Supplement for RC1 and RC2 responses

This supplement contains the new text relating to Sections 4.2 and 4.3.1 of the original submitted manuscript, which have changed as a result of applying a bias-correction to ECMWF EPS precipitation and hence drought forecasts (EPS-P).

We also include all new plots e.g. a new model schematic and updates of the radar plots as map plots. All figures are after the text.

4.2 Precipitation forecasts

We first discuss the skill of the three true forecast models, EPS-WP, EPS-P and Markov. For the most part, all three models are more skilful than climatology independent of season and lead-time, with greater skill in autumn and winter compared to spring and summer (Figs. 4 and 5). For a 16-day lead-time, there is little to choose between EPS-WP and EPS-P, except in ES, for which the latter model is less skilful than climatology in winter and spring (Fig. 4). Markov is the least skilful model at this lead, offering only a marginal improvement on climatology (Fig. 4). The skill of EPS-WP and EPS-P reduces when a 31-day lead is considered, bringing their skill more in line with Markov (Fig. S2). At a 46-day lead the differences are starker, with EPS-P notably less skilful than EPS-WP, Markov and climatology for many regions in summer and, especially, spring (Fig. 5). These results are, however, still only marginally superior to climatology. EPS-WP has greater skill than EPS-P at this lead-time in winter and autumn for NS, NI, CEE and SWE, although the magnitudes of these differences are small (Fig. 5). There is little evidence of coherent regional variability in model skill, except perhaps a tendency for EPS-P to score more highly for western regions in spring and summer at a 16-day lead-time (Fig. 4). Despite low skill relative to climatology at longer lead-times, there is clearly some benefit to using the WP-based models (particularly EPS-WP) for certain regions and seasons.

The potential usefulness of such approaches is highlighted by the performance of Perfect-WP. Unsurprisingly, this model is almost uniformly the most skilful model for all regions, seasons and lead-times (Figs. 4, 5 and S2). The gains in skill for this model over the other three models are most pronounced during winter and autumn and especially for longer lead-times. Skill is greatest for most western regions (NS, NI, NWE and SWE) and lowest for eastern regions ES, NEE and SEE, together with SS (Fig. 5). Perfect-WP is obviously not practical, but the results serve to show that WPs are a potentially useful tool in medium-range precipitation forecasting.

4.3 Drought forecasts

4.3.1 Forecast accuracy

Forecast accuracy is typically lower for mild drought (total precipitation over 16, 31, or 46 days below the 30.9th percentile) than for precipitation, and lower still for moderate drought (total precipitation below the 15.9th percentile). The regional and lead-time differences in precipitation skill are also evident for drought, with higher skill at shorter leads and during winter and autumn (Figs. 6, 7 and S3). Results for mild drought are not shown as they generally lie in-between those for precipitation (Figs. 4, 5 and S2) and moderate drought (Figs. 6, 7 and S3). Markov again has the poorest skill, with a climatology forecast preferable for many combinations of region and lead-time. EPS-P is either equal or more skilful than

EPS-WP at a 16-day lead (Fig. 6), and during spring for longer leads (Figs. 7 and S3). Conversely, EPS-WP outperforms EPS-P during summer at the longer two lead-times, although a climatology forecast would be just as, if not more skilful. As with precipitation forecasts, any gain in skill using EPS-WP over EPS-P in winter and autumn at longer leads is marginal, with both models showing more skill than climatology (Figs 7 and S3).

Skill, where present, is undeniably modest, but the relatively high skill of Perfect-WP in some regions and seasons again shows the potential predictability of drought using WP methods. Compared to precipitation forecasts, skill for Perfect-WP is notably lower for spring and summer, with climatology often a competitive forecast method at a 46-day lead-time (Fig. 7). For winter and autumn, however, the skill is reasonable UK-wide, and particularly high during winter in NS and NI (Fig. 7). The same east-west skill split is present for moderate drought as it was for precipitation, with some western regions benefitting from higher skill than eastern region (Fig. 7).

Daily precipitation		**Total 16-, 31- and 46-day precipitation**	
$\mathbf{p_b}$	**Range of precipitation, x, (mm)**	$\mathbf{s_c}$	**Range of summed precipitation, y, (mm)**
p_1	0	s_1	$0 < y \leq 10$
p_2	$0 < x \leq 1$	s_2	$10 < y \leq 20$
…	Intervals of 1 mm	…	Intervals of 10 mm
p_{11}	$9 < x \leq 10$	s_{25}	$240 < y \leq 250$
p_{12}	$10 < x \leq 15$	s_{26}	$250 < y \leq 300$
p_{13}	$15 < x \leq 20$	…	Intervals of 50 mm
p_{14}	$20 < x \leq 30$	s_{30}	$300 < y \leq 450$
…	Intervals of 10 mm		
p_{21}	$90 < x \leq 100$		

Table 1: Range of daily precipitation, x, for each bin p_b and of 16-, 31- and 46-day total precipitation, y, for each bin s_c.

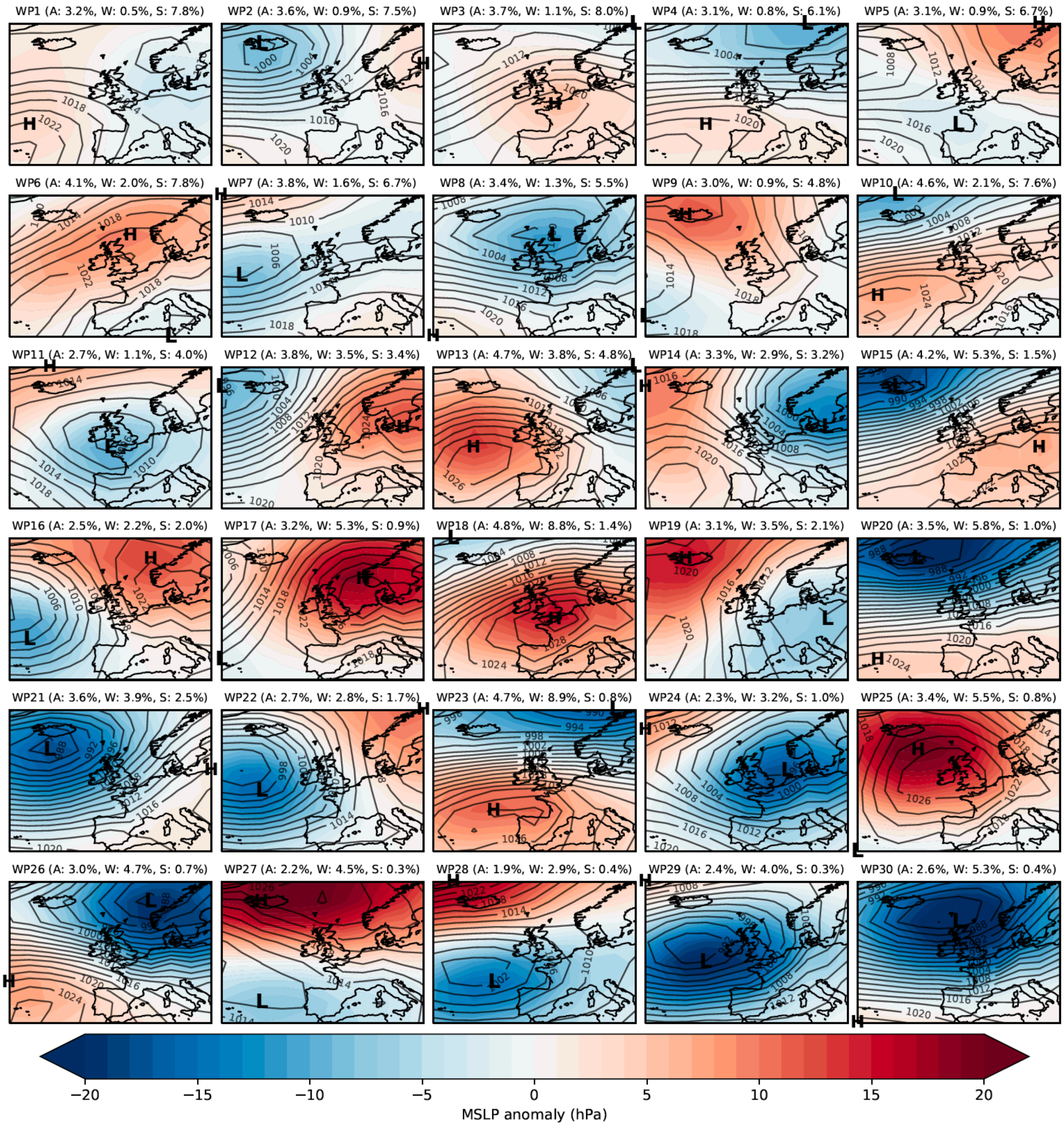

Figure 1: Weather pattern (WP) definitions according to mean sea-level pressure (MSLP) anomalies (hPa). The black contours are isobars showing the absolute MSLP values associated with each weather pattern, with the centres of high and low pressure also indicated. Next to the WP labels are the annual (A), winter (W; DJF) and summer (S; JJA) relative frequencies of occurrences of each WP (%). The frequencies of occurrence data are associated with the WPs based on ERA-Interim between 1979 and 2017, while the WP definitions were generated from a clustering process applied to EMULATE MSLP reanalysis data between 1850 and 2003. See the text for details.

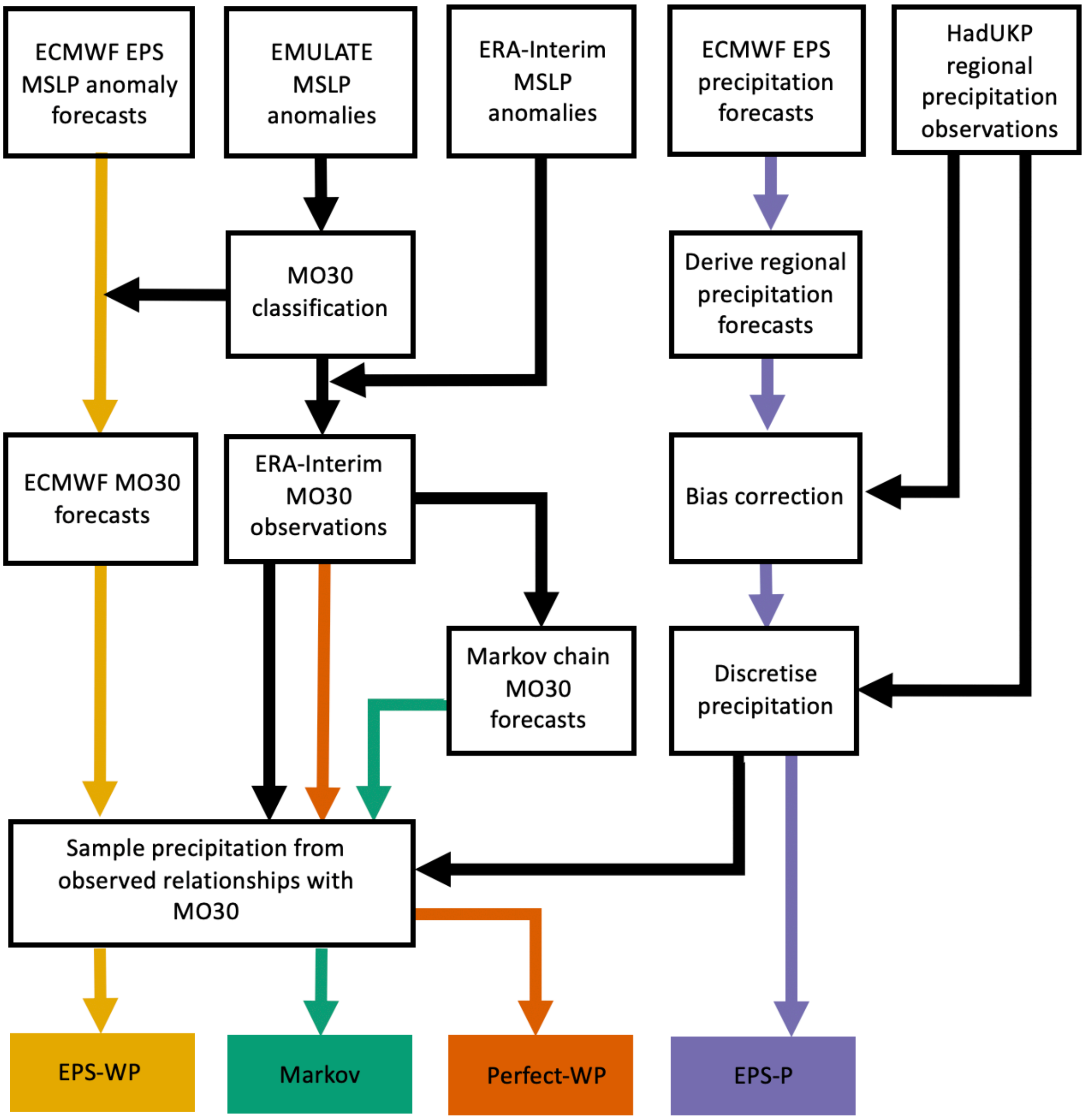

Figure 2: Schematic showing the procedure for the four precipitation forecast models. The top row shows the base data sets used and the bottom row shows the four models. Coloured arrows begin at the first stage for which forecasts are issued: EPS-WP forecasts begin with the ECMWF prediction system MSLP forecasts; Markov forecasts are produced once the ERA-Interim MO30 time series has been derived; Perfect-WP 'forecasts' are observations from the same time series, while EPS-P forecasts are the post-processed data from the ECMWF forecast system.

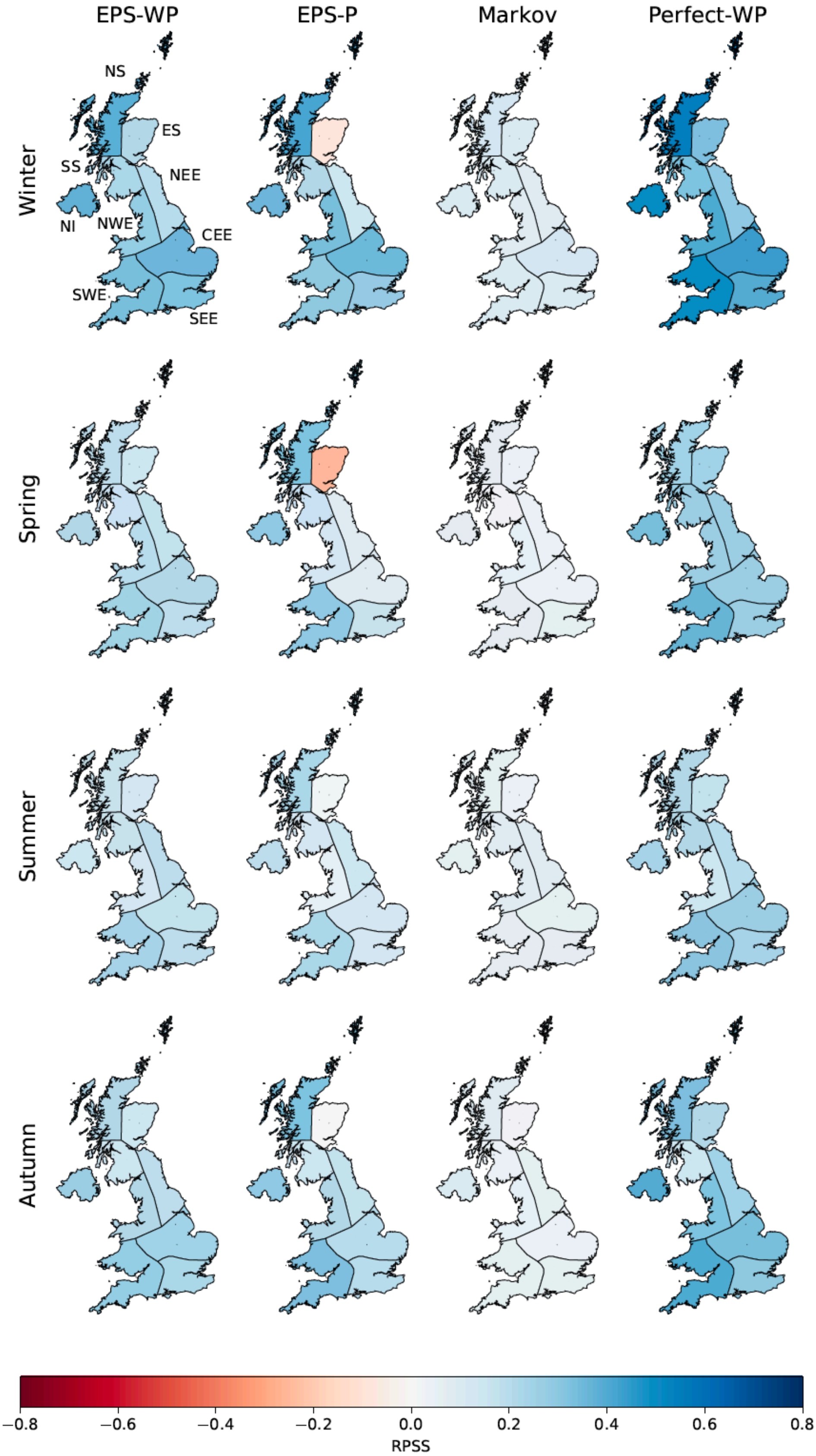

Figure 4: Ranked probability skill scores (RPSS) for precipitation forecasts at a 16-day lead for each model and season.

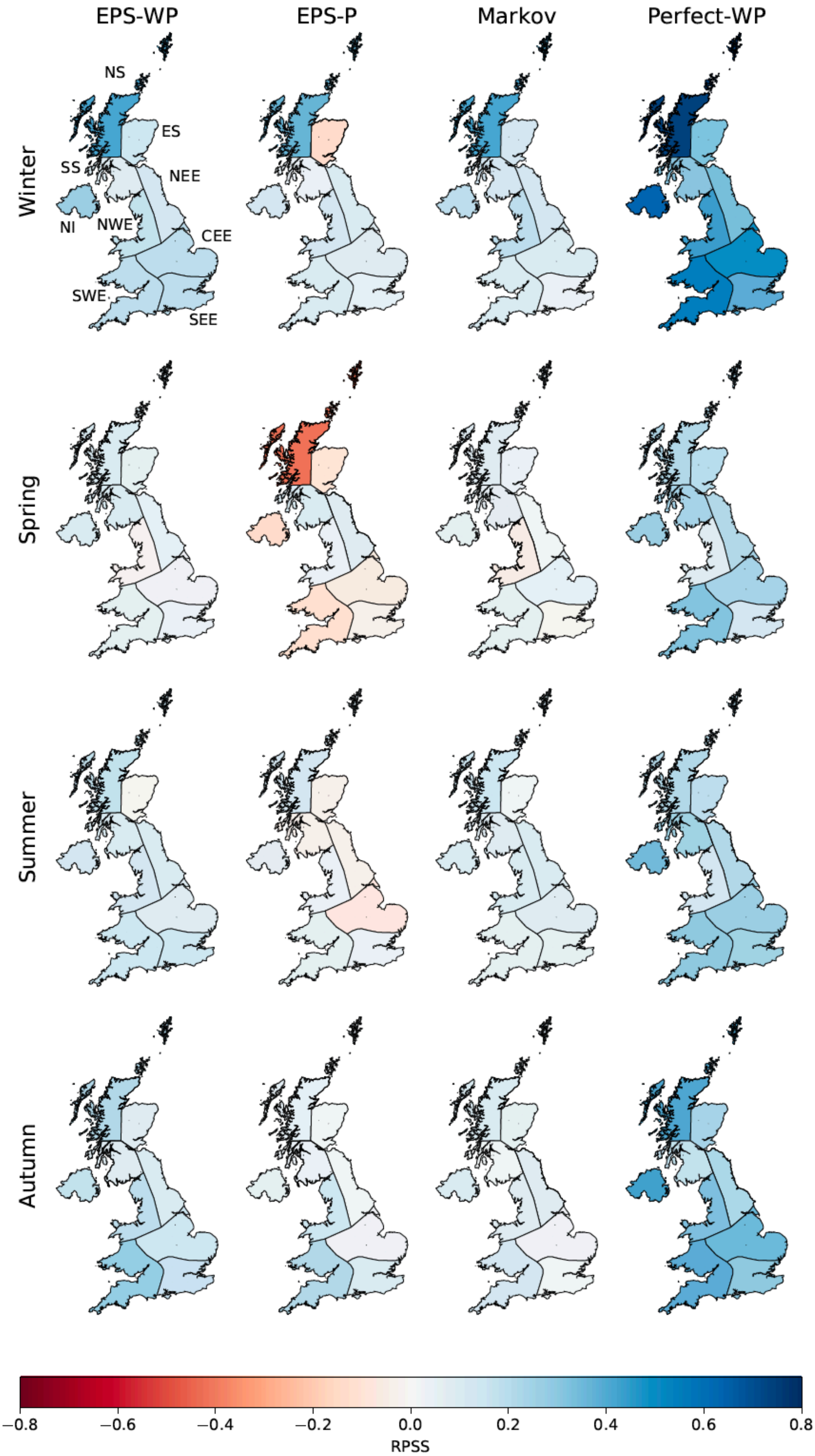

Figure 5: As Figure 4 but for a 46-day lead.

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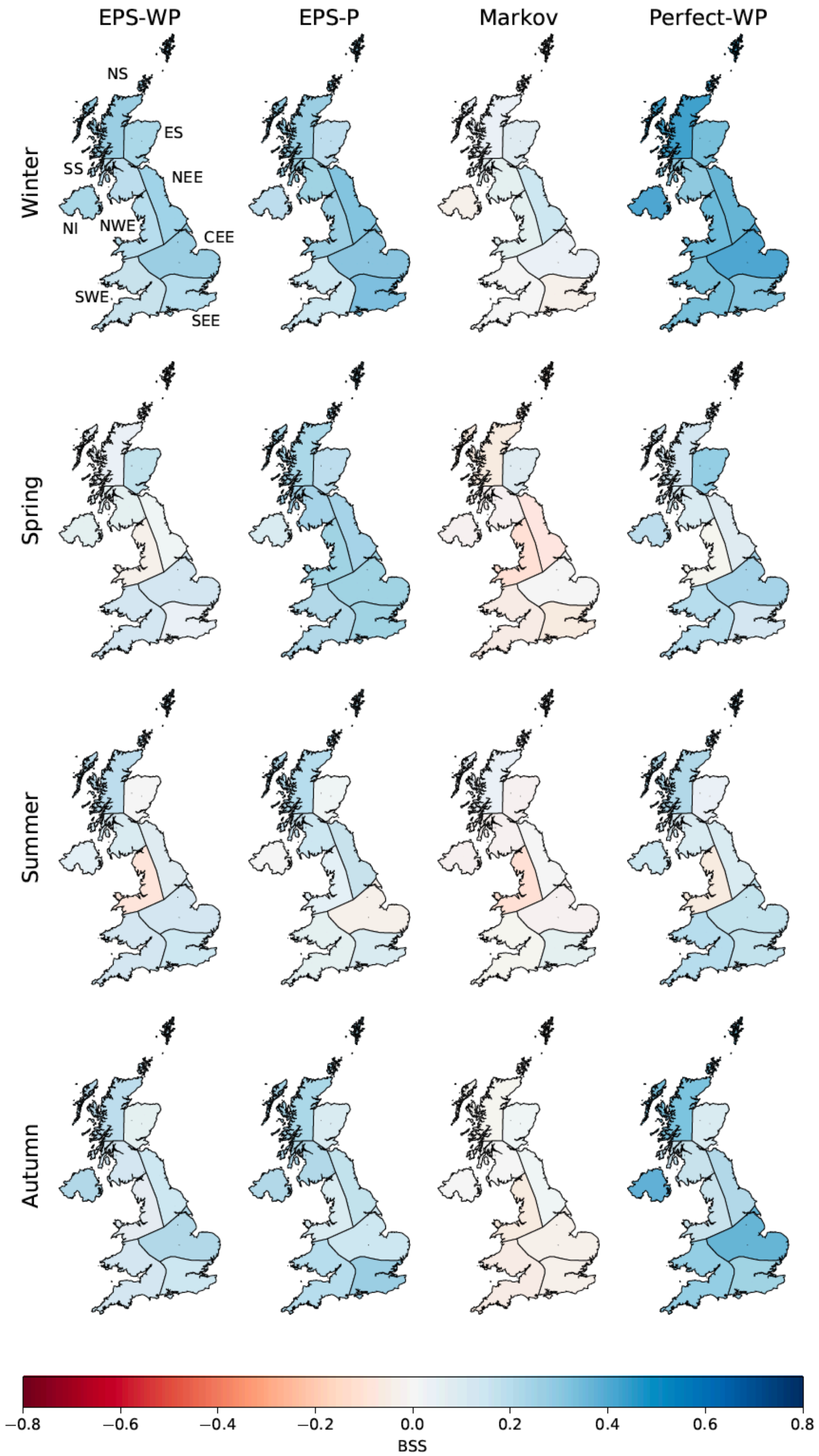
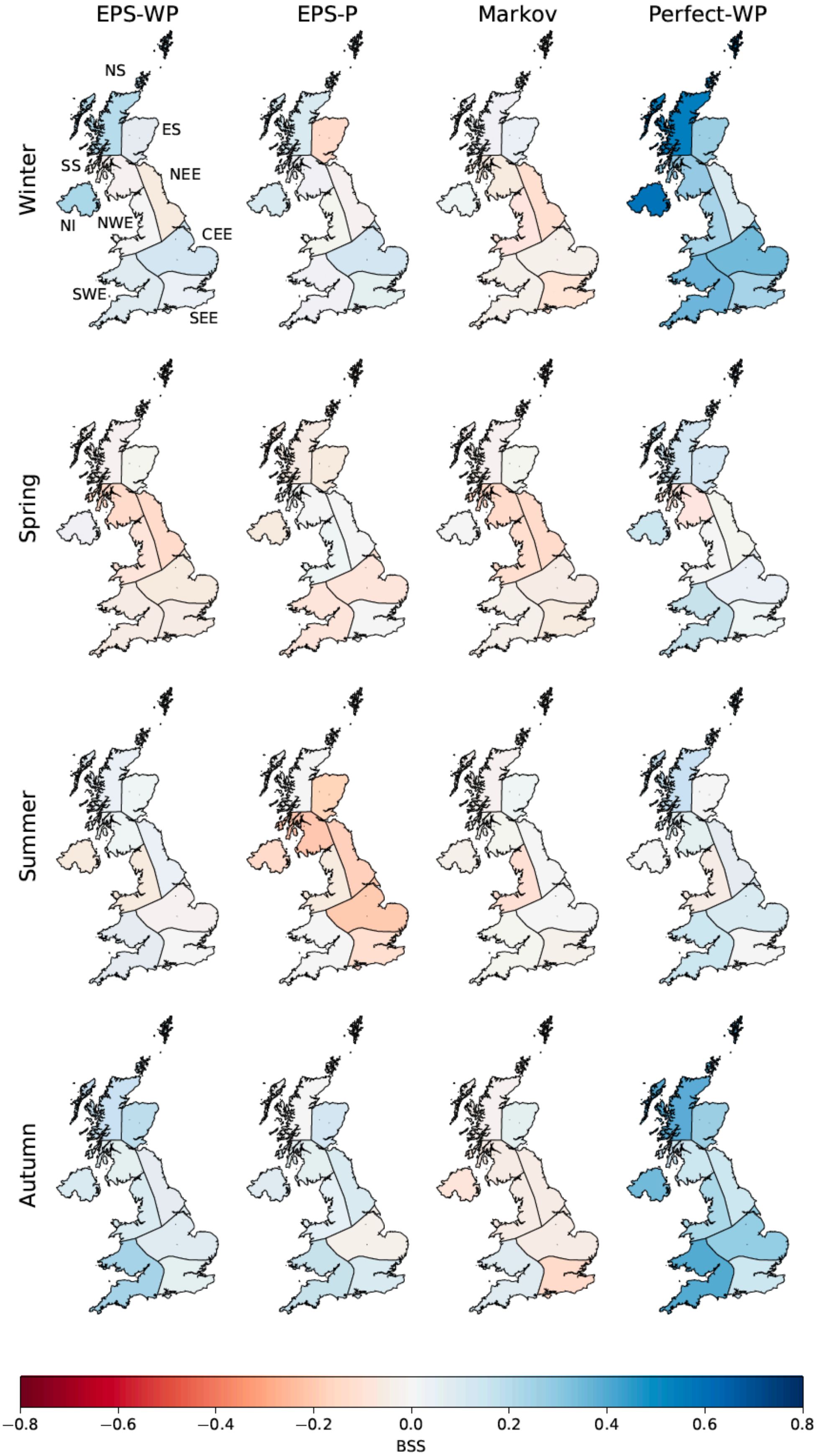


84 Figure 6: Brier skill scores (BSS) for mild drought (total precipitation below the 30.9th
85 percentile) for a 16-day lead-time for each model and season.



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87 Figure 7: As Figure 6 but for a 46-day lead.

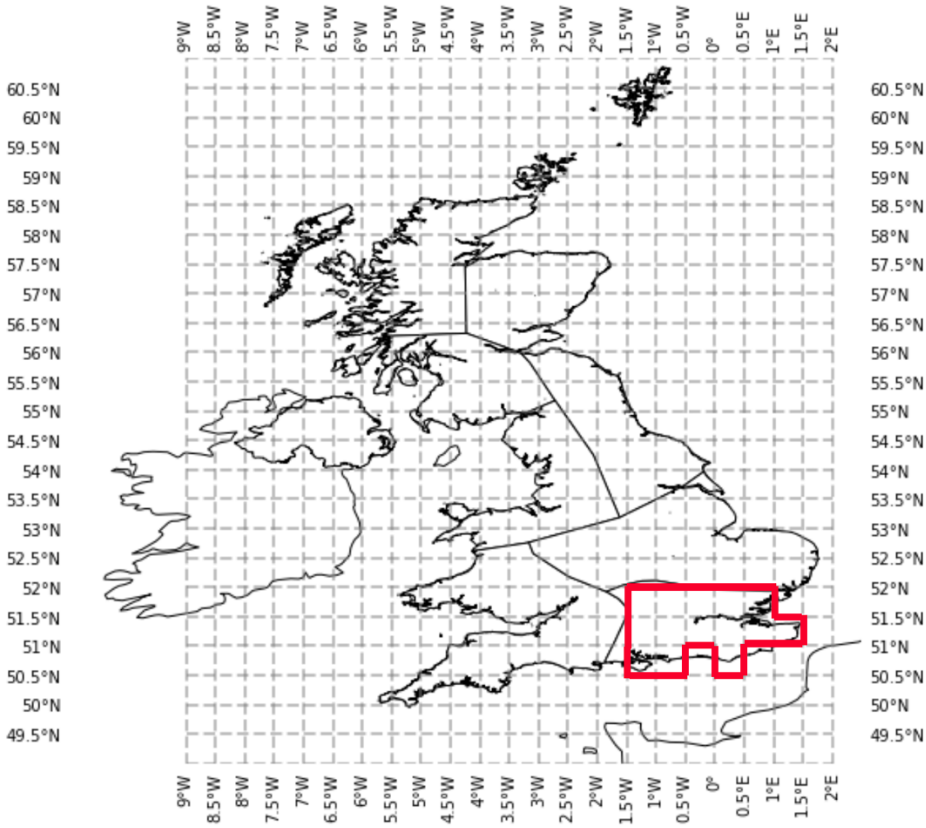

Figure S1: Schematic showing ECMWF-EPS precipitation forecast model grid, over the UK and HadUKP regions. The red box indicates the grid cells assigned to the region SEE using the cell centres.

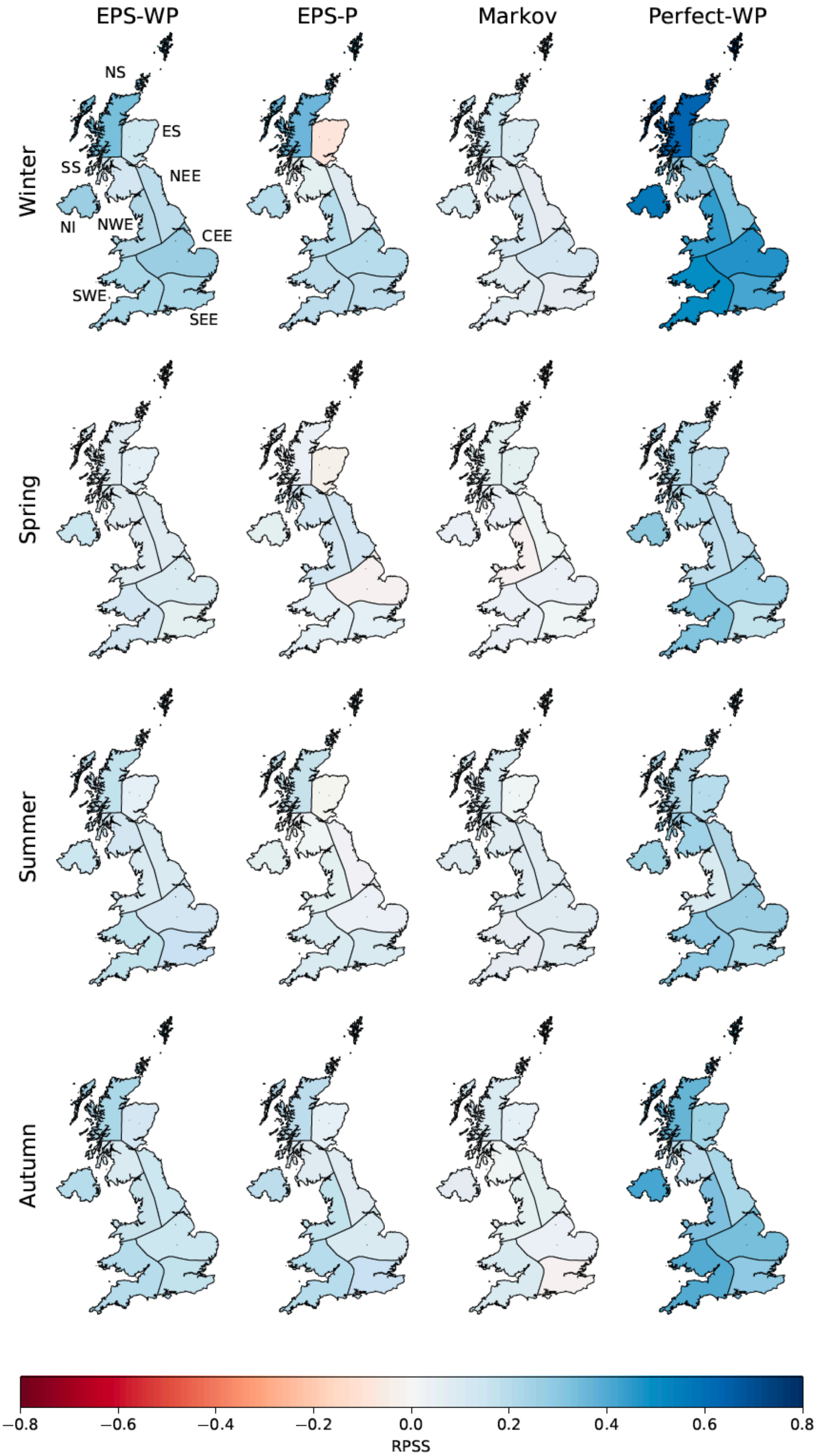

Figure S2: As Figure 4 but for a 31-day lead.

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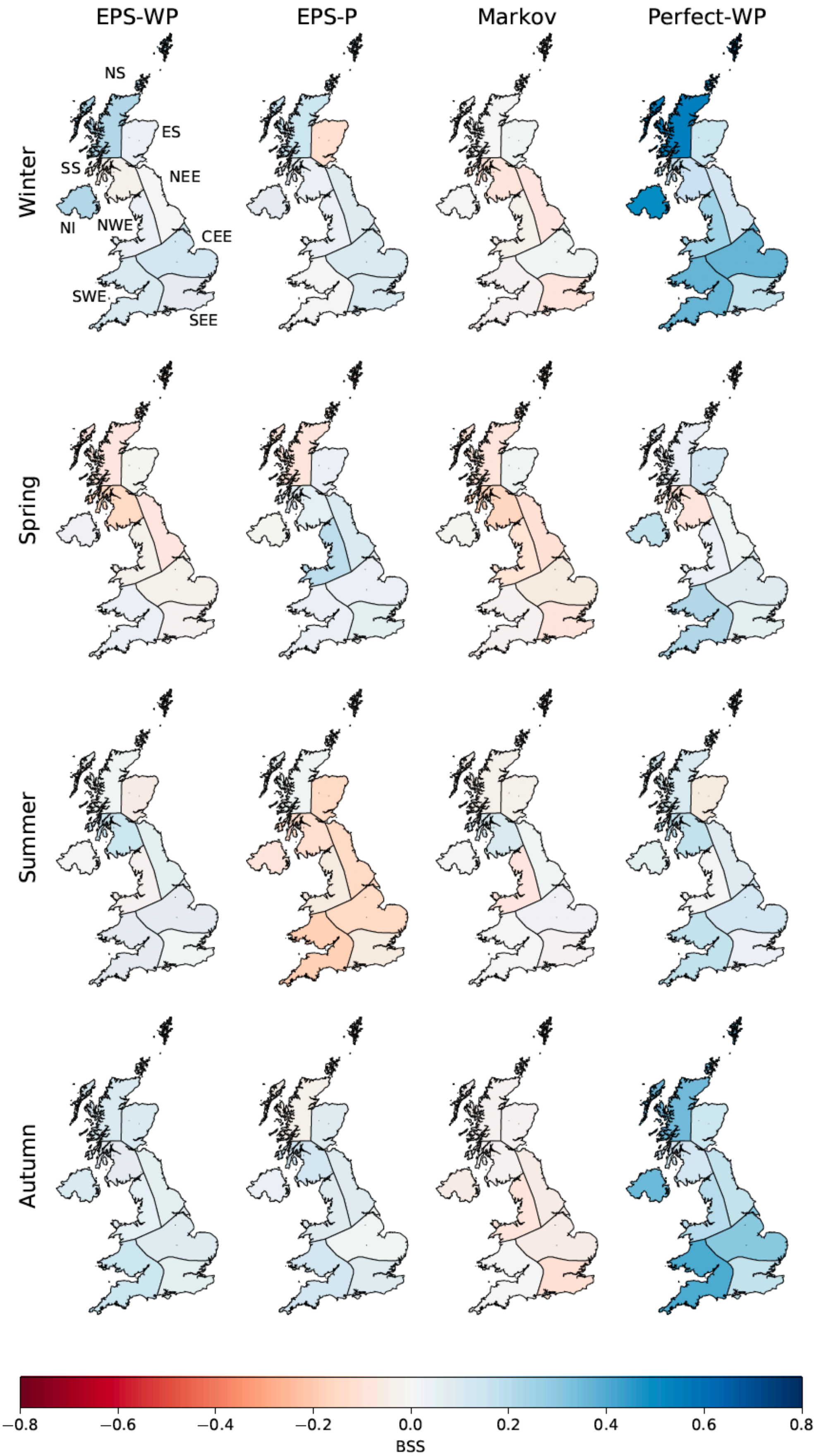

95 Figure S3: As Figure 6 but for a 31-day lead.