections for the Northern Hemisphere in the Sixth Assessment Report of the IPCC. Finally, APPLICATE will liaise with the observational community to identify, with the aid of models, new types of process-based diagnostics that are robust and stable despite the shortness of intensive observational campaigns such as YOPP.

**APPLICATE will carry out model development efforts that provide the basis for the next-generation of weather and climate models:** Model development in the Arctic has a long history. Traditionally, efforts have focussed on atmospheric or sea ice-ocean models separately. Furthermore, regional models played a relatively important role (Rinke et al. 2006, Proshutinsky et al. 2001), due to the need for locally high horizontal resolution and Arctic-specific formulations of some of the parameterisations. Despite substantial improvements over the years, however, major challenges still exist (e.g. Vihma et al., 2015). This is especially true, given that rapid Arctic climate change is associated with the emergence of new regimes (e.g. Nghiem et al. 2007). For example: the representation of stable atmospheric planetary boundary layers needs attention (Holtslag et al. 2013); the formulation of snow and sea ice models needs to be revisited (Jung et al. 2016); ocean models need to be better constrained in the Arctic (Wang et al. 2016); coupling between atmosphere, snow, sea ice and the ocean needs attention; and improved process understanding needs to feed into models.

APPLICATE will substantially increase our understanding and ability to model some of the processes thought to be essential for the prediction of the weather and climate of the Arctic and beyond. APPLICATE will take the concept of single column models (SCMs) – which have been proven very effective at constraining model parameters (e.g. Cuxart et al. 2006) – one step further, towards coupled SCMs. Using coupled SCMs will allow us to account for the full range of physical process interaction from the ocean through the ice and snow into the atmosphere. In this way, APPLICATE will be able to take into account important coupled processes and exploit the full potential of new observational capacity, such as buoys from the Ice-Atmosphere-Arctic Ocean Observing System (IAOOS, 2011-2019; Provost et al., 2015), that carry out simultaneous measurements of the coupled Arctic climate system (Figure 4). Furthermore, APPLICATE will make substantial progress in the development of next generation sea ice models following novel pathways. Firstly, the numerical efficiency of existing rheologies will be improved (e.g. Kimmritz et al. 2015) so that for the first time, long ultra-high-resolutions simulations (4.5 km) with coupled climate models will become feasible. Secondly, the novel elasto-brittle rheology (Girard et al. 2011) will be implemented and thoroughly tested. Thirdly, the representation of thermodynamic sea ice processes in models (e.g. melt ponds) will be significantly enhanced, which will improve our capacity to model important feedback processes in the Arctic. Fourthly, APPLICATE will also make significant progress in the area of snow modelling. Here the emphasis will be on harmonizing the formulation on land and sea ice by implementing multi-layer snow schemes (Lecomte et al. 2013). Finally, progress in ocean modelling will be achieved through the use of enhanced resolution. This will allow, among others, a better simulation of Arctic-Atlantic exchange processes. In this context, novel concepts such as unstructured mesh approaches, as used in AWI-CM, will be exploited (Danilov 2013, Sidorenko et al. 2015). Models formulated on unstructured meshes allow enhancing horizontal resolution – and hence focus computational resources – in dynamically active regions, and they are extremely effective at exploiting the next-generation of massively parallel HPC systems due to their excellent scalability.

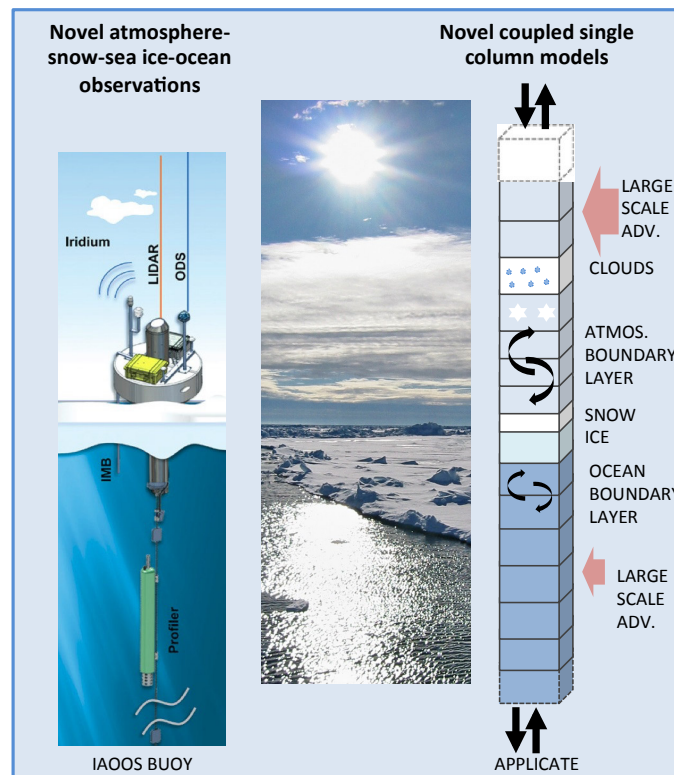


Figure 4: APPLICATE will employ a novel coupled single column model (SCMs) framework that goes from the ocean through the ice and snow into the atmosphere, and allows exploiting the full potential of new observational capacity such as IAOOS buoys that provide observations of the coupled atmosphere-snow-sea ice-ocean system.

**APPLICATE will significantly advance our understanding of the impact of Arctic climate change on mid-latitude weather and climate:** Despite substantial recent research activities, our understanding of the impact of Arctic climate change on the weather and climate of the Northern Hemisphere mid-latitudes is still at a pre-consensus state (Jung et al. 2015, Overland et al. 2016). Lack of consensus can be explained by different (related) factors: (i) the largest atmospheric changes, that have been linked to the Arctic have occurred only recently (since the early 2000s); (ii) atmospheric dynamics is known to generate sizable internal variability across a wide range of time scales (e.g. Barnes and Screen 2015); (iii) the mid latitude response may be nonlinear and thus depend on other factors such as the background flow (Harvey et al. 2014) and (iv) there has been a lack of coordinated experimentation, making it difficult to pinpoint the origin of differences between modelling studies. Finally, the recent discussion has been mostly about atmospheric linkages. However, oceanic linkages might be playing an important role in influencing the circulation and water mass characteristics of the North Atlantic Ocean, with possible implications for the blue economy (Benway et al. 2014).

APPLICATE will go beyond the state of the art by carrying out a set of *coordinated experiments* with some of the leading European climate models. These experiments are designed to address the question whether Arctic climate *can* and *will* influence the weather and climate of the Northern Hemisphere. In this context, APPLICATE will not only consider atmospheric but also oceanic linkages, thereby alleviating the bias of the recent discussion towards the atmosphere. Furthermore, APPLICATE will advance the field by providing further insight into important aspects such as non-linearity of the response. Importantly, all models participating in APPLICATE's coordinated modelling efforts will contribute to CMIP6. The fact that Arctic-mid-latitude linkages will be revisited in APPLICATE with enhanced climate models – exploiting APPLICATE's novel model development efforts mentioned above – will increase the insight into sensitivity to model formulation. APPLICATE will also exploit a completely different, and in the linkages context still largely unexplored, relaxation approach (Jung et al. 2014a). By carrying out seasonal forecasting experiments with and without relaxation of the Arctic atmosphere towards reanalysis data, it will not only be possible to assess simulated teleconnections; these experiments will also shed light on the potential that enhanced prediction capacity in the Arctic could have on mid latitude prediction skill.

**APPLICATE will make novel contributions to the future design of the Arctic observing system:** The polar regions are among the most sparsely observed parts of the globe, resulting in an Arctic “hole” in the global observing system (e.g. Jung et al. 2016). This may be one explanation as to why the skill of weather forecasts in polar regions is relatively low (Bauer et al. 2014). The relative remoteness and harsh environmental conditions of



the polar regions will always provide a barrier to enhanced observations. Therefore it is important to carefully design the observing system to meet different needs. In the past, the emphasis has been on improved process understanding, model development and long-term monitoring. With an increasing need for predictive capacity, however, recently the importance of observations for improved initialization of weather and climate forecasts has been realized (e.g. Eicken 2013), and some promising initial results for the potential of additional observations for enhanced predictions have been obtained (Inoue et al. 2015).

APPLICATE will address this timely topic by focussing on two central questions: “*What are the most important gaps in the existing observing system?*” and “*How much could predictions be improved by filling these gaps?*” APPLICATE will go beyond the state-of-the-art by applying novel diagnostic techniques that allow linking forecast improvement to the impact of individual observations, to how they are distributed in space and time, and how effectively they are assimilated in today’s systems. This will be performed by considering observational requirements across time scales and by also taking into account the needs of the model development community. APPLICATE will thus provide crucial guidance for optimizing observational data usage and for exploiting new observations to be collected during YOPP, but also for designing future reanalyses monitoring long-term climate variability in the Arctic in support of C3S.

**APPLICATE will significantly improve the fidelity of existing weather and climate prediction systems:** Traditionally, development efforts of prediction systems have focussed on lower latitudes. This is partly a result of relatively low human activities in the Arctic in the past, and the notion that sources of predictive skill mostly originate in lower latitudes (e.g., associated with ENSO). This bias led to the fact that our predictive capacity in the Arctic is still limited (e.g. Jung et al. 2016, Stroeve et al. 2012). With Arctic amplification, the perception of the relative importance of the Arctic is changing rapidly. This is reflected, among others, by the launch of major international programmes such as the PPP, YOPP and GIPPS.

APPLICATE will move the Arctic into the focus of its research efforts on prediction. Thereby it will contribute to programmes such as PPP, YOPP and GIPPS and thus close the gap that the bias of previous European and international research efforts on lower latitudes has produced. APPLICATE is ambitious in its approach by addressing the problem from a wide range of perspectives – from fundamental research on forecasting system development, covering daily to seasonal as well as multi-decadal time scales, to user-engagement and dissemination. APPLICATE will advance the field by analysing sources of predictability and by developing new empirical forecast systems that will serve as benchmarks. Furthermore, prediction systems will be enhanced by incorporating improved process representation, improved initialisation and boundary strategies, increased resolution and novel ensemble generation techniques. Finally, APPLICATE will produce a comprehensive synthesis report that will provide recommendations for the enhancements of predictions in the Arctic and beyond.

**APPLICATE will bridge between weather and climate prediction communities** by focusing on diagnostics in the coupled Earth system that target mean model errors affecting all scales and that identify error sources at process level. APPLICATE will employ a hierarchy of models to investigate their sensitivity to process parameterizations at all scales. Further examples include cross-community developments such as complex sea ice models implemented in climate models and being tested in weather prediction mode, or sensitivity experiments revealing the linkage between polar regions and lower latitudes being relevant at all forecast ranges. Long-period datasets such as CMIP-type data, different types of reanalyses and operational weather prediction model output will form a unique database benefiting the entire research community.

#### *1.4.2 Innovation potential*

APPLICATE is novel in its approach by truly addressing the prediction and linkages problem across time scales and by bringing leading experts from the weather and climate prediction communities closer together to work collaboratively on common challenges.

APPLICATE will significantly improve operational prediction in the Arctic and beyond. This will be of direct socio-economic relevance, especially in the light of the opportunities and risks that economic development will bring in a rapidly changing Arctic. Furthermore, enhanced operational predictive capacity from daily to seasonal time scales, a more user-oriented approach to model assessment, and improved trustworthiness of climate change projections will improve the foundation underlying weather and climate services. Hence, APPLICATE will support EU policy by helping to “*generate economic value from available climate data and models and ongoing climate research*” and by making sure that “*scientific research is designed to provide demonstrable benefits and solutions to the challenges facing our society*”.

APPLICATE is also at the forefront of increasing the uptake of observational data, including those generated during YOPP. This will be achieved by making effective use of available observations for model development efforts, by improving forecasting systems, and by providing guidance on the best use of observations from a



prediction perspective. In summary, thus, APPLICATE will significantly enhance the return on the sizeable investments made in the global observing system.

Reanalysis products are being increasingly used for decision-making. Examples for users include commercial enterprises such as insurances. Given that the quality of reanalysis efforts hinges critically on the quality of the forecasting system used, APPLICATE research is destined to increase the fidelity of upcoming reanalyses in the Arctic, and hence the basis for decision making.

## **2. Impact**

### **2.1 Expected impacts**

#### *2.1.1. Expected impact set out in work programme and text of call*

**Expected Impact 1: “Improve capacity to predict the weather and climate of the Northern Hemisphere, and make it possible to better forecast extreme weather phenomena”**

The advancement of our capacity to predict the weather and climate of the Northern Hemisphere is the overarching ambition of APPLICATE. To achieve its goal, APPLICATE will concentrate on the following three key-areas: (i) Improved representation of Arctic key-processes and their linkages to lower latitudes in weather and climate models, spanning time scales from days to decades; (ii) Informing the design of the future Arctic observing system from a weather and climate prediction perspective, and (iii) Advancement of forecast initialization techniques for weather and climate models.

APPLICATE will improve of extreme weather forecasts in the Arctic, through its modelling efforts, which will advance the representation of the lower atmosphere to improve predicting near-surface weather parameters such as visibility and temperature, as well as improve exchange processes at the air-sea ice-ocean interface. APPLICATE will also address the simulation of hazardous weather including intense polar storms and cold air outbreaks. Furthermore, the development of sea ice models will be taken to the next level, through the use of new rheologies (e.g. elasto-brittle) and/or extremely high-resolution global configurations (e.g. 4 km in the Arctic Ocean), thereby laying the foundation for the prediction of extreme *environmental* conditions (e.g. sea-ice deformation and pressure).

APPLICATE will also contribute to the improvement of extreme weather forecasts and climate predictions in the Northern Hemisphere mid-latitudes by directly enhancing weather forecast capacity in the Arctic, which will lead to improved forecasts at lower latitudes (Jung et al. 2014a). These improvements will benefit a wide number of users through the active contribution of APPLICATE partners to information systems such as meteoalarm.info, a web-based service to warn people travelling in Europe of severe weather events. Furthermore, through comprehensive numerical experimentation, APPLICATE will provide an assessment of how Arctic climate change can impact extreme weather in the Northern Hemisphere mid-latitudes. APPLICATE partners will demonstrate how this information could be used by governments, businesses (e.g. the insurance industry) and society at large to adapt to inevitable climate variability and anthropogenic climate change.

Importantly, the APPLICATE consortium includes Europe’s leading weather and climate prediction centres, whose forecasts and services benefit the majority of European society. This is further ensured through the expected transition from research to operations and thus service-level as APPLICATE partners operate and contribute to existing C3S. The use of global prediction systems in APPLICATE, together with strong international collaboration (USA, Canada, Russia, China, Japan and South Korea), means that APPLICATE is destined to benefit non-European citizens as well.

**Expected Impact 2: “Improve the capacity to respond to the impact of climatic change on the environment and human activities in the Arctic, both in the short and longer term”**

APPLICATE will make significant contributions to the assessment of CMIP6, with a special emphasis on Arctic climate change. This assessment will update the 5<sup>th</sup> Assessment Report (AR5), taking into account recent advances in model development, observations and process knowledge.

Through its dedicated and coordinated model development efforts, APPLICATE will improve the representation of Arctic processes, using CMIP6 models as a baseline. APPLICATE will test the impact of the model enhancements (“CMIP6-Interim”) and provide a substantial contribution from Europe to the analysis of the CMIP6 experiments in the Arctic. Furthermore, APPLICATE will provide recommendations for future coupled model intercomparison projects, especially CMIP7.

APPLICATE will develop user-relevant metrics and diagnostics that can be used for both model assessment and to determine the impact of climate change. Examples for such diagnostics include length of the growing season, ocean temperatures and boundaries of different water masses for fisheries and sea-ice-free regions for shipping.

APPLICATE will also contribute to the growing need for reliable and accurate short-term weather and environmental prediction (Fig. 1) in a changing climate. This will be achieved through the strong NWP development activities in APPLICATE that will benefit from an improved understanding of the processes governing climate time scales.

The capacity to respond to the impact of climatic change also depends on engaging the new generation of scientists, therefore APPLICATE will provide a set of training activities and materials to improve the skills and competences of those working and being trained to work within this subject. The training component will be the legacy towards the next generations of scientists.

**Expected Impact 3: “Improve the capacity of climate models to represent Arctic warming and its impact on regional and global atmospheric and oceanic circulation”**

The amplified warming in the Arctic in response to climate change is associated with the presence of stable boundary layers, which prevent vertical mixing due to turbulence and convection. Arctic warming is also associated with strong positive feedbacks involving the coupled atmosphere-sea ice-ocean system. APPLICATE will evaluate and improve the representation of these processes, which will lead to significant improvements in the ability of climate models to represent Arctic climate. Furthermore, the enhancement of sea ice models, together with increased resolution, will improve the representation of the sea ice edge. This has implications for the atmospheric response to sea ice changes, and the forecasting of cold air outbreaks, polar cyclones and other atmospheric phenomena that also affect lower latitudes.

APPLICATE will also explore the benefit of substantially increasing the horizontal resolution of ocean models in regions of strong Arctic-Atlantic exchange such as at the Fram Strait. Hence, APPLICATE has the capacity to make considerable progress in modelling the impact of Arctic climate change on the North Atlantic Ocean circulation. This will directly benefit seasonal to decadal prediction capacity and enhance the trustworthiness of longer term climate change projections. For the latter, the Arctic influence on the variability of the North Atlantic sub-polar gyre and the much-discussed stability of the North Atlantic Meridional Overturning Circulation (AMOC) will be addressed.

**Expected Impact 4: “Improve the uptake of measurements from satellites by making use of new Earth observation assets”**

APPLICATE will improve the uptake of measurements from satellites in two ways. Firstly, satellite data will play a pivotal role in APPLICATE’s model assessment and therefore development efforts. Existing and new Earth observations, such as sea ice thickness from CryoSat2 and SMOS as well as ice drift from SAR images, will be used to thoroughly evaluate the next generation of sea ice models with enhanced dynamics and thermodynamics, taking into account new approaches to introduce the observational uncertainty into the analysis. New satellite data, that turn out to be valuable for model assessment activities, will be made available to the wider scientific community through incorporation in the Observations for Climate Model Intercomparisons (Obs4MIPs) data-base.

Secondly, the model development efforts of APPLICATE will also have an indirect impact on the uptake of satellite data by operational centres, i.e. improving the representation of sea ice and snow in forecast models will improve the quality of the first guess in data assimilation. This will enable the assimilation of more high-quality satellite data, with direct benefits for predictions on daily to decadal time scales.

**Expected Impact 5: “Lead to optimised observation systems for various modelling applications”**

APPLICATE will contribute to optimised observations for various modelling applications. Firstly, a gap analysis will help to identify important shortcomings in the existing observing system. This will be achieved in APPLICATE by analysing existing data from reanalyses in the Arctic and by diagnosing current data assimilation systems using advanced diagnostics (e.g. forecasting sensitivity to observations). APPLICATE will also carry out an assessment of how much forecasts could be improved by filling the gaps in the existing observing system. This will be achieved by carrying out numerical observing system experiments with both atmosphere-only and coupled systems.

Finally, APPLICATE will synthesize the results, and make recommendations for the design of the future Arctic observing system, taking into account the needs of the prediction and model development communities, and by considering results from other related activities (e.g. H2020 BG-9, *An Integrated Arctic Observation System*). In this context, YOPP will be a major platform for synthesizing and disseminating the outcomes of APPLICATE, while APPLICATE will become a key European contribution to YOPP. Recommendations will also feed into the agenda-setting process of the European Commission through collaboration with the EU-PolarNet project.

**Expected Impact 6: “Contribute to a robust and reliable forecasting framework that can help meteorological and climate services to deliver better predictions, including at sub-seasonal and seasonal time scales”**

The concept of APPLICATE is strongly geared towards developing robust and reliable operational forecasting and numerical models across time scales. APPLICATE will make substantial contributions in the area of model development, forecast initialization and observing system design, cross-pollinating ideas to address the challenges faced by NWP and climate-change communities. Since leading weather and climate prediction centres in Europe are partners in APPLICATE, advances will be embedded within meteorological and climate services resulting in the much-needed improvement in Arctic predictions and subsequent linkages to other latitudes at sub-seasonal-to-decadal time scales.

It is essential to consider user requirements for developing meteorological and climate services. In this context, the User Group (UG) established by APPLICATE will play a critical role in co-designing some of the forecasting related research activities. UG will identify the relevant variables and metrics where the impact of the forecast system developments needs to be measured. The external user-specific perspective will provide feedback on the relevance of the results obtained in APPLICATE, and the way they are presented. The Group will operate following the spirit of the different frameworks for the development of climate services and conciliate them with the principles formulated by other initiatives like WWRP's Societal and Economic Research Applications (SERA) working group. Furthermore, an online tool for harnessing user feedback and virtual consultations and surveys will strengthen user engagement and provide a wider perspective on the challenges, discrepancies, misconceptions and issues overlooked by the experts.

***Expected Impact 7: “Improve stakeholders’ capacity to adapt to climate change”***

APPLICATE will improve stakeholders’ capacity to adapt to climate change through a comprehensive analysis of the latest generation of climate models (CMIP6), which will contribute to the next IPCC assessment report. APPLICATE aims to improve the trustworthiness of climate change projections through an improved representation of important Arctic processes in next generation climate models (CMIP6–Interim, CMIP6 and CMIP7). Furthermore, APPLICATE will contribute to narrowing the uncertainty of climate change projections (CMIP5 and CMIP6) by exploiting the concept of emergent constraints, leading to a greater adaptation capacity.

Importantly, APPLICATE will increase the stakeholder-relevance of its research by developing a set of user-relevant diagnostics (e.g. ocean temperatures for fisheries; sea ice free regions for shipping in the Arctic and at lower latitudes) developed after consulting key stakeholders in the Arctic and in mid-latitudes. In this context, the pro-active approach towards users will maximize the anticipated impact by continuously taking into account user needs via interactions with the User Group, workshops, meetings, interviews with key stakeholders and virtual consultations and surveys.

***Expected Impact 8: “Contribute to better servicing the economic sectors that rely on improved forecasting capacity (e.g. shipping, mining)”***

APPLICATE’s core scientific activities will feed into enhanced operational predictive capacity across time scales. The sectors targeted by APPLICATE include shipping, insurance and consulting companies, banks and investment firms, as well as tourism. A wide range of stakeholders and users will be consulted to effectively exchange the new knowledge from enhanced predictions. The operational centres involved in APPLICATE disseminate crucial forecasting information to many stakeholders within Europe and beyond (e.g. ECMWF has 22 member states and 12 cooperating states). Through its strong forecast and climate information user engagement, APPLICATE will be able to take user needs into account, and communicate the latest advances in forecasting system development to those needing trustworthy predictive information for decision making.

***Expected Impact 9: “Contribute to the Year of Polar Prediction (YOPP) and IPCC scientific assessments, and to the Copernicus Climate Change (C3S) services”***

APPLICATE will make significant contributions to the different components of YOPP (Jung et al. 2014b):

- Contribute to the *YOPP Modelling Component* by improving the representation of key Arctic processes in models, by providing prediction data such as the *YOPP Analysis and Forecast Data Set* (WP6) to the scientific community, and by determining polar-lower latitude linkages along with their relevance for prediction;
- Contribute to the *YOPP Observation Component* through its efforts in Arctic observation system design;
- Contribute to the *YOPP Data Component* through publicly delivering forecasting data in a form that is consistent with the YOPP data strategy;
- Contribute to the *YOPP Education and Outreach Component* (i) by developing and implementing an educational programme in collaboration with APECS that is well-aligned with the YOPP goals and (ii) by disseminating YOPP-related results, coming out of APPLICATE, widely.

The connection between APPLICATE and YOPP is strengthened by the fact that many APPLICATE partners play leading roles in the planning and implementation of YOPP: Thomas Jung (AWI) is chair of the PPP steering group and therefore responsible for the planning and coordination of YOPP; Peter Bauer (ECMWF), Trond Iversen (MET

Norway), Gunilla Svensson (SU), Matthieu Chevallier (CNRS-GAME, Météo-France) and Jonny Day (UREAD) are all members of the PPP steering group; Francois Massonnet (UCL) is a CliC YOPP fellow, who plays a key role in defining WCRP-CliC's efforts in support of YOPP; APECS is partner in the development of the YOPP educational component.

APPLICATE will also contribute to upcoming IPCC scientific assessments:

- APPLICATE will carry out a thorough assessment of CMIP6 models in the Arctic by employing novel metrics and new observational data sets. The assessment will provide insight into the fidelity of CMIP6 models in simulating Arctic key processes, an aspect that was identified in the previous IPCC report as a weakness of the models available at the time.
- Coordinated experimentation carried out in APPLICATE will, for the first time, provide robust insight into the impact that Arctic climate change will have on the weather and climate of the Northern Hemisphere, including the ocean and extreme events.
- APPLICATE will provide insight into how model enhancements will (i) improve model fidelity in the Arctic, (ii) influence the response to enhanced greenhouse gas concentrations, and (iii) influence the impact of Arctic climate on lower latitudes.
- APPLICATE will explore the concept of emergent constraints for the Arctic to reduce the uncertainty of climate change projections.

APPLICATE will make significant contributions to the C3S by contributing to the following elements of the portfolio of service products:

- **Global reanalyses** will be improved especially through analysis of strength and short-comings of existing systems; through the provision of more realistic models (e.g. representation of sea ice); and by guidance for the design of an improved Arctic observing system.
- **Multi-model seasonal forecasts** will be improved by enhancing some of Europe's most advanced seasonal forecasting systems (Met Office, Météo-France and ECMWF) that contribute to the EUROSIP multi-model ensemble.
- **Climate projections at global and regional scales** will be considered in APPLICATE by assessing the realism of CMIP6 models; by exploring the concept of emergent constraints to narrow the uncertainty of projections; and by improving the representation of Arctic key-processes in European climate models participating in CMIP6. These activities have the potential to increase the trustworthiness of climate change projections and thus contribute to developing mitigation strategies that are in line with the outcome of Paris 2015 UN climate change conference (COP21), namely to keep a global temperature rise this century well below 2 degC and to drive efforts to limit the temperature increase even further to 1.5 degC above pre-industrial levels. On top of this, substantial efforts to support the provision of information for adaptation strategies to climate variability and change, both in the Arctic and beyond, have been planned in APPLICATE. It is hoped that these efforts will satisfy some of the adaptation recommendations raised by the participants at the COP21.

***Expected Impact 10: “Improve the professional skills and competences for those working and being trained to work within this subject area”***

APPLICATE directly contributes to the education and training of the next generation of polar scientists by developing a strong educational program in collaboration with APECS that will increase the professional skills and competences. With its extensive experience in providing training and opportunities for early career researchers and in promoting education as an integral component of polar research, APECS is an effective channel for increasing the impacts of APPLICATE.

The APPLICATE education plan, which will be aligned with the educational component of YOPP, will:

- Provide online training materials and recordings of online activities (e.g. webinars) accumulated into an online repository serving as a legacy of APPLICATE for the next generation of scientists and early career experts
- Include an open and free online course on “Advancing predictive capacity of Northern Hemisphere weather and climate”
- Organise a unique and high-level summer school for PhD students and postdoctoral researchers and in connection to YOPP Summer School covering some of the theories and methods used within APPLICATE.

Furthermore, APPLICATE partners will incorporate relevant new knowledge in “in-house” training activities such as seminars, university lectures and courses on weather and climate prediction.

***2.1.2. Any other substantial impacts not mentioned in the work programme***

APPLICATE provides substantial further impacts that go well beyond the impacts mentioned in the work programme:

- Although the focus of the research will be on the Northern Hemisphere in general and the Arctic region in particular, significant indirect benefits can be expected for the Southern Hemisphere and Antarctica as well. This is especially true for the area of model development and for research activities related to the improvement of initial conditions and observing system design. Furthermore, some of the research activities could provide a blueprint for corresponding activities for the Southern Hemisphere (e.g., coordinated experiments aimed at understanding the impact on mid-latitude weather and climate).
- The use of global forecasting systems in APPLICATE opens up the opportunity for other communities to exploit the data in a different context. Perhaps one of the most prominent examples is the global *YOPP Analysis and Forecast Data Set* provided through APPLICATE and made available to the public already during the project. This data set will include high-resolution analysis and forecast fields (out to 14 days) for the YOPP core period from mid-2017 to mid-2019. Strong interest for using this data set has been expressed by the Science Steering Committee of the Years of the Maritime Continent (YMC) – an international programme with the goal of *Observing the weather-climate system of the Earth's largest archipelago to improve understanding and prediction of its local and global variability* (see letter of commitment by the co-chairs of the YMC). **Thus, APPLICATE has not only the potential to improve mid-latitude predictions directly from an Arctic but also indirectly from a tropical perspective.** In the context of the outcome of the COP21 last December in Paris, the APPLICATE partners will follow closely the developments of the new mitigation and adaptation agendas, particularly in Europe, and will be flexible to adapt its activities to the priorities identified, particularly in aspects like the illustration of the Arctic vulnerability and the additional need for adaptation to the potential influence of a changing Arctic into lower latitudes.
- The unique combination of weather and climate science experts in the consortium performing novel studies on state-of-the-art prediction systems will demonstrate the effectiveness of applying sophisticated diagnostics across time scales, common model developments and identify key elements of future seamless prediction systems. This benefit is by no means limited to polar applications but applicable to all latitudes. It also links to similar joint activities focusing on the computing and data handling aspects of weather and climate prediction that is established in the Centre of Excellence in Simulation of Weather and Climate in Europe (ESiWACE). Several partners of APPLICATE are also involved in this project, namely ECMWF, Met Office, BSC, CERFACS.

### 2.1.3. Barriers/obstacles for achieving expected impacts

APPLICATE represents the first concerted effort at a European level to address the challenges of (i) enhancing predictive capacity in the Arctic and (ii) determining the impact of Arctic climate change on the weather and climate in Northern Hemisphere mid-latitudes. However, a longer-term commitment in the assessment of the impact of an improved predictive capacity can be anticipated from all stakeholders to overcome one of the biggest challenges that the weather and climate prediction communities are facing and to provide a sustained return for society – both in Europe and beyond.

Traditionally, there is lack of “open data“ culture in the community, particularly when it comes to operational data. APPLICATE will apply the open policy requested by the EC and will actively look for external partners interested in exploring relevant output of the experiments performed in the framework of the project. An example for this approach is the provision of the YOPP Analysis and Forecast Dataset, a two-year long time series covering the YOPP core period.

There is a gap in the understanding of **cultural differences** between local communities and the scientific community, particularly those in the natural sciences. This may pose obstacles when it comes to effectively engaging with local communities. This issue will be addressed by building on existing networks.

There is a lack of consensus on the impact of a changing Arctic on lower latitudes weather and climate. Consensus may be necessary, however, to engage some of the potentially interested parties (European energy sector, crop yield forecasters and agricultural managers etc.) in the project from the beginning. The participation of the project partners in several international fora where these issues are discussed in detail will allow the project to be kept updated on the progress in other continents and promote the conclusions reached during the project implementation. Besides, the stakeholders will be kept regularly informed, using an appropriate language, of the conclusions of the scientific community about this important issue.

Finally, there may be a possible lack of well-trained personnel on issues such as the end-user engagement in high latitudes or climate modelling to start the work at strength from the early stages of the project. The partners have a strong reputation in the field of modelling, prediction, user-engagement and education, which should help in attracting excellent personnel. Furthermore, the partners have started to identify profiles and engage with professional associations that could help to find the necessary workforce. In addition, some of the partners are

increasingly engaged with student programmes at the graduate and master level (psychology, marketing, economy, etc.) where the appropriate profiles are formed.

## 2.2 Measures to maximise impact

To maximise the impact of the project activities and outcomes, APPLICATE has a strong emphasis on user engagement, dissemination and training. APPLICATE has selected three highly-experienced organizations with extensive experience in maximising impact: the **Arctic Portal** (AP), the Earth Sciences Department of the **Barcelona Supercomputing Center** (BSC), and the **Association of Polar Early Career Scientists** (APECS) represented by the UiT-Arctic University of Norway (UiT). In WP7 (*User-engagement, dissemination and training*), the three partners responsible for user engagement, dissemination and training and will be supported by AWI (the project coordinator).

**AP** has a very strong track record in communicating and disseminating the outcomes of scientific projects at local/national level (to national authorities and national associations), European level (to European institutions and associations) and circumpolar Arctic (to the Arctic Council, business community and organisations representing indigenous people). AP has extensive experience in engaging stakeholders and enabling exposure to Arctic-related information and data.

**BSC** is the supercomputing provider for public research in Spain with a strong programme in training in computing and big data. BSC has a dedicated communication team that has demonstrated the benefits of supercomputing to many different scientific fields, including weather, climate and air quality, and to engage with a wide range of stakeholders and users at different levels. In addition, the Earth Sciences Department hosts a team of multi-disciplinary scientists working to foster the development of climate services for both the public and private sectors, with a special focus on energy and food production and a special link to the Joint Research Centre of the European Commission. This team is pioneering the implementation of the principles of the different climate services frameworks, is involved in several C3S initiatives and is investing in the implementation of new user-engagement strategies.

**APECS** has an extensive experience in providing training and opportunities for career development for both traditional and alternative polar and cryosphere professions, as well as in promoting education and outreach as an integral component of polar research. By hosting a network of more than 5,000 polar researchers across disciplines and national boundaries APECS provides an effective channel for increasing the impacts of APPLICATE.

To achieve the maximum impact of APPLICATE, user engagement, dissemination and training will be developed to increase the awareness of the improved ability to predict Arctic changes and their impact on the weather and climate of the Northern Hemisphere amongst a wide range of users and stakeholders. APPLICATE will utilise modern communication tools for online facilitation and the most efficient channels for communication and dissemination of both information and data to users, stakeholders and the general public. This is augmented by tailor-made training activities to improve the professional skills and competences among those working within this subject area.

A crucial step towards maximising impact is to identify the **key, primary and secondary users**, and engage them in two-way communication and co-production of results. In order to do this effectively, the appropriate and tested structures need to be in place. Especially in the area of user identification, APPLICATE will build on previous experiences, including relevant users that have been identified in initiatives implemented by APPLICATE partners: YOPP, Polar Prediction Project, PRIMAVERA, EUPORIAS, EU-PolarNet, European Climate Research Alliance, IMO, WCRP, WWRP, RCOFs, WMO, ECOMS2, ESCAPE, ACCESS, WISC, SECTEUR, Preparatory Action on Strategic Environmental Impact Assessment of Development of the Arctic, ICE-ARC, INTERACT, and others. APPLICATE defines users by three categories:

**(i) Key users: Scientific community and intergovernmental organisations** benefit from advancements in model development, predictive capacity and understanding of the impact of Arctic changes on the weather and climate of the Northern Hemisphere as well as from educational activities. There is a wide range of beneficiaries, from individual scientists working on related topics all the way to networks of scientists working collaboratively together in networks and projects (e.g. US Sea Ice Prediction Network and US CLIVAR Arctic-Midlatitude Working Group). Furthermore, research departments in operational weather and climate prediction centres with an interest in polar regions will directly benefit. Importantly, APPLICATE will directly support coordinated international research efforts. Enabling development of improved weather and environmental prediction services for the polar regions, on time scales from hours to seasonal, for example, will directly benefit the World Meteorological Organization's (WMO) Polar Prediction Project within WWRP. APPLICATE outputs will also be relevant to scientific community umbrella institutions and projects such as the European Climate Research Alliance (ECRA), International Arctic Science Committee (IASC), EU-PolarNet, as well as to the working groups of the Arctic

Council and experts of international organisations such as the International Maritime Organisation (IMO). APPLICATE partners have strong links to these organizations and communities, with many consortium members being directly involved within their activities.

(ii) **Primary users: Private sector stakeholders** benefit from enhanced operational predictive capacity across time scales. The forecast improvements at hourly-to-decadal timescales developed by APPLICATE will lead directly to improved services for the economic sectors that rely on forecasts. Insurance, shipping, tourism, mining and fisheries industries are increasingly in need of weather and climate information on these timescales and effective transfer of new knowledge is a crucial component. APPLICATE members have strong relations with stakeholders within Europe and beyond (e.g. ECMWF has 22 European member states and 12 cooperating states). This allows not only user needs to be incorporated into the development of forecasting systems, but also the exploration of well-established two-way communication channels between the consortium and those needing trustworthy forecasts on which to make decisions. Outputs of APPLICATE will directly contribute to private sector stakeholders allowing them to adjust products and services according to science-based information. **Public sector stakeholders** benefit directly from the improved forecasting capacity provided by APPLICATE. Already established national networks of APPLICATE consortium members together with engaged national authorities will become effective co-designers of APPLICATE via workshops, the User Group and feedback tools. Active engagement in APPLICATE will help the public sector to shape the necessary actions and instruments (including financial) to address future challenges. As the accurate weather and climate predictions are of high importance to public sector stakeholders, not only in the Arctic but also in mid-latitudes, APPLICATE will communicate with targeted users on the national level with face-to-face meetings. Direct engagement of users via workshops, meetings and User Group builds trust and understanding and incorporates user requests and suggestions in APPLICATE activities, which eventually provides public sector stakeholders with the information they need to make high quality decisions. Active engagement and the two-way information exchange between APPLICATE and its key and primary users provides stakeholders with access to the expert network, serves as an additional link between science, private and public sectors, and therefore supports smart, sustainable and inclusive growth in accordance with the Europe 2020 strategy.

(iii) **Secondary users: General public/society/communities including indigenous peoples** – weather and climate change can have large impacts on the environment and human societies. Climate change and weather extremes (such as flooding, fires, storm surges, heat waves and severe snowstorms) are therefore areas of great interest to the global community. Specific communities, however, are more likely to be engaged with specific issues, e.g. indigenous peoples in the Arctic and the impacts of regional Arctic climate change. The main outcomes of APPLICATE, that is an improved ability to simulate and predict changes in the Arctic and their impacts on the weather and climate of the Northern Hemisphere, will be of great interest to the general public and to specific communities.

#### **a) DISSEMINATION AND EXPLOITATION OF RESULTS**

APPLICATE's dissemination strategy covers all WPs, but it is specifically addressed in WP7: User engagement, dissemination and training is implemented by AP, BSC, and APECS represented by UiT. All APPLICATE partners have a solid track record of disseminating project results and pro-actively engaging users and stakeholders. APPLICATE will actively build upon the outreach activities of related national, European and international Arctic initiatives. Importantly, APPLICATE will work closely together with YOPP, as well as the upcoming BG9 and BG11 projects funded by Horizon2020 to multiply the effect of dissemination and user engagement.

This section describes the strategic approach that will be taken within APPLICATE to disseminate and maximize the impact of the project through dissemination, user engagement and training. The plan also addresses synergies with other relevant projects and initiatives, follow-up and exploitation, open research data, knowledge management, IPR and open access. More detailed plans will be produced at the beginning of the project relating to communication and dissemination (D7.2), user engagement (D7.3) and training (D7.4) to define the most relevant timeframes and sequences of interactions. These individual plans will be consistent with each other and will be revised and updated when needed to ensure their integration into the project as a whole.

The implementation of the dissemination and exploitation strategy will rely on the following critical pro-active approaches:

- Integration of dissemination and communication efforts throughout and within APPLICATE;
- Effectiveness of communication flow within APPLICATE and with users;
- Involvement of stakeholders in an active dialogue with APPLICATE to elicit user need and perspectives;
- Diversity of dissemination and two-way communication tools according to different audiences;
- Accessibility of disseminated results and project legacy.
- Co-production of outcomes and results with users and stakeholders;

The APPLICATE's strategic approach will be flexible, innovative and user-relevant and will include the following components to develop the approaches mentioned above:

### **a.1) DISSEMINATION**

Dissemination aims at maximizing exposure of the science produced to all audiences (scientists, end-users, stakeholders and the public at large) and aims at communicating project results, including collecting all available feedback, in order to assure knowledge sharing and knowledge exchange with stakeholders. Successful dissemination requires a comprehensive understanding of the perspective and needs of different audiences. We propose a comprehensive set of modern communication tools for online facilitation, and the most efficient channels for communication, dissemination and exploitation including:

- **APPLICATE Website:** The APPLICATE official website (we have purchased the [www.apply.eu](http://www.apply.eu) domain) will provide a high-level description of the project and its objectives aimed at the general public and users. The website will also contain more detailed outputs, such as links to scientific publications, public reports, general information, and news and dissemination material. Initially, the website will be set up to provide a project identity (for example, providing visual identity materials and templates for partners in their password protected area) and promote early engagement with other EU projects, international initiatives and communities. In the second phase, the structure and content will be critically revised, taking into account feedback collected from both partners and stakeholders, and modified accordingly (MS7.5) to serve more specific needs: promoting project results with high impact multimedia communication material, disseminating promotional campaigns of the project through social media (Facebook and Twitter accounts), publishing press releases and providing online feedback mechanisms to the target audiences, including the users and stakeholders contacted in Task 7.2. The website will include a compilation of training resources relevant for early career researchers in the APPLICATE project. Maintenance and updates of on-line content will be outlined in the communication and dissemination plan (D7.2).
- **Social media campaign:** The social media campaign covering Facebook and Twitter will utilise the modern forms of communicating science to wide audiences across the globe. By regular updates on project progress, news and events, activities and results, as well as information related to relevant APPLICATE topics, the social media campaign will assure strong online visibility of the project. Using visual forms of communication including photos, graphs, maps etc. we intend to make APPLICATE more attractive and accessible to the general audience. The campaign will also take advantage of all partners' social media resources to multiply the dissemination effect and visibility of the project.
- **Visual identity materials:** APPLICATE visual identity materials including the APPLICATE logo, letterhead, report template, meeting template, and power point templates will provide consistent branding for the project.
- **Dissemination materials:** Dissemination materials will be created to present a selection of project activities and results. Material will be mainly online (although some printed material will be made available at key events) and will include brochures, leaflets, factsheets, etc. The materials will be made available in different versions to accommodate to the various levels of experience in weather and climate and needs of those audiences and will be revised regularly to accommodate the feedback provided by the three categories of users. Materials will be available in English.
- **Press releases:** In addition to engagement with various users, APPLICATE proposes targeted media outreach action involving national newspapers, media outlets specialising in weather and climate (e.g. [climatebrief.org](http://climatebrief.org)), and EU policy and specialist media. Building upon media interest, APPLICATE will develop targeted press releases for both the general and specialist press to share results of the project with a wider audience. Press releases will include both information material and visual materials i.e. graphs, photos etc. The communication departments of the APPLICATE partners will support press releases with national languages versions where appropriate.
- **Project reports:** The project deliverables that are in report format and defined as public will be made openly accessible on the APPLICATE website to widely share useful results and conclusions.
- **Papers for peer-reviewed literature:** Scientific papers created within APPLICATE will be published in open access peer-reviewed literature to reach the scientific community. Scientific papers will be advertised through the website.
- **Promotion and dissemination of results in international fora of relevance:** To strengthen the role of the project as a base of cutting edge research, the project will be advertised and explained during relevant international events, particularly outside the EU. Additional promotion, dissemination of results and illustration of the implications (e.g. impact and opportunities for socioeconomic sectors) will help strengthen project recognition and role of the EU in commissioning internationally leading research. Special attention will be given to the interaction with other projects with a strong coordination and support objectives (H2020



ECOMS2, C3S activities, and especially the contribution to YOPP).

*Table 3 First list of selected international fora of relevance*

Event name	Expected audience	Date
YOPP planning meetings	Scientists, operational prediction centres, observational community, projects and institutions that plan to make significant contributions to YOPP	Sep 2016
YOPP launch event	Scientists, national weather services, WMO member state representatives, international organizations stakeholders, general public	Jun 2017
Arctic Circle 2017-20	Stakeholders, policy makers, scientists	Oct 2017-20
Arctic Frontiers 2017-20	Stakeholders, policy makers, scientists	Jan 2017-20
EGU 2017-20 (scientific sessions, town-hall meetings)	Scientists, press	Apr 2017-20
Arctic Science Summit Week 2017-2020	Scientists, Arctic Council, press	Mar 2017-20

- **FrostBytes videos:** Production of FrostBytes videos, which are short videos (up to 60 seconds) from the Summer School that explain to the general public what research participants are conducting (public outreach activity). FrostBytes will be also posted on external websites, for instance, that of APECS.
- **On-line training material:** APPLICATE aims to promote the next generation of polar scientists. To this end an on-line repository of training materials will be created by APPLICATE jointly with APECS. This repository includes recordings of the webinar series and online courses provided as an open resource on the websites of the APPLICATE project and that of APECS.

## **a.2) USER ENGAGEMENT**

To maximise impact and knowledge exchange and to elicit feedback from users, it is crucial to proactively engage with groups of interest within and outside the EU. The APPLICATE partners have developed over time a network of contacts among potential users and stakeholders. Private-sector stakeholders include companies involved in polar shipping such as the Arctic Expedition Cruise operators (Friggs, Hapag-Lloyd), shipping companies (A.P. Møller-Maersk, COSCO, Hanjin Shipping Company, Mitsui O.S.K. Lines, ICS), the insurance industry with emphasis on Shipping and Polar Code issues (DWF London, Lloyd's, GARD, Norwegian Hull CLUB, DNV GL, Marsh's Global, SKULD), research expedition logistics, etc. Furthermore, we plan to engage large consulting companies with previous experience regarding the Arctic (McKinsey & Company, the Boston Consulting Group, Bain & Company, Deloitte Consulting, Booz Allen Hamilton, PricewaterhouseCoopers Advisory Services LLC, EY LLP Consulting Practice, Accenture, KPMG LLG Consulting Practice, IBM Global Business Services). Representatives of relevant regional and global mining companies (Glencore Xtrata, BHP Billiton, Rio Tinto, Vale, Anglo American, China Shenhua Energy, Freeport McMoRan, Barrick Gold, Coal India Limited, Fortescue Metals Group) will be encouraged to participate in user engagement activities. Banks, investment firms and business analysts (PT Capital, Commerzbank Germany, Credit Agricole CIB France, HSBC Holdings PLC United Kingdom, BNP Paribas France, China International Capital Corporation, Mizuho Financial Group, Mitsubishi UFJ Financial Group) are also potentially interested in APPLICATE results. The users will be invited to participate in the APPLICATE.

In the mid-latitudes, there is also strong interest in the impacts and opportunities of potential changes in the Arctic and related changes in lower latitudes of the Northern hemisphere from users in the energy sector. Users that have already expressed an interest include energy trading firms (EnBW, EDF trading), transmission system operators (UK National Grid, Red Eléctrica Spain, France TSO RTE), wind farm owners/investors (EDPR, GE, IBERDROLA) and energy consultants (DNV-GL, AWS Truewind, Vortex). Agriculture related stakeholders such as the Joint Research Center or private wineries (Torres, Sogrape) will also be engaged.

The full list of users that will be approached by APPLICATE will be categorized in key, primary and secondary users as described above and further detailed in the user engagement plan (D7.3) with their level of use of weather and climate information. Engaging users will be based on three main components:

- **User Group:** A group of users and stakeholders will be established. This will help support the APPLICATE by providing, i) an external user-specific perspective and feedback on the relevance and presentation of project outcomes and ii) an external perspective on user needs. The group will be composed from 7-10 representatives from private and public sector stakeholders. The WP7 co-leads will chair the group and organize its meetings. The group will meet regularly either in person or on-line.
- **Workshops, meetings at professional conferences and interviews with key stakeholders:** To illustrate the

benefits of improved weather and climate forecasts to a range of stakeholders in the Arctic and mid-latitudes, APPLICATE partners will participate in relevant external events or initiatives organized by the target sectors (half-a-day events at professional conferences rather than general-purpose workshops). APPLICATE workshops and interviews will provide direct feedback from a user perspective by actors not usually linked to the weather and climate research communities. These activities will be jointly organized with other EU projects such as PRIMAVERA, IMPREX or C3S contracts such as CLIM4ENERGY, WISC and SECTEUR.

- **Virtual consultations and surveys:** An on-line user feedback tool for collecting feedback and organizing virtual consultations will improve the interaction with the stakeholders identified by the project. The virtual tools will provide additional feedback mechanisms and traceability (always respecting all due confidentiality), while providing a wider perspective on the challenges, discrepancies, misconceptions and important issues overlooked by the experts. The outcome of this task will be provided to the key players in the C3S User Interface Platform to ensure a long-lasting and wider impact of this effort.

By continuously taking into account user needs via the User Group, workshops and meetings at professional conferences, interviews with key stakeholders and virtual consultations and surveys APPLICATE will increase the stakeholder-relevance of its research and hence directly improve stakeholders' capacity to adapt to climate change. By pro-active user-engagement the latest advances in forecasting system development can be effectively communicated to and benefit those economic sectors that rely on improved forecasting capacity. Furthermore, knowledge exchange with and feedback from users within APPLICATE will be utilized to contribute to YOPP, IPCC scientific assessments, and to the C3S.

### a.3) TRAINING

Training aims to improve the professional skills and competences of those working and being trained to work within this subject area. We see the training component as the legacy that APPLICATE creates towards the next generations of scientists and early career experts. All training materials, recorded webinars, lectures and presentations from the summer school will be provided as an open resource on the website of APPLICATE and the website of APECS. The tailor-made set of training activities will include:

- **On-line networking tools:** Networking tools for increasing connection and training opportunities for early career researchers will include: a) an email list, b) the compilation of a thematic website with skill training resources relevant for early career researchers in the APPLICATE and the other projects that will serve as an open resource, and c) dedicated "mentor" sessions connecting early career and senior researchers involved in the project at meetings and workshops related to the project throughout the project.
- **Webinar series:** Webinar series in connection with the APPLICATE project and directed towards early career researchers (but open to the general public) will introduce the APPLICATE project and increase the awareness about the impact of Arctic changes on the weather and climate of the Northern Hemisphere. The webinars will be recorded and provided as an open resource on the websites of the APPLICATE project and APECS.
- **On-line course:** An online three-month course on "Advancing predictive capacity of Northern Hemisphere weather and climate" will be organized for early career scientists (but open to anyone interested) with weekly interactive online sessions. Materials will be provided as an open resource on the websites of the APPLICATE project and APECS.
- **Summer school:** A summer School for PhD students and postdoctoral researchers from APPLICATE partners organized jointly with the YOPP Summer School will provide a unique, high-level, summer school program for 30 PhD students and postdoctoral researchers, covering some of the theories and methods used within the research project. This 10-day training course will be organized by UiT and other project partners in cooperation with other external partners. Members of APPLICATE are running a Polar Prediction School in April 2016 organized by WCRP-CLIC and APECS in Abisko Field Station, in Northern Sweden. The APPLICATE summer school will build on this experience and aim at including YOPP as co-sponsor for the proposed summer school. Participants of the summer school will also create short FrostBytes videos on their research projects. FrostBytes and materials from the summer school will be provided as an open resource on the websites of the APPLICATE project and APECS.

### a.4) Synergies with EU projects, international committees and steering groups

Effective coordination and communication with other national, European and international activities will be a key factor for maximizing the impact of APPLICATE. As outlined in WP8 on Clustering, this will be achieved through a pro-active approach towards cooperation with relevant ongoing activities. However, APPLICATE will also exploit the fact that many of its PIs participate in relevant EU projects, international committees and steering groups (Table 2.2.2). These PIs will serve as ambassadors for APPLICATE and help to widely disseminate relevant project information to the scientific community, policy makers and stakeholders.

Table 4 *APPLICATE synergies with other initiatives through selected project ambassadors*

Partner	Project/committee
<b>T. Jung,</b> AWI	<ul style="list-style-type: none"> <li>- Chair of the steering group of the Polar Prediction Project overseeing the planning and implementation of YOPP</li> <li>- Co-chair of the Arctic programme of the European Climate Research Alliance (ECRA)</li> <li>- Member of the WMO Executive Council Panel of Experts on Polar Observations, Research and Services (EC-PORS, since 2011)</li> <li>- Coordinator of the Galway theme <i>Arctic-Atlantic Interplay</i></li> <li>- Member of the US CLIVAR Arctic-Midlatitude Working Group</li> </ul>
<b>F. Doblas-Reyes,</b> BSC	<ul style="list-style-type: none"> <li>- Coordinator of the FP7 project SPECS</li> <li>- Co-chair of the World WCRP's Working Group on Seasonal to Interannual Prediction</li> <li>- Member of the World Climate Research Programme's Modelling Advisory Council</li> <li>- Member of the ENES High-Performance Computing Task Force</li> <li>- Member of the H2020 ECOMS2 Coordination and Support Action</li> </ul>
<b>P. Bauer,</b> ECMWF	<ul style="list-style-type: none"> <li>- Coordinator of the H2020 project ESCAPE</li> <li>- Co-coordinator of the H2020 project ESiWACE</li> <li>- Member of the WWRP Scientific Steering Committee</li> <li>- Member of the PPP steering group</li> <li>- Member of the European Space Agency Scientific Advisory Committee</li> </ul>
<b>H. Johannsson,</b> AP	<ul style="list-style-type: none"> <li>- Chair of Outreach Board of China-Iceland Aurora Observatory station</li> <li>- Member of the consultancy panel of the H2020 project EU-PolarNet</li> <li>- Member of the steering group of the European Polar Board</li> <li>- Member of the Steering Group of SAON</li> <li>- IASC/SAON Arctic Data Committee</li> <li>- Board Member of Iceland Arctic Cooperation Network</li> <li>- UArctic Council Member</li> <li>- Leading Expert in Communication and Outreach: Changing Permafrost in the Arctic and its Global Effects in the 21st Century (FP7 project PAGE21)</li> </ul>
<b>G. Fugmann,</b> UiT, APECS	<ul style="list-style-type: none"> <li>- Executive Director of the Association of Polar Early Career Scientists (APECS)</li> <li>- Member of the Steering Committee for the Arctic Frontiers conference</li> <li>- Member of the Steering Committee for US NSF funded EarthCube RCN for High-Performance Distributed Computing in the Polar Sciences</li> </ul>

#### **a.5) Follow-up and exploitation**

APPLICATE is committed to continue research after the end of the project funding period and to continue the exploitation of the results produced within the project. This includes, for example, the implementation of APPLICATE results into operational prediction systems and the incorporation of sea ice-ocean models in 'weather' prediction. Many of these exploitation activities (e.g. operational implementation and publications) will be carried out under the umbrella of the YOPP Consolidation Phase (mid-2019 to 2022, Jung et al. 2014b), whose purpose it is to generate a long-term legacy. It is also our ambition to strengthen the network that will contribute to the research on the impact of Arctic changes on the weather and climate of the Northern Hemisphere. We are convinced that our dissemination strategy approaches will be of interest to a wide audience, which will result in future opportunities to continue the research.

The consortium will closely monitor funding possibilities including the Horizon 2020 programme. Supported by the consortium and its User Group, the Project Coordinator will maintain a constant dialogue with relevant representatives from National Contact Points for the APPLICATE consortium to be able to provide input to the planned funding instruments and Horizon 2020 draft Work Programmes. Furthermore, special attention will be paid to the funding instruments for transatlantic cooperation regarding research on forecasting system development and the impacts of Arctic changes on the weather and climate globally. APPLICATE has also received commitment letters from the Korea Maritime Institute and the Polar Research Institute of China and will seek further cooperation and funding possibilities. Finally, the Project Coordinator will give annual status updates to the Advisory Board on potential follow-up and exploitation of results. Additionally, calls for proposals under national funding agencies will be monitored.

#### **a.6) Open Research Data**

The APPLICATE partners are expected to produce a large number of weather and climate simulations. These simulations are of very different character because they try to respond to various questions, which are linked between them through the Arctic focus of their origin. At the same time, the public availability of the data produced

is a key part of the dissemination in a project of this type. The heterogeneity of the simulations made the partners in charge of this task to consider a holistic approach. In this approach, the documentation of the experiments, the data formatting with an appropriate documentation, the technology chosen for the dissemination, the data curation and the assurance that the methodology chosen complies with the standards of the different communities involved (both weather and climate) will be considered in a single plan for data dissemination.

The project will produce mostly model data. As indicated in Tab. 2, most of the data will be made publicly available. This is especially true for all multi-model experiments, including those designed to establish the impact of Arctic climate change on mid-latitudes. A large number of forecast experiments will be also made publicly available. This includes seasonal forecasting experiments carried out in WP5 as well as the YOPP Analysis and Forecast Data Set (produced and disseminated in WP6). Some of the observational data sets gathered for model evaluation will be considered for dissemination through the Obs4MIPs data-base.

APPLICATE data management is based on a metadata driven approach through which standardised discovery metadata (compatible with GCMD DIF and ISO19115) are used to describe datasets and interfaces to these. Formatting data using NetCDF following the Climate and Forecast convention provides self-explaining datasets which relates to UNIDATAs Common Data Model allowing automated utilisation of the datasets and long term data preservation. All results will be maintained for at least 10 years. Metadata will be exposed using OAI-PMH and data using THREDDS Data Server and HTTP, OGC WMS and OPeNDAP primarily.

#### **a.7) Knowledge management, Intellectual Property Rights and open access**

The management of Intellectual Property Rights (IPR) for APPLICATE will be the responsibility of the Management Support Team. This Team will follow up publications, licensing, patents and other exploitation of the results. They will advise the Coordinator and the partners about IPR issues. The IPR and confidentiality issues will be developed in the Consortium Agreement. The Management Support Team is in charge of advising and warning the Coordinator and Partners about the management of the pre-existing know-how and knowledge. By doing so, the team will anticipate and help solving the problems of IPR shares at the start of the project, provide advice about possible extensions of the tasks that offer new patenting possibilities, and deliver a fair and efficient use of the knowledge produced by APPLICATE. All scientific publications made during the project will be made available in a project repository according to the “green” model for open access. However, APPLICATE strongly advises all authors to consider using the “gold” model if possible.

#### **b) COMMUNICATION ACTIVITIES**

Communication in APPLICATE is designed to develop and utilize the most relevant forms of communication within and outside the EU (and possibly national) services to adequately spread results that could be used for either policy or socioeconomic action. APPLICATE will update the outline provided below in the Communication and dissemination plan (D7.2) to define the goals and objectives of communication, and to provide a full framework for the development of communication tasks along the lifetime of the project detailing target audiences, communication tools and channels, key messages and practical information such as branding project style, logo, guide, templates, etc. This plan will be revised and updated during the project lifetime.

- **Internal** communication within APPLICATE will assist with timely completion of tasks and deliverables and contribute towards a better integration through and across WPs. Face-to-face and online meetings of APPLICATE teams and the yearly General Assembly will strengthen the scientific-relations between consortium members. Mailing lists and personalized user accounts on the APPLICATE website, as well as joint groups on APPLICATE’s Facebook account will contribute to the smooth implementation of the project. Communication via email, video conferencing, Skype and phone will be encouraged to contribute to the cost effectiveness, family friendliness and reduced environmental impact of APPLICATE activities (for example, through JPI-Climate Friendly Research policy). By this informal, yet effective communication approach APPLICATE promotes openness and aims at creating a flexible working environment.
- The APPLICATE **external** communication will be based on communication principles outlined in H2020’s ‘Communicating EU research and innovation guidance for project participants’ document as published on 25 September 2014. To ensure the cost effectiveness of the external communication, APPLICATE will follow the EU principles of economy, effectiveness and efficiency, as it will be described in the Grant Agreement. Specifically with regard to the communication means, online digital methods will be used whenever possible. These will be backed up by printed or physical communications tools only where necessary (including APPLICATE leaflets, roll-ups and brochures). APPLICATE consortium members rely on experienced and widely connected communication services of their institutions. Highly-experienced teams of the Arctic Portal (AP), Science Communication, Earth Sciences Department of the Barcelona Supercomputing Center (BSC), and APECS represented by the UiT-Arctic University of Norway (UiT) will be responsible for the external

communication of APPLICATE. The communication will further benefit from the support of the communications service of all the consortium members, and from the experience of AWI from EU-PolarNet and other international projects and activities.

*Table 5 APPLICATE communication activities by target audience*

Target audience	Communication measures	Objective	WPs
Scientific community and intergovernmental organisations i.e.: WMO, PPP, WWRP, ECRA, SIPN, CLIVAR, IASC, EU-PolarNet, AC, IMO.	<ul style="list-style-type: none"> <li>- Website <a href="http://www.applycate.eu">www.applycate.eu</a></li> <li>- Social Media campaign</li> <li>- Visual identity materials</li> <li>- Dissemination materials</li> <li>- Press releases</li> <li>- Project reports</li> <li>- Papers for peer-reviewed literature</li> <li>- Promotion and dissemination of results in international fora of relevance</li> <li>- FrostBytes videos</li> <li>- On-line Training material</li> <li>- Workshops, meetings at professional conferences and interviews with key stakeholders</li> <li>- Virtual consultations and surveys</li> </ul>	<ul style="list-style-type: none"> <li>- provide an online information repository on APPLICATE</li> <li>- utilize modern forms of communicating science</li> <li>- provide consistent branding/recognition of APPLICATE</li> <li>- present project activities and results</li> <li>- provide information to experts from topic-oriented press</li> <li>- sharing result and conclusions of APPLICATE</li> <li>- contribute to the scientific community</li> <li>- strengthen recognition of APPLICATE and the EU as a state-of-the-art research provider</li> <li>- explain what research participants are conducting</li> <li>- support the next generation of polar scientists</li> <li>- illustrate the benefits of weather and climate forecasts with improved polar representation</li> <li>- provide a wider perspective from scientific community</li> </ul>	7
APPLICATE consortium	<ul style="list-style-type: none"> <li>- General Assemblies (GAs)</li> <li>- Work Package meetings</li> <li>- Website <a href="http://www.applycate.eu">www.applycate.eu</a></li> <li>- Mailing lists</li> <li>- Password protected area of the website</li> </ul>	<ul style="list-style-type: none"> <li>- internal communication</li> <li>- better information flow</li> <li>- provide central information point for APPLICATE</li> <li>- organized and efficient internal communication</li> <li>- internal area dedicated for consortium members</li> </ul>	9, 7
Polar Early Career Scientists	<ul style="list-style-type: none"> <li>- On-line networking tools</li> <li>- Webinar series</li> <li>- On-line course</li> <li>- Summer school</li> <li>- Website <a href="http://www.applycate.eu">www.applycate.eu</a></li> <li>- Social Media campaign</li> </ul>	<ul style="list-style-type: none"> <li>- increase connection to YOPP and other initiatives</li> <li>- increase training opportunities</li> <li>- provide education for 30 PhD students and postdoctoral researchers</li> <li>- provide an online information repository on APPLICATE</li> <li>- utilize modern forms of communicating science</li> </ul>	7
Private sector stakeholders (shipping, insurance industry, consulting companies, mining industry, banking and investment sector, energy sector) in the Arctic and in the mid-latitudes	<ul style="list-style-type: none"> <li>- User Group</li> <li>- Workshops, meetings at professional conferences and interviews with key stakeholders</li> <li>- Virtual consultations and surveys</li> <li>- Face-to-face meetings</li> <li>- Website <a href="http://www.applycate.eu">www.applycate.eu</a></li> </ul>	<ul style="list-style-type: none"> <li>- support the project with an external perspective</li> <li>- illustrate benefits of forecasts within APPLICATE and incorporate feedback from stakeholders</li> <li>- increase interaction with users</li> <li>- collect and exchange information and knowledge</li> <li>- general promotion and providing information</li> </ul>	7

Public sector stakeholders (regional authorities, organizations, coast guards, ship-owners associations, chambers of commerce)	<ul style="list-style-type: none"> <li>- User Group</li> <li>- Workshops, meetings at professional conferences and interviews with key stakeholders</li> <li>- Virtual consultations and surveys</li> <li>- Face-to-face meetings</li> <li>- Website <a href="http://www.applycate.eu">www.applycate.eu</a></li> </ul>	<ul style="list-style-type: none"> <li>- support the project with an external perspective</li> <li>- illustrate benefits of forecasts within APPLYCATE and incorporate feedback from stakeholders</li> <li>- increase interaction with users</li> <li>- collect and exchange information and knowledge</li> <li>- general promotion and providing information</li> </ul>	7
General public/society/communities including indigenous peoples	<ul style="list-style-type: none"> <li>- Website <a href="http://www.applycate.eu">www.applycate.eu</a></li> <li>- Social Media campaign</li> <li>- Dissemination materials</li> <li>- Press releases</li> <li>- Project reports</li> <li>- User Group</li> <li>- Workshops</li> <li>- FrostBytes videos</li> <li>- Virtual consultations and surveys</li> </ul>	<ul style="list-style-type: none"> <li>- provide understanding on impacts and opportunities of potential changes in the Arctic</li> <li>- Raise awareness about APPLYCATE</li> <li>- organize and maintain engagement to harness feedback from communities</li> </ul>	7
Media	<ul style="list-style-type: none"> <li>- Website <a href="http://www.applycate.eu">www.applycate.eu</a></li> <li>- Dissemination materials</li> <li>- Press releases</li> <li>- FrostBytes videos</li> <li>- Workshops, meetings at professional conferences and interviews with key stakeholders</li> </ul>	<ul style="list-style-type: none"> <li>- provide an online information repository on APPLYCATE</li> <li>- present project activities and results</li> <li>- provide popularized information to press</li> <li>- explain what research participants are conducting</li> <li>- illustrate the benefits of weather and climate forecasts with improved polar representation</li> </ul>	7, All
International fora outside the EU	<ul style="list-style-type: none"> <li>- Social media campaign</li> <li>- Visual identity materials</li> <li>- Dissemination materials</li> <li>- FrostBytes videos</li> </ul>	<ul style="list-style-type: none"> <li>- Integration with international stakeholders and projects</li> <li>- Ensure project visibility</li> </ul>	7, 9
EC Project Officer	<ul style="list-style-type: none"> <li>- Project reports</li> </ul>	<ul style="list-style-type: none"> <li>- Inform on project progress and results</li> </ul>	9
Other EU bodies and projects	<ul style="list-style-type: none"> <li>- Website <a href="http://www.applycate.eu">www.applycate.eu</a></li> <li>- Dissemination materials</li> <li>- Press releases</li> </ul>	<ul style="list-style-type: none"> <li>- Understanding impacts and opportunities of potential changes in the Arctic</li> <li>- Integration with other projects</li> </ul>	All

### 3. Implementation

#### 3.1 Work plan – Work packages, deliverables

The work plan builds on the iterative interaction between the different work packages centred around the central idea of using advanced metrics and diagnostics to observationally constrain weather and climate model (WP1); developing enhanced weather and climate models (WP3); determining the impact of Arctic climate change on mid-latitude weather and climate also considering linkages from a prediction perspective (WP3); providing support for the design of the future Arctic observing system (WP4); carrying our research on predictability and synthesising the results in order to deliver improved predictive capacity (WP5); supporting the scientific work packages through a strong data and HPC management component (WP6); employing effective user-engagement, dissemination of the results to a wide range of stakeholders and ensuring future recruitment opportunities by adequate education and training (WP7); ensuring effective collaboration with other ongoing and planned activities (WP8); and finally ensuring appropriate project management (WP9).

The dependencies and timings of the different work packages are presented in Figures 3 (Pert Chart) and 5 (Gantt Chart), the project work packages are detailed in Table 6, the work packages are listed in Table 7, and all deliverables are listed in Table 8. The major project milestones are listed in Table 10.



## Work package descriptions – Table 6 (#Tables 3.1a)

### WP1 ‘Weather and climate model evaluation’

Work package number	1		Lead beneficiary					AWI, UREAD (Co-lead)					
Work package title	Weather and climate model evaluation												
Participant number	1	2	3	4	5	7	8	9	10	11	12	15	16
Short name of participant	AWI	BSC	ECMWF	UiB	UNI Research	Met Office	UCL	UREAD	SU	CNRS-GAME	CERFACS	IORAS	MGO
Person/months per participant:	24	5	12	1	2	10	19	23	2	18	18	33	25
Start month	1			End month				48					

#### Objectives

- Develop metrics and diagnostics that facilitate effective model assessment (Arctic-specific, process-oriented, user-relevant);
- Incorporate new metrics in ESMValTool and make them available to all project partners and the wider scientific community;
- Apply existing and newly developed metrics and diagnostics to assess models used across time scales;
- Develop a new generation of process-based heat budget diagnostics to narrow model uncertainty in Arctic climate change response;
- Explore the concept of emergent constraints in an Arctic context to narrow the uncertainty of climate change projections;
- Develop and apply diagnostics that can be used to infer atmospheric and oceanic linkages from observational and model data sets;
- Provide guidance for the model development activities in APPLICATE and beyond.

#### Description of work and role of participants (in bold, task leaders)

##### WP1 will be led by AWI (Thomas Jung) and UREAD (Len Shaffrey).

The aim of WP1 is threefold. Firstly, an Arctic-specific framework, entailing advanced metrics and diagnostics for model assessment and analysis, will be developed and disseminated through ESMValTool to the APPLICATE partners and the wider scientific community. Secondly, this framework will be applied to establishing a baseline understanding of the realism of models across time scales, which will provide insight into the mechanisms governing Arctic climate change and the linkages between the Arctic and the rest of the Northern Hemisphere. Thirdly, the concept of emergent constraints will be explored to test the possibility of narrowing the uncertainty of regional climate change projections.

##### Task 1.1 – Development of a model assessment plan (AWI, UREAD, UCL, IORAS) (M1-M4)

This task will develop a detailed plan (**D1.1**) that outlines the model assessment strategy of APPLICATE exploiting the concept of metrics and diagnostics, and utilizing comprehensive sets of observational data. The focus of Task 1.1 will be on expanding the subset of metrics currently available in ESMValTool. The plan will also include details for an ESMValTool training workshop that will be held during the Kick-off meeting (Month 3). The plan will be developed in close cooperation with other related European and international activities.

##### Task 1.2 – New targeted metrics for model assessment (AWI, CERFACS, CNRS-GAME, UiB, UREAD, UCL, SU, UNI Research, BSC, IORAS, MGO) (M1-M24)

##### Task 1.2.1 – Development of process-based metrics for the Arctic and implementation in ESMValTool (AWI, SU, CNRS-GAME, UCL, UiB, UNI Research, IORAS, MGO) (M1-M12)

This task will develop a series of metrics to enable the assessment of the ability of weather and climate models to represent processes important for the Arctic. Emphasis will be placed on those processes being targeted in APPLICATE’s model developments efforts (WP2). This includes atmospheric boundary layer and clouds, snow on sea ice, sea ice dynamics and thermodynamics, atmosphere-sea ice-ocean coupling as well as the circulation and water mass characteristics in the Arctic Ocean. This task will also consider other aspects such as the atmospheric circulation and storm track activity. Central to this task is gathering relevant high-quality observational data sets, both from existing (e.g. Obs4MIPs- and reanalysed) and new sources (e.g. Earth observations). Key-metrics will be made available through ESMValTool (**D1.2**).

##### Task 1.2.2 – Co-Development of user-relevant impact metrics and implementation in ESMValTool (UREAD, AWI, BSC, IORAS) (M1-M12)



This task will co-develop with stakeholders a series of metrics with stakeholders (as defined in section 2.2 of the proposal) interested in the impacts and opportunities of potential changes in the Arctic and their effects on the Northern Hemisphere. Initial conversations that APPLICATE partners have held with stakeholders have revealed the following list of possible foci: ocean temperatures for fisheries; sea ice free regions for shipping; severity and frequency of strong winds associated with storms as a hazard to shipping, fishing vessels and coastal communities; winds for wind farm operators and transmission systems; temperature and precipitation for food security in the Arctic and beyond. This task will co-develop the list of user-relevant metrics together with stakeholders. Key-metrics will be made available through ESMValTool.

**Task 1.2.3 – Development of metrics that describe linkages in atmosphere and ocean and implementation in ESMValTool (CNRS-GAME, AWI, CERFACS, UREAD, IORAS) (M1-M24)**

This task will develop metrics that can be used to quantify and assess linkages between the Arctic and the Northern Hemisphere atmosphere and ocean. This includes developing diagnostics to investigate mass, heat and fresh water fluxes through the passages connecting the North Atlantic and Arctic Oceans. Here the focus will be on Fram Strait, the Barents Sea and the Canadian Arctic Archipelago. Furthermore techniques will be developed to quantify interannual lead-lag relationships between Arctic sea ice/Siberian snow cover and the AO/NAO and ENSO. Finally, the flow-dependence of atmospheric Arctic-mid-latitude linkages will be addressed by investigating changes in the equator-to-pole temperature gradients in the lower troposphere, upper troposphere and lower stratosphere, and their impact on mid-latitude jet streams, storm tracks and blocking across the Northern Hemisphere. Key-metrics developed in this task will be made available through ESMValTool (D1.2).

**Task 1.2.4 – Development of novel sea ice metrics from YOPP intensive observing periods and implementation in ESMValTool (UCL) (M1-M36)**

YOPP will include several intensive observing periods (IOPs) during which comprehensive observational datasets will be generated. This task will work with YOPP observational groups to develop new sea ice metrics focused on specific processes and/or feedbacks which will be robustly sampled even though the observing periods are relatively short (e.g. heat conduction through sea ice and sea ice albedo feedback). These novel metrics will be used for the assessment of models in Task 1.3. The novel metrics will also be disseminated to the groups participating in the YOPP IOPs, thereby further establishing links between modelling and observational experts. Metrics will be made available through ESMValTool (D1.3)

**Task 1.3 – Assessment of weather and climate prediction models (UREAD, AWI, ECMWF, MGO) (M9-M48)**

This task will assess the ability of weather and climate models to represent key processes in the Arctic, linkages between the Arctic and Northern Hemisphere, and user-relevant metrics. The assessment will serve as the baseline from which the model developments carried out in WP2 of APPLICATE will be evaluated.

**Task 1.3.1 – Assessment of CMIP5 and CMIP6 climate models (UREAD, AWI, MGO) (M9-M30)**

This task will initially assess the metrics developed in Task 1.2 in the CMIP5 HISTORICAL simulations and the CMIP5, RCP2.6, RCP4.5 RCP6.0 and RCP8.0 climate change simulations. This assessment will determine i) the systematic errors in the CMIP5 models and ii) the ensemble mean and inter-model spread in CMIP5 climate projections. Particular attention will be paid to assessing the sampling uncertainties in metrics that arise from the internal variability inherent in observations and climate models. As they become available during 2017, the WP1 metrics will be used to assess the CMIP6 climate model simulations, especially those carried out by the APPLICATE partners. The assessment of CMIP6 models will also identify any potential reductions in systematic errors between CMIP5 and CMIP6 and potential changes in climate projections. This task will also provide the baseline assessment for model developments in WP2 and inform the numerical experiments in WP3 (D1.4).

**Task 1.3.2 – Assessment of NWP systems (ECMWF) (M12-M48)**

This task will establish and test the diagnostic framework that will be applied to short-to-medium range predictions and initial conditions to establish sources of model error in WP2 and the impact of observational data in WP4. The task will contribute to the revision of atmosphere and snow model components in WP2 and guide observing system experiments in WP4. Novel diagnostics targeting the coupled surface-atmosphere-snow-sea ice system will be developed and applied to identify key sensitivities in coupled models and key sources of model error. These diagnostics will also be used to support the model development in single-column mode (WP2, Task 2.2.1).

Diagnostics linking the contributions from individual physical processes to model tendencies and analysis increments in the atmosphere will be developed. These diagnostics will allow model error to be traced back to individual processes represented in the short-range forecast. Furthermore, statistics of analysis increments will enable the impact of observations in the analysis to be evaluated (WP4, Task 4.1.2).

The statistics from ensemble data assimilation can also be used to assess model and observation contributions to ensemble spread in NWP systems. This provides guidance for model error formulation in ensemble systems, but

also information on the observational impact in the analysis. This will be further exploited in WP4, Task 4.1.1 and 4.1.2. This task will also support recommendations for operational monitoring and evaluation capabilities dedicated to polar requirements. A demonstration of such monitoring will be introduced with a focus on surface radiation, cloud and snow observation networks and satellite retrievals.

#### **Task 1.3.3 – Synthesis: Growth of model error across time scales (AWI) (M24-M36)**

In this task, the insight gained from Tasks 1.3.1 to 1.3.2 will be synthesized to improve our understanding of the processes that lead to common model errors in both weather and climate models. To this end, also the YOPP Analysis and Forecast Data Set (WP6) will be exploited. This understanding will enable APPLICATE to identify error in climate models that are determined by processes occurring on shorter time scales of hours to weeks. This in turn will inform the model development activities in WP2. Understanding the commonalities in error growth will also help foster the exchange of ideas for model development between the weather and climate modelling communities.

#### **Task 1.4 – Assessment of the Arctic heat budget in climate models (Met Office, CERFACS, IORAS) (M12-48)**

This task will assess the ability of the climate models used in APPLICATE to represent the seasonal cycle and long-term trends in the heat budget of the Arctic – including atmosphere, ocean, sea ice and snow components. Building on the approach of Keen et al. (2013), the assessment of the Arctic heat budget will identify important feedbacks and processes that govern Arctic climate variability and change.

A more detailed assessment of the heat budget of the Arctic Ocean will also be performed. It will focus on the links between changes in oceanic heat transport into the Arctic and Arctic sea ice. The vertical mixing processes that redistribute heat within the Arctic Ocean, and thus lead to impacts on sea ice, will also be evaluated. The ability of the APPLICATE models to capture the observed heat budget of the Arctic will be evaluated using the metrics developed in Tasks 1.2 and Tasks 1.3. Coordinated analysis of the CESM climate model will also be performed at NCAR in the US. A synthesis of the two heat budget approaches will be made (D1.5). This task will also contribute to the IPCC through SIMIP (Sea Ice Model Intercomparison Project).

This task will be done in collaboration with colleagues from NCAR.

#### **Task 1.5 – Assessing the utility of observational emergent constraints in reducing the uncertainty of CMIP5 and CMIP6 climate change projections in the Arctic and mid-latitudes (Met Office, CERFACS, CNRS-GAME, UCL, UREAD) (M12-M48)**

This task will explore the potential of the metrics and analysis in Tasks 1.2, 1.3 and 1.4 to provide observational emergent constraints on climate model projections. Emergent constraints are metrics which show strong relationships between the biases in historical climate model simulations and the sensitivity of climate projections. An example of an emergent constraint is the relationship found between biases in Arctic sea ice cover and future trends in CMIP3 climate models (Boé et al, 2009). Emergent constraints potentially enable the uncertainty in climate model projections to be reduced, since projections from climate models with smaller biases should be more plausible. Emergent constraints in the Arctic will be investigated using biases in the seasonal cycle, past trends, interannual variability, and their relationship with Arctic climate change. Emergent constraints will also be investigated in the context of links between the Arctic and Northern Hemisphere atmospheric and oceanic circulation, e.g. through changes in Arctic warming, in the equator-to-pole temperature gradient and in subsequent impacts on mid-latitude atmospheric circulation. A synthesis of the results on emergent constraints will be made (D1.6).

#### **Deliverables (brief description and month of delivery)**

- D1.1 Model assessment plan (M4)
- D1.2 Provision of process-focused, user-relevant and Arctic linkages metrics through ESMValTool (M12)
- D1.3 Provision of novel metrics, which can be effectively determined from short time series, through ESMValTool (M24)
- D1.4 Assessment of CMIP5 and CMIP6 experiments including recommendations for model development activities in WP2 (M30)
- D1.5 Report on the synthesis of heat budget approaches for the Arctic (M48)
- D1.6 Report on potential for emergent constraints to reduce uncertainty in projections of Arctic climate and linkages to Northern Hemisphere circulation (M48)

#### **WP2 ‘Enhanced weather and climate models’**

<b>Work package number</b>	2	<b>Lead beneficiary</b>	SU, CNRS-GAME (Co-lead)
<b>Work package title</b>	<b>Enhanced weather and climate models</b>		

<b>Participant number</b>	1	3	5	7	8	<b>10</b>	11	12
<b>Short name of participant</b>	AWI	ECMWF	UNI Research	Met Office	UCL	<b>SU</b>	CNRS-GAME	CERFACS
<b>Person/months per participant:</b>	20	15	19	11	44	<b>58</b>	43	12
<b>Start month</b>	1			<b>End month</b>		48		

### Objectives

- Improve models in their representation of Arctic weather and climate through improved process descriptions, more consistent coupling methodology and a better representation of feedbacks;
- Develop innovative methods, using observations and a variety of model configurations, to facilitate parameter optimization for physical processes in coupled model systems for NWP and climate;
- Assess the added value of the APPLICATE development on process representation in weather and climate models in the Arctic.

### Description of work and role of participants (in bold, task leaders)

#### **WP2 will be led by SU (Gunilla Svensson) and CNRS-GAME (Matthieu Chevallier).**

Improved modelling capabilities will be achieved through improved process descriptions in the various components of the models. Our primary targets will be to address well-known problems in processes that contribute to momentum transfer at the surface and to the surface energy budget. Other improvements are related to coupling processes between the atmosphere and the land or sea-ice/ocean surface. A novel approach of a coupled single-column model will be extensively used as an intermediate step to constrain the model physics towards fully coupled modelling for NWP and climate. Based on a set of coordinated model experiments, using available and coming observations, we will assess the impact of model improvements.

#### **Task 2.1 – Improve process representation (M1-M42)**

##### Task 2.1.1 – Improve description of atmospheric processes (SU, CNRS-GAME, AWI) (M1-M36)

This task will focus on the representation of the atmospheric boundary layer (ABL) and clouds that strongly impact the energy and moment exchange at the surface. An improved description of these atmospheric processes is expected to be important for forecasts on time scales spanning weather to climate. Recently developed schemes for the atmospheric ABL and surface exchange will be tested. Information from Large-Eddy Simulation (LES) and observations will also be used to better constrain parameters in cloud and cloud microphysics schemes, with the goal to improve the representation of their effect on the surface radiative energy fluxes. The improved process descriptions will be incorporated in the atmospheric model components that are shared by NWP (IFS, AROME and ARPEGE) and climate models (EC-Earth and CNRM-CM). This will allow for assessing their impact for both weather and climate time scales.

##### Task 2.1.2 – Improve description of snow on land and sea ice (ECMWF, CNRS-GAME, UCL) (M1-M20)

The focus of this task is to achieve a better representation of snow on the land surface and on sea ice. The role of snow in the surface energy balance is well known. Over sea ice, it directly contributes to the sea ice heat/mass balance. A good knowledge of the snow cover is also needed for satellite retrieval of sea ice thickness. Given the high vertical heterogeneity of the snow cover, multi-layer snow models are well adapted to capture the different types of snow.

At CNRS-GAME, a multi-layer snow scheme will be implemented in the sea ice model (GELATO), with the same complexity as the snow scheme present in the land surface module of CNRM-CM (SURFEX). UCL will refine its already comprehensive representation of snow over sea ice by accounting for the sub-grid scale distribution of snow depth and by improving the formulation of the radiative transfer through snow. An advanced multi-layer snow scheme will be implemented in the IFS over land and the UCL-model will be imported over sea ice. The initialisation of snow will be performed based on the developments in WP4, Task 4.3. Observational data will be used in the model development and for evaluation.

##### Task 2.1.3 – Improve sea ice properties affecting the momentum transfer between the atmosphere and ocean, and the surface energy budget (CNRS-GAME, UCL, Met Office) (M1-M18)

The descriptions of surface properties and processes in the different sea ice models used in climate models will be improved, focusing on aspects that directly impact the energy and momentum budgets. Parts of these developments will benefit NWP models that share the sea ice component of a climate model (IFS, AROME, ARPEGE).

Existing parameterisations for melt ponds will be implemented and/or refined in CICE and GELATO. This will allow a better representation of the seasonal cycle of the surface albedo, and it will provide new prognostic information on the surface roughness. New parameterisations for the surface roughness will be tested in CICE and

GELATO, including form drag. This will allow for a better representation of the energy transfer from the atmosphere to the ocean through sea ice, and will contribute to the improved representation of ABL done in Task 2.1.1. Parameterisations for land-fast ice will be included in GELATO and LIM3, which will allow for a more realistic representation of sea ice growth in some areas of ice formation. The representation of lateral ice melt will also be improved, and an ice-floe size distribution will be included in LIM3. Thus, the representation of the seasonal cycle of sea ice formation/melting will be more realistic.

Such developments will also be included in the sea ice component of the Canadian systems (Environment and Climate Change Canada), depending on resources.

**Task 2.1.4 – Improve the representation of oceanic circulation and sea ice conditions in the Arctic (UNI Research, AWI, Met Office, CERFACS, UCL) (M24-M42)**

In this task, the role of enhanced horizontal resolution in the representation of the Arctic Ocean circulation and sea ice conditions will be explored. The focus will be on exchange processes at the Arctic gateways: Bering Strait, Fram Strait and the Barents Sea Opening. Outflows of Arctic water through the Canadian Arctic Archipelago should also benefit from a better representation of the different channels due to enhanced resolution.

The role of enhanced resolution will be explored using unstructured meshes (AWI-CM). AWI-CM will be run globally with horizontal resolutions typical for CMIP6 climate models; except the Arctic, where it will be increased to 4 km. Met Office will use a global configuration with zooms over selected areas (Arctic gateways to the North Atlantic Ocean). NorESM will be run in global configuration with 0.25° nominal horizontal resolution (~10 km in the Arctic) of ocean and sea ice components (D2.6).

The role of novel sea ice rheology schemes (Maxwell elasto-brittle or anisotropic) will be assessed in LIM3 and CICE. In FESOM sea ice module, new schemes for sea ice dynamics will be tested, based on an adaptive version of the widely used Elasto-Viscous-Plastic rheology. These schemes will be more stable and numerically more efficient to get converging solutions. Furthermore, a multi-column ocean module that resolves exchanges of mass, momentum and energy for each sea ice thickness category will be implemented in NEMO-LIM3 and tested in coupled mode in EC-Earth.

Tasks 2.3.1 and 2.3.2 will assess the improved representation of oceanic circulation and sea ice conditions in coordinated experiments.

**Task 2.2 – Improve atmosphere-sea ice-ocean coupling (M1-M36)**

**Task 2.2.1 – Test parameterizations and optimize parameters in the Single Column Model framework (SU, CNRS-GAME, ECMWF) (M1-M36)**

At the ocean-sea-ice-atmosphere, time steps, horizontal resolution, treatment of sub-grid scale heterogeneity and energy fluxes vary between the model components. The impact of these differences in comparison to the parameterisation issues are difficult to assess in the full global coupled model. A novel Single Column Model (SCM) framework will therefore be developed to help constrain the problem. The SCM will extend from the deep ocean, include the sea ice and snow, and continue through the atmosphere (D2.1).

Procedures will be developed on how to perform simulations in the SCM framework, handling the conceptual difficulties with different advection directions and speed of the subcomponents of the system, to be able to test new parameterisations in coupled mode and to constrain the coupling fluxes.

A number of test cases will be defined and run in coordinated SCM experiments with the aim to isolate errors in the representation of these parameterized processes and their influence on the surface energy fluxes. These will be designed based on existing past observations (e.g. SHEBA, AOE, ASCOS, ACSE, Eureka, Barrow and IAOOS buoys), LES cases and the coming intensive observing periods during YOPP (D2.4). It will be possible to study the full atmosphere-snow-sea ice-ocean system using the coupled SCM and observations, especially targeting the observations from the drifting station during MOSAiC<sup>3</sup> that will provide observations for the entire coupled column. The atmospheric-surface component of the SCM will be imported into the IFS and the coupling between surface, boundary layer and clouds will be evaluated in the full three-dimensional context. New diagnostics for coupled processes developed in WP1, Task 1.4 will be employed. Environment and Climate Change Canada plans to carry out similar experiments with an SCM based on GEM and CICE.

**Task 2.2.2 – Develop optimal coupling framework in global models (CNRS-GAME, SU, CERFACS, ECMWF,**

<sup>3</sup> The multi-disciplinary drifting Observatory for the Study of Arctic Climate is a planned year-round campaign (mid-2019 to mid-2020) that will provide detailed, and comprehensive measurements of the central Arctic Basin, extending from the atmosphere through the sea-ice into the ocean, As outlined in the MOSAiC science plan ([www.mosaicobservatory.org](http://www.mosaicobservatory.org)) "Developing a coupled ocean-ice-atmosphere single-column model would greatly facilitate such studies."

**Met Office) (M18-M30)**

In this task, the focus will be on implementing the best practices found from the SCM framework experiments (Task 2.2.1) into the global fully coupled models. Effects of how to aggregate fluxes, spatial heterogeneity on the sub-grid scale, and transfer of heat and momentum are issues that need to be optimized in the full three-dimensional coupled model. Temporal inconsistency also arises from the fact that the time steps of the ocean model, of the sea ice model and of the coupling are often different. We will use the SCM framework to compare the methodology used in a NWP model, where a more direct coupling is used, and using a flux coupler (OASIS) as is usually done in climate models. This will also include a comparison with models that use an alternative location for the atmosphere-sea ice interface. New approaches to improve the consistency of the full air-ice-ocean surface layer will then be implemented and tested in the three-dimensional configurations of IFS, EC-Earth and CNRM-CM. The experience gained in WP2 Task 2.2.1 from integrating the SCM-physics in the IFS will guide the recommendations (D2.2).

**Task 2.3 – Assess model enhancements in coordinated experiments (M12-M48)****Task 2.3.1 – Coordinate experiments for the evaluation of model enhancements (AWI, CNRS-GAME, SU, Met Office, UNI Research) (M12-M36)**

Model enhancements, as well as improvements of the coupling methodology, will be assessed in the five participating global climate models: AWI-CM, CNRM-CM, EC-Earth, HadGEM and NorESM. A numerical experimentation plan has been developed. The target is to be able to directly compare the performance of enhanced models to the set of CMIP6-DECK and CMIP6 historical experiments that will be run by all models outside the project, and that will be considered as “stream 1”.

Modelling centres will test the impact of each individual feature, using their usual practices (e.g. atmosphere-only or ocean-only modes and control runs). Once the implementation of model enhancement is completed, modelling centres will perform a “stream 2” suite of experiments, using a version of their models with the set of new features that appear the best based on their own evaluation. Stream 2 experiments will consist of a 200-year long control simulation under preindustrial forcing, a CMIP historical experiment, and a +1%CO<sub>2</sub> simulation.

**Task 2.3.2 – Assess the influence of model developments on the simulated state and dynamics of the atmosphere-sea ice-ocean system in the Arctic (UCL, CERFACS, AWI, UNI Research) (M24-M48)**

This task is devoted to the comprehensive analyses of coordinated experiments for assessing the benefit of new model developments in Task 2.3.1. It will use the metrics developed in WP1 and other related projects (e.g. PRIMAVERA). The focus will be put on a suite of dedicated diagnostic. This task will produce a an interim report (D2.5), that includes aspects related to: (i) changes in the various components of the Arctic surface energy budget (radiative, turbulent); (ii) changes in the transfer of momentum from the atmosphere to the ocean; (iii) the overall realism of the simulated climate system; (iv) effects on the Arctic Ocean circulation; and (v) changes in the Arctic climate sensitivity in the +1%CO<sub>2</sub> simulation. A synthesis report on priorities for future model developments in coupled models will be issued towards the end of the project (D2.7).

**Task 2.3.3 – Recommend model enhancements to be included in weather prediction systems (SU, CNRS-GAME, ECMWF, Met Office) (M24-36)**

This task aims at providing recommendations for weather prediction systems. Based on the tests run with SCM and climate models, a synthesis report will be produced (D2.3), in which the inclusion in NWP systems of selected model enhancements developed during APPLICATE will be discussed. This report will guide dedicated tests carried on within WP5 with participating NWP systems.

**Deliverables** (brief description and month of delivery)

- D2.1 Demonstrator of a fully coupled SCM (M18)
- D2.2 Recommendations on the coupling methodology in prediction and climate models (M30)
- D2.3 Recommendations on the inclusion of APPLICATE model enhancements in NWP models (M30)
- D2.4 Report on the application of the fully coupled SCM to test cases based on Arctic YOPP IOPs (M36)
- D2.5 Interim report on model developments and their evaluation in coupled mode (M36)
- D2.6 Report on the impact of increased resolution on the simulated Arctic Ocean circulation and on Arctic-Atlantic and Arctic-Pacific oceanic linkages (M40)
- D2.7 Synthesis on priorities for future model developments for coupled models (M48)

**WP3 ‘Atmospheric and oceanic linkages’**

Work package number	3		Lead beneficiary				MET Office, UiB (Co-lead)				
Work package title	Atmospheric and oceanic linkages										
Participant number	1	2	4	5	6	7	9	11	12	15	16

Short name of participant	AWI	BSC	UiB	UNI Research	MET Norway	Met Office	UREA D	CNRS-GAME	CERFACS	IORAS	MGO
Person/months per participant:	24	27	11	18	23	27	12	6	24	25	33
Start month	1			End month			48				

### Objectives

- Advance our understanding of the mechanisms by which the mid-latitude weather and climate could respond to the substantial Arctic climate change that is expected in the coming decades;
- Coordinate a suite of novel multi-model experiments designed to identify the oceanic and atmospheric linkages between the Arctic region and the northern mid-latitudes.

### Description of work and role of participants (in bold, task leaders)

#### WP3 will be led by Met Office (Doug Smith) and UiB (Helge Drange).

Coordinated multi-model experiments with coupled and atmosphere-only models will be performed to assess the impact of substantial Arctic sea ice depletion as expected in the coming decades on the atmospheric and oceanic circulation. The systematic use of coordinated multi-model experiments will minimize the potential model-dependence of the results and conclusions, which is a major concern in most existing studies. The models to be used in these experiments are summarized in Tab. 2. MGO will be participating with the atmospheric model MGO-3.

Analysis of these experiments will particularly focus on understanding the physical mechanisms, both thermodynamic and dynamic, through which Arctic climate change impacts mid-latitude weather and climate. This will include analysis of the North Atlantic Oscillation (including the potential role of wave-mean flow interactions), the strength of the Siberian High, the potential for sea ice anomalies to initiate Rossby wave trains with subsequent downstream influences over USA, Europe and Asia, and changes in the ocean including the AMOC.

#### Preliminary Task – Liaise with the international community over the design of coordinated multi-model numerical experiments to investigate the influence of Arctic sea ice decline on lower latitude climates prior to the start of the project (all partners, in kind contribution)

Our initial suggested experiments are detailed below, but the details may be changed slightly in order to be consistent with experiments to be performed by the international modelling community. International coordinated experiments will be discussed at a meeting at the Aspen Global Change Institute (July 2016, co-chairs Doug Smith, Clara Deser and James Screen) and at a meeting of the US CLIVAR Arctic Mid-latitude Working Group (tentatively scheduled for 1-3 February 2017).

In Tasks 3.1 to 3.6 the impact of Arctic sea ice will be assessed by comparing two ensembles of model integrations, a control ensemble generated with present day Arctic sea ice conditions, and a perturbed ensemble generated with reduced Arctic sea ice conditions.

#### Task 3.1 – Coupled model experiments to assess the impact of Arctic sea ice depletion on lower latitude climate (BSC, AWI, CERFACS, MET Norway, Met Office) (M1-M36)

Fully coupled model experiments are essential in order to simulate both oceanic and atmospheric linkages between the Arctic region and northern mid-latitudes and to include the effects of ocean-atmosphere coupling. This task will assess linkages on seasonal to inter-annual time scales (D3.1, D3.4) whereas Task 3.5 will assess decadal and longer time scales.

##### Task 3.1.1 – Control experiment. Coupled model constrained by observed sea ice (BSC, AWI, CERFACS, MET Norway, Met Office) (M1-M36)

Sea ice will be constrained by relaxing models to the monthly varying observed climatological average concentration over the period 1980 to 1999. Each simulation will be at least 12 months long, starting June 1<sup>st</sup>. At least 50 (preferably 100) ensemble members (generated by bit level perturbations to the initial conditions).

##### Task 3.1.2 – Perturbed Arctic sea ice experiment (BSC, AWI, CERFACS, MET Norway, Met Office) (M1-M36)

Repeat Task 3.1.1 but with reduced Arctic sea ice. This will be achieved by relaxing models to the monthly varying climatological average sea ice concentration and thickness over the period 2080 to 2099 from the ensemble mean CMIP5 simulations (RCP8.5 scenario).

#### Task 3.2 – Atmosphere-only model experiments to assess the impact of Arctic sea ice depletion on the atmospheric circulation (MET Norway, BSC, CERFACS, Met Office, MGO) (M1-M36)

Further understanding of the processes linking Arctic climate change with the northern mid-latitudes will be gained by repeating Task 3.1 but with atmosphere-only models. The comparison with Task 3.1 will allow some assessment

of the roles of atmospheric and ocean pathways and of ocean-atmosphere coupling (**D3.2, D3.4**). However, the model background state will also be different between Tasks 3.1 and 3.2, so that Task 3.3 is also required to fully assess the different factors.

**Task 3.2.1 – Control experiment (MET Norway, BSC, CERFACS, Met Office, MGO) (M1-M36)**

The atmospheric model forced by observed sea surface temperatures (SSTs) and sea ice. Models will be forced by monthly varying observed climatologies of sea ice concentration and SST averaged over the period 1980 to 1999. Each simulation will be at least 12 months long, starting June 1st. At least 50 (preferably 100) ensemble members (generated by bit level perturbations to the initial conditions).

**Task 3.2.2 – Perturbed Arctic sea ice experiment (MET Norway, BSC, CERFACS, Met Office, MGO) (M1-M36)**

Repeat Task 3.2.1 but with reduced Arctic sea ice. This will include the same sea ice concentration as used in the coupled model experiments (Task 3.1.2), with projected SSTs imposed where the sea ice has vanished.

**Task 3.3 – Atmosphere model experiments to assess how the response to Arctic sea ice depletion depends on the background flow (Met Office, BSC, CERFACS, MET Norway, MGO) (M24-M48)**

Differences between Tasks 3.1 and 3.2 can be caused by two factors: coupling or differences in the model background state (especially the climatological location and strength of the jet stream). This task will isolate the influence of the background state (**D3.4**). This will be achieved by repeating Task 3.1, but using climatological SSTs from the ensemble mean of the coupled model control experiments (Task 3.1.1). Tasks 3.1 to 3.3 will therefore enable the relative importance of the model background state and of ocean-atmosphere coupling on the linkages between the Arctic and mid-latitudes to be deduced.

**Task 3.4 – Atmosphere model experiments to assess how the response depends on the pattern of Arctic sea ice anomalies (Met Office, BSC, MGO) (M24-M48)**

Some studies suggest that sea ice changes in the Atlantic and Pacific sectors may have opposing influences on the mid-latitude atmospheric circulation. This task will investigate this possibility by repeating the perturbed sea ice experiments (Task 3.2.2) but imposing sea ice reductions in the Atlantic and Pacific (if resources allow) sectors separately (**D3.4**). This will improve our understanding of the physical processes, especially the potentially important role of interference between background waves and those induced by sea ice.

**Task 3.5 – Coupled model experiments to assess the decadal and longer time scale impact of Arctic sea ice on the ocean (CERFACS, AWI, UREAD, UiB, UNI Research) (M1-M36)**

**Task 3.5.1 – Control experiment (CERFACS, AWI, UREAD, UiB, UNI Research) (M1-M36)**

Coupled model simulations with present day sea ice (as in Deser et al 2015). They will start in 1990 and run for 75 years, with radiative forcing kept constant at year 2000 values.

**Task 3.5.2 – Perturbed Arctic sea ice experiment (CERFACS, AWI, UREAD, UiB, UNI Research) (M1-M36)**

Repeat Task 3.5.1, but with reduced Arctic sea ice by applying an artificially enhanced longwave heat flux warming over sea ice following Deser *et al.* (2015) to determine the impact of Arctic sea ice decline on longer time scales, especially for the ocean (**D3.3**). Specifically designed tracers will be used to map the transport and the age of key water masses leaving the Arctic, quantifying multi-model, large-scale, decadal to long-term changes in the ocean state induced by Arctic sea ice loss. Duration of the coupled model runs: 75 years.

**Task 3.6 – Improved coupled model experiments to assess the impact of Arctic sea ice depletion on lower latitude climate using improved models from WP2 (UiB, UNI Research, AWI) (M36-M48)**

This task will assess the impact of model improvements (**D3.4**) developed in APPLICATE by repeating Task 3.1 and/or 3.5, but using some of the improved models proposed by WP2. The improved understanding of the physical mechanisms through which the Arctic influences mid-latitude weather and climate gained from Tasks 3.1 to 3.5 will be used to assess the linkages simulated by the improved models.

**Task 3.7 – Study atmospheric linkages between the Arctic and mid-latitudes from a prediction perspective (AWI, CNRS-GAME, IORAS) (M1-M48)**

In this task the influence of the Arctic atmosphere on mid-latitude weather and climate will be studied from a prediction perspective (**D3.5**). More specifically, seasonal forecast experiments will be carried out in which the atmosphere is relaxed towards ERA-Interim data in the Arctic troposphere, leaving the model run freely elsewhere. This approach, which has been successfully applied by Jung et al. (2014a) for medium-range and subseasonal predictions during boreal winter, provides insight into the potential that enhanced predictive capacity in the Arctic has on mid-latitude forecast skill. Here, previous work will be extended by carrying out coordinated experiments with two different coupled models (EC-Earth and CNRM-CM) to explore sensitivity to model formulation. Furthermore, the forecasts horizon will be extended to include seasonal time scales, and spring, summer and autumn seasons will also be considered. Finally, the relaxation experiments will be thoroughly analysed, including

the verification of teleconnections, the diagnosis of mechanisms including storm tracks and the investigation of a possible flow-dependence of the atmospheric linkages.

**Deliverables** (brief description and month of delivery)

- D3.1 Report on coordinated coupled multi-model assessment of the seasonal to inter-annual impact of Arctic sea ice decline on lower latitudes (M36)
- D3.2 Report on coordinated atmosphere-only multi-model assessment of the seasonal to inter-annual impact of Arctic sea ice decline on lower latitudes (M36)
- D3.3 Report on coordinated coupled multi-model assessment of the decadal and longer impact of Arctic sea ice decline on lower latitudes (M36)
- D3.4 Final report on coordinated multi-model assessment of seasonal to inter-annual impact of Arctic sea ice decline on lower latitudes, including influence of background state and pattern of anomalies (M 48)
- D3.5 Report on the influence of the Arctic atmosphere on mid-latitude weather and climate and role for mid-latitude prediction (M48)

**WP4 'Support for Arctic observing system design'**

Work package number	4		Lead beneficiary				ECMWF, UCL (Co-lead)	
Work package title	Support for Arctic observing system design							
Participant number	1	2	3	7	8	9	11	
Short name of participant	AWI	BSC	ECMWF	Met Office	UCL	UREAD	CNRS- GAME	
Person/months per participant:	2	6	12	6	26	15	3	
Start month	1			End month		48		

**Objectives:**

- Derive recommendations for the design of the future observing system in the Arctic by examining the spatio-temporal variability of key climatic variables and linkages as represented in current systems and by dedicated numerical experiments representing enhanced systems;
- Assess the impact of Arctic observations (type, coverage, frequency) on the skill of coupled predictions from medium to seasonal time scales;
- Produce recommendations for a coupled experimentation strategy and for the set up observing system experiments for YOPP and its consolidation phase;
- Produce recommendations for future coupled reanalysis system design in support of YOPP related to (i) analysis system set-up and (ii) observational data usage.

**Description of work and role of participants** (in bold, task leaders)

**WP4 will be led by ECMWF (Peter Bauer) and UCL (Thierry Fichefet).**

This work package will provide guidance for a better exploitation of existing observational datasets and the optimal design of future observing systems. This guidance will be based on (1) an assessment of the representation of the natural climate variability in the Arctic in long-term reanalyses, (2) the use of observations for process understanding of the Arctic weather/climate and its linkages to lower latitudes, and (3) the enhancement of initial condition accuracy leading to improved forecast skill from short/medium-to-seasonal time scales. Guidance for future observing system configurations will be provided by making use of model experiments and by focusing on data-rich periods such as YOPP. As in other WPs, the aspect of prediction will be central to WP4. WP4 will define an experimentation plan to (i) characterize the sensitivity of forecast skill across time ranges to the initial conditions in the atmosphere, the cryosphere and ocean, (ii) define the key observations that are crucial for constraining physical processes and their coupling, (iii) define temporal and spatial sampling set-ups, and (iv) employ key metrics for assessing skill as compiled in WP1.

Forecast skill assessment from short/medium-to-seasonal time ranges requires a focus on the characterization of analysis accuracy using diagnostics that quantify the exploitation of observational information content. A wide range of existing datasets (e.g., operational datasets, reanalyses) and new types of simulations based on data-denial type observing system experiments will be employed to derive conclusions on the importance of the initial conditions and the observations constraining the initial conditions. The results will be directly relevant for further experiments to be performed during the YOPP consolidation phase employing YOPP observations. This work package presents an obvious link to the successful proposal funded under Horizon 2020 BG-09-2016 'An integrated Arctic observation system'.

The configuration of parameters, observational datasets, models and numerical experiment types planned for each forecast range is summarized in the following table:



	Forecast range:	
	<i>Short/medium range</i>	<i>Sub-seasonal to seasonal</i>
Parameters	Surface pressure, wind, moisture, temperature snow depth, sea ice cover	Sea ice concentration, sea ice thickness
Observations	Buoys, SYNOP, NOAA, MetOp, DMSP, MSG	CryoSat-2, SMOS, SSMI/S, Envisat, IceSat, ERS-1/2
Models	IFS	EC-Earth, HadGEM, GloSea
Experiment	Data denial (operational configuration)	Data denial (idealized configuration)

#### **Task 4.1 – Evaluation of existing datasets with a polar focus (CNRS-GAME, ECMWF, UCL, UREAD) (M1-M24)**

This task will gather datasets existing at the start of the project. A comprehensive assessment will be made of the added value, quality and relevance of these datasets for understanding the Arctic climate system's variability and for improving predictions.

##### **Task 4.1.1 – Assessment of reanalyses in the Arctic (CNRS-GAME, UCL, UREAD) (M1-M24)**

Existing oceanic and coupled reanalyses will be investigated to assess the added value of observational constraints on our understanding of long-term variability of atmosphere, sea ice and ocean states. For that purpose, these reanalyses will be evaluated against both assimilated and non-assimilated observations and compared to free model simulations. Particular attention will be given to the relationship between variables across components, for example between the sea ice cover and the Arctic atmospheric circulation (e.g., storm paths and intensities). This task will build upon the data collected as well as the lessons from the GODAE/OceanView ORA-IP, and be carried out in collaboration with the COST (EOS) action on ocean reanalyses.

The work will be carried out in collaboration with scientists from Environment and Climate Change Canada.

##### **Task 4.1.2 – Assessment of operational analyses in the Arctic (ECMWF, UCL) (M1-M24)**

Advanced data assimilation diagnostics available from operational atmospheric analyses will be used to identify areas where observations provide significant impact in analysis and forecast, with a focus on short time ranges. Key skill measures are the forecast sensitivity to observation influence (FSOI, Cardinali 2009) and the ensemble data assimilation spread analyses produced in WP1 (Task 1.3.2). These tools will be applied in full-observing-system and data-denial (Task 4.2) contexts to characterize whether the observational impact is consistently represented in both.

The output of Task 4.1 will be a report (**D4.1**, CNRS-GAME; MS4.1) that assesses the added value of observations in existing datasets and that provides guidance for future reanalyses, but also for the numerical experiments to be performed in Task 4.2 and the YOPP experiment/reanalysis preparation works in Task 4.4.

#### **Task 4.2 – Numerical observing system experiments (UREAD, UCL, ECMWF) (M1-M48)**

This task will use numerical models to infer which enhancements to the existing observational network would benefit forecast skill the most, pushing further the current predictability of the Arctic climate system and its impacts to lower latitudes.

##### **Task 4.2.1 – Coupled observing system experiments (UREAD, UCL) (M1-M36)**

As part of the APPOSITE research programme, Day et al. (2014) devised an original method to assess the importance of sea ice initial conditions for prediction skill of sea ice and the atmospheric circulation within a perfect model framework (i.e., using the model as the true reference state). It was found that sea ice thickness initialization was crucial for the skilful prediction of summer sea ice cover. This work will be extended to a wider range of models, including the latest versions of HadGEM and EC-Earth, to assess the robustness of this finding. These data-denial experiments will be performed with a focus on the importance of sea ice initialization for atmospheric forecast skill. The idealized experiments conducted in this task will provide a theoretical understanding, which will also allow conclusions to be drawn on the outcomes of the sea ice thickness assimilation work to be done in Task 4.3.

##### **Task 4.2.2 – Atmospheric observing system experiments (ECMWF) (M1-M36)**

Observing system experiments will be performed to assess the importance of selected observations for short/medium-range predictive skill in the atmosphere. The experiments will be run as data-denial experiments, whereby selected data types will be withdrawn from the analysis. A sub-set of experiments will apply this methodology for selected regions to investigate hot spots of data impact. The importance of key observing platform types, such as buoys (providing surface pressure), atmospheric motion vectors (providing atmospheric winds), microwave radiances (providing estimates of atmospheric moisture and clouds), and station data over land (providing snow depth), will be evaluated. Forecast skill will be evaluated using standard NWP metrics. Data-rich

periods (e.g. IPY, YOPP) will be selected to produce robust data denial experiments.

#### **Task 4.2.3 – Optimal sampling (UCL) (M13-M48)**

A number of key sea ice, ocean and atmosphere parameters exhibit significant covariance in space, time, and with each other. For that reason, it is not required to observe these components at all times and everywhere: a minimal number of well-chosen stations can already reveal the dominant mode of Arctic climate variability. Analyses of EC-Earth historical simulations will be conducted to reveal these dominant modes and the number of degrees of freedom associated with each of them. Such a study will bring a quantitative support to important design questions: where, when and at what frequency should observations be taken?

Task 4.2 will produce a comprehensive report (**D4.2, UREAD; MS4.2**) assessing the numerical experimentation output from both idealized pseudo-observing system and actual data-denial experiments. It will present an investigation into the sensitivity of forecast skill to the initial conditions in the atmosphere and the coupled atmosphere–ocean–sea ice system, constrained by both conventional and satellite observations.

#### **Task 4.3 – Sensitivity of forecast skill to initialization approach and use of novel observations (UCL, ECMWF, BSC, Met Office) (M12-48)**

This task will provide support to WP5 by recommending which initial conditions and/or initialization strategies to use for improved sub-seasonal-to-seasonal predictions. It will also consider novel products for data assimilation in prediction systems.

##### **Task 4.3.1 – Forecast skill assessment (UCL, BSC) (M12-M48)**

Three methods of initialization will be investigated and compared with each other for the prediction of Arctic conditions at the seasonal scale using EC-Earth. Method 1: interpolation of existing oceanic and atmospheric reanalyses (e.g., ORAS4, ERA-Interim) on the model grid. Method 2: use of ocean and sea ice states from an ocean–sea ice reconstruction forced by the atmosphere, along with the use of existing atmospheric reanalyses. Method 3: same as Method 2 but with additional data assimilation of ocean salt content, heat content and sea ice concentration. Adequate metrics of verification will be developed together with WP1 in order to attribute skill enhancements in the Arctic and at lower latitudes (WP3).

##### **Task 4.3.2 – Sea ice thickness assimilation (Met Office, UCL) (M24-M48)**

An assessment of the potential impact of sea ice thickness assimilation within the EC-Earth and GloSea seasonal prediction systems will be performed. This will include an evaluation of the sea ice thickness fields used to initialize EC-Earth and GloSea – initially via comparisons with Earth observation data (such as CryoSat-2, SMOS, Envisat, IceSat, ERS-1/2) – and an empirical analysis of the relationship between winter sea ice thickness conditions and summer sea ice extent errors.

##### **Task 4.3.3 – Snow assimilation (ECMWF) (M24-M48)**

Consistent snow initial conditions will be generated in collaboration with WP2 (Task 2.1.2), taking full advantage of recent snow observations. The focus will be on snow over land. In IFS, the two-dimensional optimal interpolation scheme used at ECMWF will be extended to account for model developments in WP2. In-situ observations of snow depth and satellite snow cover information will be used and a new operator to transform satellite snow cover into snow depth will be developed and tested. Pilot experiments initializing snow cover will be conducted to assess the benefit of this method on the representation of land-atmosphere and ocean-atmosphere heat fluxes in late fall/winter. The assimilation experiments will be compared to forecasts from open-loop integrations. Task 4.3 will produce a report recommending the initialization strategy to use in WP5. (**D4.3, UCL; MS4.2**).

#### **Task 4.4 – Design of the future Arctic observing system – Gap analysis (AWI, ECMWF, UCL) (M36-M48)**

This task will evaluate the experiments and diagnostics produced in Tasks 4.2 and 4.3 to derive an analysis of observational gaps and identify shortcomings in current data assimilation methods and models limiting predictive skill from short/medium-to-seasonal time scales (**D4.4, AWI; MS4.2**). Recommendations for overcoming these limitations will be made with reference to:

- short-term enhancements of the observing system during YOPP, and longer-term improvements that feed into the global integrated observing system efforts coordinated by WMO;
- the initialization of community models used within GloSea and EC-Earth, i.e. the NEMO ocean model, with particular emphasis on the inclusion of sea ice thickness;
- the initialization of operational prediction models such as IFS;
- future model improvements through process parameterization allowing a better use of observations.

Further, Task 4.4 will produce recommendations for further numerical experimentation that should be performed in the period after YOPP in order to benefit from the experience of APPLICATE through complementary studies.

#### **Deliverables (brief description and month of delivery):**

D4.1 Initial assessment of the added value of observations in existing long time-series datasets, also providing

guidance for dedicated observing system experiments (M24)
D4.2 Evaluation of the contribution of the Arctic observing system to forecast skill from short/medium-to-seasonal time scales (M48)
D4.3 Evaluation of initialization experiments investigating the impact of novel observations in the coupled atmosphere–land–ocean–sea ice system (M48)
D4.4 Recommendations for the design of the future Arctic observing system (M48)

#### WP5 ‘Improved predictive capacity’

Work package number	5		Lead beneficiary			BSC, MET Norway (Co-lead)	
Work package title	Improved predictive capacity						
Participant number	1	2	3	6	7	8	11
Short name of participant	AWI	BSC	ECMWF	MET Norway	Met Office	UCL	CNRS- GAME
Person/months per participant:	12	48	12	25	9	15	21
Start month	1			End month		48	

#### Objectives

- Advance our understanding of the predictability mechanisms by analysing extensive data-bases for weather to seasonal prediction as well as climate projection;
- Provide a strong contributions to the next generation of weather and climate prediction systems by enhanced exploitation of Arctic observations, improved weather and climate models and advanced understanding of linkages between the Arctic and mid-latitudes;
- Assess the added-value of APPLICATE developments in terms of weather and climate predictions.

#### Description of work and role of participants (in bold, task leaders)

##### WP5 will be led by BSC (Virginie Guemas) and co-led by MET Norway (Trond Iversen).

WP5 synthesises the main results of the APPLICATE project. This synthesis will serve as a basis for, providing recommendations for the development of future weather and climate prediction system and their operational use. Reliable regional weather and climate information from daily to decadal time scales are crucial for socio-economic planning and societal preparedness. WP5 will exploit the knowledge gained in WP3 about the mechanisms linking the Arctic with mid-latitudes, the model developments carried out in WP2 and the strategies proposed in WP4 on how to make the best use of observational data in the Arctic. Thus, WP5 builds on WP2, WP3 and WP4 in order to propose and evaluate new weather and climate prediction systems to better capture impacts of polar features on the large-scale atmospheric circulation in mid-latitudes as well as fast-developing meso-scale events in the vicinity of polar regions, such as polar lows.

##### Task 5.1 – Numerical experimentation plan for WP5 Stream 1 and Stream 2 experiments (BSC, MET Norway, CNRS-GAME, Met Office, ECMWF, AWI) (M1-M3)

This task aims at defining the experimental protocol for the two streams of experiments that will carried out within WP5: Stream 1 with the operational or near-operational forecast systems available at the start of APPLICATE; Stream 2 with the same forecasting systems incorporating model developments from WP2 and refined initialization schemes from WP4.

##### Task 5.1.1 - Numerical weather prediction (NWP) (MET Norway, ECMWF) (M1-M3)

Numerical weather prediction experiments will include deterministic and ensemble runs. The evaluation of datasets from the operational output of the IFS will comprise 10-day single forecasts (medium range) at higher resolution and 51-member ensemble 15-30 day forecasts that will be initialized twice per day. The amount of cases will depend on the investigated phenomena: for severe weather events targeted periods will be selected, while for larger-scale phenomena regular forecasts over several months may be required. Limited-area models with boundary data from IFS for predictions up to 3 days will focus on Arctic sub-regions covering open and ice-covered sea-areas, where meso-scale weather systems are known to develop very fast. Deterministic forecasts from AROME-Arctic over a winter season with favorable conditions for polar lows in the Atlantic sector, preferably the first winter of YOPP, will be used to evaluate the state-of-the-art of limited-area predictions. A similar protocol will be used for AROME with dynamical adaptation over a subdomain of the AROME-Arctic domain, with higher resolution (1.3km), using lateral boundary data from the global ARPEGE and initial conditions from the ARPEGE-4DVAR system.

##### Task 5.1.2 – Seasonal prediction (BSC, CNRS-GAME, Met Office) (M1-M3)

Seasonal prediction experiments will consist of 10-member 7-month long simulations initialized from reanalyses

every 1<sup>st</sup> November and 1<sup>st</sup> May every year from 1992 to 2015. EC-Earth, CNRS-CM and GloSea forecast systems will be employed.

#### **Task 5.1.3 – Climate change simulations (AWI, BSC, MET Norway) (M1-M3)**

Climate change simulations will follow the simplified protocol proposed for the HighResMIP project. This protocol consists in a 50-year spin-up from the EN4 observational database under 1950 conditions followed by a 3-member 1950-2050 simulation. AWI-CM and EC-Earth will be employed. MET Norway considers participation in this task on an in kind basis, if technical aspects have been addressed when the experiments will start.

#### **Task 5.2 – State-of-the-art weather and climate prediction and projection (CNRS-GAME, BSC, ECMWF, MET Norway, Met Office, UCL) (M1-M30)**

This task will provide a comprehensive assessment of the performance of state-of-the-art weather and climate forecasting systems available at the start of APPLICATE. Aspects addressed include capturing the Arctic state, variability as well as impacts on the mid-latitude variability and forecast skill on daily, subseasonal and seasonal time scales. Climate change will also be considered, but only in terms of projection uncertainties. This task will contribute to **(D5.2)**, which summarizes the strengths and limitations of current forecasting systems. This assessment will serve as a reference for further forecasting system developments carried out in APPLICATE.

##### **Task 5.2.1 – Scores of weather and climate prediction performance and projection uncertainties (CNRS-GAME, BSC, ECMWF, MET Norway, UCL, AWI) (M1-M24)**

An atlas of prediction scores, or score card, will be built based on existing databases at the start of APPLICATE. Multi-model databases available from other projects, such as the THORPEX Interactive Grand Global Ensemble (TIGGE), the Subseasonal-to-Seasonal (S2S), Sea Ice Prediction Network (SIPN), C3S and ScenarioMIP will be exploited. Probabilistic scores for the short-range will be evaluated making use of operational grand limited area ensemble prediction system (GLAMEPS). Uncertainties on multi-decadal time scales will be assessed by estimating the spread of the multi-model ensembles.

This task will be carried out in collaboration with the US Sea Ice Prediction Network (SIPN).

##### **Task 5.2.2 – APPLICATE stream 1 (MET Norway, CNRS-GAME, Met Office, AWI, BSC, ECMWF) (M3-M30)**

Stream 1 of experiments will be conducted with the forecasting systems available at the start of APPLICATE following the experimental protocol described in Task 5.1 leading to **(D5.1)**. The performance of weather and climate predictions and the projection uncertainties will be compared with the atlas built under Task 5.2.1. This approach will help to estimate to which extent our multi-model ensembles are representative of wider databases and to what degree conclusions from APPLICATE can be generalized.

##### **Task 5.2.3 – Sources of predictability for polar climate and its influence on the mid-latitudes (Met Office, CNRS-GAME, BSC) (M1-M24)**

The contribution of relatively slow oceanic and sea ice processes for the seasonal predictive skill the Arctic in general and regional sea ice conditions in particular, will be quantified. Arctic processes, including those in the stratosphere, will also be evaluated in terms of their impact on the predictive skill in mid-latitudes. Furthermore, possible precursors (e.g. sea ice, snow and ocean heat content anomalies) for mid-latitude weather and climate anomalies will be considered by employing statistical approaches. Emphasis will be put on the role of autumn sea ice in the Barents-Kara Seas as a potentially strong precursor.

##### **Task 5.2.4 – Empirical statistical models for benchmarking (UCL) (M1-M24)**

Empirical prediction systems will be developed from the statistical analyses conducted in Task 5.2.3. These systems will be used as a benchmark, against which dynamical prediction systems will be tested, both those available at the start and at the end of APPLICATE. The performance of our empirical predictions systems will be compared with those from the SIPN summer Sea Ice Outlook for the period 2008 to today.

This task will be carried out in collaboration with the US Sea Ice Prediction Network (SIPN).

##### **Task 5.2.5 – Evaluating forecasts of extreme events (ECMWF, BSC, CNRS-GAME, AWI) (M1-M24)**

The ability to capture extreme events will be assessed on time scales of days to seasons. Supported by sensitivity experiments and advanced diagnostics (WP1), an attribution of causes for extreme events will be carried out. For shorter time scales the impact of the initial conditions on predictability of extreme events will be addressed. The emphasis will be on polar lows and severe snow storms on daily time scales; on subseasonal and seasonal time scales the focus will be on blocking, cold waves and September sea ice minima. Particular importance will be given to, extreme events that will happen during the relatively well-observed YOPP core period (mid-2017 to mid-2019).

#### **Task 5.3 – Added value of improved process representation for operational or near-operational prediction systems (MET Norway, BSC, CNRS-GAME, ECMWF, UCL) (M13 – M42)**

Although model enhancements could improve the climate of models the impact on actual prediction skill may be neutral or even detrimental. It is necessary, therefore, to assess the impact of model enhancements in a prediction

framework. This task will provide a thorough assessment of the added value of various individual model developments (WP2) on the forecast quality on daily to seasonal time scales. The conclusions, which will be gathered in **(D5.3)**, provide the basis for recommendations on which of the APPLICATE developments to include in Stream 2 **(D5.4)**.

**Task 5.3.1 – Enhanced sea ice models and air-sea interactions in weather and climate prediction (UCL, BSC, CNRS-GAME, ECMWF) (M13 – M36)**

In this task, the impact of the enhanced formulation for air-sea ice interactions will be assessed with AROME, and also tested in a seasonal forecasting framework using CNRS-CM6. The role of improved snow schemes and of the number of sea ice categories on numerical weather prediction performance will be assessed with the IFS. The role of an improved sea ice rheology scheme (Maxwell-Elasto-Brittle) and of the number of sea ice categories on seasonal forecast quality will be assessed with EC-Earth.

**Task 5.3.2 – Increased atmospheric resolution in weather prediction (MET Norway, CNRS-GAME) (M13 – M36)**

The use of Limited Area Models (LAMs) is one way of increasing resolution, and hence our ability to simulated small-scale features, in a geographical area of interest. Traditionally, the value of LAMs has been determined by comparing their skill with that of comparable global NWP systems. Given the need for high-resolution observational data for such an assessment, this classical approach is of limited value in the data sparse Arctic. Here, we will exploit an approach that has been recently pioneered by the Regional Climate Model (RCM) community (e.g. Di Luca et al, 2015), which follows the “Big-Brother Experiment” protocol (Denis et al., 2002). The expected outcome will be recommendations for more optimal LAM configurations and use of LAM output. The results will also provide insight into added value of LAMs when global models continue to increase their resolution in the future and how to distribute resources between resolution, domain size, lead times and number of ensemble members. The impact of high-resolution analysis will be tested with AROME in dynamical adaptation: AROME will be run on the same subdomain as AROME-Arctic (similar to Stream 1), using initial conditions from AROME-Arctic (2.5 km) instead of from the global ARPEGE model with coarser (8 km).

**Task 5.3.3 – Increased atmospheric and oceanic resolution in seasonal prediction (BSC, CNRS-GAME) (M13 – M36)**

With both the CNRM-CM and EC-Earth seasonal forecasting system, sets of retrospective seasonal predictions will be run with two different resolutions: about 1 degree (for both the atmosphere and ocean) and about 0.25 degree (for both the atmosphere and ocean) globally. This set will be complemented with similar experiments performed with the Canadian system CanSIPS.

This task will be carried out in collaboration with Environment and Climate Change Canada.

**Task 5.3.4 – Improved ensemble generation techniques for weather and climate predictions (CNRS-GAME, MET Norway) (M13 – M36)**

An innovative ensemble generation technique will be jointly developed for CNRM-CM and EC-Earth to account for model uncertainties on seasonal time scales in both the ocean and atmosphere. Stochastic modeling of temperature and salinity in the ocean (based on Brankart, 2013) will be combined with stochastically perturbed parameterization tendencies (SPPT) in the atmosphere in both coupled models. Uncertainties in the sea ice and sea surface temperature boundary conditions for LAMs will be accounted for through a novel ensemble generation approach in a NWP framework using a high-resolution limited area model for an Arctic domain.

**Task 5.4 – Performance of weather and climate forecast systems developed under APPLICATE (ECMWF, AWI, CNRS-GAME, Met Office, MET Norway, UCL) (M37 - M48)**

Based on the recommendations on the optimal initialisation strategy (WP4) and on those from the evaluation of the impact of model enhancements in a prediction framework (Task 5.3), optimal configurations will be defined to maximize weather and climate prediction skill in Stream 2. Recommendations for configurations used in climate change simulations will be solely based on recommendations from WP2. Stream 2 will be launched following the common experimental protocol defined in Task 5.1. The progress achieved within APPLICATE will be evaluated in this task and conclusions will be gathered in **(D5.6)**.

**Task 5.4.1 – Benefits from APPLICATE in numerical weather prediction (MET Norway, ECMWF, CNRS-GAME) (M37 - M48)**

Stream 2 will be carried out with the ECMWF, MET Norway and CNRS-GAME forecasting systems. For AROME-Arctic, the lessons learned from Task 5.3.2 will guide the choice of domain-size and forecast lead-time. This may release computer time, which may be utilized for improving other aspects, such as grid-resolution or small ensembles where sea ice and SSTs are perturbed. For AROME, Stream 2 will use the same configuration as in Task 5.3.2 with improved boundary conditions from global ARPEGE, resulting from the implementation of model enhancements in WP2.

**Task 5.4.2 – Benefits from APPLICATE in seasonal prediction (BSC, CNRS-GAME, Met Office) (M37 - M48)**  
Stream 2 will be carried out with the EC-Earth, CNRM-CM and GloSea seasonal forecasting systems. These improved seasonal forecast systems will take part in the Sea Ice Prediction Network (SIPN) sea ice outlook exercise during the last year of APPLICATE (D5.5). Physical understanding will be used as much as possible to explain possible improvements from Stream 1 and Stream 2.

This task will be carried out in collaboration with the US Sea Ice Prediction Network (SIPN).

**Task 5.4.3 – Benefits from APPLICATE for climate change projections (AWI, BSC) (M37 - M48)**

Stream 2 will be carried out with AWI-CM and EC-Earth. The spread of the multi-model ensemble climate change projections in Stream 1 and 2 will be compared to assess the extent to which APPLICATE research impacts of climate change projections along with their uncertainties. The refined projections from Stream 2 will be disseminated through WP7, standing as the top-quality climate information for the coming years available for end users.

**Task 5.5 – Recommendations for future forecasting system development (BSC, CNRS-GAME, MET Norway, ECMWF, Met Office, AWI, UCL) (M45-M48)**

This task will synthesize the knowledge gained during the APPLICATE project. Recommendations and prioritization will be formulated regarding future forecasting system development. A synthesis report will be produced (D5.7) which we aim to publish in a high-level journal such as Bulletin of the American Meteorological Society.

**Deliverables** (brief description and month of delivery)

- D5.1 APPLICATE WP5 Stream 1 (M12)
- D5.2 Strengths and limitations of state-of-the-art weather and climate prediction systems (M24)
- D5.3 Individual impacts of improved process-representation, ensemble generation and increased resolution on the weather and climate prediction performance (M36)
- D5.4 APPLICATE WP5 Stream 2 (M42)
- D5.5 Sea ice predictions with the APPLICATE forecast systems as contributions to the SIPN exercise (M44)
- D5.6 Integrated added-value from APPLICATE on weather and climate prediction and projection (M48)
- D5.7 Synthesis report on priorities for future forecasting system development (M48)

#### WP6 ‘Data and HPC Management’

<b>Work package number</b>	6	<b>Lead beneficiary</b>	MET Norway
<b>Work package title</b>	<b>Data and HPC Management</b>		
<b>Participant number</b>	1	3	6
<b>Short name of participant</b>	AWI	ECMWF	MET Norway
<b>Person/months per participant:</b>	11	3	11
<b>Start month</b>	1	<b>End month</b>	48

#### Objectives

- Oversee and coordinate, if needed, the HPC activities of the APPLICATE consortium.
- Prepare and disseminate the YOPP Analysis and Forecast Dataset.
- Guide the partners on structured data management, including principles on data documentation, publication and sharing.  
Establish a unified data management system allowing partners to archive and share data produced.
- Link the project data management to relevant Arctic and stakeholder data management frameworks.
- Provide a post processing environment simplifying analysis of simulations across models and contributing communities

#### Description of work and role of participants (in bold, task leaders)

**WP6 will be led by MET Norway (Øystein Godøy).**

The work in this WP will focus on activities related to producing and managing data and products. Existing HPC resources are utilised for production, but coordination is required to exploit emerging resources on the European scene. Data management (sharing and preservation) is focused on integration with WMO activities, including WMO Information System, which is supporting YOPP. In addition to products developed during the project, ECMWF operational output is prepared for sharing through a dedicated service. For coordinated analysis of the project results a common post-processing environment is established. WP6 will also act as a hub for sharing information among the work packages.

**Task 6.1 – Oversee HPC activities (AWI) (M1-M48)**

As part of APPLICATE, comprehensive numerical experimentation will be carried out. Therefore, it is important

that sufficient HPC resources will be available. APPLICATE partners have access to some of Europe's leading HPC resources, including model and forecasting systems that are well adjusted to the available HPC and data facilities. Therefore, rather than coordinating all modelling activities on one HPC system, a more distributed approach will be followed. In this task, progress on the HPC side of the project will be overseen. This included periodic enquiries regarding availability of HPC resources in relation to the upcoming tasks and deliverables. Furthermore, this task will inform partner about upcoming opportunities for applying for HPC resources. Finally, this task will consider joint proposals for PRACE supercomputing resources.

### **Task 6.2 – Preparation and publication of operational ECMWF model output for YOPP (ECMWF) (M1-M30)**

This task comprises the preparation and dissemination of operational model output from the ECMWF archives in support of forecast performance studies and model error analyses. This *YOPP Analysis and Forecast Dataset* will contain two full years (mid 2017—mid 2019) that are aligned with the YOPP period (D6.4). Selected data on model levels, pressure levels and surface fields will be made available. In addition to standard output also model tendencies (physical and dynamical processes) will be included along the first steps of the forecast for detailed process studies. A commitment by ECMWF of this kind has already been made in the past in support of the Year of Tropical Convection (YOTC), which produced significant impact on the science community (Moncrieff et al. 2012). Apart from process studies, the dataset can be used to force sea ice-ocean models<sup>4</sup>, carry out predictability studies and serve as a basis for Transpose-AMIP experiments (Williams et al. 2013).

Producing this dataset requires the definition of output fields, the definition of data structures to accommodate this data (grib\_api, MARS, and entire software stack), the definition of the data server layout, and the development of a suite that will reformat data into the YOPP convention, its archival in the ECMWF meteorological archiving system (MARS), and the establishment of a data catalogue on the data server (D6.2). The web interface will follow the YOTC template (<http://apps.ecmwf.int/datasets/data/yotc-od/levtype=sfc/type=an/>). A server is required to add to the webapi infrastructure for serving this data. The data will be stored in GRIB following WMO standards applicable to NWP. Since the data will be archived in MARS, full back-up and recovery capabilities will be made available, as for other operational model output.

### **Task 6.3 – APPLICATE data framework (MET Norway) (M1-M48)**

This task consists of 4 subtasks: Development of a data management plan, development of guidance material, Data management implementation and maintenance and Post-Processing Environment implementation, maintenance and support. In order to streamline the data documentation, sharing and preservation, best practices are developed. Data management is focused on linking datasets to user communities internally in the project as well as presentation of results to external stakeholders. This calls for the adoption of internationally accepted standards for documenting and accessing data. The work on data management will be linked to observational frameworks, both through WMO (WIS and WIGOS) and of EU origin. At the data management level there is a strong linkage to a proposal (Arctic-UNION) for an Arctic Observing System. However, as long internationally accepted interoperability standards are used any community or framework can be connected. This approach is directly linked to YOPP data management.

#### **Task 6.3.1 – Development of a data management plan (MET Norway) (M1-M6)**

The purpose of this task is to develop a data management plan, which provides a detailed outline of APPLICATE data management strategy, including technical details and time lines (D6.1).

#### **Task 6.3.2 – Development of guidance material (MET Norway) (M1-M12)**

The purpose of this task is to provide guidance material (Best practises) and tools enabling the partners to properly document and format their data in order to facilitate long term data preservation including life cycle management of data, data publication and data sharing (D6.3). This work will draw on existing material developed in the context of the Arctic Data Committee (SAON/IASC), WMO, GEO, ICSU, RDA etc. but is adapted to the specific challenges of this project and its stakeholders. Standardisation of data documentation and interfaces to data is a prerequisite for cost effective data curation, sharing and consumption.

#### **Task 6.3.3 – Data management implementation and maintenance (MET Norway) (M1-M48)**

The purpose of this task is to provide a structured approach to data management including sharing and consumption. Following a distributed data management approach similar to Copernicus Marine Environment Monitoring Service (CMEMS) and Earth System Grid Federation (ESGF) standardizing on NetCDF following the Climate and Forecast Convention, including embedded discovery metadata according the NetCDF Attribute

<sup>4</sup> The Forum for Arctic Ocean Modeling and Observational Synthesis (FAMOS), expressed a strong interest in such a data set at their last meeting in autumn 2015, since this dataset would allow to exploit the full potential of the next generation of high-resolution sea ice-ocean models.

Convention for Dataset Discovery and data transportation/access using OPeNDAP allows for integration of data across data repositories and for combination with other relevant data (e.g. in situ products). This solution supports life cycle management, dataset publication, dataset search and retrieval as well as data streaming into applications used for analysis following the Common Data Model (CDM). Discovery metadata describing the products and how to retrieve them will be exchanged with relevant Arctic and stakeholder data management frameworks through the efforts of the combined SAON and IASC Arctic Data Committee, and WMO Information System (WIS). Metadata technologies utilised will e.g. be OAI-PMH (exchange of metadata) and ISO19115/GCMD DIF (metadata standards). Linkages to WMO Information System will be provided through the approved WIS Data Collection and Production Centre the Arctic Data Centre. This work package has a commitment beyond the project duration. Usually, modelling data are archived at least for 10 years, observational data on an indefinite temporal horizon. Each dataset handled require specification of the life cycle management. This task includes a dedicated web portal providing an overview of the projects data catalogue.

#### **Task 6.3.4 – Post-Processing Environment implementation, maintenance and support (MET Norway) (M1-M48)**

A dedicated post-processing environment will be set up to support analysis of multiple datasets and creation of new combined datasets (**D6.5**). This will be available for partners and include a storage system for processing and staging of datasets for long term archival and data sharing through task 7.2. Support will be provided to facilitate remote visualisation (e.g. Vapor, ParaView, VisIt, Jupyter/iPython Notebook) and other software tools (e.g. Python, R) the project community is requiring. The post processing environment can utilise datasets stored in connection to the environment or access remote datasets using OPeNDAP if supported by the remote data centre. This task cover implementation, maintenance and user support.

#### **Deliverables** (brief description and month of delivery)

- D6.1 Data management plan (M6)
- D6.2 Data catalogue and services (M 12)
- D6.3 Provision of guidance material and tools for effective data management (M 12)
- D6.4 Start with the archiving and dissemination of YOPP Analysis and Forecast Dataset (M18)
- D6.5 Post Processing Environment (M 30)

#### **WP7 ‘user engagement, dissemination and training’**

Work package number	7	Lead beneficiary	AP, BSC (Co-lead), UiT (Co-lead)
Work package title	<b>User engagement, dissemination and training</b>		
Participant number	2	13	14
Short name of participant	BSC	AP	UiT
Person/months per participant:	44	52	11
Start month	1	End month	48

#### **Objectives**

- Increase the awareness about the impact of Arctic changes on the weather and climate of the Northern Hemisphere;
- Develop relevant forms of communication within and outside the EU (and possibly national) services to adequately spread results that could be used for either policy or socioeconomic action;
- Maximise exposure of the science produced to end-users, stakeholders and the public at large, and aims at communicating project results, including collecting all available feedback, in order to assure knowledge sharing and knowledge exchange with stakeholders (Dissemination);
- Contribute to servicing those socioeconomic sectors in the Northern Hemisphere that benefit from improved forecasting capacity (e.g. shipping, energy generation and mining) at a range of time scales, as well as enhancing their capacity to adapt to long-term climate change (end-user-engagement);
- Improve the professional skills and competences for those working and being trained to work within this subject area (Training).

#### **Description of work and role of participants** (in bold, task leaders)

**WP 7 will be led by AP (Halldor Johannsson / Kamil Jagodzinski) and BSC (Francisco Doblaz-Reyes / Isadora Jiménez), supported by UiT (Gerlis Fugmann).**

WP7 integrates three main areas of action: communication and dissemination of the project results, user engagement and training. All the activities will be carefully targeted to different groups of potential audiences (e.g. research community, EU projects, general public) and stakeholders defined as key (business and governmental stakeholders in the Arctic within and outside the EU), primary (meteorological and climate national services, NGOs or local communities) and secondary stakeholders (business stakeholders from mid-latitudes). The



interaction with this wide range of stakeholders will be also fostered by the actual involvement and contact of APPLICATE partners with many of them.

#### **Task 7.1 - Communication and dissemination (AP, BSC, UiT) (M1-M48)**

Task 7.1 will apply modern communication tools for online facilitation, and the most efficient channels for communication and dissemination of information and data. The focus will be on the impact of Arctic changes on both weather and climate, not only in the Arctic area, but also its linkages with lower latitude phenomena in the Northern Hemisphere.

##### **Task 7.1.1 - Communication and dissemination plan (AP, BSC) (M1-M2)**

An outline of the Communication and dissemination plan (CDP) is provided in section 2.2 and will be further discussed during the kick-off meeting with all the partners. This plan will be further developed in **D7.2**, providing a full framework for the development of this task along the lifetime of the project detailing target audiences, communication tools and channels, key messages and practical information such as branding project style, logo, guide, templates, etc. This plan will be revised and updated during the project lifetime.

##### **Task 7.1.2 - On-line communication and tools (AP, BSC) (M3-M48)**

A website will be designed to contain and offer the project description and its various outputs like public reports, general information, and news and dissemination material. The website will be initially set up to identify the project (providing visual identity materials and templates in a password protected partners area) and promote early engagement with other EU projects, international initiatives and communities (**D7.1**). In a second phase, the structure and contents will be critically revised, taking into account all the feedback collected from both partners and stakeholders, and modified accordingly (MS 7.5) so that it can take a role in serving more specific needs: promoting project results with high impact multimedia communication material, disseminating promotional campaigns of the project through social media (Facebook and Twitter accounts), publishing press releases and providing online feedback mechanisms to the target audiences, including the users and stakeholders contacted in Task 7.2. The website will include a compilation of skill training resources relevant for early career researchers in the APPLICATE project. Maintenance and updates of on-line content will follow the sequence set in the Communication and dissemination plan (**D7.2**).

##### **Task 7.1.3 - Dissemination materials (AP, BSC) (M3-M48)**

Dissemination materials (mainly online, although some printed material will be made available at key events) presenting a selection of project activities and results will be prepared in English in order to reach the audiences identified in **D7.2** and **D7.3**. The material will be made available in different versions to accommodate to the various levels of experience in weather and climate and needs of those audiences. Materials will include: brochure, leaflets, roll-ups, factsheets etc. (**D7.5, D7.6, D7.7, D7.8, D7.9**).

##### **Task 7.1.4 - FrostBytes videos (AP, UiT) (M3-M48)**

Production support for the FrostBytes videos, which are short videos (up to 60 seconds) from the Summer School that explain to the general public what research participants are conducting (public outreach activity). FrostBytes will be also posted in external websites, for instance, that of APECS.

##### **Task 7.1.5 - Promoting project and disseminating results in international fora of relevance (AP, BSC) (M6-M48)**

To strengthen the role of the project as a base of cutting edge research, the project will be advertised and explained during international relevant events, particularly outside the EU. Additional promotion, dissemination of results and illustration of the implications (e.g. impact and opportunities for socioeconomic sectors) will help strengthening the recognition of the project and the EU as a state-of-the-art research provider for the objectives that APPLICATE addresses. Special attention will be given to interaction with other projects (ECOMS2, link to C3S activities, and especially contribution to YOPP).

#### **Task 7.2 - User engagement (AP, BSC) (M1-M48)**

Active engagement with all groups of interest within and outside the EU including users and intermediaries (e.g. national services, NGOs, industrial sectors and indigenous communities, among others) is crucial for maximizing knowledge exchange and obtaining the necessary feedback that can guide some aspects of APPLICATE research. Task 7.2 will aim to understand the impacts and the opportunities of potential changes in the Arctic through a proactive dialog with users and intermediaries from Arctic and mid-latitudes.

##### **Task 7.2.1 - User engagement plan (BSC, AP) (M1-M2)**

A first draft of the strategic plan for user engagement will be presented during the kick-off meeting to all the partners to complete the vision of the potential users of Arctic and lower latitude weather and climate information and to maximize the synergies that the APPLICATE partners can create with the users identified in other EU funded projects and committees where they participate (see section 2.2.a.4). This plan will be further developed in **D7.3** that will identify key, primary and secondary stakeholders, their contact details and their level of use of

weather and climate information, effective mechanisms for engaging users in the implementation of the project, Key performance indicators (KPI) for each mechanism, etc. This plan will be revised and updated during the project's lifetime.

#### **Task 7.2.2 - The user group (AP, BSC) (M3-M48)**

To support the project with an external user-specific perspective and to provide continuous feedback on the relevance of the results obtained and the way they are presented, a group of 7-10 representatives of key stakeholders - the User Group (UG) will be defined. The UG will serve the WP, the project, Coordinator and Management Support Team as an additional advisory mechanism. The UG will meet either in person or on-line following a frequency defined in the user engagement plan (D7.3). Feedback and comments of the UG will be provided by WP7 to support implementation of the management and decision making structure (Task 9.1.2) of WP9 Project Coordination and Management.

#### **Task 7.2.3 - Organizing and performing workshops, meeting and interviews with key stakeholders (BSC, AP) (M3-M48)**

To illustrate the benefits of climate forecasts with improved polar representation to a range of stakeholders in the Arctic and mid-latitudes, the partners will participate in relevant external events or initiatives organized by the target sectors (half-a-day events at professional conferences rather than general-purpose workshops) and will carry out workshops and interviews during those events to get direct feedback from a user perspective by actors not usually linked to the weather and climate research communities. These activities will be jointly organized with other EU projects such as PRIMAVERA, IMPREX or CLIM4ENERGY when linked to a common target stakeholder.

#### **Task 7.2.4 - Online user feedback tool (AP, BSC) (M3-M48)**

An online tool for collecting feedback and organizing virtual consultations will improve the interaction of the stakeholders identified by the project. The virtual tools will provide additional feedback mechanisms and traceability (always respecting all due confidentiality), while providing a wider perspective on the challenges, discrepancies, misconceptions and important issues overlooked by the experts. The outcome of this task will be provided to the key players in the C3S User Interface Platform (MS 7.7)

#### **Task 7.3 - Training (UiT, AP, BSC) (M1-M48)**

The tailor-made set of training activities will include webinar series, summer school, online course on project-relevant aspects, and other training options. Training will be organized in relation to the usual training activities carried out by each partner (i.e. YOPP Summer School in mid-2018 organized by AWI, PRACE Advance Training Courses (PATC) organized by BSC). Coordination of training activities and synergy with ongoing and planned projects will increase the desired impact, ensure cost-effectiveness and potentially help to get external funding.

##### **Task 7.3.1 - Training plan (UiT, AP, BSC) (M1-M48)**

The plan defining all the training activities and their time of execution will be detailed in D7.4 that will take into account the possibility of coordination with other activities (BG-9, BG-10, YOPP, WCRP, WWRP, RCOFs, etc.) and the alignment with other training activities in the context of the YOPP. This plan will be revised and updated during the project's lifetime.

##### **Task 7.3.2 - Connection and training opportunities for early career researchers (UiT) (M1-M48)**

This will include several components: a) an email list; b) the compilation of a thematic website with skill training resources relevant for early career researchers in the APPLICATE project that will serve as an open resource; c) dedicated "mentor" sessions connecting early career and senior researchers involved in the project at meetings and workshops related to the project throughout the project.

##### **Task 7.3.3 - Webinar series in connection with the APPLICATE project (UiT, AP) (M9-M12)**

A webinar series directed towards early career researchers (but open to the general public) will introduce the APPLICATE project and increase the awareness about the impact of Arctic changes on the weather and climate of the Northern Hemisphere. The webinars (2) will be recorded and provided as an open resource on the websites of the APPLICATE project and that of the Association of Polar Early Career Scientists.

##### **Task 7.3.4 - Summer School for PhD students and postdoctoral researchers from APPLICATE partners and in connection to YOPP Summer School (UiT, AP, BSC) (M17-M19)**

APPLICATE will benefit from a unique, high-level, summer school program for 30 PhD students and postdoctoral researchers, covering some of the theories and methods used within the research project. This 10-day training course will be organized by UiT in cooperation with other projects and external partners. WP will investigate the possibility of including YOPP as co-sponsor for the summer school. Participants will also create FrostBytes on their research projects (in connection to Task 7.1.4).

##### **Task 7.3.5 - Online course (UiT, AP, BSC) (M26-M28)**

A 3 months course on “Advancing predictive capacity of Northern Hemisphere weather and climate” will be organized for early career scientists (but open to anyone interested) with weekly interactive online sessions. Recordings will be made openly available afterwards on the APPLICATE website and the website of the Association of Polar Early Career Scientists.

**Task 7.3.6 - Follow up assessment of the outcomes of the learning experience (UiT) (M46-M47)**

A report assessing the lessons learnt from summer school and online course will contribute to the improvement of these training tools into future APECS teaching strategy (D7.10).

**Deliverables**

D7.1	Website, incl. online tool for end-users feedback (M2)
D7.2	Communication and dissemination plan (CDP) (M6)
D7.3	User-engagement plan (M6)
D7.4	Training plan (M6)
D7.5, D7.6, D7.7, D7.8, D7.9	Dissemination materials (M6, M13, M25, M37, M45)
D7.10	Final assessment of the outcomes of the training experience (M47)

**WP8 ‘Clustering’**

<b>Work package number</b>	8	<b>Lead beneficiary</b>	AWI
<b>Work package title</b>	<b>Clustering</b>		
<b>Participant number</b>	1	3	
<b>Short name of participant</b>	AWI	ECMWF	
<b>Person/months per participant:</b>	4	2.5	
<b>Start month</b>	1	<b>End month</b>	48

**Objectives**

- Coordinate APPLICATE activities with EU projects;
- Coordinate APPLICATE activities with international projects (e.g. YOPP and Belmont Forum);
- Coordinate APPLICATE with WMO WWRP PPP.

**Description of work and role of participants (in bold, task leaders)**

**WP8 will be led by AWI (Thomas Jung) and ECWME (Peter Bauer).**

**Task 8.1 – Develop draft clustering plan (AWI, ECMWF) (M1-M3)**

There are a number of European and international activities that are or will be related to some of the activities planned in APPLICATE. In order to exploit synergies, APPLICATE will establish a strong clustering component. At the heart of APPLICATE’s clustering strategy, lies a draft clustering plan that will be developed at the beginning the project (D8.3). The plan outlines:

- A list of related projects and activities, including points of contact, for which clustering is envisaged
- A proposal for forming a coordinator network
- A proposal for specific clustering activities within the coordinator network (teleconferences, joint communication activities)
- A proposal for specific clustering activities with different projects and activities (e.g. project-exchange days, invitation of coordinators to APPLICATE GAs)
- A proposal for holding the first coordination meeting in conjunction with the YOPP planning meetings that will be held from 5—9 September 2016 in Reading, UK. All coordinators of existing activities and those known to have submitted related proposals will be send a save-the-dates email by the International Coordination Office (ICO) for Polar Prediction (D8.1).

More specific elements of the draft clustering plan are outlined below for some of the most strongly related European and international activities. The clustering plan will be a living document that will be revised and updated during the project lifetime.

**Task 8.2 – Specific clustering activities with EU projects**

**Task 8.2.1 – Projects funded under H2020-BG09-2016 and BG10-2016 (AWI) (M1-M48)**

The projects funded under H2020-BG09-2016 and especially BG10-2016 are expected to have strong links to APPLICATE. It will be important therefore to strongly coordinate activities for exploiting synergies and thus increase the critical mass for delivering the expected impacts set out in the work programme and call texts. The following activities are part of the draft clustering plan and are specific to the link between APPLICATE and the projects funded under H2020-BG09-2016 and BG10-2016:

- Organize teleconferences with the project coordinators to agree on a roadmap for developing a coordinated

clustering strategy.

- Invite the coordinators of collaboration projects to the GAs of APPLICATE to report on the progress and challenges of their projects and to agree on coordinated activities.
- Participation of the APPLICATE Project Coordinator or another member of the Executive Board at GAs of BG-09 and the other BG-10 project.
- Coordinators of BG-09 and other BG-10 projects will be invited to become members of the external advisory board in APPLICATE (D8.2).
- Identify common dates and places for GAs for all 3 projects and have a shared 'project-exchange-days'.
- Develop a joint cooperation strategy and update the clustering plan accordingly (D8.4)
- It is possible that some of the APPLICATE partners will be contributing to some of the other projects. These partners will be identified and tasked to contribute to the coordination activities between the projects.

#### Task 8.2.2 – Projects funded under earlier calls of H2020 and FP7 (AWI, ECMWF) (M1-M48)

This task will ensure that APPLICATE activities are well coordinated with projects funded under earlier calls of H2020 and FP7 (call text: *"build on other projects funded under earlier calls"*):

- Compile a list of relevant projects, including points of contacts. Relevant projects include PRIMAVERA, CRESCENDO and EU-PolarNet.
- Invite the coordinators of those projects to the GAs of APPLICATE to report on the progress and challenges of their projects and to agree on coordinated activities.
- Identify APPLICATE partners involved in these projects and task them to contribute to the coordination activities between the projects.
- Participation of the APPLICATE Project Coordinator or another member of the Executive Board in project meetings, if no APPLICATE partner is directly involved.
- Agree on common clustering activities with each of the projects and update clustering plan accordingly (D8.6).

#### **Task 8.3 – Specific coordination activities with international projects**

##### Task 8.3.1 – Year of Polar Prediction (YOPP) (AWI, ECMWF) (M1-M48)

PPP aims to enable a significant improvement in environmental prediction capabilities for the polar regions and beyond, for which YOPP represents a major milestone. Therefore, APPLICATE is very well aligned with the aims of YOPP, and there is a need to coordinate planned activities. In this context APPLICATE will strongly benefit from the fact that partners take leading roles in the preparation and implementation of YOPP, including the Project Coordinator, Thomas Jung, who is overseeing the planning and coordination of YOPP and in his role as the chair of PPP. Therefore, upcoming YOPP planning meetings and meetings of the PPP steering group will provide excellent opportunities to ensure coordination of APPLICATE with other ongoing activities.

Specific clustering activities related to YOPP include:

- If applicable, present and discuss APPLICATE at the next YOPP planning meeting that will be held from 5-9 September 2016 in Reading, UK.
- Present and discuss APPLICATE activities at annual meetings of the PPP steering group.
- Project Coordinator provides regular updates on YOPP at APPLICATE GAs.
- Exploit YOPP outreach and communication activities to disseminate APPLICATE results.
- Align stakeholder engagement activities in YOPP and APPLICATE.
- Explore the possibility for aligning the APPLICATE summer school with that planned for YOPP (D8.7).

##### Task 8.3.2 – Sea Ice Prediction Network (SIPN) (AWI) (M1-M48)

The Sea Ice Prediction Network (SIPN) is a collaborative network of scientists and stakeholders (mostly from the US) working to improve and communicate sea ice prediction. Coordination of SIPN and APPLICATE will be ensured as follows:

- The Co-PI of SIPN, Cecilia Bitz, has agreed to serve as a member of the external Advisory Board of APPLICATE. This will allow for regular exchanges that will be reflected in updates of respective sections of the clustering plan.
- APPLICATE partners (e.g. UCL and BSC) are actively involved in the SIPN. These partners will be tasked to contribute to the coordination activities between the projects by providing regular updates and raising potential issues.

##### Task 8.3.3 – Projects resulting from Belmont Forum call on climate predictability and inter-regional linkages (AWI) (M1-M48)

The Belmont Forum has recently issued a call on *"Climate Predictability and Inter-Regional Linkages"*. Given the nature of the call, it can be anticipated that APPLICATE and some of the Belmont Forum projects will mutually benefit from coordination. To ensure effective coordination the draft clustering plan contains the following actions:

- Identify relevant projects and establish points of contact (Project Coordinators).

- Hold meeting and agree on specific clustering activities that will feed into the APPLICATE clustering plan (D8.5).
- Invite Project Coordinator(s) of relevant projects to participate in APPLICATE GA to report on the progress and challenges of their projects and to agree on coordinated activities.
- Identify APPLICATE partners involved in these projects and task them to contribute to the coordination activities between the projects.
- Have APPLICATE representatives participate in Belmont project GAs.
- Consider inviting Belmont Project Coordinator(s) to be member of the external Advisory Board.
- Hold regular teleconferences to monitor progress and identify potential issues.

#### **Task 8.3.4 – US CLIVAR Working Group on Arctic Change and Possible Influence on Mid-latitude Climate and Weather (AWI) (M1-M48)**

The US CLIVAR Working Group has been established to further the understanding of the coupling between Arctic variability and mid-latitude climate and weather. Its aims are strongly related to that of WP3 in APPLICATE. It will be imperative therefore to jointly develop a strong clustering concept. This activity will be led by the APPLICATE Project Coordinator, Thomas Jung, who is also a member of the US CLIVAR working group. The draft clustering plan includes the following actions:

- Agree on a joint clustering concept, including an agreement on coordinated numerical experimentation, at the next meeting of the US CLIVAR Working Group that is tentatively scheduled for 1-3 February 2017 in the US (D8.5). The meeting will be attended by the APPLICATE Project Coordinator along with the leader of WP3.
- Invite WG co-chairs to participate in APPLICATE GA to report on the progress and challenges of their projects and to agree on coordinated activities.
- Participate in upcoming meetings of the US CLIVAR Working Group.
- Invite Belmont GA to be member of external advisory board.

Establish regular exchanges in the context of teleconferences of the US CLIVAR Working Group.

#### **Deliverables (brief description and month of delivery)**

- D8.1 Invite coordinators of relevant projects to the YOPP planning meetings (M1)
- D8.2 Invite coordinators of BG-09 and other BG-10 projects to become members of external advisory board in APPLICATE (M1)
- D8.3 Draft clustering plan (M3)
- D8.4 Update the dissemination plan to reflect specific clustering strategy with projects funded under H2020-BG09-2016 and BG10-2016 (M3)
- D8.5 Provide report from US CLIVAR Working Group meeting including recommendations for adjustments to the WP3 part of the APPLICATE numerical experimentation plan (M4)
- D8.6 Update the dissemination plan to reflect specific joint clustering activities with projects funded under earlier H2020 and FP7 calls (M5)
- D8.7 Provide draft concept for a joint YOPP-APPLICATE summer school including a list of possible co-sponsors (M7)

#### **WP9 ‘Project Coordination and Management’**

<b>Work package number</b>	9	<b>Lead beneficiary</b>	AWI
<b>Work package title</b>	<b>Project Coordination and Management</b>		
<b>Participant number</b>	<b>1</b>		
<b>Short name of participant</b>	<b>AWI</b>		
<b>Person/months per participant:</b>	<b>24</b>		
<b>Start month</b>	1	<b>End month</b>	48

#### **Objectives**

- Setting up, negotiate and implement the APPLICATE Consortium Agreement (CA)
- Implement the project management structure as set out in Annex I (section 3.2) of the Grant Agreement and the CA
- Management and coordination of the projects financial and administrative terms
- Ensuring project progress according to the project plan, deliverables and milestones
- Identification and mitigation of possible risks related to the project
- Overseeing and manage gender issues and balance during the project and within the consortium

**Description of work** (where appropriate, broken down into tasks), lead partner and role of participants

**WP9 will be led by AWI (Thomas Jung).**

### **Task 9.1 – Administrative project management (AWI) (M1-M48)**

The administrative management of APPLICATE will be conducted by the Project Coordinator together with his Management Support Team. Its main responsibility will be to set-up and implement an efficient project management and decision making structure according to Annex I (section 3.2) of the Grant Agreement and to draft and implement the Consortium Agreement of APPLICATE.

#### **Task 9.1.1 – Design and implementation of the Consortium Agreement (CA) (AWI) (M1-M48)**

Before the start of the project and the signature of the Grant Agreement a Consortium Agreement (CA) will be designed by the Management Support Team together with Coordinator. The CA will be based on the DESCA model <http://www.desca-2020.eu/>, which is widely used and accepted as a model for projects under Horizon 2020. The CA will govern the interaction between the APPLICATE consortium in defining the following terms: Management structure and decision making bodies; Financial project management; Intellectual property rights; Liability and responsibilities of partners

The CA shall be negotiated and signed by all members of the Consortium before the signature of the Grant Agreement (D9.1). It will be implemented with the start date of the project and maintained throughout the duration of APPLICATE.

#### **Task 9.1.2 – Implementation of the management and decision making structure (AWI) (M1-M48)**

The Management and decision making structure is described in section 3.2 and will be defined in more detail regarding obligations, responsibilities and rights in the project Consortium Agreement. The Management structure involves the set-up of three different levels of decision making bodies, where the General Assembly will form the highest decision making unit, the Executive Board will be responsible for the coordination and implementation of the scientific project tasks and where the Coordinator together with his Management Support Team will take care of the overall project management. Those three units will be supported by the Advisory Board. The Advisory Board is set up by external and international experts and stakeholders, providing their expert opinion and advice to the APPLICATE consortium. All decision making bodies will be established at the Kick-Off meeting in Bremerhaven. Throughout the project duration they will meet regularly as set out in section 3.2 and the Consortium Agreement. The minutes of the annual project meetings, where all decision making bodies will convene, will be send to the EC (D9.2, D9.6, D9.8, D9.10).

### **Task 9.2 – Financial management of APPLICATE (AWI) (M1-M48)**

The financial management of APPLICATE will be within the responsibility of the Management Support Team of the Project Coordinator. Its main tasks will be to provide financial guidance to all members of the Consortium, to conduct the financial reporting and to distribute the EC financial contribution according to the rules set out in the project Consortium Agreement.

#### **Task 9.2.1 – Provide financial guidance (AWI) (M1-M48)**

To guarantee a timely and smooth financial management of APPLICATE a guide will be developed at the beginning of the project. This guide will on the one hand give a concise overview on the rules and obligations concerning the Consortium budget according to the regulations of the EC Grant Agreement and on the other hand this guide will serve as a manual on how to conduct the financial reporting. The guide will be made available to the consortium via a password protected area of [www.applicate.eu](http://www.applicate.eu) website and shall serve as basis for the periodic financial reporting (D9.3).

#### **Task 9.2.2 – Distribution of EC financial contribution (AWI) (M1-M48)**

In addition to providing financial guidance to all partners, the distribution of the EC financial contribution will also form an integral part of the financial management. The provisions regarding the distribution of the EC financial contribution will be detailed in the Consortium Agreement according to the Grant Agreement. The distribution itself will be carried out by the Coordinator.

### **Task 9.3 – Scientific Management and the coordination of work package and task leaders (AWI) (M1-M48)**

The scientific management of APPLICATE and the coordination of the work package and task leaders will be one of the main responsibilities of the Project Coordinator. Together with the Management Support Team the Coordinator will ensure that the project is implemented according to the project plan, deliverables and milestones and identify possible risks and respective mitigation measures.

#### **Task 9.3.1 – Monitor project progress and conduct scientific reporting (AWI) (M1-M48)**

In order to observe the project progress the Coordinator will be in very close contact with all WP and task leaders to ensure that deadlines are kept, deliverables are fulfilled and milestones are reached. Part of this task will be to provide the WP and task leaders with templates and guidelines on how to write deliverables, to ensure a timely and coherent submission of the deliverables to the EC. All information on the project progress, challenges and results

will be gathered by the Coordinator in collaboration with all members of the Consortium and transferred into a scientific report, which will be submitted during the periodic reporting (D9.7, D9.9, D9.11, D9.12).

#### **Task 9.3.2 – Risk Management (AWI) (M1-M48)**

The risk management will form a very important part of the scientific project management. The close contact to WP and task leaders ensures that the Coordinator is always informed on the latest developments and the overall progress. Consequently the Coordinator will be able to identify possible risks and delays in due time. This will enable the Coordinator to find very early mitigation measures and to consult the EC Project Officer in case of major difficulties to seek the advice of the EC. To fulfil this task the MST will develop, monitor and maintain a risk management plan as a list of potential risks and mitigation measures (D9.4). The plan will be presented to the Executive Board during their regular meetings every three months.

#### **Task 9.4 – Internal Project Communication (AWI) (M1-M48)**

Whereas the external project communication with stakeholders, interested public, etc. will be coordinated by WP7, the internal communication of APPLICATE will be managed by WP9. The internal project communication will focus on the communication between the consortium and the communication with the European Commission.

##### **Task 9.4.1 – Coordinating the communication of the APPLICATE consortium (AWI) (M1-M48)**

The internal communication of the project consortium will be coordinated via a password protected, interactive area of the [www.applycate.eu](http://www.applycate.eu) webpage designed within WP7. This area will provide the consortium with the possibility to store and exchange documents and to discuss issues online. In addition the consortium will have access through this platform to all templates, manuals and guidelines needed to ensure a proper and efficient project reporting, as well as to an updated list of the contact details of all consortium members.

##### **Task 9.4.2 – Communication with the European Commission (EC) (AWI) (M1-M48)**

The communication with the European Commission will be the sole responsibility of the Project Coordinator together with his Management Support Team. The Coordinator will maintain regular contact with the Project Officer (PO) of the EC to inform the PO on the project progress. This will be done through the regular periodic scientific and financial reporting and through regular contact to keep the PO updated and informed about the progress, arising challenges or risks to seek advice and solutions if necessary, ensuring a timely and efficient project management according to EC rules. The PO of APPLICATE will be invited to all annual General Assemblies and other important project meetings.

#### **Task 9.5 – Management of the APPLICATE gender dimension (AWI) (M1-M48)**

The Project Coordinator together with the MST will be responsible to oversee and manage gender issues and balance during the project and within the consortium. APPLICATE will endorse the principle of the *European Charter for Researchers and Code of Conduct for the Recruitment of Researchers* and whenever possible implement actions (such as predictable working times and travel, stimulate use of electronic meetings, etc.) to support male and female researchers with children or other dependants. The MST will gather statistics on and monitor the role of women within APPLICATE and take action if needed. Attention will be paid to how meeting programs, high profile presentations (keynote talks at conferences) on project results and educational programs are planned from a gender perspective. To fulfil this task APPLICATE will develop a Gender Strategy to be adopted by the General Assembly (D9.5).

#### **Deliverables** (brief description and month of delivery)

D9.1	Signed Consortium Agreement (M1)
D9.2, D9.6, D9.8, D9.10	Minutes of the annual General Assemblies (M2, M18, M32, M48)
D9.3	Manual, guide & templates for deliverables and reporting (M3)
D9.4	Risk Management Plan, including potential risks and mitigation measures (M5)
D9.5	Gender Strategy (M6)
D9.7, D9.9, D9.11	Periodic reports, including financial reports (M18, M36, M48)
D9.12	Final project report (M48)

Table 7 List of work packages (# Table 3.1b)

Work package No	Work Package Title	Lead Participant No	Lead Participant Short Name	Person-Months	Start Month	End month
1	Weather and climate model evaluation	1, 9	AWI, UREAD	192	1	48

2	Enhanced weather and climate models	10, 11	SU, CNRS-GAME	222	1	48
3	Atmospheric and oceanic linkages	7, 4	Met Office, UiB	230	1	48
4	Support for Arctic observing system design	3, 8	ECMWF, UCL	70	1	48
5	Improved predictive capacity	2, 6	BSC, MET Norway	142	1	48
6	Data and HPC management	6	MET Norway	25	1	48
7	User engagement, dissemination and training	13, 2, 14	AP, BSC, UiT	107	1	48
8	Clustering	1	AWI, ECMWF	6,5	1	48
9	Project Coordination and Management	1	AWI	24	1	48
				1018,5		

Table 8 List of Deliverables (#Table 3.1c)

Deliverable (number)	Deliverable name	Work package number	Short name of lead participant	Type	Dissemination level	Delivery date (in months)
D1.1	Model assessment plan	1	AWI	R	PU	4
D1.2	Provision of process-focused, user-relevant and Arctic linkages metrics through ESMValTool	1	AWI	Software	PU	12
D1.3	Provision of novel metrics through ESMValTool	1	UCL	Software	PU	24
D1.4	Assessment of CMIP5 and CMIP6 experiments including recommendations for model development activities in WP2	1	UREAD	R	PU	30
D1.5	Report on the synthesis of heat budget approaches for the Arctic	1	Met Office	R	PU	48
D1.6	Report on potential for emergent constraints to reduce uncertainty in projections of Arctic climate and linkages to Northern Hemisphere circulation	1	Met Office	R	PU	48
D2.1	Demonstrator of a fully coupled SCM	2	SU	DEM	PU	18
D2.2	Recommendations on the coupling methodology in prediction and climate models	2	CERFACS	R	PU	30
D2.3	Recommendations on the inclusion of APPLICATE model enhancements in NWP models	2	CNRS-GAME	R	PU	30
D2.4	Report on the application of the fully coupled SCM to test cases based on Arctic YOPP IOPs	2	SU	R	PU	36
D2.5	Report on model developments and their evaluation in coupled mode	2	UCL	R	PU	36
D2.6	Report on the impact of increased resolution on the simulated Arctic Ocean circulation and on Arctic-Atlantic and Arctic-Pacific	2	UNI Research	R	PU	40



	oceanic linkages					
D2.7	Synthesis on priorities for future model developments for coupled models	2	CNRS-GAME	R	PU	48
D3.1	Report on coordinated coupled multi-model assessment of the seasonal to inter-annual impact of Arctic sea ice decline on lower latitudes	3	BSC	R	PU	36
D3.2	Report on coordinated atmosphere-only multi-model assessment of the seasonal to inter-annual impact of Arctic sea ice decline on lower latitudes	3	MET Norway	R	PU	36
D3.3	Report on coordinated coupled multi-model assessment of the decadal and longer impact of Arctic sea ice decline on lower latitudes	3	CERFACS	R	PU	36
D3.4	Final report on coordinated multi-model assessment of the seasonal to inter-annual impact of Arctic sea ice decline on lower latitudes, including the influence of the background state and pattern of anomalies	3	Met Office	R	PU	48
D3.5	Report on the influence of the Arctic atmosphere on mid-latitude weather and climate	3	AWI	R	PU	48
D4.1	Initial assessment of the added value of observations in existing long time-series datasets, also providing guidance for dedicated observing system experiments	4	CNRS-GAME	R	PU	24
D4.2	Evaluation of the contribution of the Arctic observing system to forecast skill from short/medium-to-seasonal time scales	4	UREAD	R	PU	48
D4.3	Evaluation of initialization experiments investigating the impact of novel observations in the coupled atmosphere–land–ocean–sea ice system	4	UCL	R	PU	48
D4.4	Recommendations for the design of the future Arctic observing system	4	AWI	R	PU	48
D5.1	APPLICATE WP5 Stream 1	5	BSC	DEM	PU	12
D5.2	Strengths and limitations of state-of-the-art weather and climate prediction systems	5	CNRS-GAME	R	PU	24
D5.3	Individual impacts of improved process-representation, ensemble generation and increased resolution on the weather and climate prediction performance	5	MET Norway	R	PU	36
D5.4	APPLICATE WP5 Stream 2	5	MET Norway	DEM	PU	42

D5.5	Sea ice predictions with the APPLICATE forecast systems as contributions to the SIPN exercise	5	UCL	DEM	PU	44
D5.6	Integrated added-value from APPLICATE on weather and climate prediction and projection	5	ECMWF	R	PU	48
D5.7	Synthesis report on priorities for future forecasting system development	5	BSC	R	PU	48
D6.1	Data management plan	6	MET Norway	R	PU	6
D6.2	Data catalogue and services	6	MET Norway	R	PU	12
D6.3	Provision of guidance material and tools for effective data management	6	MET Norway	R	PU	12
D6.4	Start with the archiving and dissemination of YOPP Analysis and Forecast Dataset	6	ECMWF	R	PU	18
D6.5	Post Processing Environment	6	MET Norway	R	PU	30
D7.1	Website, social media accounts and identity materials	7	AP, BSC	DEC	PU	2
D7.2	Communication and dissemination plan	7	AP, BSC	R	PP	6
D7.3	User-engagement plan	7	BSC, AP	R	PP	6
D7.4	Training plan	7	UiT, AP, BSC	R	PP	6
D7.5, D7.6, D7.7, D7.8, D7.9	Dissemination materials	7	AP, BSC	DEC	PU	6, 13, 25, 37, 45
D7.10	Final assessment of the outcomes of the training experience	7	UiT	R	PU	47
D8.1	Invite coordinators of relevant projects to the YOPP planning meetings	8	AWI	R	PU	1
D8.2	Invite coordinators of BG-09 and other BG-10 projects to become members of external advisory board in APPLICATE	8	AWI	R	PU	1
D8.3	Draft clustering plan	8	AWI	R	PU	3
D8.4	Update the dissemination plan to reflect specific clustering strategy with projects funded under H2020-BG09-2016 and BG10-2016	8	AWI	R	PU	3
D8.5	Provide report from US CLIVAR Working Group meeting including recommendations for adjustments to the WP3 part of the APPLICATE numerical experimentation plan	8	AWI	R	PU	4
D8.6	Update the dissemination plan to reflect specific joint clustering activities with projects funded under earlier H2020 and FP7 calls	8	AWI	R	PU	5

D8.7	Provide draft concept for a joint YOPP-APPLICATE summer school including a list of possible co-sponsors	8	AWI	R	PU	7
D9.1	Signed Consortium Agreement	9	AWI	R	CO	1
D9.2, D9.6, D9.8,D9.10	Minutes of the annual General Assemblies	9	AWI	R	CO	2, 18, 32, 48
D9.3	Manual, guide & templates for deliverables and reporting	9	AWI	R	CO	3
D9.4	Risk management plan	9	AWI	R	CO	5
D9.5	Gender Strategy	9	AWI	R	CO	6
D9.7, D9.9, D9.11	Periodic reports, including financial reports	9	AWI	R	CO	18, 36, 48
D9.12	Final project report	9	AWI	R	CO	48

## 3.2 Management structure and procedures

### 3.2.1 Organisational Structure and decision making in the consortium

APPLICATE will bring together the expertise and know-how of 16 partners from 9 countries, forming an excellent network for advancing predictive capacity of the weather and climate of the Northern Hemisphere. Considering the size of the Consortium the organisational structure of APPLICATE has to be extremely efficient, allowing a fast and coherent decision-making process. The management structure of APPLICATE will thus be based on three levels, ensuring an efficient and success-oriented project management (Figure 6):

- **The decision making level:** This level consists of the APPLICATE General Assembly which will be the highest authority and the central body for strategic discussions within the project consortium, being responsible for the overall performance, the compliance with the Grant Agreement and its Annexes as well as with the Consortium Agreement.
- **The management level:** This level is shared by the Project Coordinator with his Management Support Team for operational management and the Executive Board for strategic management.
- **The executive level:** The WP leaders and Task Leaders within this level are responsible for carrying out all activities and tasks as described in the individual work packages, keeping close contact with the partners involved in specific tasks and WPs.

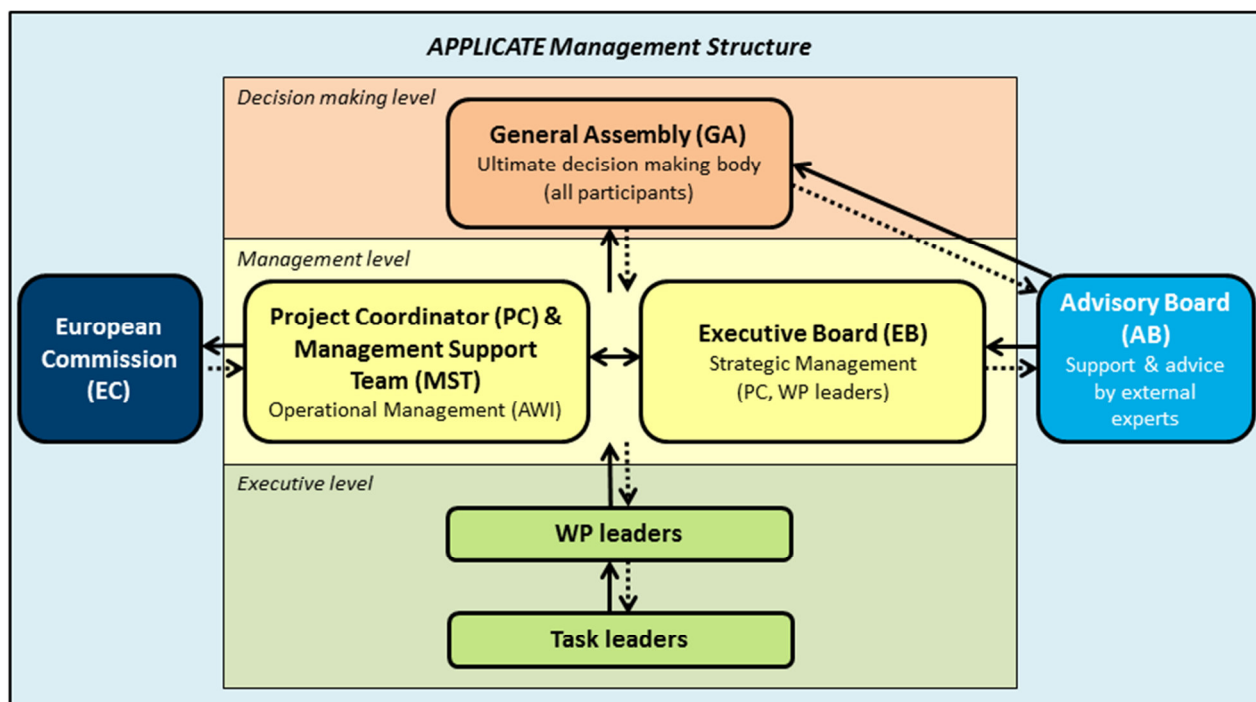


Figure 6 APPLICATE Project Management Structure showing the reporting flows (solid arrows) and the feedback flows (dashed arrows) of the different management bodies and the decision making in APPLICATE.

The composition, responsibilities and tasks of each Consortium body will be described in more detail below and will be formalised in the APPLICATE Consortium Agreement.

#### *3.2.1.1 The General Assembly (GA)*

The GA is the ultimate decision-making body of the consortium. It is responsible for the strategic policy and decision-making, and consists of one senior representative from all partners of the project. Guests from the Advisory Board, representing international partners and stakeholders, will assist and advise the GA in its decisions, without own voting rights.

The main role of the GA is to make sure that the strategy adopted for APPLICATE is respected and that the desired standards of excellence are achieved. The GA will decide on reorientations, validate project reviews and deal with any changes in the consortium. Further responsibilities of the GA include:

- Strategic planning and direction of the project and definition of the overall project strategy plan.
- Approval of the project deliverables in terms of quality and relevance as defined in the Grant Agreement.
- Approval of periodic and final reports to the EC.
- Review of project progress against milestones, approval of changes and recommendations for improvements in the work or dissemination plan.
- Approval of the project implementation plans and their associated financial plans and subsequent monitoring of technical and financial progress against deliverables.
- Approval of withdrawal, replacement or addition of consortium participants.
- Monitoring and implementation of any changes necessary in the Consortium Agreement.

The GA meets at least once a year, over the duration of the project. In order to facilitate the decision-making process, the GA is chaired by the Project Coordinator (PC), who consults with other members through intermediate meetings, when required by the project course.

#### *3.2.1.2 The Project Coordinator (PC) and Management Support Team (MST)*

The overall project management and coordination is the responsibility of AWI. The Project Coordinator of APPLICATE is Prof Thomas Jung, head of the Climate Dynamics Section at AWI. He has extensive experience in leading large-scale projects such as the Polar Prediction Project, which has established YOPP, and he oversees its planning and implementation. Furthermore, he is spokesperson of AWI's research programme, PACES-II, which has an annual budget of about 140 million EUR and includes large-scale infrastructure such as the research icebreaker Polarstern.

The PC will lead the General Assembly and the Executive Board. Supported by the MST, the PC will manage the consortium as a whole and ensure that within APPLICATE all mechanisms are in place to ensure project progress and the successful achievement of all project objectives. He is the intermediary between the European Commission (EC) and the consortium in all matters, as well as in contribution-related concerns regarding allocations between participants and activities. The PC will be responsible for the day-to-day management and for collecting, reviewing and verifying consistency and submitting reports and deliverables to the EC. He will be the contact point for all disputes within the consortium and will present disputes, which cannot be resolved by mutual agreement, to the GA for final decision.

The Management Support Team will also be located at AWI to ensure the most efficient assistance to the PC in the day-to-day project management and in particular with the administrative, financial and contractual issues for APPLICATE. The MST is led by the project manager Nancy Lange, who has proven experience as a member of the management team of the FP7 collaborative project PAGE21, the H2020 coordination and support action EU-PolarNet and as project manager of the FP7 Marie Curie IRSES project IMCONet. She will be assisted by the project secretary. The responsibilities of the MST will be:

- Management of all administrative, contractual and financial aspects of the project, such as accurate scientific and financial reporting, and consortium management.
- Organisation of intra-consortium communication.
- Meeting and organisational support to the APPLICATE management bodies: GA, EB, AB and WP Leaders.
- Preparing the Grant Agreement, drafting and negotiating the Consortium Agreement and amendments.
- Setting up a quality management routine for the project management (standards of documents, proofreading, validation workflow), to be implemented from the outset of the project.
- Allocation of EC contribution to the beneficiaries in accordance with EC requirements and the Consortium Agreement.
- Advice to the Partners' administrative and financial departments.

- Overseeing and manage gender issues and balance during the project and within the consortium.
- Development, monitoring and maintaining a risk management plan as a list of potential risks and mitigation measures.

#### *3.2.1.3 The Executive Board (EB)*

The role of the Executive Board is fundamental for the project: It will ensure the successful execution of the project by taking care of the coordination and correct implementation of the scientific project tasks. The EB reports to and is accountable to the GA. It will consist of the APPLICATE WP leaders and co-leaders and be chaired by the Project Coordinator. International and external experts from the Advisory Board will be invited to meetings of the EB for assistance and advice as needed.

The role of the EB will be to ensure the successful implementation of all aspects of the project work plan and to formulate the overall strategy and development of the project, which will be proposed to the GA for discussion and decision. The EB's main responsibilities will include:

- Delivery of the project work plan.
- Review of the project progress and the resources status.
- Facilitating the relationship of the project with other new and existing projects and strategic forums and initiatives related to enhancing the predictive capacity of Northern Hemisphere weather and climate.
- Ensuring the execution of the risk management plans of the project if necessary.
- Ensuring the smooth internal cooperation and relationship between consortium members as well as external project stakeholders.

The EB will meet at least quarterly, or more often as required in the course of the project. Any member of the EB can call for an extraordinary meeting by a written request. The meetings will be scheduled if possible in conjunction with other meetings such as the General Assemblies, but they will also be held via video- and teleconferences to reduce travel time and cost.

#### *3.2.1.4 The Work Package and Task leaders*

While the PC and the MST have the overall responsibility for the execution of the work plan, the work package leaders, in conjunction with the appointed task leaders, will conduct the project activities. They will collaborate closely, using a system of regular internal reporting. At least every third month, task leaders will summarise their progress towards project deliverables to the WP Leaders, who will review the activity against the work plan and, following discussion with the task leaders, consider if interim targets or measures are required. These reviews will also serve as the basis for more formal reports to the EB, PC, GA and, ultimately, the European Commission.

The WP leaders will be responsible for:

- Delivery of the WP objectives and management of tasks and deliverables.
- Management of the WP as a sub-project with regular WP meetings (video-teleconferenced/web-based virtual meetings, if appropriate).
- Frequent communication with the PC and the MST.
- Quarterly monitoring of the overall progress for each task in cooperation with the task leaders.
- Compilation and distribution of WP progress reports.
- Establishing and maintaining links with other WPs as necessary.
- Managing WP administrative issues, referring to the MST as necessary.
- Reporting to the EB, PC and MST.

The task leaders will be responsible for:

- Implementation of the individual tasks as set out in the work plan.
- Establishing and managing interactions between individual partners involved in the task.
- Reporting of task progress to WP leaders.
- Arranging individual task meetings (video-teleconferenced/web-based virtual meetings, if appropriate).
- Establishing and maintaining links to other tasks as necessary.

#### *3.2.1.5 The Advisory Board (AB)*

In addition to the Consortium bodies described above, APPLICATE will be supported by the Advisory Board. The AB comprises internationally recognised external experts in the fields of dynamics and prediction of weather and climate and representatives of the different stakeholder groups relevant to APPLICATE. In addition to those experts, the Coordinators of the funded projects under the topics H2020-BG09-2016 and H2020-BG10-2016 as well as the Coordinator(s) of the relevant projects funded under the Belmont Forum call on climate predictability and inter-regional linkages will be invited to become members of the APPLICATE AB. Due to its nature and

composition, the AB will increase the international visibility of APPLICATE and strengthen the international collaboration in weather and climate predictions for the Northern Hemisphere as well as with other European initiatives and projects within this research area. Its role is to give recommendations and support to the strategic steering of the project in close collaboration with the EB and the GA. The AB will:

- Provide independent advice to the EB and the GA to support strategic decisions.
- Critically review project progress (e.g. deliverables) to ensure their relevance and excellence and to provide important feedback to the APPLICATE consortium.

The members of the AB are appointed by the GA. The chair of the AB will be elected from and among the board members and recommended to the GA for approval. The following international experts have agreed to advise and support APPLICATE as members of the AB (letters of commitment are attached in section 6):

*Table 9 Members of the APPLICATE Advisory Board*

Name	Institution	Country
Cecilia Bitz	University of Washington	USA
Gilbert Brunet	Environment and Climate Change Canada	Canada
Clara Deser	National Centre for Atmospheric Research (NCAR)	USA
Veronika Eyring	Deutsches Zentrum für Luft- und Raumfahrt (DLR)	Germany
Inger Hansen-Bauer	Norwegian Meteorological Institute	Norway
Jean-Noel Thepaut	Copernicus Climate Change Service (C3S)	United Kingdom
Tero Vauraste	CEO Arctia Shipping	Finland

Ideally, meetings of the AB will take place adjacent to the yearly GA to give the AB members the opportunity to follow project progress most closely and to be directly involved in the discussions leading to strategic decisions. The GA and EB will seek the advice of the AB whenever it is necessary for the project course. They can call for extraordinary AB meetings or consult the AB members by video- or teleconferences and electronic communication.

### 3.2.2 Organisational structure and decision-making in relation to the project complexity and scale

APPLICATE adopts a management structure that takes into account the ambition of the project, as well as the size of its consortium. The management structure has been based on the structure used in previous projects of the participants where it has proven its effectiveness. It involves the sharing of responsibilities in both vertical and horizontal directions.

The *General Assembly* ensures that all 16 partners are represented in the decision-making process, with each of them having a voting right. The General Assembly and the Executive Board will be chaired by the *Project Coordinator*. The PC, together with the support of the *Management Support Team*, will take care of the day-to-day project management. The PC and his MST will play a key role in APPLICATE as central contact point for all project partners, the GA, EB and the European Commission. In addition we have appointed for every WP a *WP Leader* and for every task a *Task Leader*. All WP leaders (and Co-Leaders) are represented in the EB, which ensures appropriate interaction between all WPs but also an optimal flow of information on progress, potential risks or delays and necessary adaptations towards the PC and the GA. The additional appointment of task leaders supports and eases the work of the WP Leaders, especially for complex tasks involving several partners.

GA, EB, PC and WP Leaders will monitor the progress of the project along the following Milestones:

*Table 10 List of milestones (#table 3.2a)*

Milestone number	Milestone name	Related WPs	Due date (month)	Means of verification
MS1.1	Enhanced version of ESMValTool available	1-3, 5	12	Metrics in ESMValTool have been incorporated, tested and accepted.
MS2.1	Coupled ocean-sea ice-atmosphere SCM ready for parameter optimisation studies	2	18	The SCM is used in a case study with at least one observational data set
MS2.2	Final design of enhanced models to be assessed in climate and prediction mode	2, 5	36	Enhanced models can be used to evaluate their predictive skill in WP5
MS3.1	Final design of coordinated multi-model numerical experiments in liaison with the international community	3	2	The numerical experimentation plan has been updated.

MS4.1	Initial assessment of the value of observations for producing reanalyses and initial conditions for forecasts	4	24	Draft recommendations have been formulated
MS4.2	Synoptic analysis of observational data gaps and recommendations for future observing systems	4	48	Draft recommendations have been formulated
MS5.1	Database downloaded	5	3	Databases for the atlas of prediction scores downloaded by the partners
MS5.2	Sensitivity experiments	5	30	Sensitivity experiments to improved process representation performed
M6.1	Setup YOPP Analysis and Forecast Dataset Infrastructure	6	15	Data can be archived and external access has been setup and tested
MS7.1	Start of social media campaign on Facebook and Twitter	7	7	Active accounts, regular updates, online visibility statistics
MS7.2	First meeting of User Group	7	10	List of participants. Meeting minutes and conclusions of the User Group.
MS7.3	1 <sup>st</sup> Strategic meeting of WP7 – revision of communication and dissemination, user engagement, and training plans	7	17	Minutes of the meeting, suggestions to Project Manager
MS7.4	Summer school	7	19	List of attendance of Summer school
MS7.5	Start of website second phase	7	20	Changes in the contents and structure of the website
MS7.6	2 <sup>nd</sup> Strategic meeting of WP7 – revision of communication and dissemination, user engagement, and training plans	7	35	Minutes of the meeting, suggestions to Project Manager
MS7.7	Share outcomes of user feedbacks with key players in the C3S User Interface Platform	7	41	Information made available from APPLICATE website
MS8.1	Network of coordinators	8	6	Network of project coordinators has been established and regular teleconference have been set up
MS8.2	Consolidated clustering plan	1-8	9	Revised version of clustering plan after consultation with all APPLICATE key partners

### 3.2.3 Innovation Management

Effective innovation management within APPLICATE will require an overview of the project in its entirety. For this reason the PC will be responsible for the process of innovation management. Through the PC and within the management structure already identified above these elements will be brought together and will ensure effective innovation management.

The main innovation coming out of APPLICATE entails concrete guidance on how to improve weather and climate prediction systems for the Arctic and beyond. In this regard, innovation management will focus on two target groups: APPLICATE partners and collaborators as well as other related institutes and organisations not directly involved in APPLICATE. Regarding APPLICATE partners and collaborators, the PC will work closely with the PIs from the different partner institutions. Innovations will be closely monitored and recommendations for their implementation in operational prediction systems and climate models will be considered on a bi-annual basis. APPLICATE will also strive for sharing innovation with other institutes and organisations. In this regard, clustering (WP8) will play a pivotal role. Partners will also advocate and discuss APPLICATE innovations at a national, European and international level, taking advantage of workshops and conferences as well as of the fact that APPLICATE partners are strongly engaged in many relevant high-level committees such as the Polar Prediction Project Steering Group (overseeing YOPP), the World Climate Research Programme's Modelling Advisory Council and the World Weather Research Programme's Scientific Steering Committee.

WPs 1-7 are designed to incorporate end-user feedback into the project, with WP7 taking a leading role in designing and implementing an effective user-engagement strategy. Incorporation of end-user feedback will be achieved through a careful timing of the deliverables and milestones of the work packages. In this way the project will be responsive to any external opportunities that are identified. The PC will also ensure that any internal opportunities are addressed and incorporated if necessary.

The Advisory Board of experts along with the User Group (see WP7) will play a very important role in delivering innovation by acting as a knowledge broker for those seeking information about the Polar Regions. If the Advisory Board or User Group cannot provide all the answers, they will be able to signpost the likely sources of the necessary knowledge.

### 3.2.4 Critical Risks for the project implementation and risk-mitigation measures

APPLICATE brings together a highly qualified team with proven expertise in managing large-scale European and international projects. The management structure employed by APPLICATE is similar to those of previous successful EU projects. This is a proven scheme, which is very effective at resolving any significant deviations from the project plan efficiently and transparently through dialogue with the relevant partners. If a partner encounters a problem which delays a deliverable or milestone, the WP leader will notify the MST, and together they will decide if it will be necessary to convene a conference call of the Executive Board to solve the problem. In case of a more serious delay both the Executive Board and the EC Project Officer will be notified immediately. This level of management engagement will enable efficient tactical and planning decisions to be performed with ease. The MST will be set up templates and guidelines at the outset of the project and will give clear advice on standards for deliverables, proofreading, validation and workflow.

While the project is running, the MST will develop, monitor and maintain a risk register and present this to the Executive Board at their regular meetings. The risks register contains the following information for each risk identified: risk description (fact or event which could jeopardize the correct functioning of the project), work package/task involved, likelihood (high medium, low), impact (insignificant, minor, moderate, major, catastrophic), risk response (type and description), responsibility, due date, and status (open, closed). This approach will ensure that potential risks are discovered without delay and immediate countermeasures can be applied.

Risk management will be performed at all project levels and will adopt a uniform and systematic approach across the project team to:

- Identify and evaluate risks;
- Define and plan proactive and efficient actions for risk reduction;
- Start, perform and control planned mitigation activities;
- Document the progress of risk management activities, and evaluate their results with continuity in order to implement needed corrections.

Table 11 shows risks to project implementation that have the potential to impact the achievement of project objectives. These risks will be actively managed and monitored throughout the project. Risks that exist specifically for individual WPs are mentioned in the WP descriptions together with proposed preventative measures.

*Table 11 Critical risks for implementation of APPLICATE (#table 3.2b)*

<b>Description of risk (level of likelihood: Low/Medium/High)</b>	<b>WPs involved</b>	<b>Proposed risk-mitigation measures</b>
Availability of CMIP6 model output may be delayed: Medium	1, 2, 3, 5	CMIP5 and a subset of CMIP6 data will already be available to APPLICATE to test and refine WP1 approach.
The development of metrics in Task 1.2 includes many partners. Delays from one partner (or a partner leaving the consortium) will delay Task 1.2: Low	1, 2, 3, 5	APPLICATE partners have broad expertise in other areas. This expertise can be made available in case of delays or a partner leaving the consortium.
Delay in provision of model enhancements from WP2: Medium	2, 5	Use of a subset only of WP2 model improvements in WP5 Stream 2 experiments.
Delay in guidance on optimal initialisation strategy from WP4: Medium	4, 5	Selection of an initialisation strategy tested in WP4 and showing improvements in prediction performance for WP5 Stream 2 experiments
Delay in achieving deliverables or milestones / need for assignment of unanticipated tasks: Low	All	The Coordinator will stay in close contact to WP and task leaders. Thus he will always be informed on the latest developments and the overall progress and be able to identify possible risks and delays in due time. This will



		enable him to find very early mitigation measures and to consult the EC Project Officer in case of major difficulties. Mitigation measures will be discussed during the quarterly meetings of the Executive Board.
Communication problems among partners. Disagreement among consortium partners: Low	All	Regular meetings (face to face, video- and teleconferences) among partners. The management structure provides rules for de decision making and conflict resolution. This risk is also mitigated by the history of collaboration between several project partners and by the coordinator's experience in EU project management.
Related European and international projects/activities are reluctant to engage in the clustering process: Low	8, all	APPLICATE will take a pro-active approach offering to organize, co-lead and synthesize clustering activities. Make use of existing links with any APPLICATE partner.
Severe damage to the central data repository: Low	All	The data repository will be maintained to the highest level of rigour as it is a crucial infrastructure. Copies of model output will be kept at partner institutes, and backups of web pages and code repositories maintained.
Model integrations encounter fundamental technical problems such as HPC availability, stability, spin-up: Medium	All	Seek and share experience between groups and from external sources (ENES, ESiWACE, the centre of excellence for weather and climate); if necessary shorten integration period; look for PRACE resources whenever necessary.
Key staff assigned to project become unavailable for any reason: Medium	All	All consortium members to have appropriate succession planning, with deputies for all key roles appointed. Coordination between partners to ensure expertise is available.
Russian partner(s) do(es) not get funding from the Russian side: Medium	All	The deliverables have been set up such that they can be produced even in case there should be no funding from the Russian side.

### 3.2.5 Conflict Resolution

The project could be affected by conflicts of various types: strategic, technical, shortage of resources, and others. WP Leaders, PC and MST will seek to anticipate the emergence of such conflicts, and discuss the best way to resolve them with the partners. The project employs a multi-level escalation strategy. Conflicts at work level should first be reported to Task leaders and then WP leaders. If not resolved at this level, problems and possible solutions will be formally discussed at the EB, moderated by the PC, where, if necessary, a vote can take place. If no decision can be found, the EB will report the issue to the GA where the final decision will be taken in a meeting moderated by the PC.

## 3.3 Consortium as a whole

### 3.3.1 Partners

The APPLICATE consortium comprises research institutions, universities, one international European organisation, national meteorological centres, one supercomputing centre and one small/medium-sized enterprise (SME). This composition ensures that the relevant **expertise** is well covered by the consortium:

- Scientific and technical excellence needed to make significant progress in developing predictive capacity for the weather and climate of the Northern Hemisphere;
- Representation of some of the world-leading European modelling and prediction centres providing an effective transition of APPLICATE research into operational prediction across a wide range of time scales;
- Participation of leading experts in the field of climate services, user-engagement and knowledge transfer ensuring effective stakeholder involvement and widest possible dissemination;
- Proven expertise in developing strong educational programmes.

The combination of technical and scientific excellence as well as experience will support early and sustained progress towards the overarching mission of APPLICATE – *To develop enhanced predictive capacity for weather and climate in the Arctic and beyond, and to determine the influence of Arctic climate change on mid-latitudes, for the benefit of policy makers, businesses and society.* This objective cannot be fulfilled with a less experienced team. Each partner brings a particular expertise needed for the successful development and deployment of the project's

outcome. The composition of the consortium will also be a legacy after the end of the project through the strong involvement of operational centres, and also in its support of existing Copernicus services such as C3S.

Several partners have already successfully worked together, and there is substantial experience working in an international multi-disciplinary context. This ensures strong **synergies** within the team and with other ongoing European and international activities.

In particular:

- The consortium is coordinated by one of the world's leading polar research organisations. AWI is embedded in a number of European Research initiatives, such as the European Polar Board (EPB) and the European Climate Research Alliance (ECRA). Furthermore, the office of the International Arctic Science Committee (IASC) and that of the International Coordination Office for Polar Prediction (ICO) are hosted by AWI. Next to the involvement in numerous EU-funded projects as a partner, AWI has a strong track record of coordinating large EU projects (e.g. PAGE21, StratoClim and EU-PolarNet).
- The project management capacity of the consortium is strengthened through the involvement of partners with experience in coordinating EU projects (e.g. BSC and ECMWF); and the coordination with other relevant ongoing European and international activities is facilitated by involving partners that take leading roles in European and international coordination programmes such as WMO, WWRP and WCRP (e.g. AWI, BSC, ECMWF and SU).
- The consortium brings together experts in the field of atmospheric modelling (SU, ECMWF, CNRS-GAME, Met Office, MET Norway), snow modelling (ECMWF, CNRS-GAME, UCL), sea ice modelling (AWI, UCL, CNRS-GAME), ocean modelling (AWI, UiB, UNI Research, Met Office, CERFACS), as well as in the field of coupling between the different climate system components (CNRS-GAME, SU, Met Office). Therefore, the consortium can draw on the expertise needed to bring the modelling of the coupled climate system to the next level, both in the Arctic and beyond.
- The consortium includes some of the leading European climate modelling groups, and all climate models that participate in APPLICATE (AWI-CM, EC-Earth, CNRM-CM, NorESM, HadGEM) will be contributing to CMIP6. It will therefore be possible to evaluate the impact of model enhancements, coming out of APPLICATE, in a CMIP framework, and to provide an interim update on the CMIP6 results ('CMIP6-Interim').
- To make significant advances in our understanding of the impact of Arctic climate change on the weather and climate of the Northern Hemisphere – from the source region, via teleconnections, to where the impacts are felt – the consortium includes Arctic experts (AWI, BSC, SU, UiB, UNI Research, UCL, MET Norway, CNRS-GAME), experts on mid-latitude dynamics (Met Office, UREAD, BSC, CERFACS, ECMWF) as well as scientists with a track-record in research on atmospheric and oceanic teleconnections (AWI, CERFACS, Met Office, UiB, UREAD, CNRS-GAME).
- The consortium includes some of the world-leading operational prediction centres, including global (ECMWF, Met Office, Météo-France as third party of CNRS-GAME) as well as limited area (MET Norway, Météo-France) prediction systems. The involvement of these centres contributes excellent research infrastructure, such as a framework for carrying out comprehensive experiments for designing observing systems and testing developments in full-sized prediction systems. Furthermore, this research is supported by some of the largest high-performance computing structures in Europe (e.g. ECMWF and Met Office HPC facilities). Furthermore, having operational centres involved (ECMWF, Met Office, MET Norway and Météo-France) ensures that scientific progress can be effectively translated into improved prediction services. This includes the transition from operational prediction systems to Copernicus services and their users.
- To ensure effective knowledge transfer, end-user engagement and dissemination the consortium includes one of the pioneers in the area of climate services (BSC), as well as the provider of one of the leading gateways to Arctic information and data on the internet with excellent connections to a wide network of stakeholders (AP). The consortium also benefits from the fact that many of the partners have strong outreach and dissemination facilities that can be exploited by APPLICATE.
- The educational programme will be developed and implemented in partnership with one of the leaders in the field of Arctic education APECS, hosted by the partner UiT. Furthermore, the consortium will bring together partners that have successfully developed strong educational programmes in the past (e.g. UiT/APECS, AWI, UREAD and SU).
- The consortium is augmented by distinguished partners from Russia, namely Sergey Gulev from the P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences (IORAS), and Vladimir Kattsov from the Voeikov Main Geophysical Observatory. These partners will contribute their outstanding expertise in the field

of model assessment (WP1) as well as in studying the response of mid-latitude weather and climate to Arctic sea ice decline (WP3).

### 3.3.2 External collaborators

APPLICATE is dedicated to collaborate effectively with European and international partners. Our strategy is to actively engage with those high-level projects and organisations that coordinate activities of a wide range of relevant partners. In this context, YOPP is an excellent example of how effective coordination with a wide number of groups can be achieved by strongly engaging in a single activity. Other examples of high-level committees and projects with which the APPLICATE consortium will be engaging include the US CLIVAR Working Group on Arctic Change and Possible Influence on Mid-latitude Climate and Weather, the Sea Ice Prediction Network (SIPN) as well as EU projects such as those that will be funded under H2020-BG09-2016 and H2020-BG10-2016 as well as the ongoing H2020 project PRIMAVERA. Furthermore, there will be strong engagement with projects resulting from the Belmont Forum call on *Climate predictability and inter-regional linkages*. Finally, the strong engagement with EU-PolarNet will be of mutual benefit for the research planning process as well as for the process of stakeholder engagement and policy advice.

In addition to this general cooperation with projects and organisations we will also engage with some key partners on a more individual basis. Examples include Environment and Climate Change Canada (formerly Environment Canada), which has a very strong expertise in the area of model development and weather and climate prediction with coupled atmosphere-sea ice-ocean systems. Furthermore, we will engage with the International Arctic Research Centre (IARC) for coordinated experiments using coupled and uncoupled climate models on polar regional climate prediction research, the National Centre for Atmospheric Research (NCAR) for diagnosing Arctic heat budgets within model simulations. Strong collaboration is also planned with the Polar Research Institute of China (data sharing, dissemination of APPLICATE results), the Korea Maritime Museum (APPLICATE User Group), the Institute of the North in Alaska (APPLICATE User Group).

Our previous experience from EU funded projects has shown that the inclusion of international, non-EU partner organisations as full project partners is often very difficult and was in many cases impossible. The reason for this is that those partner organisations would need to sign the EC Grant Agreement as well as the Consortium Agreement if they become full partners within the project. However the EC Grant Agreement as well as the Consortium Agreement include specific clauses on intellectual property rights, liability and governing law, which are in many cases impossible to accept for international partners. Therefore the APPLICATE Consortium decided to include all International partner organisations from Canada, USA, Switzerland, China, Republic of Korea and Japan through a letter of commitment. Once the project has been chosen for funding the Project Coordinator will enter on behalf of the consortium a **coordination agreement** with those partner organisations in order to formalise and align the work of APPLICATE with those partner organisations. This approach of including international partner organisation has been chosen by the APPLICATE consortium on purpose in order to prevent partner organisations from withdrawing from the project once they have to sign the EC Grant Agreement and the Consortium Agreement. This will give APPLICATE a high grade of flexibility of involving international partner organisations according to the project's needs, whilst ensuring that all legal standards and requirements are met by signing the coordination agreement.

## 3.4 Resources to be committed

### 3.4.1 Summary of staff effort

Table 12 Summary of staff effort (# Table 3.4a)

	W P1	W P2	W P3	W P4	W P5	W P6	W P7	W P8	W P9	Total Person/ Months per Participant
<b>1 – AWI</b>	<b>24</b>	20	24	2	12	11	0	<b>4</b>	<b>24</b>	<b>121</b>
<b>2 – BSC</b>	5	0	27	6	<b>48</b>	0	44	0	0	<b>130</b>
<b>3 – ECMWF</b>	12	15	0	<b>12</b>	12	3	0	2.5	0	<b>56.5</b>
<b>4 – UiB</b>	1	0	11	0	0	0	0	0	0	<b>12</b>
<b>5 – UNI Research</b>	2	19	18	0	0	0	0	0	0	<b>39</b>
<b>6 – MET Norway</b>	0	0	23	0	25	<b>11</b>	0	0	0	<b>59</b>
<b>7 – Met Office</b>	10	11	<b>27</b>	6	9	0	0	0	0	<b>63</b>
<b>8 – UCL</b>	19	44	0	26	15	0	0	0	0	<b>104</b>
<b>9 – UREAD</b>	23	0	12	15	0	0	0	0	0	<b>50</b>

<b>10 – SU</b>	2	<b>58</b>	0	0	0	0	0	0	0	<b>60</b>
<b>11 – CNRS-GAME</b>	18	43	6	3	21	0	0	0	0	<b>91</b>
<b>12 – CERFACS</b>	18	12	24	0	0	0	0	0	0	<b>54</b>
<b>13 – AP</b>	0	0	0	0	0	0	<b>52</b>	0	0	<b>52</b>
<b>14 – UiT</b>	0	0	0	0	0	0	11	0	0	<b>11</b>
<b>15 – IORAS</b>	33	0	25	0	0	0	0	0	0	<b>58</b>
<b>16 – MGO</b>	25	0	33	0	0	0	0	0	0	<b>58</b>
<b>Total Person/Months</b>	<b>192</b>	<b>222</b>	<b>230</b>	<b>70</b>	<b>142</b>	<b>25</b>	<b>107</b>	<b>6.5</b>	<b>24</b>	<b>1018,5</b>

### 3.4.2 ‘Other direct cost’ items (travel, equipment, other goods and services, large research infrastructure)

Table 13 ‘Other direct cost’ items (# Table 3.4b)

<b>1 – AWI</b>	<b>Cost (€)</b>	<b>Justification</b>
<b>Travel</b>	35.000	Travel to General Assemblies, project meeting and outreach meetings
<b>Equipment</b>	0	
<b>Other goods and services</b>	181.300	38.000 – for the invitation of stakeholders and end-users to project meetings 65.000 – invitation of external international experts and members of advisory board to project meetings 70.000 – to cover costs for General Assemblies and project meetings 2.500 – to cover publication costs 5.800 – to cover costs for Certificates of the Financial Statement
<b>Total</b>	216.300	
<b>2 - BSC</b>	<b>Cost (€)</b>	<b>Justification</b>
<b>Travel</b>	39.000	Travel to General Assemblies, project meeting and outreach meetings
<b>Equipment</b>	3.000	Computer Hardware
<b>Other goods and services</b>	29.5000	22.000 – To cover costs for outreach meetings targeting stakeholders and end-users 2.500 – to cover publication costs 5.000 – to cover costs for Certificates of the Financial Statement
<b>Total</b>	71.500	
<b>4 - UiB</b>	<b>Cost (€)</b>	<b>Justification</b>
<b>Travel</b>	14.000	Travel to General Assemblies and project meetings
<b>Equipment</b>	0	
<b>Other goods and services</b>	2.500	To cover publication costs
<b>Total</b>	16.500	
<b>6 – MET Norway</b>	<b>Cost (€)</b>	<b>Justification</b>
<b>Travel</b>	14.000	Travel to General Assemblies and project meetings
<b>Equipment</b>	100.000	Costs for PPI and storage capacity and costs for application server for the EGSF node/data management
<b>Other goods and services</b>	7.500	2.500 – to cover publication costs 5.000 – to cover costs for Certificates of the Financial Statement
<b>Total</b>	121.500	
<b>13 - AP</b>	<b>Cost (€)</b>	<b>Justification</b>
<b>Travel</b>	35.000	Travel to General Assemblies, project meeting and outreach meetings
<b>Equipment</b>	26.700	Hardware for online and communication tools necessary for WP7
<b>Other goods and services</b>	45.500	22.000 – outreach material (roll-ups, fact sheets, etc.) 16.000 – organisation of 4 end-user meetings 2.500 – to cover publication costs 5.000 – to cover costs for Certificates of the Financial Statement
<b>Total</b>	107.200	
<b>14 - UiT</b>	<b>Cost (€)</b>	<b>Justification</b>
<b>Travel</b>	14.000	Travel to General Assemblies, project meeting and outreach meetings

<b>Equipment</b>	0	
<b>Other goods and services</b>	32.500	30.000 – organisation of summer school for young scientists 2.500 – to cover publication costs
<b>Total</b>	46.500	
<b>15 - IORAS</b>	<b>Cost (€)</b>	<b>Justification</b>
<b>Travel</b>	40.000	Travel to General Assemblies, project meeting and outreach meetings
<b>Equipment</b>	0	
<b>Other goods and services</b>	11.000	6.000 – consumables 5.000 – to cover publication costs
<b>Total</b>	51.000	
<b>16 - MGO</b>	<b>Cost (€)</b>	<b>Justification</b>
<b>Travel</b>	40.000	Travel to General Assemblies, project meeting and outreach meetings
<b>Equipment</b>	0	
<b>Other goods and services</b>	11.000	6.000 – consumables 5.000 – to cover publication costs
<b>Total</b>	51.000	

### 3.4.3 Large Research Infrastructure

APPLICATE does not involve the use of large research infrastructures.

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