AGU PUBLICATIONS

Water Resources Research

Supporting Information for

A precipitation recycling network to assess freshwater vulnerability:

Challenging the watershed convention

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Introduction

This supporting information provides additional information on the watersheds used in this study (Figures S1-S3), the methodology (Figures S3-S4, Tables S1-S2), data sets (Figure S5-S6) and figures that support our results (Figures S7-S15).

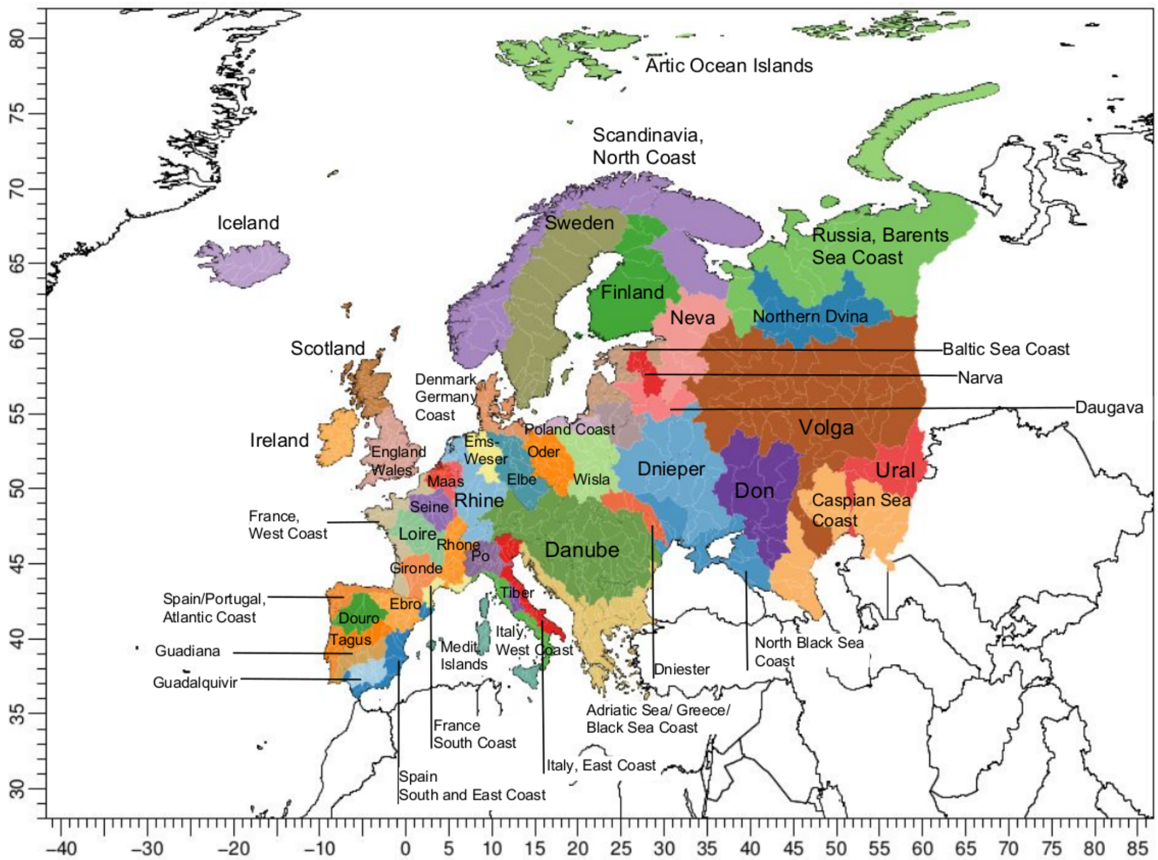

Figure S1. The 51 major basins defined by the FAO, based on data from HydroSHEDS (Lehner et al., 2006). All major basins, except for the Arctic Ocean Islands, are used in this study.

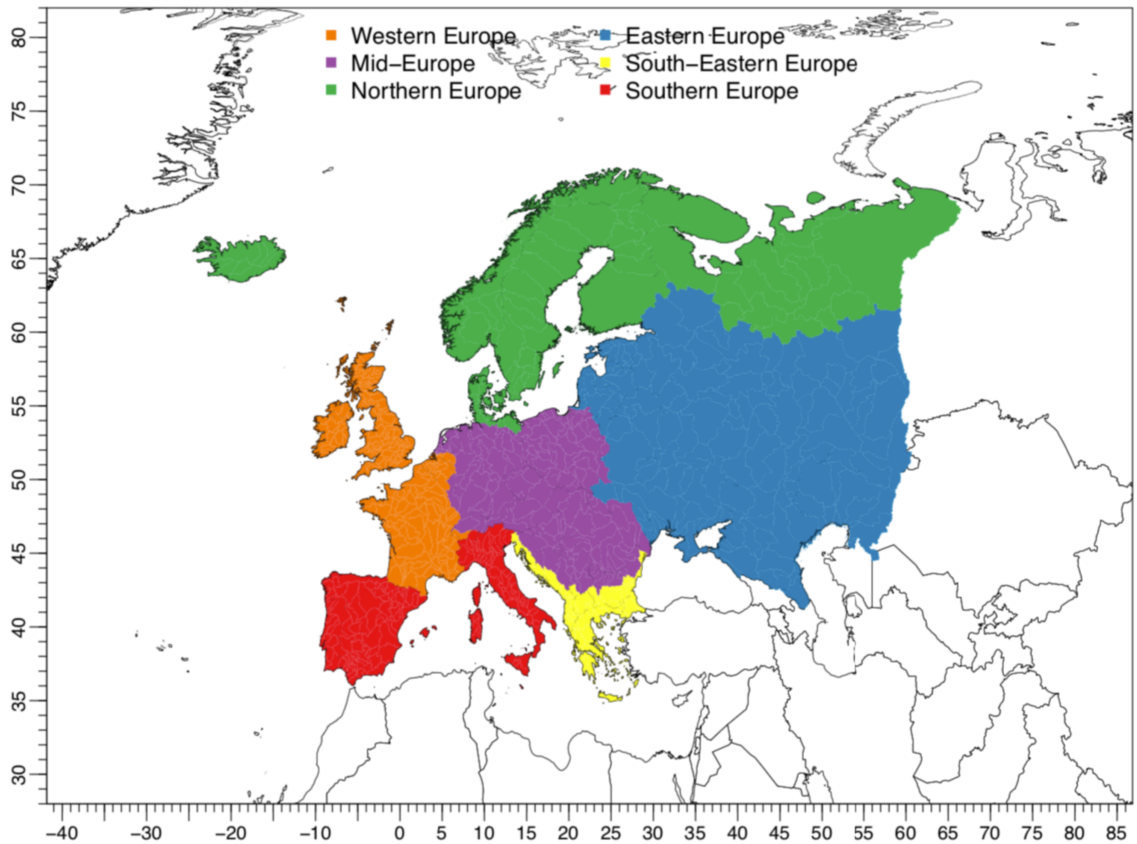

Figure S2. Attribution of watersheds to the 6 geographical regions used in this study, as used in Figure 2.

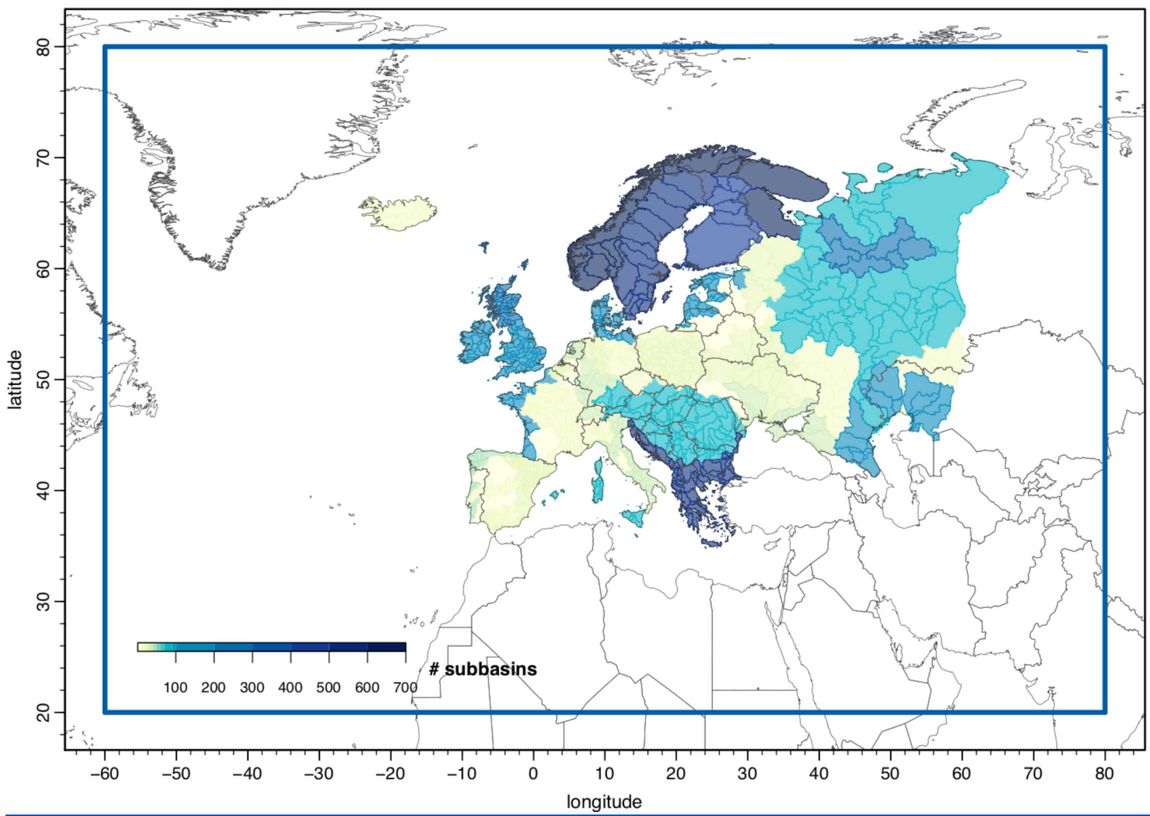

Figure S3. Nested FLEXPART-ERA-Interim modeling domain from 60°W to 80°E and from 20°N to 80°N. The colors indicate the number of sub-basins contained in the 50 major basins used in this study.

COMMAND	
1	FORWARD RUN
10800	INPUT TIME STEP IN S
10800	OUTPUT TIME STEP IN S
900	SAMPLING TIME STEP
900	SYNC
2.0	CTL
4	IFINE
1	IOUT
1	IPOUT
1	LSUBGRID
1	LCONVECTION
0	LAGESPECTRA
0	IPIN
1	IOFR
0	IFLUX
1	MDOMAINFILL
1	IND_SOURCE
1	IND_RECEPTOR
0	MQUASILAG
0	NESTED_OUTPUT
0	LINIT_COND
RELEASES	
1	TOTAL NUMBER OF SPECIES EMITTED
19791215 0000000	BEGINNING DATE AND TIME OF RELEASE
19791215 0000000	END DATE AND TIME OF RELEASE
-60	LONGITUDE OF LOWER LEFT CORNER
20	LATITUDE OF LOWER LEFT CORNER
80	LONGITUDE OF UPPER RIGHT CORNER
80	LATITUDE OF UPPER RIGHT CORNER
2	1 FOR M ABOVE GROUND; 2 FOR M ABOVE SEA LEVEL
0	LOWER Z-LEVEL (IN M AGL OR M ASL)
10000	UPPER Z-LEVEL (IN M AGL OR M ASL)
2000000	TOTAL NUMBER OF PARTICLES TO BE RELEASED

Table S1. FLEXPART namelist settings.

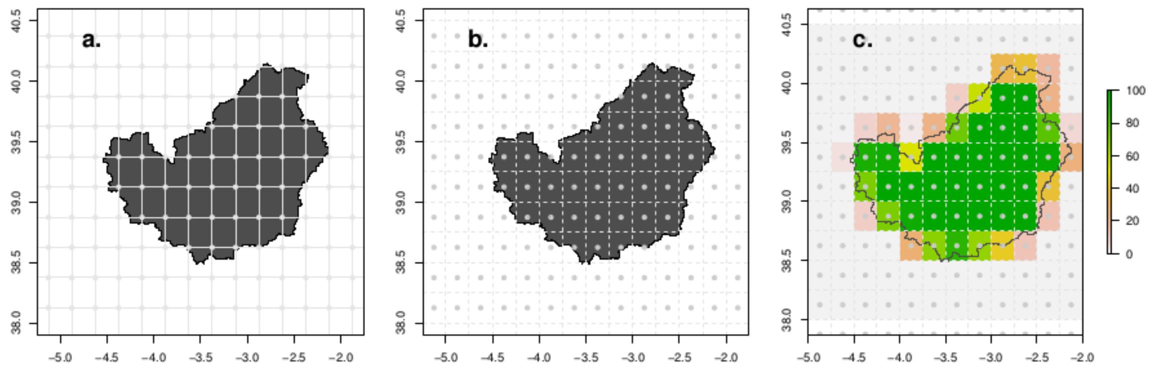

Figure S4. Sketch of the watershed aggregation of observations. (a) shows the watershed delineations and the grid and grid points from the underlying dataset; (b) shows the representative grid cell area of each grid point from (a); and (c) shows the percentage of each grid cell area that is covered by the watershed and attributed to the grid point. The percentages from (c) are used to calculate the watershed averages of precipitation and evaporation.

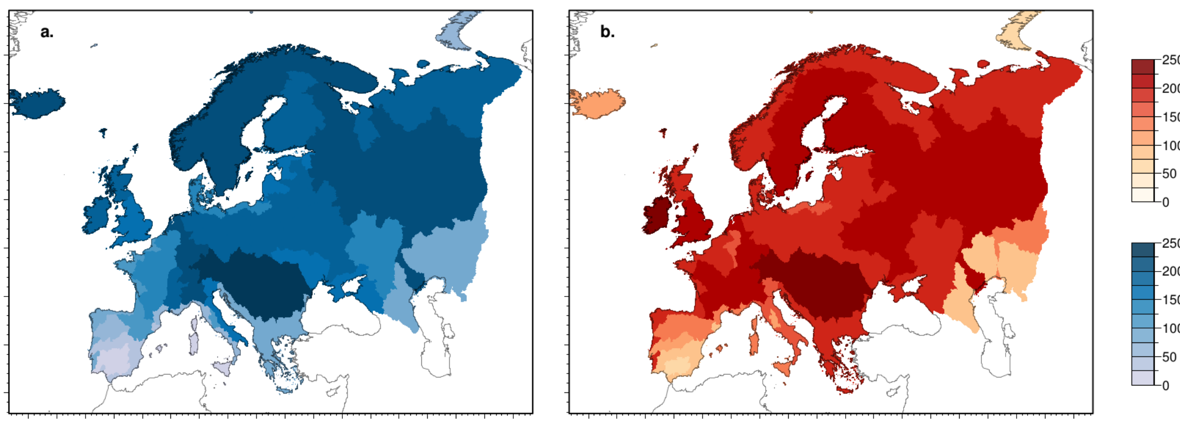

Figure S5. Climatological (1980–2016) basin-averaged summer (June–August) **(a)** precipitation [mm / summer] and **(b)** evaporation [mm / summer] over the 50 major basins from MSWEP and GLEAM, respectively.

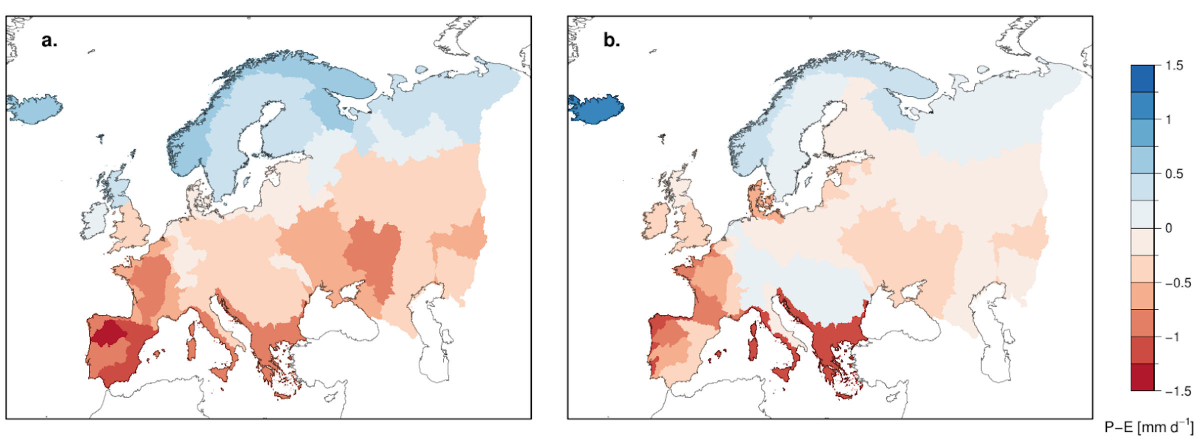

Figure S6. Average daily values of (P-E) [mm d^{-1}] over all major watersheds from this study (a) using P and E from ERA-Interim and (b) using P from MSWEP and E from GLEAM.

	detection of p		detection of e	
member	Δq [g kg^{-1}]	RH [%]	Δq [g kg^{-1}]	r_{HPBL} [-]
1	< 0	> 80	> 0.2	1.5
2	< 0	> 80	> 0.2	1.25
3	< 0	> 80	> 0.3	1.5
4	< −0.1	> 80	> 0.2	1.5
5	< 0	> 90	> 0.2	1.5
6	< 0	> 80	> 0.3	1.25
7	< −0.1	> 90	> 0.2	1.5
8	< −0.1	> 80	> 0.2	1.25
9	< −0.1	> 80	> 0.3	1.5
10	< 0	> 90	> 0.2	1.25
11	< 0	> 90	> 0.3	1.5
12	< −0.1	> 90	> 0.2	1.25
13	< −0.1	> 90	> 0.3	1.5
14	< 0	> 90	> 0.3	1.25
15	< −0.1	> 80	> 0.3	1.25
16	< −0.1	> 90	> 0.3	1.25

Table S2. Construction of the ensemble in this study, using variable thresholds for the detection of *e* and *p* from trajectory data (moisture change Δq, relative humidity *RH*, and the relaxation factor considered for the mean planetary boundary layer height r_{HPBL}).

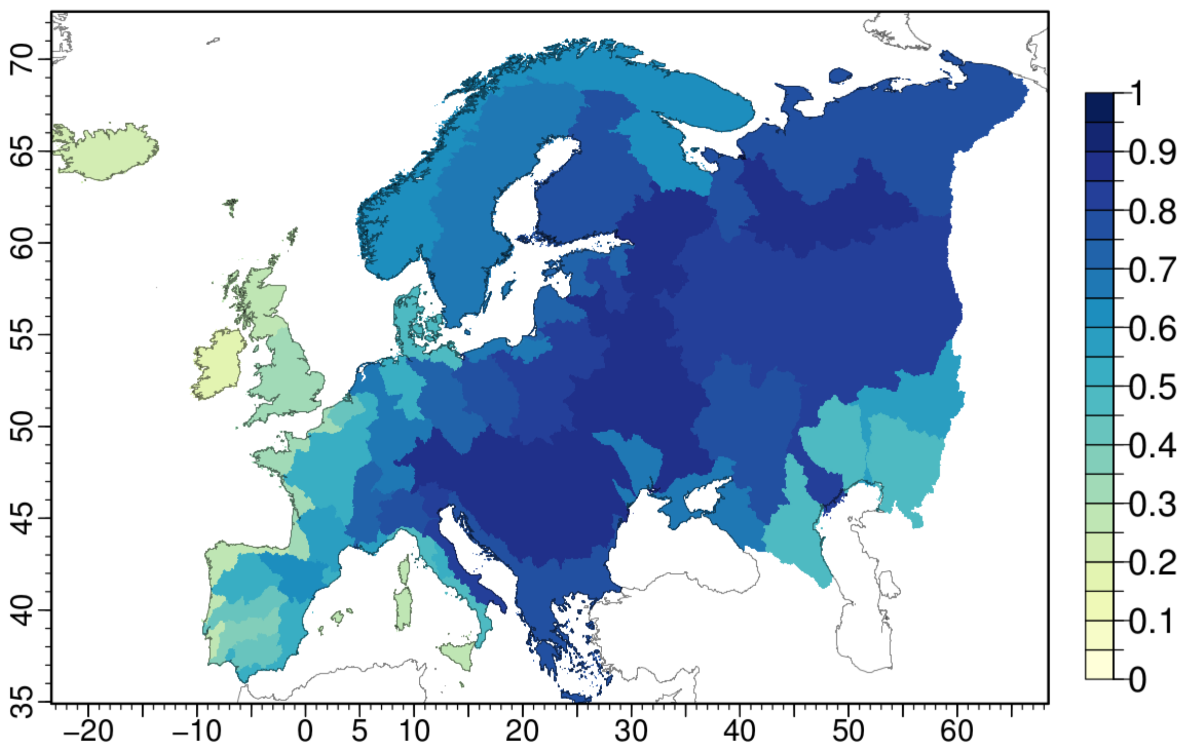

Figure S7. EU Land precipitation recycling ratio (LPR) as the sum of moisture supplied by the watershed itself ('self-supply', PRR) and moisture supplied by other European watersheds ('supply by other watersheds', ELPR). Values represent the ensemble mean. The maximum LPR is 0.80 for the Northern Dvina, minimum is

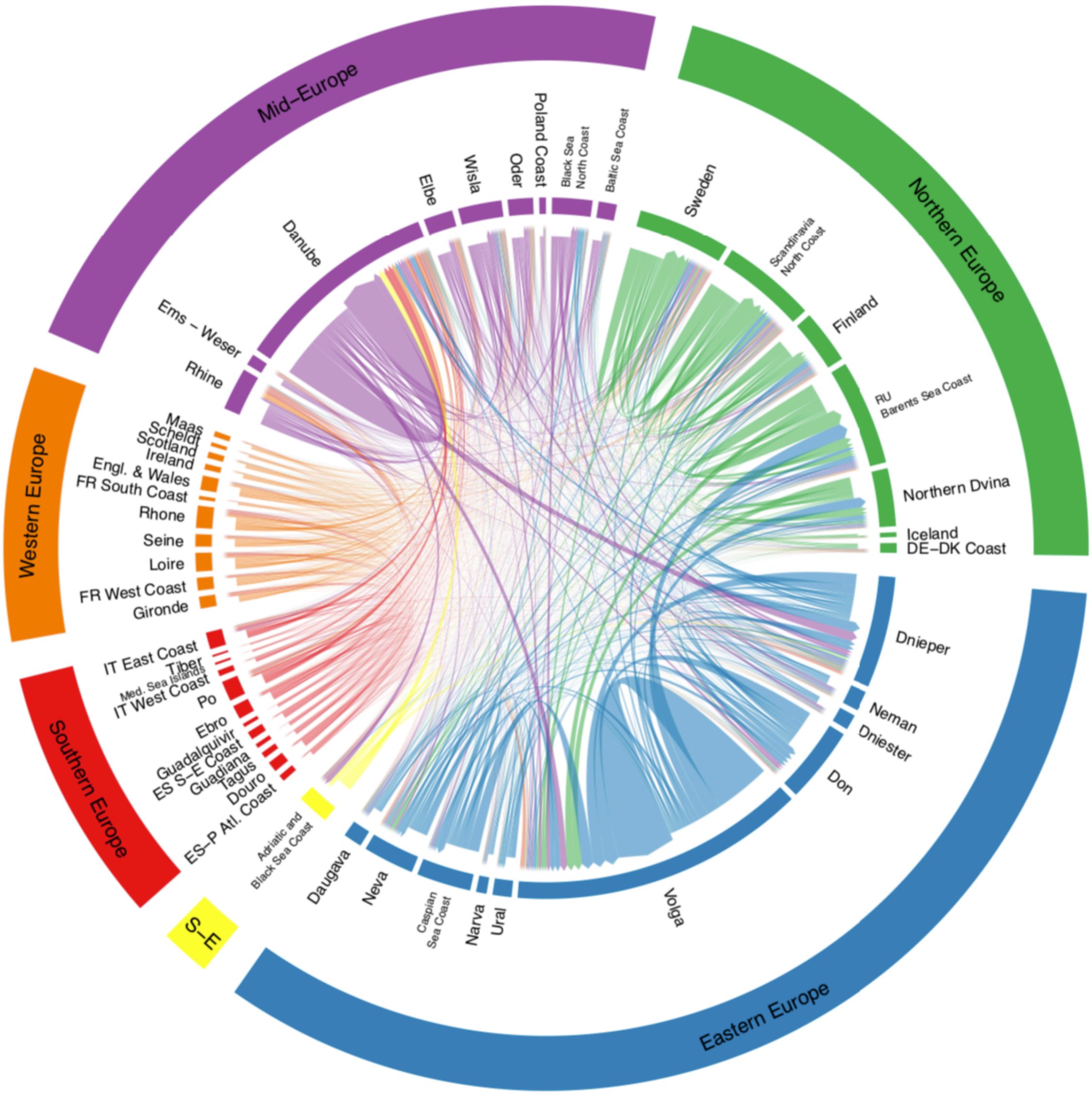

Figure S8. Climatological chord diagram visualizing the watershed precipitation recycling network for the 50 major European watersheds during summertime (1980–2016). Lines between watersheds illustrate the quantitative ensemble mean source–sink relationships between evaporation [km^3] and precipitation [km^3]. Colors represent the region of the source watershed. Flows are illustrated from the evaporating watershed (represented by a gap between the watershed bar and flow line) to the precipitating watershed (represented by an arrow towards the watershed bar). Extra-European sources are excluded. For better illustration, contributions below the 0.1 quantile of all contributions are not represented.

Figure S9. Same as Figure 2 of the main manuscript, but lines illustrate the quantitative source–sink relationships between evaporation and precipitation in mm/summer, normalized by the area of the precipitation watershed.

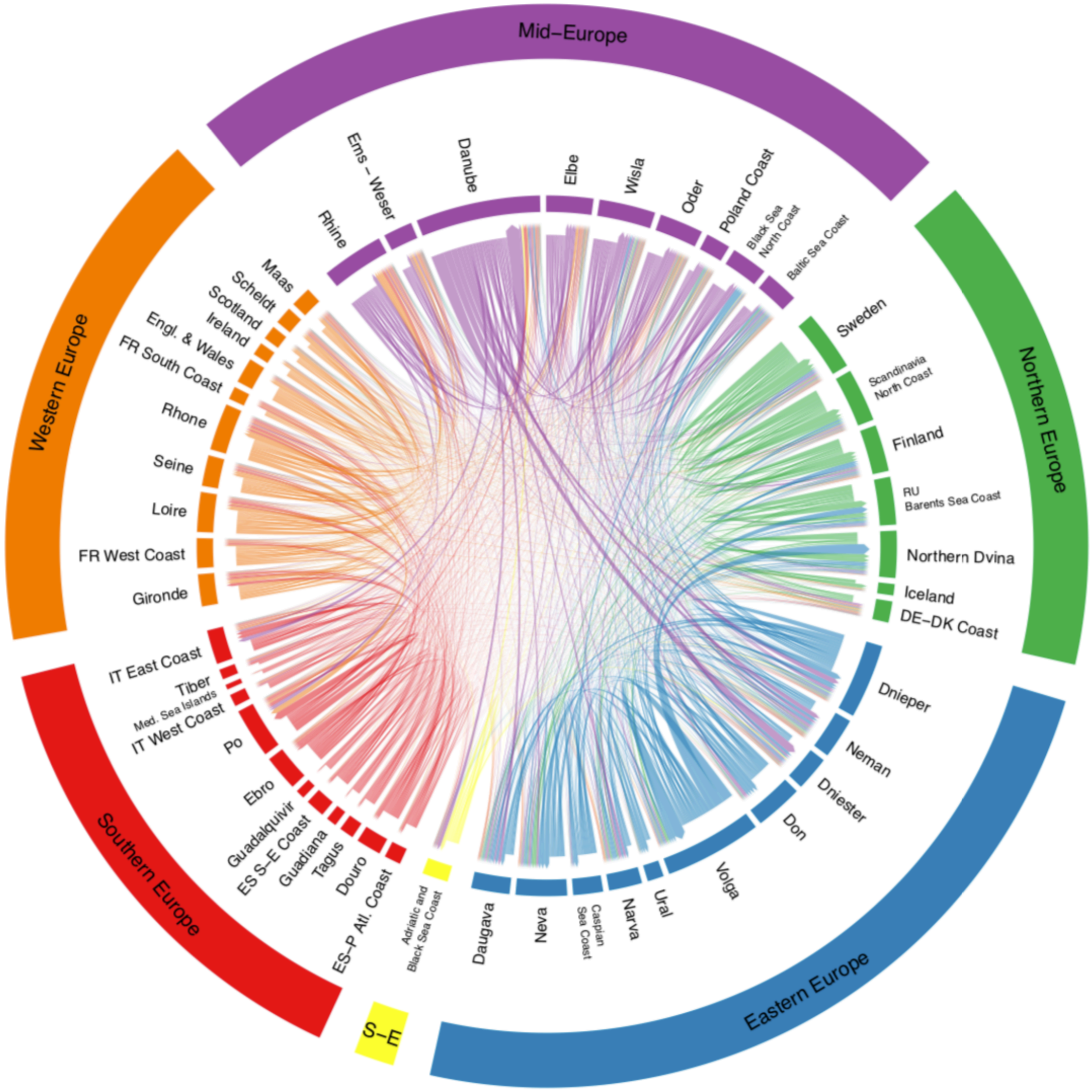

Figure S10. Same as Figure S9, but excluding Extra-European source regions.

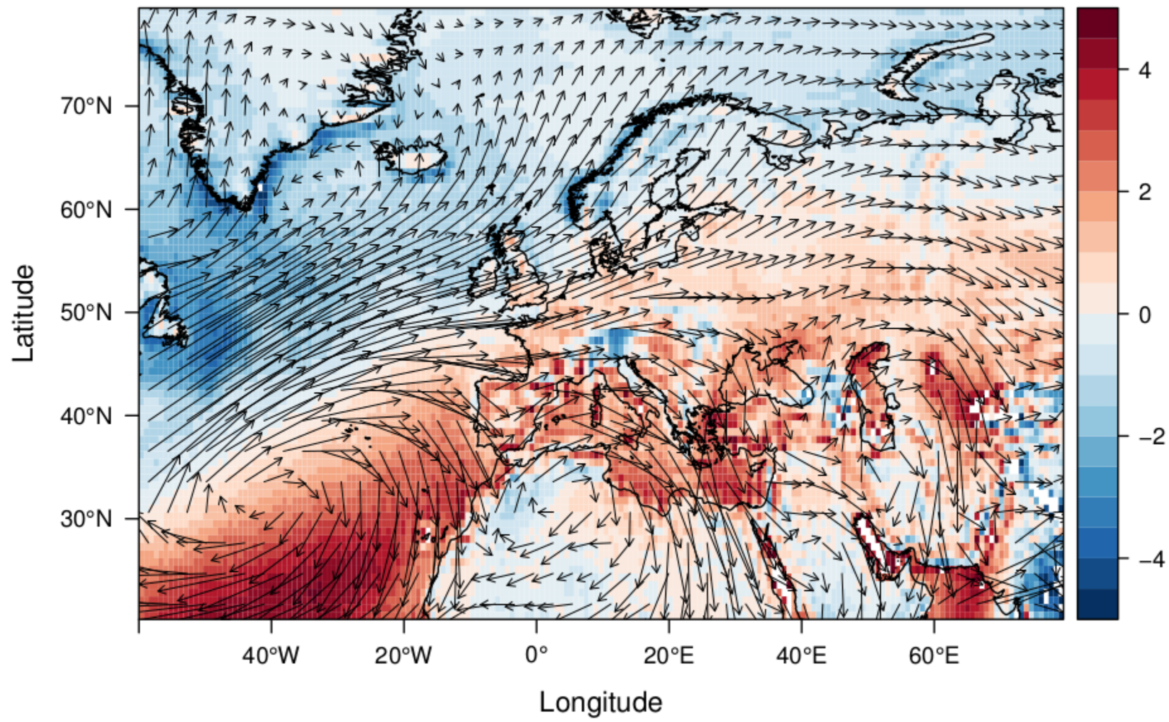

Figure S11. Daily divergence of the vertically integrated moisture flux [mm d^{-1}], averaged over summer days (June-July-August) from 1980–2016. Arrows indicate the vertically integrated moisture flux.

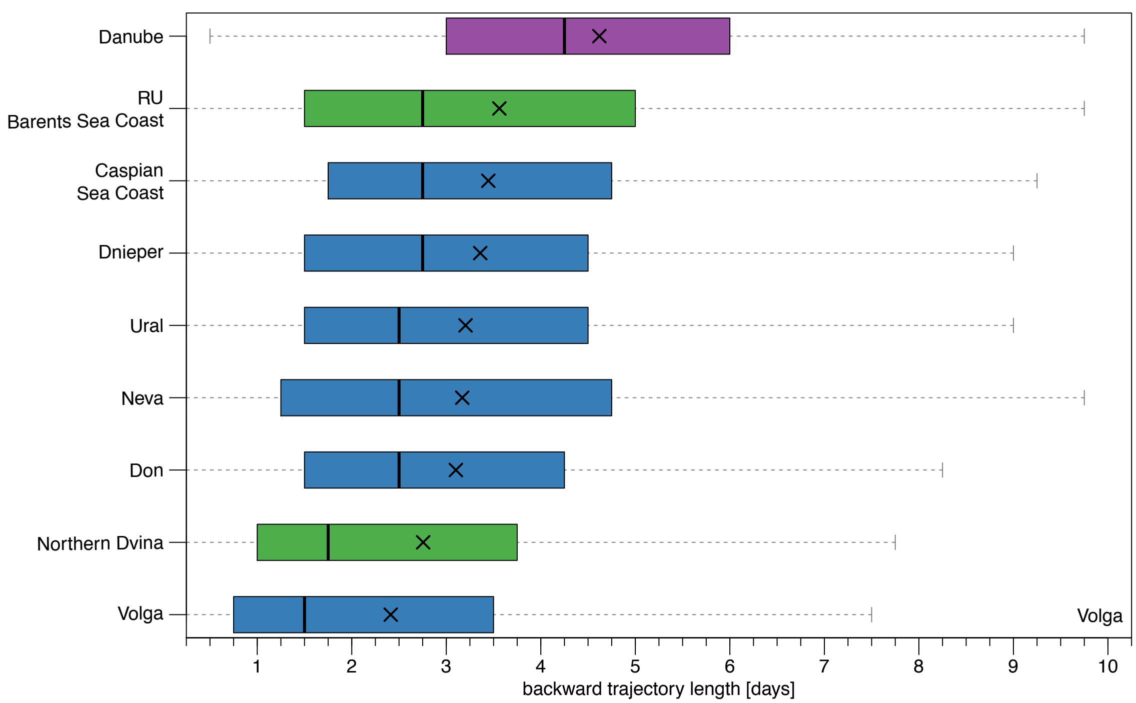

Figure S12. Travel time of water vapor in the atmosphere from the source watersheds (y-axis) to the Volga (sink watershed). All watersheds that contribute to 90% of the precipitation over the Volga are shown and the corresponding boxplots are colored according to their geographical affiliation (see Figure S2). Crosses denote the mean travel time. Watersheds are ordered according to the mean travel time.

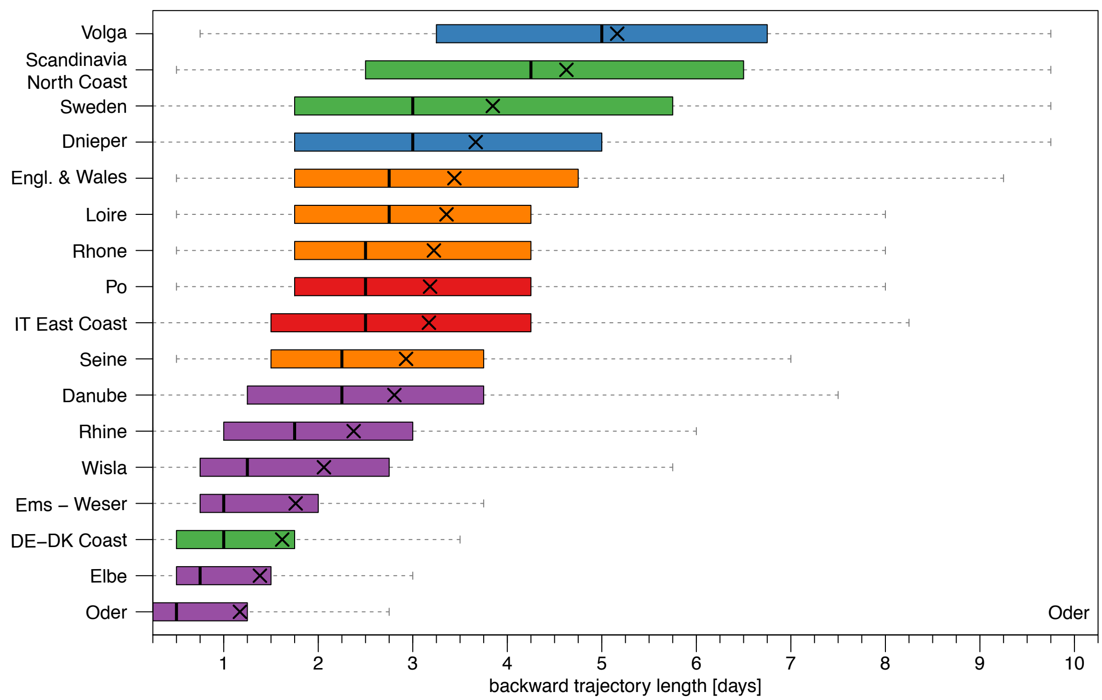

Figure S13. Same as Figure S12, but for the Oder.

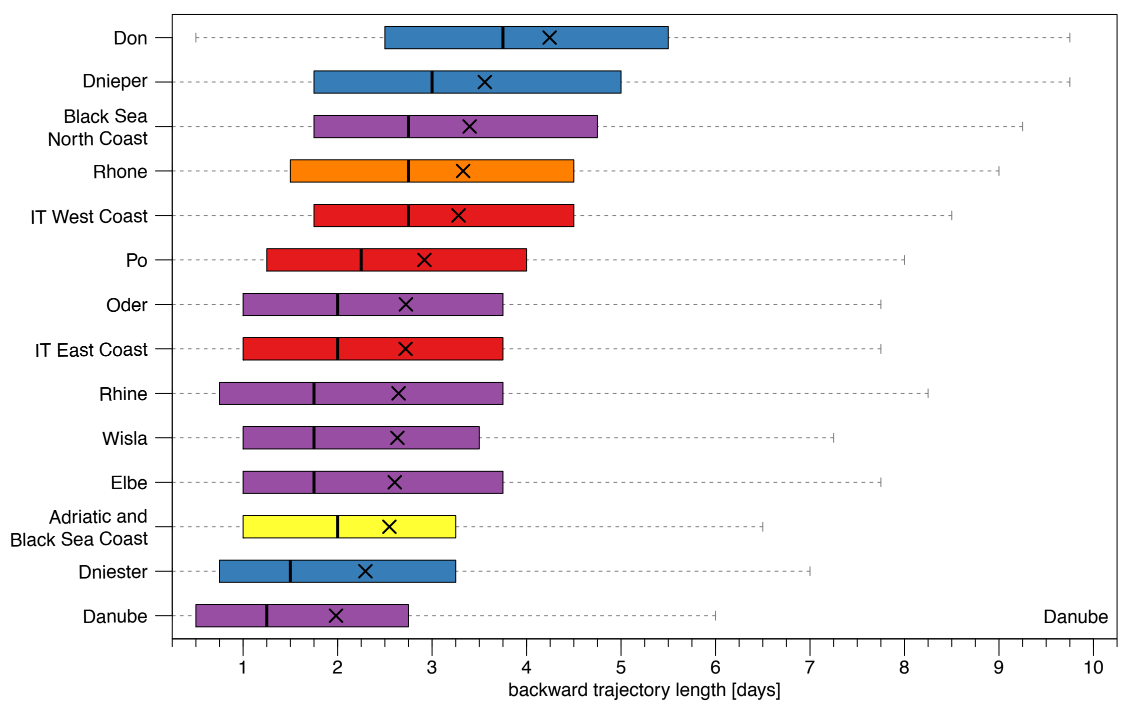

Figure S14. Same as Figure S12, but for the Danube.

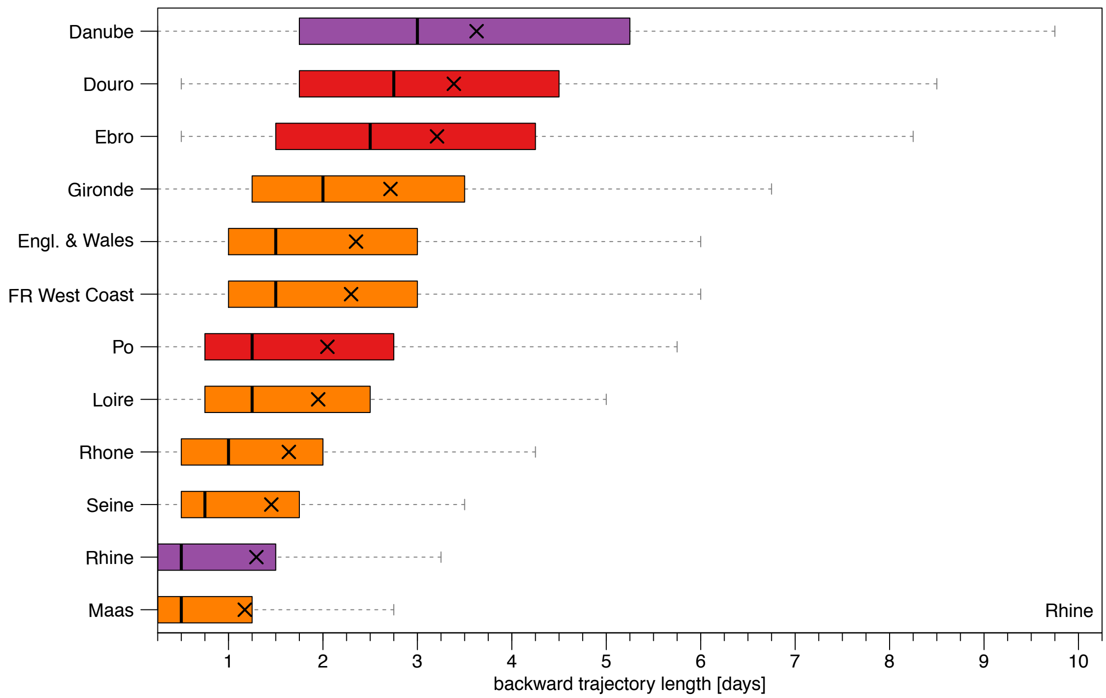

Figure S15. Same as Figure S12, but for the Rhine.