SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Seasonal forecasts of the 20th Century: Reliability, attribution and the impact of stochastic perturbations
Computer Project Account:	spgbawsf
Start Year - End Year :	2015 - 2016
Principal Investigator(s)	Dr. Antje Weisheimer
Affiliation/Address:	University of Oxford Atmospheric, Oceanic and Planetary Physics Clarendon Lab Dept. of Physics University of Oxford Oxford OX1 3PU Email: Antje.Weisheimer@physics.ox.ac.uk
Other Researchers (Name/Affiliation):	Dr. Nathalie Schaller (now at CICERO, Oslo) Dr. Peter Watson Prof. T.N. Palmer Chris O'Reilley Dave MacLeod - all Oxford University -

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

This special project was requested in order to perform extended seasonal re-forecast (or hindcasts) sets and sensitivity experiments for the entire 20th Century. Being in possession of such an unprecedented dataset will allow us to assess the reliability of seasonal forecasts in the context of the attribution extreme weather events to anthropogenic influence. In addition, it will be possible for the first time to quantify whether the skill of seasonal forecast changes throughout the century, as studies showed that, for example, there is higher skill in predicting the North Atlantic Oscillation for the 1980-2000 period than for the 1960-1980 period (*Müller et al., 2005; Shi et al, 2015*).

Summary of problems encountered

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

No problems encountered.

Experience with the Special Project framework

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

We have found the experience very productive; the access to supercomputer resources has enabled experiments to be carried out which would have otherwise been quite limited. In practice, carrying out these experiments would have been impossible without help from user support at ECMWF, which was invaluable.

Summary of results

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

A large amount of hindcast data was generated from this project. The main objective, of performing atmosphere-only seasonal hindcasts for the 20th Century, was achieved. Hindcasts of four month forecasts, for four start-dates per year (1st of Feb, May, Aug, Nov) covering the entire period 1900-2009 are now available in MARS, with 51 ensemble members for each start date.

Analysis of the output to date has resulted currently in publication of two peer-reviewed papers, the abstracts for these are provided below. Given the wealth of data generated by these experiments, several investigations are active, including assessment of flow-dependent spread and dispersion, representation of blocking, the long-term context of predictability of precipitation over East Africa as well as impacts of upper-air initialisation and the QBO on forecast skill. Results from these topics are forthcoming and not described in this report

After performing the main 110-year seasonal hindcast run some computing resources remained. These were used to perform some additional sensitivity experiments at the end of the project (late 2016), using the original 110-year run as a control. These additional experiments are described in this report along with some initial results, following the summary of the published papers. Analysis is ongoing and there is ample potential for additional analysis of the data and interested researchers are encouraged to get in contact with the principle investigator.

List of publications/reports from the project with complete references

Paper #1: Weisheimer, A., Schaller, N., C. O'Reilly, D. MacLeod and T.N. Palmer (2017). Atmospheric seasonal forecasts of the twentieth century: multi-decadal variability in predictive skill of the winter North Atlantic Oscillation (NAO) and their potential value for extreme event attribution. *Q. J. R. Meteorol. Soc.*, 143, 917-926, doi:10.1002/qj.2976.

Based on skill estimates from hindcasts made over the last couple of decades, recent studies have suggested that considerable success has been achieved in forecasting winter climate anomalies over the Euro-Atlantic area using current-generation dynamical forecast models. However, previous-generation models had shown that forecasts of winter climate anomalies in the 1960s and 1970s were less successful than forecasts of the 1980s and 1990s. Given that the more recent decades have been dominated by the North Atlantic Oscillation (NAO) in its positive phase, it is important to know whether the performance of current models would be similarly skilful when tested over periods of a predominantly negative NAO. To this end, a new ensemble of atmospheric seasonal hindcasts covering the period 1900–2009 has been created, providing a unique tool to explore many aspects of atmospheric seasonal climate prediction. In this study, we focus on two of these: multi-decadal variability in predicting the winter NAO, and the potential value of the long seasonal hindcast datasets for the emerging science of probabilistic event attribution. The existence of relatively low skill levels during the period 1950s–1970s has been confirmed in the new dataset. The skill of the NAO forecasts is larger, however, in earlier and later periods. Whilst these inter-decadal differences in skill are, by themselves, only marginally statistically significant, the variations in skill strongly co-vary with statistics of the general circulation itself suggesting that such differences are indeed physically based. The mid-century period of low forecast skill coincides with a negative NAO phase but the relationship between the NAO phase/amplitude and forecast skill is more complex than linear. Finally, we show how seasonal forecast reliability can be of importance for increasing confidence in statements of causes of extreme weather and climate events, including effects of anthropogenic climate change.

Paper #2: 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 twentieth century. *Geophys. Res. Lett.*, doi:10.1002/2017GL073736.

Seasonal hindcast experiments, using prescribed sea surface temperatures (SSTs), are analysed for Northern Hemisphere winters from 1900 to 2010. Ensemble mean Pacific/North American index (PNA) skill varies dramatically, dropping toward zero during the mid-twentieth century, with similar variability in North Atlantic Oscillation (NAO) hindcast skill. The PNA skill closely follows the correlation between the observed PNA index and tropical Pacific SST anomalies. During the mid-century period the PNA and NAO hindcast errors are closely related. The drop in PNA predictability is due to mid-century negative PNA events, which were not forced in a predictable manner by tropical Pacific SST anomalies. Overall, negative PNA events are less predictable and seem likely to arise more from internal atmospheric variability than positive PNA events. Our results suggest that seasonal forecasting systems assessed over the recent 30-year period may be less skilful in periods, such as the mid-twentieth century, with relatively weak forcing from tropical Pacific SST anomalies.

Description of additional experiments performed based on the long seasonal hindcasts

Several seasonal hindcast sensitivity experiments were run in late 2016, based on the long hindcast control runs described in the papers above. The setup of these experiments is described below, along with some initial results; analysis of these experiments is on-going.

To test the impact of the anomalies in the Indian and West Pacific Ocean region, experiments were run with the SST forcing in the region shown in Figure 1 replaced by daily climatology. A smoothing is applied at the edges to avoid non-physical steps in the applied forcing field and any resulting spurious model behaviour. This experiment gives an indication of the sensitivity of the seasonal forecast to anomalies in this region. The run follows the setup described in paper #1 above, with a reduced ensemble size of 25 members. The experiment was run for 1st November start dates, to look at Northern Hemisphere winter and compare with the results of the published papers.

Initial results from the November start date are shown in Figure 2. A drop in skill is seen for correlation skill of 2m air temperature over the SST denial region, as is expected. However, the drop in skill is not uniform across the region, and latitude band across the central Indian Ocean retains significant skill. Figure 2 also shows impact on 500hPa geopotential height, revealing that the removal of the anomalies leads to reduction in skill across a larger domain extending westward from the region, across Africa, the Atlantic and South America.

An additional experiment for the 1st February start date was run, using the same denial box as the 1st November run. This was run in order to study the impact on predictability of the East African long rains, which will be used as part of the NERC/DFID project ForPAc.

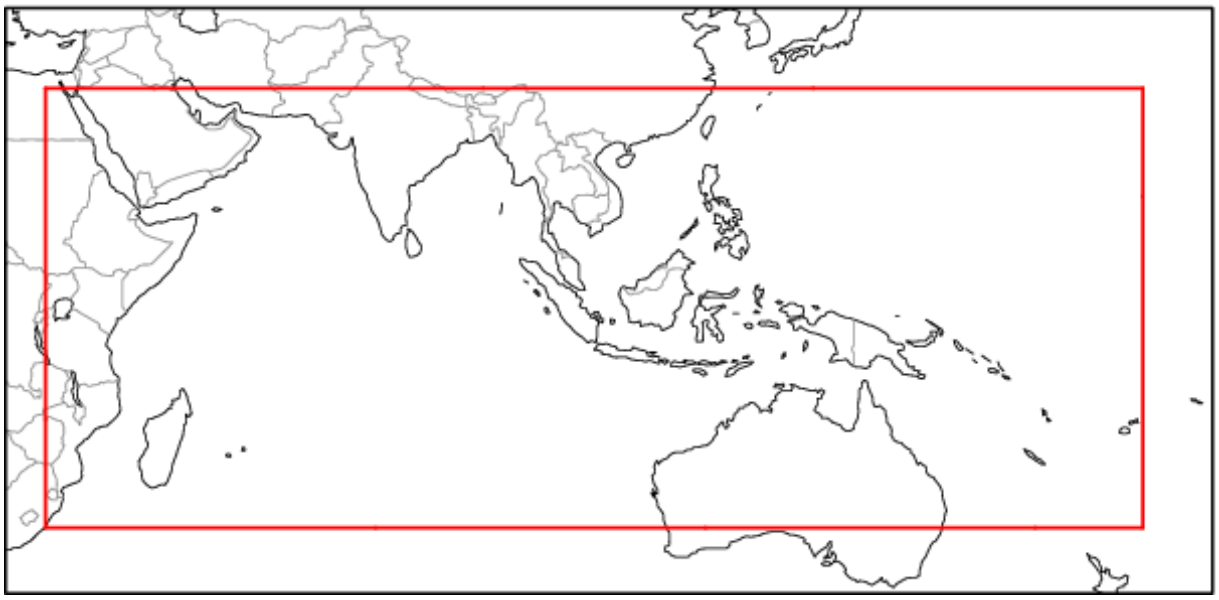

Figure 1: Region used to remove SST anomalies for the SST denial experiments

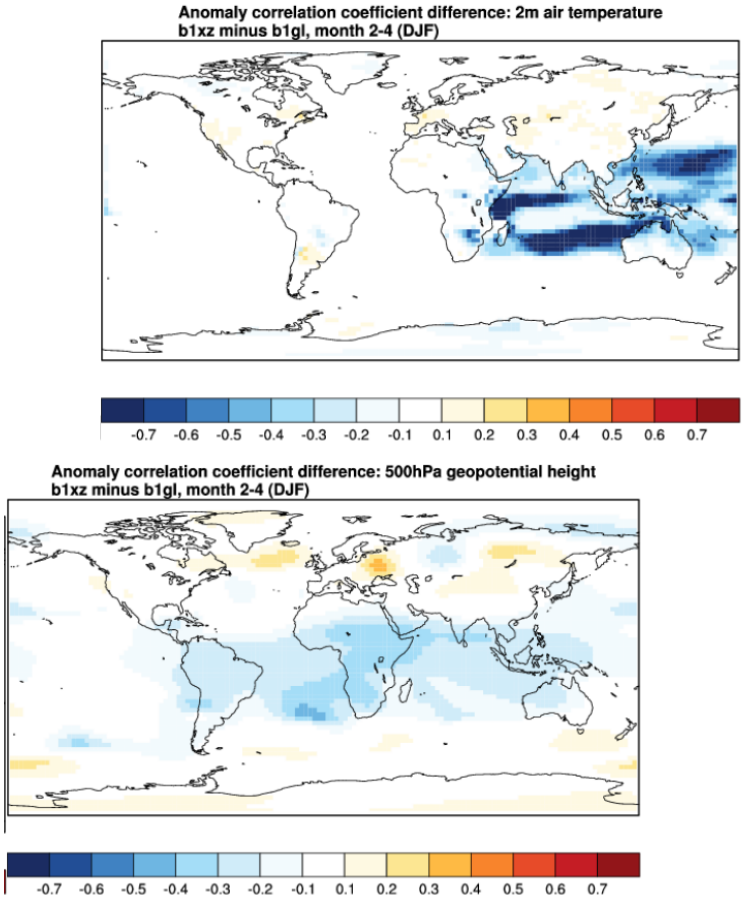

Figure 2: Impact of removing SST anomalies in the box shown in figure 1: DJF ensemble mean anomaly correlation coefficient for 2m air temperature (left) and 500hPa height (right).

Scrambled Initial Conditions

For this experiment, the 1st November start date was re-run following the control hindcasts, except for each year the initial condition is chosen from a year at random. This experiment is able to reveal the aspects of sensitivity of the forecast to initial conditions in a long-term context. Additionally, since the initial condition years are chosen randomly without replacement, it will also be possible to reorder the hindcast and study the sensitivity of the predictions to the SST forcing. Analysis of this experiment is planned, with an initial result shown in Figure 3. This shows the impact of the initial condition on the DJF 2m air temperature ensemble mean correlation, indicating some importance of initial states for the forecast skill, over India, Asia and the Sahel. It is hypothesised that this predictable component arises from the initial conditions of the land surface, rather than the atmosphere.

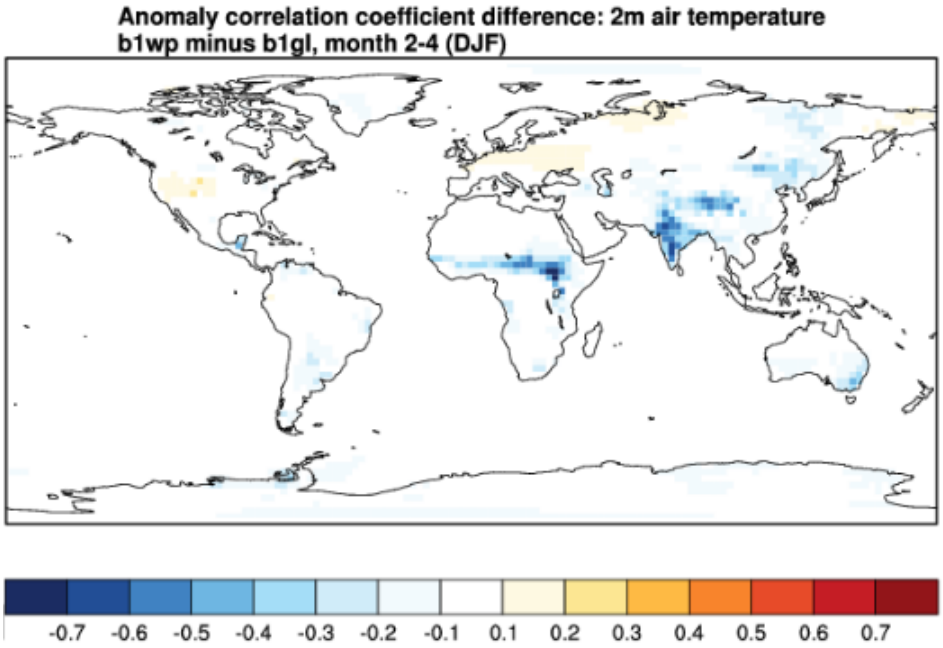

Figure 3: Impact of the scrambled initial condition experiment on ensemble mean correlation of DJF 2m air temperature

Tropical Relaxation

For this experiment a band in the tropics (20N-20S, 0-360E) is 'relaxed' to the ERA20C reanalysis. That is, throughout the model simulation all atmospheric fields in this region are pushed back toward the reanalysis if they start to diverge. This experiment has only been carried out for the 1st November start date, for a 15-member ensemble. A smaller ensemble is sufficient as the relaxation reduces the potential for dispersion. Analysis of this experiment will be carried out soon.

References cited above

Müller W, Appenzeller C, Schär C. 2005. Probabilistic seasonal prediction of the winter North Atlantic Oscillation and its impact on near surface temperature. *Clim. Dyn.* **24**: 213–226, doi: 10.1007/s00382-004-0492-z.

Shi W, Schaller N, MacLeod DA, Palmer TN, Weisheimer A. 2015. Impact of hindcast length on estimates of seasonal climate predictability. *Geophys. Res. Lett.* 42:1554–1559

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.)

In this project, the seasonal hindcasts of the 20th Century were based on atmosphere-only simulations with prescribed SSTs and sea ice initialised with the atmospheric reanalysis ERA-20C. The next step is to perform a similar set of hindcasts but with a fully coupled ocean-atmosphere model. The availability of ECMWF's first coupled reanalysis of the 20th Century CERA-20C will make this possible. This work is being carried out as part of the 2017-2018 special project spgbweis "Coupled seasonal forecasts of the 20th Century (CSF-20C)".

Analysis of the experimental data produced above will continue. Particularly of note is that Bart van den Hurk (KNMI) has extended the scrambled initial condition run in Spring 2017 whilst working as a visitor to ECMWF. Bart has carried out experiments based on the long-term seasonal hindcast, where only the land surface initial conditions are randomised, to assess the sensitivity of the predictability to land initial state, and examine any decadal-scale variability of the relationship.

The 1st February SST denial experiment as well as the control seasonal hindcasts will be used as part of the NERC/DFID project ForPAc, which is working toward improved forecast based action for humanitarian planning in East Africa (Oxford lead Tim Palmer, with Dave MacLeod). The experiments here will be used to establish baseline reliability and economic value of seasonal forecasts for the two rainy seasons across the region.