REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: The Netherlands ......……………………………………………………..…

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Project Title: Blue Action …………………………………………………………………….……

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If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2019	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☐

Computer resources required for 2019-2021: (To make changes to an existing project please submit an amended version of the original form.)		**2019**	**2020**	**2021**
High Performance Computing Facility	(SBU)	36M		
Accumulated data storage (total archive volume)[2]	(GB)	130K		

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project’s activities, etc.

[2] If e.g. you archive x GB in year one and y GB in year two and don’t delete anything you need to request x + y GB for the second project year etc.

Principal Investigator: Jisk Attema

Project Title: Blue Action

Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific and Technical Advisory Committees. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more will receive a detailed review by members of the Scientific Advisory Committee.

Abstract

In this proposal we study mechanisms and predictability of a specific climatic event, the "cold blob" event of 2015. This event was characterized by a sharp decrease in sea surface temperatures in the subpolar Atlantic. It has been hypothesized that ocean processes play a key role in forming and maintaining the cold conditions and that remote regions were affected by it. Notably the heat wave over Europe in the same year could be linked to this event. To this end, we propose to extend an initialized decadal prediction ensemble with EC-Earth V3.2. We will use the high resolution version of this model with similar configuration as seasonal forecast system 5 of ECMWF. By extending the ensemble around this specific event we can further study mechanisms, the predictability of such events and potentially learn about the biases in model systems based on IFS and NEMO.

Scientific plan

Motivation

The proposed work is based on a wider collaboration the H2020 funded Blue Action project where predictability of subpolar Atlantic and Arctic climate is addressed with a special focus on the ocean's role in midlatitude and high latitude climate variability and predictability (http://www.blue-action.eu/).

The Arctic is a vulnerable region that warms faster than the rest of the globe, a feature known as Arctic Amplification (Cohen et al. 2014). Year to year variations are large as well, but at decadal time scales clear trends are visible that exceed the noise of year to year variations. These changes are very likely related to enhanced greenhouse gas concentrations in the atmosphere due to anthropogenic activities. In addition there is also evidence that natural patterns of decadal and multidecadal variability, in particular the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation, affect Arctic climate. Arctic amplification can be accelerated or slow down, depending on the phase and amplitude of natural variability in the midlatitudes (Screen and Francis 2016). The aforementioned Atlantic Multidecadal Oscillation is strongly connected to subpolar gyre dynamics and this region may therefore affect the Arctic. In this project we aim to study the predictability of the subpolar Atlantic ocean region and its teleconnection via oceanic and atmospheric pathways to the Arctic.

Previous studies have shown that the subpolar Atlantic heat content and circulation strength is predictable beyond the seasonal time scale (Hazeleger et al 2012, Wouters et al 2013, Robson et al. 2012; Yeager et al. 2012; Msadek et al. 2014). The predictability seems to be related to a combination of persistence, due to deep mixed layers, and strength of ocean currents associated with the subpolar gyre strength and Atlantic meridional overturning circulation (Figure 1 shows an example from Wouters et al 2013, a result obtained with the predecessor of the model system proposed here). The region is of considerable interest as climate models show a lack of warming in future projections. The reduced future temperature trends have been attributed to a reduced overturning circulation in the Atlantic (Drijfhout et al 2012).There is evidence that weakening of the Atlantic overturning is ongoing already leading to reduced temperature trends in recent decades in the region (Rahmstorf et al 2015).

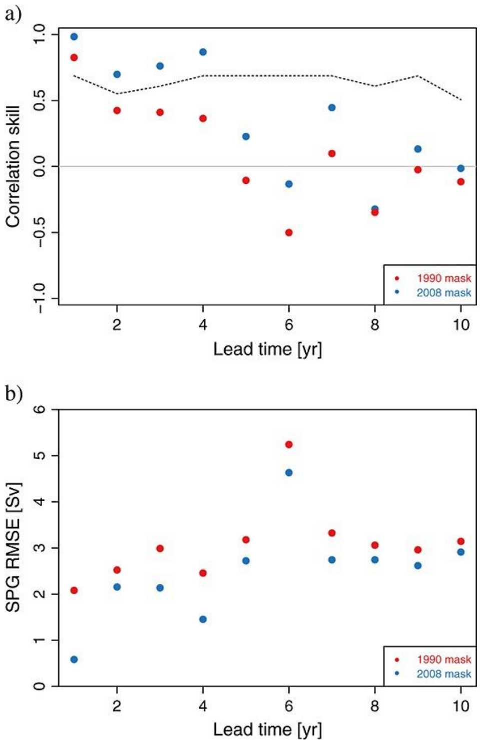

Figure 1. Correlation skill (a) and root mean square error in Sverdrups (million m3 s-1) of the subpolar gyre strength in a perfect model decadal prediction ensemble of EC-Earth V2.3, the coarse resolution predecessor of the EC-Earth model proposed to use here. The stippled line denotes 90% confidence. Red dots and blue dots denote a mask of initialisation data used to mimic observational coverage in two periods (See Wouters et al 2013 for more details).

The oceanic variability in the region may impact remote regions. An atmospheric response to SST variations is implied by several studies and also there is evidence that oceanic signals can propagate northward and affect the Arctic region. Arthun et al 2017 find evidence for an oceanic connection along the path of the North Atlantic Current, while others find atmospheric connections through energy and moisture transport and anomalous standing atmospheric eddies (Graversen and Burtu 2016). Gastineau and Frankignoul (2015) show indications of active ocean-atmosphere coupling at low frequencies. Other studies (e.g. Clement et al 2015) emphasize the dominant role of the atmosphere in driving SST variability with an AMO-like pattern.

So, while skill in multiyear predictions in the region has been shown, there are considerable uncertainties on the mechanisms that cause variability and hence there is uncertainty on predictability. Case studies of anomalous extreme events can shed light on the mechanisms at play. In this study it is proposed to study a very remarkable cold event, which took place in 2014 and 2015, in more detail. The subpolar Atlantic "cold blob" refers to a dramatic, rapid cooling of the high latitude North Atlantic. The cooling started in a period with above average SSTs which was associated with the most recent positive phase of the Atlantic Multidecadal Oscillation. The event took place in a year which was, at that time, the warmest since instrumental observations have been made. A simple visual inspection of the temperature anomaly in 2015 shows the remarkable cooling in the order of degrees C (Figure 2).

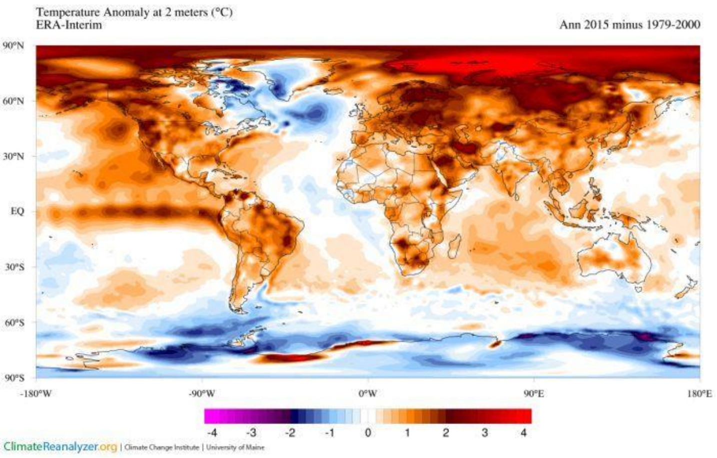

Figure 2: Annual mean surface air temperature differences in 2015 from 1979-2000 values derived from ERA-interim.

The exceptionally cold conditions in the subpolar gyre during summer 2015 may have had a wider impact. It has been linked to summer heat wave activity in Europe (Duchez et al. 2016b). Whereas some studies argue that the cold anomaly was largely attributable to atmospheric forcing (e.g., Duchez et al. 2016a; Duchez et al. 2016b, Josey et al. 2018), others show a non-trivial role for oceanic mechanisms in driven the cooling (Yeager et al. 2016). Still, the strong event, which took place in a region that is predictable according to decadal initialized hindcast simulations, has not been predicted by the models that indicate the strong role of the ocean. The CESM1 decadal prediction system of NCAR shows some ability to predict a subpolar gyre cooling in 2015 at annual lead times, but neither a 10- nor a 40-member large initialized ensemble of CESM1 is able to encompass the magnitude of cooling that was actually observed (Yeager et al. 2016).

The reported results from seasonal and decadal prediction systems are likely model dependent and dependent on initialization and perturbation methods used in coupled models. For instance, Hazeleger et al 2012 showed that models, despite all showing similar prediction skill in the subpolar gyre, differ in their relation between heat and freshwater content and the Atlantic Multidecadal Oscillation. Clearly, decadal initialized predictions are still in an early phase of development and multi-model intercomparisons can aid in increasing our understanding of the predictability in the region of interest.

Experimental set up

We will use EC-Earth V3 at a resolution which is high for decadal forecasts. We will make use of the DCPP set up and protocol as part of CMP6 (Boer et al 2016). Within the EC-Earth consortium several partners are involved in creating a decadal prediction ensemble. In particular BSC is committed to perform predictions starting from a range of start dates, using initial conditions from ECMWFs atmospheric reanalysis ERA5, the ORAP5 and ORAS5 ocean reanalyses, land conditions from an H-Tessel spinup and sea ice conditions obtained using an Ensemble Kalman Filter method.

In the present study we will only focus on the cold blob event of 2015. We will start re-forecasts from two start dates, 1st of November 2014 and 1st of May 2015. We will perform 5 year long simulations with 10 members for each start date. This will enhance the DCPP ensemble and allow more detailed analyses on the uncertainties in the ensemble. We can use the entire ensemble with all start dates to analyse the drift and potentially correct for it.

This experimental setup allows us answer the following questions:

a) Can the model maintain the subpolar gyre in an anomalous cold state and if so, for how long?

b) Can the model simulate the observed atmospheric response to the cold blob in winter 2014/2015 with its record high positive NAO-index?

c) Can the model recover the interannual co-variability of sea-ice extent and subpolar gyre sea surface temperature?

d) Can the model demonstrate impact on the atmosphere (i.e. NAO, EAP) in relation to interannual variations of the subpolar gyre?
e) Can the model predict the European summer heat wave 9 months in advance?

Partners in the Blue Action project will perform the same initialized hindcasts and predictions with the coarse resolution EC-Earth V3 (Shuting Yang, DMI) and with other models (Juliet Mignot IPSL, Daniela Matei MPI-M, Alessio Bellucci CMCC, Noel Keenlyside UiB and Stephen Yeager NCAR).

Relevance to ECMWF

In this project we use EC-Earth V3.2, a model version very close to the seasonal forecasting system 5 used by ECMWF. Lessons learned on mechanisms will likely apply to ECMWFs seasonal forecast system as well. The region is of particular interest to ECMWF because large biases have been reported in seasonal forecast system 5. Despite the relatively high resolution of the ocean the path of the Gulf Stream extension seems off. This project may shed insights in causes of the biases.

The project will give insight in the predictability from months to a decade in the Atlantic, Arctic and the atmospheric impacts which is relevant to the extended range and seasonal forecasting activities of ECMWF.

Lessons can also be learned from the initialization strategy, for which we collaborate with Barcelona Supercomputing Center, in particular the initialization of sea ice with an Ensemble Kalman Filter approach.

Justification of requested compute resources

We will use EC-Earth V3.2. Since EC-Earth V3.2 has IFS cycle 36 as its atmospheric component, this sub-model is well optimized for running on the ECMWF infrastructure, and its scaling is well-known. For the coupled model however, we should take into account the performance of the ocean model NEMO and the overhead of the OASIS coupling library and XIOS output server for the ocean data. Fortunately, a concise performance study on ECMWFs CCA has been carried out within the H2020 PRIMAVERA project, resulting in the following optimal configuration for the high-resolution version of EC-Earth:

Component	MPI tasks	CCA Nodes
IFS T511L91	720	20
NEMO ORCA025	1030	29
XIOS + runoff mapper	3	1

Note that for IFS and NEMO all MPI reserve a CPU core (taking 36 cores on the CCA Broadwell nodes), and OpenMP is disabled for this version of EC-Earth. The runoff mapper and output server do not utilize all cores, but the output streaming is so memory intensive that a full node is required to achieve acceptable performance.

Given this setup, the performance of the model reached about 1.94 simulated years per day, or equivalently 21774 core-hours per simulated year or roughly 351000 ECMWF system billing units. To achieve acceptable statistical significance, the model will simulate 10 ensemble members of 5 years each for the two start dates, which yields 35 million billing units (see table below). We believe this is an upper bound to the actual run because the output of the blue action runs will involve fewer fields than the HighResMIP data request the PRIMAVERA runs had to comply with. The remaining one million compute hours will be used for post-processing the atmospheric output of the system.

Simulated years	Cost per SY (core x hours)	Total cost (core x seconds)	SBU conversion factor P	Total cost (SBU)
1	21774	78386400	0.004476775	350918.29
100	21774	7838640000	0.004476775	35091829

Earlier Blue-Action AMIP-type experiments have produced an output size of roughly 1 TB per simulated year, of which 90% is raw model output which can be stored on tape, and 10% is post-processed data that should be sent to local facilities of blue action partners for further analysis. Typically, the ocean output is much smaller than this because it is post-processed during the simulation; we estimate the ocean output to be 250 GB per simulated year. Adding everything with an additional 5 TB buffer yields the requested 130 TB for storage.

Technical characteristics of the software

EC-Earth V3.2 is based upon two major components: the atmospheric part is the ECMWF IFS model cycle 36 with climate forcing modifications, and the ocean component, the widely used NEMO code. Both components are Fortran 90 programs parallelized with MPI. The additional OpenMP multi-threading of IFS will be disabled in our runs because this needs still validation within EC-Earth. The codes are coupled over MPI, with the OASIS library mediating the fluxes at the ocean surface and runoff-mapper the land-ocean coupling completing the water budget. Furthermore, the XIOS output server for NEMO requires some MPI tasks. XIOS is written in C++ and can be expected to require a significant amount of memory for the ORCA-0.25 grid, and should therefore run on a dedicated node, which can still be a regular compute node.

Since both IFS and NEMO are well-established codes within the weather and climate research communities, they have been optimized extensively and display good scaling behaviour. Their performance is bound by memory throughput rather than computational intensity, and both programs have been tuned to optimally make use of the available processor cache. The domain decomposition is well-balanced for the IFS, and we are planning use the ELPiN tool developed at BSC to ensure a well-distributed workload for NEMO too. Limiting factors to the parallel scaling of the atmosphere are the collective communication during transformations from grid-point to spectral space and the I/O routines. For NEMO the limiting factor seems to be MPI point-to-point communication associated with lateral diffusion and advection across domain boundaries.

At the time of writing, the Cray compilation of EC-Earth is not well-established; the Intel compiler is therefore the tool of choice for the proposed production runs. Recent developments however have shown stable 50-year runs with the Cray-compiled version and further testing of climate reproducibility and model performance is underway.

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