REQUEST FOR A SPECIAL PROJECT 2013–2015

MEMBER STATE: Spain

Principal Investigator[1]**:** Francisco J. Doblas-Reyes

Affiliation: IC3 - Institut Català de Ciències del Clima

Address: Doctor Trueta 2033, 08005 Barcelona, Spain

E-mail: f.doblas-reyes@ic3.cat

Other researchers: Muhammad Asif, Virginie Guémas

Project Title: Seasonal climate forecast quality with EC-Earth: role of initialization and stochastic physics

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SPESICCF** _________________	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2012	
Would you accept support for 1 year only, if necessary?	YES X	NO ☐

Computer resources required for 2012-2014: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2014.)	**2013**	**2014**	**2015**
High Performance Computing Facility (units)	3,960,000	5,880,000	
Data storage capacity (total archive volume) (gigabytes)	3,300	4,200	

An electronic copy of this form ***must be sent*** *via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date): 2/5/2012

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 an annual progress report of the project's activities, etc.

Principal Investigator: F.J. Doblas-Reyes

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Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (500,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

The seasonal-to-interannual (s2i) predictions deal with a time horizon ranging from a season to several years. On these time scales, the storage of heat by the ocean and moisture by the land, together with the presence or absence of snow and sea ice become important factors in determining the atmospheric variability. Based on knowledge of the initial conditions, important aspects of climate are predictable up to a year ahead (Kirtman and Pirani, 2009). This predictability is primarily, though not solely, associated with the El Niño Southern Oscillation (ENSO). Besides, the natural variability of temperature and other climate variables at the s2i time scale should be considered as superimposed on externally forced low-frequency variability due to external forcing: human-induced changes in greenhouse gas and aerosol (GHGA) concentrations, land-use changes as well as natural variations in solar activity and volcanic eruptions.

The ocean anomalies associated with ENSO events and other ocean phenomena, soil moisture and snow and ice cover are taken into account when initializing dynamical s2i predictions. Unfortunately, less information is available about the state of the ocean, sea-ice, snow and land than about the atmosphere (Saha et al., 2010), and often the forecasts are penalized by a lack of understanding of the interactions among the subsystems (Pegion and Kirtman, 2008). Initial-condition and GHGA concentration uncertainties are not the only sources of forecast error. Model inadequacy, a result of the lack of knowledge about relevant processes and the limitations in available computational resources (Palmer et al., 2005), also limits the ability to make predictions on time scales longer than two weeks.

Current climate forecast systems can provide accurate predictions of the tropical SST anomalies associated with ENSO and other tropical phenomena in some regions with forecast times of several months (Saha et al., 2006; Stockdale et al., 2011), although the spread among different forecast systems is substantial, sometimes even differing in the sign of the tropical Pacific SST anomaly (Weisheimer et al., 2009; Alessandri et al., 2010). Instead, over the extratropics the skill of current seasonal forecast systems is very limited (Rodwell and Doblas-Reyes, 2006; Frías et al., 2010), although skill has been found over North America associated with ENSO teleconnections (Quan et al., 2006) and with other sources of s2i predictability such as soil moisture (Douville, 2004; Koster et al., 2010; van den Hurk et al., 2011) or snow (Shongwe et al., 2007; Orsolini and Kvamsto, 2009). Until recently most seasonal forecasts did not explicitly include the effects of anthropogenic GHGA forcing but assumed that the effect is small compared to that of the natural variability and that the global warming signal is, in any case, largely incorporated into the forecast in the observation-based initial conditions. However, a warming trend due to the GHGA forcing has also been identified as a main source of skill in temperature forecasts (Doblas-Reyes et al., 2006).

In the last two decades, a considerable effort has been made to improve the understanding of the physical phenomena responsible for the observed seasonal variability and trends, and to transfer the advances to operational numerical forecast systems. This transfer requires an appropriate assessment of the forecast quality achieved in different regions for different variables and times of the year. Most efforts to estimate the forecast quality of dynamical prediction systems involve the analysis of predictions carried out in the framework of collaborative s2i research projects (e.g., CHFP, ENSEMBLES, GLACE2). These projects include a variety of different experimental designs, different forecast periods, initial condition start dates, and levels of data availability that allow addressing different aspects of the s2i prediction problem by offering a benchmark to compare specific experiments.

The Climate Forecasting Unit (CFU) of the IC3 has undertaken research in climate forecasting with the EC-Earth Earth System Model (Hazeleger et al., 2010; ESM) to help constraining the sources of uncertainty in both short-term climate prediction and climate-change projections by increasing the understanding of the climate system. The EC-Earth system (http://ecearth.knmi.nl) is an ESM with global atmosphere, soil, ocean and sea-ice components, versions of which are regularly run on ECMWF's supercomputers. To reach this goal, and building on the lessons learned during the execution of the 2010-2011 Special Project "Assessment of the limit of initial-condition useful skill in interannual climate prediction", the CFU intends to further develop EC-Earth as a subseasonal and seasonal forecast system. In this proposal, climate simulations with different time horizons will be carried out and analysed to better understand the development of forecast errors and spread in EC-Earth. Among the processes that will be investigated are the role of the soil moisture and sea ice initial conditions, the impact of improving the model (by, for instance, increasing the horizontal and vertical atmospheric resolution) and the benefit from using a simplified stochastic physics scheme.

By developing the subseasonal and seasonal forecast capability, the CFU expects to continue implementing the seamless approach (Palmer et al., 2008), whose basic premise is that there are fundamental physical processes in common to both seasonal and decadal forecast, as well as climate-change projections. If essentially the same ESM using a similar ensemble system can be validated both probabilistically and from a physical point of view on time scales where validation data exist, that is, on subseasonal, seasonal and interannual time scales, the EC-Earth users will have the possibility of a) modifying the probabilistic estimates of regional climate-change, b) gaining insight into the ESM limitations to reduce the systematic error and c) improve the realism of the physical parameterizations used. The seamless approach makes no distinctions about the relevance of particular processes in an ESM as a function of the time scale of the target problem, the correct representation of all physical processes affecting all types of climate simulations. It is important to bear in mind that, as s2i variability can be observed at a relatively high frequency (typically multiple times per year) when compared to longer-term phenomena (e.g., decadal or multi-decadal oscillations), users are provided with a relatively greater number of realizations to exploit within the observational record than in the decadal prediction case. The larger sample of forecasts available in the s2i experiments has recently encouraged a number of studies that use the seamless approach (e.g. Martin et al., 2010). That was the spirit of the previous Special Project proposed by IC3 and is a framework that will be used, if approved, in this one too.

This Special Project proposes to carry out the following experiments:

1. Reference seasonal forecast experiment: Recognizing that forecast skill is likely to be dependent on specific atmosphere-ocean-ice initial conditions and that quality assessment requires large enough samples, we consider the construction of a seasonal re-forecast (also known as hindcast) dataset over a period as long as possible rather than the analysis of a few case studies. The length of the sample is limited by, among other aspects, the quality of the data used to provide the initial conditions and to verify the predictions. As a consequence, the experiments will be carried out first for the period starting in 1979, when the observational network has reasonable quality and coverage and for which atmospheric re-analyses either already exist or will be available in the near future. A ten-member ensemble experiment with four start dates per year (first of February, May, August and November) over the period 1979 to 2011 using initial conditions from ERA-40 and ERA-Interim for the atmosphere, the ECMWF System 4 ocean reanalysis, sea-ice restarts from a LIM2 forced run, and soil restarts from the ECMWF stand-alone soil moisture analysis. The hindcasts will be run for a forecast period of several months into the future, with the forecast length depending on the start date: one year for the May and November start dates and six months for the other two. EC-Earth version 2 with T159L62 and ORCA1 configurations will be used in this experiment.

2. Impact of sea-ice initialization: This experiment will initialize the sea-ice component with no interannual variability, that is, all start dates in a given calendar month will use the same initial sea-ice initial conditions that will be obtained as the climatology of the sea-ice restarts used in Experiment 1. All other components will be initialized in the same way as Experiment 1. To properly assess the influence of sea-ice initialization on summer and winter season predictions, as well as the autumn sea-ice minimum, the start dates will be May, August and November over the period 1991 to 2011 with the same ensemble size and forecast length as Experiment 1. The comparison of the forecast quality assessment of Experiments 1 and 2 should allow for an estimate of the relative impact of the initial conditions in the forecast quality of seasonal predictions because

the second ensemble does not contain any sea-ice initial-condition information. However, an analysis of specific cases such as the autumn 2007 will also be carried out. The outcome of this experiment will feed in the design of ECMWF's plans to implement a sea-ice component in its seasonal forecast system.

3. Impact of soil initialization: An extension to GLACE2 (http://gmao.gsfc.nasa.gov/research/GLACE-2), which aimed at elucidating the role of the land initialization in forecast systems with realistic land-atmosphere coupling, has been planned following discussions between scientists at ECMWF, KNMI and IC3. The main focus consists in assessing the influence of the correct soil moisture initialization in the subseasonal forecast quality of the prediction of climatic risk like heat waves and droughts over the Northern Hemisphere continental regions (e.g. Weisheimer et al., 2011). Beyond the purely scientific purpose, the objective of this experiment consists of effectively enhancing the accuracy of the early warnings of drought and heat waves in current operational seasonal forecast systems. This will be done by comparing the results of this experiment with a similar one carried out by ECMWF with VarEPS. While GLACE2 covers the period 1986-1995, the extension considered here will cover the period 2001-2011, which is the interval for which the ERA-Interim re-analysis uses a consistent analysis that gives homogeneity to the soil initial conditions. Three start dates per year will be used (May, June and July) to run ten-member ensembles. The experiment focuses on boreal summer for two reasons: a) land-atmosphere interaction tends to be larger in summer, when evaporation is higher, and b) the Northern Hemisphere has a much greater land mass. Nevertheless, characteristics of Southern Hemisphere winter extreme events could be considered too because the forecast system is global. The forecast length is variable, the hindcasts extending until the first of October. The resolution of this experiment will mimic the resolution of ERA-Interim, which is T255L62, to avoid any loss of initial-condition quality due to grid interpolation. This prevents using Experiment 1 as a reference and requires an additional control. The experiment has six parts where this scheme is repeated, but changing the set of land-surface initial conditions. The six parts are organized in two types of simulations: those denoted as Series 1 initialized with realistic initial conditions and the Series 2 type initialized with uninformative initial conditions. In more detail:

    a. Series1.a: uses restarts from an offline run produced with the H-TESSEL land surface scheme forced by ERAInterim

    b. Series1.b: uses restarts from an offline run produced with the H-TESSEL land surface scheme forced by ERAInterim bias corrected with GPCPv2.1 following Balsamo et al. (2010)

    c. Series1.c: uses the ECMWF full land data assimilation system initial conditions (with a two-month spinup prior to the forecast initial date)

    d. Series1.d: uses the ECMWF stand-alone data assimilation system initial conditions (with a two-month spinup prior to the forecast initial date)

    e. Series2.a: uses randomised initial conditions extracted from Series1.a

    f. Series2.b: uses climatological initial conditions for all the land-surface variables extracted from Series 1.a

   Some parts of the experiment use as initial conditions the land states produced by the soil model at selected times during a free-running simulation forced by observational data, such as in Series 1.a and 1.b. The comparison with the other Series 1 experiments will allow a) illustrating the degree of improvement in forecast quality coming from assimilating observations and b) providing an optimal estimate of the forecast system forecast quality. The reduction in potential predictability in the model with increasing lead time (and how this varies over the course of the boreal summer) will be quantified. EC-Earth is not implemented as an operational forecast system but the results of the assessment will be used to guide changes in the ECMWF's operational forecast system in order to improve the quality of the prediction of extreme events.

4. Reference EC-Earth version 3 experiment: An updated version of the EC-Earth ESM is expected to be released some time in 2012. This system will be based upon IFS Cy36R4 T255L91, NEMO3.3 with the ORCA1 configuration and OASIS4. After carefully testing this version, part of the Experiment 1 will be repeated using this new system using the same set of initial conditions. A set of ten-member ensembles starting in May and November over the period 1991 to 2011 will be run with a forecast length of one year. The objective of this experiment is to assess the changes in forecast quality due to the ESM improvement and build up a reference seasonal forecast dataset to carry out sensitivity experiments such as the one described as Experiment 5.

5. Impact of a simple stochastic physics scheme: An approach to representing model uncertainty has emerged in recent years and relies on the idea of the stochastic parameterisation (Palmer et al., 2009). In this approach the underlying deterministic bulk-formulae are replaced by an inherently stochastic formulation, recognising that the problem of representing sub-grid tendencies as a function of the resolved variables may not be consistent with the underlying dynamical equations or with observations of the real atmosphere. To test the potential benefits of this approach in a seamless system such as EC-Earth, the stochastically perturbed parameterisation tendency scheme (SPPT; Palmer et al., 2009) will be implemented in EC-Earth version 3. This stochastic parameterisation applies univariate Gaussian perturbations to the wind, temperature and humidity tendencies of physical processes in the form of multiplicative noise with a smoothly varying pattern in space and time. A two-scale version of the perturbations with a shorter characteristic spatio-temporal scale on the order of hours and hundreds of km together with a longer scale of weeks and thousands of km will be used. The benefit of using SPPT will be tested by running an experiment similar to Experiment 4. Experiment 5 will be compared with Experiment 4 to assess the improvements in terms of forecast quality and systematic error reduction. This effort to implement and validate the SPPT scheme will benefit, according to the seamless approach, other groups using the EC-Earth ESM for time scales other than subseasonal and seasonal where the impact of systematic error is also important.

The forecast quality assessment will be carried out using a probabilistic framework. The assessment will focus on seasonal means of temperature and precipitation over the main ocean areas, the European and extended Mediterranean area, the Northern Hemisphere continental areas, as well as on the major teleconnection modes.

Experiment 1 will run a total of 132 start dates (4 start dates per year over a 33 year period) with a varying forecast length (one year for the May and November start dates and six months for the February and August start dates) that makes a total of 990 years of simulation when using ten-member ensembles. Experiment 2 has a smaller size with 275 years (two start dates of one year forecast length and one of six months forecast length with 10 member ensembles over 11 years). Experiment 3 has six parts running 110 years each (three start dates of five, four and three months forecast length, respectively, with ten-member ensembles over 11 years) that makes a total of 660 years of simulation. Experiments 4 and 5 will both run 42 start dates (two start dates per year over a 21 year period), each one of one year forecast length and ten ensemble members, which makes a total of 420 years of simulation for each experiment. Table 1 summarizes the resources required and the year expected to run these experiments.

	Forecast length (yr)	Total SBU (kilounits)	Total archive (Gb)
Experiment 1 (2012)	990	2,970	3,960
Experiment 2 (2012)	275	825	1,100
Experiment 3 (2013)	660	3,960	3,300
Experiment 4 (2014)	420	2,940	2,100
Experiment 5 (2014)	420	2,940	2,100
Total		13,635	12,560

Table 1: Resources required by the experiments proposed. The estimates have been made on the basis of a cost of 3,000 SBUs and 4 Gb of output per year of simulation with the T159L62 atmospheric resolution, 6,000 SBUs and 5 Gb of output per year with T255L62 and 7,000 SBUs and 5 Gb of output per year with T255L91.

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