REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: Germany

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Project Title: Interaction between the tropics and extratropics and the implications for seasonal and interannual prediction

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** DEGREA	
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 X☐	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)	15,100,000	12,700,000	
Accumulated data storage (total archive volume)[2]	(GB)	45,000	80,000	

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.

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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.

Background

Several efforts, including our own former ECMWF special projects led by Prof. Dr. Richard J. Greatbatch, have identified and confirmed sources of seasonal predictability for the weather and climate in the North Atlantic / Europe region, which during the winter season is profoundly influenced by the North Atlantic Oscillation (NAO). One important source of NAO seasonal predictability is the tropics, influencing the North Atlantic region both via a tropospheric or a stratospheric pathway (Butler et al., 2014). The tropics have been found to be important for the North Atlantic/European climate in some outstanding winters, for example 1962/63 (Greatbatch et al., 2015), 2005/06 (Jung et al., 2010), 2009/10 (Fereday et al., 2012) and 2013/14 (Huntingford et al., 2014), but also for its year to year variability and general trend (Greatbatch et al., 2012). Major influence is coming from precipitation anomalies in the tropics (Scaife et al., 2017), especially in the context of anomalies which are due to the El Nino Southern Oscillation (ENSO) (e.g. Ineson and Scaife, 2009). Phenomena such as the Madden-Julian Oscillation (MJO) (Cassou, 2008; Gollan et al., 2015; Gollan and Greatbatch, 2017) or the Quasi-Biennial Oscillation (QBO) (Holton and Tan, 1980, 1982) have also been shown to exercise an influence on the extratropics that is important for seasonal predictability (see also Gollan and Greatbatch, 2015). On the other hand, the extratropical atmosphere can also significantly influence the tropics, as described, e.g. in Fedorov et al. (2003) for ENSO or Vitart and Jung (2010) for the MJO. However, the underlying dynamical processes underpinning the extratropical-tropical connection, and the implications for predictability, are so far still not fully understood.

Another source often mentioned in the context of North Atlantic seasonal predictability is the stratosphere. Surface influence from the stratosphere is observed mainly after major stratospheric sudden warmings (SSWs) which occur about every second winter (Erlebach et al., 1996; Labitzke and Najokat, 2000) and can descend down to the troposphere, projecting onto the negative phase of the NAO (Quiroz, 1977; Baldwin and Dunkerton, 2001). Like for the tropics, the stratosphere has been shown to play a role for extreme winters like 1962/63 (Greatbatch et al., 2015), but also for the general predictability as highlighted, e.g., in Scaife et al. (2016) or Hansen et al. (2017).

Latest generation seasonal forecasting systems have shown significant skill at predicting the wintertime NAO when initialized about one month ahead. However, predictions that extend beyond that range to one or even multiple years are also of large interest to a number of societal, economic and scientific sectors. Recently, Dunstone et al. (2016) found significant skill also for the second winter NAO prediction and, like for the seasonal predictions, suggested the tropics, solar influence on the stratospheric vortex as well as Arctic sea ice to be potential sources of predictability for the second winter.

In the past years, we have been able to collect an extensive archive of model experiments, run with the ECMWF seasonal forecast model in different cycles (40r1, 41r1, 43r1). We have used both the atmosphere-only model version with prescribed sea surface temperatures (SSTs) and sea ice at the lower boundary, and the coupled model version with the NEMO ocean model. In many of these experiments, we have made use of a relaxation technique where different parts of the atmosphere are relaxed towards reanalysis data. This technique allows us to obtain "perfect forecasts" for the relaxed regions and, by comparing to experiments without relaxation, investigate their respective importance for seasonal predictability, e.g. for the NAO. A major task at the end of our last special project (spdegrea) has been to extend the seasonal forecast runs to multi-year or, more precisely, 2-year forecast runs. Using the relaxation technique also for these longer forecasts, we now hope to identify sources of predictability also on time scales beyond seasonal.

Our existing set of experiments contains already two 2-year (2yr) experiments, run with the coupled atmosphere-ocean model. One of them is a simple hindcast experiment covering the ERA-Interim period (1979-2013), initialized from ERA-Interim fields on each November 1st of this period and run without any relaxation for 24 months (**CTL2yr**). The other experiment uses the same setup, but additionally applies relaxation in the Northern Hemisphere (NH) stratosphere (20-90°N, roughly above 100hPa) in the course of the simulation (**STRAT2yr**). For both experiments, we ran an ensemble of five members. Results of first analyses of these experiments can be seen in Figure 1, where the prediction skill (i.e. correlation of the experiment ensemble mean with ERA-Interim) of the NAO index for each forecast month is shown for both experiments. As we have learnt before from our seasonal forecast experiments (Hansen et al. (2017)), the skill in the experiment using stratospheric relaxation is substantially higher than in the control experiment in the first forecast winter, indicating that perfect knowledge of the NH stratosphere is important for a skilful prediction of North Atlantic/European winter weather and climate on seasonal time scales. Figure 1 reveals one major issue we are so far facing with the interpretation of the two year experiments: comparing the NAO skill in the first winter computed from the 2yr experiments (red and blue line and circles) with the skill computed from the respective equivalent seasonal forecast experiments (magenta and cyan line and circles), shows that the NAO skill computed from the seasonal forecast experiments appears to be considerably higher than in the 2yr experiments. The general setup of the two experiment types should be very similar during the first winter (although different model cycles are used), but the major difference between them so far is the size of the ensembles. Similar to Scaife et al. (2014), Hansen et al. (2017) showed how the NAO (first-winter) seasonal prediction skill depends on the size of the forecast ensemble in different relaxation experiments, and we show a reprint of their Figure 3 here in Figure 2. Dunstone et al. (2016) highlighted this point also for the second winter NAO skill, attributing the increasing skill with increasing ensemble size to the small signal-to-noise ratio in the model. Figure 1 clearly shows that the 5 ensemble members we so far have for both the CTL2yr and the STRAT2yr experiments are not enough for statistically reliable results. In the new special project, we would therefore like to increase the size of both ensembles (see Table 1).

Garfinkel (2017) found a link between Arctic spring ozone (i.e. NH stratospheric variability) and ENSO 20 months later, and we designed the STRAT2yr experiment (see above) to investigate if perfect prediction of the stratosphere can enhance the predictive skill of ENSO at lead times where many current models are not skilful. Figure 3 shows the skill of the ENSO Nino3.4 index for all lead times in CTL2yr and STRAT2yr. Interestingly, we see higher skill in CTL2yr than in STRAT2yr at longer lead times (20 months and later) which is counter-intuitive having in mind Garfinkel's (2017) findings. However, the skill is not significant in both experiments at these lead times, and it is difficult to estimate to what extent this is due to the small ensemble size. To investigate this potential link between the NH extratropical stratosphere and the tropics further, it seems again necessary for us to increase the size of the CTL2yr and the STRAT2yr experiments.

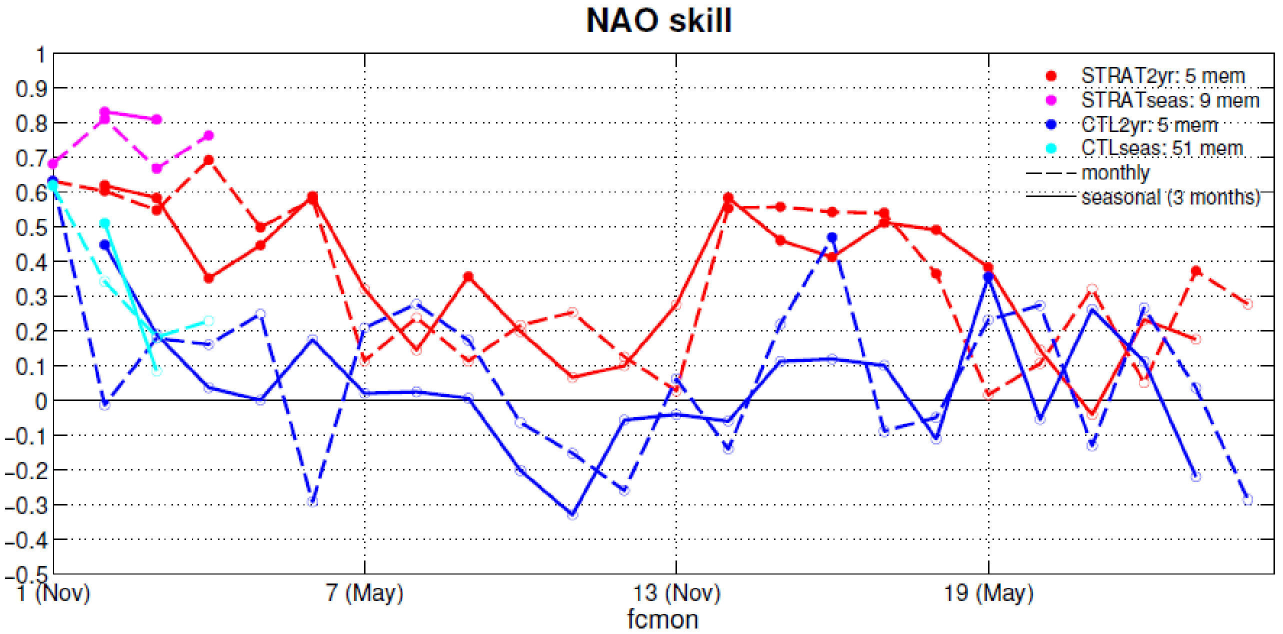

Figure 1: Skill (that is, correlation of the experiment ensemble mean with ERA-Interim) of the NAO monthly (dashed line) and seasonal (continuous line) index against forecast lead time (1-24 months) for the CTL2yr (blue) and STRAT2yr (red) experiments as well as their equivalent seasonal forecast experiments (CTLseas (cyan) and STRATseas (magenta)). Filled circles indicate 95% statistical significant skill as tested with a two-sided t-test.

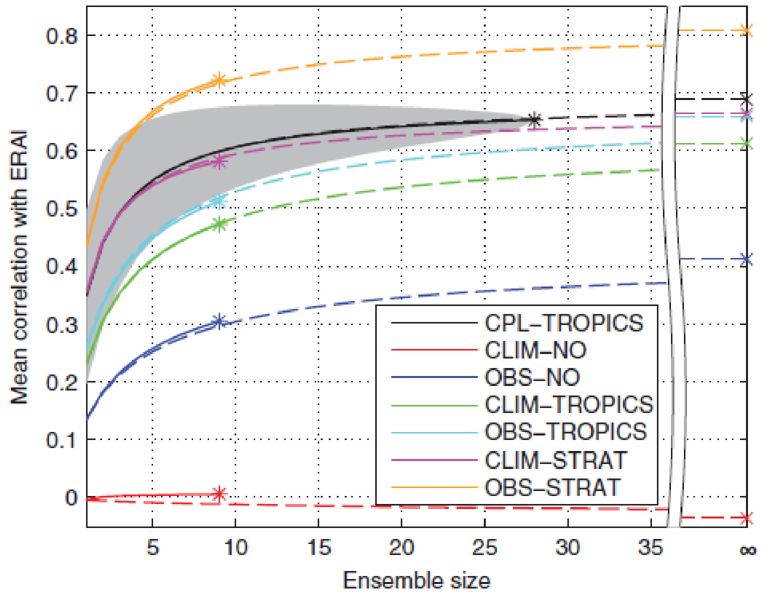

Figure 2: Reprint from Figure 3 in Hansen et al. (2017): NAO correlation between relaxation experiments and ERA-Interim as function of ensemble size. Solid curves: average of correlations between all possible ensemble mean combinations created from the existing ensemble members for each ensemble size and ERA-Interim; asterisks indicate the correlation value for the full ensemble. Dashed curves: theoretical estimate of the variation of NAO correlation with ensemble size following Murphy (1990); crosses indicate the asymptotes of the theoretical estimates for an infinite-sized ensemble.

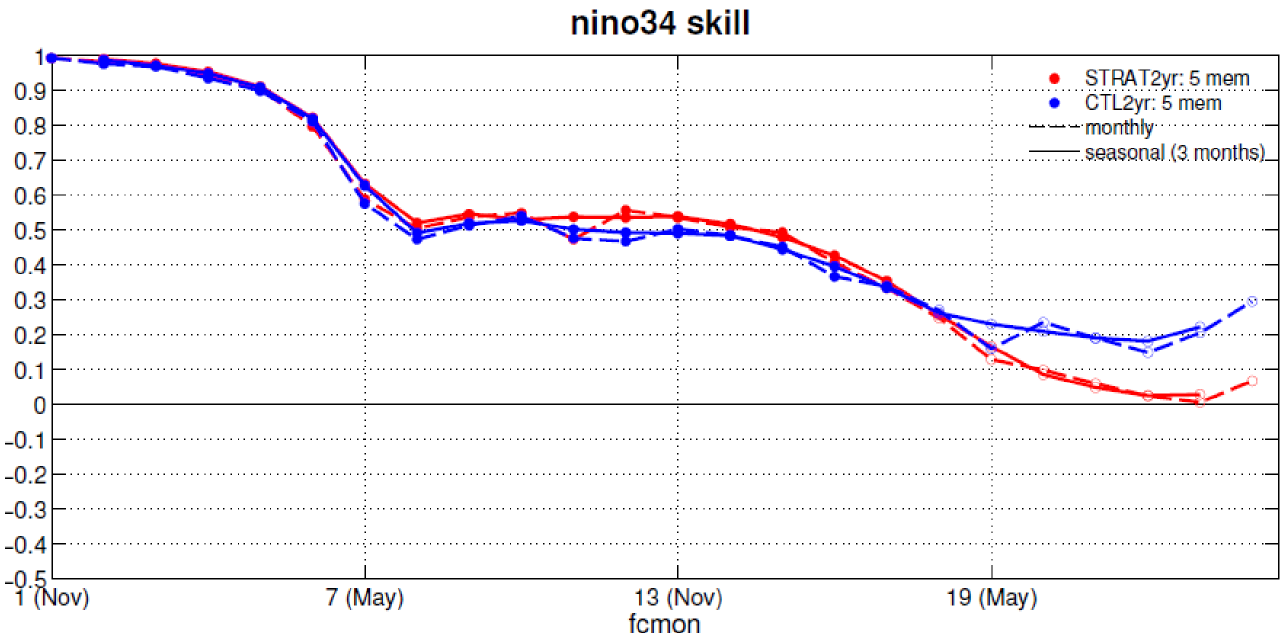

Figure 3: Skill (that is, correlation of the experiment ensemble mean with ERA-Interim) of the Nino3.4 monthly (dashed line) and seasonal (continuous line) index against forecast lead time (1-24 months) for the CTL2yr (blue) and STRAT2yr (red) experiments. Filled circles indicate 95% statistical significant skill as tested with a two-sided t-test.

To investigate the influence of the extratropical troposphere on the dynamics and predictability of tropical phenomena like ENSO or the MJO on the seasonal time scale and beyond, we would like to perform a 2yr forecast experiment applying relaxation in the NH extratropical troposphere north of 45°N (**EXTROP2yr**). We note also that the skill of a forecast depends on the time of year the forecast is initialized. A special role in this context is played by the so-called “spring prediction barrier” for ENSO prediction, meaning that forecasts initialized in spring are less accurate than those initialized in other seasons (see, for example, the recent discussion by Lai et al., 2018). One suggested reason for this is that spring is a transitional time of year for ENSO, where ENSO often shifts from one phase to another, resulting in low signals together with high noise. The influence of the spring prediction barrier is illustrated in Figure 3 by the drop in hindcast skill performance in the first spring of the integrations. In order to tackle this issue, we would like to carry out one hindcast experiment and one extratropical relaxation experiment initialized in May (**CTL2yr_summer** and **EXTROP2yr_summer**). These experiments would not have to be run for 24 months, but should cover lead times up to the end of the second forecast winter, i.e. 21 months.

In the experiments proposed above, relaxation is suggested to be applied throughout the course of the simulation. However, it might be more realistic in an actual forecast initialized in November that, e.g. conditions in the stratosphere are still predicted with some skill for the first winter, but that skill vanishes afterwards. An implementation of this in a 2yr experiment would be to relax the respective part of the atmosphere, e.g. the NH stratosphere or also the extratropical troposphere, towards ERA-Interim only during the first months of the simulation, but to switch off relaxation after the first winter. As we do not know how easily this procedure can be implemented in the existing relaxation codes, we would like to apply for some additional computing time to be used for tests in this context (**TEST**).

Experimental design – details

We plan to carry out experiments using the ECMWF seasonal forecast system in its cycle Cy43r1. The atmospheric model will be run at spectral truncation T255 with 60 levels in the vertical, extending up to 0.01 hPa. The horizontal and vertical resolution is hence the same as in the ERA-Interim reanalysis towards which relaxation shall be applied in some of the experiments, so that no interpolation of the relaxation fields has to be done. The underlying NEMO ocean model will be run at 1° horizontal resolution with higher resolution near the equator. The experiments will be initialized at the beginning of November (May) during the ERA-Interim period (1979-2015, i.e. 37 start years) and run for 24 (21) months. The ensemble will be created using initial conditions perturbations and stochastic physics as described in Molteni et al. (2011).

Estimates of computer resources needed are based on the existing two 2yr-forecast experiments CTL2yr and STRAT2yr, consisting of five ensemble members each. Based on this experience, the estimated computer resources needed for one forecast month are 500 SBU. The 2yr experiments initialized in November are planned for 2019, and those initialized in May are planned for 2020, together with some tests regarding switching off relaxation after the first winter.

Experiment	Forecast months (years x months x ens.members)	SBU (units of 10^6)	Archive (GB)
CTL2yr	37 x 24 x 15 =13320	6.700	19,000
STRAT2yr	37 x 24 x 7 = 6216	3.100	8,900
EXTROP2yr	37 x 24 x 12 = 10656	5.300	15,500
CTL2yr_summer	37 x 21 x 20 = 15540	7.800	22,300
EXTROP2yr_summer	37 x 21 x 12 = 9324	4.600	13,500
TEST		0.300	800
Total	55056	27.800	80,000

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