Supporting Information for "Improved seasonal prediction of European summer temperatures with new 5-layer soil-hydrology scheme"

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Introduction In order to supplement the results of the main article, we show one table and a few additional figures here. Figure S1 shows the anomaly correlation coefficients (ACCs) corresponding to those shown in Figure 1 but computed from the linearly detrended time series of JJA-mean 2-meter temperatures. Table S1 lists ACCs for different regions and periods. ACC maps for the sub-periods analysed in Table S1 are provided in Figure S2. In order to highlight the different soil behaviour of the two model configurations in spring 2003 we show the time series of the April soil moisture anomaly in Southern Europe for both model setups and reanalysis data (Fig. S3). We computed correlation coefficients presented in Figure 3 also for reanalysis data, and show the results and differences to the two model configurations in Figure S4.

The atmospheric blocking frequency yields an important index for European summer temperature anomalies [*Scherrer et al.*, 2006]. It is based on the 500 hPa geopotential height surface, which is evaluated in Figure 4. We supplement our findings here by showing ACCs and mean values of the atmospheric blocking frequency in Figures S5 and S6, respectively. Figure S5 shows a significant improvement in predicting blocking frequency anomalies when the 5-layer scheme is used. However, after evaluating the blocking frequency time series in a single grid cell (Fig. S7) we conclude that neither the mean value nor the correlation coefficient provides a robust measure for the quality of blocking frequency predictions.

In order to evaluate the impact of extreme events on ACCs obtained for the atmospheric blocking frequency and the 500 hPa geopotential height, we removed the years 2003 and 2006 from the time series and re-computed the respective ACC (Fig. S8, S9).

References

Goddard, L., A. Kumar, A. Solomon, D. Smith, G. Boer, P. Gonzalez, V. Kharin, W. Merryfield, C. Deser, S.J. Mason, et al. (2013), A verification framework for interannual-to-decadal predictions experiments, *Clim. Dyn.*, *40*(1-2), 245–272.

Scherrer, S. C., M. Croci-Maspoli, C. Schwierz, and C. Appenzeller (2006), Two-dimensional indices of atmospheric blocking and their statistical relationship with winter climate patterns in the euro-atlantic region, *Int. J. Climatol.*, *26*(2), 233–250.

Siegert, S., O. Bellprat, M. Ménégoz, D.B. Stephenson, and F.J. Doblas-Reyes, (2017), Detecting improvements in forecast correlation skill: Statistical testing and power analysis, *Mon. Weather Rev.*, *145*(2), 437–450.

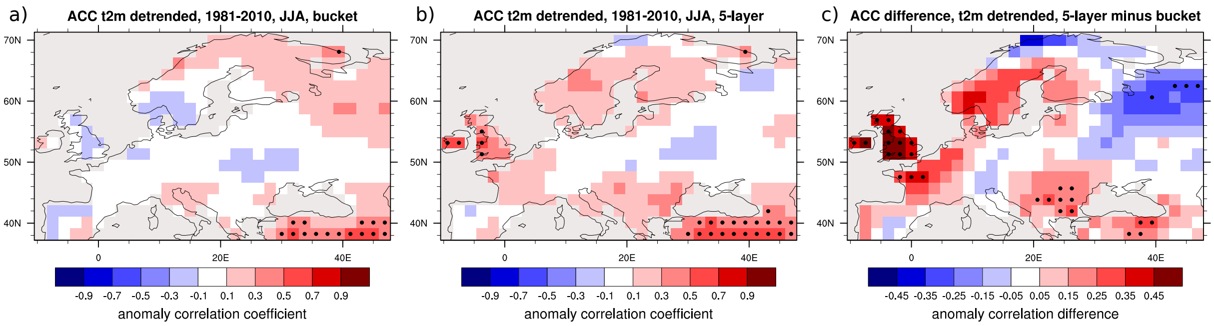

Figure S1. Anomaly correlation coefficients (ACCs) for detrended JJA-mean 2-meter air temperature over Europe, computed from the ensemble mean of seasonal hindcasts started each year on 1 May within 1981-2010 with respect to ERA-Interim reanalysis data. Results are shown for (a) the bucket soil scheme, and (b) the 5-layer soil-hydrology scheme. Dotted regions indicate significant ACCs at the 95%-level obtained from a distribution of 1000 re-sampled 10-member ensemble means [*Goddard et al.*, 2013]. (c) The ACC difference is depicted with significances computed after the modified Fisher transformation described by *Siegert et al.* [2017].

Table S1. Anomaly correlation coefficients (ACCs) for JJA-mean 2-meter temperatures in different regions and periods. For both bucket and 5-layer soil scheme ACCs were computed for averages over all land grid boxes in the regions Europe (-10° to 30°E, 38° to 70°N), Balkans (15° to 30°E, 40° to 48°N), and Scandinavia (5° to 30°E, 58° to 68°N), with ERA-Interim used as reference data. Numbers in brackets indicate for each ACC the standard deviation obtained after a bootstrap significance test [*Goddard et al.*, 2013]. Bold values show significant ACCs at the 95%-level.

	1981-2010		1981-1995		1996-2010	
Region	bucket	5-layer	bucket	5-layer	bucket	5-layer
Europe	**0.55** (0.04)	**0.64** (0.03)	0.28 (0.09)	0.25 (0.07)	0.34 (0.08)	**0.57** (0.06)
(detrended)	0.08 (0.07)	0.14 (0.06)	0.00 (0.10)	-0.10 (0.09)	0.18 (0.09)	0.43 (0.07)
Balkans	**0.40** (0.05)	**0.49** (0.04)	0.08 (0.07)	0.05 (0.08)	0.49 (0.06)	**0.63** (0.05)
(detrended)	0.06 (0.05)	0.19 (0.05)	-0.34 (0.07)	-0.34 (0.07)	0.41 (0.07)	**0.57** (0.05)
Scandinavia	0.28 (0.10)	**0.55** (0.07)	-0.05 (0.20)	0.03 (0.13)	0.14 (0.12)	**0.59** (0.12)
(detrended)	0.04 (0.12)	0.30 (0.10)	-0.05 (0.20)	-0.01 (0.14)	0.12 (0.13)	**0.68** (0.14)

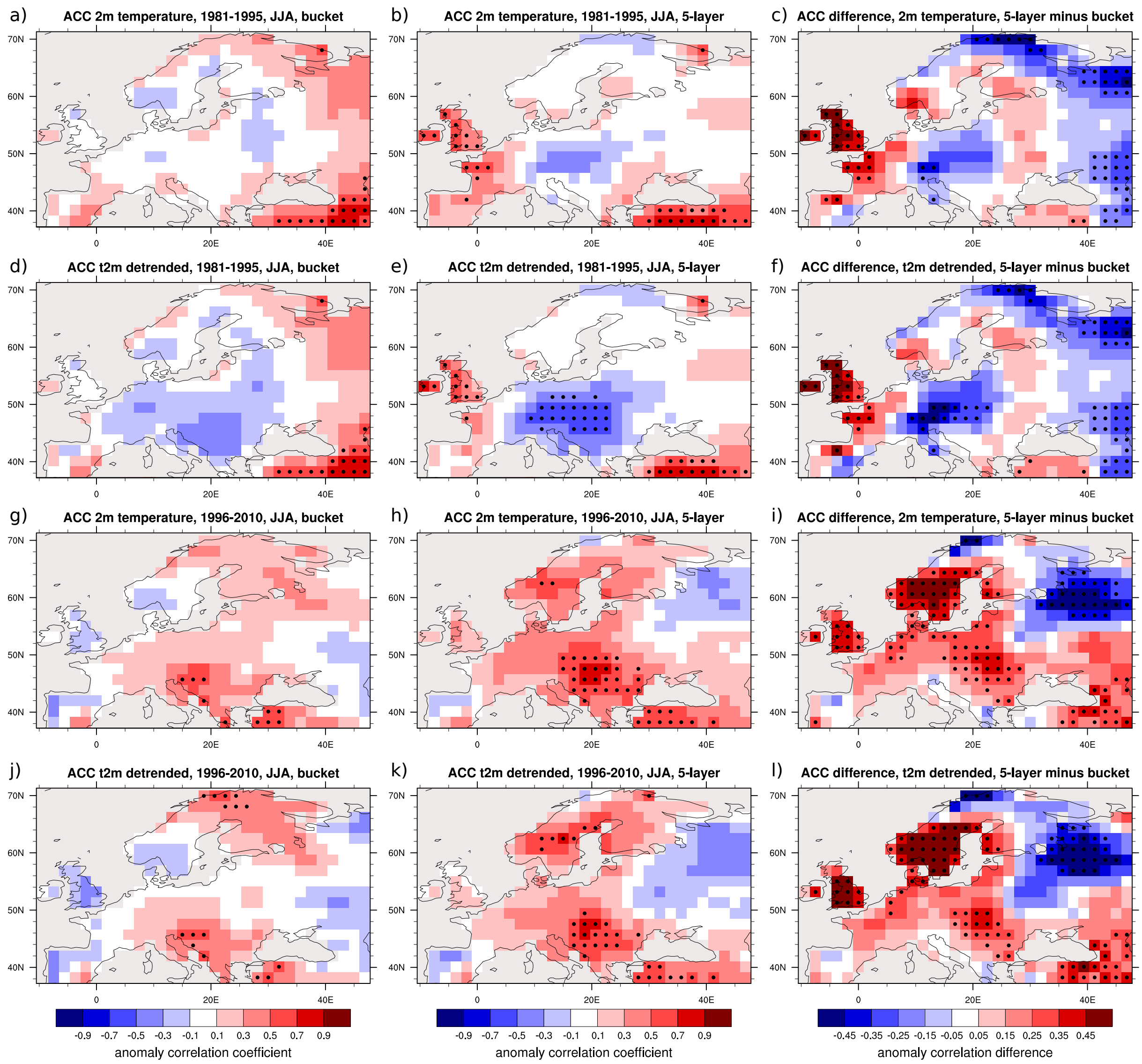

Figure S2. Anomaly correlation coefficients (ACCs) for JJA-mean 2-meter air temperature over Europe (a,b,g,h), computed from the ensemble mean of seasonal hindcasts started each year on 1 May within 1981-2010 with respect to ERA-Interim reanalysis data. ACCs computed from detrended time series are also presented (d,e,j,k). Dotted regions indicate significant ACCs at the 95%-level obtained from a distribution of 1000 re-sampled 10-member ensemble means [*Goddard et al.*, 2013]. Results are shown for the bucket soil scheme (left column), the 5-layer soil-hydrology scheme (center column), and its difference (right column). ACC differences are depicted with significances computed after the modified Fisher transformation described by *Siegert et al.* [2017] (c,f,i,l).

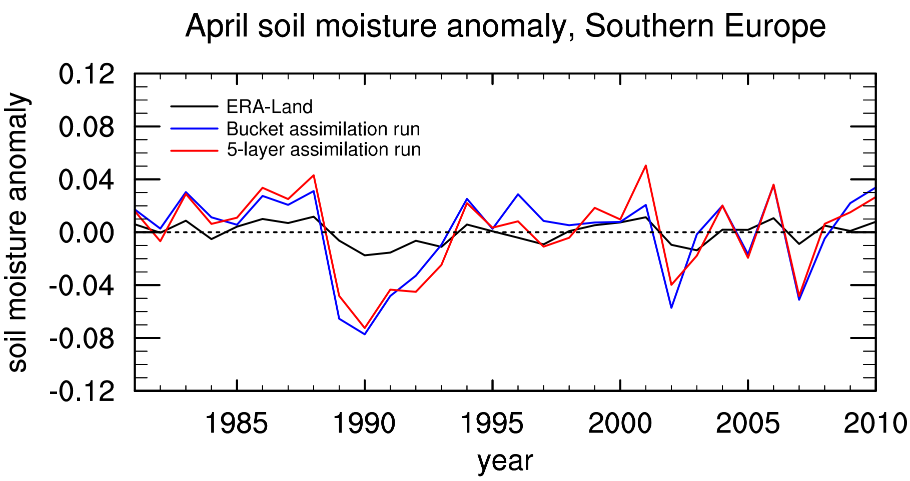

Figure S3. Time series of the April-mean soil moisture anomaly in Southern Europe (0° to 25°E, 42° to 52°N), as computed from the two assimilation runs performed with MPI-ESM differing only in the employed soil configuration (blue, red), and from ERA-Land reference data (black). For model simulations the root-zone soil moisture anomaly measured as the fraction of the maximum soil-water capacity is used. For ERA-Land reference data, the anomaly in soil water content in the uppermost 2.55m in m^3m^{-3} is used.

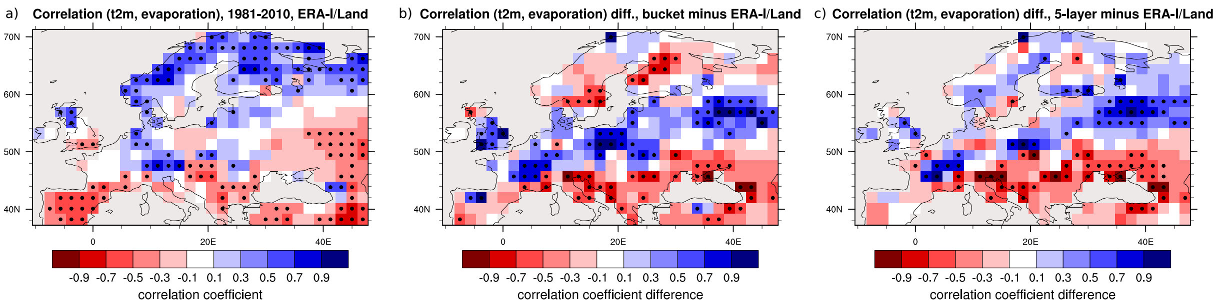

Figure S4. (a) The correlation coefficient between JJA-mean 2-meter air temperature and evapotranspiration computed from ERA-Interim/Land reanalysis data. The difference between correlation coefficients obtained with (b) the bucket soil scheme and (c) the 5-layer soil-hydrology scheme to correlation coefficients obtained from ERA-Interim/Land data is also shown. Dotted regions indicate significant correlation coefficients at the 95%-level obtained from a distribution of 1000 re-sampled 10-member ensemble means [*Goddard et al.*, 2013].

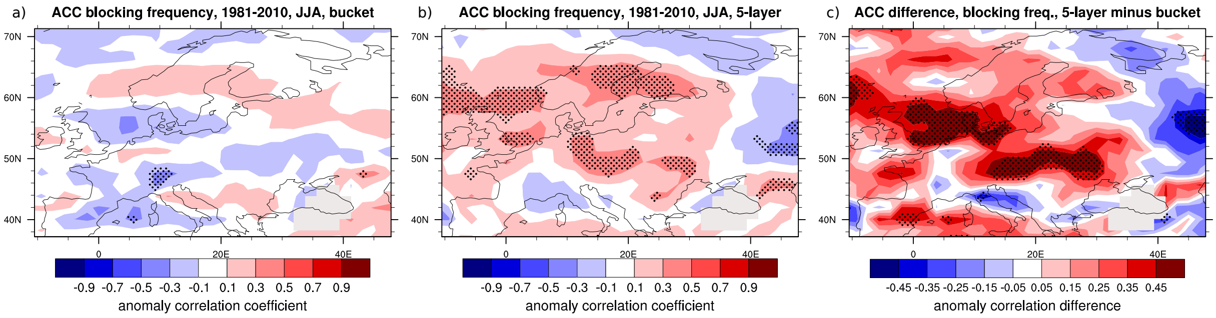

Figure S5. Anomaly correlation coefficients (ACCs) for ensemble-mean summer atmospheric blocking frequency over Europe as computed from hindcasts using (a) the bucket soil scheme and (b) the 5-layer soil scheme. ERA-Interim was used as reference data. The blocking frequency was computed after *Scherrer et al.* [2006]. Dotted regions indicate significant ACCs at the 95%-level obtained from a bootstrap significance test [*Goddard et al.*, 2013]. (c) The ACC difference is depicted with significances computed after the modified Fisher transformation described by *Siegert et al.* [2017].

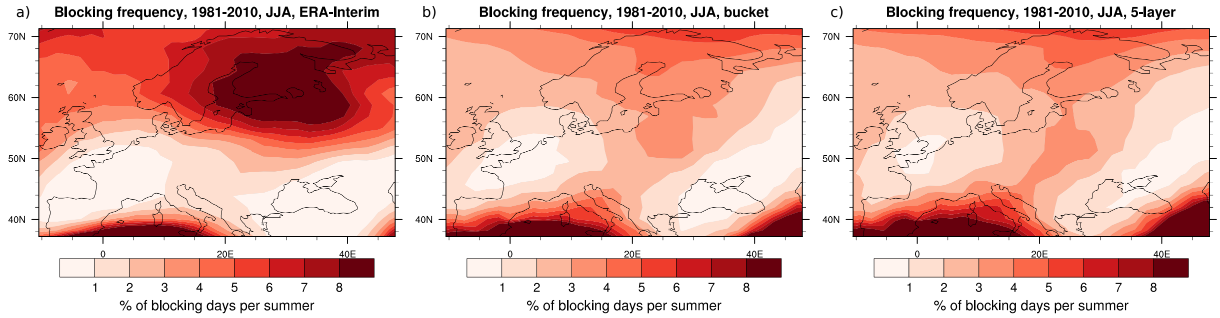

Figure S6. The atmospheric blocking frequency over Europe is shown for (a) ERA-Interim reference data and (b,c) the two hindcast sets (b: bucket soil scheme, c: 5-layer soil scheme) as the average over all summers within 1981-2010. The methodology of *Scherrer et al.* [2006] was used to compute blocking frequencies.

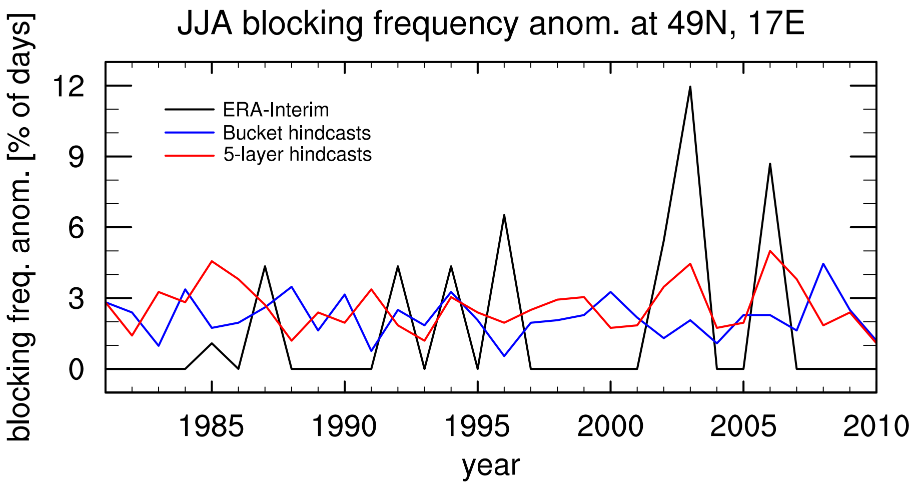

Figure S7. Time series of the JJA blocking frequency anomaly in a single grid cell at 49°N, 17°E for ERA-Interim reference data (black) and the two hindcast sets (blue, red). The methodology of *Scherrer et al.* [2006] was used to compute blocking frequencies.

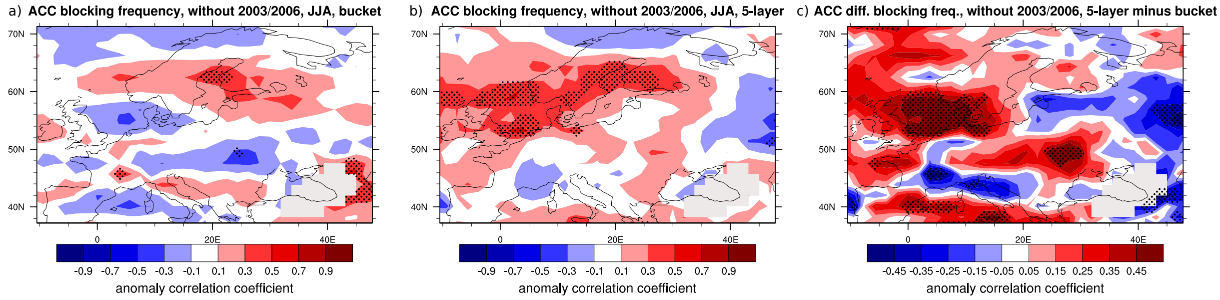

Figure S8. Anomaly correlation coefficients (ACCs) for ensemble-mean summer atmospheric blocking frequency over Europe as computed from hindcasts using (a) the bucket soil scheme and (b) the 5-layer soil scheme. Years 2003 and 2006 were removed from the original time series (1981-2010). ERA-Interim was used as reference data. The blocking frequency was computed after *Scherrer et al.* [2006]. Dotted regions indicate significant ACCs at the 95%-level obtained from a bootstrap significance test [*Goddard et al.*, 2013]. (c) The ACC difference is depicted with significances computed after the modified Fisher transformation described by *Siegert et al.* [2017].

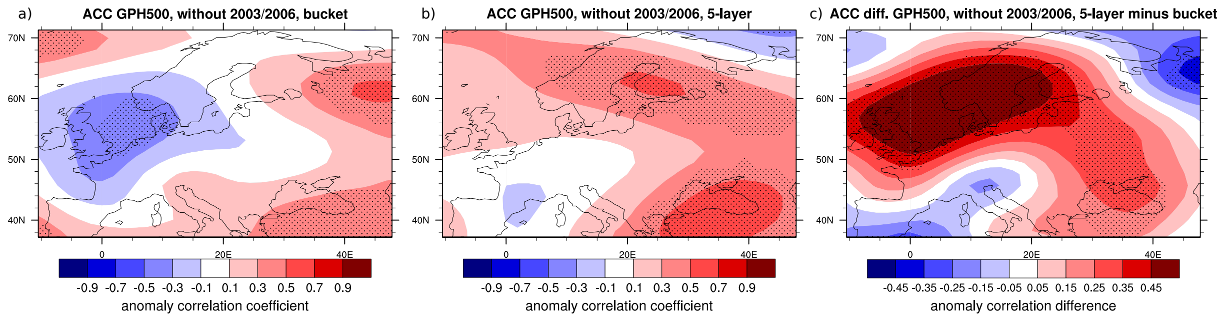

Figure S9. Anomaly correlation coefficients (ACCs) for ensemble-mean 500 hPa geopotential height over Europe as computed from hindcasts using (a) the bucket soil scheme and (b) the 5-layer soil scheme. Years 2003 and 2006 were removed from the original time series (1981-2010). ERA-Interim was used as reference data. Dotted regions indicate significant ACCs at the 95%-level obtained from a bootstrap significance test [*Goddard et al.*, 2013]. (c) The ACC difference is depicted with significances computed after the modified Fisher transformation described by *Siegert et al.* [2017].