Supplement to

Influence of solar activity changes on European rainfall

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1. Overview

Statistical analysis is indispensable in the climate sciences and has enabled us to systematically map out areas of solar influence on European precipitation on a month-by-month basis. Yet, visual comparison of the respective solar and precipitation time series adds important additional information. We are therefore presenting in Supplement Chapter 2 detailed graphs for each European country, showing the month yielding the most positive correlation coefficient. Fig. S1 shows the time series of all countries (in alphabetic order) without any shift of the solar signal, whilst Fig. S2 shows the same months with the solar signal shifted according to the lag associated with the most positive r values. The correlation coefficients and solar lag times are listed in Table 1 of the main paper and Tables S1-S3 of supplement chapter 3.

Supplement Chapter 4 presents coefficient maps for the months not illustrated in the main paper.

Supplement Chapter 5 visualizes how the Pearson r correlation coefficients progressively change as a function of variations in the solar lead/lag relationship

Supplement Chapter 6 compares solar activity and Germany's February precipitation for the period 2000-2018 and speculates about possible solar triggers of oberserved precipitation anomalies, lagging the solar signal by 3-4 years. Furthermore, the chapter contains time series for May rainfall in Poland, demonstrating a significantly inverse relationsship with solar activity.

Supplement Chapter 7 shows historical precipitation series, wavelets and cross wavelet transforms of Edinburgh, Paris and Stockholm that reach back more than 200 years.

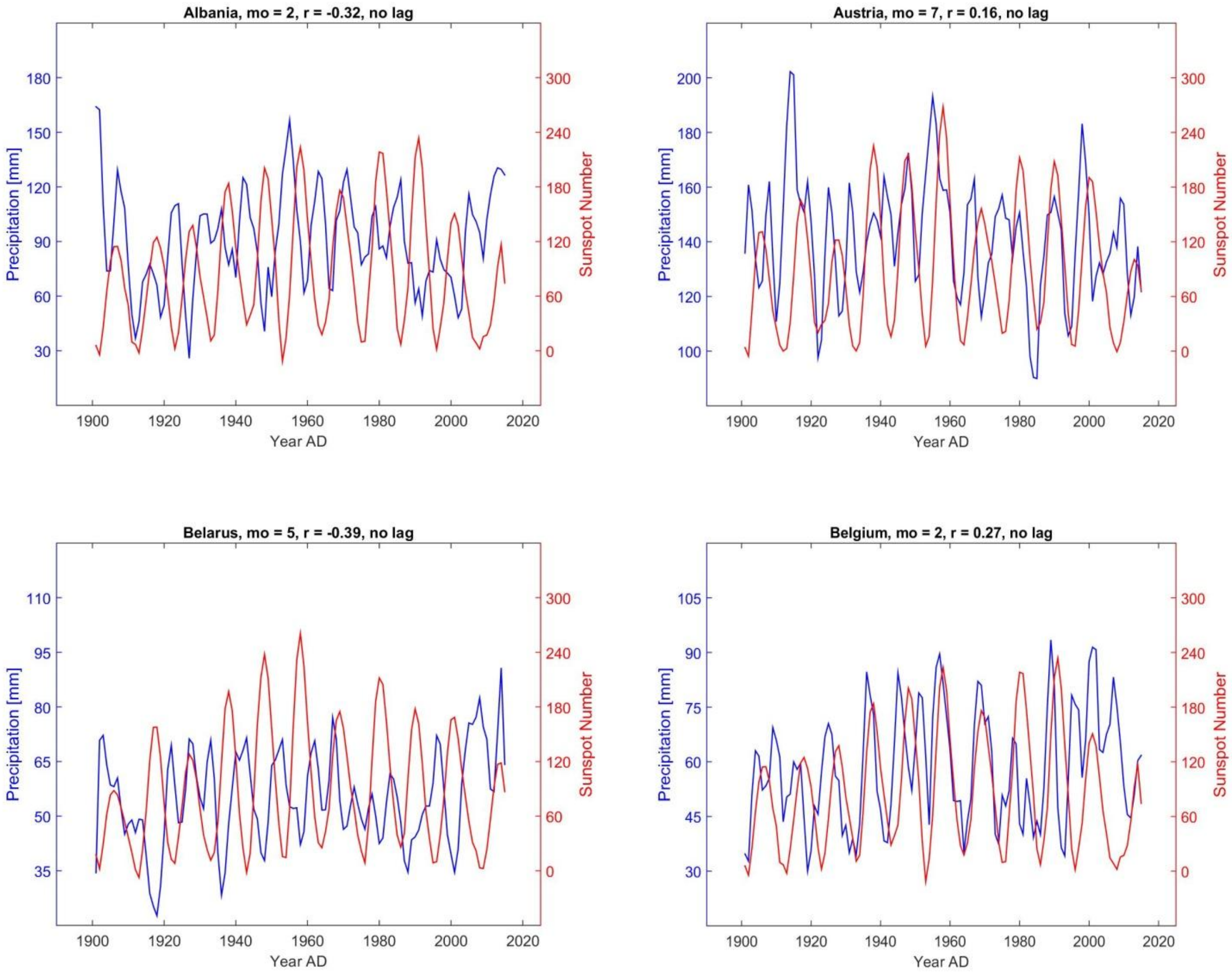
Supplement Chapter 8 compares the effect of the Savitzky-Golay Filter with the results of a Simple Moving Average.

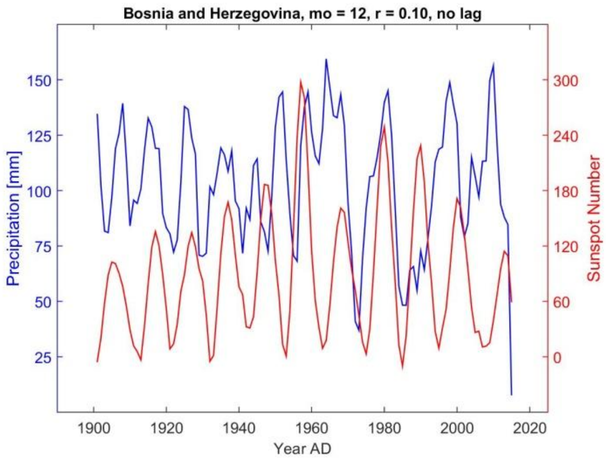
Supplement Chapter 9 illustrates the long term December-February NAO development, compared to sunspots for the period 1830-2000 (van Loon et al., 2012), which could help to better understand long term changes in the stability of the solar influence on European precipitation.

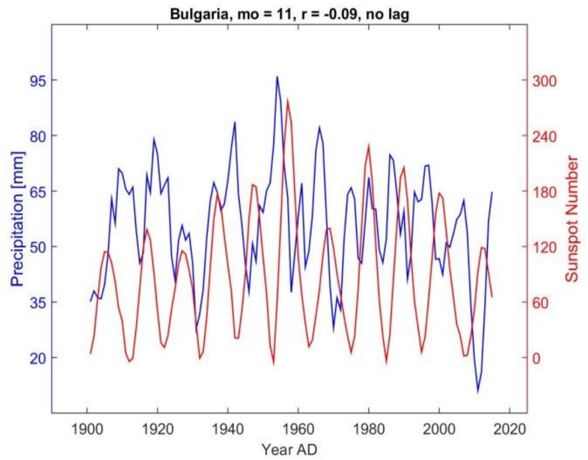
2. Precipitation and Solar Times Series

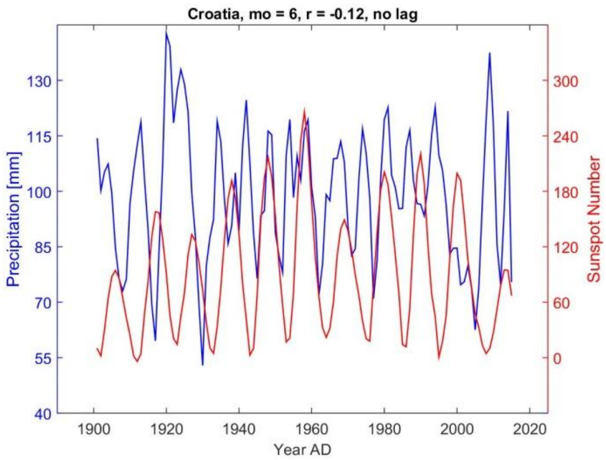
2.1. Plots without lags

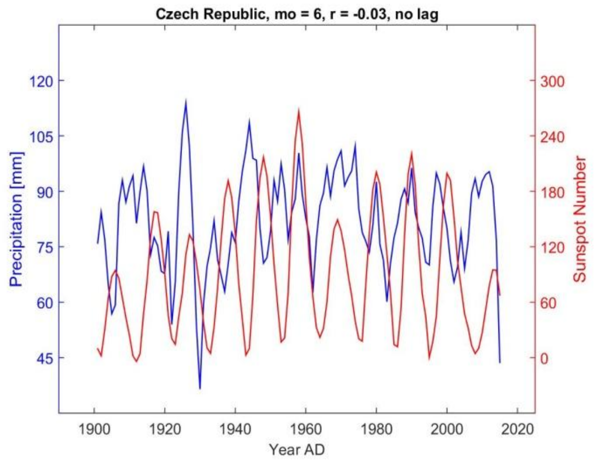
Fig. S1: *Precipitation of European countries (in alphabetic order) compared to changes in sunspots, plotted without lag (solar signal unshifted). Country name, month (1=January, 12=December), and Pearson r correlation value are stated above the individual diagrams.*

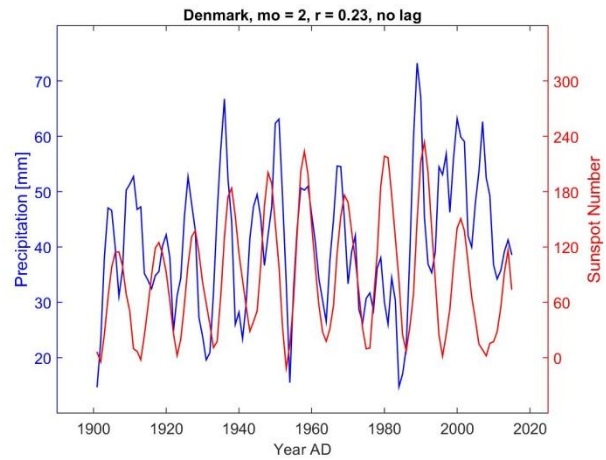


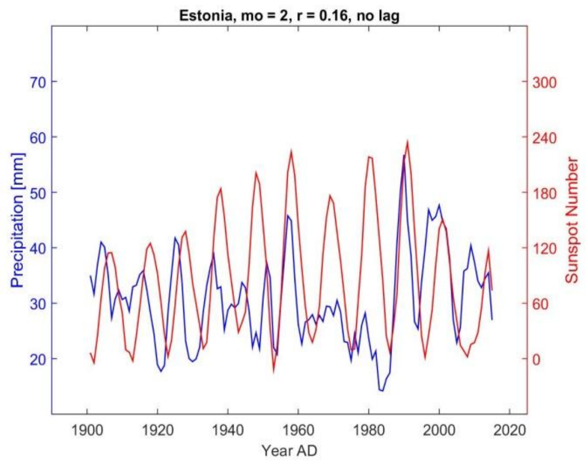

Bosnia and Herzegovina, mo = 12, r = 0.10, no lag
Precipitation [mm]
Sunspot Number
Year AD

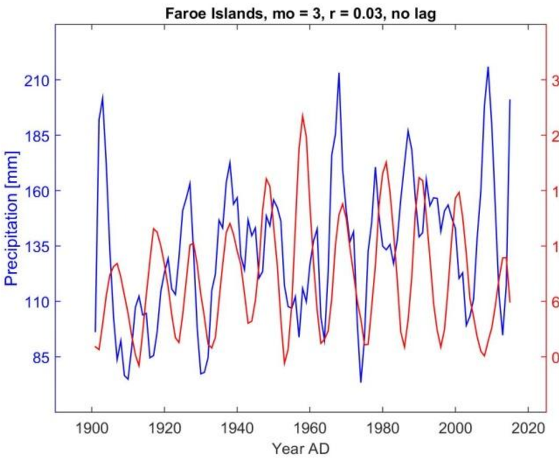

Bulgaria, mo = 11, r = -0.09, no lag
Precipitation [mm]
Sunspot Number
Year AD

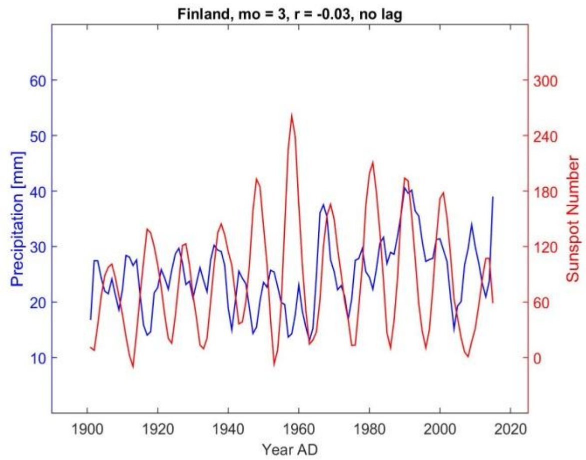

Croatia, mo = 6, r = -0.12, no lag
Precipitation [mm]
Sunspot Number
Year AD

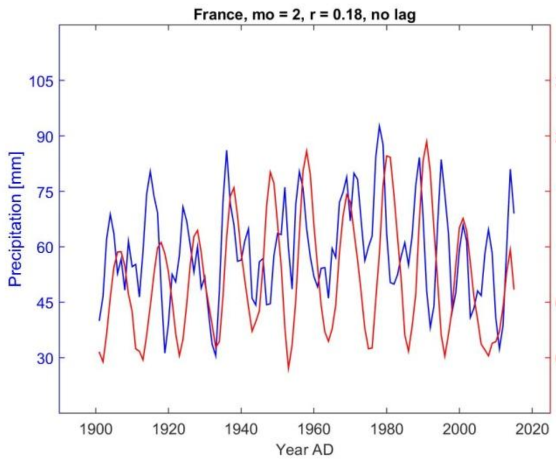

Czech Republic, mo = 6, r = -0.03, no lag
Precipitation [mm]
Sunspot Number
Year AD

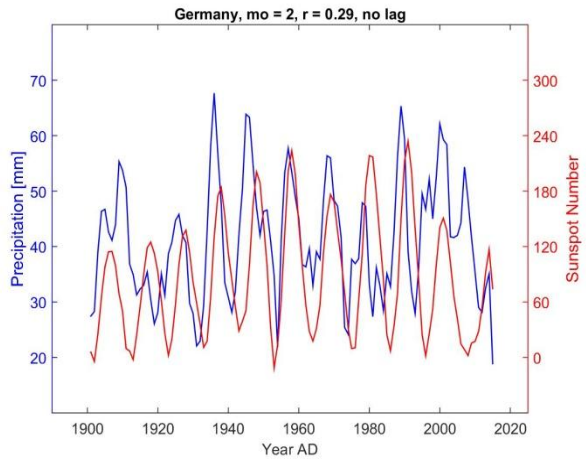

Denmark, mo = 2, r = 0.23, no lag
Precipitation [mm]
Sunspot Number
Year AD

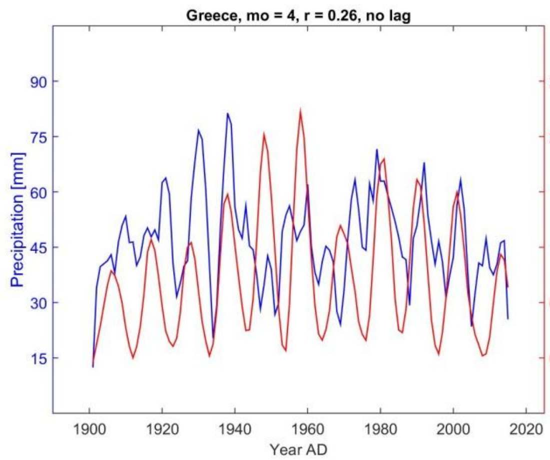

Estonia, mo = 2, r = 0.16, no lag
Precipitation [mm]
Sunspot Number
Year AD

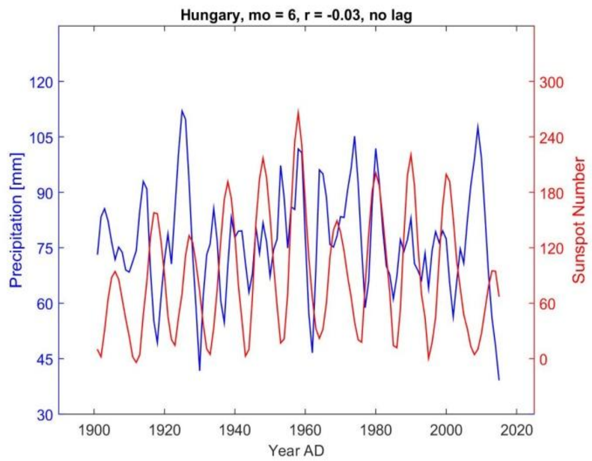

Faroe Islands, mo = 3, r = 0.03, no lag
Precipitation [mm]
Sunspot Number
Year AD

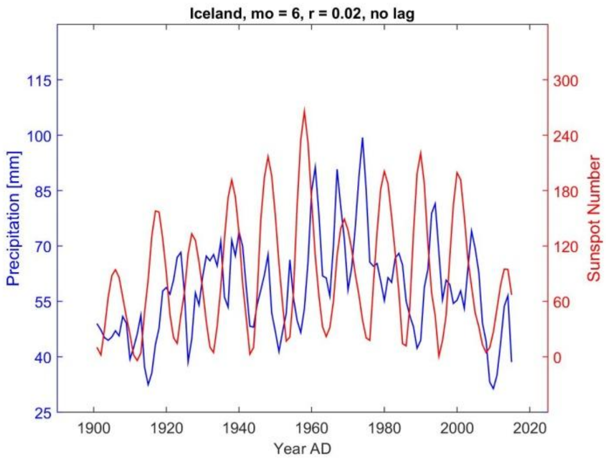

Finland, mo = 3, r = -0.03, no lag
Precipitation [mm]
Sunspot Number
Year AD

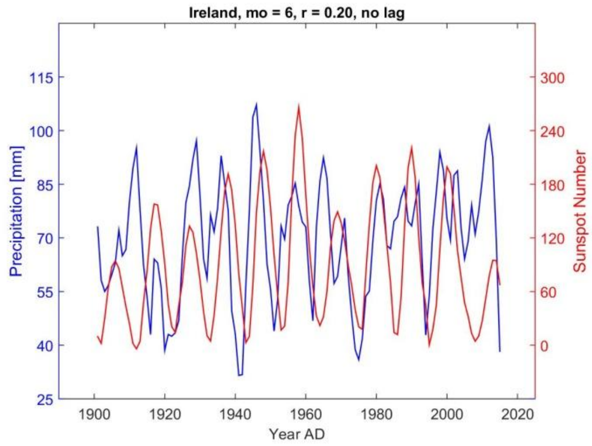

France, mo = 2, r = 0.18, no lag
Precipitation [mm]
Sunspot Number
Year AD

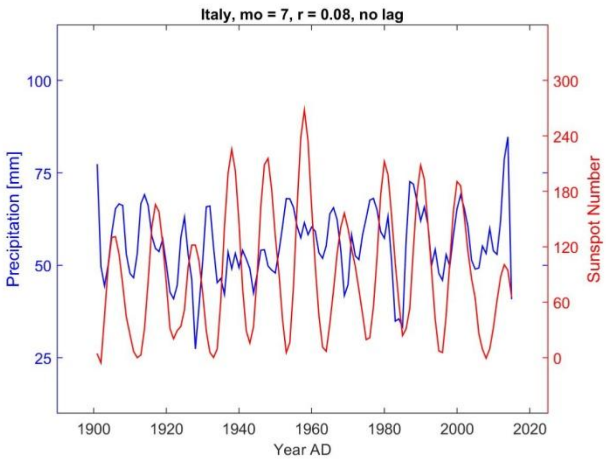

Germany, mo = 2, r = 0.29, no lag
Precipitation [mm]
Sunspot Number
Year AD

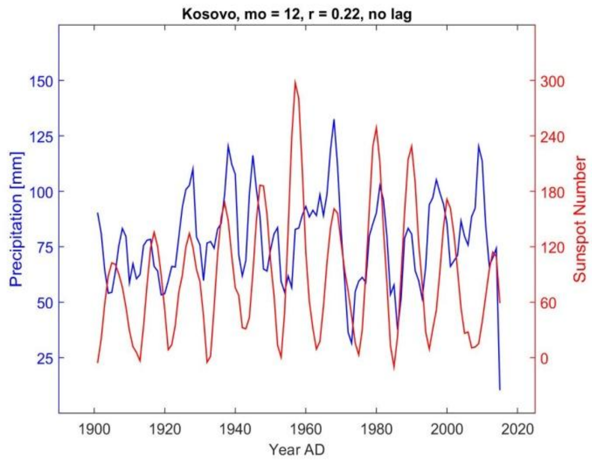

Greece, mo = 4, r = 0.26, no lag
Precipitation [mm]
Sunspot Number
Year AD

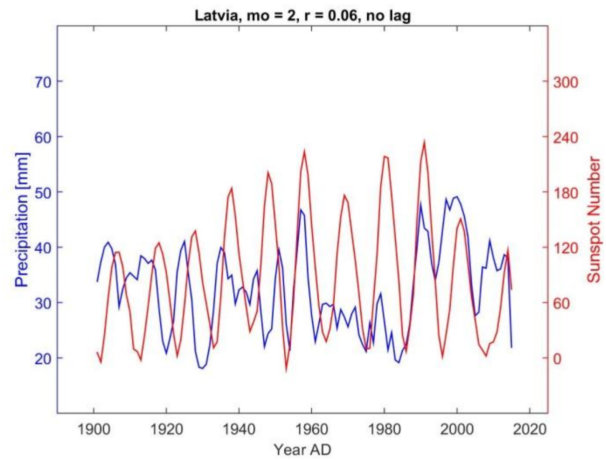

Hungary, mo = 6, r = -0.03, no lag
Precipitation [mm]
Sunspot Number
Year AD

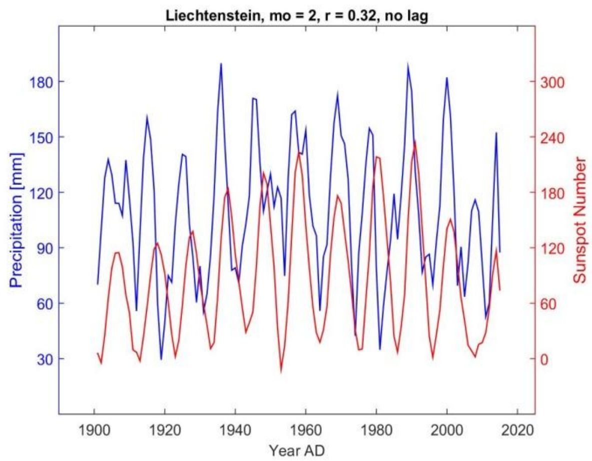

Iceland, mo = 6, r = 0.02, no lag
Precipitation [mm]
25 40 55 70 85 100 115
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

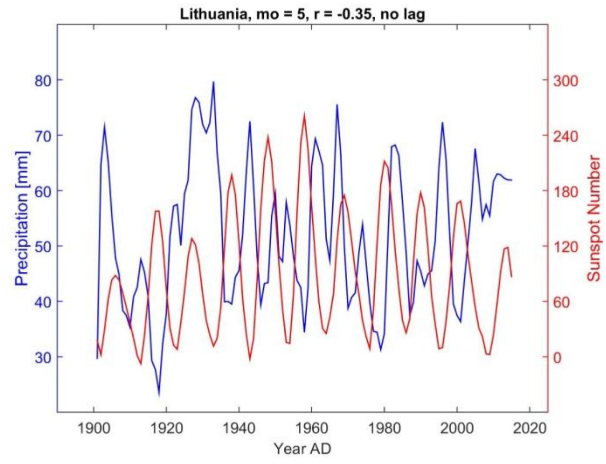

Ireland, mo = 6, r = 0.20, no lag
Precipitation [mm]
25 40 55 70 85 100 115
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

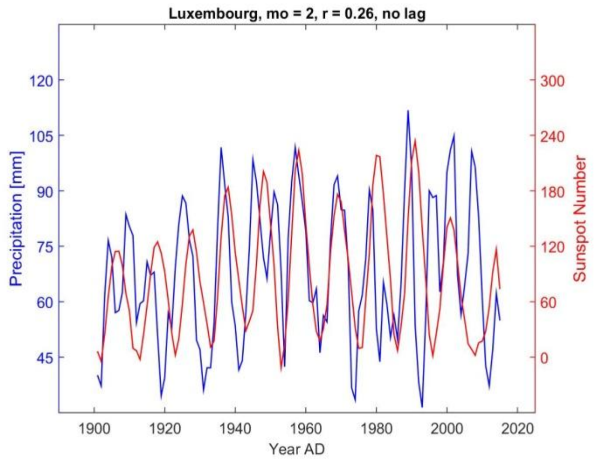

Italy, mo = 7, r = 0.08, no lag
Precipitation [mm]
25 50 75 100
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

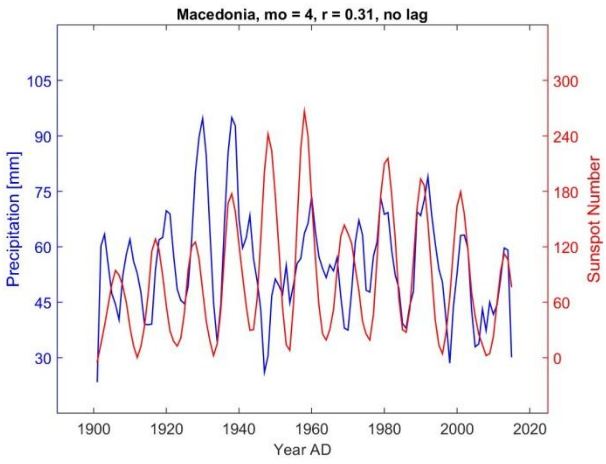

Kosovo, mo = 12, r = 0.22, no lag
Precipitation [mm]
25 50 75 100 125 150
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

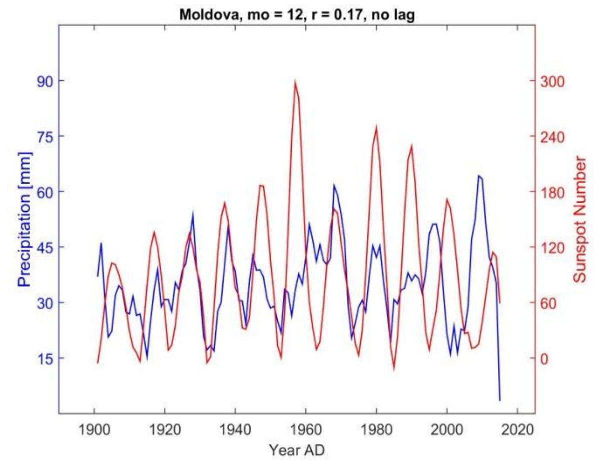

Latvia, mo = 2, r = 0.06, no lag
Precipitation [mm]
20 30 40 50 60 70
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

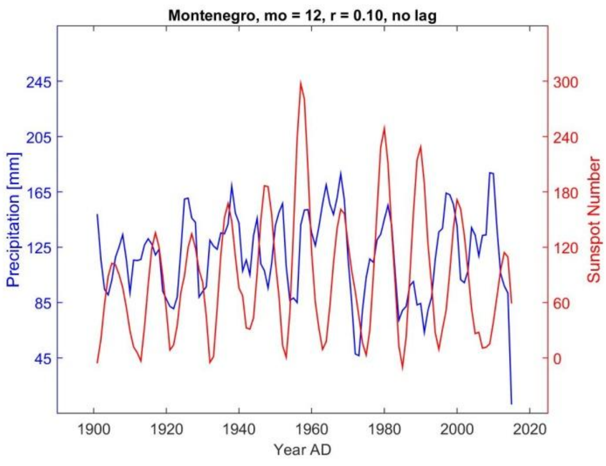

Liechtenstein, mo = 2, r = 0.32, no lag
Precipitation [mm]
30 60 90 120 150 180
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

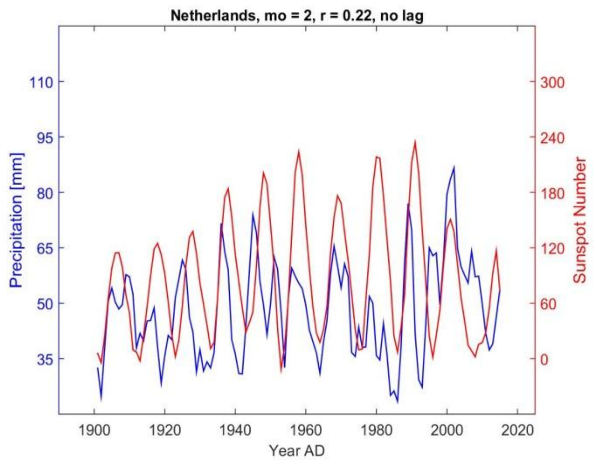

Lithuania, mo = 5, r = -0.35, no lag
Precipitation [mm]
Sunspot Number
Year AD

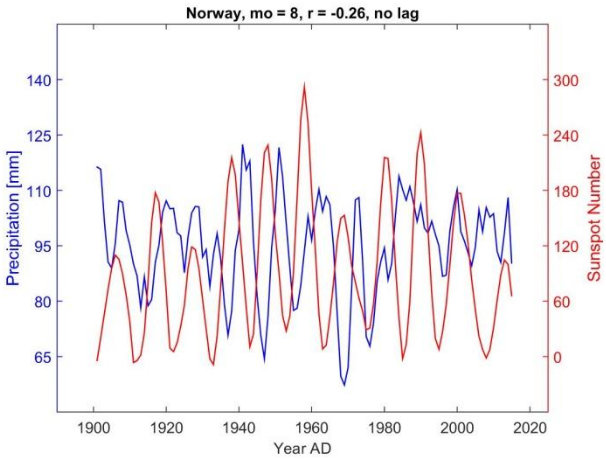

Luxembourg, mo = 2, r = 0.26, no lag
Precipitation [mm]
Sunspot Number
Year AD

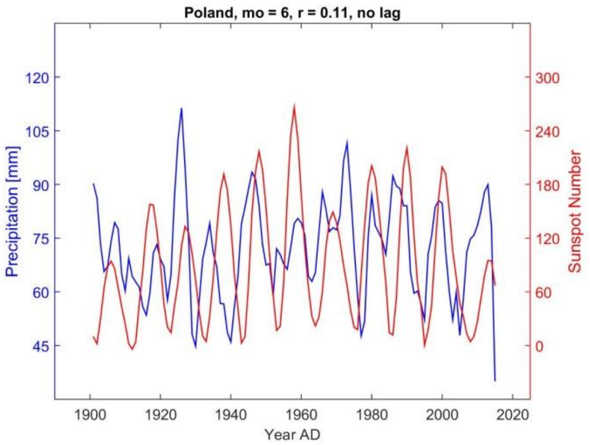

Macedonia, mo = 4, r = 0.31, no lag
Precipitation [mm]
Sunspot Number
Year AD

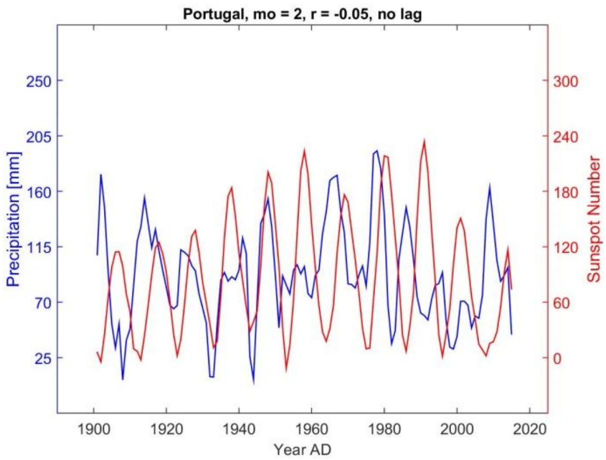

Moldova, mo = 12, r = 0.17, no lag
Precipitation [mm]
Sunspot Number
Year AD

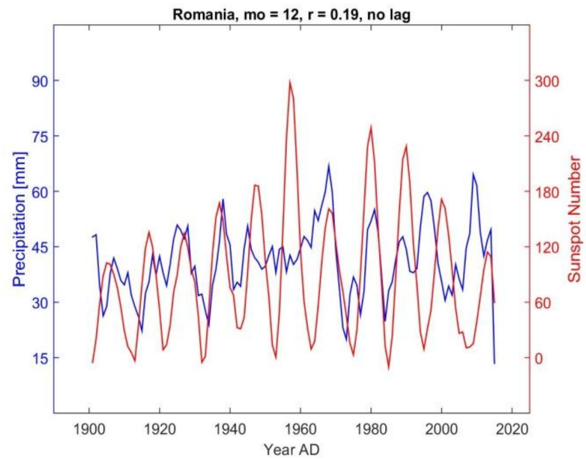

Montenegro, mo = 12, r = 0.10, no lag
Precipitation [mm]
Sunspot Number
Year AD

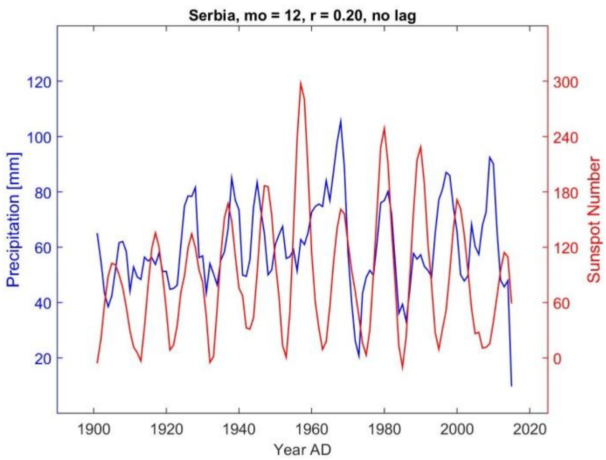

Netherlands, mo = 2, r = 0.22, no lag
Precipitation [mm]
Sunspot Number
Year AD

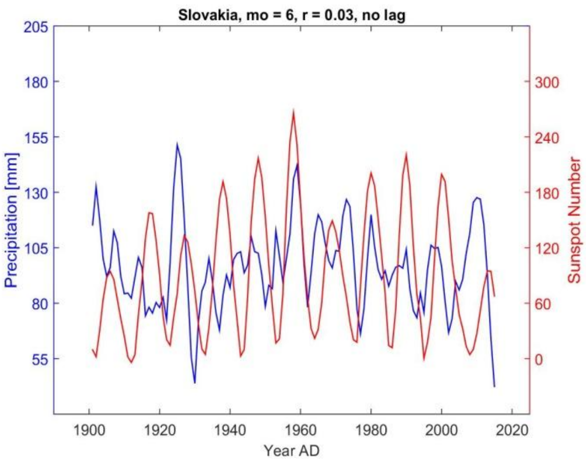

Norway, mo = 8, r = -0.26, no lag
Precipitation [mm]
Sunspot Number
Year AD
65 80 95 110 125 140
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

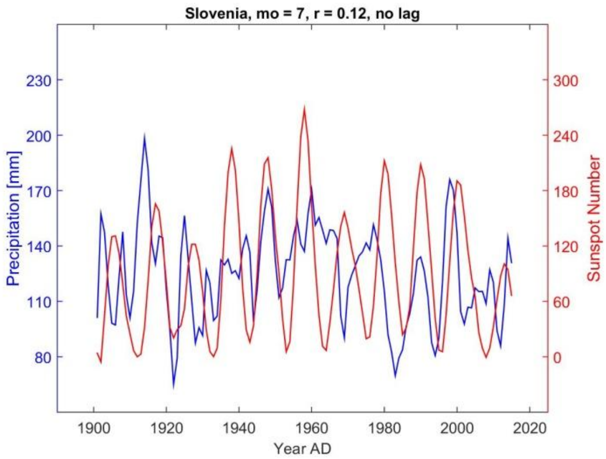

Poland, mo = 6, r = 0.11, no lag
Precipitation [mm]
Sunspot Number
Year AD
45 60 75 90 105 120
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

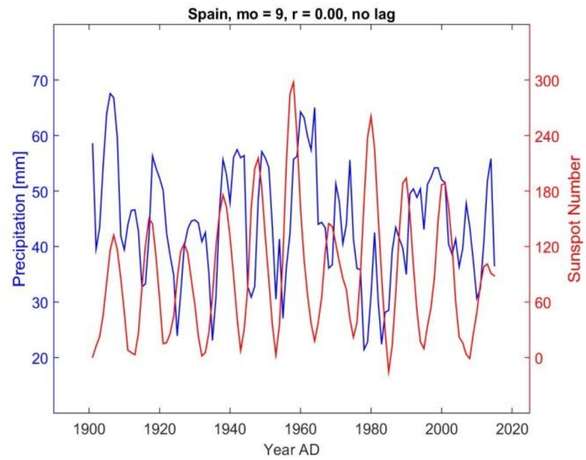

Portugal, mo = 2, r = -0.05, no lag
Precipitation [mm]
Sunspot Number
Year AD
25 70 115 160 205 250
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

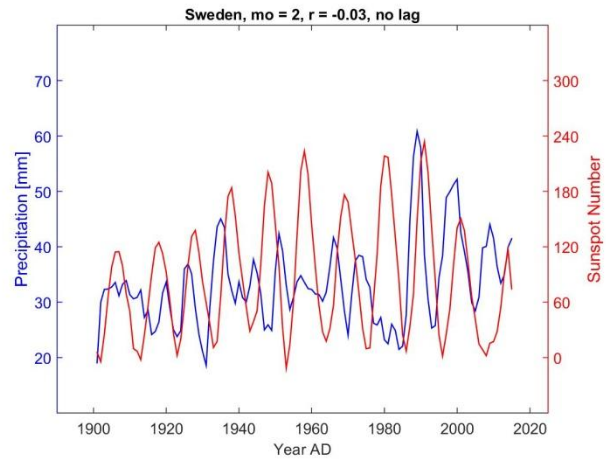

Romania, mo = 12, r = 0.19, no lag
Precipitation [mm]
Sunspot Number
Year AD
15 30 45 60 75 90
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

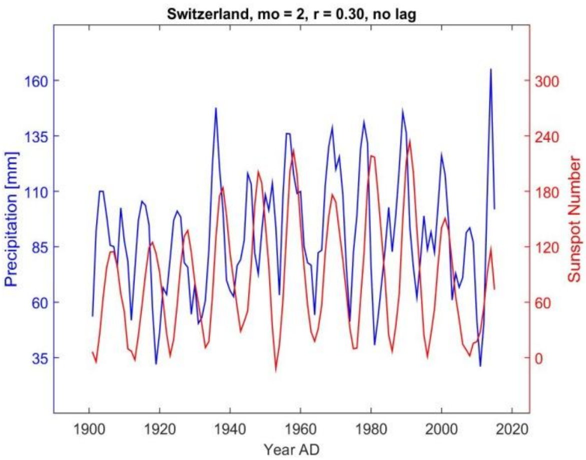

Serbia, mo = 12, r = 0.20, no lag
Precipitation [mm]
Sunspot Number
Year AD
20 40 60 80 100 120
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

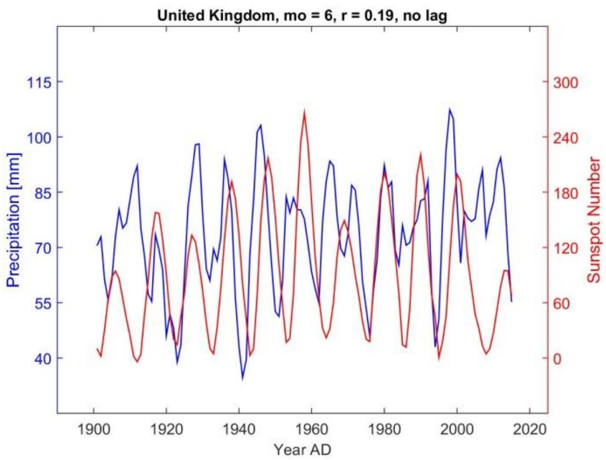

Slovakia, mo = 6, r = 0.03, no lag
Precipitation [mm]
Sunspot Number
Year AD
55 80 105 130 155 180 205
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020


Slovenia, mo = 7, r = 0.12, no lag
Precipitation [mm]
Sunspot Number
Year AD


Spain, mo = 9, r = 0.00, no lag
Precipitation [mm]
Sunspot Number
Year AD

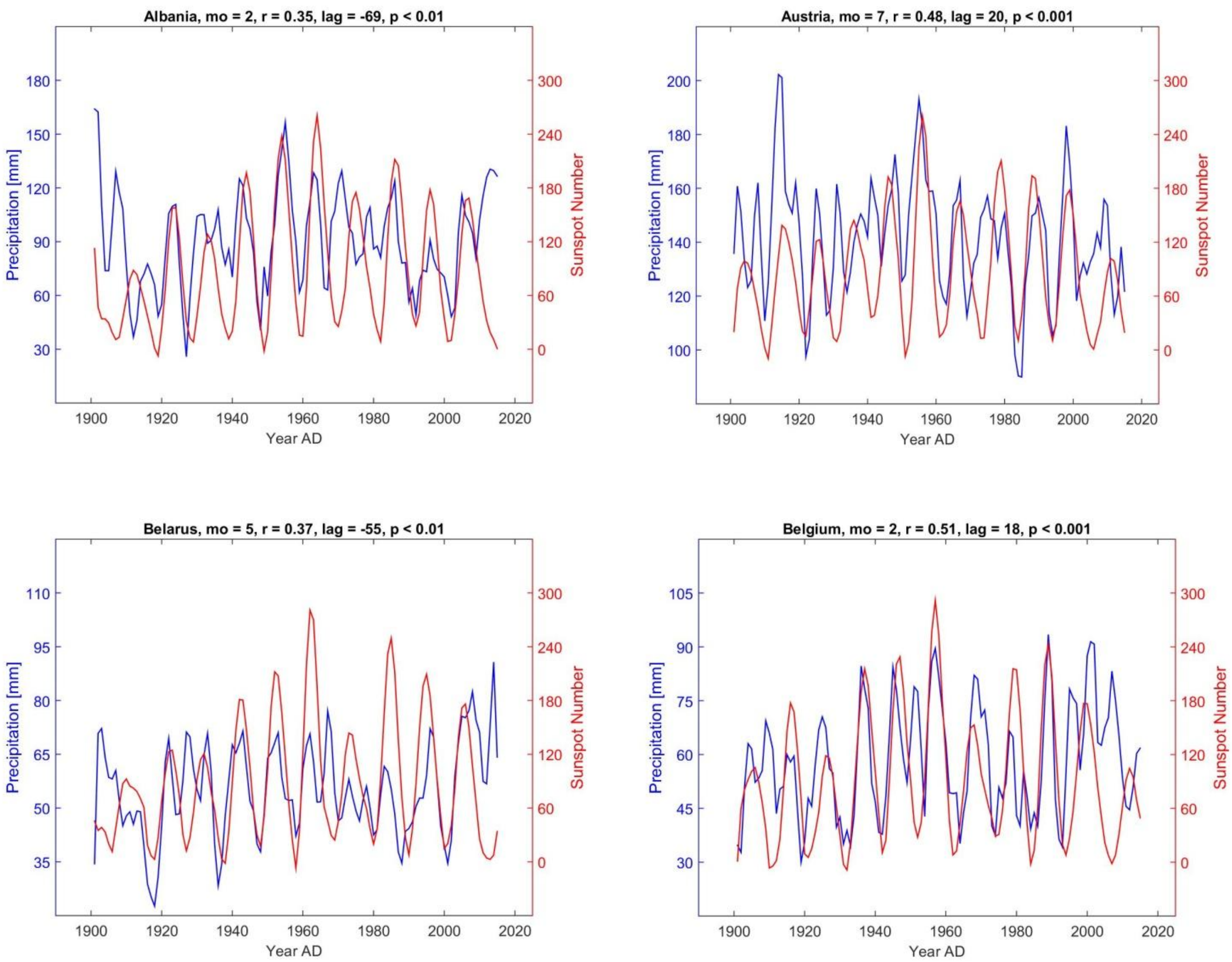

Sweden, mo = 2, r = -0.03, no lag
Precipitation [mm]
Sunspot Number
Year AD

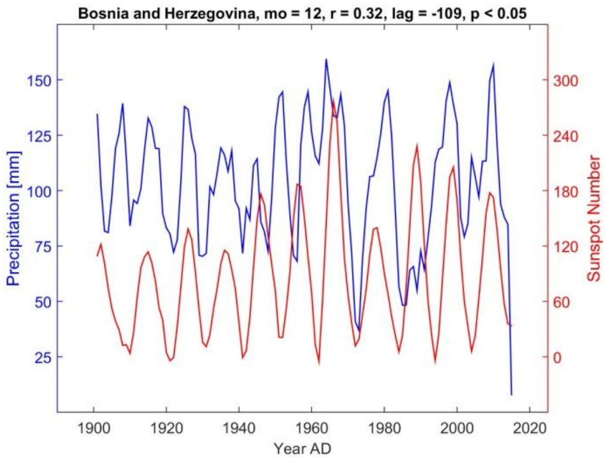

Switzerland, mo = 2, r = 0.30, no lag
Precipitation [mm]
Sunspot Number
Year AD

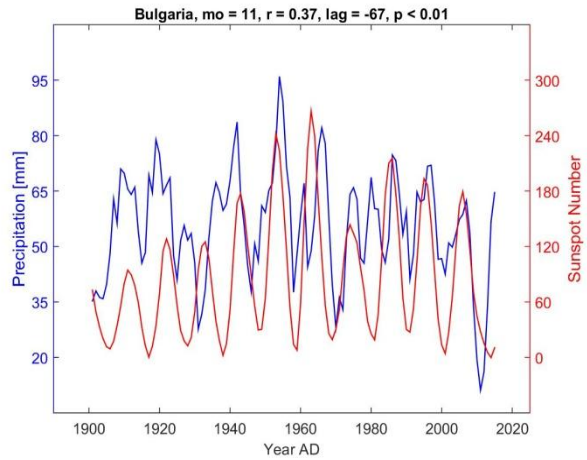

United Kingdom, mo = 6, r = 0.19, no lag
Precipitation [mm]
Sunspot Number
Year AD

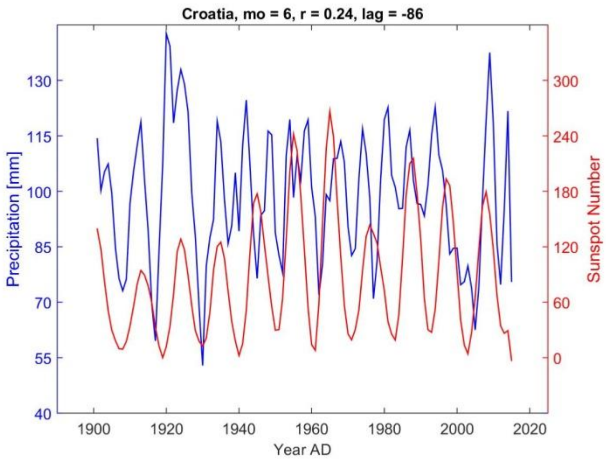
2.2. Plots with lags

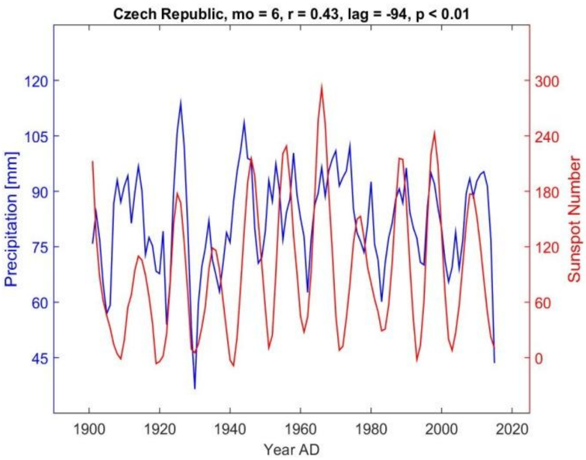
Fig. S2: *Precipitation of European countries (in alphabetic order) compared to changes in sunspots, plotted with solar lag of best positive r value. A solar lag of -69 months (example Albania) means that the sunspot curve from 69 months earlier has been shifted towards younger ages onto the rainfall series (precipitation lags sunspots by 69 months). Positive lags are purely mathematical and imply that sunspots would lag precipitation. Information stated above the individual diagrams: Country name, month (1=January, 12=December), Pearson r correlation value, solar lag, and probability that the correlation r is by chance (false alarm probability)*

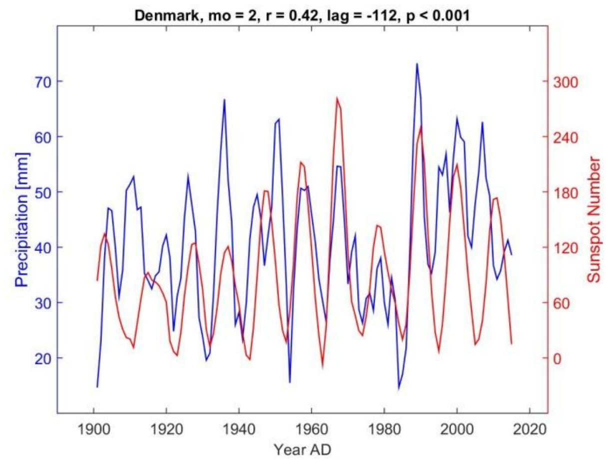


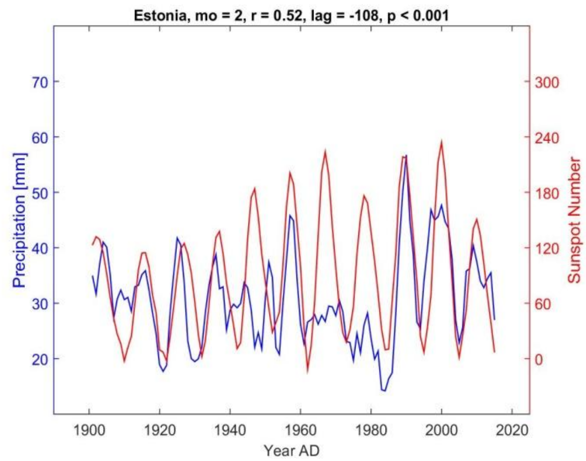

Bosnia and Herzegovina, mo = 12, r = 0.32, lag = -109, p < 0.05
Precipitation [mm]
25 50 75 100 125 150
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

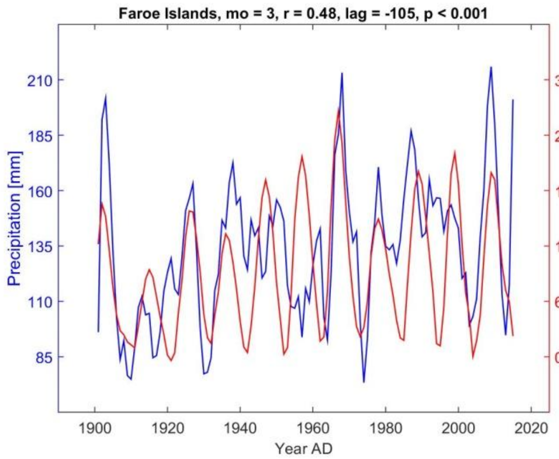

Bulgaria, mo = 11, r = 0.37, lag = -67, p < 0.01
Precipitation [mm]
20 35 50 65 80 95
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

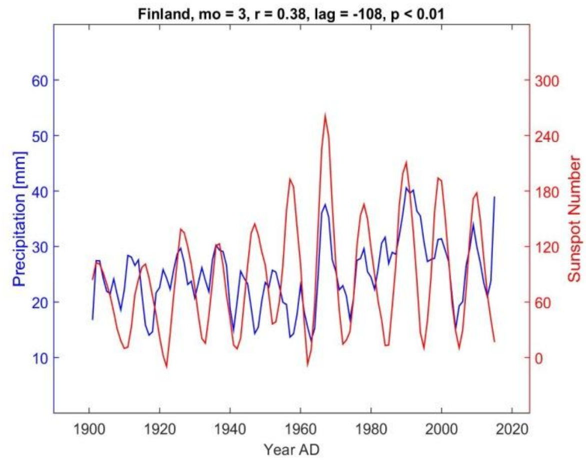

Croatia, mo = 6, r = 0.24, lag = -86
Precipitation [mm]
40 55 70 85 100 115 130
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

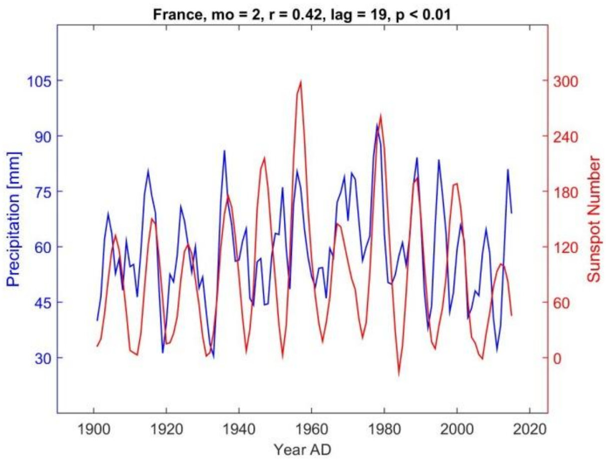

Czech Republic, mo = 6, r = 0.43, lag = -94, p < 0.01
Precipitation [mm]
45 60 75 90 105 120
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

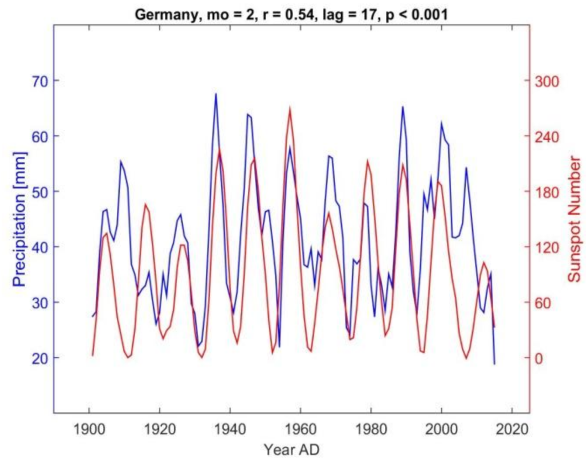

Denmark, mo = 2, r = 0.42, lag = -112, p < 0.001
Precipitation [mm]
20 30 40 50 60 70
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

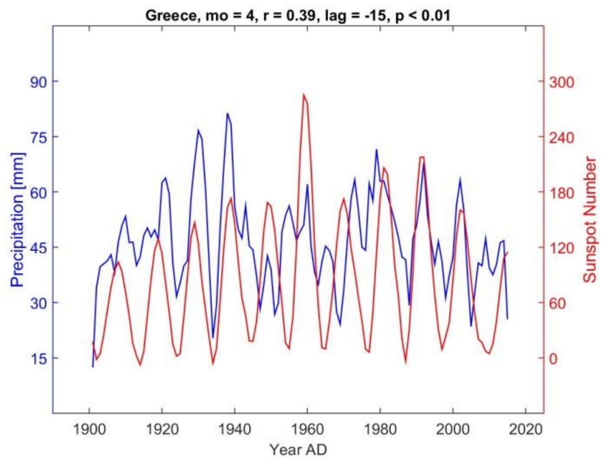

Estonia, mo = 2, r = 0.52, lag = -108, p < 0.001
Precipitation [mm]
20 30 40 50 60 70
Sunspot Number
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020
Year AD

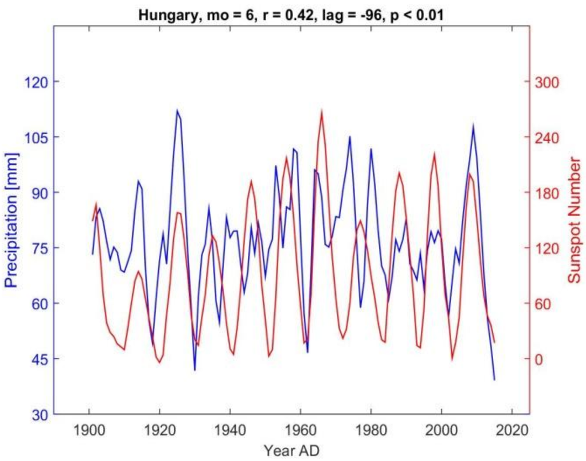

Faroe Islands, mo = 3, r = 0.48, lag = -105, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD
85 110 135 160 185 210
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

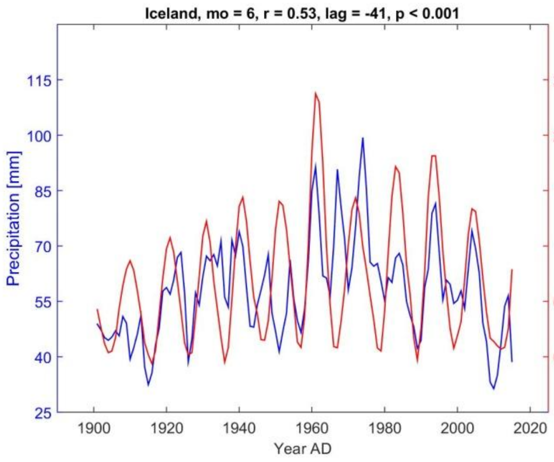

Finland, mo = 3, r = 0.38, lag = -108, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD
10 20 30 40 50 60
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

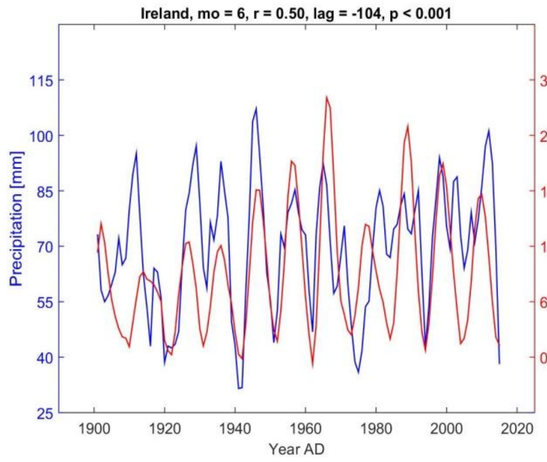

France, mo = 2, r = 0.42, lag = 19, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD
30 45 60 75 90 105
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

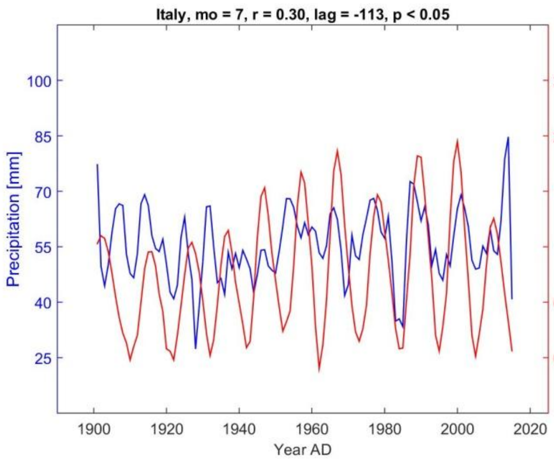

Germany, mo = 2, r = 0.54, lag = 17, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD
20 30 40 50 60 70
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

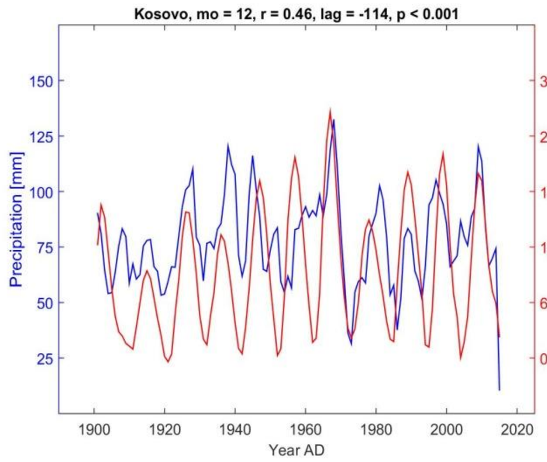

Greece, mo = 4, r = 0.39, lag = -15, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD
15 30 45 60 75 90
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

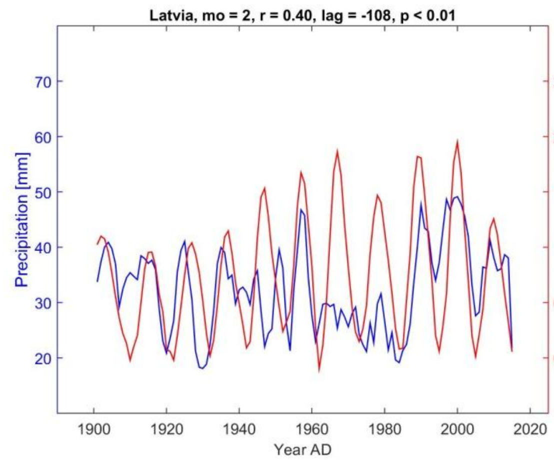

Hungary, mo = 6, r = 0.42, lag = -96, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD
30 45 60 75 90 105 120
0 60 120 180 240 300
1900 1920 1940 1960 1980 2000 2020

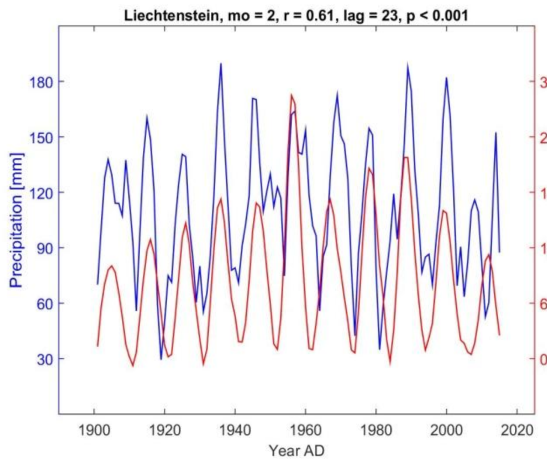

Iceland, mo = 6, r = 0.53, lag = -41, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD

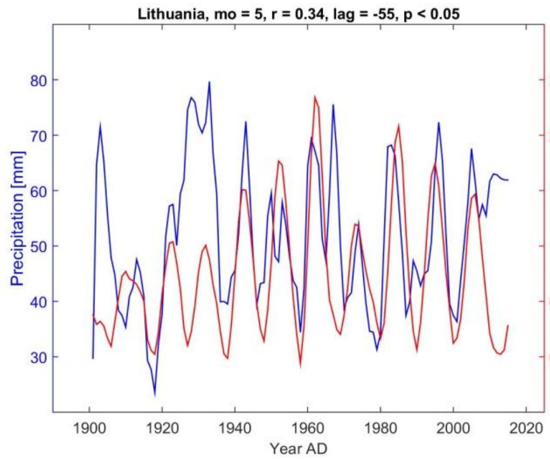

Ireland, mo = 6, r = 0.50, lag = -104, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD

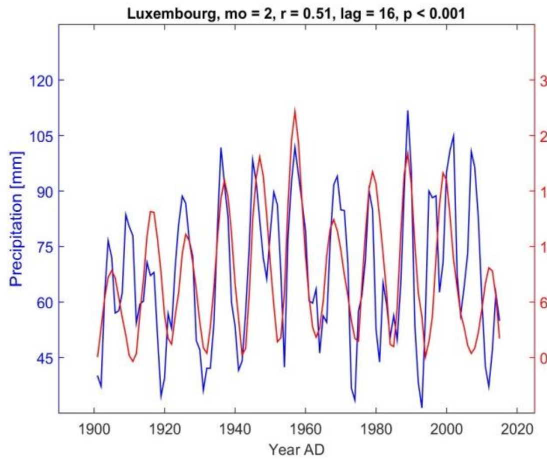

Italy, mo = 7, r = 0.30, lag = -113, p < 0.05
Precipitation [mm]
Sunspot Number
Year AD

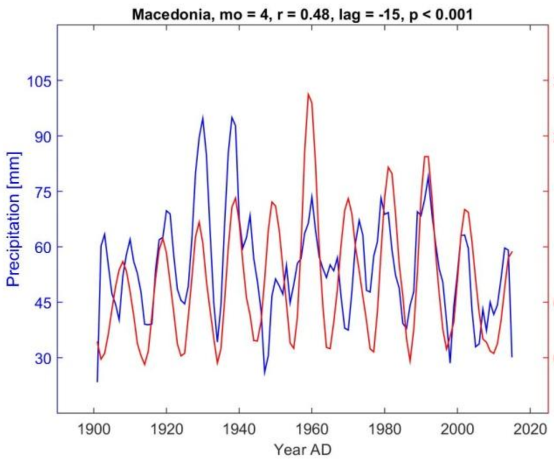

Kosovo, mo = 12, r = 0.46, lag = -114, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD

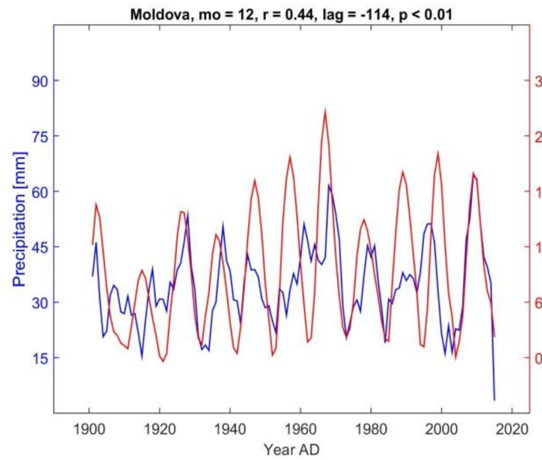

Latvia, mo = 2, r = 0.40, lag = -108, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD

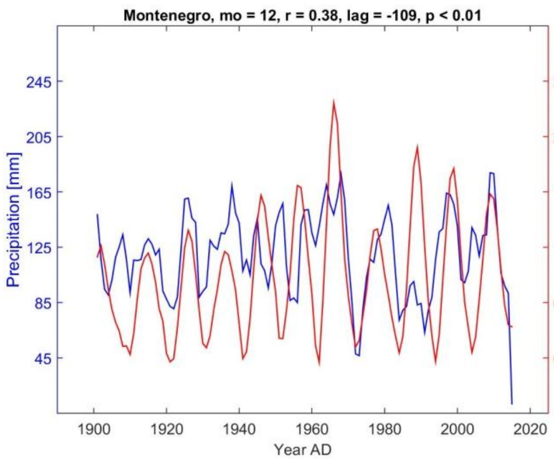

Liechtenstein, mo = 2, r = 0.61, lag = 23, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD

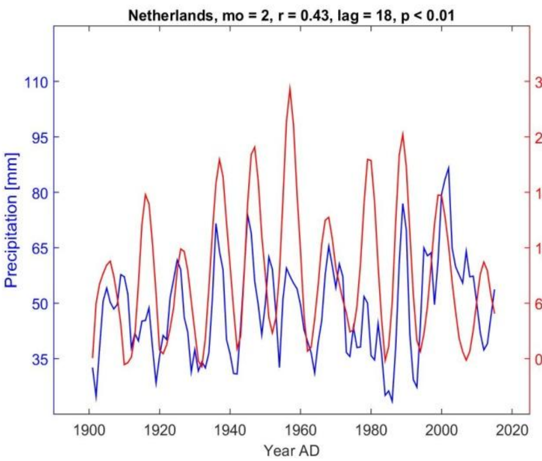

Lithuania, mo = 5, r = 0.34, lag = -55, p < 0.05
Precipitation [mm]
Sunspot Number
Year AD

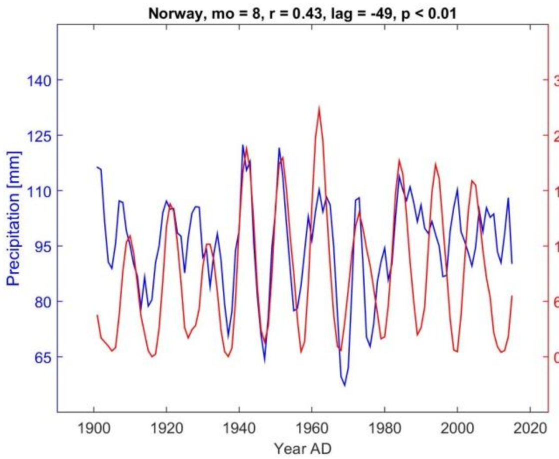

Luxembourg, mo = 2, r = 0.51, lag = 16, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD

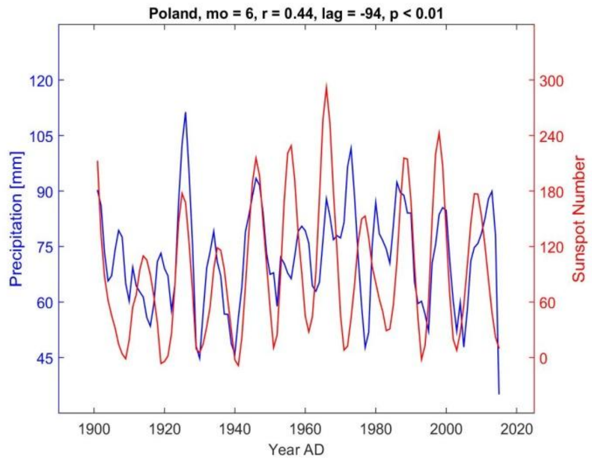

Macedonia, mo = 4, r = 0.48, lag = -15, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD

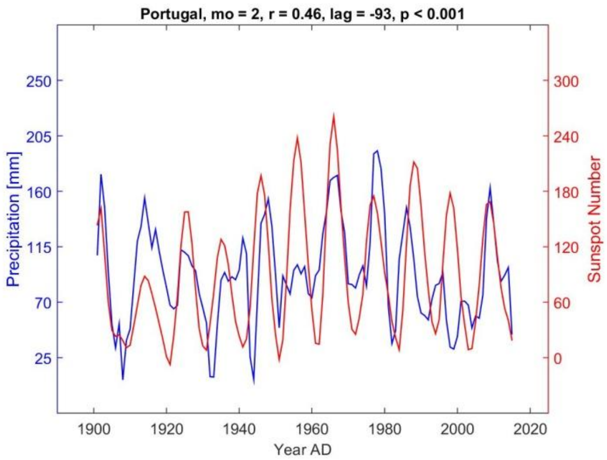

Moldova, mo = 12, r = 0.44, lag = -114, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD

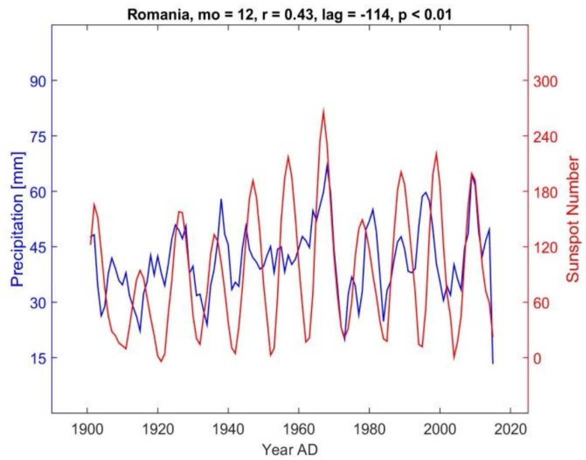

Montenegro, mo = 12, r = 0.38, lag = -109, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD

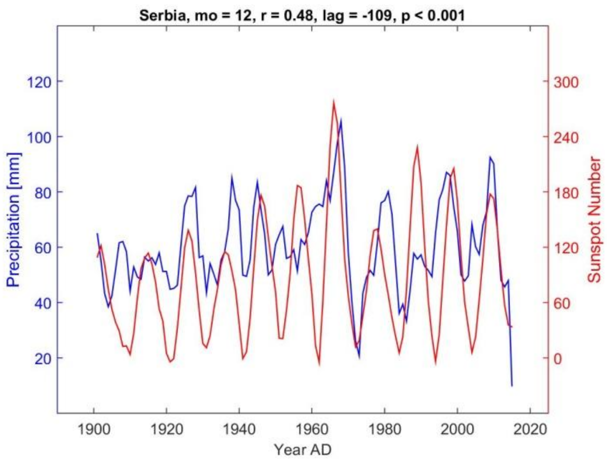

Netherlands, mo = 2, r = 0.43, lag = 18, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD

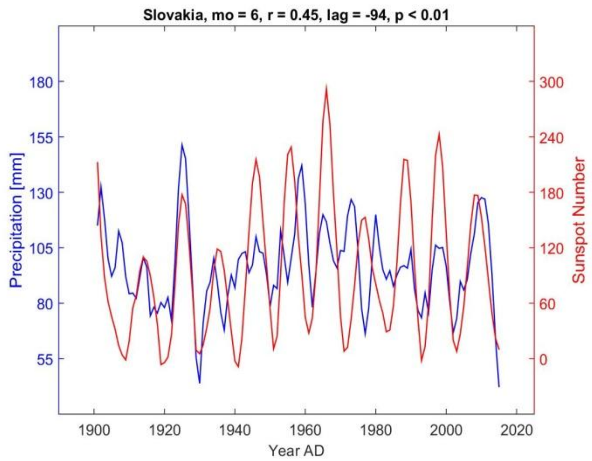

Norway, mo = 8, r = 0.43, lag = -49, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD
140
125
110
95
80
65
300
240
180
120
60
0
1900
1920
1940
1960
1980
2000
2020

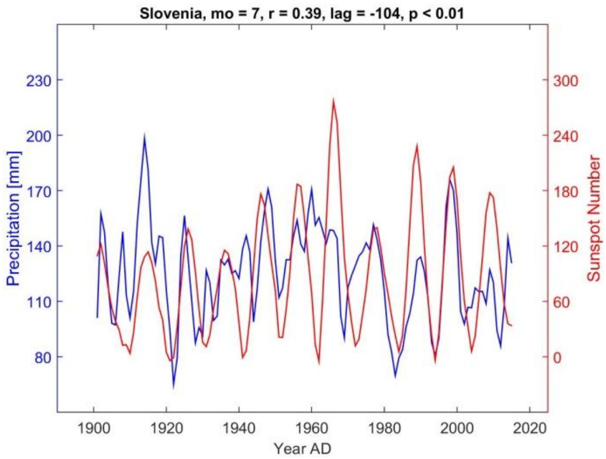

Poland, mo = 6, r = 0.44, lag = -94, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD
120
105
90
75
60
45
300
240
180
120
60
0
1900
1920
1940
1960
1980
2000
2020

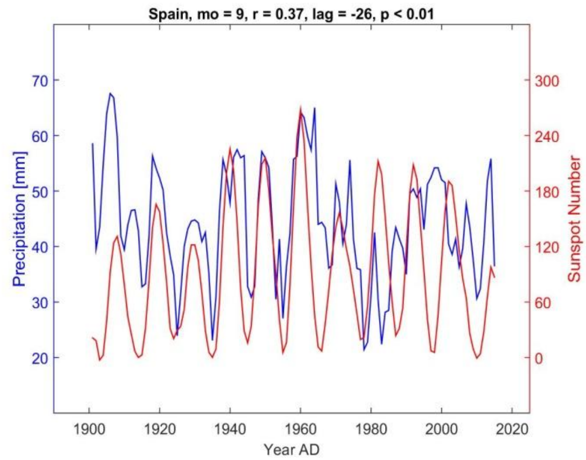

Portugal, mo = 2, r = 0.46, lag = -93, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD
250
205
160
115
70
25
300
240
180
120
60
0
1900
1920
1940
1960
1980
2000
2020

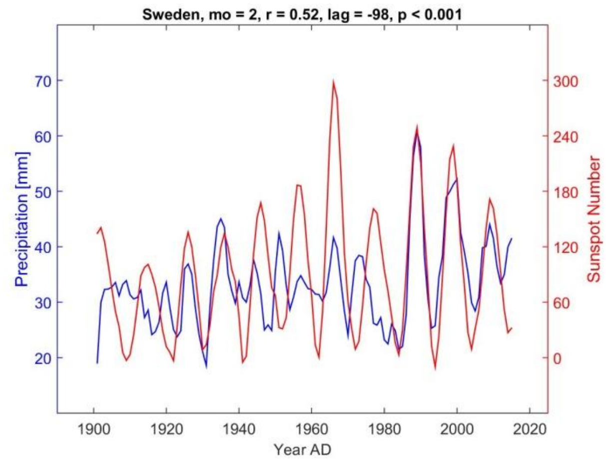

Romania, mo = 12, r = 0.43, lag = -114, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD
90
75
60
45
30
15
300
240
180
120
60
0
1900
1920
1940
1960
1980
2000
2020

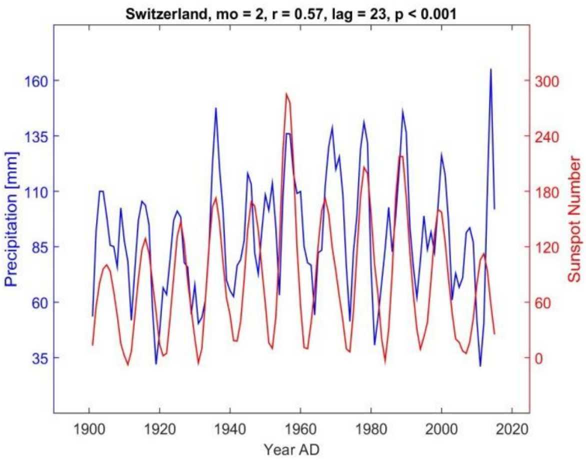

Serbia, mo = 12, r = 0.48, lag = -109, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD
120
100
80
60
40
20
300
240
180
120
60
0
1900
1920
1940
1960
1980
2000
2020

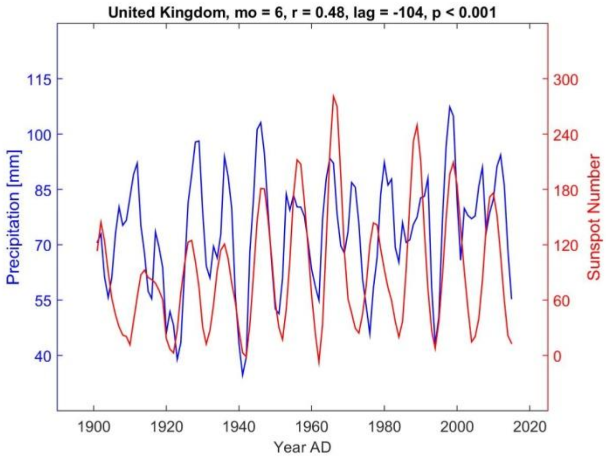

Slovakia, mo = 6, r = 0.45, lag = -94, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD
180
155
130
105
80
55
300
240
180
120
60
0
1900
1920
1940
1960
1980
2000
2020


Slovenia, mo = 7, r = 0.39, lag = -104, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD


Spain, mo = 9, r = 0.37, lag = -26, p < 0.01
Precipitation [mm]
Sunspot Number
Year AD


Sweden, mo = 2, r = 0.52, lag = -98, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD


Switzerland, mo = 2, r = 0.57, lag = 23, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD


United Kingdom, mo = 6, r = 0.48, lag = -104, p < 0.001
Precipitation [mm]
Sunspot Number
Year AD

3. Pearson correlation coefficients and lags

A table with the most positive correlation coefficients of precipitation vs. sunspots for 39 European countries (1901-2015) is shown in Table 1 in the main paper. Table S1 contains the respective solar lags. Tables S2 and S3 contain the most negative r values and the associated lags.

Table S1: *Lags of sunspots against precipitation, interval 1901-2015, by European country. The values refer to the* ***most positive*** *correlations found in a cross correlation window of -120 to +24 months, given in Table 1 of the main paper.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Albania	20	-69	-66	-15	4	-107	-22	-18	-35	-3	-72	-119
Austria	-20	23	-97	-75	-64	-94	20	-95	-93	-11	-9	-4
Belarus	2	-87	-88	-111	-55	-105	24	16	-71	-10	-22	-111
Belgium	-22	18	-97	2	-55	-92	-8	-83	-67	-94	-31	-117
Bosnia and Herz.	20	-57	-78	-25	20	-81	-116	-74	-92	-3	-104	-109
Bulgaria	-64	-64	-10	-3	7	-31	-54	-96	-94	23	-67	-119
Croatia	-41	-57	-78	-25	-75	-86	20	-83	-92	-14	3	-117
Czech Republic	-30	15	-109	20	-54	-94	20	-83	24	21	-9	-118
Denmark	-21	-112	-97	-10	-56	-104	-10	-48	-64	-112	-21	-95
Estonia	-2	-108	-120	-116	-68	-21	16	-83	-76	-103	-116	-100
Faroe Islands	-114	-99	-105	-117	-45	-36	-30	-51	-74	-76	-16	-57
Finland	-26	-98	-108	-23	-80	-107	-44	-51	-76	-100	-34	-39
France	20	19	6	-110	-39	-120	-113	-59	-43	-25	-31	17
Germany	-28	17	-97	-2	-52	-92	14	-120	-91	1	-31	-110
Greece	-53	-57	-22	-15	-20	-94	-34	-109	-12	23	-67	-7
Hungary	-64	22	-78	-57	-63	-96	-107	-77	-80	-40	-39	-117
Iceland	-27	-13	-26	-48	-119	-41	-61	-20	2	-60	-41	-43
Ireland	-13	12	-5	-32	-50	-104	-59	-83	-97	-117	-18	-7
Italy	-20	-65	-78	-3	-118	-86	-113	-91	-43	-13	-120	-27
Kosovo	-64	-62	-38	-15	16	-107	-22	-66	-68	-3	-61	-114
Latvia	-10	-108	-104	21	-55	-106	15	16	-76	-112	-21	-109
Liechtenstein	-40	23	-109	-86	-56	16	-100	-83	-36	1	-30	-104
Lithuania	-10	-108	-1	24	-55	-94	14	16	-59	-115	-21	-105
Luxembourg	-22	16	-97	2	-68	-93	-8	-120	-71	-82	-31	-117
Macedonia	-62	-62	-38	-15	16	-94	-22	-89	-36	22	-50	-119
Moldova	-76	-57	-54	-74	-28	-25	-22	22	-80	-3	-26	-114
Montenegro	20	-69	-78	-15	22	-107	8	-7	-92	9	-72	-109
Netherlands	-13	18	-97	-10	-64	-89	-112	-120	-79	1	-31	-107
Norway	-82	-98	-111	12	-71	-1	-118	-49	-64	-70	-77	-57
Poland	-18	-100	-109	15	-52	-94	14	-93	-68	21	-119	15
Portugal	20	-93	14	-106	-27	-49	-53	-106	-22	-118	-61	23
Romania	-64	-69	-54	-86	-28	-109	-22	-86	-80	-3	-52	-114
Serbia	-76	-69	-78	-34	20	-107	-22	-66	-80	-11	-52	-109
Slovakia	-44	20	-109	20	-51	-94	-116	-83	-80	-40	-27	-117
Slovenia	4	23	-78	9	-64	-85	-104	-83	-80	-20	-120	-27
Spain	20	-89	2	-98	13	-41	-65	-46	-26	-21	-59	18
Sweden	-119	-98	-111	-116	-119	-83	-115	-48	-64	-112	-19	-95
Switzerland	-40	23	-109	-97	-68	16	-108	-83	-43	-11	-31	-116
United Kingdom	-13	16	11	-37	-68	-104	-109	-51	-97	-118	-30	3

Table S2: *Correlation coefficients of precipitation vs. sunspots, interval 1901-2015, by European country. The values represent the* ***most negative*** *results in a cross correlation window of -80 to +24 months. Respective solar lags are shown in Table S3. Coefficients ≤0.40 are highlighted in bold red, coefficients -0.30 to -0.39 are marked in bold blue. p is the probability that the correlation r is by chance (false alarm probability). For values of |r| > 0.45 p < 0.001; for |r| > 0.35 p < 0.01; and for |r| > 0.25 p < 0.05.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Albania	-0,12	**-0,35**	-0,22	**-0,40**	-0,15	**-0,32**	-0,08	-0,05	-0,18	-0,24	-0,02	-0,28
Austria	-0,23	**-0,36**	-0,28	-0,16	**-0,42**	-0,25	**-0,42**	-0,19	-0,29	-0,23	-0,13	-0,21
Belgium	-0,24	**-0,30**	-0,15	**-0,33**	-0,18	**-0,30**	-0,25	-0,17	-0,16	-0,12	-0,29	-0,25
Belarus	**-0,36**	-0,28	-0,24	**-0,36**	**-0,48**	-0,21	**-0,45**	**-0,34**	-0,15	-0,28	-0,25	**-0,47**
Bosnia and Herz.	-0,08	-0,23	-0,24	-0,29	-0,23	-0,18	-0,15	-0,08	**-0,31**	-0,27	-0,02	-0,22
Bulgaria	-0,13	**-0,36**	-0,14	-0,15	-0,23	-0,18	**-0,30**	-0,23	-0,20	-0,21	-0,10	-0,14
Croatia	-0,14	-0,18	-0,21	-0,25	-0,26	-0,15	-0,22	-0,13	-0,27	**-0,31**	-0,06	-0,21
Czech Republic	-0,16	-0,20	-0,20	-0,17	**-0,45**	-0,25	**-0,38**	-0,13	**-0,32**	-0,16	-0,16	**-0,31**
Denmark	-0,20	**-0,32**	-0,17	**-0,31**	-0,23	-0,26	-0,14	**-0,31**	-0,04	-0,25	-0,21	-0,07
Estonia	-0,26	**-0,53**	-0,18	**-0,32**	-0,27	-0,14	-0,13	-0,26	-0,26	-0,21	-0,15	-0,19
Faroe Islands	-0,27	-0,27	-0,18	-0,19	-0,24	-0,06	-0,19	-0,27	-0,04	-0,17	**-0,43**	**-0,30**
Finland	-0,13	**-0,34**	-0,19	-0,25	-0,13	-0,14	-0,13	-0,21	**-0,33**	-0,20	-0,17	-0,22
France	-0,06	-0,28	-0,19	-0,19	-0,09	-0,25	-0,27	-0,27	-0,23	-0,29	**-0,36**	-0,27
Germany	-0,21	**-0,35**	-0,21	-0,17	**-0,37**	**-0,30**	-0,18	-0,18	**-0,31**	-0,23	**-0,30**	-0,22
Greece	-0,15	**-0,43**	-0,14	**-0,34**	-0,23	-0,22	-0,22	-0,18	-0,24	-0,14	-0,09	**-0,33**
Hungary	-0,18	-0,19	-0,25	-0,19	**-0,39**	-0,27	**-0,31**	-0,22	**-0,36**	-0,23	-0,03	-0,23
Iceland	-0,17	**-0,36**	-0,16	-0,05	-0,18	-0,19	-0,07	-0,04	-0,14	-0,29	-0,04	**-0,42**
Ireland	-0,08	**-0,43**	-0,06	-0,21	-0,25	**-0,40**	-0,14	-0,27	-0,02	-0,26	**-0,32**	-0,15
Italy	-0,18	**-0,40**	-0,23	-0,18	-0,20	-0,27	**-0,30**	-0,16	-0,28	-0,21	-0,21	-0,16
Kosovo	-0,19	**-0,35**	-0,19	**-0,39**	-0,29	-0,24	-0,13	-0,16	-0,20	-0,15	-0,08	-0,26
Latvia	-0,23	**-0,42**	-0,20	-0,28	**-0,32**	-0,12	-0,25	**-0,33**	-0,10	-0,21	-0,21	-0,21
Liechtenstein	-0,19	**-0,42**	**-0,39**	-0,19	-0,23	**-0,36**	**-0,39**	-0,28	-0,10	-0,29	**-0,31**	-0,13
Lithuania	-0,20	**-0,31**	-0,18	-0,23	**-0,44**	-0,17	**-0,35**	-0,28	-0,02	-0,20	-0,25	-0,25
Luxembourg	-0,24	**-0,32**	-0,19	**-0,31**	-0,10	-0,23	-0,22	-0,22	-0,24	-0,14	**-0,34**	-0,29
Macedonia	-0,19	**-0,35**	-0,23	**-0,42**	-0,29	-0,24	-0,17	-0,16	-0,24	-0,18	-0,06	-0,27
Moldova	-0,19	-0,21	-0,13	-0,20	-0,22	-0,09	-0,07	-0,15	-0,24	**-0,32**	-0,13	-0,20
Montenegro	-0,15	**-0,35**	-0,20	**-0,30**	-0,20	**-0,32**	-0,14	-0,10	-0,23	-0,27	0,03	-0,22
Netherlands	-0,19	**-0,32**	-0,17	-0,26	-0,28	**-0,38**	-0,13	-0,15	-0,09	-0,14	-0,23	-0,17
Norway	-0,15	-0,15	-0,23	-0,18	-0,16	-0,03	-0,16	**-0,51**	0,02	-0,16	-0,07	-0,18
Poland	**-0,31**	-0,22	**-0,37**	**-0,45**	**-0,48**	**-0,30**	**-0,35**	**-0,32**	-0,23	-0,25	-0,10	-0,25
Portugal	-0,03	**-0,38**	-0,17	-0,09	**-0,30**	**-0,31**	-0,14	-0,11	-0,16	-0,18	-0,22	-0,28
Romania	**-0,30**	-0,29	-0,21	-0,20	-0,21	-0,19	-0,15	-0,18	-0,27	-0,26	-0,19	-0,17
Serbia	-0,25	**-0,32**	-0,07	-0,21	**-0,33**	-0,15	-0,13	-0,18	-0,23	-0,20	-0,06	-0,19
Slovakia	-0,16	-0,19	-0,22	-0,27	**-0,43**	-0,26	**-0,39**	-0,22	**-0,32**	-0,18	-0,05	-0,25
Slovenia	-0,15	-0,25	-0,24	-0,11	-0,28	-0,10	**-0,31**	-0,17	**-0,33**	**-0,31**	-0,24	-0,15
Spain	-0,10	-0,25	-0,26	-0,29	-0,26	-0,23	-0,24	-0,06	**-0,37**	-0,20	-0,22	-0,14
Sweden	-0,12	**-0,32**	-0,19	-0,21	-0,18	-0,04	-0,05	-0,27	-0,21	-0,11	-0,15	-0,12
Switzerland	-0,11	**-0,35**	**-0,30**	-0,12	-0,25	-0,19	**-0,44**	-0,28	-0,13	**-0,31**	-0,29	-0,22
United Kingdom	-0,29	**-0,47**	-0,16	-0,24	**-0,35**	**-0,41**	-0,22	-0,20	-0,03	**-0,31**	**-0,31**	-0,12

Table S3: *Lags of sunspots against precipitation, interval 1901-2015, by European country. The values refer to the* ***most negative*** *correlations found in a cross correlation window of -80 to +24 months, which are shown in Table S2 of this supplement.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Albania	-3	-4	23	-79	-48	-38	-73	17	17	-61	-4	-57
Austria	-79	-32	-34	-24	-2	-37	-40	-46	-28	-79	-57	-70
Belarus	-71	-21	-22	-46	13	-45	-33	-42	-24	-72	23	-52
Belgium	-79	-41	-40	-68	3	-35	-77	-30	-8	-50	24	-58
Bosnia and Herz.	-5	-6	-7	24	-26	-9	-59	-36	-13	-76	-57	-45
Bulgaria	1	-16	23	-67	-67	-80	15	-48	-27	-36	-7	-53
Croatia	-80	-14	-7	24	-14	-11	-29	-36	13	-76	-57	-57
Czech Republic	13	-32	-49	-41	17	-29	-46	-23	-28	-54	-79	-67
Denmark	-74	-49	-33	-68	21	-35	-77	22	-24	-50	-79	-34
Estonia	-59	-41	-58	-55	-9	-73	-42	-18	-22	-39	19	2
Finland	-76	-29	-18	-79	-21	-49	10	9	-8	-27	14	23
France	-78	-32	-49	-48	18	-60	-51	6	14	-78	23	-57
Faroe Islands	-16	-41	-18	-38	21	19	14	21	-19	-15	-77	2
Germany	-79	-37	-36	-69	21	-35	-28	-78	-24	-66	24	-53
Greece	9	-1	23	-80	-75	16	16	-50	17	-36	-10	-71
Hungary	-1	-14	-12	-12	-2	-34	-41	-17	1	11	24	-57
Iceland	20	-77	-78	22	-68	17	2	-59	-60	16	-73	24
Ireland	-75	-53	-58	16	13	-35	7	-22	-38	-50	-79	-67
Italy	-78	-14	-32	-68	-57	-26	-43	-26	15	-76	-56	-69
Kosovo	-13	-4	23	-79	-35	-47	-73	14	17	-60	14	-55
Latvia	-70	-41	-58	-53	2	-53	-42	-42	-14	-38	23	-52
Liechtenstein	-80	-44	-37	-18	7	-44	-46	-12	12	-66	23	-55
Lithuania	-70	-33	-58	-41	16	-41	-46	-30	-12	-49	23	-49
Luxembourg	-79	-37	-40	-68	-9	-35	-66	-66	-8	-50	24	-57
Macedonia	-5	-4	23	-79	-43	-47	-75	-24	17	-56	2	-56
Moldova	-11	-4	23	-11	16	-71	13	-37	-29	-61	-80	-51
Montenegro	-36	-7	-7	-79	-38	-52	-61	-48	-13	-50	-46	-45
Netherlands	-78	-49	-33	-69	3	-35	24	-42	-24	-50	24	-47
Norway	16	-53	-63	-46	21	-69	-77	21	-20	-15	-27	17
Poland	-72	-33	-58	-48	17	-34	-58	-33	-13	-50	-57	-53
Portugal	-28	-27	-49	-38	-72	9	10	-25	20	21	-1	-43
Romania	-11	-16	23	-23	-79	-48	-72	-29	-16	-61	24	-49
Serbia	-11	-4	16	24	-33	-27	-59	7	-13	-71	14	-43
Slovakia	13	-28	-49	-43	10	-34	-51	-23	-12	11	-77	-57
Slovenia	-78	-12	-19	-80	-14	-26	-41	-36	7	-76	-57	-69
Spain	-28	-27	-73	-28	-72	11	3	15	20	-80	-1	-31
Sweden	-64	-24	-51	-67	-33	-37	-58	9	-8	23	24	-22
Switzerland	-80	-37	-44	-7	3	-48	-46	-18	12	-73	23	-43
United Kingdom	-75	-53	-58	23	-11	-35	-65	22	-34	-62	23	-67

4. Monthly Correlation Coefficient Maps

The maps shown in this supplement chapter complement those shown in the main paper in Fig. 3 (February), Fig. 4 (May), Fig. 6 (June), Fig. 7 (July), and Fig. 8 (December).

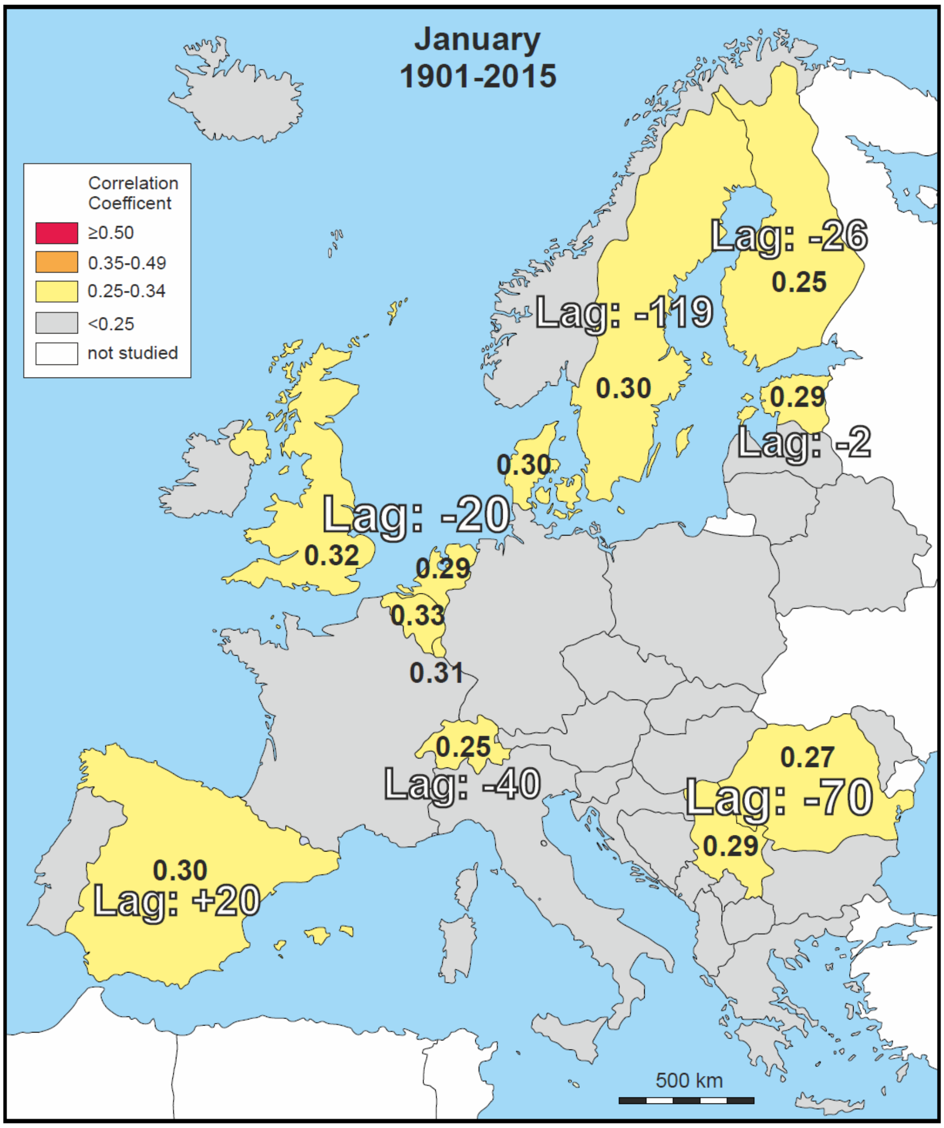


Fig. S3: *Map showing the 1901-2015 most positive correlation coefficients for January precipitation and sunspots on a country-by-country basis. Pearson r values from Table 1. All maps: Lags are simplified and generally fall within ±10 months of the statistically calculated value (Table S1).*

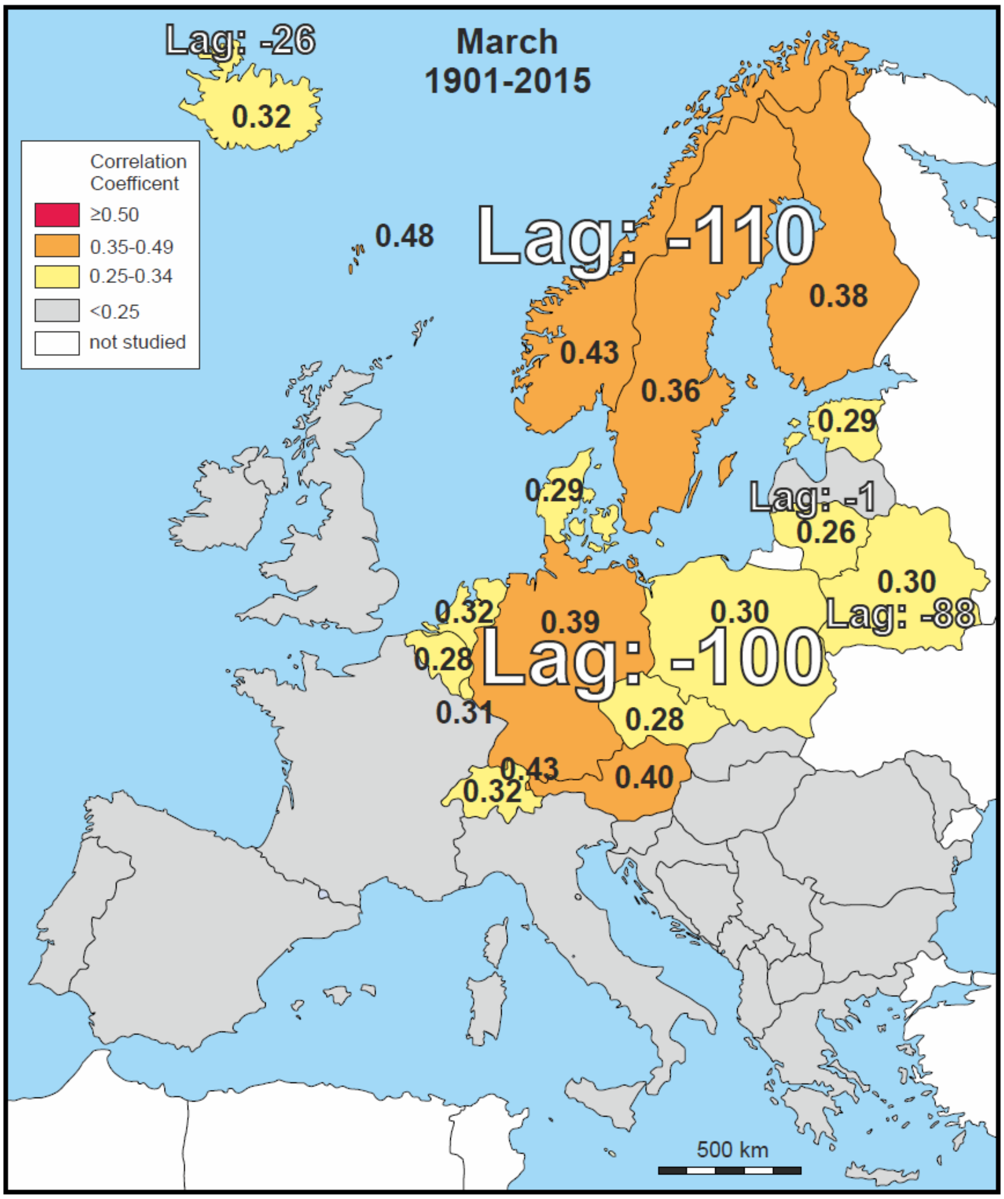


Fig. S4: *Map showing the 1901-2015 most positive correlation coefficients for March precipitation and sunspots on a country-by-country basis. Pearson r values from Table 1. All maps: Lags are simplified and generally fall within ±10 months of the statistically calculated value (Table S1).*

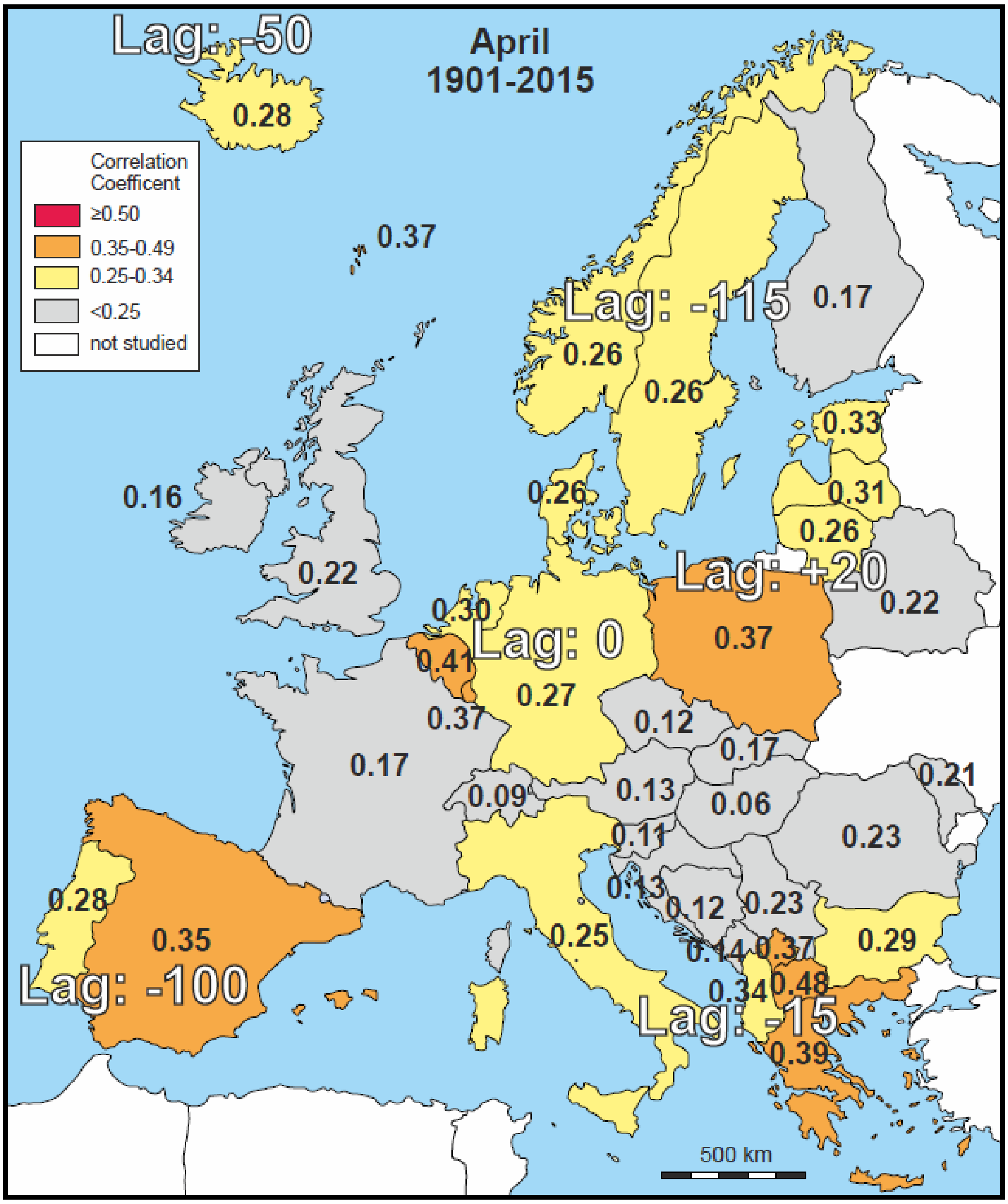


Fig. S5 *Map showing the 1901-2015 most positive correlation coefficients for April precipitation and sunspots on a country-by-country basis. Pearson r values from Table 1. All maps: Lags are simplified and generally fall within ±10 months of the statistically calculated value (Table S1).*

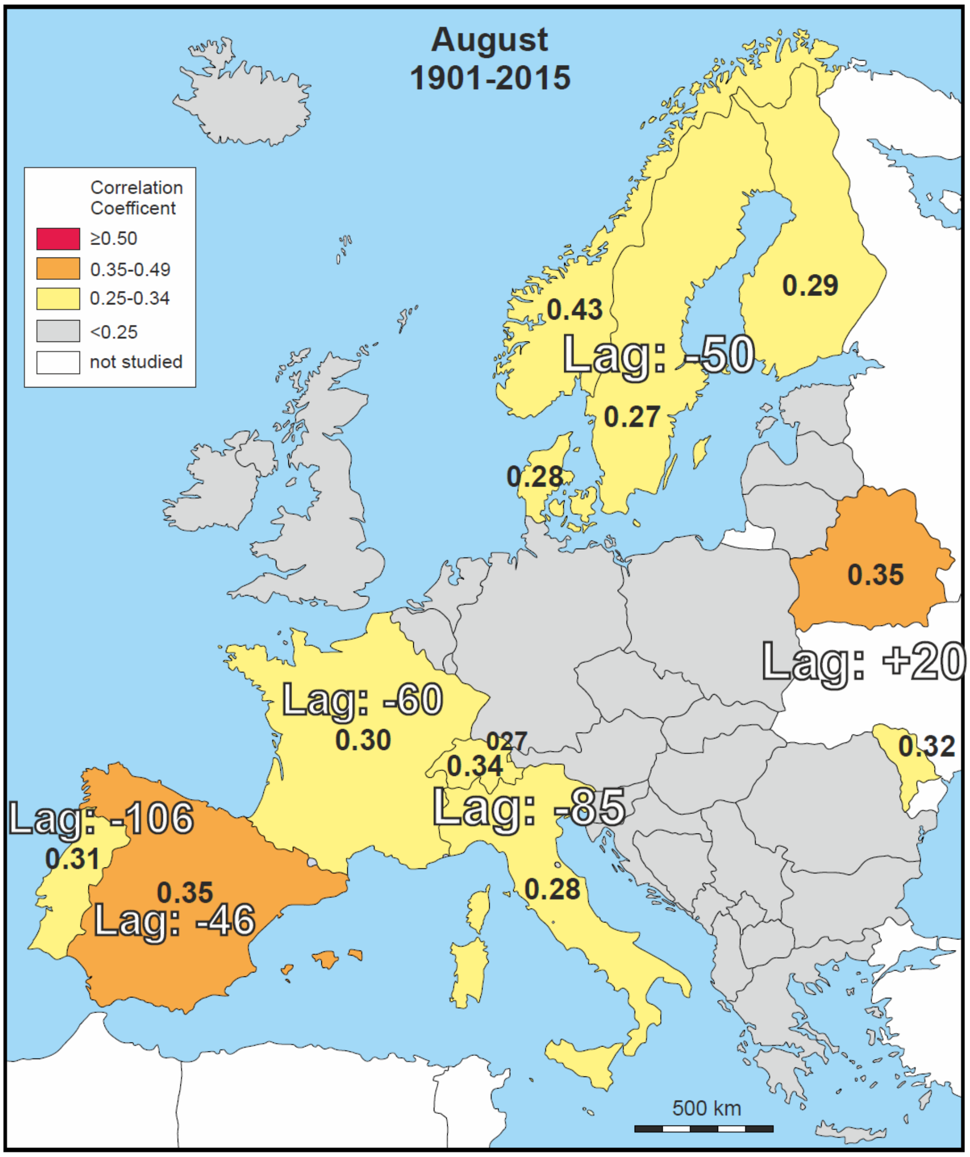


Fig. S6: *Map showing the 1901-2015 most positive correlation coefficients for August precipitation and sunspots on a country-by-country basis. Pearson r values from Table 1. All maps: Lags are simplified and generally fall within ±10 months of the statistically calculated value (Table S1).*

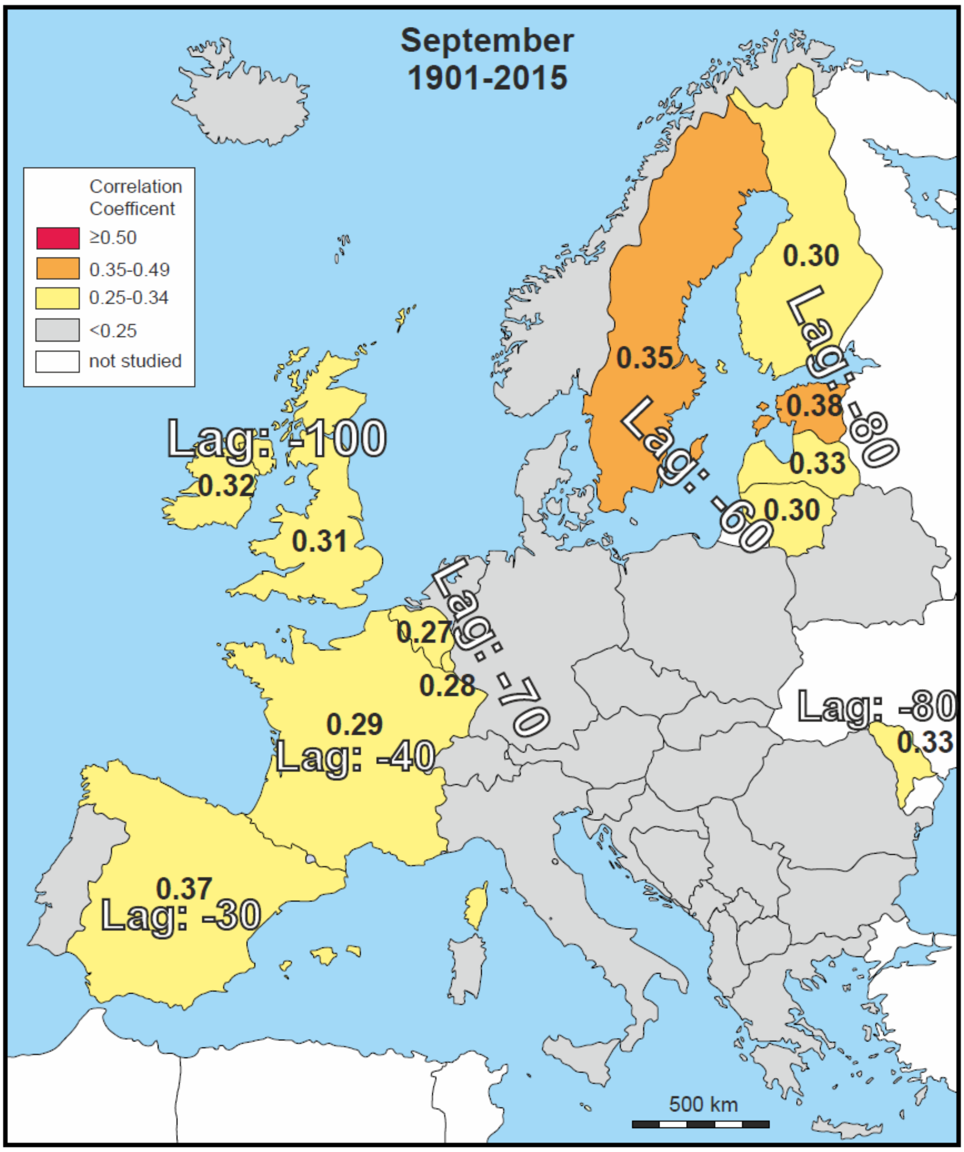


Fig. S7: *Map showing the 1901-2015 most positive correlation coefficients for September precipitation and sunspots on a country-by-country basis. Pearson r values from Table 1. All maps: Lags are simplified and generally fall within ±10 months of the statistically calculated value (Table S1).*

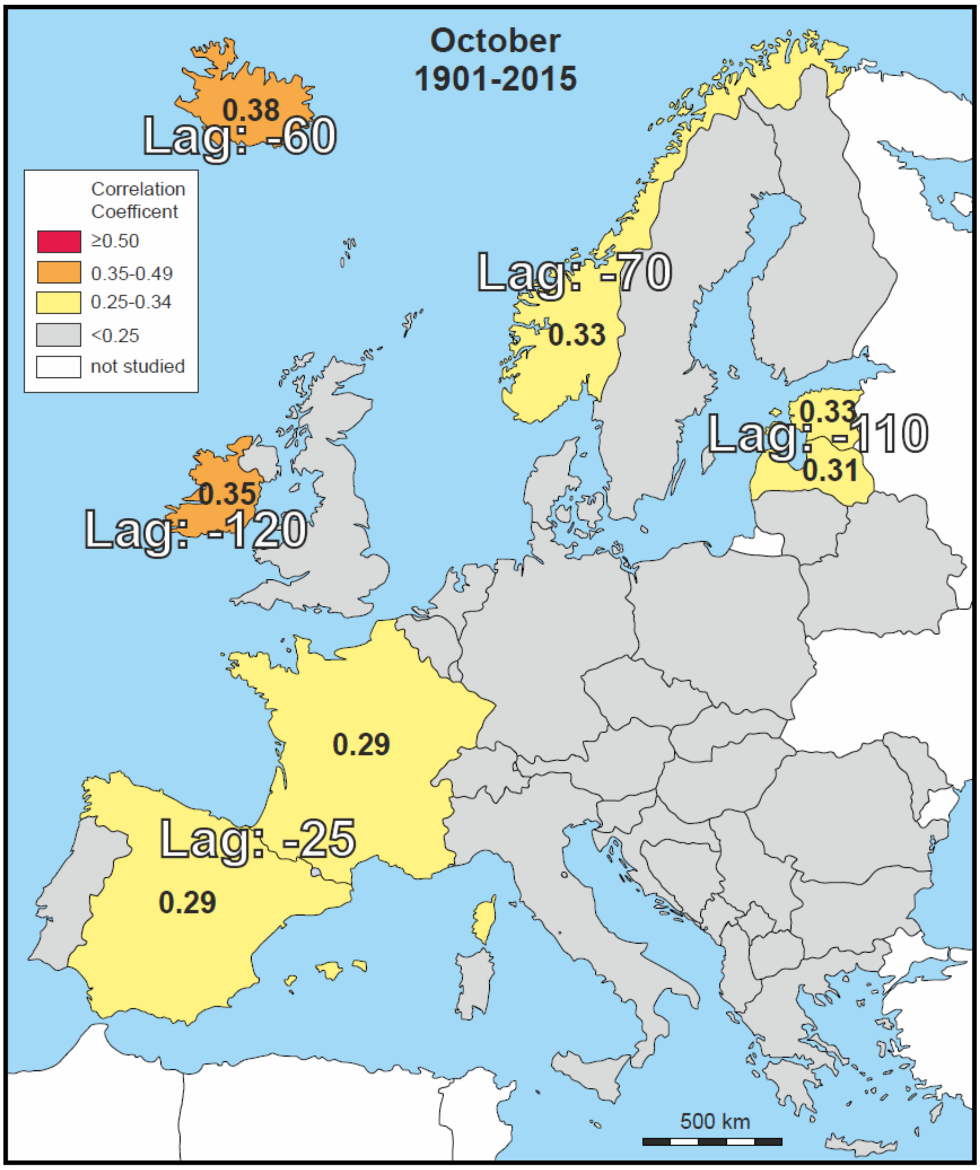


Fig. S8: *Map showing the 1901-2015 most positive correlation coefficients for October precipitation and sunspots on a country-by-country basis. Pearson r values from Table 1. All maps: Lags are simplified and generally fall within ±10 months of the statistically calculated value (Table S1).*

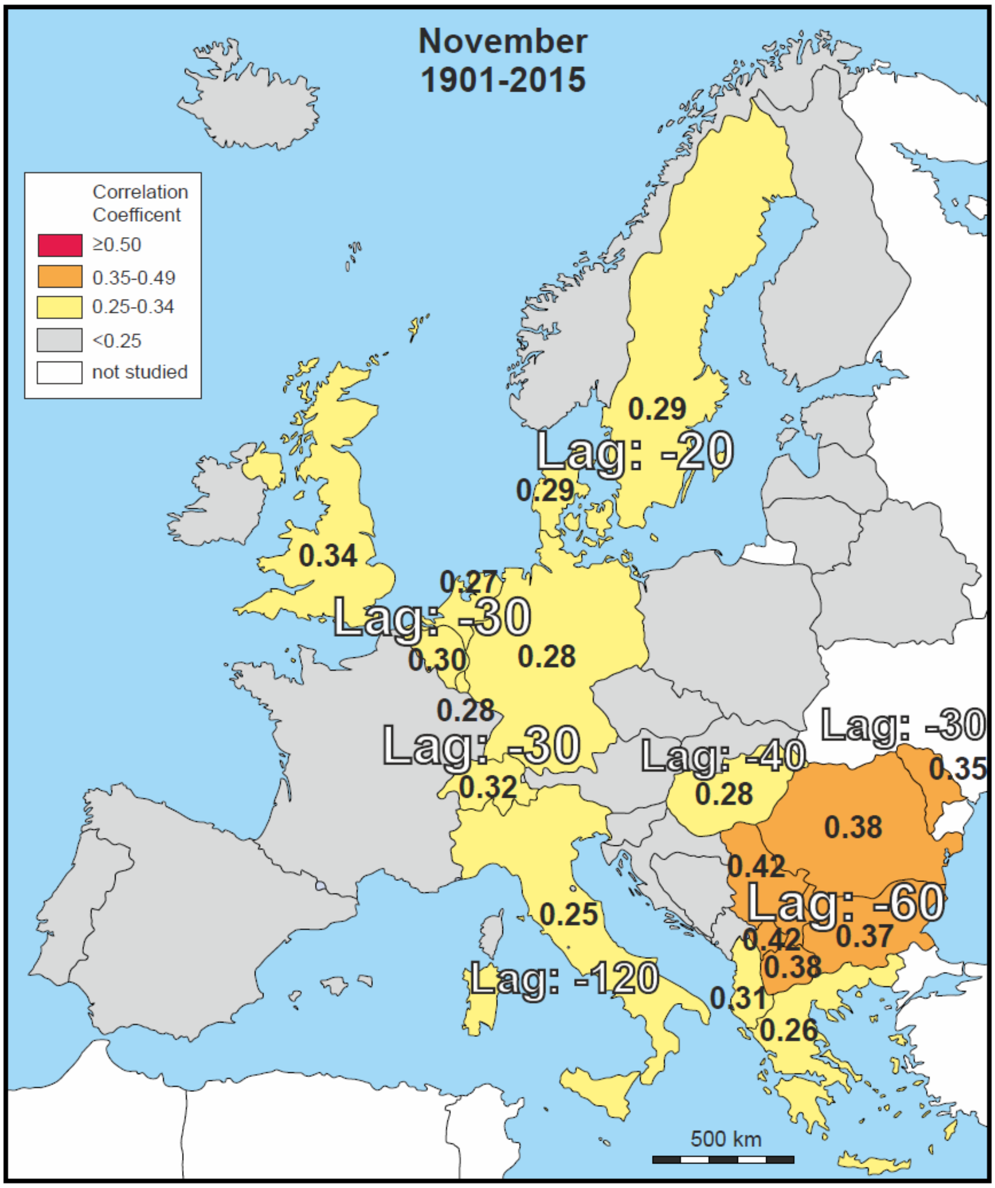


Fig. S9: *Map showing the 1901-2015 most positive correlation coefficients for November precipitation and sunspots on a country-by-country basis. Pearson r values from Table 1. All maps: Lags are simplified and generally fall within ±10 months of the statistically calculated value (Table S1).*

5. Correlation coefficient against Sun lag

In order to find the best positive and negative correlation coefficients, the sunspot series is progressively shifted against the precipitation series, the latter being kept stable. Negative solar lags imply that the precipitation lags the solar signal. Positive solar lags are purely mathematical and would mean that the solar signal lags precipitation. When plotting r values against the solar lag for individual monthly country precipitation series, the result is an oscillating curve, with the extreme values represented by the most positive and most negative correlation coefficients. The period of the oscillation corresponds to one ~11 year Schwabe solar cycle, whilst the minimum and maximum values are offset by about half a Schwabe cycle. The graphs in this supplement chapter show example plots of r values against solar lag which inform about important phase relationships.

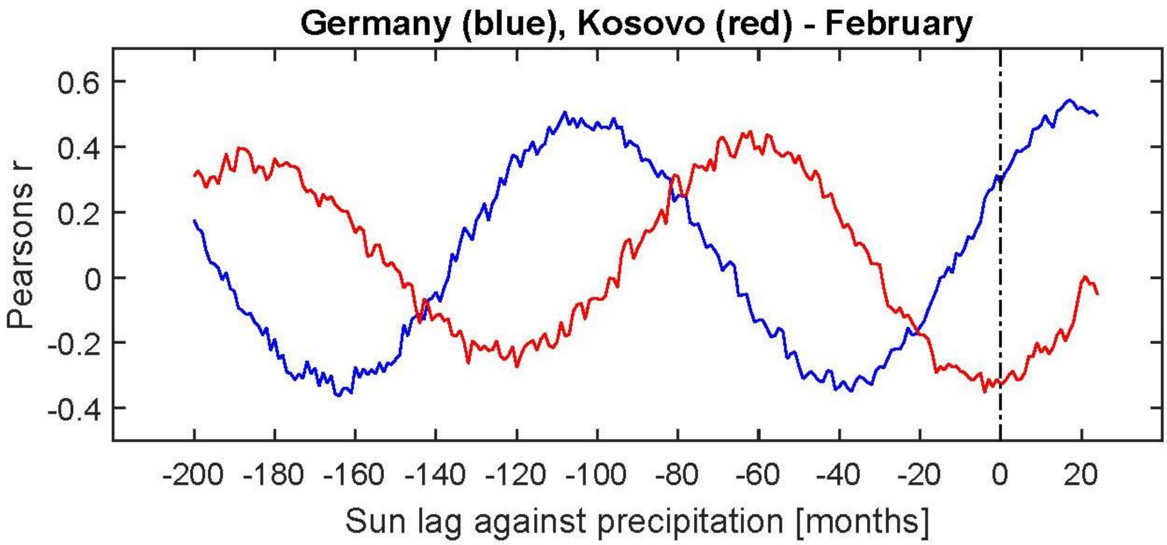


Fig. S10: *Plot of r values against solar lag: Germany and Kosovo (both February)*

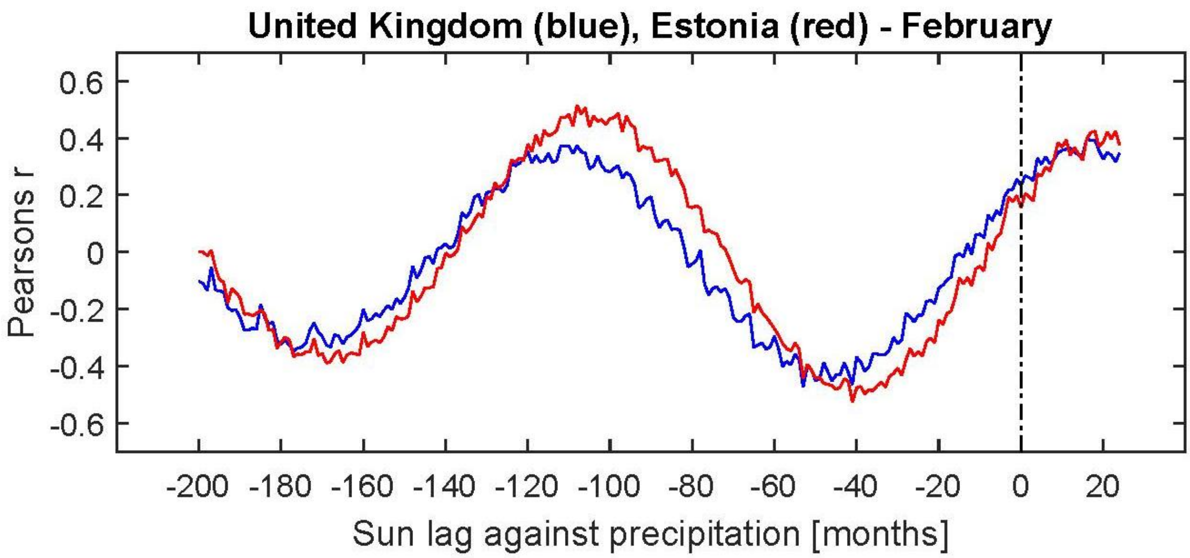


Fig. S11: *Plot of r values against solar lag: UK and Estonia (both February)*

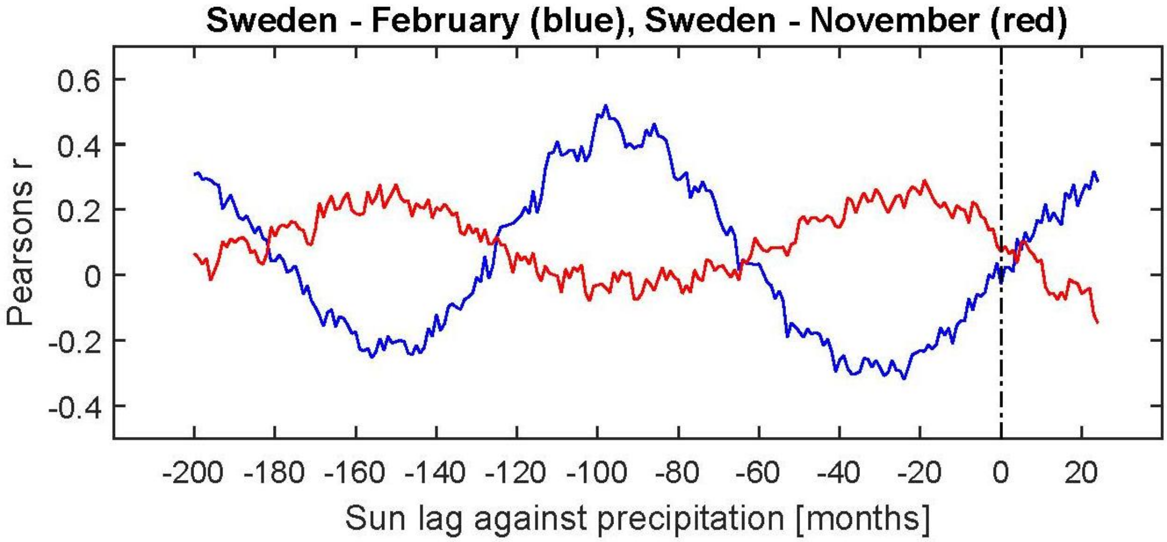


Fig. S12: *Plot of r values against solar lag: Sweden (February and November)*

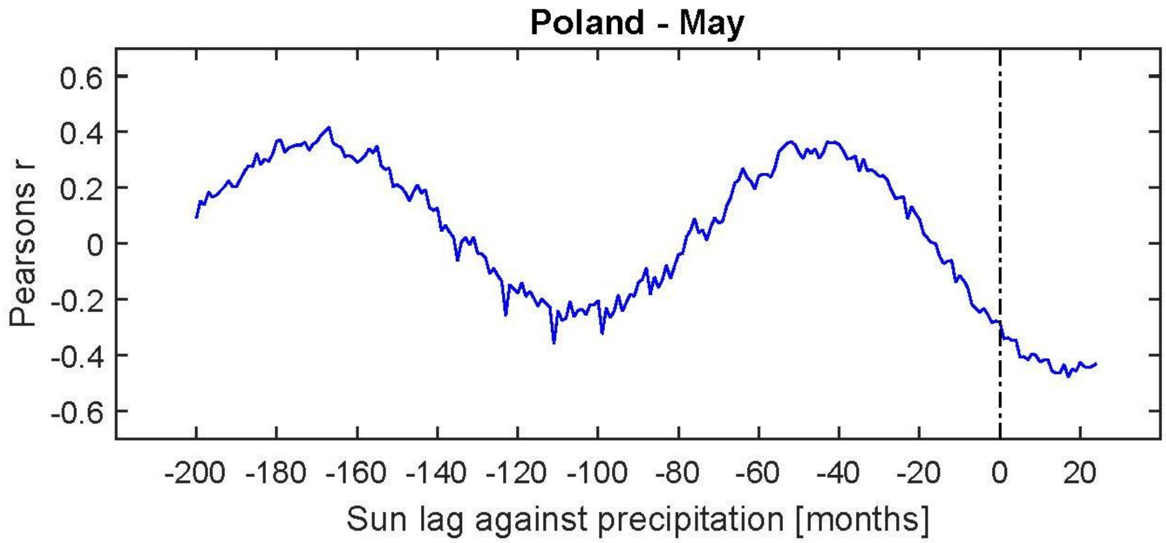


Fig. S13: *Plot of r values against solar lag: Poland (May)*

6. Examples Germany and Poland

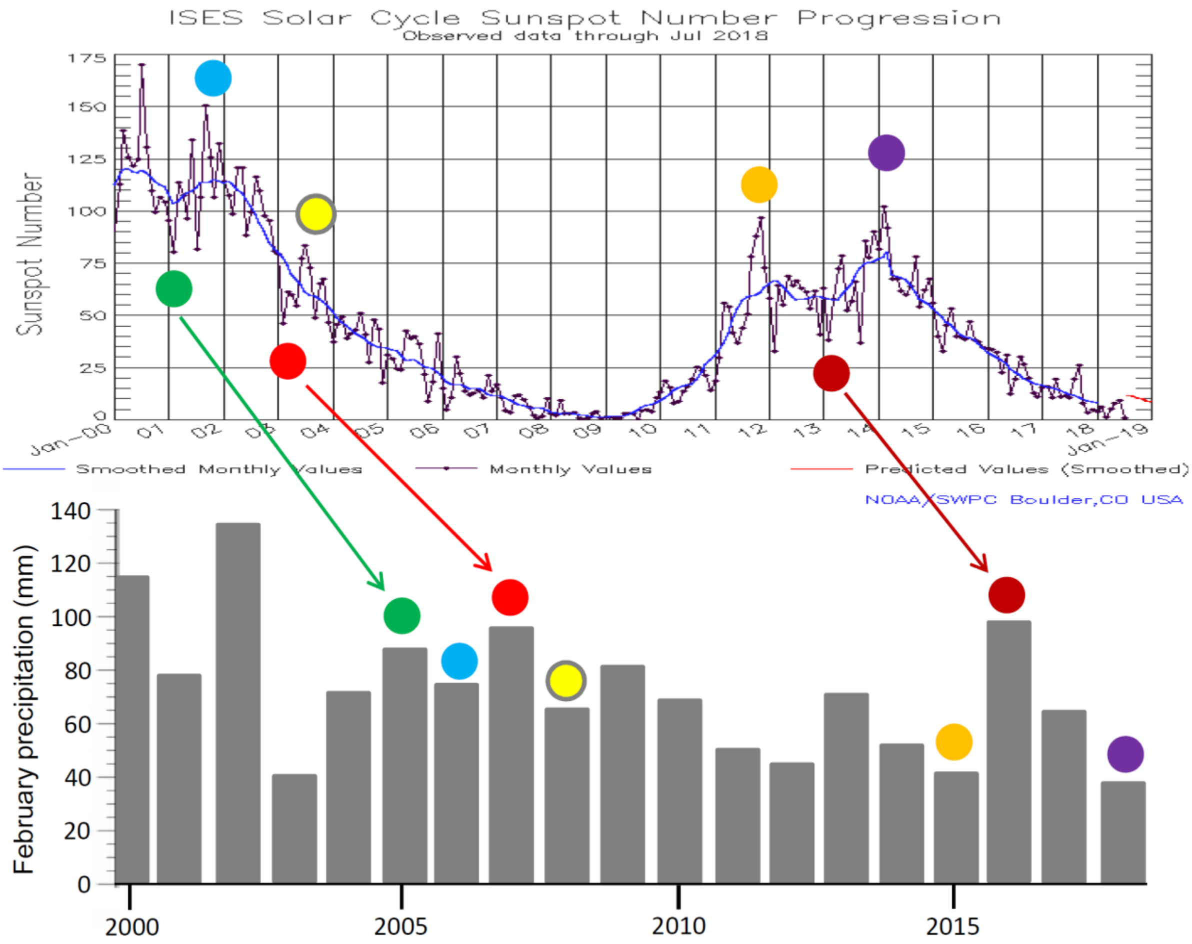
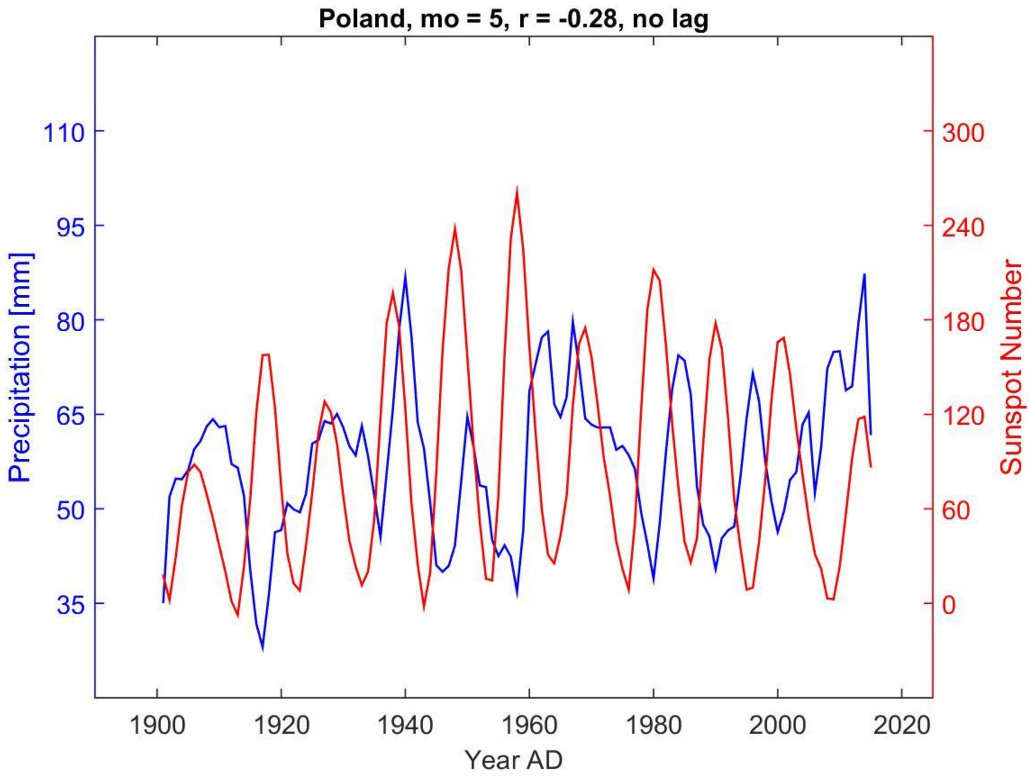
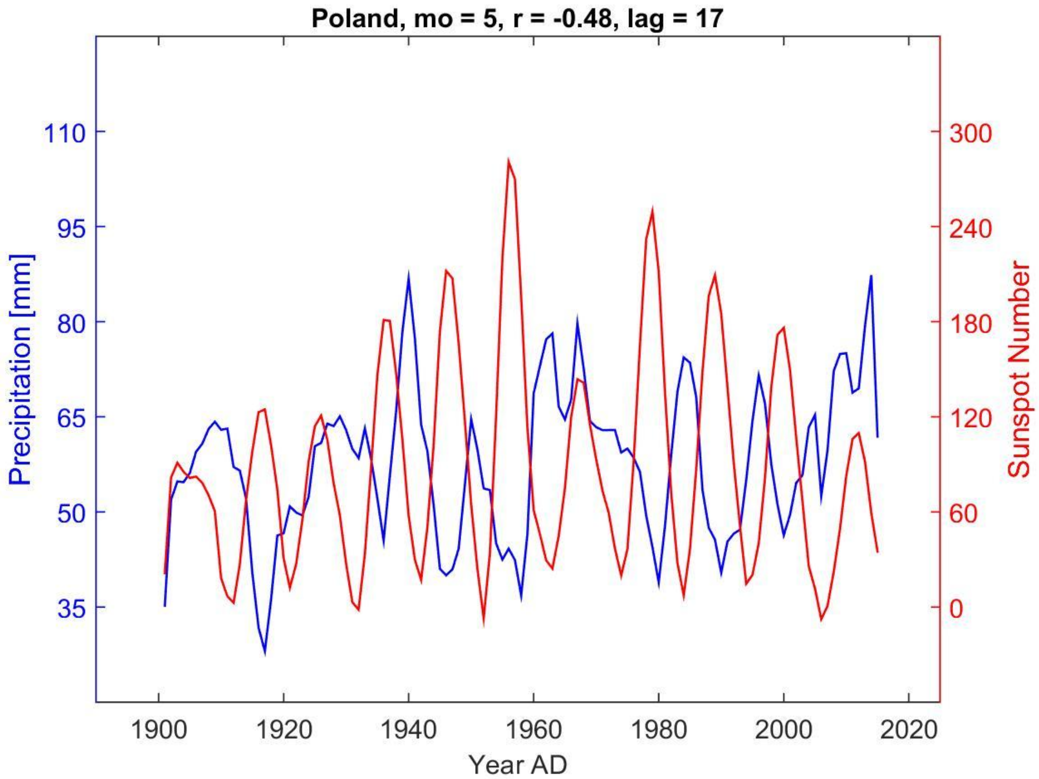


Fig. S14: *Comparison of solar activity and February rainfall in Germany 2000-2018 to illustrate potential inverse correlation with the rain lagging by 4-5 years. Colour-coded dots mark prominent highs and lows in the sunspot time series which seem to appear in an inverse manner in the rainfall time series about half a solar Schwabe cycle later. For example, a solar high at the beginning of 2014 is thought to correspond to low precipitation in 2018 (purple dot). Correlation arrows only drawn for solar lows to avoid graphical overloading of figure. Sunspot graph in upper part of figure is from from Space Weather Prediction Center of the National Oceanic and Atmospheric Administration, https://www.swpc.noaa.gov/, accessed on 1 August 2018).*

Fig. S15: *May rainfall in Poland compared to sunspots, plotted without (top) and with (bottom) solar lag shift. The time series in the lower diagram refers to the most negative r.*





7. Historical precipitation series

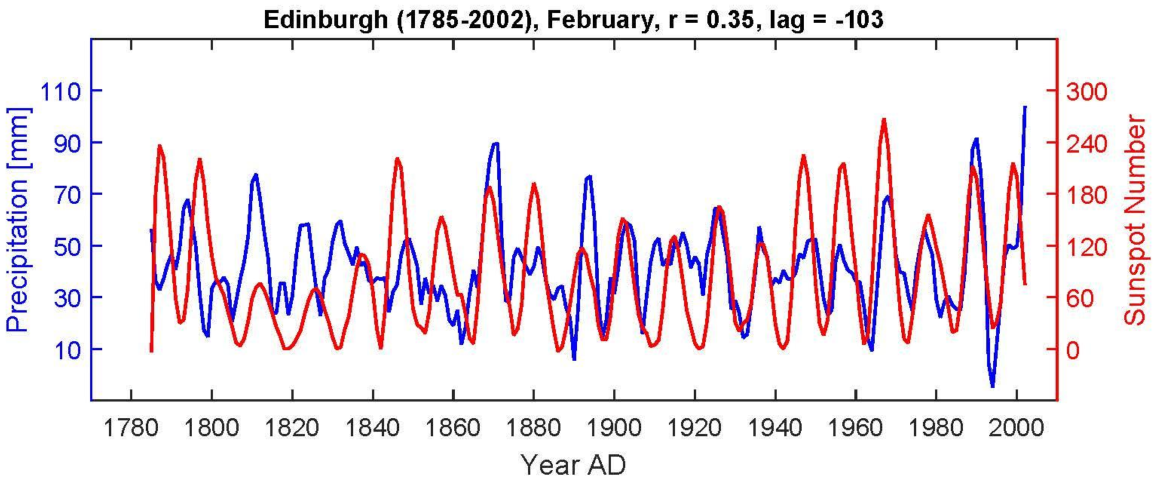


Fig. S16: *Edinburgh February precipitation compared to changes in sunspots for the period 1785-2002. The precipitation lags the solar signal by 103 months. p < 0.001 is the probability that r = 0.35 is caused by chance.*

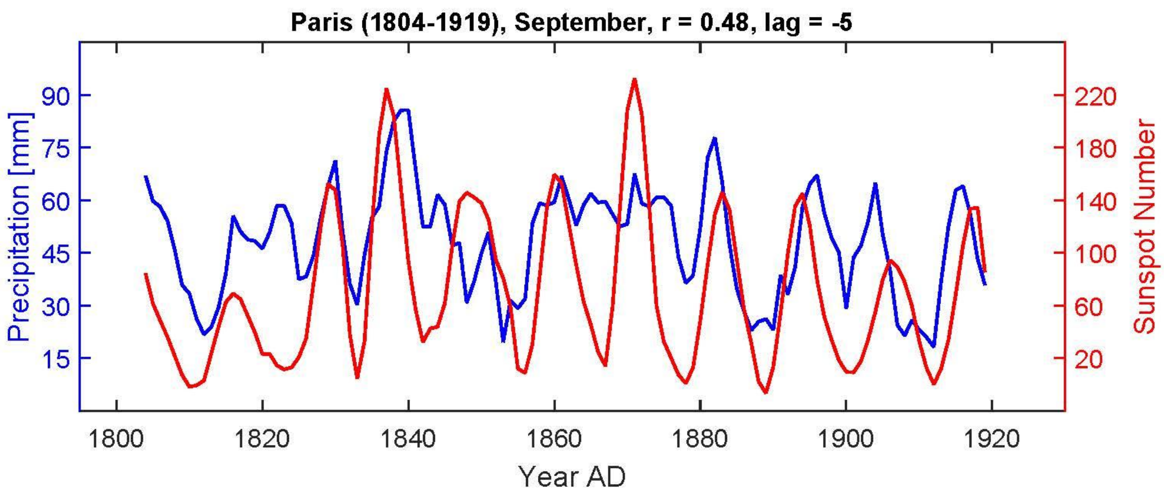


Fig. S17: *Paris September precipitation compared to changes in sunspots for the period 1804-1919. The precipitation lags the solar signal by 5 months. p < 0.001 is the probability that r = 0.48 is caused by chance.*

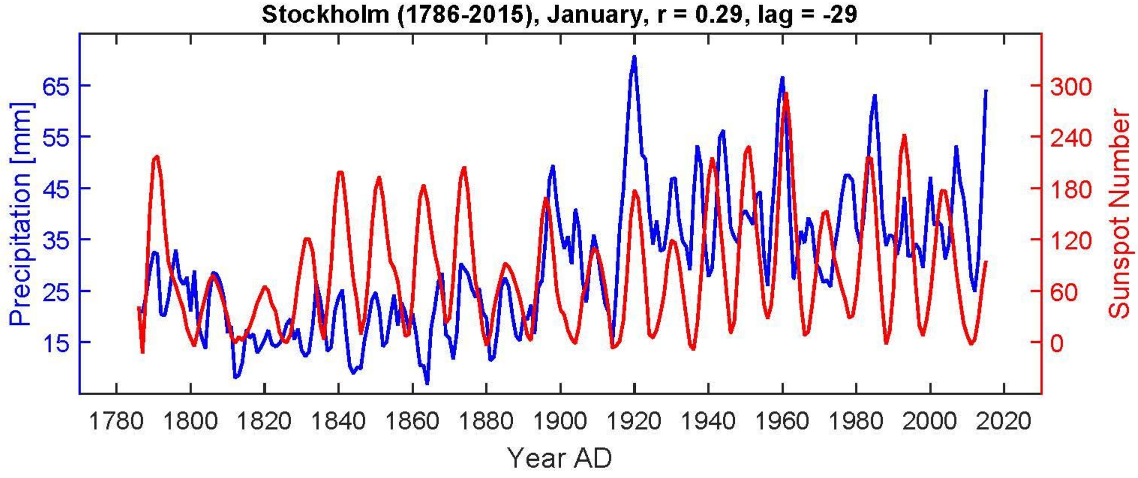


Fig.S18: *January precipitation compared to changes in sunspots. The precipitation lags the solar signal by 29 months. p < 0.001 is the probability that r = 0.35 is caused by chance.*

Table S4: *Correlation coefficients of precipitation vs. sunspots, historical series. The values represent the **most positive** results in a cross correlation window of -120 to +24 months. Respective solar lags are shown in in Table S5. Coefficients ≥0.40 are highlighted in bold red, coefficients 0.30-0.39 are marked in bold blue.*

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Edinburgh	**0.30**	**0.35**	0.18	0.11	0.19	0.28	0.15	0.05	**0.32**	0.11	**0.33**	0.13
Stockholm	0.29	0.24	0.22	0.10	0.22	0.22	0.12	0.16	0.21	0.08	0.17	0.18
Paris	0.25	0.14	0.20	**0.50**	0.19	**0.40**	0.25	0.18	**0.48**	0.20	0.18	0.06

Table S5: *Lags of sunspots against precipitation, historical city series. The values refer to the **most positive** correlations found in a cross correlation window of -120 until +24 months, shown in Table S4.*

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Edinburgh	-11	-103	1	-98	-92	-111	-3	-4	-88	-27	-38	-79
Stockholm	-29	-78	18	-116	-78	-45	-118	-59	-104	-111	-22	-89
Paris	-64	-82	15	-107	-76	-26	4	5	-5	-39	-22	19

Table S6: *Correlation coefficients of precipitation vs. sunspots, historical series. The values represent the* ***most negative*** *results in a cross correlation window of -80 to +24 months. Respective solar lags are shown in in Table S7. Coefficients -0.30 to -0.39 are marked in bold blue.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Edinburgh	-0.07	**-0.35**	-0.18	-0.18	-0.17	-0.11	-0.11	-0.10	-0.00	-0.11	-0.26	-0.08
Stockholm	-0.03	-0.15	-0.13	-0.13	-0.25	-0.23	-0.18	-0.06	-0.13	-0.11	-0.10	-0.13
Paris	-0.16	-0.23	-0.18	-0.29	**-0.32**	-0.20	-0.24	-0.06	-0.17	-0.19	-0.12	**-0.31**

Table S7: *Lags of sunspots against precipitation, historical city series. The values refer to the* ***most negative*** *correlations found in a cross correlation window of -80 until +24 months, shown in Table S6.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Edinburgh	-66	-49	-79	-26	-33	-47	-45	-54	-20	-80	24	-28
Stockholm	24	-24	-60	-73	-21	20	20	20	-13	23	16	-10
Paris	-21	-30	-35	-43	-20	24	-51	-25	-70	21	24	-40

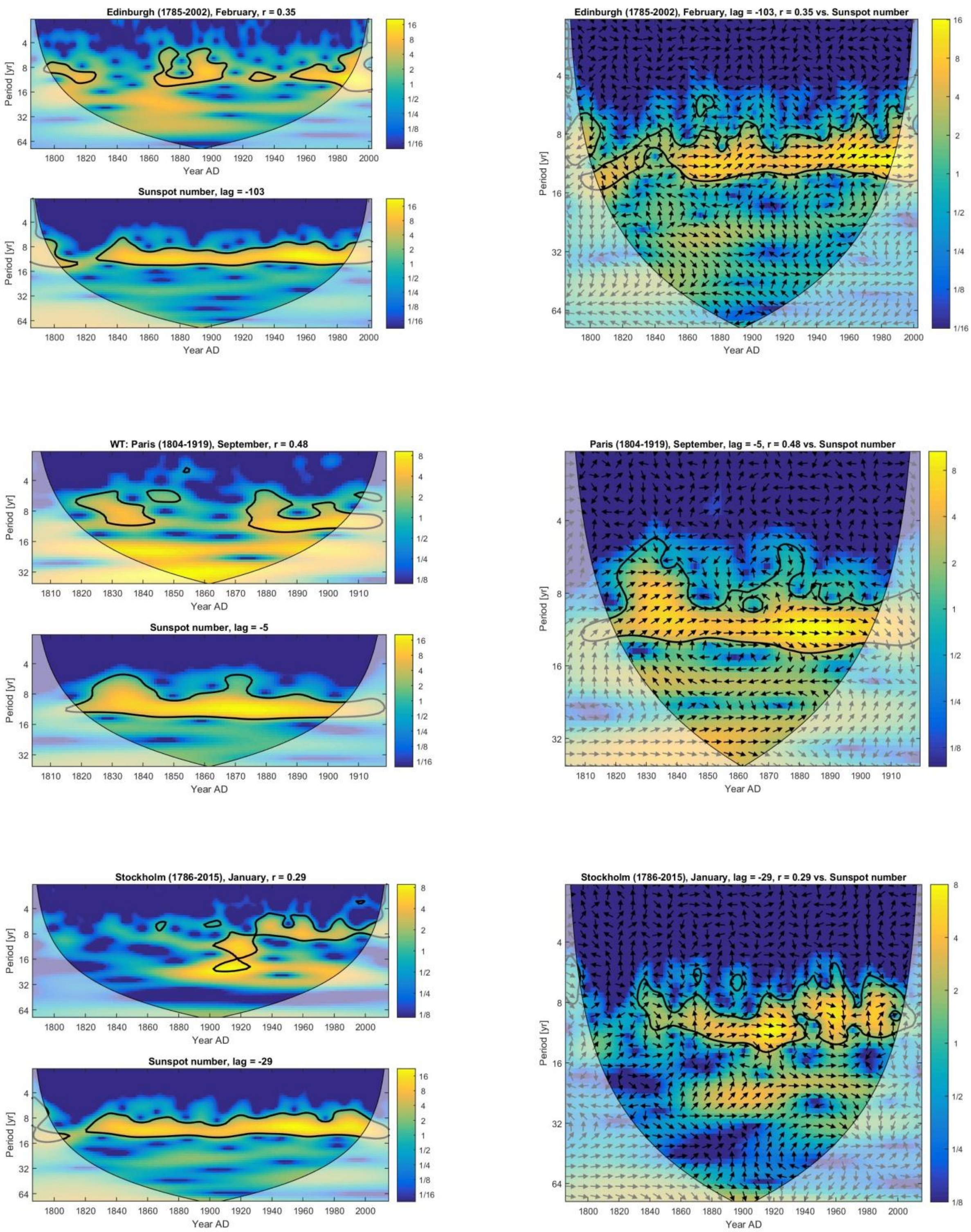


Fig. S19: *Frequency analysis of the historical precipitation series of Edinburgh (top), Paris (middle) and Stockholm (base), compared to sunspots. The panels in the upper left of each series are the wavelet graphs of precipitation, parameters given in the heading. The panels in the lower left show the wavelet graphs of the sunspot numbers with lags (months) indicated in the heading. The panels on the right show the cross wavelet transform in which the relative phase relationship between precipitation and solar signal is shown as arrows with in-phase pointing right, anti-phase pointing left. The cone of influence in all wavelet graphs is indicated by a black contour and designates the 5% significance level against red noise.*

8. Savitzky-Golay Filter vs. Simple Moving Avarage

A Savitzky-Golay filter (SGF) of frame size 11 and polynomial order 5 was used for all precipitation and sunspot time series. The following graphs compare the results of the SGF with those of a simple moving average (SMA) using a window-width of 3 data points. The r values achieved with SGF are between 5-10% stronger than based on the SMA.

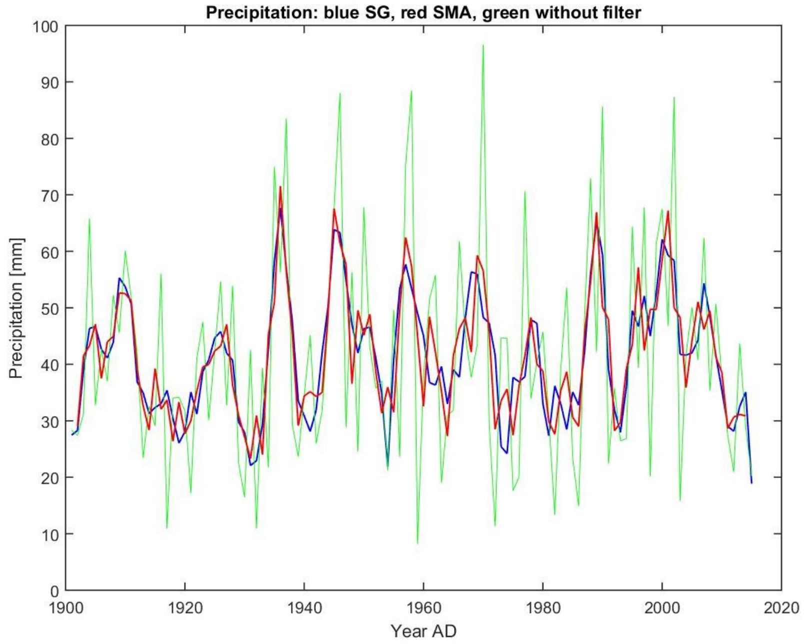


Fig. S20: *Precipitation of Germany in February a) unfiltered (green), b) SGF (blue), and c) SMA with a window-width of 3 data points (red).*

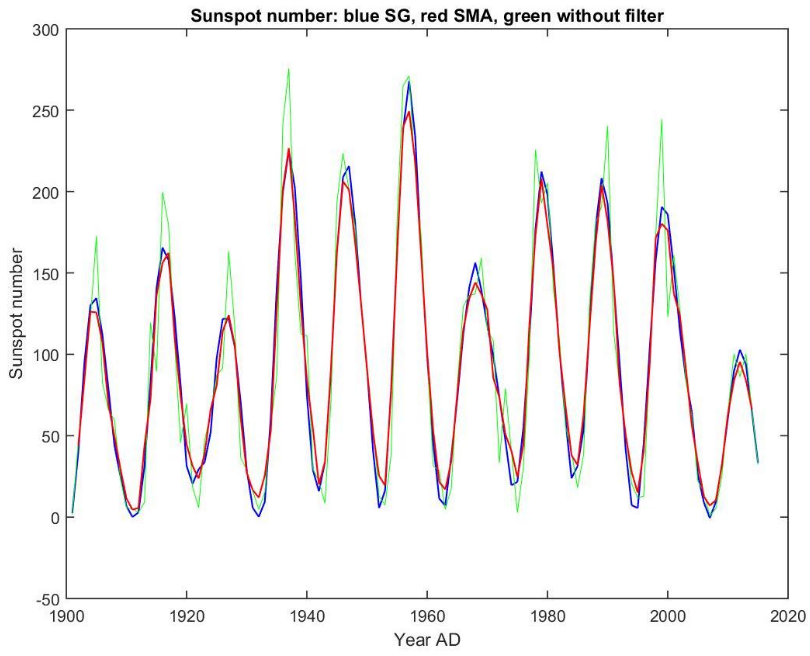


Fig. S21: *Sunspot numbers a) unfiltered (green), b) SGF (blue), and c) with a window-width of 3 data points (red).*

9. North Atlantic Oscillation (NAO)

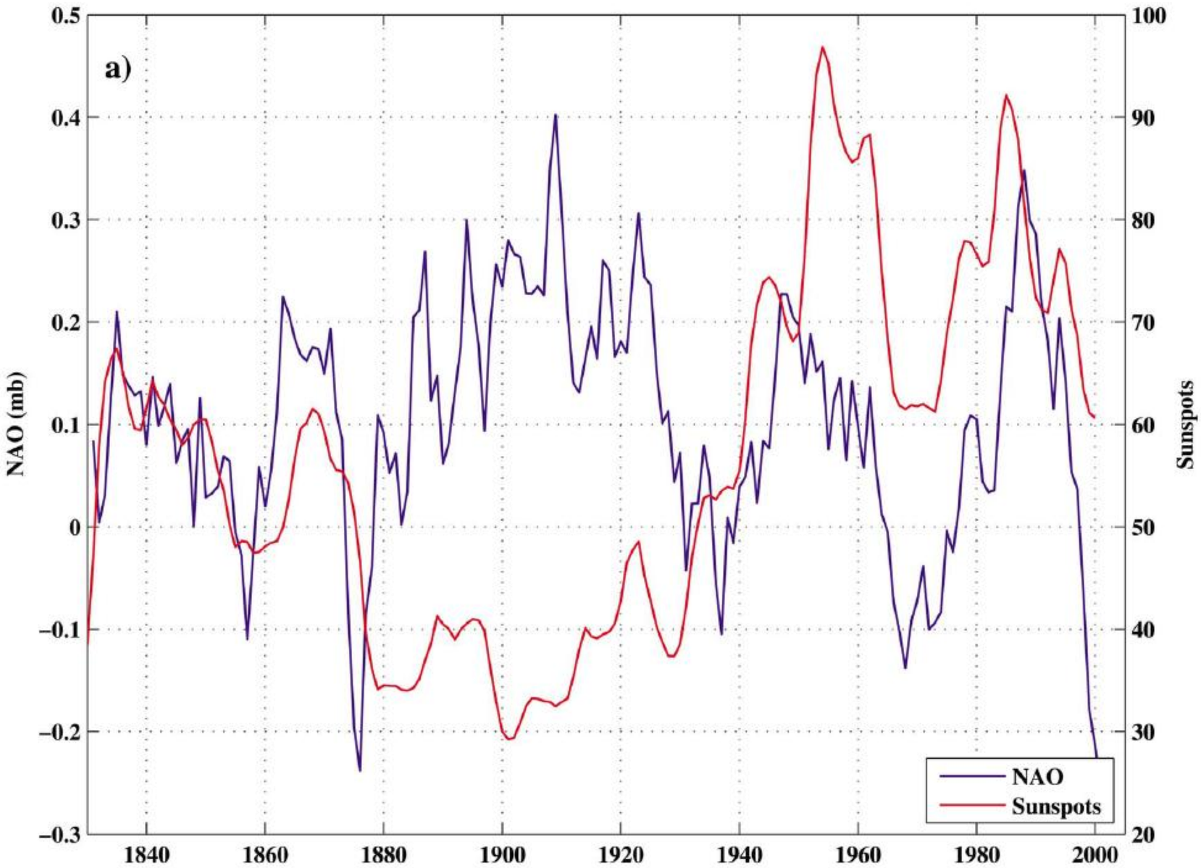


Fig. S22: *Comparison of long term December-February NAO and sunspots (11 year solar cycle filterered out), 1830-2000. From: van Loon et al. (2012)*

10. References

van Loon, H., Brown, J., and Milliff, R. F., 2012, Trends in sunspots and North Atlantic sea level pressure: J. Geophys. Res., v. 117, no. D7, p. D07106.