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Evaluating key aspects of large-scale circulation for Europe in a coupled PPE

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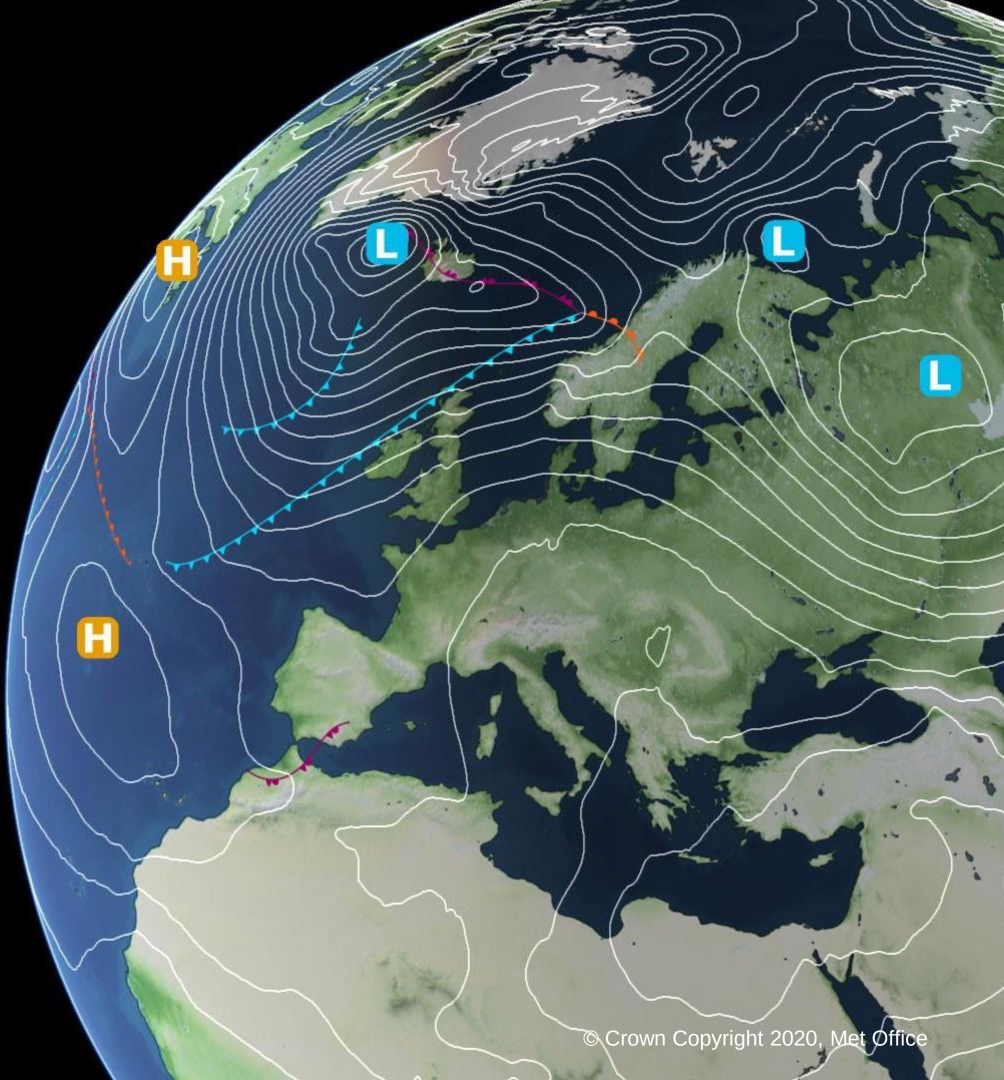

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A global coupled model PPE for exploring future UK and European climate

The UKs latest national projections (UKCP18) include a 15-member global coupled model perturbed parameter ensemble (PPE) based on HadGEM3-GC3 (Sexton *et al*, submitted; Murphy *et al*, 2018). These models are run at 60km atmosphere, quarter degree ocean, and are flux corrected (Yamazaki *et al*, submitted).

These projections, together with a filtered subset of 13 CMIP5 members, offer a set of physically coherent and spatially & temporally complete projections, complementing the probabilistic projection information that is also included on UKCP18. These global models are also drive the downscaled European (12km) and local (2.2km) datasets.

A key motivation in generating a coupled PPE for use in UKCP18 was to exploit the significant improvements in regional dynamics that have been demonstrated at higher vertical and horizontal resolutions (e.g. Scaife *et al.* 2014). A realistic representation of the large scale regional characteristics is considered particularly important to enable these simulations to be used as a basis for 'storyline' approaches to understanding and communicating projection characteristics and their uncertainty, which is an important aspiration for the UKCP18 project.

Here we show a results form the evaluation of the 15-member global coupled PPE for a number of metrics of large scale circulation, including jet latitude and strength, weather type frequencies, blocking & North Atlantic storm tracks.

Seasonal mean regional circulation

Climatological mean circulation is broadly realistically represented in PPE compared with ERA40. RMSE of PSL typically lower than CMIP5-13 (fig 1, bottom))

There is a tendency for a slightly weaker Atlantic pressure gradient than observed hence weaker mean flow at 850hpa over UK, particularly in SON/DJF (fig 1 top and, fig 1 bottom right).

CMIP5-13

We show evaluation results for the 15-member PPE alongside equivalent analysis of a 13-member subset of CMIP5 (McSweeney *et al,* 2018). This subset was filtered to exclude least realistic members regionally and globally, and some of those with significant shared components, in order to provide a plausible and diverse subset. This subset serves 2 purposes:

1) It augments the 15-member PPE to enhance the diversity in future projections and;

2) It acts as a benchmark for acceptable regional performance for the PPE.

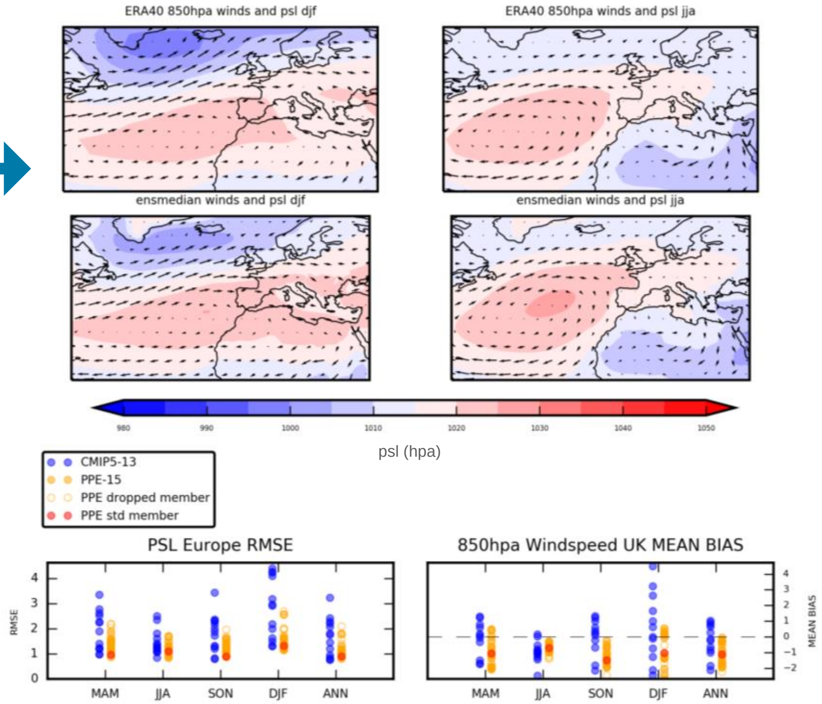

Fig 1: (top) Seasonal mean 850hpa windspeed (vectors) and mean sea level pressure (psl) (hpa) in ERA40 and 15 member-PPE ensemble mean. (bottom) Root-mean-square error of psl over Europe (left) and UK mean seasonal mean absolute bias in 850hpa windspeed (right).

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Eddy-driven jet latitude and strength

The daily jet latitude and strength is derived using diagnostic described in Woollings *et al* 2010, essentially as the location and magnitude of the daily maximum in the smoothed tropospheric zonal wind speed in the North Atlantic sector.

The latitudinal positions of the jet are characterised in DJF and SON by a distinctive trimodal distribution (Fig 2) with those three preferred positions mapping onto NAO and blocking states. The central jet position (45-50N) typically tracks weather systems directly across the UK.

The PPE members clearly capture this trimodal distribution in DJF and SON well, while CMIP5 models tend to underestimate northern and jet position in favour of the central-southern position. In SON and JJA however, the PPE members reverse this pattern and underestimate jets in this central position (Fig 3), contributing to a dry bias in UK rainfall in SON (see slide 7).

The PPE tends to underestimate the number of days with stronger jet streams in DJF and SON, consistent with the weaker Atlantic pressure gradient in Fig 1.

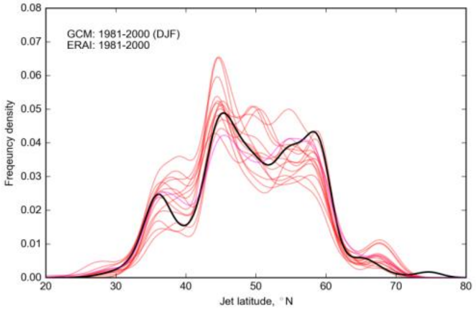

Fig 2: Tri-polar structure of the distribution of DJF daily latitudes of the eddy-driven jet in ERA-Interim and PPE members.

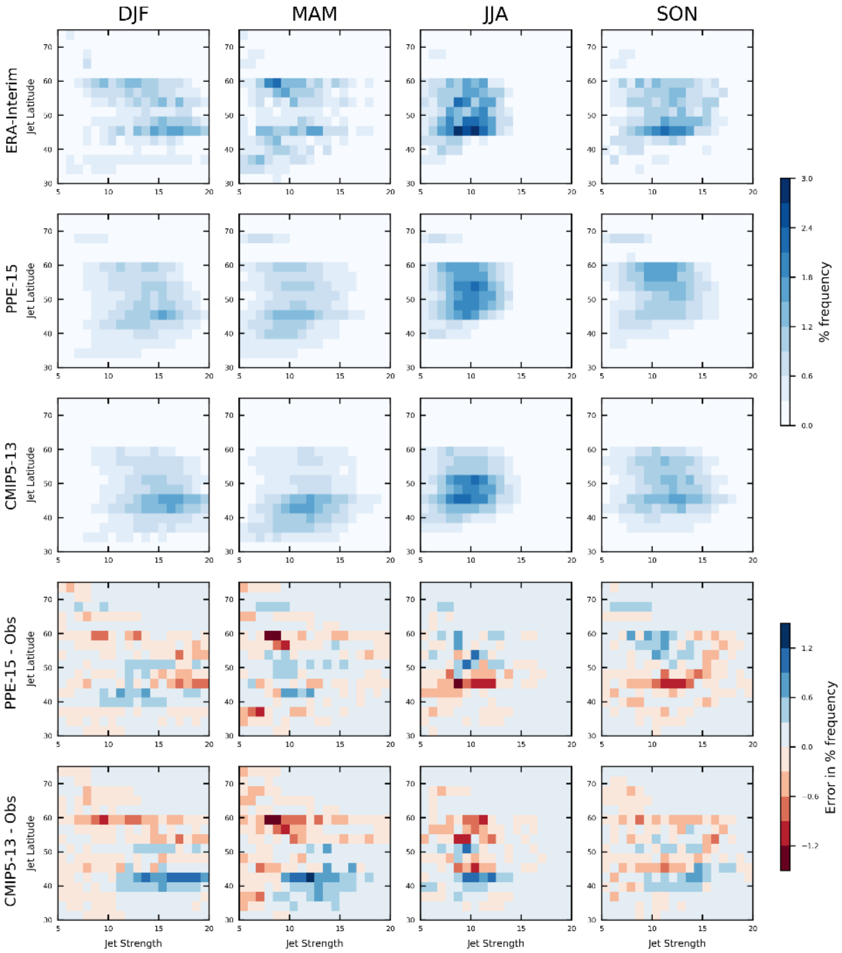

Fig 3: Seasonal 2d histograms of jet latitude and strength (m/s) in ERA-Interim, PPE15 ensemble mean and CMIP5-13 (10 members) ensemble mean, 1981-2000.

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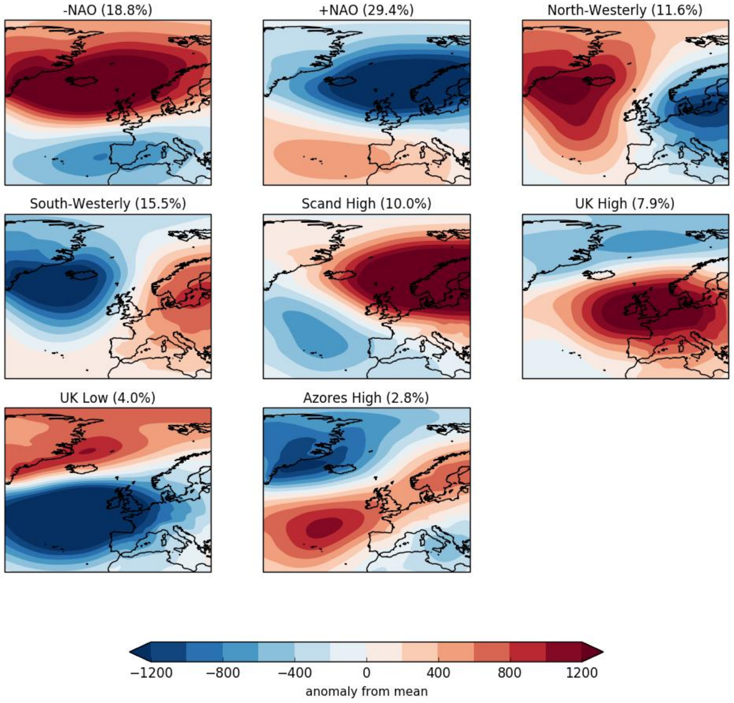

Fig 4: Pressure anomaly associated with each of the 8 weather-type clusters, generated by averaging pressure anomalies on days allocated to that cluster in EMSLP observed record. Numbers in brackets indicates % DJF frequency 1981-2000.

Weather regimes and their frequencies

A set of 8 weather patterns, generated objectively by clustering daily MSLP anomaly fields into 30 weather regimes which are subsequently amalgamated into 8 key clusters, describe climatological variability in weather pattern occurrence for Europe throughout the year (Neal *et al.*, 2016) (Fig 4).

Using these regimes to assess the variability of UK weather patterns, we find that the PPE and CMIP5-13 capture the relative frequencies of these regimes and their seasonal variations realistically (Fig 5).

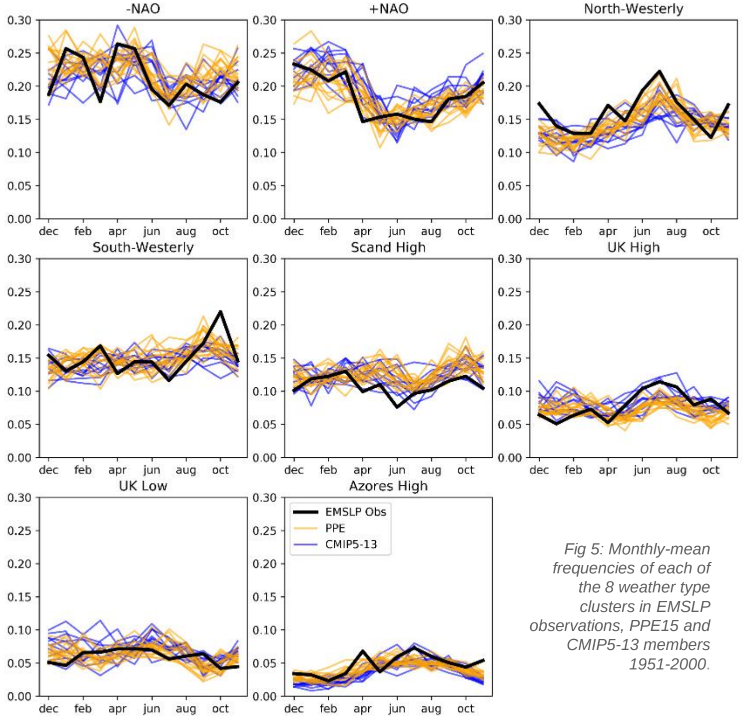

Fig 5: Monthly-mean frequencies of each of the 8 weather type clusters in EMSLP observations, PPE15 and CMIP5-13 members 1951-2000.

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North Atlantic winter storm tracks

The winter zonal mean track density between -5 and 25E shows that the model captures the locations of the peak storm activity. Most members have too many Mediterranean storms and too many storms over the UK. Further north there are too few storms and the peak activity is not always at the correct latitude. The storm tracks are better simulated during the rest of the year (Fig 7)..

Counts of the number of storm tracks that cross Western Europe show that most of the PPE members have more storms than in the reanalysis data. The PPE spread is within the CMIP5 spread but all the PPE members are towards the upper end of CMIP5. The regional RMSEs across the PPE are typically lower than CMIP5-13 (Fig 6).

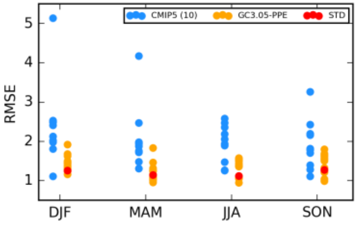


Fig 6: Root-mean square error of seasonal-mean storm track density over Europe (30°N to 75°N and 50°W to 5°E) in PPE15 and CMIP5-13 (10-members) relative to ERA-Interim (1981-2000).

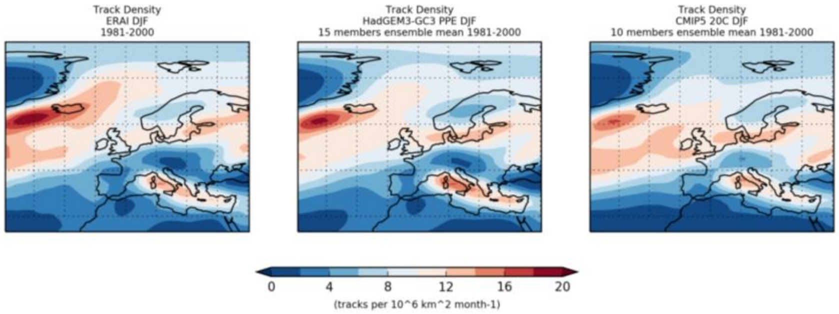
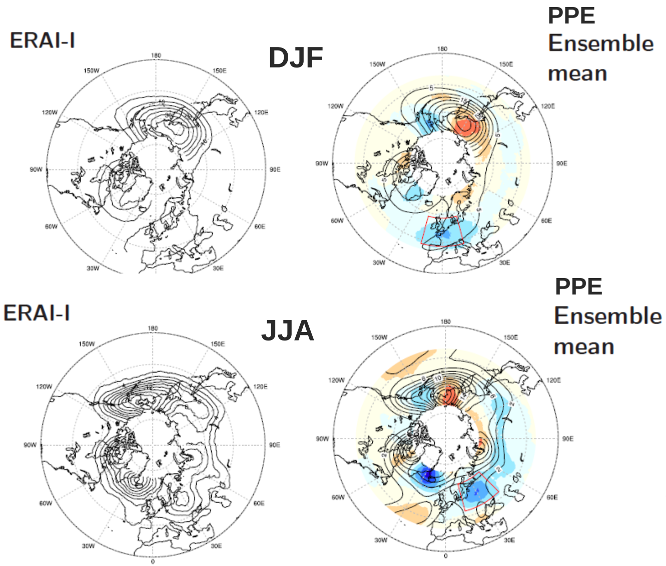


Fig 7: Seasonal mean DJF Track density in ERA-Interim, PPE-15 and CMP5-13 (10 members), 1981-2000.

Blocking

GCMs typically underestimate the frequency of blocking events in western Europe. The PPE captures key geographical patterns of blocking frequency, but as for many models, most members underestimate winter and summer blocking frequencies (Fig 8, left). As is the case for for CMIP5, there is significant spread in the ensemble with some members having equivalent numbers to observations. Across the ensemble, for the UK the frequency of blocked days in PPE members typically are slightly closer to the observations than CMIP5 (Fig 8, right), although blocking frequencies are less realistic than CMIP5 in Eastern Europe.



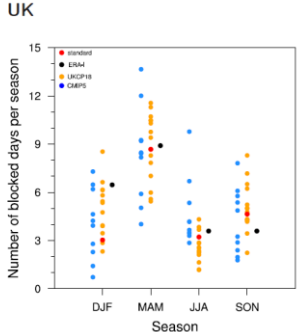


Fig 8: Left: Seasonal total number of blocked days for DJF and JJA in ERA-interim and PPE ensemble mean. Right: UK average number of blocked days per season in ERA-Interim, PPE (UKCP18) and CMIP5-13 (10 members).

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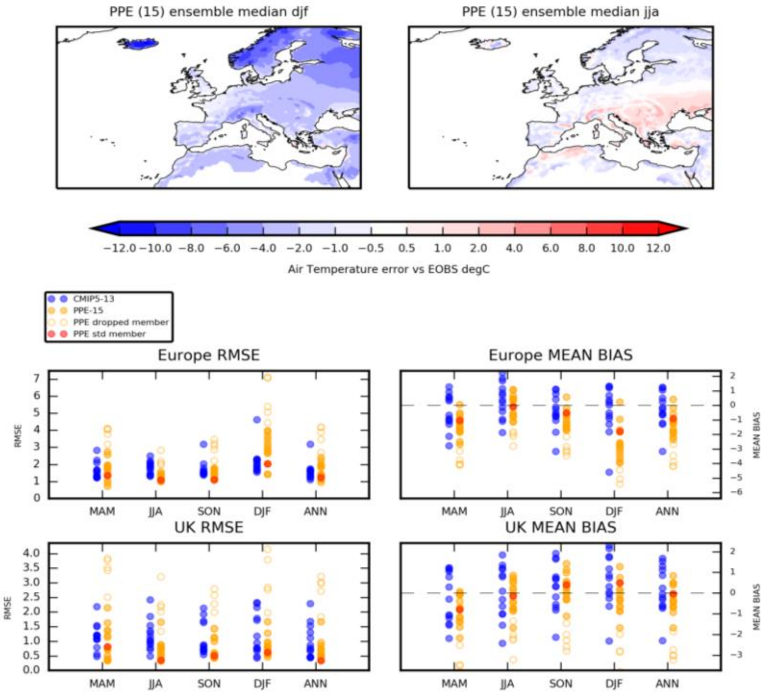


Fig 9: (top) Seasonal mean temperature bias relative to E-OBS observations in 15 member-PPE ensemble median (DJF and JJA). (bottom) Root-mean-square error of temperature over Europe and UK (left) and Europe and UK mean seasonal mean absolute bias in temperature (right), 1981-2000.

Winter cold bias

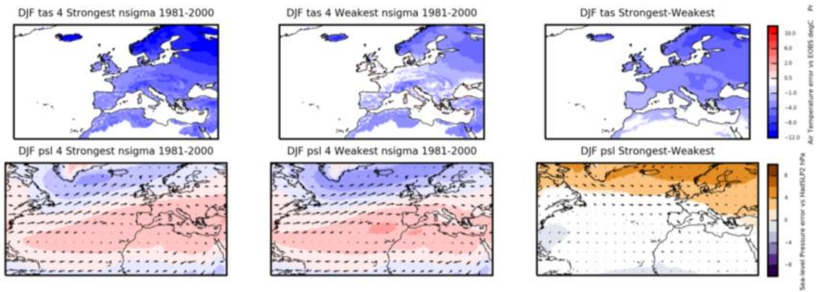
While for most seasons, European mean surface temperature is closer to observations than CMIP5-13, the PPE does suffer with a notable structural cool-bias in northern Europe in Winter, particularly affecting northernmost parts of Europe.

We know that the members with the largest cool bias share several characteristics including:

- Weakest DJF mean atlantic pressure gradient, and weakest westerlies over UK
- Weakest AMOC (Yamazaki *et al, Submitted*)
- Strongest cooling in 20thC in response to aerosol forcing
- Highest values of the 'n-sigma' parameter (represents degree of drag over orography)

But it is not clear whether one of these factors is the dominating driver of the bias. The shared characteristics of the cool bias and circulation are illustrated below in composites of mean temperature and psl anomaly in the 4 members with weakest n-sigmas vs 4 members with strongest n-sigma.

Fig 10: Composite mean temperature bias (top) and circulation bias as psl and vectors of 850hpa winds (bottom) of 4 PPE members with strongest –n-sigma parameter settings (left) vs 4 with weakest n-sigma parameter settings (centre). Difference between strongest – weakest n-sigma members (right).



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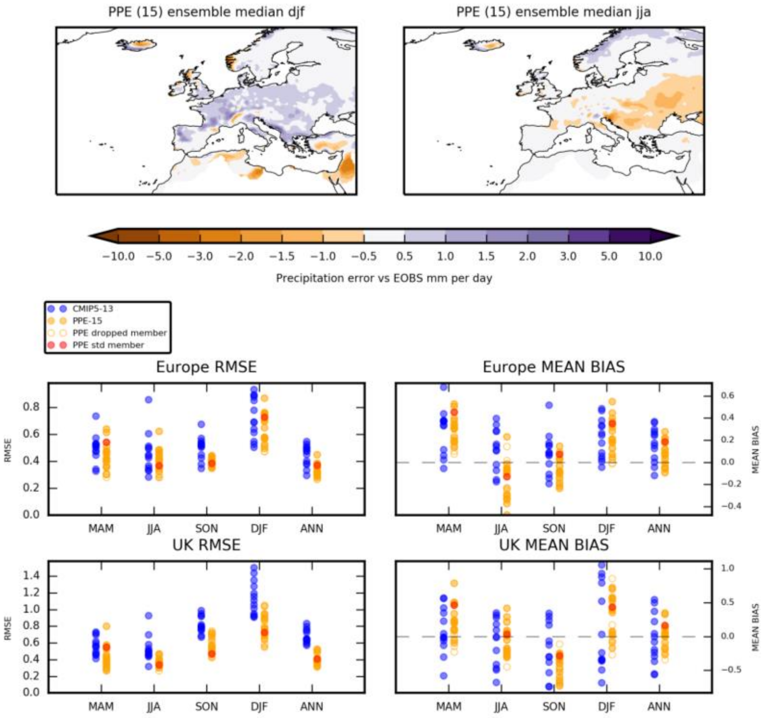


Fig 11: (top) Seasonal mean precipitation bias relative to E-OBS observations in 15 member-PPE ensemble median (DJF and JJA). (bottom) Root-mean-square error of precipitation over Europe and UK (left) and Europe and UK mean seasonal mean absolute bias in precipitation (right), 1981-2000.

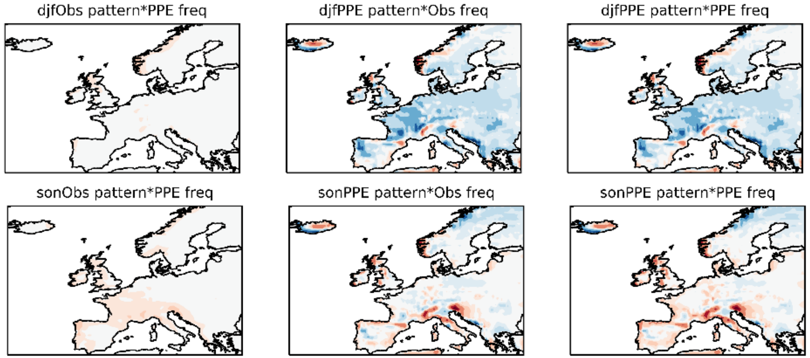
Seasonal mean precipitation

Seasonal mean precipitation distribution across Europe is RMSE is realistic, with small mean biases manifesting as wet bias in winter/spring and dry in summer/autumn.

RMSE values indicate typically more realistic values in the PPE than CMIP5-13, particularly for the UK.

The characteristic dry-summer/wet-winter implies a thermodynamic source of precipitation error. This is reinforced by breaking down error into dynamical vs thermodynamical component – in this case using regime frequencies determined by jet latitude and strength bins and their respective precipitation intensity patterns. This suggests only small fraction of precipitation error relates to the error in *frequencies* of different large scale conditions associated with the jet stream, whilst most of the error arises from the surface conditions associated with the large scale regime (Fig 12).

Fig 12: Mean seasonal precipitation bias broken down into component arising from bias in the frequencies of jet latitude and strength regimes vs the intensity patterns of precipitation associated with each jet regime.



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Summary

- The 15-member global coupled model PPE forms offers a set of physically coherent and spatially & temporally complete projections, complementing the probabilistic projection information that is also included on UKCP18.
- We have assessed their representation of the large scale regional climate characteristics using a range of indicators, benchmarking against 13 of the more realistic CMIP5 members.
- We have considered the representation of the latitude and strength of the jet stream, frequencies of 8 weather-type clusters, the Atlantic storm track, frequency of blocked days; as well as surface characteristics of mean temperature and precipitation.
- We find that the PPE performs well, typically performing at least as well, or improving on CMIP5-13 where objective measures such as RMSE are compared. Exceptions do of course occur – notably the significant northern European cold bias.
- Where there are errors in characteristics relating to the large scale circulation such as frequencies of large scale regimes, these do not seem to contribute significantly to errors in surface precipitation. Rather, it is more likely that those errors are thermo-dynamic in origin.
- The strong performance of the PPE with respect to the regional dynamics is encouraging for the use of these simulations in the development of 'storylines' approaches in UKCP18, and also in EUCP.
- Data from these simulations is available at : https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/download-data
- **Questions or comments are very welcome via email! (carol.mcsweeney@metoffice.gov.uk).**

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