# SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

| | |
|---|---|
| **Project Title:** | The role of coupled ocean/atmosphere interactions in the tropics for seasonal and decadal prediction |
| **Computer Project Account:** | spdegrea |
| **Start Year - End Year :** | 2015 - 2017 |
| **Principal Investigator(s)** | Prof. Dr. Richard J. Greatbatch (GEOMAR) , |
| **Affiliation/Address:** | GEOMAR Helmholtz Zentrum für Ozeanforschung Kiel, Düsternbrooker Web 20, 24105 Kiel, Germany |
| **Other Researchers (Name/Affiliation):** | Dr. Felicitas Hansen (GEOMAR), Dr. Gereon Gollan (GEOMAR), Prof. Dr. Thomas Jung (AWI), Prof. Dr. Katja Matthes (GEOMAR), Dr. Sebastian Wahl (GEOMAR), Herr Ole Wulff (GEOMAR) |

The following should cover the entire project duration.

## Summary of project objectives
(10 lines max)

To determine how seasonal and decadal predictions in the mid-latitudes, especially over Europe, will benefit from improved predictions in the tropics and the stratosphere.

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

(i) When the proposal was written in 2014, we envisaged carrying out continuous runs using the coupled model initialised in 1980 and run to as close as possible as to the present. However, we soon realised that this is not possible using the scripts available to us, e.g. for initialisation and implementing the relaxation technique. Nevertheless, it is an achievement from the project that we can now run model experiments over a 2 year period, as we report below. We are grateful to Carsten Maass for help and advice in getting this to work.

(ii) The extratropical relaxation experiments using ERA-40 were not successful with some of the dynamic variables exhibiting strange and unrealistic behaviour. As a consequence, we have not explored extratropical relaxation as much as was originally envisaged.

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

The administrative aspects work really well. So far, we have no complaints.

## 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.)

In the original proposal we envisaged running a number of experiments using relaxation in either the extratropical atmosphere or the stratosphere with a view to assessing the impact of these regions on the tropical coupled ocean-atmosphere system. One motivation was the severe European winter of 1962/63 (Greatbatch et al., 2015). We have already shown using relaxation experiments, as part of a previous Special Project, that the severe weather in Europe that winter was associated with a suppression of the Madden Julian Oscillation (MJO) and an associated extreme easterly zonal wind anomaly in the upper equatorial troposphere near 150 hPa (Gollan and Greatbatch, 2015). The question was whether the unusual conditions in the tropics were themselves a consequence of the extreme conditions on the extratropics over Europe, implying that the severe weather winter could be a consequence of a positive feedback between the tropics and the extratropics. Unfortunately we have not been able to answer this question, not least because of the technical difficulties noted above. Nevertheless, an experiment using the coupled model with relaxation in the extratropical troposphere (not including the stratosphere) north of 45 N was successfully carried out in seasonal forecast mode, i.e. an ensemble of 4 month model runs initialised in November. Some preliminary analysis of this experiment has been done comparing the impact of the extratropical and tropical atmosphere on the occurrence of stratospheric sudden warmings (SSWs). We plan further analysis of this experiment in the future.

We have also carried out an ensemble of experiments using the coupled model with relaxation in the northern hemisphere stratosphere. Again these are 4 month runs initialised in November. The first results are utilised in Hansen et al. (2018) submitted to Geophysical Research Letters. We show there that the frequency of severe winter storms over Europe is strongly influenced by conditions in the stratosphere. Forecasting SSW risk is therefore important for forecasting severe winter storm frequency over Europe and it turns out that the experiment using the coupled model combined with relaxation in the tropics is the most successful at assessing both SSW risk and severe winter storm frequency.

The coupled model runs using relaxation in the tropics mentioned above were made available to us by Dr. Antje Weisheimer from the University of Oxford. Dr. Weisheimer also made a set of seasonal hindcasts for both boreal winter and summer available to us that use the coupled model without any relaxation. Results for severe winter storm frequency appear in Hansen et al. (2018) indicating some, be it marginal, skill and further analysis of these experiments is planned.

A major task in the past year has been to find out how to extend the seasonal forecast runs to multi-year runs with the result that Dr. Hansen can now carry out runs over a 2 year period. We are currently preparing a new proposal that will exploit this capability and will look at multiyear predictability associated with the stratosphere and/or the tropics (see, Dunstone et al. (2016) for an example).

We now have an extensive archive of model experiments using relaxation for the ERA-40 and ERA-Interim periods mostly using versions of the atmospheric model alone but also now some coupled model experiments. Analysis of these experiments has been continuing throughout the reporting period and beyond. A particular achievement of Hansen et al. (2017), as noted in our previous report, was the assessment of SSW risk across a range of experiments. The coupled seasonal forecast model exhibits a bias towards too strong zonal winds over the Atlantic that, in turn, is associated with a cold bias in the subpolar North Atlantic in the model that quickly develops during the forecast period. Taking account of this bias as part of the model diagnostics, Hansen et al. (2017) show that the coupled model combined with tropical relaxation has the best skill of all our model experiments at assessing SSW risk, indicating the importance of both correctly forecasting the tropics and of allowing for coupled air/sea interaction processes in the extratropics. The main focus of the paper is the seasonal prediction of the North Atlantic Oscillation (NAO) and the role of the stratosphere in determining the predictive skill (see the progress report submitted in June 2017 for the details).

We have continued our work on mid-latitude blocking and, in particular, influences from the tropics on blocking (Gollan et al., 2015; Gollan and Greatbatch, 2017). We make extensive use of the relaxation experiments in the these papers and find a significant and important influence on blocking from the tropics, notably associated with the MJO and El Nino Southern Oscillation (ENSO).

Concerning boreal summer, we have successfully identified the Summer East Atlantic (SEA) pattern and have shown that this pattern is influenced by rainfall anomalies in the tropics, in particular associated with the onset phase of El Nino (Wulff, 2017; Wulff et al., 2017). The SEA is important because it is associated with summer heatwaves over Europe, notably the summer heatwave of 2015, and the link to tropical rainfall and ENSO implies some predictability for these heatwaves. However, we spent a lot of time struggling to understand the results from the relaxation experiments for boreal summer. Indeed, boreal summer offers the first example we have found where relaxation in the tropics fails to excite the correct response at higher latitudes. This is illustrated in Figure 1.The figure uses a rainfall index (PCD) obtained by subtracting the rainfall averaged over the tropical North Pacific box in the upper panel of the figure from that in the Caribbean Sea box. The figure shows the regression of Z500 on this index for ERA-Interim (top box) as well as for the ensemble members for a set of model experiments using the atmosphere-only set-up. OBS-NO is clearly the most successful at capturing what we see in ERA-Interim. This is the experiment that uses specified sea surface temperature and sea-ice (SSTSI) but no relaxation.

Comparison with CLIM-NO, which uses climatological SSTSI and no relaxation, suggests a role for North Atlantic extratropical SSTSI in shaping the SEA, noting that the basic wave train, be it shifted eastwards over Europe, is present in this experiment. The issue here is the complete failure of the experiments that use relaxation (CLIM-TRPCS/OBS-TRPCS which use climatological/realistic SSTSI and relaxation in the tropics) to capture the wave train over Europe. This is despite the fact that the stationary wave number diagnostic for the wave guide (see Hoskins and Ambrezzi, 1993) is indistinguishable amongst the experiments from that diagnosed from ERA-Interim (see Figure 2). However, what this diagnostic shows in a region of negative absolute vorticity gradient in the subtropical Atlantic (hatched region in Figure 2) which Rossby waves avoid (in effect, the hatched regions act as reflecting surfaces). The problem seems to be the exhanced dissipation associated with the relaxation that is being applied in the hatched region in the tropical North Atlantic up to the edge of the relaxation zone at 30 N. It certainly appears as though this enhanced dissipation corrupts the Rossby wave signal that emanates from the tropics in these experiments. This is the only example we have found in which the relaxation experiments fail and offers a note of caution when interpreting relaxation experiments. In boreal winter, the region of negative relative vorticity gradient is largely missing in the tropical North Atlantic, and we have never seen behaviour suggesting a problem with the relaxation technique in our experiments for boreal winter.

We have also used the experiments carried out using ERA-Interim to identify a mode of variability in the austral winter circulation that is excited by the diabatic heating anomalies that go along with the East Asian Summer Monsoon (Ding et al., 2016). This is an interesting example of a teleconnection in the southern hemisphere that is excited by diabatic heating anomalies in the northern hemisphere.

References:

Ding, H., Greatbatch, R.J., Lin, H., Hansen, F., Gollan, G., and Jung, T., 2016, Austral winter external and internal atmospheric variability between 1980 and 2014. Geophys. Res. Lett., 43 (5), 2234-2239, doi: 10.1002/2016GL067862.

Dunstone N., Smith D., Scaife A.A., Hermanson L., Eade R., Robinson N., Andrews M. and Knight J., 2016, Skilful predictions of the winter North Atlantic Oscillation one year ahead, Nat. Geosci., 9, 809–567 814, doi:10.1038/ngeo2824.

Gollan, G., and Greatbatch, R.J., 2015, On the extratropical influence of variations of the upper tropospheric equatorial zonal mean zonal wind during boreal winter, J. Climate, 28 (1), 168-185, doi: 10.1175/JCLI-D-14-00185.1.

Gollan, G., Greatbatch, R. J. and Jung, T., 2015, Origin of variability in Northern Hemisphere winter blocking on interannual to decadal time scales, Geophys. Res. Lett., 42 (22). 10,037-10,046. doi: 10.1002/2015GL066572.

Gollan, G. and Greatbatch, R. J. , 2017, The relationship between northern hemisphere winter blocking and tropical modes of variability. J. Climate, 30 (22), 9321-9337, doi 10.1175/JCLI-D-16-0742.1.

Greatbatch, R. J., Gollan, G., Jung, T. and Kunz, T., 2015, Tropical origin of the severe European winter of 1962/63, Q. J. R. Meteorol. Soc., 141, 153-165, doi: 10.1002/qj.2346.

Hansen, F., Greatbatch, R. J., Gollan, G., Jung, T. and Weisheimer, A., 2017, Remote control of

NAO predictability via the stratosphere, Q.J.R. Meteor. Soc., 143 (703), 706-719, 10.1002/qj.2958.

Hansen, F., Kruschke, T., Greatbatch, R.J. and Weisheimer, A., 2018, Key factors for seasonal predictability of northern hemisphere severe winter storms, Geophys. Res. Lett., submitted.

Hoskins, B J and Ambrizzi , T., 1993, Rossby wave propagation on a realistic longitudinally varying flow, J. Atmos. Sci., 50 (12), 1661–1671.

Wulff, C. O., 2017, Summer Climate Variability in the North Atlantic-European region, Master thesis at the Faculty of Mathematics and Natural Sciences, Christian-Albrechts-Universität zu Kiel.

Wulff, C. O., Greatbatch, R. J., Domeisen, D. I. V., Gollan, G. and Hansen, F., 2017, Tropical forcing of the Summer East Atlantic pattern, Geophys. Res. Lett., 44 (21). 11,166-11,173, doi: 10.1002/2017GL075493.

## List of publications/reports from the project with complete references

This list includes only publications that appeared in 2015 or later.

Ding, H., Greatbatch, R.J., Gollan, G., 2015, Tropical impact on the interannual variability and long-term trend of the Southern Annular Mode during austral summer from 1960/61 to 2001/02, Climate Dynamics, 44 (7-8), 2215-2228, doi:10.1007/s00382-014-2299-x.

Ding, H., Greatbatch, R.J., Lin, H., Hansen, F., Gollan, G., and Jung, T., 2016, Austral winter external and internal atmospheric variability between 1980 and 2014, Geophys. Res. Lett., 43 (5), 2234-2239. doi: 10.1002/2016GL067862.

Gollan, G., and Greatbatch, R.J., 2015, On the extratropical influence of variations of the upper tropospheric equatorial zonal mean zonal wind during boreal winter, J. Climate, 28 (1), 168-185, doi: 10.1175/JCLI-D-14-00185.1.

Gollan, G., Greatbatch, R. J. and Jung, T., 2015, Origin of variability in Northern Hemisphere winter blocking on interannual to decadal time scales, Geophys. Res. Lett., 42 (22). 10,037-10,046. doi: 10.1002/2015GL066572.

Gollan, G. and Greatbatch, R. J. , 2017, The relationship between northern hemisphere winter blocking and tropical modes of variability. J. Climate, 30 (22), 9321-9337, doi 10.1175/JCLI-D-16-0742.1.

Greatbatch, R. J., Gollan, G., Jung, T. and Kunz, T., 2015, Tropical origin of the severe European winter of 1962/63, Q. J. R. Meteorol. Soc., 141, 153-165, doi: 10.1002/qj.2346.

Hansen, F., Greatbatch, R. J., Gollan, G., Jung, T. and Weisheimer, A., 2017, Remote control of NAO predictability via the stratosphere, Q.J.R. Meteor. Soc., 143 (703), 706-719, 10.1002/qj.2958.

Wulff, C. O., 2017, Summer Climate Variability in the North Atlantic-European region, Master thesis at the Faculty of Mathematics and Natural Sciences, Christian-Albrechts-Universität zu Kiel.

Wulff, C. O., Greatbatch, R. J., Domeisen, D. I. V., Gollan, G. and Hansen, F., 2017, Tropical forcing of the Summer East Atlantic pattern, Geophys. Res. Lett., 44 (21). 11,166-11,173, doi: 10.1002/2017GL075493.

## 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.)

As noted above, we are preparing a new proposal, to be led by Dr. Hansen, that will exploit the capability we now have to run experiments over a 2 year period. We shall also continue to analyse and exploit the existing experiments.

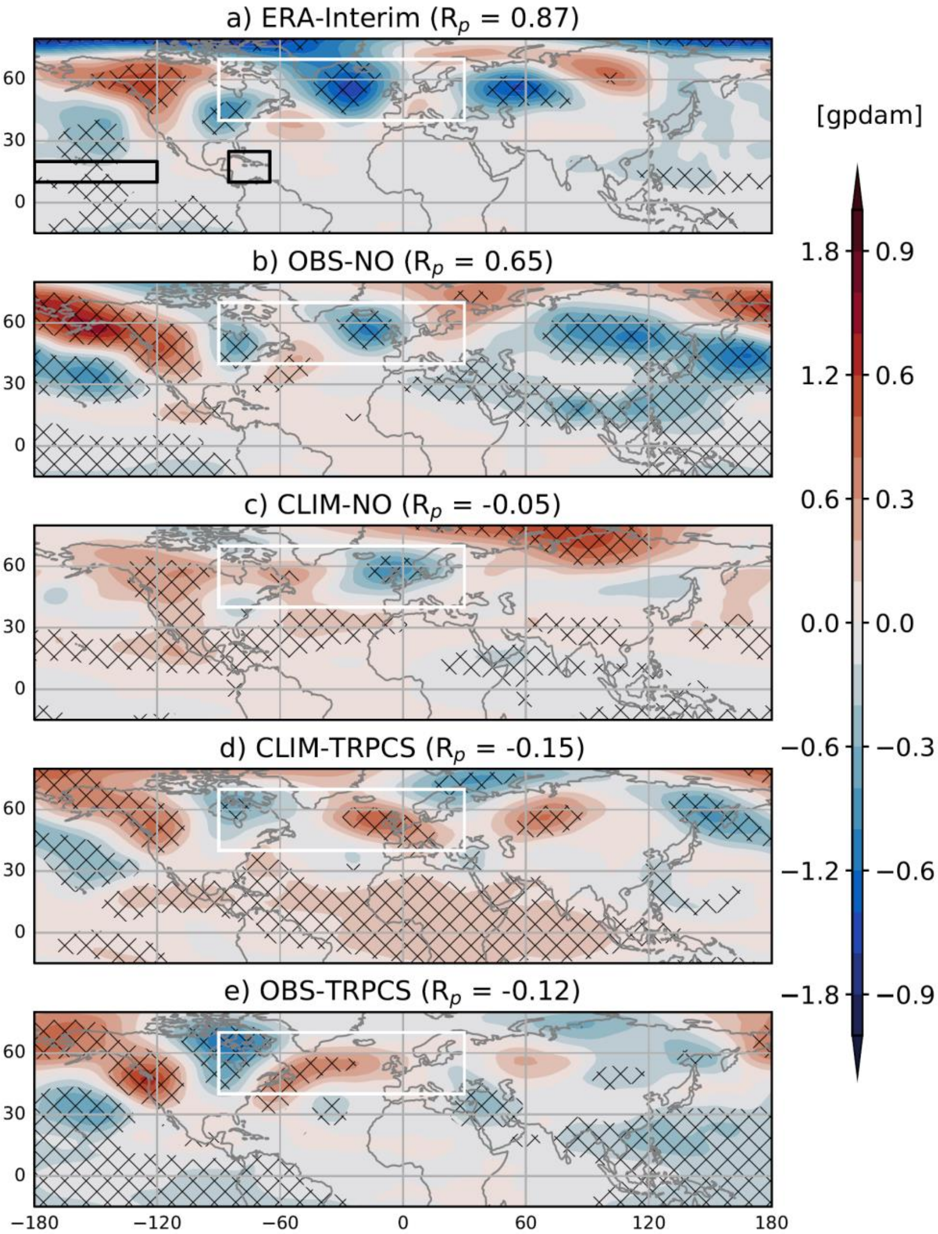


Figure 1: Regression of June/July/August (JJA) geopotential height at 500hPa (Z500) on the Pacific minus Caribbean precipitation dipole (PCD) index for ERA-Interim and in the different model experiments, noting that the individual ensemble members are used for the regression in the case of the model experiments. Here the PCD index is the JJA mean precipitation for the box in the tropical North Pacific minus that in the box in the Caribbean Sea shown in panel (a). The numbers in brackets are the pattern correlation with the SEA pattern which is the second EOF of JJA mean Z500 inside the white box. Note that the experiments that include relaxation in the Tropics (CLIM-TRPCS and OBS-TRPCS) completely fail to capture the centre of action to the west of the British Isles seen in (a), whereas this feature is quite well reproduced in OBS-NO, the experiment that does not include relaxation but includes realistically varying SSTSI. Interestingly, this feature is also found in CLIM-NO, the experiment that also does not include relaxation but uses climatological SSTSI, although it is displaced eastwards in this experiment. Comparing CLIM-NO with OBS-NO suggests a role for North Atlantic SSTSI in the dynamics of the SEA. From Wulff (2017).

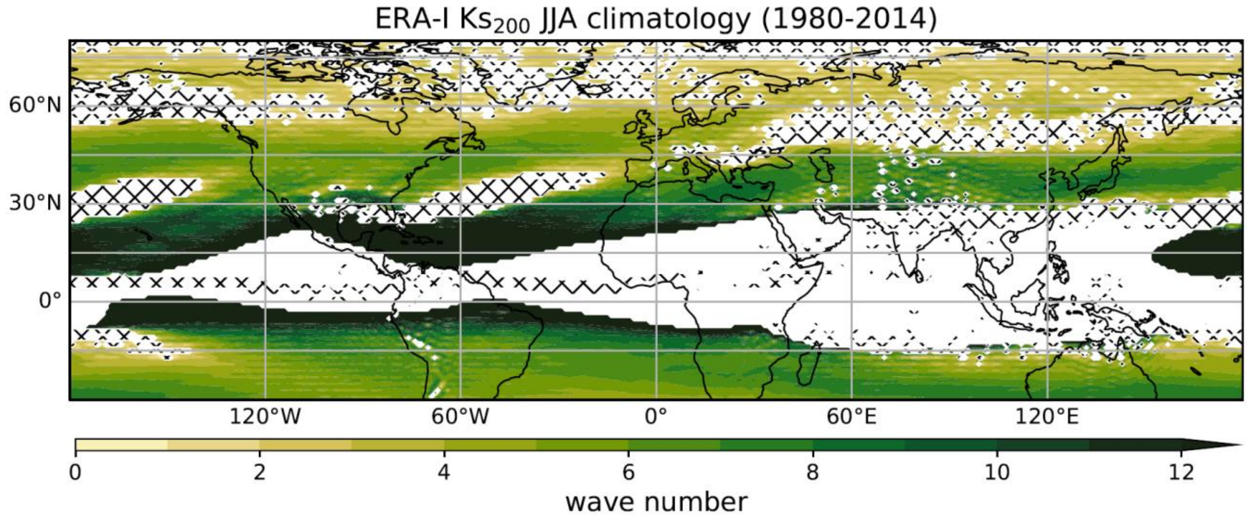


Figure 2: The stationary wave number diagnostic (Hoskins and Ambrezzi, 1993) for the boreal summer climatological mean flow computed from ERA-Interim. Hatching indicates regions of negative relative vorticity gradient and white without hatching regions of easterly mean winds. From Wulff (2017).