

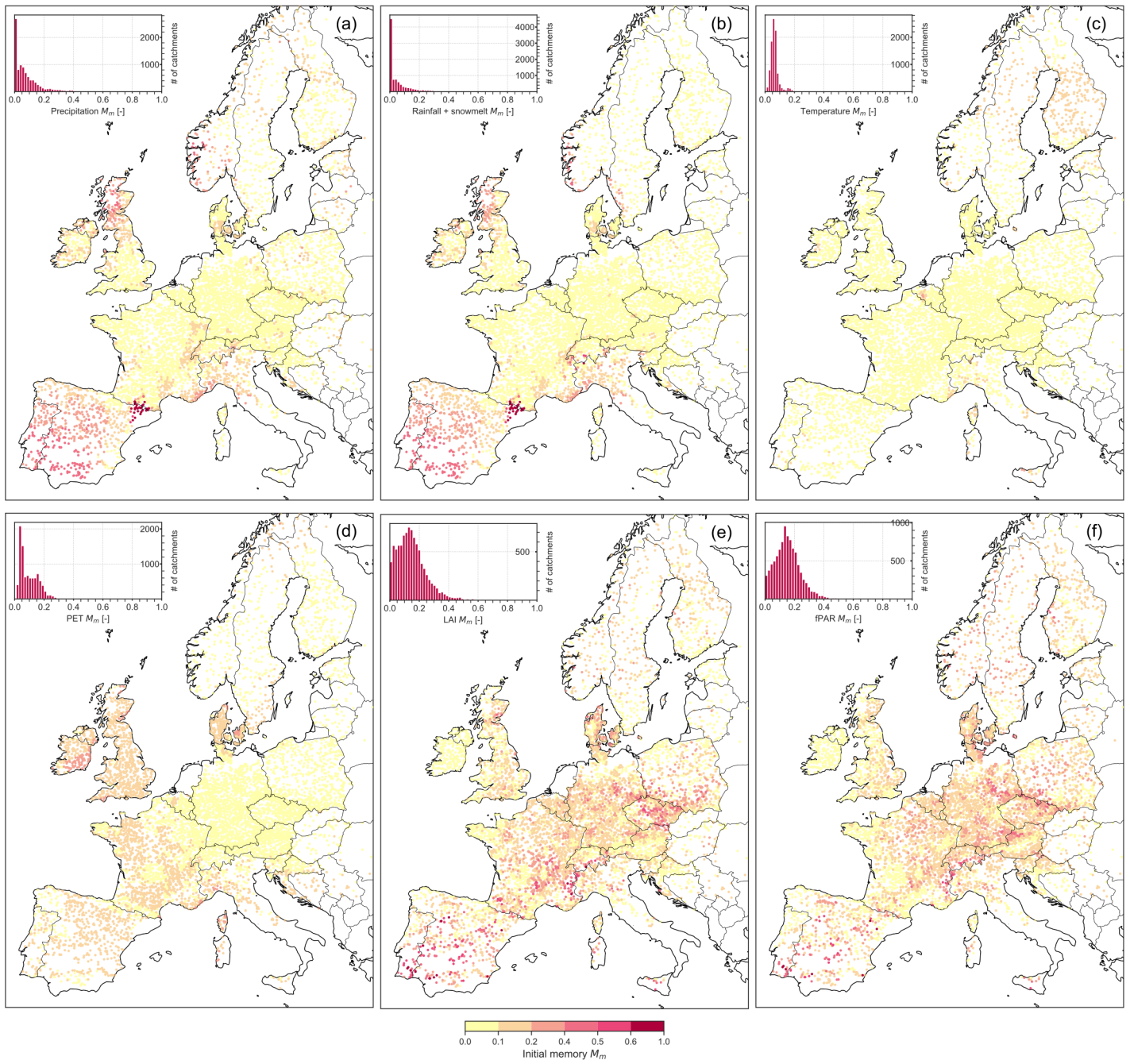
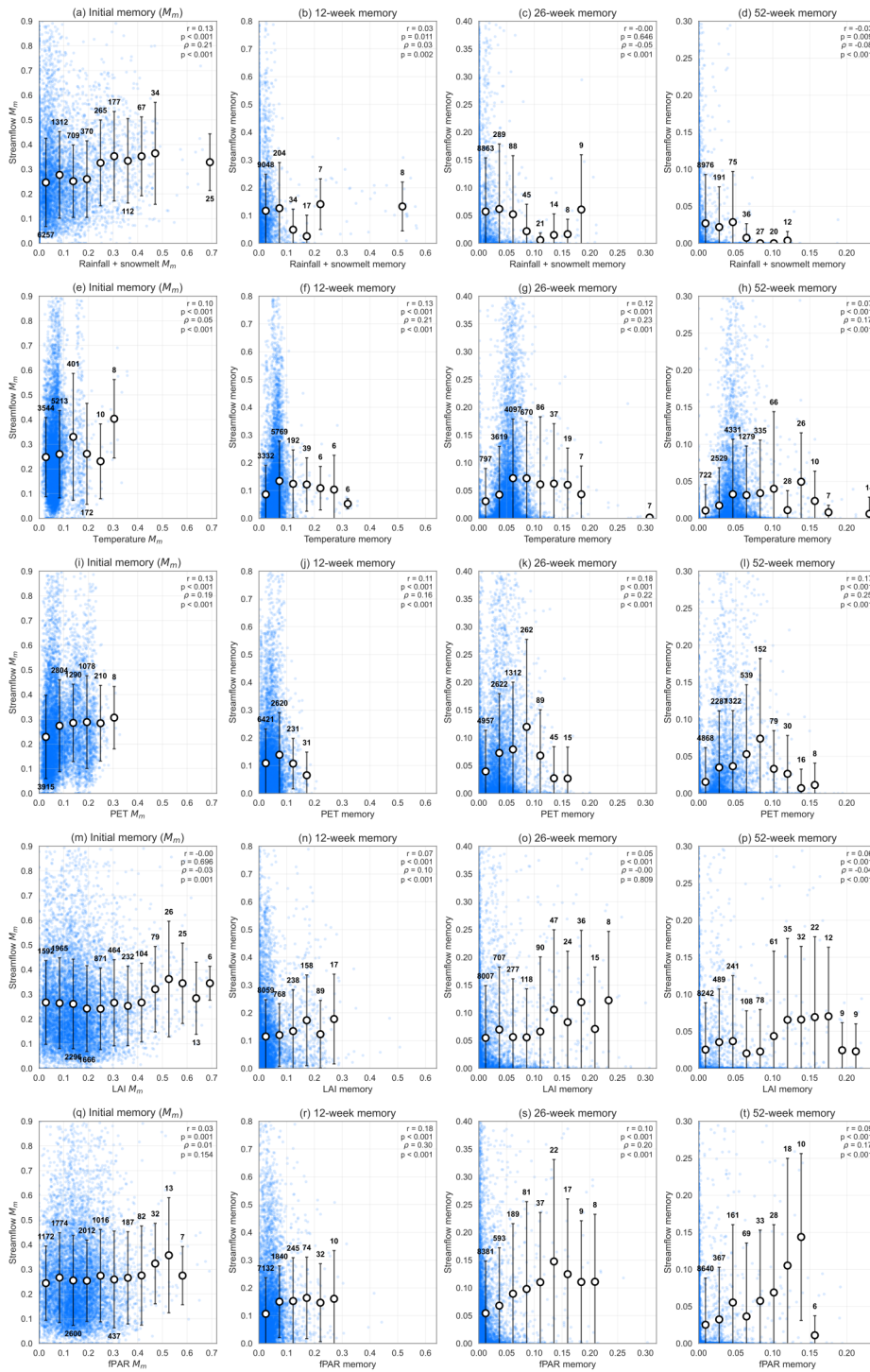


Figure S1 Initial memory (M_m) of precipitation (a), rainfall + snowmelt (b), temperature (c), potential evapotranspiration (d), LAI (e), and fPAR (f).



5 **Figure S2** Comparison of memory in climate and vegetation variables and streamflow memory at four different timescales. Correlation coefficients are calculated for non-binned data (shown in the background in blue). Markers show the mean streamflow memory values for each bin, whiskers show the standard deviation, and counts indicate the number of stations in each bin.

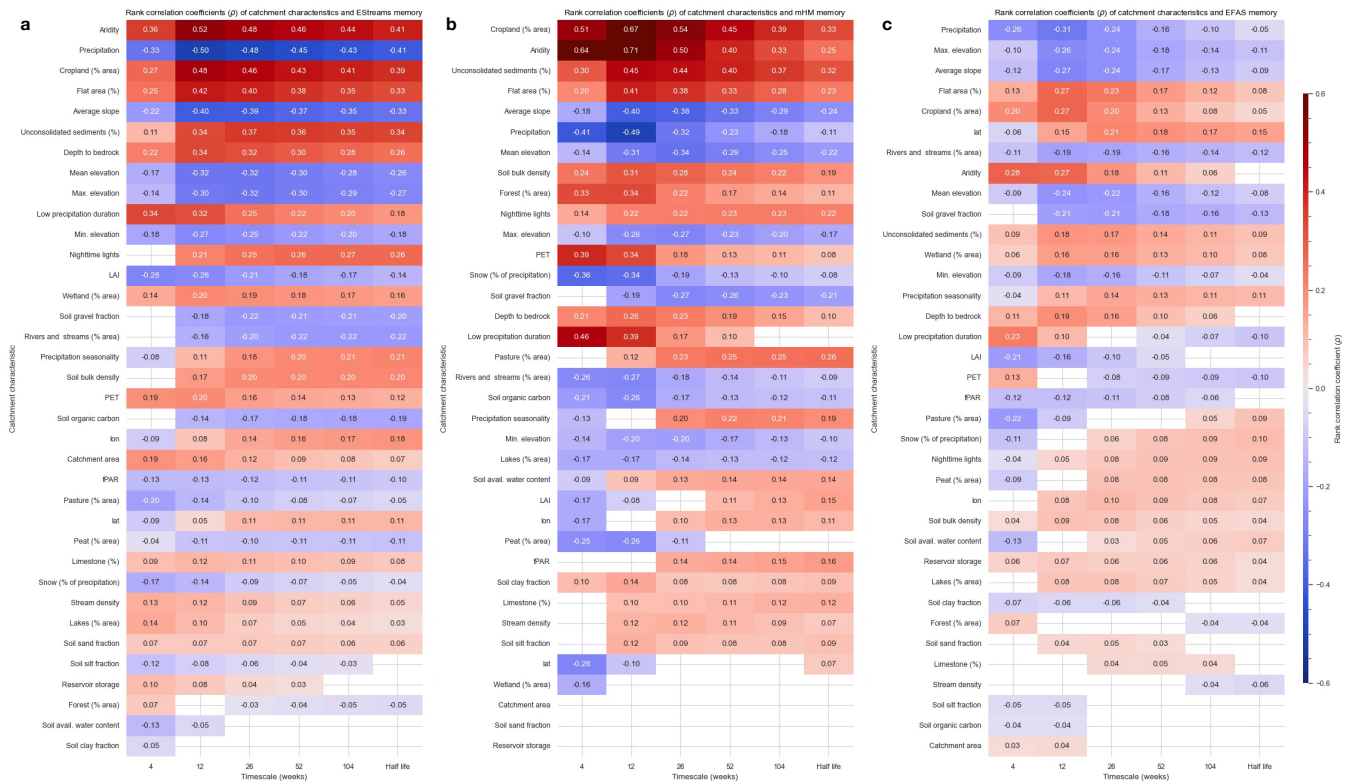


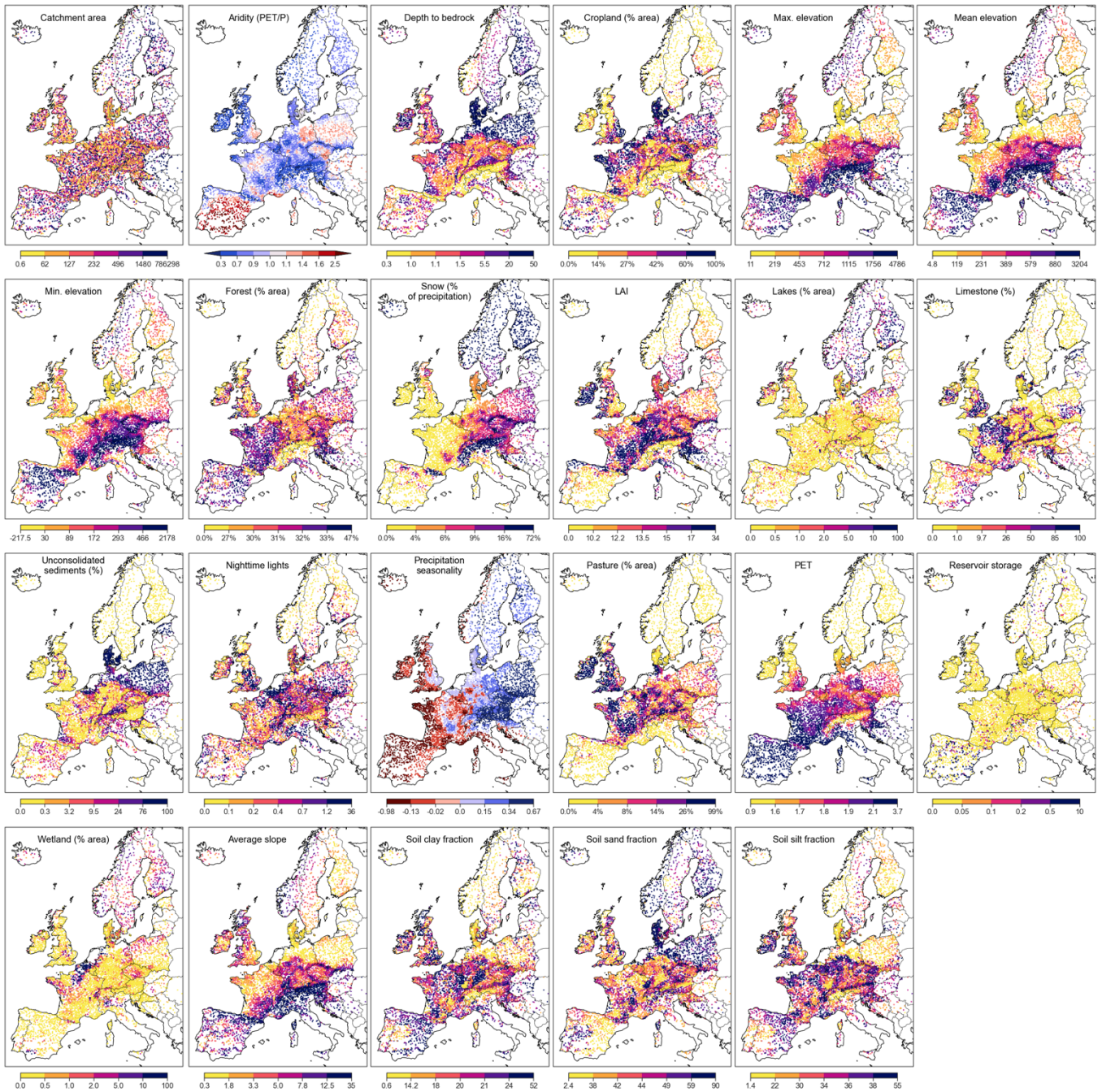
Figure S3 Rank correlation coefficients showing the relationship of streamflow memory from observations **(a)**, mHM **(b)**, and EFAS **(c)** at timescales of 4, 12, 26, 52, and 104 weeks, and half-life of streamflow memory, to different catchment characteristics. Blue shades indicate negative correlations, and red shades indicate positive correlations, with darker colours indicating stronger correlations. Correlations where significance $p \geq 0.01$ are not shown.

15 **Table S1 Description of features used for random forest model**

Variable	Description	Obtained from
Potential evapotranspiration	Mean daily potential evapotranspiration calculated using Penman-Monteith	EStreams
Aridity	Ratio between E_p and precipitation (E_p/P)	EStreams
Precipitation seasonality	Seasonality ranging from -1 (highly seasonal, cold season dominated) to 1 (highly seasonal, warm season dominated), where a value of 0 indicates uniform precipitation	EStreams
Snow fraction	Fraction of precipitation falling on days with a temperature below 0°C	EStreams
Limestone fraction	Combined fractional extent of ‘Limestones’, ‘Limestones and marls’, ‘Limestones and clays’, and ‘Limestones and sands’ from Level 3 of the International Hydrogeological Map of Europe (IHME) (Duscher et al., 2015)	EStreams
Depth to bedrock	Thickness of permeable layers above bedrock (Pelletier et al., 2016)	EStreams
Soil PC	PCA combination of sand, silt, and clay fraction of soil from European Soil Database Derived data (ESDD) (Hiederer, 2013)	EStreams
Unconsolidated sediments	Fraction of catchment classified as ‘unconsolidated sediments’ from the first level classification of the Global Lithological Map Database (GLiM) (Hartmann and Moosdorf, 2012)	EStreams
LAI	Average catchment LAI from 2002-2021(Myneni et al., 2021)	MODIS
Cropland	Average catchment fraction of cropland (classes 211, 212, 213, 221, 222, 223, 241, 242, 243, 244) for the years 1990, 2000, 2006, 2012, and 2018 from CORINE land cover inventory (2020)	EStreams
Pasture	Average catchment fraction of pasture and grassland (class 231) for the years 1990, 2000, 2006, 2012, and 2018 from CORINE land cover inventory (2020)	EStreams
Forest	Average catchment fraction of forest and shrub cover (classes 311, 312, 313, 322, 323, 324) for the years 1990, 2000, 2006, 2012, and 2018 from CORINE land cover inventory (2020)	EStreams
Elevation PC	PCA combination of catchment mean, minimum, and maximum catchment elevation and average catchment slope from MERIT-Hydro (Yamazaki et al., 2017)	EStreams
Catchment area	Area delineated by EStreams catchment	EStreams
Lakes	Combined fractional coverage of lake, reservoir, saline lake, uncategorized permanent water, and lacustrine floodplain classes (Lehner et al., 2025)	GLWD v2
Wetlands	Combined fractional coverage of all seasonally saturated, palustrine, and ephemeral wetland classes (Lehner et al., 2025)	GLWD v2
Nightlights	Mean catchment nighttime light intensity for the years 2013—2021, as a measure of anthropogenic influence (Elvidge et al., 2021)	VIIRS
Reservoir capacity	Total storage capacity of all upstream reservoirs (Wang et al., 2022) as a fraction of mean annual river discharge. We capped values at 10x annual discharge.	EStreams

Table S2 Parameters for streamflow memory prediction

	Monthly	Seasonal	Half-yearly	Yearly
Maximum depth	20	None	20	None
Min. leaf samples	2	2	2	2
Min. split samples	2	2	2	5



20 **Figure S4** Maps of all catchment characteristics used in random forest models.

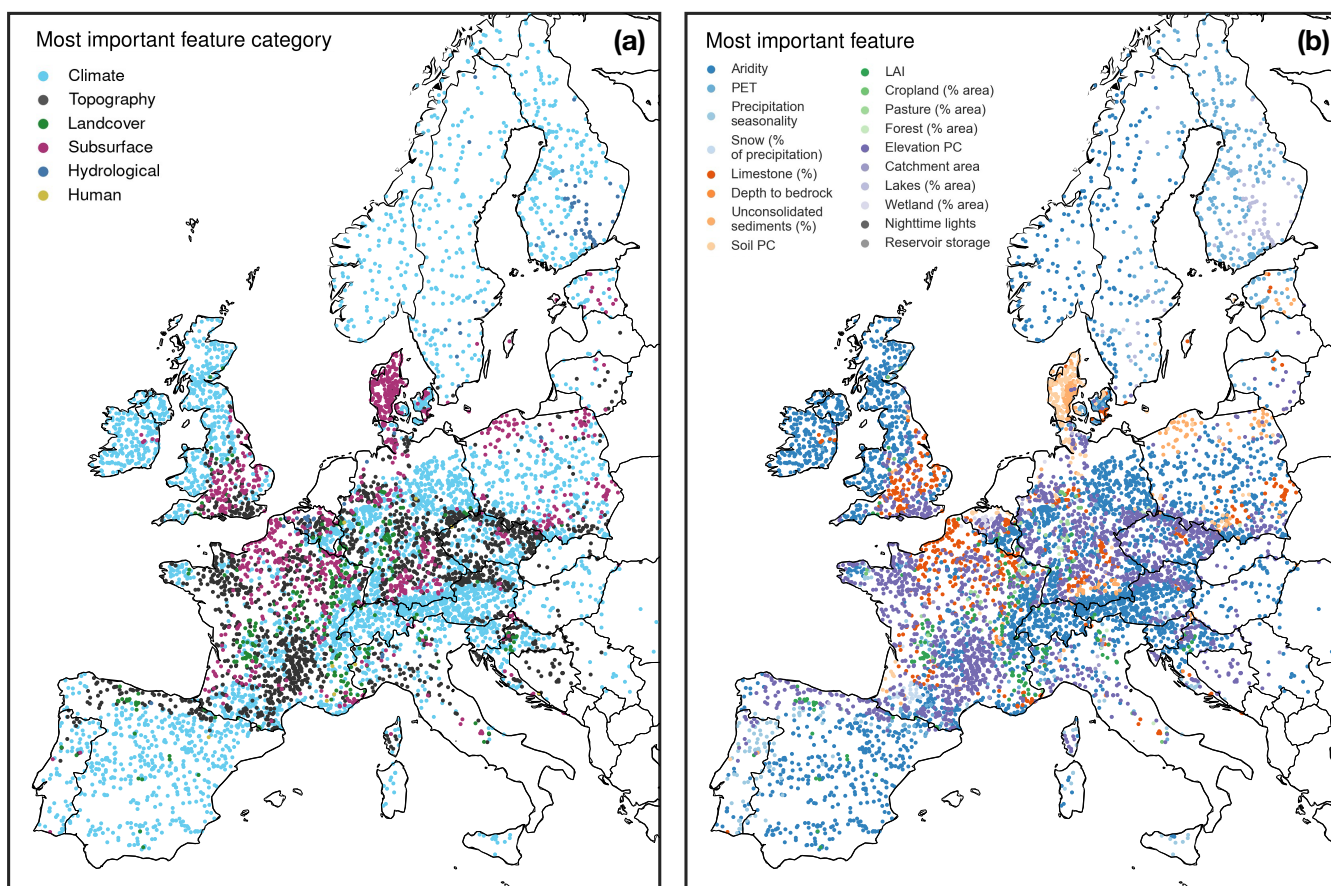


Figure S5 Feature categories (a) and individual features (b) which are most frequently ranked as the top contributor to streamflow memory for each catchment based on Shapley values. Catchments without a single dominant category or feature are not displayed.

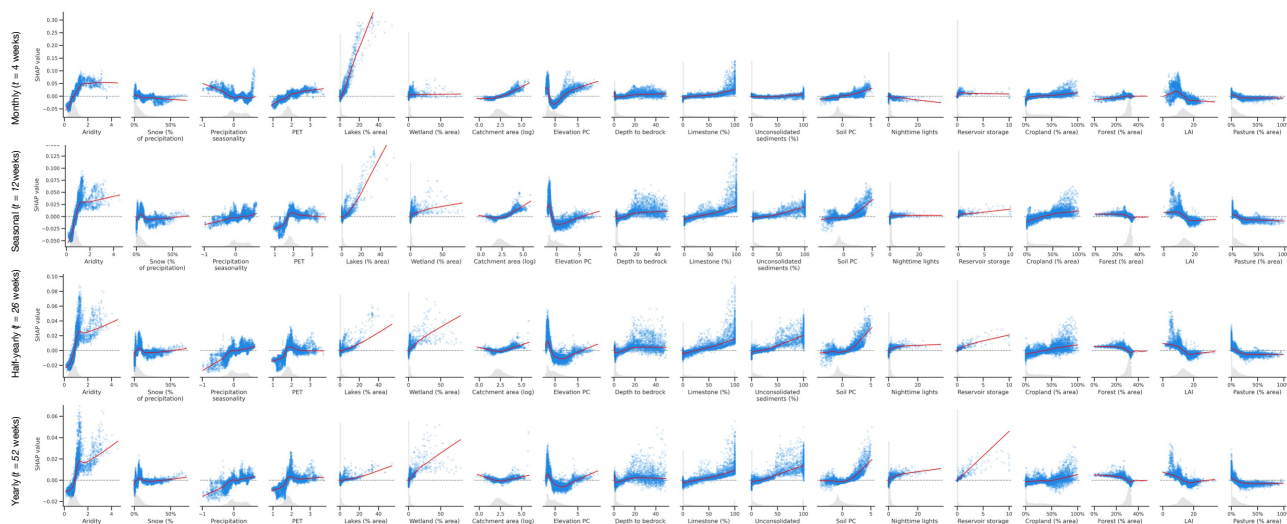


Figure S6 Distribution of Shapley values for all features. Each row corresponds to one timescale of memory, and each column contains one feature. These plots demonstrate the marginal contribution of each feature to memory predictions at each station, overlaid with a lowess moving regression in red, demonstrating the often non-linear and sometimes non-monotonic relationships between catchment characteristics and streamflow memory predictions.

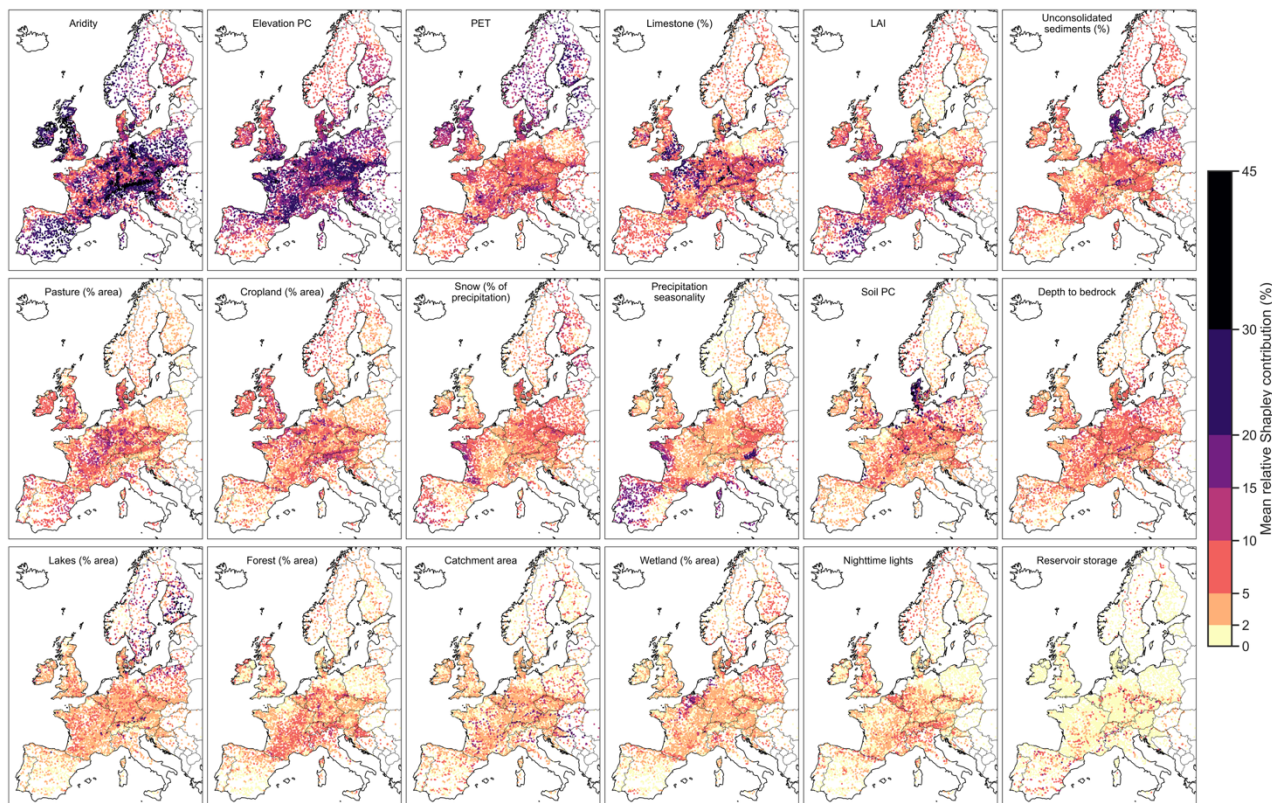


Figure S7 Maps indicating the mean relative Shapley contribution of each feature to memory predictions at monthly, seasonal, half-yearly, and yearly timescales.

35 References

- CORINE Land Cover, European Union's Copernicus Land Monitoring Service information [dataset], 2020.
- Duscher, K., Günther, A., Richts, A., Clos, P., Philipp, U., and Struckmeier, W.: The GIS layers of the “International Hydrogeological Map of Europe 1: 1,500,000” in a vector format, *Hydrogeology journal*, 23, 1867-1875, <https://doi.org/10.1007/s10040-015-1296-4>, 2015.
- 40 Elvidge, C. D., Zhizhin, M., Ghosh, T., Hsu, F.-C., and Taneja, J.: Annual Time Series of Global VIIRS Nighttime Lights Derived from Monthly Averages: 2012 to 2019, *Remote Sensing*, 13, 922, <https://doi.org/10.3390/rs13050922>, 2021.
- Hartmann, J. and Moosdorf, N.: The new global lithological map database GLiM: A representation of rock properties at the Earth surface, *Geochemistry, Geophysics, Geosystems*, 13, <https://doi.org/10.1029/2012GC004370>, 2012.
- Hiederer, R.: Mapping soil properties for Europe – Spatial representation of soil database attributes, 45 <https://doi.org/doi/10.2788/94128>, 2013.
- Lehner, B., Anand, M., Fluet-Chouinard, E., Tan, F., Aires, F., Allen, G. H., Bousquet, P., Canadell, J. G., Davidson, N., Ding, M., Finlayson, C. M., Gumbricht, T., Hilarides, L., Hugelius, G., Jackson, R. B., Korver, M. C., Liu, L., McIntyre, P. B., Nagy, S., Olefeldt, D., Pavelsky, T. M., Pekel, J. F., Poulter, B., Prigent, C., Wang, J., Worthington, T. A., Yamazaki, D., Zhang, X., and Thieme, M.: Mapping the world's inland surface waters: an upgrade to the Global Lakes and Wetlands Database (GLWD 50 v2), *Earth Syst. Sci. Data*, 17, 2277-2329, <https://doi.org/10.5194/essd-17-2277-2025>, 2025.
- Myneni, R., Knyazikhin, Y., and Park, T.: MODIS/Terra+Aqua Leaf Area Index/FPAR 4-Day L4 Global 500m SIN Grid V061, NASA Land Processes Distributed Active Archive Center [dataset], <https://doi.org/10.5067/MODIS/MCD15A3H.061>, 2021.
- Pelletier, J. D., Broxton, P. D., Hazenberg, P., Zeng, X., Troch, P. A., Niu, G.-Y., Williams, Z., Brunke, M. A., and Gochis, 55 D.: A gridded global data set of soil, intact regolith, and sedimentary deposit thicknesses for regional and global land surface modeling, *Journal of Advances in Modeling Earth Systems*, 8, 41-65, <https://doi.org/10.1002/2015MS000526>, 2016.
- Wang, J., Walter, B. A., Yao, F., Song, C., Ding, M., Maroof, A. S., Zhu, J., Fan, C., McAlister, J. M., Sikder, S., Sheng, Y., Allen, G. H., Crétau, J. F., and Wada, Y.: GeoDAR: georeferenced global dams and reservoirs dataset for bridging attributes and geolocations, *Earth Syst. Sci. Data*, 14, 1869-1899, doi.org/10.5194/essd-14-1869-2022, 2022.
- 60 Yamazaki, D., Ikeshima, D., Tawatari, R., Yamaguchi, T., O'Loughlin, F., Neal, J. C., Sampson, C. C., Kanae, S., and Bates, P. D.: A high-accuracy map of global terrain elevations, *Geophys Res Lett*, 44, 5844-5853, <https://doi.org/10.1002/2017GL072874>, 2017.