SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2016
Project Title:	Reducing drift and correcting biases in coupled seasonal hindcasts
Computer Project Account:	spgbhain
Principal Investigator(s):	Keith Haines
Affiliation:	University of Reading
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Patrick Laloyaux, Magdalena Balmaseda
Start date of the project:	September 2013
Expected end date:	December 2016

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	1,500,000	1,500,000	500,000	0
Data storage capacity	(Gbytes)	1000	2000	1000	0

Summary of project objectives

The special project is focused on studying and improving initialisation of coupled systems. The first strand of the work is within a UK NERC project (ERGODICS, running to 2016), and involves analysis of initialisation shocks and model drifts in existing coupled hindcasts, on daily and seasonal timescales. We are also exploring the use of bias correction methods, particularly in the ocean, to improve coupled forecasts and analyses. A second piece of work, on analysing coupled covariances from coupled reanalyses run at the European Centre as part of the ERA-CLIM2 project, began in 2015. This work is on assessing the benefits and difficulties of creating a 'strongly coupled' data assimilation system, and so is also relevant to our goal of improving initialisation of coupled systems.

Summary of problems encountered (if any)

In late 2015, we found that to confirm some encouraging first results concerning the impact of initialisation shocks on forecast skill (see below) would require more computational resources than were allocated to the project for 2015 (the original allocation was 500,000 SBU). However, we were able to obtain additional resources (a further 1,000,000 SBU) from the Special Project reserve, and with these were able to carry out the experiments using a coupled ensemble size that was sufficient to achieve an acceptable level of statistical significance in our forecast skill comparisons. The results were written up and submitted in early 2016. This paper has now been accepted for publication in QJRMS. The results appear to suggest significant improvements in seasonal forecasting of tropical SSTs may be possible with some small adjustment to retain bias correction forces in the upper ocean during coupled forecasts.

However to go further and test this in the current ECMWF operational forecasting scheme requires direct involvement of ECMWF personnel because external personnel do not have permission to run the current model system until after an embargo period. It is therefore likely that the extension of the work this year will use ECMWF resources rather than the special project computational resource allocation, and will be run by Magdalena Balmaseda at the centre.

Summary of results of the current year (from July of previous year to June of current year)

Work in the past year has focused on the impact of the equatorial ocean bias correction scheme that is currently used in the ECMWF ocean reanalysis (in its recent incarnations, ORAS4 and ORAS5). This 'pressure correction' scheme is used at the equator, to stabilise the upper ocean against spurious circulations produced when subsurface density information is assimilated into an ocean model that possesses biases in the upper ocean momentum mixing and in its treatment of the forcing by surface wind stresses. The scheme has been shown to lead to an improved ocean reanalysis, but it has not previously been properly explored for use in coupled forecasts. The current ECMWF operational seasonal forecast system (S4) uses ORAS4 for initialisation of its ocean component, but the bias correction scheme that is applied during the reanalysis is switched off instantaneously at the beginning of the forecast.

Using a group of seasonal hindcast experiments each with different initialisation and forecast treatments of equatorial ocean bias correction, we have found that the operational approach leads to a discernible initialisation shock in the equatorial thermocline (Figure 1). The excitation of the thermocline occurs in all three equatorial ocean basins in the operational-type method ('OP') only, and not in the other three methods shown, each of which avoids the sudden change in ocean forcing at the beginning of the forecast that is present in OP. The shock can be seen as an increase in spectral power in the depth variations of the 20°C isotherm at periods of 4–8 days in particular, and this enhancement of power was found to exist out to lead times of around 50 days.

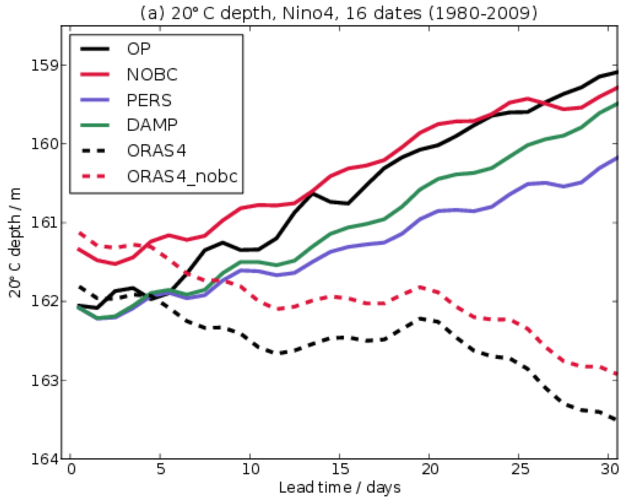

Figure 1: Mean depth of the 20°C isotherm in the Nino4 region, for each of the four forecast sets run (OP, NOBC, PERS, and DAMP), and the ocean reanalyses ORAS4 and ORAS4_nobc. The initialisation shock can be seen in OP as an increase in temporal variability and a shift in phase relative to ORAS4.

The occurrence of this shock in the tropical ocean, although it is small in amplitude, creates a pathway for a relatively long-lived impact, through the generation and propagation of oceanic Kelvin and Rossby waves. This signal in the operational-type forecasts is contrasted particularly to the preferred alternative method 'DAMP', in which the bias correction term in the form of a monthly climatology, is used temporarily at the beginning of the forecast before being damped to zero by day 20, in order to avoid the generation of the shock while leaving any longer-term model drift unaffected.

Differences in SST seasonal forecast skill were found among the different methods. These were particularly large in the eastern tropical Pacific, a crucial region for ENSO forecasting, where DAMP showed increases in SST anomaly correlation coefficient (ACC) over OP of up to 0.05, at lead times of ~5–7 months (hindcasts ran for 7 months only). Measured across various SST forecast skill metrics, DAMP was found to perform the best of the four methods tested, and therefore it is recommended for consideration for further testing with a larger hindcast set within the current operational system (see future work section below).

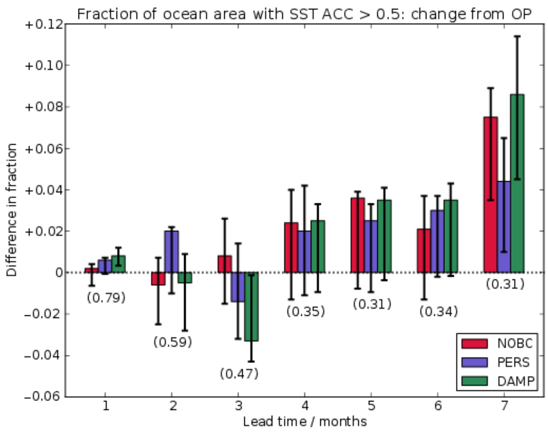

Figure 2: Difference in the fraction of ocean area with SST ACC greater than 0.5, for NOBC, PERS and DAMP, compared to OP. The area fractions for OP are shown in brackets.

It was also noted that the method ‘NOBC’, which was initialised using an ocean analysis (ORAS4_nobc) that did not include pressure correction, performed as well or better than OP (at least in the limited hindcast set used here), despite having less accurate ocean initial conditions (less consistent with observations) than ORAS4 used in OP (Figure 2). This highlights the point that avoiding an initialisation shock through a careful coupled initialisation process can be just as important as improving the accuracy of the individual components of the coupled initial state itself.

These results are presented in a paper (‘Improving seasonal forecasting through tropical ocean bias corrections’; see below), which has now been accepted for publication in the Quarterly Journal of the Royal Meteorological Society.

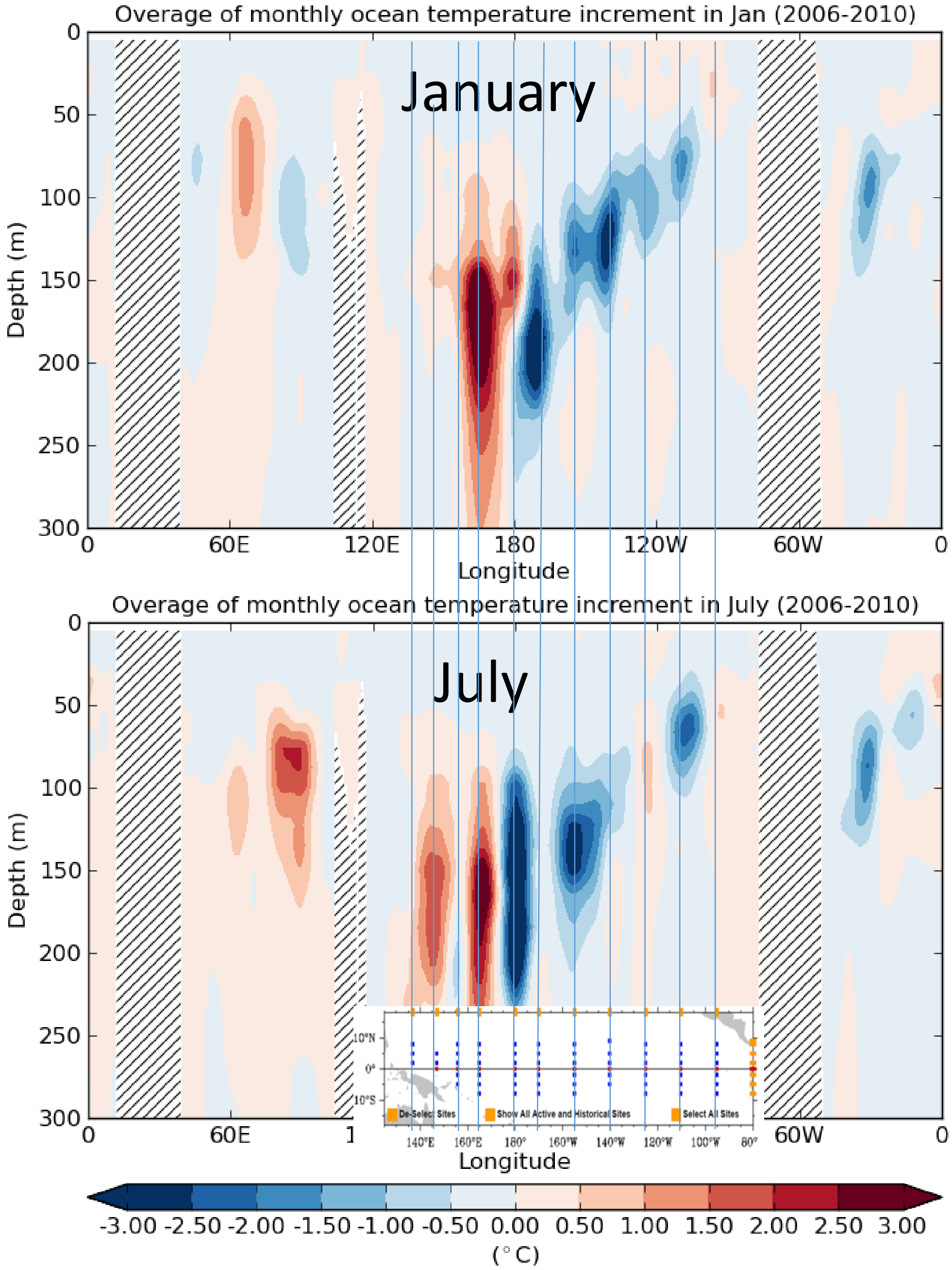

Figure 3: Five year men temperature increments in CERA-20C coupled reanalysis. The cooling (E Pacific) and warming (W Pacific) thermocline biases suggest that a pressure correction approach to bias correction could probably usefully be implemented

In the EU ERACLIM2 project we have also calculated increment biases from the CERA reanalysis which can be compared to the bias in the ORAS4 and ORAS5 systems. Figure 3 shows the mean CERA increments over 5 years in the Equatorial band. In further work we will examine the potential for bias corrections within CERA.

Work to study coupled atmosphere-ocean covariances has also continued in the ERACLIM2 project. Recently, we have used the ensemble approach to calculating the covariances, using the 10 members of the new CERA-20C coupled reanalysis. Daily outputs of SST, near-surface air temperature and near-surface winds have provided a large dataset with which to measure covariance patterns, and to compare to our previous estimates produced using single-member analysis and/or forecast data only.

List of publications/reports from the project with complete references

D. P. Mulholland, K. Haines and M. A. Balmaseda. Improving seasonal forecasting through tropical ocean bias corrections. *Quarterly Journal of the Royal Meteorological Society*, Accepted.

D. P. Mulholland, P. Laloyaux, K. Haines and M. A. Balmaseda, 2015. Origin and impact of initialization shocks in coupled atmosphere-ocean forecasts. *Monthly Weather Review*, 143(11):4631-4644.

X. Feng, D. Mulholland and K. Haines, 2015. Strengths and weaknesses of coupled ocean/atmosphere data assimilation systems. ERA-CLIM2 Deliverable Report D2.8.

J. Waters, D. Mulholland, X. Feng, I. Mirouze and M. J. Martin, 2015. Estimating forecast error covariances for coupled models. ERA-CLIM2 Deliverable Report D2.9, available at http://www.era-clim.eu/ERA-CLIM2/Products/.

Summary of plans for the continuation of the project

The results of Figure 2 above are of potential interest to operational seasonal forecasting activities at ECMWF, but were produced using sets of hindcasts containing only 16 start dates (4 in each of 4 seasons), which limits the confidence in the observed increases in skill shown for DAMP. Accordingly, a more thorough evaluation of the bias correction impact is underway, in collaboration with Magdalena Balmaseda at ECMWF. Two larger hindcast sets, covering 60 start dates will be run, following the methods OP and DAMP, using the most recent (seasonal forecast) model cycle 42R1, and will be analysed in due course. However because of the restrictions on external users these new runs will not use any of our allocated computing resources for 2016. It is hoped that robust improvements from this new set of experiments will lead both to an ECMWF internal report, a further paper publication and then the adoption of a similar method into operational use.

We have also begun work aimed at employing the equatorial bias correction scheme within the coupled analysis system CERA, where it is not currently used (see Fig 3 above). If possible, we hope to deploy the bias correction scheme in a short test run of CERA, with the intention that a gradual removal of the correction field, as in DAMP, would be used for any forecasts initialised using CERA-20C. This work will be performed by our ERACLIM2 PDRA Dr Xiangbo Feng and proceed in close collaboration with Patrick Laloyaux at ECMWF. We may seek to extend this special project for one further year (as the ERACLIM2 project was recently extended to the end of 2017) in order to carry out this work.