SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Coupled seasonal forecasts of the 20th Century (CSF20C)
Computer Project Account:	spgbweis
Start Year - End Year :	2017 - 2018
Principal Investigator(s)	Dr Antje Weisheimer
Affiliation/Address:	University of Oxford Atmospheric, Oceanic and Planetary Physics (AOPP) Clarendon Laboratory Parks Road Oxford OX1 3PU United Kingdom
Other Researchers (Name/Affiliation):	Dr. Patrick Laloyaux (ECMWF)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

While the sources of predictability on seasonal timescales are dominated by the influence of the tropical Pacific (ENSO), the question of whether the North Atlantic Oscillation (NAO) and associated climate anomalies over the North Atlantic-European area can be predicted with any confidence is still a matter of on-going scientific debate. Of particular interest is the question if the findings of relatively high levels of NAO forecast skill over recent decades provide a sound manifestation of improved predictions in the presence of decadal-scale climate variability. Following on a previous project using atmosphere-only simulations, this project aims at providing coupled seasonal hindcasts over the 20th Century period from 1900 to 2010

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

No problems encountered that are worth reporting here.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

I find the time frame of applications, start to end of the project and final report not quite optimal. The applications have to be in half a year before the start of the project, once a year. However, at Universities it happens that people start jobs throughout the year and then these deadlines mean that there can be up to 1.5 years between planning a project and start date. For example, I had a postdoc starting shortly after the application deadline who wanted to apply for special project resources. Since the official deadline had just passed, he would have needed to wait almost a year for the next round of applications and a further half year until the start. I am aware of the option to submit late applications and my postdoc eventually did that. However, the cap on the resources that we were allowed to ask for in that late application was so low, that hardly any meaningful experimentation with the seasonal system could be done. I also don't find it very helpful that the final report is due half a year after the official end of the project. A closer deadline for this report would be better.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

This project is a based on a successful previous special project (Seasonal forecasts of the 20th Century: Reliability, attribution and the impact of stochastic perturbations) which ended in 2016. The aim of the previous project was to generate, for the first time, an atmosphere-only seasonal hindcast data set that was substantially longer in the hindcast period covered than what is usually the case. We performed atmospheric seasonal hindcasts experiments with the ECMWF atmospheric seasonal forecast model (IFS cycle 41R1) over the period 1900 to 2010 for several start dates around the year. The forecasts were initialised with ECMWF's atmospheric reanalysis of the 20th Century ERA-20C.

These hindcast data sets provided us with the opportunity to study decadal variability in seasonal hindcast skill. Recent state-of-the-art seasonal hindcasts from forecasting centres around the world indicated rather high levels of forecast skill for the NAO but questions were raised about the robustness of these results. A particular concern is that these promising results were obtained over an often-used hindcast length of 20-30 years covering the most recent decades. However, some studies in the literature hinted on substantially less skill in predicting the NAO for hindcast periods before the 1980s or so. Indeed, our findings from the 20th-Century seasonal hindcasts confirmed a substantial level of decadal variability in NAO forecast skill over the period 1900 to 2010. In particular, we found that the skill during a prolonged period in the middle of the Century dropped to non-significant levels while it was higher again in earlier decades of the 20th Century (*Weisheimer et al., 2017; Weisheimer et al., 2018*). Our analysis pointed towards a more global pattern of climate variability that showed a change in behaviour between the middle of the Century and more recent decades which included tropical sea surface temperatures, circulation indices like the PDO and most remarkably also the Pacific North American (PNA) pattern (*O'Reilly et al., 2017*).

The objectives for the current project directly link to the previous project but here we would like to go one step further: to run a fully coupled ocean-atmosphere seasonal hindcast for the 20th Century. The recent completion of ECMWF's coupled reanalysis of the 20th Century (CERA-20C) made such an endeavour feasible as it provides coupled ocean-atmosphere state estimates from 1901 onward. The coupled hindcasts will allow us, by comparison with the data from the previous project, so study the impact of air-sea interaction on seasonal predictability and will provide a more realistic framework for analysing the NAO prediction question.

CERA-20C is a coupled reanalysis of the twentieth century which aims to reconstruct the past weather and climate of the Earth system including the atmosphere, ocean, land, ocean waves, and sea ice (*Laloyaux et al., 2018*). This reanalysis is based on the CERA coupled atmosphere-ocean assimilation system developed at ECMWF. In CERA-20C, the evolution of the global weather for the period 1901–2010 is represented by a ten-member ensemble of 3-hourly estimates for ocean, surface and upper-air parameters. The ensemble technique takes into account inevitable uncertainties in the observational record and the forecast model to provide an indication of the analysis confidence. CERA-20C benefited from the prior experience of the retrospective atmospheric analysis ERA-20C.

One of the improvements expected from a coupled assimilation system is a more consistent treatment of the air-sea interface. When decoupled, the ocean and atmospheric systems are fed by boundary conditions that do not take into account ocean-atmosphere feedbacks. In ERA-20C, the atmospheric lower boundary conditions come from the HadISST2 sea-surface temperature and sea-ice monthly analysis. It is important for a product such as CERA-20C to capture seasonal and sub-seasonal coupled processes as they will have a crucial impact for climate monitoring and predictability studies.

Both CERA-20C and ERA-20C agree very well over the tropical Pacific indicating that CERA-20C is doing a reasonable job at capturing the ENSO signal at the air-sea interface. Capturing the signature of the ENSO events in the ocean subsurface is also relevant as predictability studies based on coupled reforecasts will use initial conditions from the CERA-20C coupled reanalyses.

Within this special project we have completed two sets of coupled hindcasts for the period 1901 to 2010. These were using IFS cycle 41R1 in TL255L91 resolution coupled to the default version of

NEMO3.4 in 1 degree configuration with 42 vertical levels and the LIM2 sea-ice model. This choice of model configuration was very much motivated by the configuration of the uncoupled hindcasts from our previous project as it allows not only cost-effective simulations but also a direct comparison with the uncoupled simulations. The initial conditions for both the atmosphere and the ocean were provided by CERA-20C. We have used the full 10-member ensemble of CERA-20C to initialise the ocean. For the atmosphere, only one member (member=0) was used for the time being. The sets of simulations consist of 4-month forecasts initialised at the 1st November and 1st May of each year during the 110-year hindcast period. The hindcast ensemble consists of a total of 51 perturbed ensemble members. In order to be able to successfully run these hindcasts, we carried out a range of test simulations to technically enable the use of the coupled reanalysis for initialisation and to check the impact of the different initialisation data. To this end, we have run several hindcast experiments over the recent period 1981-2009 with different initialisation: one experiment with the "standard" initialisation based on ERA-I data for the atmosphere and ORA-S4 data for the ocean; another experiment where we used ERA-20C for the initial conditions in the atmosphere and ORA-S4 in the ocean and the experiment with both atmosphere and ocean initialised with the new coupled reanalysis CERA-20C. The intention here is mostly to sanity check whether the new coupled hindcasts initialised with CERA20C perform reasonable within the expected range from other experiments where the (uncoupled) initialisation is based on analyses using a wider range of atmospheric and oceanic observation. All reported experiments have an ensemble size of 51 members.

In Fig 1 we compare the performance of these three experiments in terms of anomaly correlation skill (of the ensemble mean) for SST forecasts of the NH extratropics in winter. The overall level of skill is around 0.4-0.5. As can be seen, there is overlap in the skill estimation for all three experiments with a weak indication that the CERA-20C run might have perhaps slightly higher levels of skill (though the uncertainty ranges largely overlap). A similar diagnostic for SSTs in the tropical belt (not shown) reveals very similar levels of skill in predicting the SSTs there.

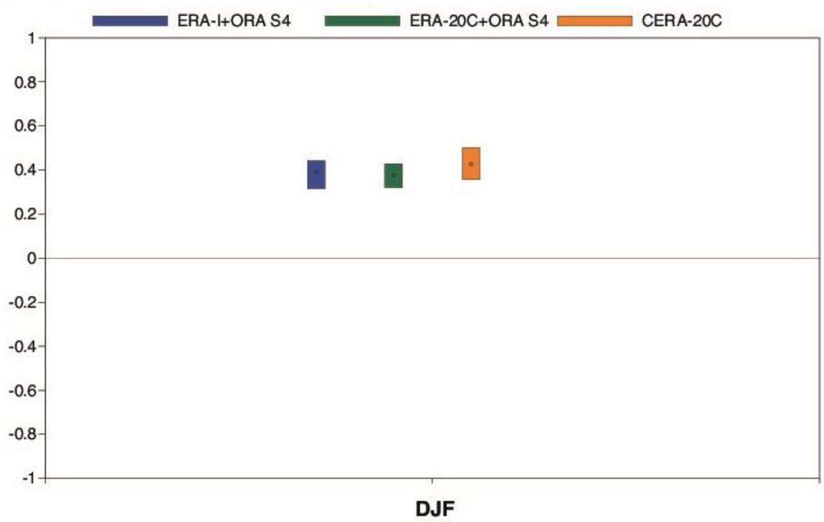

Fig 1: Anomaly correlation coefficient for SST forecasts over the NH extratropics for DJF (1st Nov start date) over the hindcast period 1981-2009 for different initialisation data. The first experiment (blue bar) was initialised with ERA-I in the atmosphere and ORA S4 in the ocean. The second experiment (green bar) was initialised with ERA-20C in the atmosphere and ORA S4 in the ocean. The third experiment (orange bar) indicates the new hindcasts as part of this special project with initialisation of both the atmosphere and ocean from CERA-20C. The vertical bars show the 95% confidence intervals for these estimates.

Forecast skill for 2m temperature over the NH extratropics is shown in Fig 2. Whereas initialisation with ERA-20C seems to slightly degrade the forecast skill compared to the "standard" initialisation with ERA-I, the experiment with the coupled reanalysis initialisation performs very similarly to the "standard" experiment.

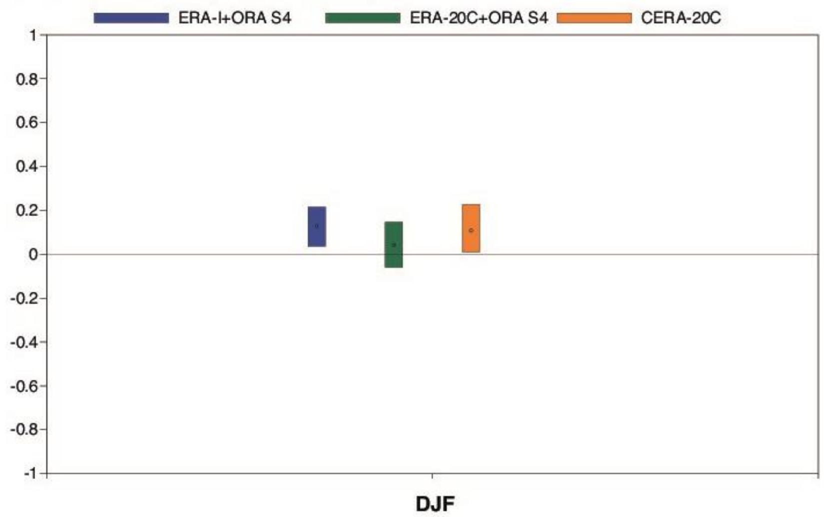

Fig 2: Anomaly correlation coefficient for 2m temperature forecasts over the NH extratropics (land and sea points) for DJF (1st Nov start date) over the hindcast period 1981-2009 for different initialisation data. The first experiment (blue bar) was initialised with ERA-I in the atmosphere and ORA S4 in the ocean. The second experiment (green bar) was initialised with ERA-20C in the atmosphere and ORA S4 in the ocean. The third experiment (orange bar) indicates the new hindcasts as part of this special project with initialisation of both the atmosphere and ocean from CERA-20C. The vertical bars show the 95% confidence intervals for these estimates.

Results for mean sea level pressure (Fig. 3) reveal similar levels of skill in all three experiments.

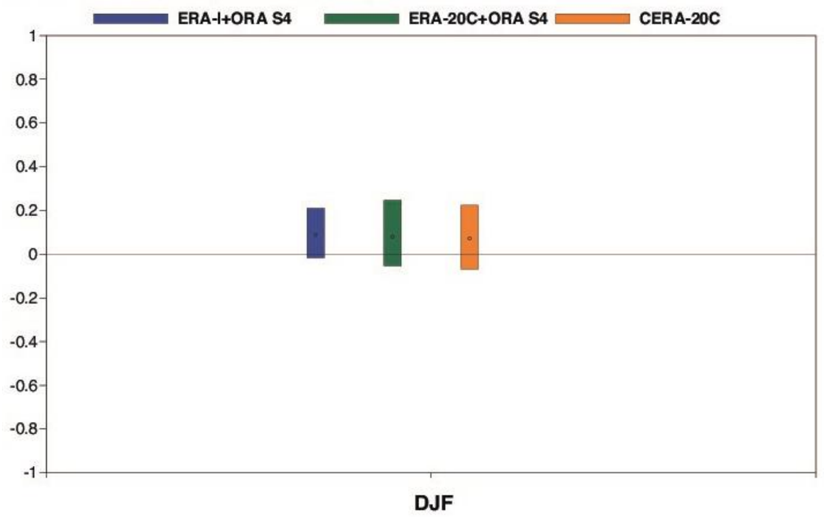

Fig 3: Anomaly correlation coefficient for mean sea level pressure forecasts over the NH extratropics (land and sea points) for DJF (1st Nov start date) over the hindcast period 1981-2009 for different initialisation data. The first experiment (blue bar) was initialised with ERA-I in the atmosphere and ORA S4 in the ocean. The second experiment (green bar) was initialised with ERA-20C in the atmosphere and ORA S4 in the ocean. The third experiment (orange bar) indicates the new hindcasts as part of this special project with initialisation of both the atmosphere and ocean from CERA-20C. The vertical bars show the 95% confidence intervals for these estimates.

The quantity that we are going to use to evaluate the NAO will be based on the Z500 fields (with the NAO index being the projection on the 1st EOF over the Euro-Atlantic region). In Fig 4 we see that the skill in forecasting Z500 anomalies over the NH extratropics is again very similar in our CERA20C experiment when compared to the standard ERA-I plus ORA S4 initialisation.

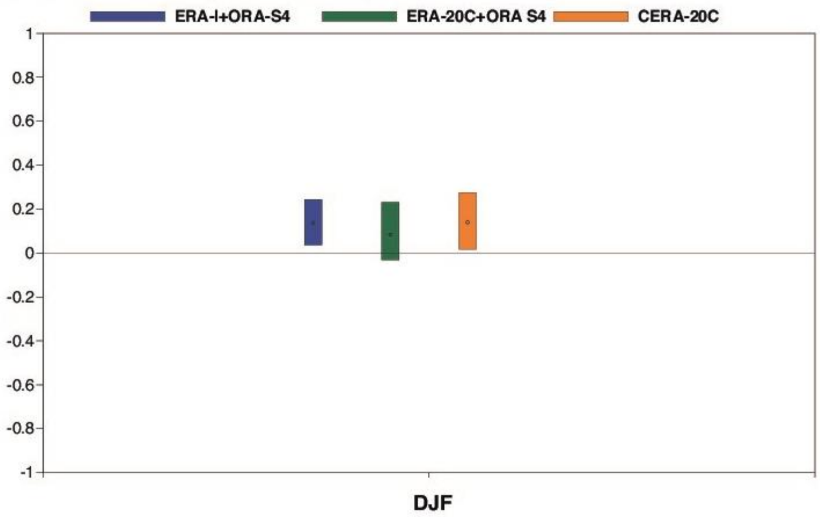

Fig 4: Anomaly correlation coefficient for Z500 forecasts over the NH extratropics (land and sea points) for DJF (1st Nov start date) over the hindcast period 1981-2009 for different initialisation data. The first experiment (blue bar) was initialised with ERA-I in the atmosphere and ORA S4 in the ocean. The second experiment (green bar) was initialised with ERA-20C in the atmosphere and ORA S4 in the ocean. The third experiment (orange bar) indicates the new hindcasts as part of this special project with initialisation of both the atmosphere and ocean from CERA-20C. The vertical bars show the 95% confidence intervals for these estimates.

First results of this study were presented in an oral presentation "Seasonal Forecasts of the 20th Century: Multi-Decadal Variability in Predictive Skill of the Winter NAO" at the Second International Conference on Subseasonal to Decadal Predictions in Boulder, USA, in September 2018.

The Bjerknes Climate Prediction Unit organised a workshop on Climate Prediction in the Arctic and North Atlantic sector in Bergen in June 2019. The aim was to bridge the gap between weather forecast and long-term climate change projections, to better understand climate predictability and to develop skilful climate prediction. Patrick Laloyaux gave a talk in the session on "Data assimilation for reanalysis and model initialization" where he discussed the potential of CERA-20C to initialise seasonal hindcasts and the NAO skill scores for all boreal winter seasons during the period 1901 to 2009 based on the simulations carried out as part of this special project.

List of publications/reports from the project with complete references

No publications or reports on these simulations are available yet. For presentations, see last paragraphs above.

Publication from a previous special project on which this project builds on:

Laloyaux, P. and 15 co-authors (2018). CERA-20C: A Coupled Reanalysis of the Twentieth Century. *JAMES*, doi:10.1029/2018MS001273.

O'Reilly, C.H., J. Heatley, D. MacLeod, A. Weisheimer, T.N. Palmer, N. Schaller, and T. Woollings (2017). Variability in seasonal forecast skill of Northern Hemisphere winters over the 20th Century. *Geophys. Res. Lett.*, doi:10.1002/2017GL073736.

Weisheimer, A., N. Schaller, C. O'Reilly, D. MacLeod and T.N. Palmer (2017). Atmospheric seasonal forecasts of the 20th Century: multi-decadal variability in predictive skill of the winter North Atlantic Oscillation and their potential value for extreme event attribution. *Q. J. R. Meteorol. Soc.*, **143**, 917-926, doi:10.1002/qj.2976.

Weisheimer, A., D. Decremer, D. MacLeod, C. O'Reilly, T.N. Stockdale, S. Johnson and T.N. Palmer (2018). How confident are predictability estimates of the winter North Atlantic Oscillation? *Q. J. R. Meteorol. Soc.*, doi:10.1002/qj.3446.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

The preliminary results for the recent hindcast period where we have several initialisation data sets available, are very promising for the performance of seasonal hindcasts initialised form the new coupled re-analysis CERA-20C and increases our confidence in the usefulness of analysing skill throughout the full hindcast period from 1901 onwards in the near future. Evaluation of these simulations is on-going, perhaps at a slower pace due to my part-time working arrangement at Oxford University. Since these simulations provide a wealth of data, a much more detailed analysis will follow over the coming years. We plan to make a sub-set of these simulations publicly available through the Oxford Research Archive and to write scientific papers on the results of these analyses once we have finalised them.