PRACE Project Access for Seasonal Prediction with a high ResolUtion Climate modEl (SPRUCE)

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Abstract

SPRUCE aim is to attempt to improve our capacity to predict climate variations six months ahead, by co mbining our best present tools and data with a high performance computation capacity which is not yet available in our production machines but is offered by PRACE Tier0 platforms. The two modelling aspects we aim to improve in SPRUCE are thus horizontal resolution and ensemble size.

Climate models, which simulate the joint evolution of the global atmosphere and ocean beyond the limit of deterministic atmospheric predictability (one to two weeks), have been developed since the 1990's, driven for a larg e part by increasing offer of the numerical computation hardware. They have been used to predict the statistical properties of the a tmosphere few months ahead. Although substantial progress has been made in the past, the current performance of climate mod els at seasonal to decadal scale is still not sufficient to meet the expectations and needs of the various stakeholders a t European, regional and local levels. Nevertheless, reliable seasonal-to-decadal climate predictions are of strong potential value, since society and key economic sectors (energy, agriculture, ...) have to base their short and medium term planning and decisions on robust climate information and the associated environmental and socio-economic impacts.

Horizontal resolution has always been one of the major limiting factor in climate modelling. At coarser resolution than 0.5°, the mountain pattern is unrealistic and lower atmosphere winds may have a wrong direction on average. In the ocean, high resolution is required to represent the eddies which transport heat from equator to poles. Many climate studies have shown the benefits of increasing horizontal resolution on the mean simulated climate and its variability. The standard CNRM-CMIP5 Météo-France model uses a 1.6° resolution for the atmosphere and 1° for the ocean. SPRUCE proposes to increa se this resolution to respectively 0.5° and 0.25°, to bring a significant jump in the seasonal predictability.

The second aspect of the improvement in SPRUCE is the ensemble size. Due to the chaotic nature of the atmosphere at monthly to seasonal scale, a seasonal prediction is necessarily probabilistic. A single realization of the forthcoming months has little chance, even on time average, to resemble the observed behaviour. In the mid latitude, very recent results on northern mid latitude winter predictability suggest that increasing the ensemble size to 60 leads to a significant improvement. A size of 120 is necessary at SPRUCE's model resolution.

The predictability evaluation is based on a series of re-forecasts, or hindcasts, covering the past years, starting from the 0.25° ocean reanalysis GLORYS, during the 1993-2009 period. The exploitation of the results will concern first the winter mid-latitude regimes (e.g. NAO) and local predictability of temperature over Europe. We will then examine the predictability of summer heat waves over Europe and North America, with a focus on 2003 summer. Our results will contribute to defin e a strategy for operational seasonal forecasting in Europe.

1. Research Project

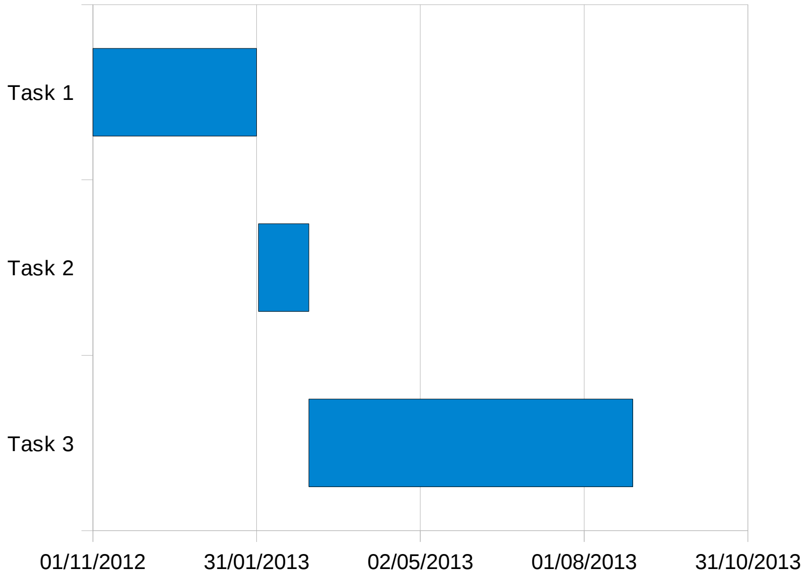
Climate models, which simulate the joint evolution of the global atmosphere and ocean beyond the limit of deterministic atmospheric predictability (one to two weeks), have been developed since the 1990's, driven technically for a large part by increasing offer of the numerical computation hardware and scientifically by the need to understand the physical mechanisms associated with the observed variability and global change. When initialized from observations, they have been used to predict the statistical properties of the atmosphere few months ahead (Palmer and Anderson, 1994) ; when forced by external factors (like greenhouse gases concentration, solar activity, volcanism) they have been used to produce climate scenarios for the forthcoming decades in response to anthropogenic forcing (Cubasch et al., 1992). More recently, these two approaches using both initial conditions and anthropogenic+natural forcings have been merged to explore decadal variability and predictability with these models (e.g. Du et al., 2012). The concept of seamless prediction was raised by WMO to encourage modellers involved in short-range prediction as well as in climate scenarios to develop, as far as possible given computational constraints, common numerical software to deal with 24h forecasts to centennial projections. Although substantial progress has been made in the past, the current performance of climate models at seasonal to decadal scale is still not sufficient to meet the expectations and needs of the various stakeholders at European, regional and local levels. Nevertheless, reliable seasonal-to-decadal climate predictions are of strong potential value, since society and key economic sectors (like Energy or Agriculture) have to base their short and medium term planning and decisions on robust climate information and the associated environmental and socio-economic impacts. Besides other factors such as the availability of observed data over a long period or the progresses in physics as well as algorithmic sciences, the main limiting factor is the capacity to solve accurately the geophysical equations which govern the climate. The aim of this proposal is to attempt to improve our knowledge and capacity to predict climate variations six months ahead, by combining our best present tools and data with a high performance computation capacity, which is not yet available in our usual production machines but is offered by PRACE Tier0 platforms.

A general framework for improving seasonal-to-decadal forecast will be the FP7-SPECS project starting end of 2012. Thos project is based on a multi-model (all European global climate models) and multi-scope (exploration of many modelling aspects) approach. SPRUCE, which can be seen as a first contribution to SPECS, involves one of the models and addresses two modelling aspects. The model we will use is a high-resolution version (around 50km for the atmosphere and a quarter of a degree for the ocean) of CNRM-CM5 (Voldoire et al., 2012) involving the ARPEGE atmosphere model and the NEMO ocean model. It has been recently used in the CMIP5 project and will be used in summer 2012 as the operational contribution of Météo-France to the European consortium EUROSIP. The EUROSIP consortium produces each month an ensemble of seasonal forecasts based on three lower (compared to SPRUCE) resolution European ocean-atmosphere models (ECMWF, Met-Office and Météo-France) and one US model (NCEP).

The two modelling aspects we aim to improve in SPRUCE are thus horizontal resolution and ensemble size. At section 4, we detail our strategy and explain why a Tier-0 platform only is suitable for this kind of experiment. A difficulty that arises when increasing the resolution is the potential enhancement of some biases, due to the fact that the physical parametrization of unresolved phenomena is finely tuned for a given resolution. Changing resolution implies many months of experiments for re-calibrating some empirical parameters. Given the cost of a 0.5° atmosphere coupled to a 0.25° ocean simulation, it would take years to finely tune the new model, as we did when going from the CMIP3 (~2°) to the CMIP5 (~1°) version. To overcome this problem, which could artificially mask the benefits of a higher resolution in terms of predictability, we will apply a new technique described in Batté and Déqué (2012). This technique combines in-line model correction and stochastic dynamics. The principle is to launch a first coupled simulation weakly nudged in the atmosphere towards observation, to save the increments due to nudging, and to reinject them in random order into a free forecast.

Seasonal predictability is highly variable in space and in time. The scientific approach toward predictability cannot be based solely on case studies. The predictability evaluation is based on a series of re-forecasts, or hindcasts, covering the past years. The longer the period, the more accurate the evaluation. In the FP5-DEMETER project (Palmer et al. 2004) which was the starting point of any further experiments, we used a period of 44 years. But if we start from too far in the past, the quality of the initial situation is degraded due to sparse observations, which in turn lowers the scores. This is particularly true for the ocean initial states, which benefit from altimeter data since 1992. Mercator-Ocean has produced a 0.25° ocean reanalysis of the 1993-2009 period, named GLORYS (Ferry et al., 2012). At such a resolution, they contain both the large scale and the meso-scale information, which suits particularly well the context of high resolution coupled seasonal forecast. We will therefore use the GLORYS reanalysis as initial conditions for NEMO. As far as the atmosphere is concerned, we will use ECMWF ERA-interim reanalysis which covers this period at 0.7° resolution (Dee et al., 2011). Climatological prescribed sea-ice conditions will be preferred because, in the seasonal range, the predictability improvement brought by an interactive sea-ice is limited to first order to polar regions. Results will be first produced for the winter mid-latitude regimes (e.g. NAO) and local predictability of temperature over Europe. We will then examine the predictability of summer heat waves over Europe and North America, with a focus on the 2003 summer. In the tropics, we will look at western African monsoon and onset of El Niño, with a focus on the 1997 event. The potential gain in predictability obtained by increasing the resolution by a factor of 4 with respect to current state-of-the-art coupled models will be disseminated through conferences and publications. In the framework of the FP7-SPECS project, other partners plan to launch similar experiments. Comparing the benefits of high resolution in several European models will consolidate our results and help to define a strategy for operational seasonal forecasting in Europe.

2. Requested resources management



Schedule of project tasks

The design of the experiment we propose will consist of three tasks. The first task will be based on single-member, six month range hindcasts starting at 1st February, 1st May, 1st August and 1st November each year for the 1993-2008 period. The atmospheric variables will be weakly relaxed towards ERA-interim: 10-day e-folding time for vorticity, 30-day e-folding time for temperature and moisture. During this period, Curie will be loosely exploited (maximum of 2048 cores simultaneously). The second task consists of a short period of validation and the building of an “increment” file based on the relaxation terms of the first step (local management). Finally the last task will consist of 120-member hindcasts similar to the first step, but in which the nudging part is replaced by a random perturbation using the increments saved in the first task. To evaluate the resolution impact independently from any other model particularity, a similar experiment will be run on our own computer resources, with the same model, at standard low-resolution. During this period, Curie will be intensively used (maximum of 26,000 cores simultaneously).

3. Numerical methods and algorithms

An important particularity of most of European climate models like ARPEGE-NEMO is that the different component models are independent executables, communicating (possibly with a re-gridding) through the OASIS coupler, developed and supported by CERFACS since 1995 (Redler, 2010). The last version of our coupler (OASIS3-MCT) enables a direct and parallel exchange of coupling fields between the different component model processes and avoid the previous coupler-centric bottleneck. SPRUCE will be a new opportunity to confirm OASIS3-MCT performances with a large and highly parallel test-case and enhance capacities of a tool broadly used by a large community. For example, remaining collective MPI calls could be replaced, read/write operations (for restart file or diagnostics) could be distributed and several other details could be fixed to facilitate the work of implementation to a large number of OASIS users. Finally, we will also optimally distribute available resources between the ocean and atmosphere components, in order reach the best possible load balance between them.

The atmosphere component of our climate model (ARPEGE) is used by Météo-France for operational weather forecasts. Seasonal-to-decadal predictions rely on its climate version. ARPEGE is operated on parallel supercomputers since several decades (Déqué, 1995 – Palmer, 2004 – Weisheimer, 2009). The main concern for an optimal use of a Tier-0 machine is the problem size corresponding to the resolution (< 30.000 horizontal grid points) commonly used by the climate modelling community. At such resolution, the computations/communications ratio rapidly degrade the model scalability. The resolution we propose in this project (T359, ~ 300.000 grid points) will allow us to efficiently share calculations between 1,000 sub-domains. During the project, we plan to address the I/O problem that used to slow down our simulations, reducing drastically the amount of diagnostics compared to a standard climate simulation and using the state-to-the-art parallel I/O system (see Questionnaire for a detailed description of this strategy).

The second component of our coupled system, the NEMO ocean model developed by a European consortium, is regularly used on supercomputers by a large community and is included in several AR5 IPCC configuration in Europe. NEMO has been adapted for Tier-0 machine by a specific computational task force (NEMO System Team) including several laboratories and, in the last few years, by PRACE-1IP/-2IP support teams. Here again, the chosen problem size (ORCA025, 1442 x 1021 horizontal grid points) will allow an efficient distribution of the computing over 1000 sub-domains. Using the same number of vertical levels (75) than the GLORYS reanalysis will avoid costly interpolations of the oceanic initial states, as well as unbalanced physical fields.

4. Tier-0 compliance / Scalability / Performances

Horizontal resolution has always been one of the major limiting factor in climate modelling. Due to numerical stability, each time the resolution is increased by a factor of two, the computation cost increases by a factor of eight. But high resolution is essential to resolve small scale climate entities and to produce precise results at the regional and local scales. In the atmosphere, the surface forcing with an accurate orography requires high resolution. For instance, the minimum grid size to represent mountains in the Mediterranean basin is 0.5°. At coarser resolution, the mountain pattern is unrealistic and lower atmosphere winds may have a wrong direction on average. At 0.5° resolution, atmospheric models starts producing explicitly tropical cyclones which have a realistic distribution in space and time (Chauvin et al., 2006). In the ocean, a resolution of at least 0.25° is required to represent the mesoscale eddies that transport heat from equator to poles especially along the western boundary currents. Many climate studies have also shown the benefits of increasing horizontal resolution on the mean simulated climate and its variability. The current ARPEGE-NEMO CMIP5 model has a 1.6° resolution for the atmosphere and 1° for the ocean. Compared with the previous CMIP3 version using a twice as coarse resolution, many improvements were achieved, in particular in the global mean sea-surface temperature and in the southern mid-latitude circulation. In EUROSIP, it was observed that seasonal prediction scores in the tropics (precipitation and sea-surface temperature) are significantly improved by this increase in resolution, which will soon be applied to Météo-France operational system. It is therefore not unreasonable to expect that an additional factor of four in resolution, which we propose in this project, will bring a significant jump in the seasonal predictability. Another argument for this expectation is the slow but constant improvement of short-range forecasting in the past decades, due to the combination of higher resolution and better observations of the initial state.

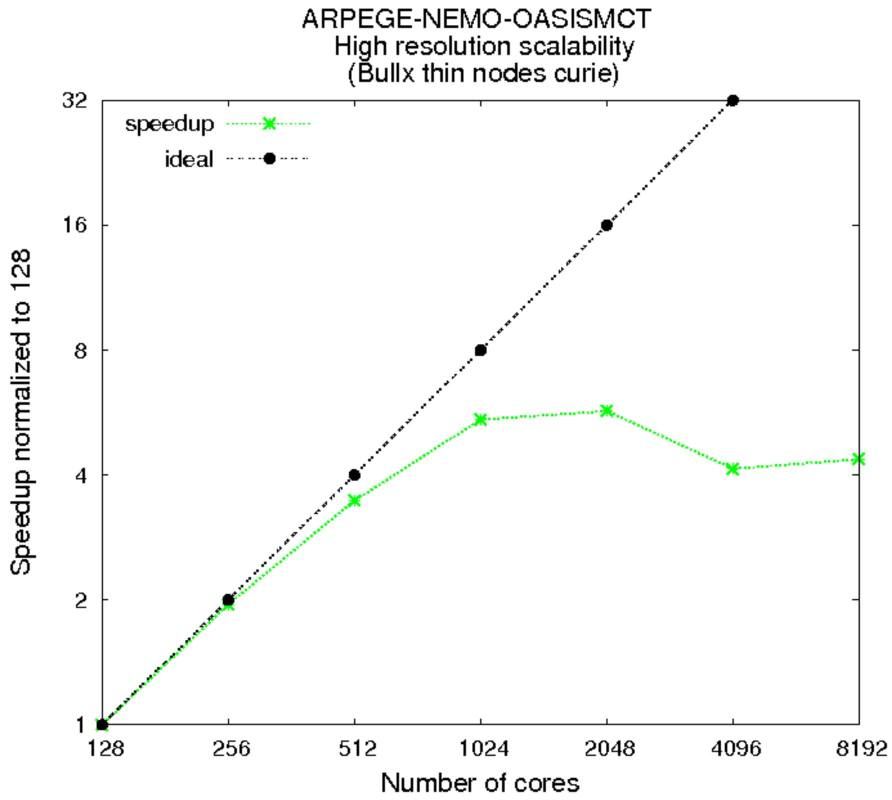
SPRUCE's second main aspect deals with the ensemble size. Due to the chaotic nature of the atmosphere at monthly to seasonal scale, a seasonal prediction is necessarily probabilistic. A single realization of the forthcoming months has little chance, even on time average, to resemble the observed behaviour, in particular outside the tropics. Due to computation constraints, past evaluations (e.g. FP6-Ensembles, Weisheimer et al., 2009) are based on ensembles of size about 10. This size is sufficient in the tropics because the atmosphere responds in an unequivocal way to the ocean on seasonal scale. In the mid latitude, very recent results (Stockdale, personal communication) on northern midlatitude winter predictability suggest that increasing the ensemble size from 15 to 60 leads to a significant improvement. At high resolution, system degrees of liberty increase and one can expect that many more members are necessary to properly filter the useful information signal.

We therefore propose here to increase the horizontal resolution of our climate model and the ensemble size of our hindcast experiments. When (i) model resolution increases, parallelism is needed to guarantee an acceptable restitution time (weak scaling). Due to both ARPEGE and NEMO characteristics (large amount of MPI communications at each sub-domain boundaries and at each time step), the chosen supercomputer must provide an efficient network interconnection between compute nodes. If (ii) ensemble size grows up, a large amount of resources is necessary to process the independent ensemble members simultaneously and then achieve the whole experiment with a reasonable restitution time. To reach SPRUCE’s targeted scales (120 members and T359 /ORCA025_L75 resolution), only a Tier-0 system can provide both sufficient and efficiently connected computing resources.

The following figures show performances of the configuration we plan to use, as recently measured, during a Grand Challenge collaboration, on the targeted PRACE “Curie” Bullx thin node system. We give the absolute duration of a climate simulation of one month (step). Except for parametrization adjustments, the coupled model is technically ready to be launched on the targeted system. Be careful that the provided figures are related to a coupled model, where two components are running simultaneously. To provide a simple information, we chose to show scalability of the whole system. For more information on single component model performances (but, this time, on fat nodes), please see PRACE Preparatory Access report (Maisonnave, 2011).

# cores	***Absolute timing (s) to simulate 1 month (step)***	***speedup***
128	10158	1
256	5190	1.95
512	2926	3.47
1024	1865	5.44
2048	1776	5.71

4096	2453	4.14
8192	2324	4.37



5. <u>Experience of using HPC resources</u>

Eric Maisonnave's work as engineer started in 1999 at CERFACS. Involved in several EU projects like DEMETER, PREDICATE or DYNAMITE, he used to configure and facilitate access to the Météo-France/CERFACS ARPEGE-NEMO climate model. He is currently participating to FP7-IS-ENES project, working on Earth System Model assembling and providing support on OASIS coupling to several European laboratories. For several years, he has been focussing in code performance analysis and model improvement (Maisonnave, 2012) and, in particular, he led last year a PRACE Preparatory Access to prepare ARPEGE-NEMO for a Curie supercomputer use. He built the coupled configuration for SPRUCE and made it available on the targeted Tier-0 machine. He will ensure the necessary set-up of the experiment. As described at section 3, this resources allocation would also give him the opportunity to keep adapting climate models to present Peta-scale architecture, in conjunction to scientific projects: FP7-SPECS (seasonal to decadal predictions). He has been involved in a joint IS-ENES/PRACE-1IP working group focusing on Ec-Earth climate model adaptation to Tier-0 machines (Donners, 2012).

As highly qualified research engineer at CERFACS, Sophie Valcke is currently leading a team of about 4 engineers for the developments of the OASIS coupler. The OASIS coupler being used to couple geophysical codes running on massively parallel platforms, Dr Valcke developed expertise in HPC in Weather, Climatology & Earth Sciences, which recently led her to participate in the PRACE Scientific Case Panel and in the related working group for the European Exascale Software Initiative.

Michel Déqué and Jean-François Guérémy, from Météo-France, have been developing ARPEGE-Climat for several years; they lead or are actively involved in different climate prediction European projects. Jean-Philippe Piedelièvre has ported and operates the coupled system on various supercomputers all over Europe. They form the best experienced team to prepare, parametrize and operate the ARPEGE-NEMO model for a seasonal prediction hindcast exercice.

Laurent Terray is a research director at CERFACS and has been involved in climate modelling and climate variability analysis for more than 20 years. He has written more than 50 scientific publications and is currently the co-chair of the CLIVAR Atlantic Panel which supervises the bulk of international CLIVAR modelling and observational activities over the Atlantic Ocean. Christophe Cassou is presently the PI of the decadal prediction initiative at CERFACS/Météo-France. He wrote several publications (35 ranked-A articles), he is a reviewer of the 5th climate assessment (chapter 11 on decadal forecast) to be due in 2013. Christophe actively participates to outreach activities in both public, scholar environments, non-governmental and non-profit organisations.

Nicolas Ferry, form Mercator-Ocean, is actively involved in GLobal Ocean ReanalYsis and Simulations (GLORYS) ocean initial state production, using a global ocean eddy permitting resolution (ORCA025) reanalysis system. He masters NEMO high resolution configurations and large dataset management. Nicolas will bring his expertise on the MERCATOR/DRAKKAR ORCA025_L75 NEMO configuration that he used to produce the GLORYS reanalysis.

6. Requested resources justification

The different tasks of the project are detailed in section 2. In the first task, increments will be calculated for 68 six-month simulations, i.e. one six-month simulation for 68 different starting dates (4 per year for 17 years). Each simulation is made by 6 sequential one month long jobs (steps). After building the increment files (second task), the third and most CPU intensive task will be performed launching this time 120 ensemble members for each of the 68 starting dates . Depending on the machine load, up to 25 independent runs could be launched simultaneously (see batch system usage planning, in the Technical Guidelines for Applicants). Assuming a full availability of the machine, the total duration of task 3 is then estimated to 40 days. Notice that future supercomputers that would be able to process all independent runs at the same time (gathering ~10 millions of cores) would allow to achieve a whole hindcast exercise within 3 hours: a revolution for seasonal forecasting.

Run type	# Runs	# Steps/Run	Walltime/Step	# CPU cores	Total core hours/Type Run
Nudged (task 1)	68	6	1776	2048	420,000
Hindcast (task 3)	8160	6	1865	1024	25,970,000

Including initial set-up requirements, 27 million core hours are requested.

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