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	2018……………………………………………………….……
Project Title:	The Role of the Asian Summer Monsoon as a driver of European Summer Circulation Variability..…………..…
Computer Project Account:	spgbwool……………………………………………….……
Principal Investigator(s):	Prof Steven Woolnough, Jonathan Beverley, Dr Laura Baker, Dr Antje Weisheimer…….……….…………….……
Affiliation:	National Centre for Atmospheric Science, University of Reading (SW, JB, LB) and University of Oxford (AW) ……………………………………………………….……
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………….…… Stephanie Johnson ……………………………………………………….……
Start date of the project:	1st January 2017……………….………………………….……
Expected end date:	31st December 2018…………………………………….……

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)	8,380,800	8,047,361	6,285,600	0
Data storage capacity	(Gbytes)	24,000	3,179	48,000	3,179

Summary of project objectives
(10 lines max)

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The main objective of the project is to assess the role of the Asian Summer Monsoon as a driver of European Summer Climate Variability. To do this we proposed a set of seasonal hindcast simulations with relaxation of the circulation in the monsoon region to determine the forced response of the European circulation.

In initial analysis of forecast skill of the model we have identified errors in both the forcing region and over Europe and we will also perform experiments to explore the role of European circulation as a driver of the Asian Summer Monsoon

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Summary of problems encountered (if any)
(20 lines max)

None……

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Summary of results of the current year (from July of previous year to June of current year)
This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

During the previous year we have carried out and begun to analyse a set of relaxation experiments designed to explore the role of the Asian Summer monsoon as a driver of European Summer Climate. The relaxation experiments showed that forcing the circulation in the Indian Summer Monsoon Centre of Action of the Circumglobal teleconnection had little impact on the simulation of the CGT or European Summer Circulation (or forecast skill for European Summer Circulation). This minimal impact likely means that **either** the Asian Summer Monsoon is not a forcing region for the CGT and European Summer Climate **or** that the errors in the CGT pattern arise because of errors in the wave propagation rather than in the wave generation. Analysis is underway to try and discriminate between these two possibilities.
We have also written up our analysis of the control simulations and a revised manuscript is under consideration by Climate Dynamics (Beverley et al, in review)
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See attached report for more detail………………………………………

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Beverley J.D, Woolnough, S.J. Baker, L.H., Johnson, S.J., Weisheimer, A: The northern hemisphere circumglobal teleconnection in a seasonal forecast model and its relationship to European summer forecast skill, *Climate Dynamics,* (in review)
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List of publications/reports from the project with complete references

None as yet, paper on the analysis of the control simulations is currently under review… (see above)………………………………………………………………

Summary of plans for the continuation of the project

(10 lines max)

1) Ongoing analysis of simulations carried out during the last year to understand the response of the CGT and European Summer Circulation to the forcing from regions in which the circulation has been relaxed to observations
2) Further relaxation experiments motivated by the results of (1)
   or
   Atmosphere only experiments to explore the role of air-sea interaction in the development of the biases in the circulation hypothesised to be responsible for the biases in the CGT………………………………………………………………………………………

1 ECMWF Special Project Progress Report

1.1 Introduction

This project is part of a PhD project at the University of Reading in collaboration with the University of Oxford and within a wider NERC-funded project (SummerTIME). The overall aim of the SummerTIME project is to explore the drivers of variability and change in the European summer circulation. The focus of the PhD project is on the role of the Asian Summer monsoon as one of these drivers. Our ability to predict European climate at extended ranges (sub-seasonal to seasonal and beyond) depends on the ability of our models to correctly represent remote drivers of the European circulation and the teleconnection pathways from those remote drivers.

Two main mechanisms have been proposed for the role of the Indian summer monsoon (ISM) in influencing the climate over Europe. Rodwell and Hoskins (1996) suggested that remote diabatic heating in the ISM region can induce a Rossby wave pattern to the west, which, through interaction with the midlatitude westerlies, can lead to enhanced decent over the Mediterranean. Ding and Wang (2005), and subsequently Ding and Wang (2007), proposed a mechanism whereby strong convection over the northern ISM (NISM) region is triggered by the west-central Asian high pressure associated with a wave train extending from northwest Europe. This convection then reinforces the west-central Asian high through the excitation of Rossby waves, which then propagate downstream to eastern Asia and beyond. They called this teleconnection pattern the circumglobal teleconnection (CGT) and it was shown in both Ding and Wang (2005) and Ding and Wang (2007) that the CGT has significant impacts on both European climate and the strength of the ISM. In addition, the ISM plays an important role in the maintenance of the CGT during the boreal summer.

1.2 Summary of results from previous progress report

We have been analysing a set of seasonal hindcasts run using model cycle 41R1 (Experiment ID: gcai). These are coupled 4-month long simulations initialised on 1st May over the hindcast period 1981-2014 using 25 ensemble members and done in a similar resolution as System 4 (TL255L91). At the time of the previous report we had been analysing the representation of the CGT in this model, and found that the model CGT is too weak, particularly in August when the observed CGT is strongest. We also found that the model has reduced skill for 200 hPa geopotential height located in the same areas as the centres of action of the CGT, and this motivated the relaxation experiments that we have carried out.

1.3 Progress since the last report

1.3.1 Analysis of control experiment

Since the last report we have carried out further analysis of the seasonal hindcasts (Experiment ID: gcai), and this work is the focus of a paper which is currently under review for *Climate Dynamics*. Given that the CGT mechanism relies on the generation and propagation of Rossby waves, we examined the Rossby wave source (RWS) in the model compared to observations. The RWS describes the forcing of Rossby waves by the divergent flow, and can be written as:

$$RWS = -\zeta D - \mathbf{v}_\chi \cdot \nabla\zeta \quad (1)$$

where ζ is the absolute vorticity, D is the horizontal divergence and $\mathbf{v}_\chi$ is the divergent part of the wind field. This is derived from the vorticity equation for a single level in the atmosphere (e.g. James, 1995), and the RWS is calculated using the u and v components of the wind at 200 hPa.

Figures 1a and 1b show the mean August RWS term, calculated using Equation 1, in ERA-Interim and the model ensemble mean respectively in the coloured contours, and the 200 hPa zonal wind in the black contours. The first thing we note is that the centre of positive RWS located at approximately 40°N, 60°E, which, along with the source over the Mediterranean, is a major wave source (Enomoto et al., 2003), is broader and is located further to the north in the model than in ERA-Interim. This appears to be associated with a northward displacement of the model jet stream by several degrees when compared to ERA-Interim. This displacement in both RWS and jet location is also present in both June and July (not shown).

In most parts of the region of interest the variance of the RWS in ERA-Interim (Figure 1c) is lower than in the model (Figure 1d). This is because the amplitude of the RWS in the model is generally larger, therefore horizontal gradients in the RWS are larger. This means that horizontal displacements in the centres of maxima and minima from year-to-year give greater variance. The northward position of the jet stream in the model may also account for the generally larger variance in RWS between 50°N and 60°N, due to the increased vorticity gradient here.

The mean divergence field (D in Equation 1) is shown in Figures 1e (ERA-Interim) and 1f (model). The centre of negative divergence (convergence) located at approximately 40°N, 60°E (in the same location as the centre of large RWS in Figure 1a) is both larger in magnitude and located further to the north in the model than in ERA-Interim. This centre of convergence was shown to be localised in this region by the presence of the Zagros mountain chain (Rodwell and Hoskins, 1996). Where the jet is located may determine where the divergence and convergence is, but we know, by comparing to the RWS computed from the rotational flow of ERA-Interim with the model divergent flow, that errors in the RWS primarily come from errors in the divergent flow (not shown). The errors in divergence are largest over both the Arabian Sea and the Bay of Bengal. Here, the divergence is much greater in the model than in ERA-Interim, associated with too much precipitation in the model in these regions (Figures 1g and 1h). If the greater precipitation in the model is also associated with larger monsoon variability, this may affect the forcing of the CGT in the model. The RWS term is also dominated by the divergence component, and therefore the convergence in the model (which is both too strong and located in the wrong place) is likely to be an important factor in the errors in RWS in the model. These errors in the RWS may impact on European summer forecast skill through errors in the CGT, so more accurate representation of the link between monsoon heating and the extratropical circulation is likely to be important for improving European summer forecasts.

We also note that the jet biases over the Mediterranean are much smaller than over west-central Asia, and the location of the centre of convergence in the model in this region closer resembles ERA-Interim. Where there are larger wind biases over west-central Asia there is a greater displacement of the centre of convergence, and this strengthens the argument that the jet location is an important factor in these errors.

The strength of the RWS is dominated by the ζD term, so to determine the role of errors in each of these quantities on the magnitude of the RWS in the model we also computed the model ζD term using either ERA-Interim ζ or divergence ($\zeta_{era} D_{model}$ and $\zeta_{model} D_{era}$). We found that using ERA-Interim ζ results in very little change in the model ζD, however using ERA-Interim divergence causes the errors in the model ζD to be much reduced. This suggests that it is errors in the model divergence that are the main cause of the errors in the RWS.

1.3.2 Analysis of relaxation experiments

We have also carried out three relaxation experiments since the last progress report, in addition to a control experiment. Details of the relaxation regions used can be found in Table 1. Each of these experiments was designed with a different purpose. The first relaxed an area approximately centred over the region used as the base-point for the CGT correlations (hereafter the D&W region), an area in which the model has poor skill for geopotential height in July and August. As this region is a potential forcing region for the CGT, this experiment was designed to determine whether correcting the circulation in this area resulted in an improved model representation of the CGT. Experiment 2 relaxed a region in northwest Europe, in a region that also has poor skill for geopotential height in July and August. This experiment was carried out to determine whether the geopotential height errors seen over the D&W region are a result of errors propagating from northwest Europe, where the errors appear first. Experiment 3, which is similar to Experiment 1 but with a larger relaxation area, was designed as a follow up to Experiment 1 to try and correct the jet location and monsoon circulation.

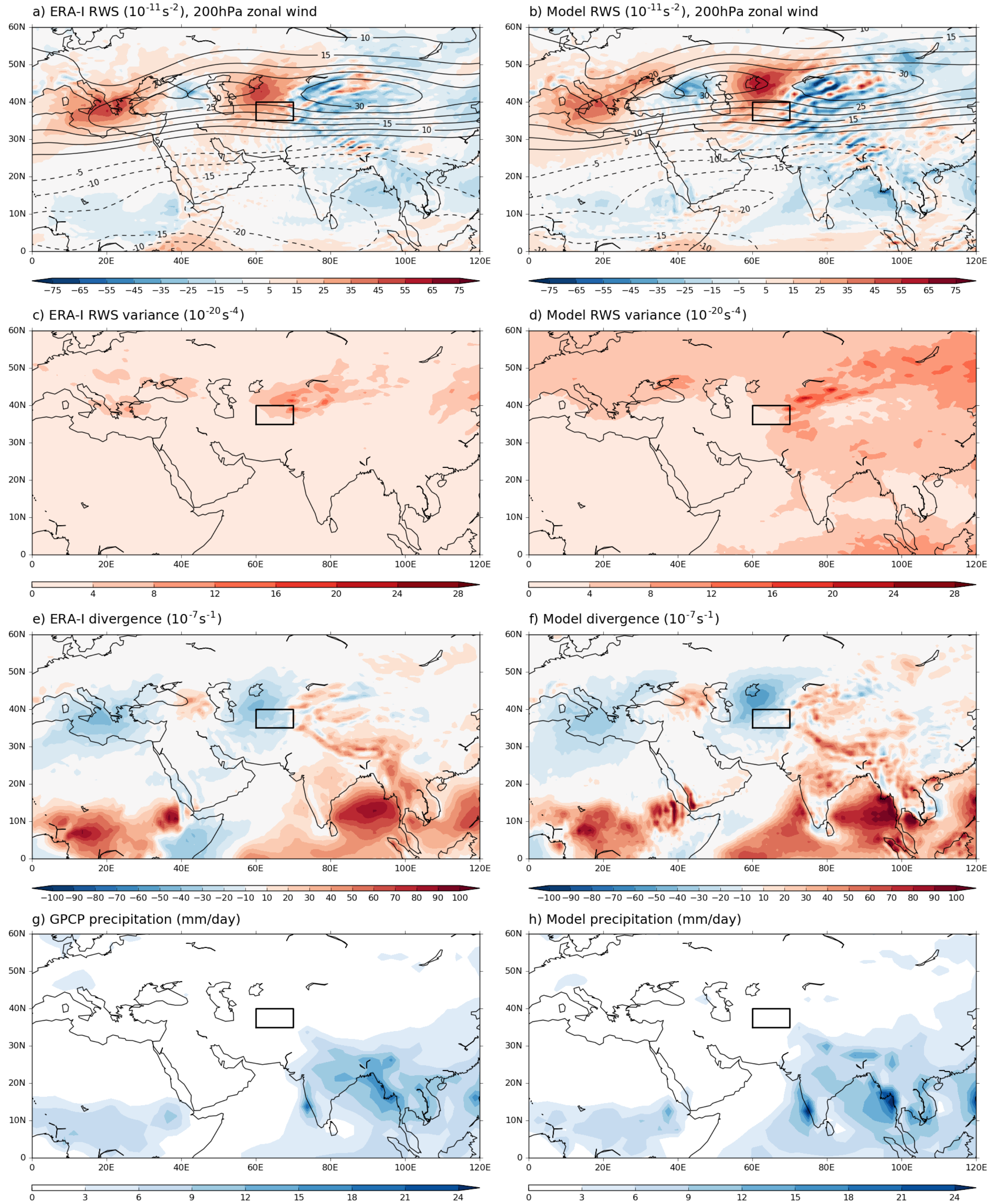

Figure 1: *(a) ERA-Interim and (b) model ensemble mean RWS term (filled contours) and 200 hPa zonal wind (black contours). (c) ERA-Interim and (d) model variance of the RWS term. The model variance is for all members concatenated together. (e) ERA-Interim and (f) model ensemble mean divergence. (g) GPCP and (h) model ensemble mean precipitation. All panels are for August, and the D&W region is marked as a box.*

Table 1: *Relaxation regions*

Experiment No.	Experiment ID	Region	Domain
1	b22b	Ding and Wang	35°-45°N, 55°-75°E
2	b22x	Northwest Europe	45°-65°N, 25°W-5°E
3	b23z	Ding and Wang (large)	25°-50°N, 50°-75°E

Figure 2 shows the model 200 hPa geopotential height skill and model CGT pattern in the new control experiment and Experiments 1, 2 and 3, and the CGT pattern from ERA-Interim for reference. We see from Figure 2d that for Experiment 1 the skill over Europe is largely unchanged. This suggests that the forecast errors in Europe are not related to errors in the D&W region. There is marginal improvement in geopotential height skill in east Asia but not much elsewhere, which suggests that errors elsewhere along the CGT pathway do not simply arise from errors in the D&W region - either they are not linked at all or errors in the Rossby wave pathways lead to errors in the teleconnection. There is also little change in the representation of the CGT (it is actually slightly worse) which may also suggest that the CGT is not directly forced from this region. However, the biases in the jet that are found in the control experiment are still present in this relaxation experiment (outside of the relaxation region) and so any waves forced in this region will not propagate in the correct manner, which may partly explain the lack of improvement in the CGT representation.

In Experiment 2 we see that there is a large improvement in the geopotential height skill over most of Asia when compared to the control (Figure 2f). This suggests that the errors in Asia propagate from Europe, and the skill over Asia in Experiments 1 and 2 is very similar. There is also some improvement in the CGT in this experiment (Figure 2g), although this is exclusively over Eurasia. The wave pattern in the correlations from Europe to Asia is much improved and closely resembles observations.

Both the 200 hPa geopotential height skill (Figure 2h) and CGT pattern (Figure 2i) in Experiment 3 are largely similar to those seen in Experiment 1. In particular, the geopotential height skill over Europe in these two experiments is very similar and the CGT patterns are almost identical. This is potentially because the jet biases outside of the relaxation region remain large, despite the region being relaxed being larger, and so Rossby wave propagation in these experiments will differ to observations.

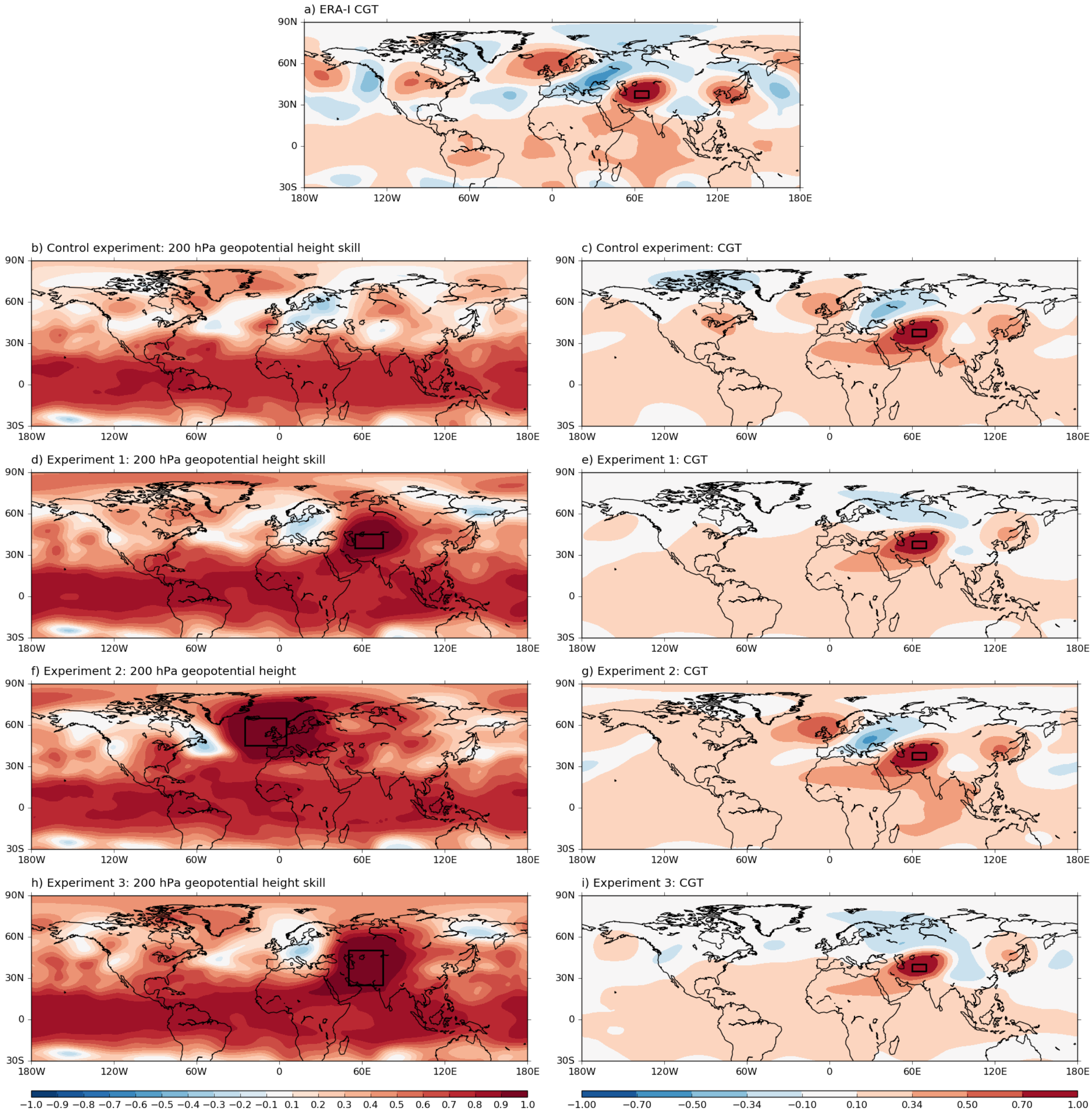

Figure 2: *(a) August CGT pattern (as defined in Ding and Wang (2005)) in ERA-Interim. 200 hPa geopotential height skill for August in (b) the new control experiment (with 60 vertical levels) (d) Experiment 1 (D&W region relaxation) (f) Experiment 2 (northwest Europe relaxation) and (h) Experiment 3 (larger D&W region relaxation). August CGT pattern in (c) the new control experiment (e) Experiment 1 (g) Experiment 2 and (i) Experiment 3. The boxes marked on d, f and h are the relaxation regions, and on a, c, e, g and i are the base point used for the CGT correlations (the D&W region). All plots use data filtered to remove the long term trend and decadal variations with a period of longer than 8.5 years, and correlations of ±0.34 are significant at the 5% level.*

1.4 Future work

We will be conducting further analysis of the relaxation experiments already carried out, in order to further understand how the CGT and European circulation are affected by forcing from the regions which have been relaxed towards observations. This analysis, and results obtained from barotropic model experiments, will inform further experiments that we will carry out this year. Potential relaxation experiments currently being considered include a full tropics relaxation (to examine the representation of tropical/extratropical teleconnections in the model) and a larger, full Asian monsoon region relaxation to correct the circulation associated with the Indian Summer Monsoon/East Asian Summer Monsoon. Also being considered are atmosphere only experiments, to explore the impact of air-sea coupling on the development of circulation biases hypothesised to be responsible for biases in the CGT.

References

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Enomoto, T., B. J. Hoskins, and Y. Matsuda, 2003: The formation mechanism of the Bonin high in August. *Quart. J. Roy. Meteorol. Soc.*, **129**, 157–178.

James, I. N., 1995: *Introduction to circulating atmospheres*. Cambridge University Press.

Rodwell, M. J. and B. J. Hoskins, 1996: Monsoons and the Dynamics of Deserts. *Quart. J. Roy. Meteorol. Soc.*, **122**, 1385–1404, doi:10.1002/qj.49712253408.