

1 **Seasonal modes of dryness and wetness variability over Europe and**  
2 **their connections with large scale atmospheric circulation and global**  
3 **sea surface temperature**

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29 **Abstract**

30 The relationship between the seasonal modes of interannual variability of a multiscalar drought  
31 index over Europe and the large-scale atmospheric circulation and sea surface temperature (SST)  
32 anomaly fields is investigated through statistical analysis of observed and reanalysis data. It is  
33 shown that the seasonal modes of dryness and wetness variability over Europe and their relationship  
34 with the large-scale atmospheric circulation and global sea surface temperature anomaly fields differ  
35 from one season to another. During winter, the dominant modes of dryness and wetness variability  
36 are influenced by the Arctic Oscillation (AO)/North Atlantic Oscillation (NAO), the Scandinavian  
37 pattern (SCA), the East Atlantic pattern (EA) and the East Atlantic/Western Russia (EAWR) pattern.  
38 The spring dryness/wetness modes are influenced mainly by the Arctic Oscillation (AO),  
39 Polar/Eurasian patterns (POL) and the Atlantic Multidecadal Oscillation (AMO) conditions. The  
40 phases (positive or negative) and the superposition of these large scale variability modes play a  
41 significant role in modulating the drought conditions over Europe. During summer, the atmospheric  
42 blocking is one of the main drivers of dryness and wetness conditions, while during autumn  
43 dryness/wetness conditions variability can be related to the NAO or with a wave train like pattern in  
44 the geopotential height at 850mb, which develops over the Atlantic Ocean and extends up to Siberia.  
45 It is also found that the response of the dryness and wetness conditions to global SST is more  
46 regional in summer, compared to the other seasons, when local processes may play a more important  
47 role.

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## 57 **1. Introduction**

58 Drought is more than a physical phenomenon or a natural event. Its impact results from the relation  
59 between a natural event and demands on the water supply, and it is often exacerbated by human  
60 activities. In the context of climate change, the frequency and intensity of drought are changing and  
61 their social and economic impact increase. Moreover, drought is one of the most complex  
62 phenomena which may have a strong impact on agriculture, society, water resources and ecosystems.  
63 One of the reasons for this is the spatial extent of drought and its duration, sometimes reaching  
64 continental scales and lasting for many years. Usually, drought is defined as a period of deficient  
65 precipitation over a long period of time (e.g a season or more). Typically, there are four types of  
66 drought: a) *meteorological drought* (characterized by months to years with precipitation deficit), b)  
67 *agricultural drought* (this includes the soil drought and soil-atmospheric drought, and is  
68 characterized by dry soils as a direct effect of reduced precipitation) c) *hydrological drought* (occurs  
69 when river streamflow and the water storages fall below long-term mean levels) and d) *socio-*  
70 *economic drought* (occurs when the demand for an economic good exceeds supply as a result of a  
71 weather-related shortfall in water supply) (Ped, 1957; WMO, 1975; Wilthie and Glantz, 1985;  
72 Farago et al., 1989; Maracchi, 2000; Dai, 2011a).

73 Dryness and wetness fluctuations can have an overwhelming effect on hydrology, agriculture, water  
74 management and ecosystems (Tao et al., 2014). To monitor and quantify dryness and wetness,  
75 various indices have been developed. However, a unique and universally accepted indicator does not  
76 exist yet (Heim, 2002; Dai, 2011b). One of the most used indices is the Palmer Drought Severity  
77 Index (PDSI) (Palmer, 1965). The PDSI is based on a supply-and-demand model of soil moisture  
78 and it enables the measurement of both wetness (positive values) and dryness (negative values). The  
79 index has proven to be the most effective in determining long-term dryness and wetness — a matter  
80 of several months — and not as good with conditions over a matter of weeks (Alley, 1984; Weber  
81 and Nkemdirim, 1998). One of the main disadvantages of PDSI is that it has a fixed temporal scale  
82 and does not allow the identification of different types of drought (e.g. agricultural, hydrological or  
83 meteorological). This may act as a drawback because drought is considered a multiscale  
84 phenomenon (McKee et al., 1993, Vicente-Serrano et al, 2010). An improvement was made by  
85 McKee et al. (1993) with the development of the Standardized Precipitation Index (SPI), which  
86 takes into account the multiscale nature of droughts. But SPI has a major drawback: it is based only  
87 on precipitation and does not take into account the effect of evapotranspiration, which has a strong

88 impact on drought conditions. Recently, a new indicator the Standardized Precipitation -  
89 Evapotranspiration Index (SPEI) (Vicente – Serrano, 2010) has been developed to quantify the  
90 drought condition over a given area. SPEI takes into account both precipitation and  
91 evapotranspiration and can be computed on time scales from 1 to 48 months. SPEI combines the  
92 sensitivity of PDSI to changes in evaporation demand with the multiscalar nature of SPI. More  
93 detailed description of SPEI and the method of computation are given by Vicente-Serrano et al.  
94 (2010).

95 During the last 150 years there has been a global temperature increase ( $0.5^{\circ}\text{C}$  -  $2^{\circ}\text{C}$ ) (Jones and  
96 Moberg, 2003) and climate models project a marked increase in global temperature during the  
97 twenty-first century (Solomon et al., 2007). An increase in global temperatures is very likely  
98 reflected in precipitation and atmospheric moisture, via induced changes in atmospheric circulation,  
99 a more intense hydrological cycle and an increase in the water holding capacity throughout the  
100 atmosphere (Folland et al., 2001). As a consequence it is very important to define a drought index  
101 which can take into account both the effect of precipitation and temperature (throughout the  
102 potential evapotranspiration). Recent studies have shown the importance of temperature in  
103 explaining recent trends in water resources (Nicholls, 2004; Cai and Cowan, 2008, Vicente-Serrano  
104 et al., 2010). Dai (2011a) and Vicente-Serrano et al. (2010) suggested that the increasing drying  
105 trends detected in the PDSI and SPEI global datasets, over many land areas, are due to a certain  
106 degree to the increasing temperature trend since the mid-1980s.

107 At the European scale, research on drought and wetness variability has been mainly focused on  
108 regional scales and/or over regions which became more exposed to severe droughts: Iberian  
109 Peninsula (Estrela et al., 2000; Vicente-Serrano, 2011), the Mediterranean region (Livada and  
110 Assimakopoulou, 2007), south-eastern Europe (Koleva and Alexandrov, 2008) and central Europe  
111 (Potop et al. 2013; Boroneant et al., 2012). Looking at other European regions, Briffa et al. (2009)  
112 showed that high summer temperatures in the western and central part of Europe are responsible for  
113 the large extent of summer drought conditions. Trnka et al (2009) emphasized that the drought  
114 conditions in the central part of Europe are triggered by different atmospheric circulation patterns  
115 and that the drought phenomenon is very pronounced in early vegetation period (April – June).  
116 Ionita et al. (2012a) showed that summer drought conditions over Europe can also be influenced by  
117 the previous winter SST anomalies in key regions and by a combination of different oceanic and  
118 atmospheric modes of variability like Atlantic Multidecadal Oscillation (AMO), Pacific Decadal  
119 Oscillation (PDO) and North Atlantic Oscillation (NAO). Altogether, when favorable phase

120 conditions are met, both these large scale atmospheric and oceanic factors could act as precursors  
121 for summer drying conditions over Europe. Although the aforementioned studies already  
122 investigated the dryness and wetness variability over Europe, they are either regional in terms of  
123 spatial extent or restricted to a particular season. Except the study of Lloyd-Hughes and Saunders  
124 (2002), which provides an analysis of drought climatology for Europe in terms of strength, number  
125 of events, mean and maximum duration of droughts, to the authors' knowledge there is no other  
126 recent study that deals with a comprehensive analysis of the short term seasonal dryness/wetness  
127 conditions over Europe and with the link between the dryness and wetness variability and the large-  
128 scale atmospheric circulation and global SST.

129 Motivated by the above mentioned considerations, this paper focuses on a comprehensive analysis  
130 of the seasonal dryness and wetness variability over Europe. Taking this into account, the main  
131 goals of this study are: i) to quantitatively describe the seasonal leading modes of dryness/wetness  
132 variability over Europe and ii) to determine to what extent the seasonal dryness and wetness  
133 variability over Europe are influence by the large-scale atmospheric circulation and global sea  
134 surface temperature. The composites of geopotential height at 850hPa (Z850) and global sea surface  
135 temperature (SST) anomalies and the correlation maps of number of rain days (WET), cloud cover  
136 (CLD) and soil moisture (SOIL) with the principal components corresponding to the main modes of  
137 SPEI variability are used to explain the seasonal dryness and wetness variability. These large scale  
138 patterns can provide information on the mechanisms by which the large scale factors can influence  
139 the European dryness and wetness variability.

140 This paper is organized as follows: the data sets used in this study and the methods employed are  
141 described in section 2. The spatio-temporal variability of the seasonal dryness/wetness, quantified  
142 by the SPEI over Europe, is presented in section 3. The relationships between the leading modes of  
143 SPEI variability and the Northern Hemisphere atmospheric circulation and global sea surface  
144 temperature are examined in section 4 and the link between the seasonal SPEI variability and three  
145 climate parameters like the number of rain days, cloud cover and soil moisture is analyzed in section  
146 5. In section 6 a discussion on the results is presented, while the main conclusions are outlined in  
147 section 7.

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## 149 **2. Data and methods**

### 150 **2.1 Data**

151 To calculate the Standardized Precipitation-Evapotranspiration Index (SPEI) we used monthly

152 precipitation totals, 2m surface air temperature means and potential evapotranspiration data from the  
153 CRU T.S. 3.20 dataset (Harris et al., 2013), with a spatial resolution of  $0.5^\circ \times 0.5^\circ$ . From the same  
154 data set we also used two meteorological parameters: monthly number of rain days (WET) and  
155 cloud cover fraction (CLD). Since the focus of this study is the short-time dryness and wetness  
156 variability, SPEI for 3 months accumulation period (SPEI3 from now on) was calculated.

157 To investigate the relationship of SPEI3 with global sea surface temperature we used the Hadley  
158 Centre Sea Ice and Sea Surface Temperature data set – HadISST (Rayner et al., 2003). This data set  
159 covers the period 1871 – 2012 and has a spatial resolution of  $1^\circ \times 1^\circ$ . For the present study we only  
160 used the data for the period 1901 – 2012.

161 To investigate the link between the seasonal modes of SPEI3 variability and the Northern  
162 Hemisphere atmospheric circulation we used the seasonal means of Geopotential Height at 850mb  
163 (Z850), the zonal wind (u850) and the meridional wind (V850) at 850mb from the Twentieth  
164 Century Reanalysis (V2) data set (NCEPv2, Whitaker et al., 2004; Compo et al., 2006; Compo et al.,  
165 2011) on a  $2^\circ \times 2^\circ$  grid, for the period 1901-2012. The Soil Moisture dataset is extracted from the  
166 same data set. In this study, we use the soil moisture content in the top layer.

167 We also used the time series of monthly teleconnection indices described in Table 2. From the  
168 monthly time series the seasonal means were computed by averaging the months  
169 December/January/February (DJF), March/April/May (MAM), June/July/August (JJA) and  
170 September/October/November (SON), respectively. The time series of the Northern Hemisphere  
171 teleconnection indices were detrended and normalized by their corresponding standard deviation.

172

## 173 **2.2 Methods**

174 The primary quantity analyzed in this study is the Standardized Precipitation-Evapotranspiration  
175 Index (SPEI). SPEI is similar to the Standardized Precipitation Index (SPI) (McKee et al., 1993) but  
176 it includes the role of temperature. SPEI is a multi-scalar drought indicator based on monthly  
177 precipitation totals (PP) and temperature means. The algorithm to calculate the SPEI uses the  
178 monthly difference between total precipitation (PP) and Potential Evapotranspiration (PET) which  
179 represents a simple climatic water balance calculated at different time-lags to obtain the SPEI for  
180 different accumulation period (Vicente-Serano et al., 2010). The estimation of PET is based on the  
181 Penmann-Monteith method (Vicente-Serano et al., 2010).

182 The patterns of the dominant modes of SPEI3 variability are based on Empirical Orthogonal  
183 Function (EOF) analysis (e.g. von Storch and Zwiers, 1999). The EOF technique aims at finding a

184 new set of variables that captures most of the observed variance from the data through a linear  
185 combination of the original variables. The EOF analysis represents an efficient method to  
186 investigate the spatial and temporal variability of time series which cover large areas. This method  
187 splits the temporal variance of the data into orthogonal spatial patterns called empirical eigenvectors.  
188 In this study the EOF was applied to the detrended anomalies of the seasonal SPEI3. For all seasons  
189 we retained just the first three leading modes, which together account for more than 40% of the total  
190 explained variance. These EOF's are well separated according to the North rule (North et al., 1982,  
191 *Table 1*). To better identify the periods characterized by persistent dryness/wetness the principal  
192 component (PCs) time series were smoothed with a centered 7-year running mean.

193 Due to data availability constraint the correlation coefficients between the time series of principal  
194 components (PCs) corresponding to the first three seasonal EOFs of SPEI3 and the Northern  
195 Hemisphere teleconnection indices were calculated over the common period 1950 – 2012 (*Table 3*).  
196 To identify the physical mechanisms responsible for the connection between SPEI3 seasonal  
197 variability and large-scale atmospheric circulation and global SST, we constructed the composite  
198 maps of Z850 and global SST standardized anomalies for each season by selecting the years when  
199 the value of normalized time series of coefficients of the first three standardized SPEI3 PCs was  $> 1$   
200 std. dev (High) and  $< -1$  std. dev (Low), respectively. This threshold was chosen as a compromise  
201 between the strength of the climate anomalies associated to SPEI3 anomalies and the number of  
202 maps which satisfy this criterion. Further analysis has shown that the results are not sensitive to the  
203 exact threshold value used for the composite analysis (not shown). The selected years according to  
204 this criteria that were used to build up the composite maps are shown in *Table 4*, for each time series  
205 of the seasonal PCs. To better emphasize the difference between wet and dry conditions the maps  
206 corresponding to the difference between High – Low years are shown and discussed.

### 207 **3. Leading modes of dryness and wetness variability and their relationship with the Northern** 208 **Hemisphere teleconnection patterns**

#### 209 **3.1 Winter**

210 The first leading mode for winter SPEI3 (Figure 1a), which describes 21.2% of the total variance, is  
211 characterized by positive loadings over the whole Europe with few exceptions located over the  
212 north-western part of the Scandinavian Peninsula and the southern half of the Iberian Peninsula. The  
213 corresponding PC1 time series of coefficients presents pronounced interannual variability (Figure 1d)  
214 and is negatively correlated with the time series of the winter EAWR index ( $r = -0.24$ , 90%

215 significance level, *Table 3*). The driest winters, in terms of winter PC1 (Figure 1d), were recorded  
216 for the years 1909, 1921, 1949 and 1954, while the wettest years were recorded in 1948, 1966, 1967  
217 and 1981, respectively.

218 The second winter EOF of SPEI3 (Figure 1b), explaining 13.6% of the total variance, shows a  
219 dipole-like structure, with negative loadings over the central and southern part of Europe and  
220 positive loadings over the Scandinavian Peninsula. The corresponding principal component (PC2)  
221 time series of coefficients presents a strong interannual variability component, which can be inferred  
222 from the time evolution of the winter PC2 time series of coefficients (Figure 1e). Moreover, from  
223 the beginning of 1980's until 2012, the winter PC2 time series of coefficients is characterized by a  
224 persistent period of positive anomalies, implying that the Scandinavian Peninsula has been exposed  
225 to prolonged wetness, while the southern part of Europe has been exposed, over the last 30 years, to  
226 a period of prolonged winter dryness. The winter PC2 time series of coefficients is negatively  
227 correlated with the winter time series of the Scandinavian (SCA) teleconnection pattern ( $r = -0.56$ ,  
228 99% significance level, *Table 3*) (Barnston and Livezey, 1987) and with the winter Niño4 index ( $r =$   
229  $-0.22$ , 90% significance level, *Table 3*). Also, the winter PC2 time series of coefficients is positively  
230 correlated with the winter time series of the North Atlantic Oscillation (NAO)/Arctic Oscillation  
231 (AO) patterns ( $r = 0.64/ r=0.79$ , 99% significance level, *Table 3*) and with the winter time series of  
232 the East Atlantic/Western Russia (EAWR) pattern ( $r = 0.34$ , 99% significance level, *Table 3*).  
233 Notably, the DJF PC2 time series of coefficients shows an upward trend after 1950s (Figure 1e).  
234 The driest years, for winter PC2 (Figure 1e), were recorded for three consecutive winters: 1940 –  
235 1942 and for the winter 1947, while the wettest years, in terms of winter PC2, were recorded for the  
236 years 1949, 2008 and 2012, respectively.

237 The third winter EOF of SPEI3 (8.8% explained variance) has a tripole-like structure (Figure 1c)  
238 with positive loadings over the north-western part of the Scandinavian Peninsula, negative loadings  
239 over the southern part of the Scandinavian Peninsula, central and western part of Europe, and  
240 positive loadings over the Balkans, eastern Europe and the central part of Russia. Outside these  
241 regions the EOF3 loadings are close to zero. The winter PC3 time series of coefficients is negatively  
242 correlated with the winter time series of the EA and SCA patterns ( $r = -0.28$ , 95% significance level,  
243 and  $r = -0.39$ , 99% significance level, respectively, *Table 3*) and positively correlated with the  
244 winter time series the EAWR pattern ( $r = 0.28$ , 95% significance level, *Table 3*). As in the case of  
245 winter PC2, the variability of drought conditions related to PC3 is the result of the overlap of several  
246 climate modes. The driest years, in term of winter PC3 (Figure 1f), were recorded in 1930, 1936,

247 1945 and 2001, while the wettest years were recorded for the winters 1905, 1963, 1984 and 2002,  
248 respectively.

249

### 250 **3.2 Spring**

251 The first spring EOF pattern of SPEI3 (Figure 2a), which explains 21.2% of the total variance, is  
252 characterized by positive loadings over the Scandinavian Peninsula and most part of Europe and  
253 negative loadings over the Iberian Peninsula and the southernmost part of Europe. The  
254 corresponding time series of coefficients (PC1 MAM) is characterized by a pronounced interannual  
255 variability (Figure 2d). Spring PC1 time series of coefficients is positively correlated with the spring  
256 time series of the EA pattern ( $r = 0.35$ , 99% significance level, Table3) and negatively correlated  
257 with the spring time series of the Polar/Eurasian pattern (POL) ( $r = -0.26$ , 95% significance level,  
258 Table 3) and the spring time series of the SCA pattern ( $r = -0.42$ , 99% significance level, Table3).  
259 The driest years, in terms of spring PC1 (Figure 2d), were recorded in 1918, 1974 and 1996, while  
260 the wettest years were recorded in 1966, 1992, 2000 and 2008, respectively.

261 The second spring EOF pattern of SPEI3 which explains 14.0% of the total variance features a  
262 dipole like pattern between the Scandinavian Peninsula and the rest of Europe (Figure 2b). The  
263 highest positive loadings are centered over Norway, while the highest negative values are centered  
264 over central Europe and the Balkans. PC2 MAM time series of coefficients (Figure 2e) emphasizes  
265 both inter-annual and decadal (~20 years) variability. Spring PC2 time series is positively correlated  
266 with the time series of spring Arctic Oscillation (AO) index ( $r = 0.52$ , 99% significance level, Table  
267 3) and negatively correlated with the spring time series of SCA index ( $r = -0.49$ , 99% significance  
268 level, Table 3). The driest years, according to spring PC2 (Figure 2e), were recorded in 1919, 1923,  
269 1941 and 1969, while the wettest years were recorded in 1921, 1938 and 1997, respectively.

270 The third spring EOF pattern of SPEI3 (Figure 2c), explaining 8.6% of the total variance,  
271 emphasizes a dipole-like structure between the eastern part of Europe and Russia (positive loadings)  
272 and the western part of Europe (negative loadings). Spring PC3 time series of coefficients presents  
273 both interannual as well as decadal variability (Figures 3f). Spring PC3 time series of coefficients is  
274 significantly positively correlated with the spring time series of the Atlantic Multidecadal  
275 Oscillation (AMO) index ( $r = 0.37$ , 99% significance level, Table 3). The AMO warm phase since  
276 the early 1930s up to 1960s is associated with positive values of PC3 coefficients, while the cold  
277 phase of AMO from the beginning of 1970s up to 1990s is associated with predominantly negative  
278 values of spring PC3 coefficients (Figure 2f). The driest years, in terms of spring PC3 time series of

279 coefficients, were recorded in 1928, 1934, 1937 and 1972, while de wetttest years were recorded in  
280 1929, 1938, 1944 and 1953, respectively.

281

### 282 **3.3 Summer**

283 The pattern of summer EOF1 of SPEI3 (12.0% of the total variance) (Figure 3a) emphasizes a north-  
284 south dipole between the Scandinavian Peninsula and the northern part of Europe (positive loadings)  
285 and the southern part of Europe (negative loadings). The corresponding PC1 time series shows  
286 pronounced decadal to multidecadal variability (Figure 3d). The time series of summer PC1 of  
287 coefficients is negatively correlated with the summer time series of the EAWR pattern ( $r = -0.47$ , 99%  
288 significance level, *Table 3*), the summer NAO/AO pattern ( $r = -0.55/ r = -0.31$ , 99% significance  
289 level, *Table 3*), the summer SCA pattern ( $r = -0.46$ , 99% significance level, *Table 3*) and positively  
290 correlated with the time series of summer AMO pattern ( $r = 0.27$ , 95% significance level, *Table 3*)  
291 and the summer EA pattern ( $r = 0.40$ , 99% significance level, *Table 3*). The driest summers, in terms  
292 of summer PC1 (Figure 3d), were recorded for the years 1927, 1928, 1985, 1992 and 2012, while  
293 the wetttest summers, in terms of summer PC1, were recorded for the years 1914, 1940, 1941, 1959  
294 and 1992, respectively.

295 The pattern of the second EOF of summer SPEI3 (Figure 3b), which explains 9.4% of the total  
296 variance, shows strong negative loadings over the western Russia and strong positive loadings over  
297 the Scandinavian Peninsula and Turkey. The time series of coefficients of summer SPEI3 PC2  
298 shows both interannual and decadal variability (Figures 4e). The time series of coefficients of  
299 summer PC2 is negatively correlated with the time series of summer EAWR index ( $r = -0.27$ , 95%  
300 significance level, *Table 3*). The driest summer years, in terms of summer PC2 (Figure 3e), were  
301 recorded for the years 1933, 1941, 1978 and 1980, while the wetttest summers, in terms of summer  
302 PC2, were recorded for the years 1936, 1981 and 1992, respectively.

303 The pattern of summer EOF3 of SPEI3 (Figure 3c), explaining 8.3% of the total variance, is  
304 characterized by negative loadings over the western Russia and north-western Scandinavia, and  
305 positive loadings over the eastern, central and most of the western part of Europe. The time series of  
306 coefficients of summer PC3 is negatively correlated with the time series of summer AO/NAO  
307 indexes ( $r = -0.31 / r = -0.26$ , 99%/95% significance level, *Table 3*) and positively correlated with  
308 the time series of summer EA index ( $r = 0.25$ , 95% significance level, *Table 3*) and the time series  
309 of summer SCA index ( $r = 0.21$ , 90% significance level, *Table 3*) (Figure 3d). The driest years,  
310 according to summer PC3 (Figure 3f), were recorded in 1904, 1921 and 1976, while the wetttest

311 years were recorded in 1910, 1972, 1980 and 1997, respectively.

312

### 313 **3.4 Autumn**

314 During autumn, the leading EOF mode of SPEI3 (Figure 4a) accounts for 15.0% of the total  
315 variance. The spatial pattern of this mode is characterized by negative loadings over the  
316 southernmost part of Europe and Turkey, and positive loadings over the central and northern part of  
317 Europe, the Scandinavian Peninsula and western Russia. The time series of coefficients of autumn  
318 PC1 of SPEI3 (Figures 4d) shows enhanced multidecadal variability since 1901 until the beginning  
319 of 1980s. After this period the PC1 time series mainly presents interannual variability. The time  
320 series of PC1 coefficients for autumn SPEI3 is negatively correlated with the time series of indices  
321 associated with the autumn POL teleconnection pattern ( $r = -0.34$ , 99% significance level, *Table 3*)  
322 and with the autumn time series of the EAWR pattern ( $r = -0.25$ , 95% significance level, *Table 3*).  
323 The driest autumns, in terms of autumn PC1 (Figure 4d), were recorded for the years 1920, 1951  
324 and 1959, while the wettest years were recorded in 1923, 1930, 1952 and 1954, respectively.

325 The second EOF mode of autumn SPEI3 variability (Figure 4b) explains 12.2% of the total variance.  
326 Structurally, this pattern resembles the second EOF mode of winter and spring, being characterized  
327 by negative loadings over the central and eastern part of Europe and positive loadings over the  
328 Scandinavian Peninsula. The time series of PC2 coefficients is positively correlated with the time  
329 series of autumn AO/NAO indices ( $r = 0.52/ r = 0.37$ , 99% significance level, *Table 3*) and  
330 negatively correlated with the time series of autumn SCA index ( $r = -0.33$ , 99% significance level,  
331 *Table 3*). The driest years, based on autumn PC2 (Figure 4e), were recorded in 1922, 1939 and 1960,  
332 while the wettest years, in terms of autumn PC2, were recorded for the years 1942, 1961, 1983 and  
333 2011, respectively.

334 The third EOF mode of SPEI3 for autumn (Figure 4c), explaining 8.8% of the total variance, is  
335 characterized by positive loadings over the western part of Russia and the coastal region of the  
336 Scandinavian Peninsula and negative loadings over the western, central and south-eastern part of  
337 Europe. Outside these regions the loadings are close to zero. The time series of PC3 coefficients  
338 shows strong interannual variability (Figure 4d). The time series of coefficients for autumn PC3 of  
339 SPEI3 is positively correlated with the time series of autumn AO/NAO indices ( $r = 0.31/ r = 0.31$ ,  
340 99% significance level, *Table 3*) and the time series of autumn EAWR index ( $r = 0.26$ , 95%  
341 significance level, *Table 3*) and negatively correlated with the time series of autumn SCA index ( $r =$   
342  $-0.39$ , 99% significance level, *Table 3*). The driest years, in term of autumn PC3 (Figure 4f), were

343 recorded in 1924, 1938, 1944 and 1974, while the wettest years were recorded for the autumns 1947,  
344 1978 and 2003, respectively.

345

#### 346 **4. Relationship with large-scale atmospheric circulation and global SST**

347 To identify the physical mechanisms responsible for the connection between SPEI3 seasonal  
348 variability and large-scale atmospheric circulation and global SST, we constructed the composite  
349 maps of the standardized anomalies of Z850, wind vectors at 850mb (W850) and global SST for  
350 each season by selecting the years when the value of normalized time series of coefficients of the  
351 first three PCs were  $> 1$  std. dev (High) and  $< -1$  std. dev (Low), respectively. In Figures 5 - 8 we  
352 will show and discuss just the difference between the High – Low maps.

##### 353 **4.1 Winter**

354 Figure 5 shows the composite maps of winter anomalies (High-Low) of Z850 and W850 (left panels)  
355 and global SST (High-Low) (right panels) corresponding to the above mentioned selection criteria.  
356 Positive values of the standardized winter PC1 of SPEI3 are associated with a center of negative  
357 Z850 anomalies over the whole Europe and central North Atlantic and, a center of positive Z850  
358 anomalies over Canada, Greenland up to Siberia (Figure 5a). This pattern is associated with  
359 enhanced precipitation over the central part of Europe and reduced precipitation over the northern  
360 part of the Scandinavian Peninsula. High values of winter standardized PC1 coefficients are also  
361 associated with a tripole-like SST pattern, characterized by a cold center of SST anomalies over the  
362 Gulf of Mexico and the eastern US coast, positive SST anomalies in the central North Atlantic that  
363 extends from the southern Greenland towards the tropical Atlantic Ocean and a center of negative  
364 SST anomalies over the North Sea and the surrounding areas (Figure 5d). Such kinds of Z850 and  
365 SST anomalies induce wet conditions over most of the European regions, in agreement with the  
366 winter EOF1 pattern (Figure 1a), via the advection of warm and moist air (see the wind vectors in  
367 Figure 5a) from the tropical and the eastern coast of the North Atlantic Ocean (positive SST  
368 anomalies in Figure 5d).

369 The composite map of winter anomalies of Z850 and W850 (Figure 5b) based on the selected PC2  
370 values fulfilling the criteria is characterized by a region of negative anomalies over Greenland, the  
371 Scandinavian Peninsula and Siberia and an extended region of positive anomalies which covers the  
372 central North Atlantic Ocean and the whole Europe and the Mediterranean region. This pattern  
373 resembles the positive phase of the AO/NAO. In section 3.1 we have identified that winter PC2 time

374 series of coefficients of SPEI3 is significantly correlated with both, the winter AO/NAO index as  
375 well as with the winter SCA index. From this finding we can argue that the second winter mode of  
376 SPEI3 variability is influenced by a combination of the different climatic modes and teleconnections.  
377 This is not so surprising, especially in the context of recent findings of Comas-Bru and McDermott  
378 (2013) showing that NAO centers of action are influenced by the phases of the East Atlantic (EA)  
379 and SCA patterns, whereas precipitation and temperature over U.K. and the northern part of Europe  
380 are differently correlated to NAO, depending on the SCA phase. Positive values of winter PC2 of  
381 SPEI3 are also associated with negative SST anomalies in the central tropical Pacific flanked by  
382 positive SST anomalies in the central north Pacific and central south Pacific (Figure 5e). This  
383 pattern resembles the SST pattern associated to the cold phase of El Niño – Southern Oscillation  
384 (ENSO) and it is consistent with the results of previous studies which showed that ENSO has a  
385 strong influence on the river streamflow in Europe (Rimbu et al., 2004; Ionita et al., 2008; 2009;  
386 2012b), on precipitation over Europe (Marriotti et al., 2002; van Oldenburgh et al., 2000) and on  
387 diurnal temperature range over Europe (Ionita et al., 2012c). It is also consistent with the results  
388 presented in Section 3 showing that the time series of standardized coefficients of winter PC2 of  
389 SPEI3 is significantly correlated with the winter Niño 4 index ( $r = -0.22$ , 90% significance level, see  
390 Table 3). It is worth to note that the positive values of winter PC2 of SPEI3 are also associated with  
391 a tripole-like SST pattern over the North Atlantic region, but it is different in its spatial structure to  
392 the one associated to winter PC1. It is characterized by positive SST anomalies along the eastern US  
393 coast, European coast and the North Sea and negative SST anomalies in the tropical Atlantic Ocean  
394 and south of Greenland. Such a SST pattern resembles the SST anomalies associated with the  
395 positive phase of the AO/NAO (Hurrell, 1996; Dima et al., 2001) and, it is in agreement with the  
396 relationship identified between winter PC2 and AO/NAO.

397 The composite map of winter anomalies of Z850 and W850 (Figure 5c) based on the selected PC3  
398 values is characterized by a center of positive Z850 anomalies centered over the British Isle, which  
399 is flanked by negative anomalies. The composite of winter SST anomalies (Figure 5f) is  
400 characterized by negative anomalies along the eastern coast of US which extend over the central  
401 North Atlantic Ocean. Positive SST anomalies emerge in the southern Greenland and in the tropical  
402 Atlantic Ocean, while negative SST anomalies extend over the North Sea and the Mediterranean Sea.  
403 Such patterns, in the Z850 and SST fields, enhance the advection of cold and dry air (see the wind  
404 vectors in Figure 5c) from the North Sea (negative SST anomalies over this area) towards the  
405 western part of Europe (where the highest negative loadings of EOF3 of SPEI3 were identified,

406 Figure 1c) favoring dry conditions over these regions. These results are in line with the findings of  
407 Madden and Williams (1977) showing that during winter months, cold and dry air has the tendency  
408 to suppress precipitation, especially over the European continent.

409

#### 410 **4.2 Spring**

411 High values of spring PC1 coefficients are associated with a wave train of Z850 anomalies (Figure  
412 6a) characterized by positive Z850 anomalies over the Greenland, North America, Northern Russia,  
413 the Iberian Peninsula and the northern part of Africa and, negative Z850 anomalies centered over the  
414 Scandinavian Peninsula. This pattern resembles the negative phase of the spring SCA pattern  
415 (Barnston and Livezey, 1987), supporting the high correlation coefficient between the time series of  
416 spring PC1 of SPEI3 and spring SCA index ( $r = -0.42$ , 99% significance level, Table 3). Positive  
417 values of spring PC1 coefficients are associated with positive SST anomalies all over the Atlantic  
418 Ocean, with only few exceptions over the Gulf of Mexico, offshore of the eastern US coast and over  
419 the Greenland-Irminger-Norwegian (GIN) Sea (negative SST anomalies). Positive SST anomalies  
420 extend over the tropical Pacific, Atlantic and Indian oceans (Figure 6d). The cyclonic center over the  
421 Scandinavian Peninsula favors the advection of warm and moist air from the Atlantic (positive SST  
422 anomalies in Figure 6d) towards most of the European continent (see the wind vectors in Figure 6a)  
423 and hence enhances precipitation over these regions. This result is also in line with the EOF1 pattern  
424 of spring SPEI3 (Fig 2a) which presents positive loadings over the Scandinavian and most part of  
425 Europe.

426 The composite map of spring anomalies of Z850 and W850 (Figure 6b) based on the PC2 values  
427 fulfilling the selection criteria is characterized by an extended area of positive Z850 anomalies over  
428 the North Atlantic Ocean and most of the Europe, with two centers, one located over the eastern  
429 coast of US and the other located over the central Europe and Mediterranean. Negative Z850  
430 anomalies cover the Greenland, North Pole and the surrounding areas. This pattern resembles the  
431 positive phase of the AO/NAO. As shown in section 3.2, the time series of spring PC2 coefficients  
432 and the time series of spring AO/NAO indices are significantly correlated (Table 3). The positive  
433 phase of AO is characterized by warmer and wetter than normal conditions over the Scandinavia and  
434 northern Russia and colder and drier than normal conditions over the southern part of Europe. These  
435 results are also in agreement with the spring pattern of EOF2 of SPEI3 (Figure 2b). The composite  
436 of spring SST anomalies associated to PC2 coefficients fulfilling the selection criteria (Figure 6e) is  
437 characterized by a tripole-like pattern, with altering signs of SST anomalies in the North Atlantic,

438 similar to those corresponding to the positive phase of AO (Dima et al., 2001). Both the composites  
439 of Z850(W850) and SST anomalies associated with high values of spring PC2 coefficients are  
440 similar to the composites of Z850 (W850) and SST anomalies associated to high values of winter  
441 PC2, implying a certain persistence from winter to spring of the driving factors and the climate  
442 anomalies that are associated to them.

443 The composite map of spring anomalies of Z850 and W850 (Figure 6c) based on the PC3 values  
444 fulfilling the selection criteria (Figure 6c) shows a tripole-like structure between the central North  
445 Atlantic Ocean (negative anomalies), the British Isle and Western Europe (positive anomalies) and  
446 eastern and south-eastern Europe and western Russia (negative anomalies). This spatial pattern  
447 projects onto the positive phase of the Atlantic Multidecadal Oscillation and, it is associated with  
448 reduced precipitation over the central Europe (Sutton and Dong, 2012) which is in agreement with  
449 the negative loading of the spring EOF3 of SPEI3 (Figure 2c) identified over this regions. Moreover,  
450 the dominant feature of the composite map of spring SST anomalies based on PC3 selected values  
451 (Figure 6f) is the quasi-monopolar positive anomalies in the North Atlantic Ocean. As indicated by  
452 other studies (Latif et al., 2004; Knight et al. 2005) such a quasi-monopolar structure is associated  
453 with the extreme phases of the Atlantic Multidecadal Oscillation (AMO). This result is also certified  
454 by the correlation coefficient between the time series of spring PC3 coefficients and the time series  
455 of spring AMO index ( $r = 0.37$ , 99% significance level, *Table 3*) suggesting that the AMO could  
456 play an important role in driving moisture variability over Europe. Positive (negative) SST  
457 anomalies over the North Atlantic are associated with positive (negative) phase of AMO which  
458 induce to dry (wet) conditions over the western Europe and wet (dry) conditions over the eastern  
459 Europe and western Russia as also confirmed by the spring EOF3 loadings of SPEI3 (Figure 2c).

460

### 461 **4.3 Summer**

462 The composite map of summer anomalies of Z850 and W850 (Figure 7a) based on the PC1 values  
463 fulfilling the selection criteria presents a large area of negative anomalies centered over Scandinavia  
464 and the British Isles which extends westward over the North Atlantic and the eastern US. Another  
465 center of positive anomalies is located over Greenland and adjacent areas, while another area of  
466 positive anomalies, centered over the Mediterranean extends eastward to Eurasia. The composite  
467 map of summer SST anomalies associated to positive values of PC1 values fulfilling the selection  
468 criteria shows negative SST anomalies over the North Sea and along the western coast of  
469 Scandinavia and positive SST anomalies along the southern coast of Greenland, central and tropical

470 Atlantic Ocean and over the Mediterranean Sea. Such patterns, in the summer Z850 and SST  
471 anomaly fields, enhance precipitation over the northern and central part of Europe through the  
472 advection of warm and moist air (see the wind vectors in Figure 7a) from the central North Atlantic  
473 (positive SST anomalies) and inhibit precipitation over the southern part of Europe through the  
474 advection of warm and dry air from the northern part of Africa. Moreover, the positive SST  
475 anomalies in the Mediterranean Sea and Indian Ocean were found to trigger very dry summers over  
476 the southern part of Europe (Hoerling et al., 2012), which is in agreement with our findings.

477 Positive values of summer the PC2 values fulfilling the selection criteria are associated with a  
478 blocking-like pattern in the field of Z850 anomalies, extending over the central and Eastern Europe  
479 (Figure 7b). The composite map of Z850 and W850 anomalies also shows two centers of cyclonic  
480 circulation, one over Iceland and the Scandinavian Peninsula and another one over the northern  
481 Africa. Such a kind of pattern was associated with central and eastern European droughts and heat  
482 waves during summer (Cassou et al., 2005; Fisher et al., 2007a). The composite map of summer  
483 SST anomalies based on selected PC2 coefficient values is shown in Figure 7e. It presents a quasi-  
484 monopolar structure in the North Atlantic with positive SST anomalies over the entire North  
485 Atlantic, except some insignificant negative anomalies south-east of Greenland.

486 The composite map of summer anomalies of Z850 and W850 based on PC3 values fulfilling the  
487 selection criteria (Figure 7c) resembles a stationary wave-train pattern with positive anomalies over  
488 the central North Atlantic Ocean, Greenland, Scandinavian Peninsula and north-western Russia and  
489 a large area of negative anomalies over the British Isle, whole Europe and Eurasia. This pattern is  
490 responsible for wet conditions over Europe and dry conditions over Scandinavia and western Russia  
491 during summer. The wave-train pattern in the Z850 anomaly field is associated with strong positive  
492 SST anomalies in the northern part of the North Atlantic Ocean and GIN Sea (Figure 7f) and  
493 negative SST anomalies along the western European coast, the Mediterranean Sea and eastern North  
494 America coast. The negative SST anomalies over the Mediterranean Sea and the western European  
495 coast could induce wet summers over the central and eastern part of Europe, in agreement with the  
496 cyclonic circulation over most of Europe and the British Isles, through the advection of cold and  
497 moist air from the eastern coast of the North Atlantic Ocean (see the wind vectors in Figure 7c).

498

#### 499 **4.4 Autumn**

500 During autumn, high values of PC1 time series of coefficients of SPEI3 fulfilling the selection  
501 criteria for building the composite maps are associated with a center of strong negative Z850

502 anomalies located over the Scandinavian Peninsula and north-western Europe which extends up to  
503 central and eastern Europe (Figure 8a). This area of Z850 negative anomalies is surrounded by a  
504 large area of positive anomalies extended over the Greenland and Kara Sea, central North Atlantic  
505 and northern Africa, Middle East and Eurasia (Figure 8a). This pattern results in a strong pressure  
506 gradient between the centers of action, with the highest gradient over the north-western part of  
507 Europe. Positive values of autumn PC1 coefficients fulfilling the selection criteria are also  
508 associated with negative SST anomalies along the eastern US coast and the western European coast  
509 which extend up to the north-western African coast and, an area of negative SST anomalies in the  
510 center of North Pacific Ocean (Figure 8a). The composite map of the autumn SST anomalies  
511 associated with selected coefficients of the PC1 fulfilling the criteria is characterized by positive  
512 SST anomalies in the central North Atlantic extending northward up to the southern Greenland.  
513 Outside these areas the SST anomalies are almost insignificant. A similar SST pattern was found to  
514 influence the streamflow variability of Rhine River in autumn (Ionita et al., 2012b) and can be  
515 obtained by applying an EOF analysis over the autumn SST anomalies over the North Atlantic  
516 region and retaining the fourth leading EOF. The atmospheric circulation anomalies and the SST  
517 anomalies identified and presented in Figures 8a and d, respectively, favor the advection of moist air,  
518 and hence increased precipitation, towards the central part of Europe while the advection of dry air  
519 from the northern part of Africa towards the southern part of Europe turns out in reduced  
520 precipitation over these regions (see the wind vectors in Figure 8a).

521 The composite map of autumn Z850 anomalies based on the selected PC2 coefficients points out on  
522 a large area of positive anomalies with two centers, one over the north-eastern US coast and the  
523 other over the southern Europe. Negative Z850 anomalies associated with a cyclonic circulation are  
524 centered northward of Scandinavia and extend over the northern part of the North Atlantic Ocean  
525 and Greenland (Figure 8b). This pattern projects onto the positive phase of autumn NAO, which is  
526 also in agreement with the significant correlation between the time series of autumn PC2 of SPEI3  
527 and the time series of autumn NAO and AO indices ( $r = 0.37/0.52$ , 99% significant level, *Table 3*).  
528 The composite map of the autumn SST anomalies based on selected PC2 coefficients (Figure 8e) is  
529 characterized by negative SST anomalies around Iceland and tropical Atlantic and Pacific Oceans,  
530 and positive SST anomalies over the central North Atlantic off shore the eastern US and western  
531 European coasts, and the Mediterranean Sea. A warm Mediterranean Sea favors dry conditions over  
532 the southern and south-eastern Europe while the cold North Sea is associated with wetter conditions  
533 over the Scandinavian Peninsula and Great Britain.

534 The composite map of autumn Z850 and W850 anomalies associated to selected PC3 coefficients  
535 fulfilling the selection criteria shows a wave train pattern characterized by a sequence of centers of  
536 positive and negative Z850 anomalies: one center of negative anomalies over the central Atlantic  
537 Ocean, one center of positive anomalies located over the British Isle and western Europe which is  
538 connected with another center of positive anomalies located over the Mediterranean and northern  
539 Africa and, a center of strong negative anomalies located over the north-western Russia (Figure 8c).  
540 This pattern resembles the negative phase of the autumn SCA pattern, which was found to be  
541 significantly correlated with the time series of autumn PC3 of SPEI3 ( $r = -0.39$ , Table 3). The  
542 composite map of the autumn SST anomalies associated to the selected PC3 coefficients presents  
543 positive SST anomalies along the eastern US and western European coast and negative SST  
544 anomalies over the central North Atlantic Ocean and the Mediterranean Sea (Figure 8f). Such a  
545 pattern of SST anomalies could drive/induce dry conditions over the central Europe and wet  
546 conditions over the Eastern Europe during autumn.

## 547 **5. Relationship with Rainday Counts, Cloud Cover and Soil Moisture**

548 In this section the relationship between the seasonal SPEI3 variability and three fields of  
549 climatological variables which are rainday counts (WET), cloud cover (CLD) and soil moisture  
550 (SOIL) is analyzed in terms of correlation maps between the first three PCs for each season and  
551 WET, CLD and SOIL fields. The results of the correlation analysis are shown in Figures 9 – 12, in  
552 which the correlations that are exceeding the 95% significance level are hatched.

553 An increase in air temperature associated with reduced precipitation, which are the main factors  
554 driving the drought conditions, can be the result of reductions of cloudiness, especially during spring  
555 and summer (Tang et al., 2010). The increase in temperature (which is an important input variable in  
556 the computation of SPEI) could also be enhanced by soil moisture reduction, which in turn reduces  
557 the evaporation and evaporative cooling on the surface. However, during the winter months positive  
558 temperature anomalies are associated with enhanced precipitation, due to the fact that the water  
559 holding capacity of the atmosphere limits precipitation amounts during cold conditions (Trenberth  
560 and Shea, 2005).

561 Soil moisture information has the potential to play an important role in predicting the occurrence of  
562 drought phenomena and to improve the seasonal prediction of precipitation (Dirmeyer and Brubaker,  
563 1999; Reichle and Koster, 2003). The influence of soil moisture has been studied especially  
564 regarding the pre-conditioning in the context of heat waves and summer droughts (Zampieri et al.,

2009; Seneviratne et al., 2006; Fisher et al., 2007b). Moreover, a strong relationship between droughts and cloud cover has been identified, periods of high drought occurrence being associated with a strong decrease in the total cloud amount (Greene et al., 2011). A positive feedback between soil moisture, cloudiness and precipitation has been also reported (Schär et al., 1999; Pal and Eltahir, 2001). A decrease in precipitation triggers dry soil conditions, which in turn would decrease the amount of moist static energy in the boundary layer and an increase in the cloud base height. Such a feedback mechanism would further lead to a decrease in the frequency of convective events, thus reducing the cloud cover and precipitation.

573

## 5.1 Winter

Figure 9 presents the correlation maps between the first three winter PCs time series of coefficients and the seasonally averaged rainday counts (left panels), cloud cover (middle panels) and soil moisture (right panels). Winter PC1 is significantly correlated (positive values) with WET (Figure 9a) and SOIL (Figure 9g) over most of the European region. The correlation map between winter PC1 and CLD shows the highest correlations (positive values) over the central and eastern part of Europe, but the correlation coefficients, though significant at 95%, are smaller compared to WET and SOIL. This might be the result of the snow cover influence during winter over these regions. During winter, these regions are more prone to precipitation fallen as snow which is a limiting factor for the heat flux exchange between the surface and the overlying air while the cloud cover role is diminished. Moreover, cloud cover may have a strong impact on suppressing evapotranspiration (Mudiare, 1985). During winter, the evapotranspiration is reduced and hence the CLD effect on SPEI3 variability is smaller compared to WET and SOIL. When analyzing the correlation patterns of winter WET, CLD and SOIL fields presented in Figures 9a, 9d and 9g we can argue that dry (wet) conditions in winter, over most of the European region are the result of a combined effect of WET and SOIL and to a smaller extent to CLD. The correlation maps between the PC2 time series of coefficients of winter SPEI3 and WET, CLD and SOIL fields are shown in Figures 9b, 9e and 9h, respectively. The correlation map between winter PC2 and WET (Figure 9b) presents a dipole-like pattern in the correlation field between the southern part of Europe (negative and significant correlations) and the Scandinavian Peninsula and northern Europe and western Russia (positive and significant correlations). Winter PC2 of SPEI3 is positively correlated with CLD over the western Russia and negatively correlated with CLD over the southern part of Europe (Figure 9e). Comparatively to WET, the values of correlation coefficients between winter PC2 and CLD are

597 much smaller. The pattern of the correlation map between winter PC2 and SOIL (Figure 9h) is much  
598 alike with the WET correlation map (Figure 9b) and with the pattern of winter EOF2 (Figure 1b). As  
599 in the case of PC1, WET and SOIL show a higher influence on moisture conditions compared to  
600 CLD and, we speculate that this result can be attributed to the direct effect of snow cover. Moisture  
601 conditions over the southern part of Europe are sensitive to WET, CLD and SOIL, while over the  
602 Scandinavian Peninsula they are more sensitive to WET and SOIL and less sensitive to CLD. In the  
603 case of PC3 time series of coefficients, the correlation maps with WET (Figure 9c) and SOIL  
604 (Figure 9i) show a similar pattern of correlation characterized by negative correlations over the  
605 Iberian Peninsula, British Isle and southern Scandinavian Peninsula and positive correlations over  
606 the eastern Europe and Russia which is in agreement with the pattern of winter EOF3 of SPEI3  
607 (Figure 1c). The correlation map between winter PC3 time series of coefficients and CLD (Figure 9f)  
608 is different compared to WET and SOIL and shows strong and significant negative correlation over  
609 the northern Europe, western Russia and the southern part of the Scandinavian Peninsula. This  
610 difference can be due to complex large-scale and regional factors that influence moisture conditions.  
611 One of the reason for which the correlation with CLD is smaller in winter can be due to the fact that  
612 SPEI3 is based on potential evapotranspiration (PET) and, it was reported that PET is sensitive to  
613 CLD mainly in spring and summer (Tang et al., 2010, Ionita et al., 2012c).

## 614 **5.2 Spring**

615 During spring, the PC1 time series of coefficients is significantly correlated with the WET field  
616 (significant and positive correlations up to  $\sim 0.7$ ) over large areas including the central and northern  
617 part of Europe, western Russia and the Scandinavian Peninsula (Figure 10a) and negatively  
618 correlated over the Iberian Peninsula, southernmost part of Europe and the Middle East. The  
619 correlation map between spring PC1 and spring CLD (Figure 10d) is similar to the correlation map  
620 of WET (Figure 10a) but the correlation coefficients are smaller compared to WET, though still  
621 significant. Dry (wet) conditions over the central and western part of Europe and western Russia are  
622 associated with decreased (increased) soil moisture content over these regions. The correlation map  
623 for SOIL also shows a low negative correlation along the western and northern coast of the  
624 Scandinavian Peninsula. This aspect may be due to the fact that the western coast of Scandinavian  
625 Peninsula is a mountain region and most of the soils are formed on glacial materials (Jones et al.,  
626 2005) and the bedrock is calcareous, this characteristic making these soils less sensitive to moisture.  
627 The correlation maps between the spring PC2 series of coefficients and spring WET (Figure 10b),

628 spring CLD (Figure 10e) and spring SOIL (Figure 10h) present similar correlation patterns. Dry  
629 (wet) conditions over the southern and central part of Europe (the Scandinavian Peninsula) are  
630 associated with reduced (enhanced) rainday counts (Figure 10b), low (high) cloudiness (Figure 10e)  
631 and decreased (increased) soil moisture content (Figure 10h). In the case of spring PC2 all three  
632 considered parameters (WET, CLD and SOIL) seem to play an important role on determining  
633 dryness/wetness conditions over the analyzed regions, in terms of correlation coefficients. Figures  
634 10c, 10f and 10i present the correlation maps between the spring PC3 time series of coefficients and  
635 WET field (Figure 10c), CLD field (Figure 10f) and SOIL field (Figure 10i). The regions exhibiting  
636 the highest correlations between spring PC3 and WET (Figure 10c), CLD (Figure 10f) and SOIL  
637 (Figure 10i) are the Eastern Europe and western Russia (positive correlations) and Western Europe  
638 (negative correlations). Dry (wet) conditions over the western Russia and Eastern Europe are  
639 associated with decreased (increased) rainday counts, low (high) cloudiness and reduced (enhanced)  
640 soil moisture content over these regions. As in the case of the winter season, the correlation between  
641 the spring PCs and spring CLD were smaller compared to spring WET and spring SOIL, especially  
642 over the northern part of Europe (areas which in spring can still be covered by snow, Brown and  
643 Robinson, 2011). Again, we can speculate that these results can be an effect of the influence of snow  
644 cover, which acts as a barrier between the surface layer and the overlying air.

### 645 **5.3 Summer**

646 Figures 11a, 11d and 11g present the correlation maps between the summer PC1 time series of  
647 coefficients and the summer WET, CLD and SOIL fields. The correlation patterns show a dipole-  
648 like structure, with the highest positive correlations over the northern part of Europe, western Russia  
649 and the Scandinavian Peninsula and negative correlations over the southern part of Europe. The  
650 magnitudes of the correlation coefficients are almost the same for all three analyzed fields (WET,  
651 CLD and SOIL). Wet (dry) conditions over the northern part of Europe, Scandinavian Peninsula and  
652 western part of Russia are associated with enhanced (reduced) rainday counts (Figure 11a), high  
653 (low) cloudiness (Figure 11d) and increased (decreased) soil moisture content (Figure 11g) over  
654 these regions. For the southern part of Europe dry (wet) conditions are associated with reduced  
655 (enhanced) rainday counts, low (high) cloudiness and decreased (increased) soil moisture content.  
656 The correlation map of summer PC2 with WET (Figure 11b) and CLD (Figure 11e) fields shows the  
657 highest negative (positive) correlations over western Russia (Scandinavian Peninsula, Western  
658 Europe and Turkey), while in the case of SOIL field, the correlation map shows significant negative

659 correlations over western Russia and positive correlations only over small regions (Turkey and  
660 northern part of Sweden). This is not surprisingly, since the highest negative loadings of summer  
661 EOF2 are found over western Russia. Therefore, enhanced (reduced) rainday counts, high (low)  
662 cloudiness and increased (decreased) soil moisture anomalies lead to wet (dry) periods over most of  
663 the western part of Russia. The correlation coefficients between summer PC3 series of coefficients  
664 with WET, CLD and SOIL fields are positive and significant over most of continental part of  
665 Europe and southern Scandinavian Peninsula. Over the north-western part of Russia the correlation  
666 is negative. In terms of correlation coefficients values the influence of CLD and SOIL on moisture  
667 conditions over the north-western part of Russia is much smaller compared to WET. Tang et al.  
668 (2012) showed that over this region the summer temperature (which is an integrated part in the  
669 definition of SPEI) is more sensitive to precipitation variability than to cloud cover and, this could  
670 also explain the highest correlation between summer PC3 and WET over north-western Russia.

#### 671 **5.4 Autumn**

672 Figures 12a, 12d and 12g show the correlation maps between the autumn PC1 time series of  
673 coefficients and the autumn WET, CLD and SOIL fields, respectively. The correlation maps show a  
674 pattern of positive (negative) correlation with the highest positive significant values centered over  
675 the northern part of Europe, the Scandinavian Peninsula and western part of Russia (southern part of  
676 Europe). The highest correlations are found between the autumn PC1 time series and WET and  
677 SOIL (Figures 12a and 12g, respectively). The autumn PC2 time series of coefficients is negatively  
678 correlated with WET (Figure 12b), CLD (Figure 12f) and SOIL (Figure 12h) over most of the part  
679 of Europe and positively correlated with WET and SOIL over the Scandinavian Peninsula and  
680 northern Russia. The correlation maps between the PC3 time series of coefficients and seasonally  
681 averaged WET, CLD and SOIL are presented in Figures 12c, 12f and 12i, respectively. They are  
682 very similar in the spatial distribution of correlation coefficients though the highest correlation  
683 coefficients are recorded between the autumn PC3 and WET (Figure 12c). Dry (wet) conditions over  
684 the western part of Europe are associated with reduced (enhanced) rainday counts, low (high)  
685 cloudiness and decreased (increased) soil moisture anomalies. At the same time, wet (dry)  
686 conditions over the western part of Russia are associated with enhanced (reduced) rainday counts,  
687 high (low) cloudiness and increased (decreased) soil moisture content. As in the case of summer, the  
688 correlation coefficients between the autumn PC3 time series of SPEI3 and WET and SOIL is  
689 stronger compared to CLD.

## 690 **6. Discussion**

691 As a complex natural hazard, drought is best characterized by multiple climatological and  
692 hydrological parameters, therefore is very important to understand the association of drought with  
693 climatic, oceanic and local factors. Persistent dry (wet) conditions are usually associated with  
694 persistent anticyclones (cyclones) (Schubert et al., 2014), while the sea surface temperature plays  
695 also an important role on dryness and wetness variability, via large scale climate modes of  
696 variability (e.g. AMO and/or ENSO) (Ionita et al., 2012a).

697 In this study the spatio-temporal variability of the seasonal short-term dryness and wetness  
698 conditions as represented by SPEI3 over the European region are investigated, and the relationship  
699 with large-scale factors is highlighted. There are relatively few studies that assess this relationship  
700 and most of them are either restricted to areas prone to drought (Iberian Peninsula, Mediterranean  
701 region or the southern part of Europe) or to a particular season (mostly summer). A strong  
702 relationship between the seasonal variability of temperature and precipitation, which are key factors  
703 in driving the dryness and wetness conditions, and the global atmospheric circulation, has already  
704 been reported (Hurrell et al., 1995; Slonosky et al., 2001; Zveryaev et al., 2006, 2009; Sutton and  
705 Hodson, 2005). The aim of this study is to provide more insights on the seasonal dryness/wetness  
706 variability over the European region based on the analysis of SPEI3 which is an index that quantifies  
707 the moisture status based on temperature and precipitation.

708 During the winter season the variability of SPEI3 was found to be linked to well-known climate  
709 modes: AO/NAO, SCA, EAWR and EA. Moreover, in our study we showed that the combined  
710 effect of these climate modes (NAO vs. SCA and EAWR), not just NAO, may have quite a strong  
711 impact on SPEI3 variability. This is a very important result, especially in the view of the recent  
712 findings of Comas-Bru and McDermott (2013), who showed that the NAO centers of actions are  
713 influence by the phase of the SCA and the EA patterns. Although NAO is one of the most  
714 prominent teleconnection patterns in all seasons (Barnston and Livezey, 1987), its relative role in  
715 regulating the variability of the European climate during non-winter months is not that clear as for  
716 the winter season. At the same time, the mechanisms which drive the European climate variability  
717 might vary from one climatic period to another and, also, they might be different for different  
718 variables (e.g. precipitation, streamflow, air temperature and drought).

719 The winters PCs series of coefficients are associated with cyclonic (anticyclonic) circulations over  
720 the regions where the corresponding EOFs have the highest positive (negative) loadings. According  
721 to the composite maps of Z850, W850 and SST anomalies based on the selected values of winter

722 PC1, the cyclonic circulation is associated with the advection of warm air from the Atlantic Ocean  
723 (positive SST anomalies) and with higher rainday counts and higher cloudiness, which in turn are  
724 responsible for the wet periods over these regions. The winter PC1 of SPEI3 was found to be more  
725 correlated with winter WET and SOIL than with CLD. Reduced (enhanced) rainday counts together  
726 with decreased (increased) soil moisture content contribute to a higher degree to drought variability  
727 during winter compared to low (high) cloud cover. The influence of the cloud cover can be  
728 diminished by the presence of snow cover, which can limit the heat flux exchange between the  
729 surface and the overlying air.

730 As in the case of winter season, dryness and wetness variability during spring is strongly related to  
731 climatic modes of variability. The leading mode of spring variability of SPEI3 is positively  
732 correlated with the EA mode and negatively correlated with POL and SCA modes. According to the  
733 second mode of spring variability of SPEI3, dry (wet) conditions over the central and southern part  
734 of Europe (Scandinavian Peninsula) are associated with an atmospheric circulation mode that  
735 projects onto the positive phase of AO/NAO modes. Also, the spring PC2 time series of coefficients  
736 is negatively correlated with the SCA mode. The spring PC3 time series of coefficients of SPEI3 is  
737 positively correlated with AMO and negatively correlated with NAO and SCA. AMO was found to  
738 play an important role in the modulation of the European climate, especially during summer (Sutton  
739 and Hodson, 2005; Ionita et al., 2013). Recent studies showed that AMO can modulate the climate  
740 variability over Europe also during the transition seasons (Ionita et al., 2012c; Sutton and Dong,  
741 2012). In general, high values of SPEI3 were associated with positive anomalies of rainday counts;  
742 cloud cover and soil moisture content over the regions where the highest positive loadings are found  
743 in the EOF maps. The highest correlation of spring PCs time series of coefficients was identified  
744 with the WET field compared with CLD and SOIL. Nevertheless, CLD and SOIL plays also a  
745 significant role in spring dryness and wetness variability, but the correlations, though significant, are  
746 smaller compared to WET field.

747 The pattern of the first mode of SPEI3 variability over Europe during summer is also the result of  
748 the influence of various teleconnection patterns. The summer PC1 of SPEI3 is negatively correlated  
749 with the NAO/AO, EAWR and SCA, and positively correlated with the EA. The influence of these  
750 large scale teleconnection modes resulted in a spatial distribution of the Z850 anomalies in a wave  
751 train pattern characterized by a center of positive anomalies over Greenland, a center of negative  
752 anomalies over the central North Atlantic extending up to the Scandinavian Peninsula and another  
753 center of positive anomalies over the Mediterranean Sea extending up to central Russia. Such kind

754 of circulation pattern favors the advection of warm and dry air from the northern part of Africa  
755 towards the southern part of Europe (see the wind vectors in the composite maps), which in turn will  
756 experience dry conditions. It is well known that the atmospheric circulation during summer seasons  
757 is mostly influenced by the atmospheric blocking as it was shown in the composite map of Z850  
758 anomalies associated to PC2 series of coefficients. Most of the extreme events related to heat waves  
759 in Europe, during summer, were triggered by such a particular atmospheric pattern. Anomalously  
760 barotropic structures are particularly strong (weak) in June (July) when the large scale anomalies are  
761 organized in wave trains that propagate from the Atlantic Ocean towards the European continent  
762 (Xopalki et al., 1995; Corte-Real et al., 1995; Cassou et al., 2005). Summer dry conditions over  
763 western Russia are associated with a blocking like pattern over Europe. It is characterized by an  
764 anticyclonic circulation over the eastern part of Europe and two centers of cyclonic circulation, one  
765 over the Scandinavian Peninsula and the British Isles, and another one over the northern part of  
766 Africa. Such a pattern of atmospheric blocking was responsible for one of the most extreme  
767 summer heat waves recorded over the eastern Europe and Russia during 2010 (Dole et al., 2011). In  
768 general, the atmospheric blocking in summer is associated with extreme temperatures and heat  
769 waves (Della-Marta et al., 2007, Garcia-Herrera et al., 2010; Feudale and Shukla, 2010). During  
770 summer, the correlation maps of PCs time series of coefficients with WET, CLD and SOIL show  
771 similar patterns (in terms of amplitude of the correlation coefficients) but the strength and the  
772 significance of the correlation coefficients demonstrate that the WET and SOIL fields have more  
773 influence on moisture variability than CLD.

774 The first mode of autumn moisture variability was found to be significantly correlated with the  
775 autumn POL and EAWR teleconnection patterns. The second mode of autumn moisture variability  
776 is strongly related to AO/NAO modes, as in the case of winter EOF2. Dry (wet) conditions over  
777 central and the southern part of Europe (Scandinavian Peninsula) are associated with Z850 and SST  
778 anomalies that project onto the positive phase of AO/NAO. The third mode of the autumn variability  
779 of SPEI3 is the result of the influence of various teleconnection patterns. The PC3 is positively  
780 correlated with NAO/AO and negatively correlated with SCA. The composite of Z850 anomalies  
781 based on selected PC3 values presents a wave train pattern (with altering signs) which develops over  
782 the Atlantic Ocean and extends up to Siberia. Higher correlations have been identified between the  
783 autumn PCs and WET and SOIL fields compared to CLD.

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## 785 **7. Conclusions**

786 The main conclusions of our study can be summarized as follows:

- 787     ➤ The leading modes of SPEI3 variability are definitely seasonally – dependent. Although the  
788     spatial structure of the leading modes of seasonal variability of SPEI3 may show  
789     resemblance between each other, the temporal evolution (in terms of principal component  
790     time series of coefficients) differs significantly from one season to another. Moreover, the  
791     leading modes of dryness and wetness variability quantified by SPEI3 are associated with  
792     particular atmospheric circulation patterns and sea surface temperature anomalies for each  
793     season. The analysis of seasonal composite maps of Z850, W850 and global SST anomalies  
794     and of seasonal correlation maps of the first three PCs of SPEI3 and WET, CLD and SOIL  
795     fields pointed out on a specific and significant role of each of these climatic variables on the  
796     seasonal short-term SPEI3 variability.
- 797     ➤ The response of dryness/wetness variability quantified by SPEI3 to SST anomalies was  
798     found to be more regional during summer, compared to other seasons. This might be due to  
799     the fact that during summer moisture conditions are more sensitive to local conditions (e.g.  
800     precipitation, soil moisture). Another reason might be that the response of air temperature  
801     over the land (which is an input parameter for the computation of SPEI) to SST anomaly  
802     variations is seasonally dependent and, this seasonality is mainly due to the warming trends  
803     of SST (Cattiaux et al., 2010).
- 804     ➤ Overall, the correlation maps between the PC time series of coefficients corresponding to the  
805     three leading modes of seasonal SPEI3 variability and the fields of WET, CLD and SOIL  
806     show much similarities with the patterns of EOF loadings, meaning that the regions with the  
807     highest loadings in the EOF field are similar to the regions where the highest correlation is  
808     recorded in the correlation maps of the seasonal PCs with WET, CLD and SOIL fields. The  
809     main difference arises from the fact that in some seasons and for particular regions WET and  
810     SOIL show stronger influence (in terms of correlation coefficient amplitude) on  
811     dryness/wetness conditions over Europe compared to CLD. This might be one of the direct  
812     results of the fact that the SPEI3 variability is modulated both by local and large scale-  
813     factors. The differences in the correlation maps between seasonal PCs and WET, CLD and  
814     SOIL fields might also be due to the different soil types that characterize different regions.  
815     One specific example is the western part of the Scandinavian Peninsula, where the effect of  
816     soil moisture is less that important due to the fact that the soils over these regions mainly

817 consist of glacial materials (which are not sensitive to soil moisture, Jones et al., 2005).  
818 ➤ The findings of this paper also suggest that dryness and wetness variability over Europe is  
819 influenced by rainday counts, cloud cover and soil moisture as a direct result of atmospheric  
820 circulation anomalies. The physical mechanisms involved in dryness/wetness variability are  
821 very complex and differ from one season to another. Precipitation deficits can be induced by  
822 various processes including decreasing cloudiness, and land surface drying can slack  
823 evapotranspiration and thus inhibiting cloud formation. This can be the result of the direct  
824 effect of atmospheric factors (e.g. cyclones and anticyclones) and global and/or regional SST  
825 anomalies. Moreover, when studying the variability of the moisture in connection to large  
826 scale circulation, one should take into account the soil characteristics to specific regions.

827 The main findings of this study are that the leading EOF modes of SPEI3 variability are  
828 characterized by seasonal differences and, their relationship with the large-scale atmospheric  
829 circulation, global SST, rainday counts, cloud cover and soil moisture is also seasonal - dependent.  
830 The results presented here also point out on how complex the drivers of the dryness and wetness  
831 variability at the European scale are. Given the complex nature of seasonal dryness/wetness  
832 variability and the temporal scales of its potential impact on various socio-economic sectors, a next  
833 logical step will be to perform a similar analysis for mid-range and long-term dryness and wetness  
834 variability quantified with SPEI.

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1091 **Figure 1.** a) Spatial patterns of the first winter EOF mode of the SPEI3 field; b) Spatial patterns of  
1092 the second winter EOF mode of the SPEI3 field; c) Spatial patterns of the third winter EOF mode of  
1093 the SPEI3 field; d) The times series of the first Principal Component (PC1) corresponding to the  
1094 first winter EOF mode and its corresponding 7-yr running mean (black line); e) The times series of  
1095 the second Principal Component (PC2) corresponding to the second winter EOF mode and its  
1096 corresponding 7-yr running mean (black line); f) The times series of the third Principal Component  
1097 (PC3) corresponding to the third winter EOF mode and its corresponding 7-yr running means (black  
1098 line).

1099  
1100 **Figure 2.** As in Figure 1, but for Spring.

1101  
1102 **Figure 3.** As in Figure 1, but for Summer.

1103  
1104 **Figure 4.** As in Figure 1, but for Autumn.

1105  
1106 **Figure 5.** a) The composite map (High – Low) between the winter PC1 and winter Z850 (shaded)  
1107 and the wind vectors at 850mb (arrows); b) As in Figure 5a, but for winter PC2; c) As in Figure 5a,  
1108 but for winter PC3; d) The composite map (High – Low) between the winter PC1 and global winter  
1109 SST; e) As in Figure 5d, but for winter PC2; f) As in Figure 5d, but for winter PC3; (The dotted  
1110 areas indicate the Z500 and SST normalized anomalies significant at 95 % significance level on a  
1111 standard t-test).

1112  
1113 **Figure 6.** As in Figure 5, but for Spring.

1114  
1115 **Figure 7.** As in Figure 5, but for Summer.

1116  
1117 **Figure 8.** As in Figure 5, but for Autumn.

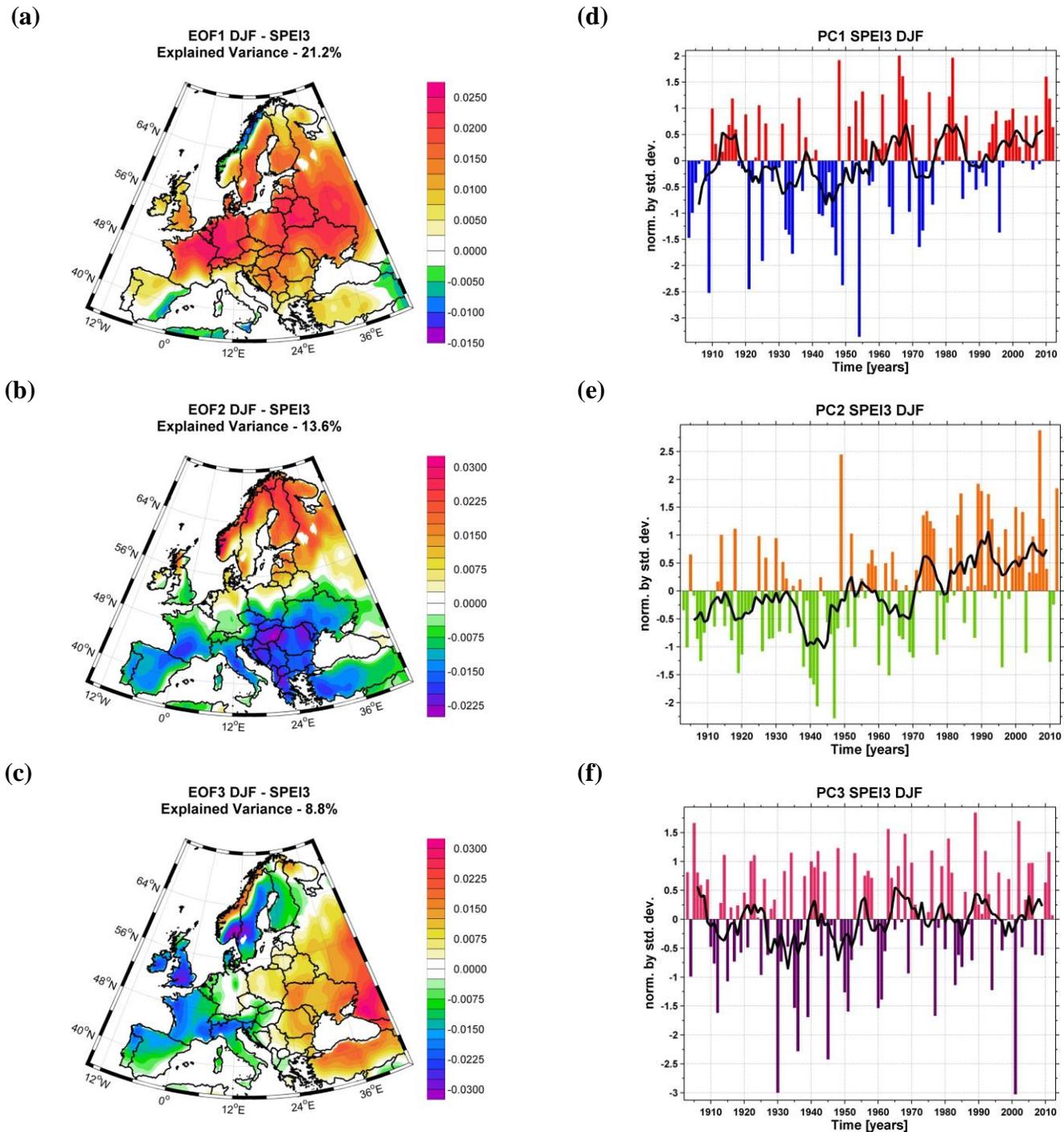
1118  
1119 **Figure 9.** a) The correlation maps between winter PC1 and winter wet days (WET); b) The  
1120 correlation maps between winter PC2 and winter wet days (WET); c) The correlation maps between  
1121 winter PC3 and winter wet days (WET); d) The correlation maps between winter PC1 and winter  
1122 Cloud Cover (CLD); e) The correlation maps between winter PC2 and winter Cloud Cover (CLD);  
1123 f) The correlation maps between winter PC3 and winter Cloud Cover (CLD); g) The correlation  
1124 maps between winter PC1 and winter Soil Moisture (SOIL); h) The correlation maps between winter  
1125 PC2 and winter Soil Moisture (SOIL); i) The correlation maps between winter PC3 and winter Soil  
1126 Moisture (SOIL); The dotted areas indicate the areas where the correlation coefficient is significant  
1127 at 95 % significance level.

1128  
1129 **Figure 10.** As in Figure 9, but for Spring.

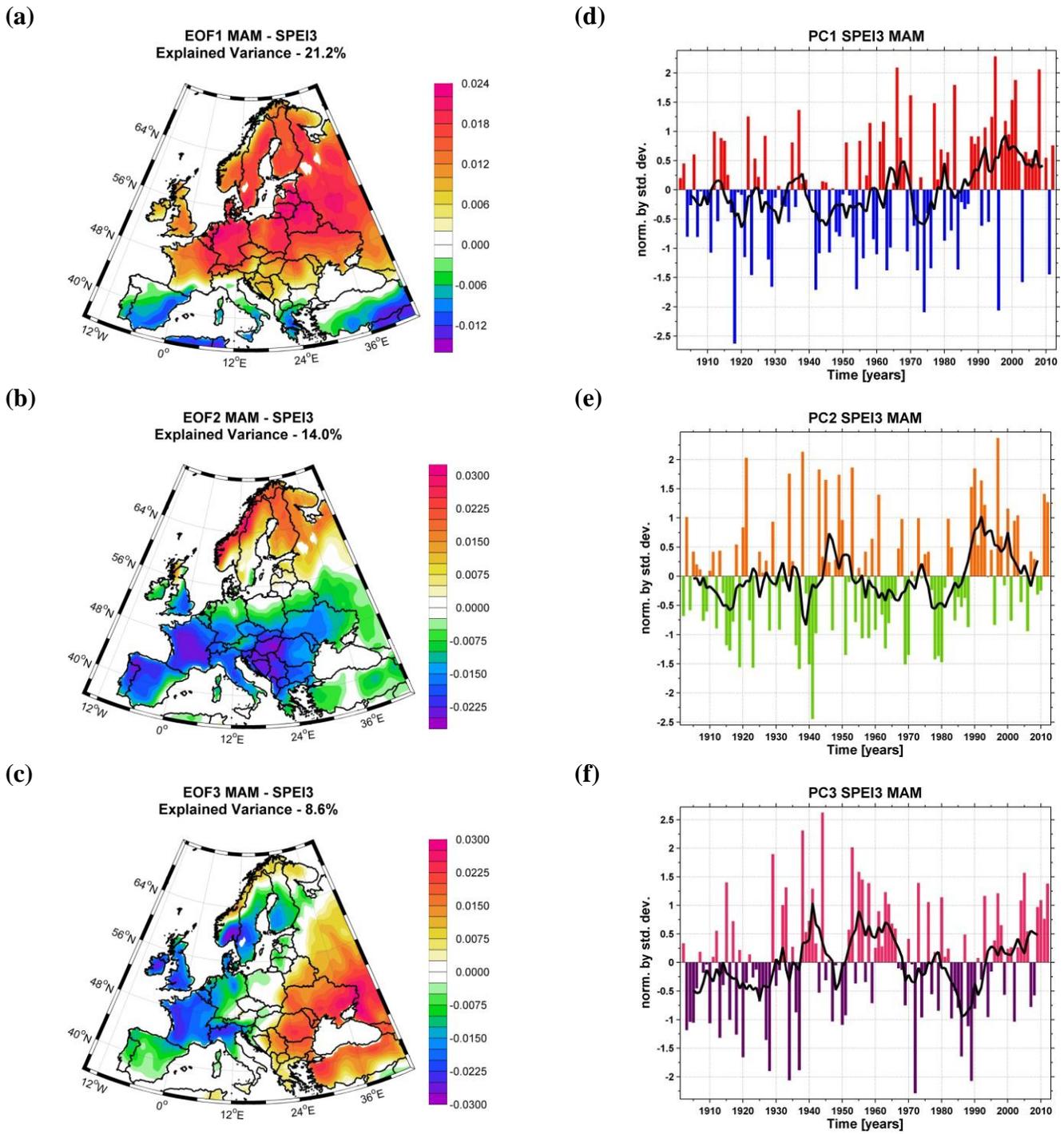
1130  
1131 **Figure 11.** As in Figure 9, but for Summer.

1132  
1133 **Figure 12.** As in Figure 9, but for Autumn.

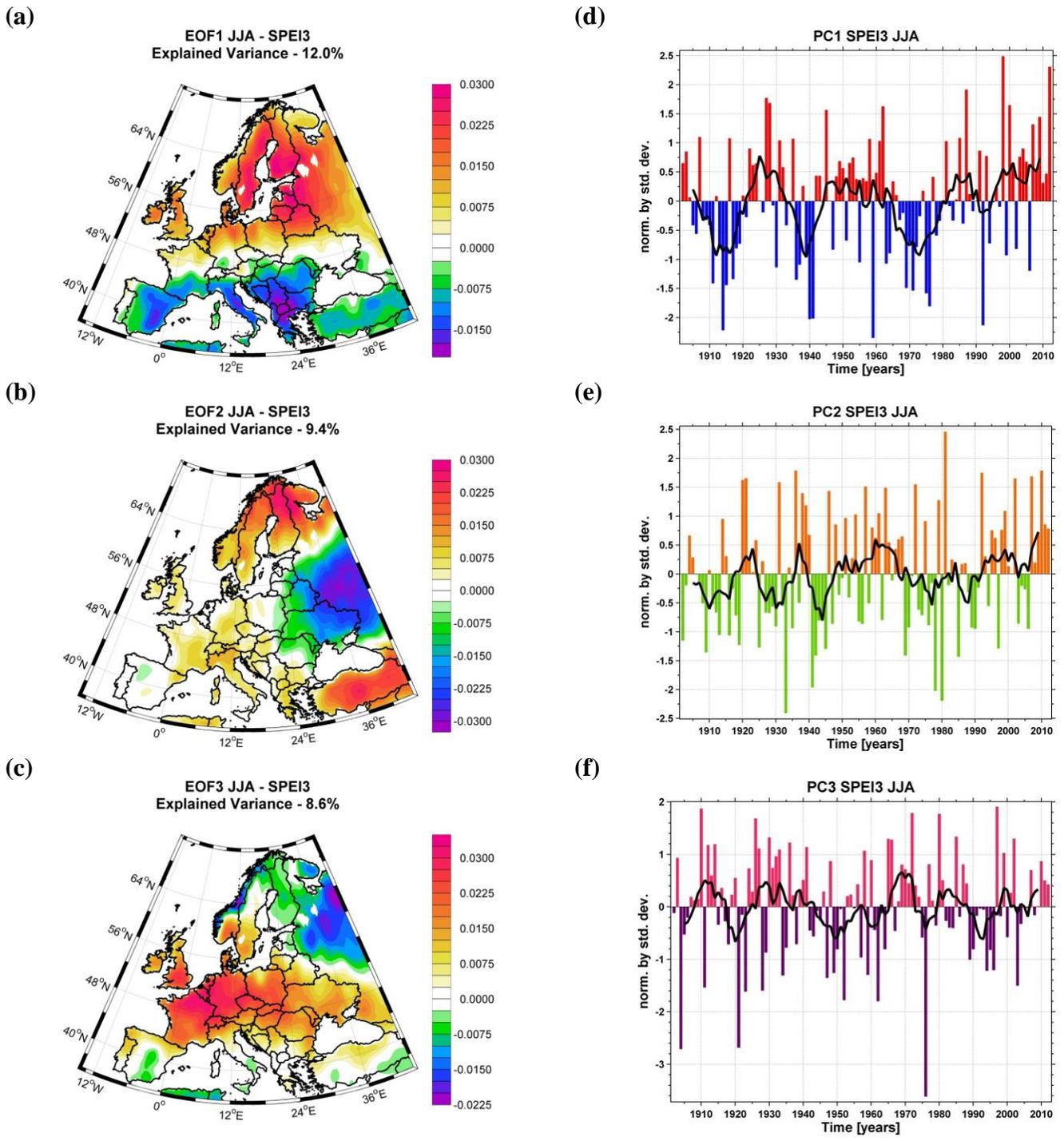
1134  
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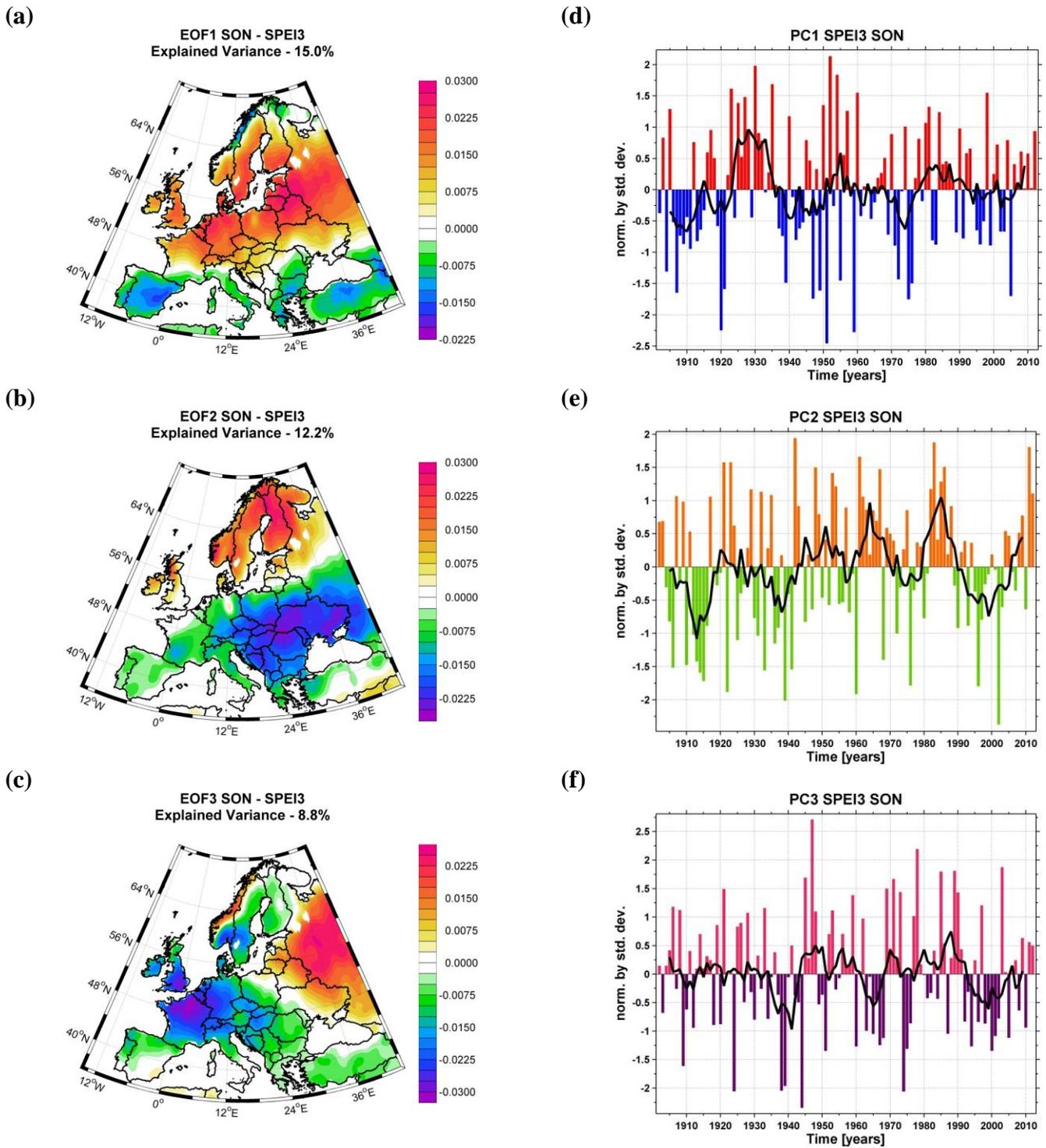
**Figure 1.** a) Spatial patterns of the first winter EOF mode of the SPEI3 field;  
 b) Spatial patterns of the second winter EOF mode of the SPEI3 field;  
 c) Spatial patterns of the third winter EOF mode of the SPEI3 field;  
 d) The times series of the first Principal Component (PC1) corresponding to the first winter EOF mode and its corresponding 7-yr running mean (black line);  
 e) The times series of the second Principal Component (PC2) corresponding to the second winter EOF mode and its corresponding 7-yr running mean (black line);  
 f) The times series of the third Principal Component (PC3) corresponding to the third winter EOF mode and its corresponding 7-yr running means (black line).



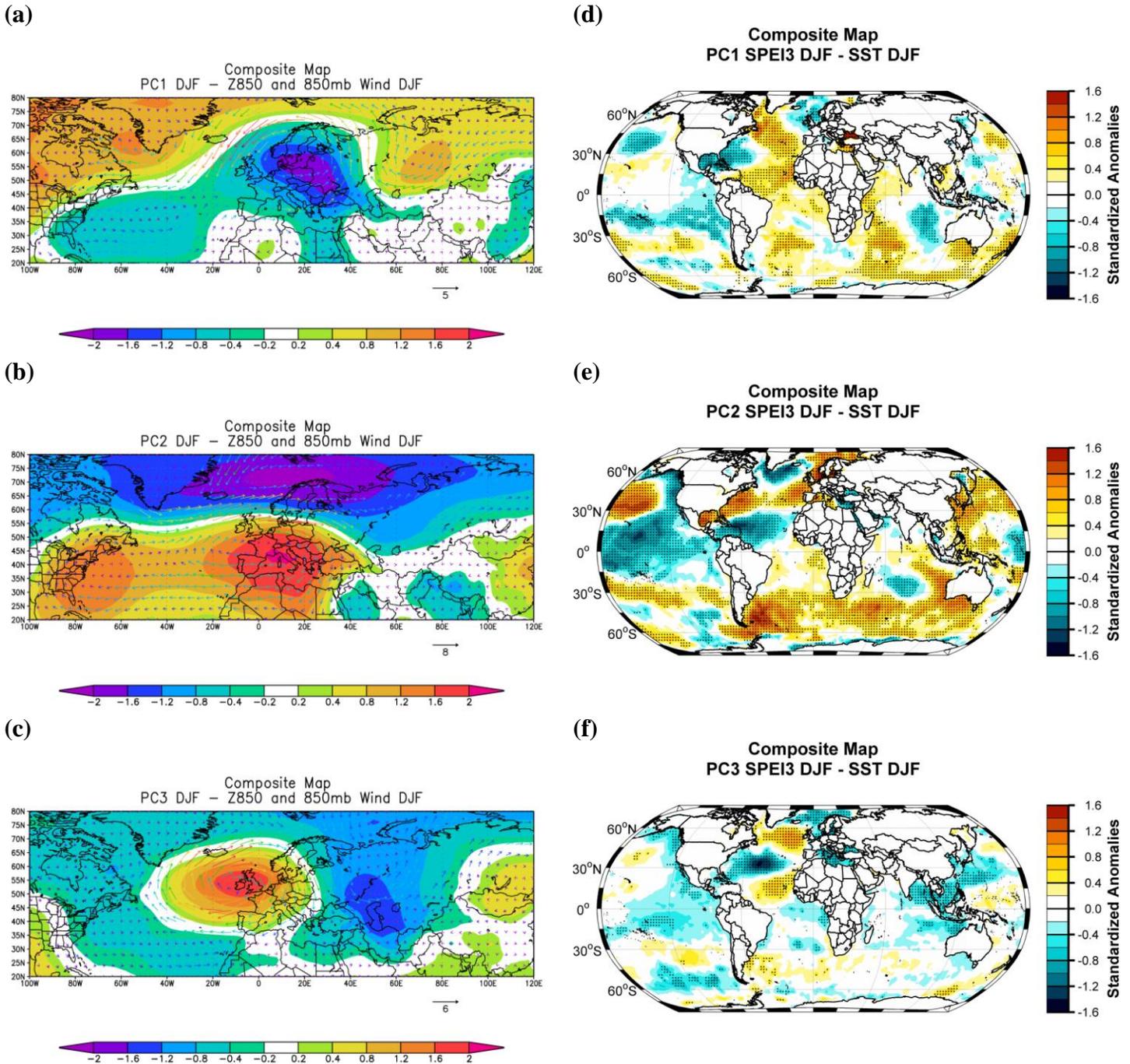
*Figure 2.* As in Figure 1, but for Spring.



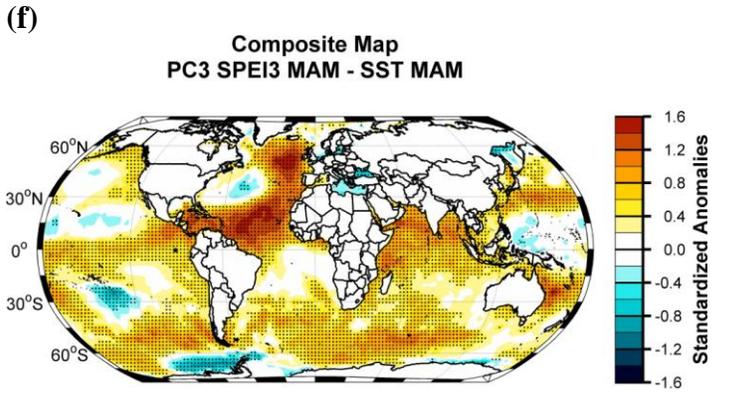
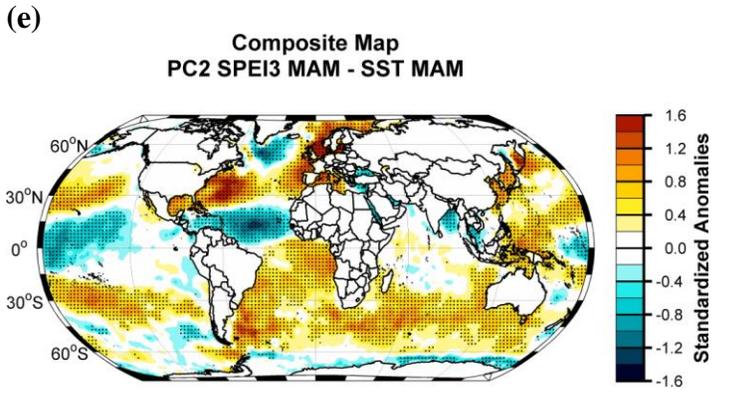
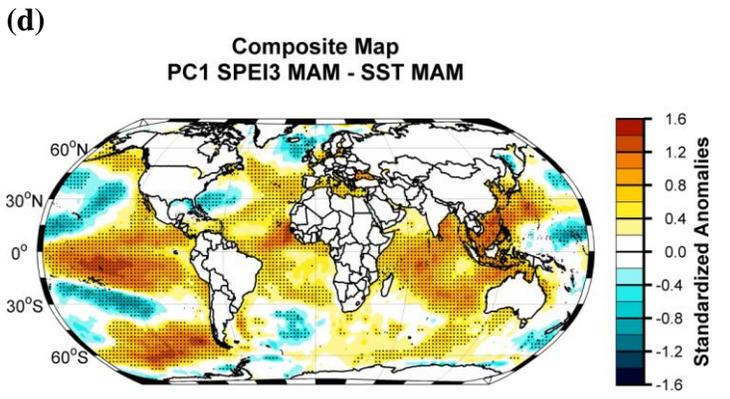
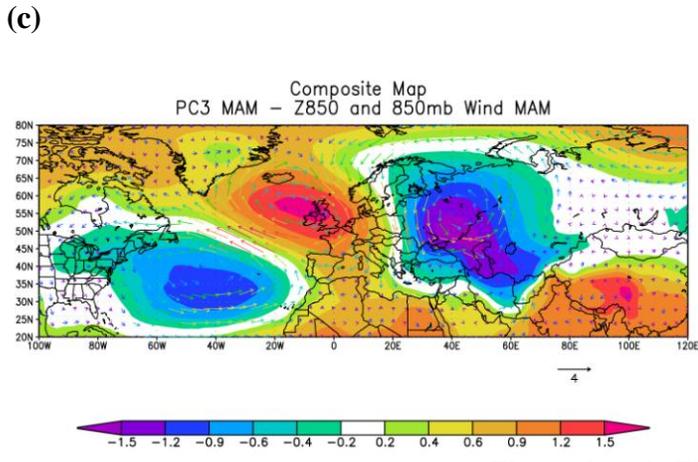
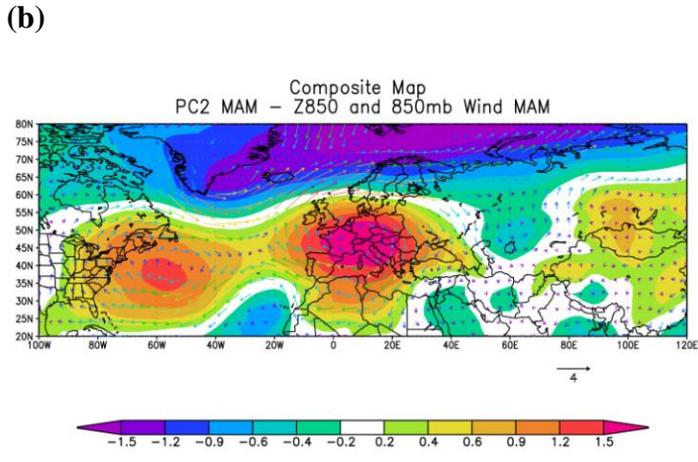
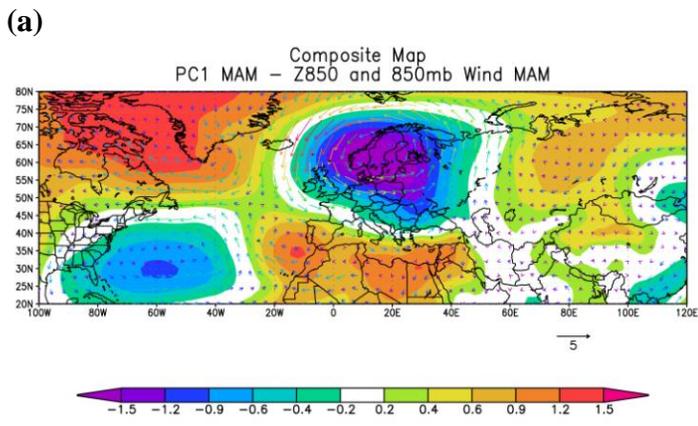
*Figure 3.* As in Figure 1, but for Summer.



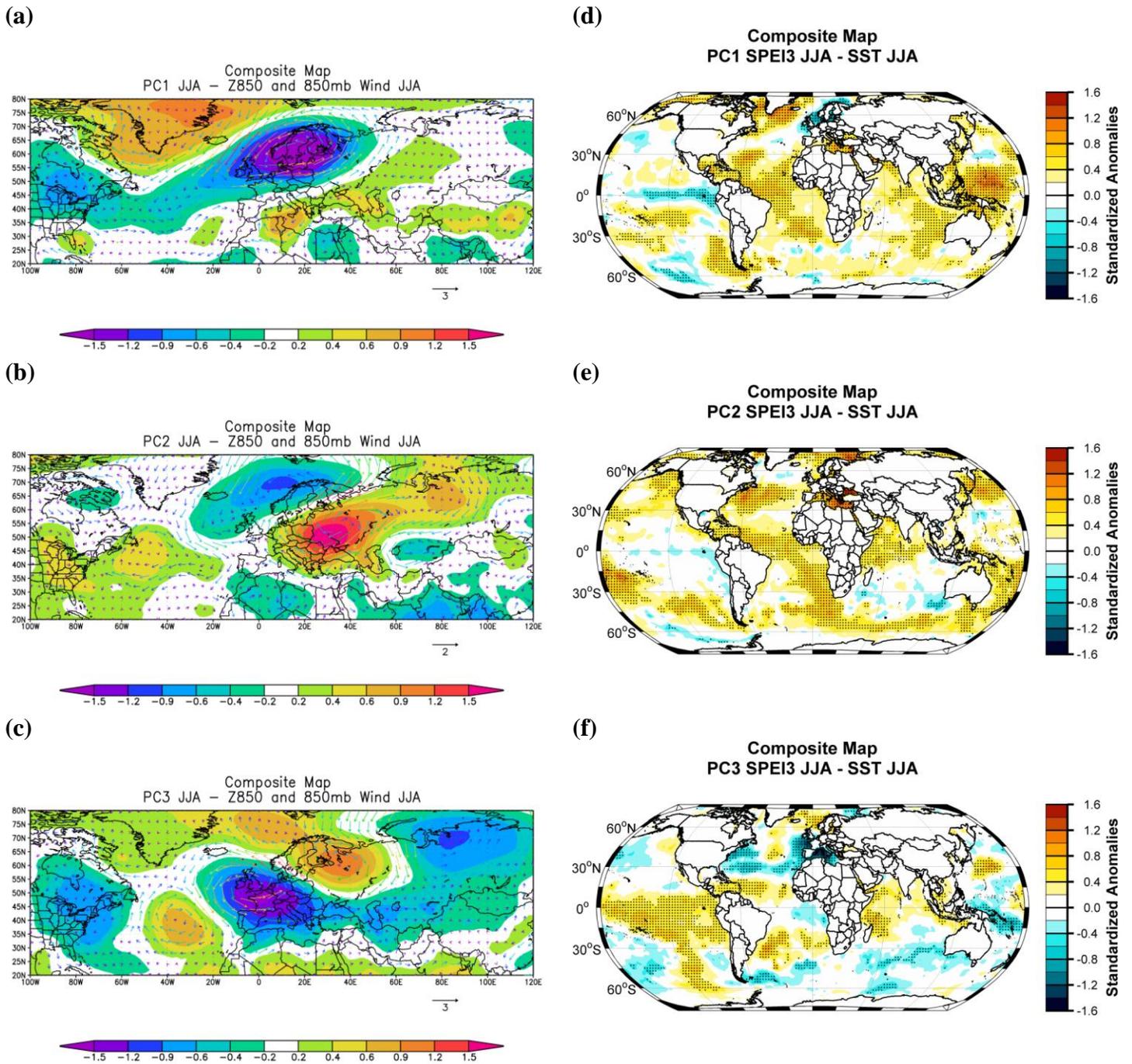
*Figure 4.* As in Figure 1, but for Autumn.



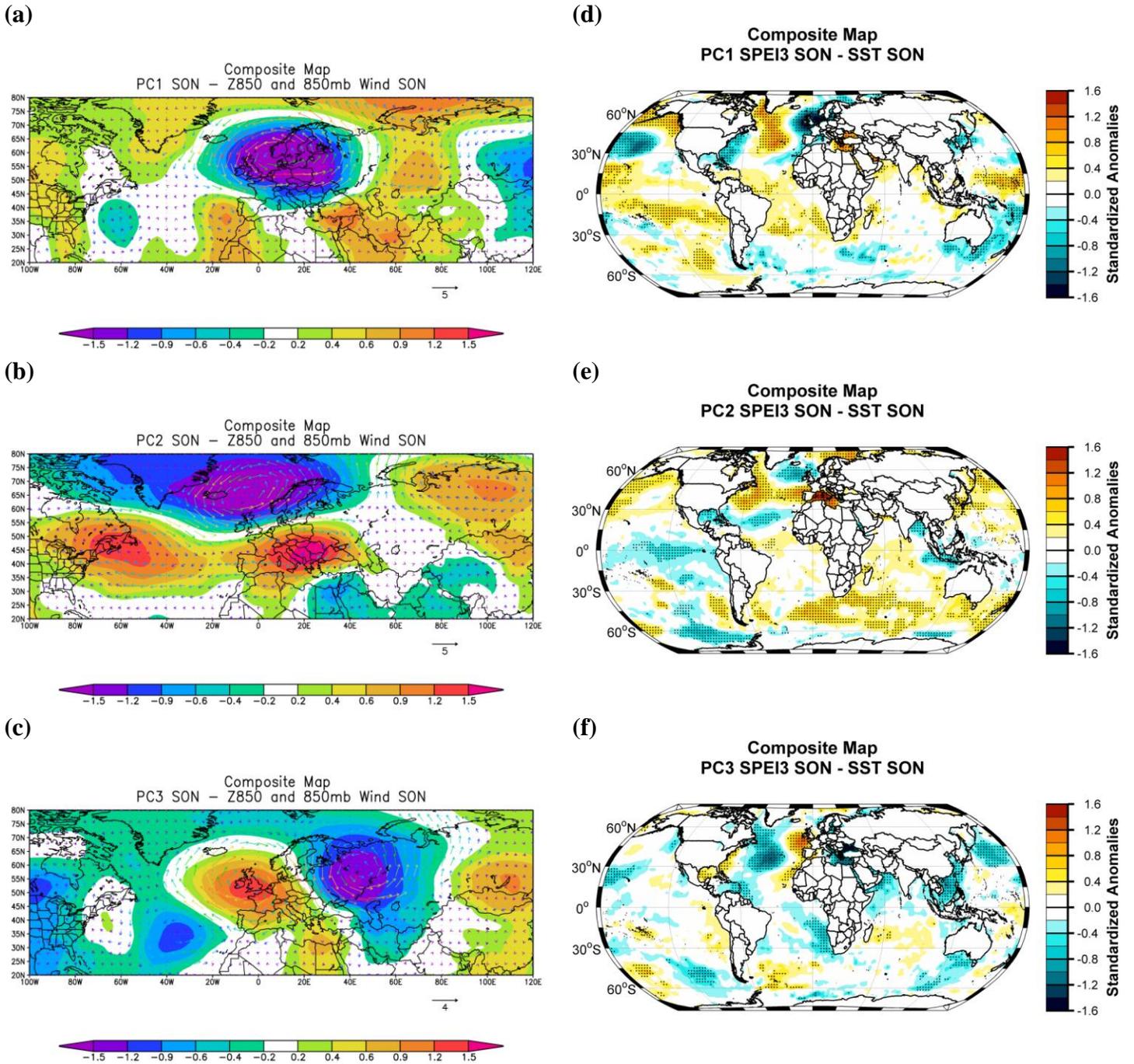
**Figure 5.** a) The composite map (High – Low) between the winter PC1 and winter Z850 (shaded) and the wind vectors at 850mb (arrows);  
 b) As in Figure 5a, but for winter PC2;  
 c) As in Figure 5a, but for winter PC3;  
 d) The composite map (High – Low) between the winter PC1 and global winter SST;  
 e) As in Figure 5d, but for winter PC2;  
 f) As in Figure 5d, but for winter PC3;  
 (The dotted areas indicate the Z500 and SST normalized anomalies significant at 95 % significance level on a standard t-test).



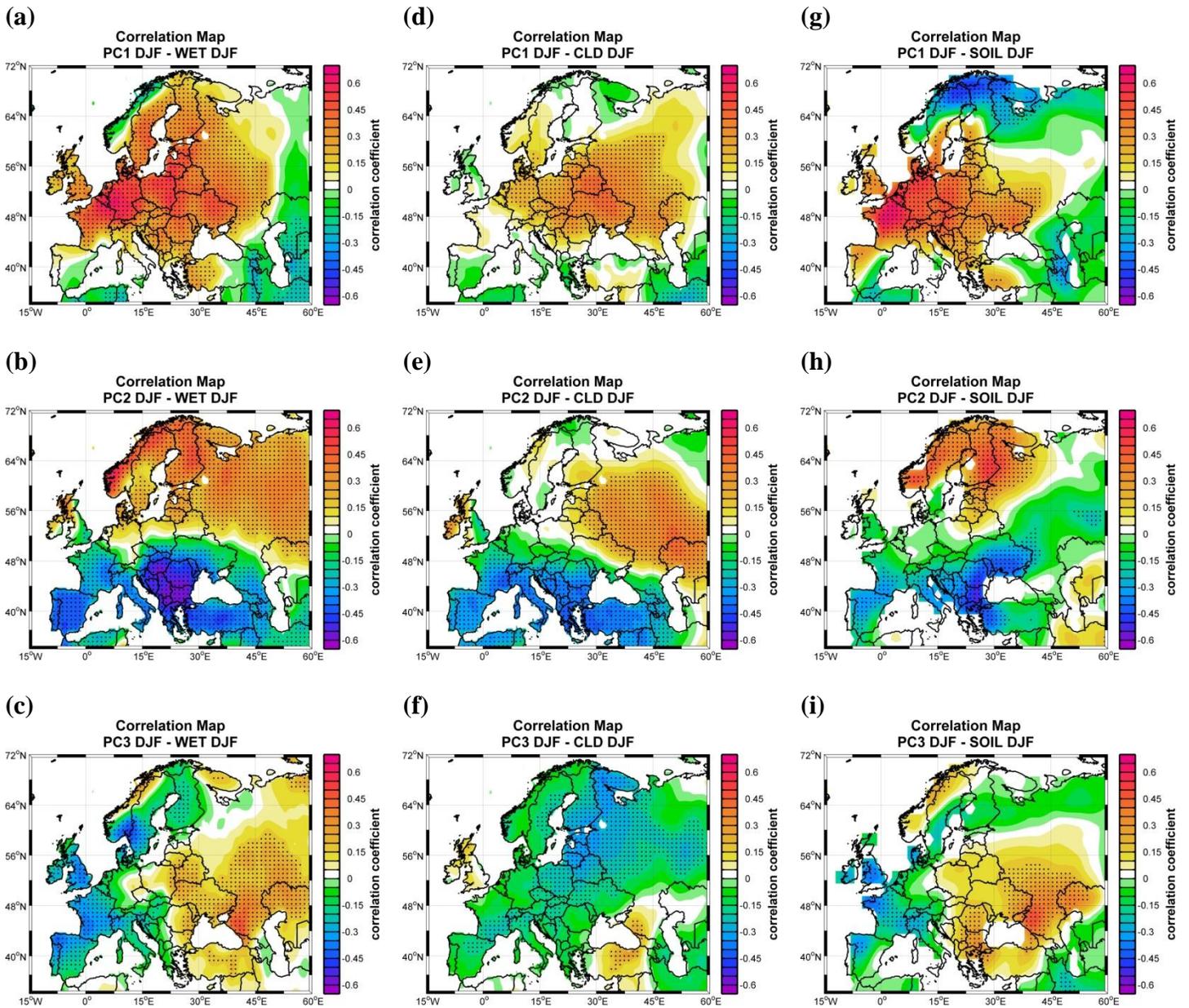
**Figure 6.** As in Figure 5, but for Spring.



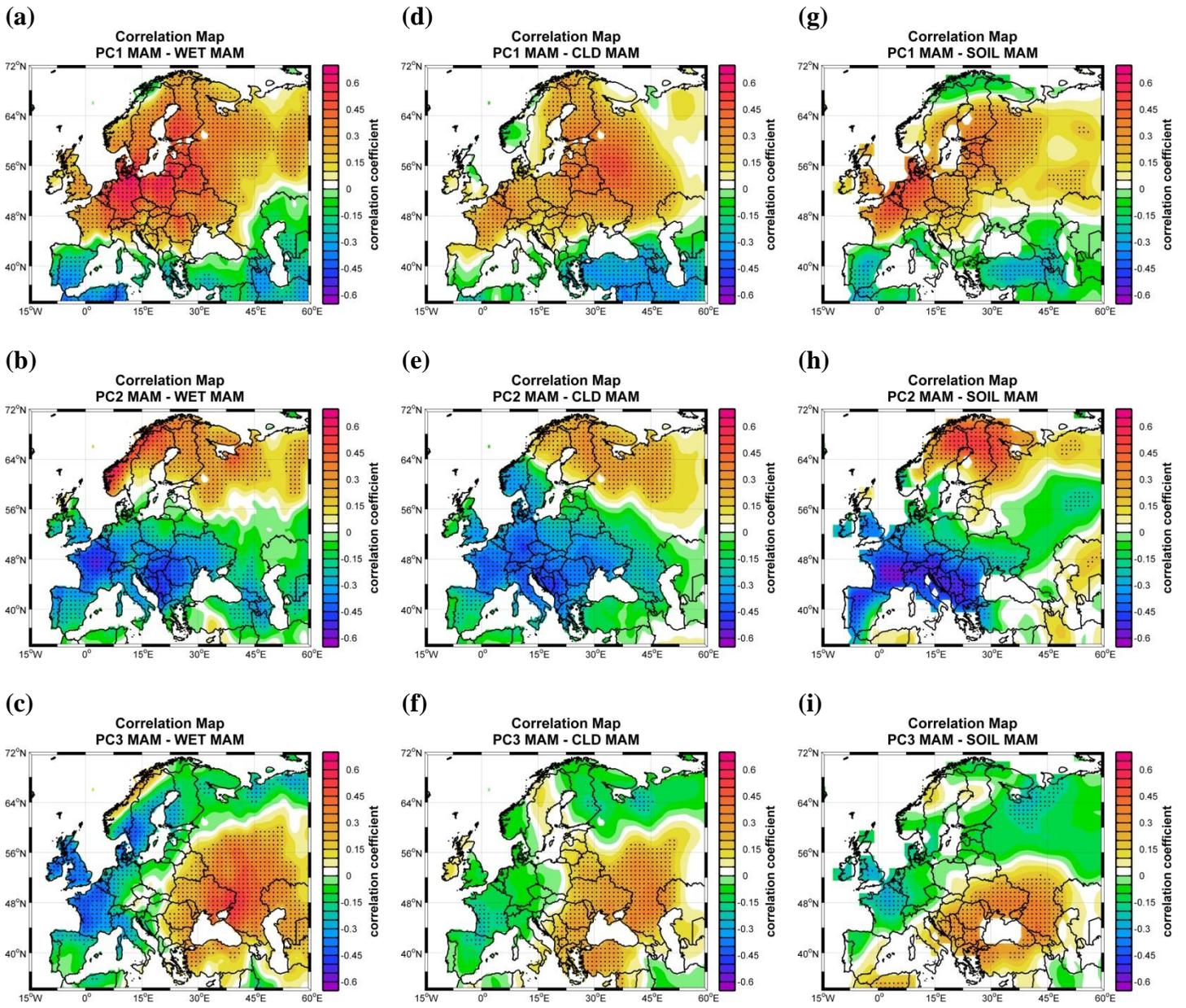
*Figure 7.* As in Figure 5, but for Summer.



*Figure 8.* As in Figure 5, but for Autumn.



**Figure 9.** a) The correlation maps between winter PC1 and winter wet days (WET);  
 b) The correlation maps between winter PC2 and winter wet days (WET);  
 c) The correlation maps between winter PC3 and winter wet days (WET);  
 d) The correlation maps between winter PC1 and winter Cloud Cover (CLD);  
 e) The correlation maps between winter PC2 and winter Cloud Cover (CLD);  
 f) The correlation maps between winter PC3 and winter Cloud Cover (CLD);  
 g) The correlation maps between winter PC1 and winter Soil Moisture (SOIL);  
 h) The correlation maps between winter PC2 and winter Soil Moisture (SOIL);  
 i) The correlation maps between winter PC3 and winter Soil Moisture (SOIL);  
 The dotted areas indicate the areas where the correlation coefficient is significant at 95 % significance level.



*Figure 10.* As in Figure 9, but for Spring.

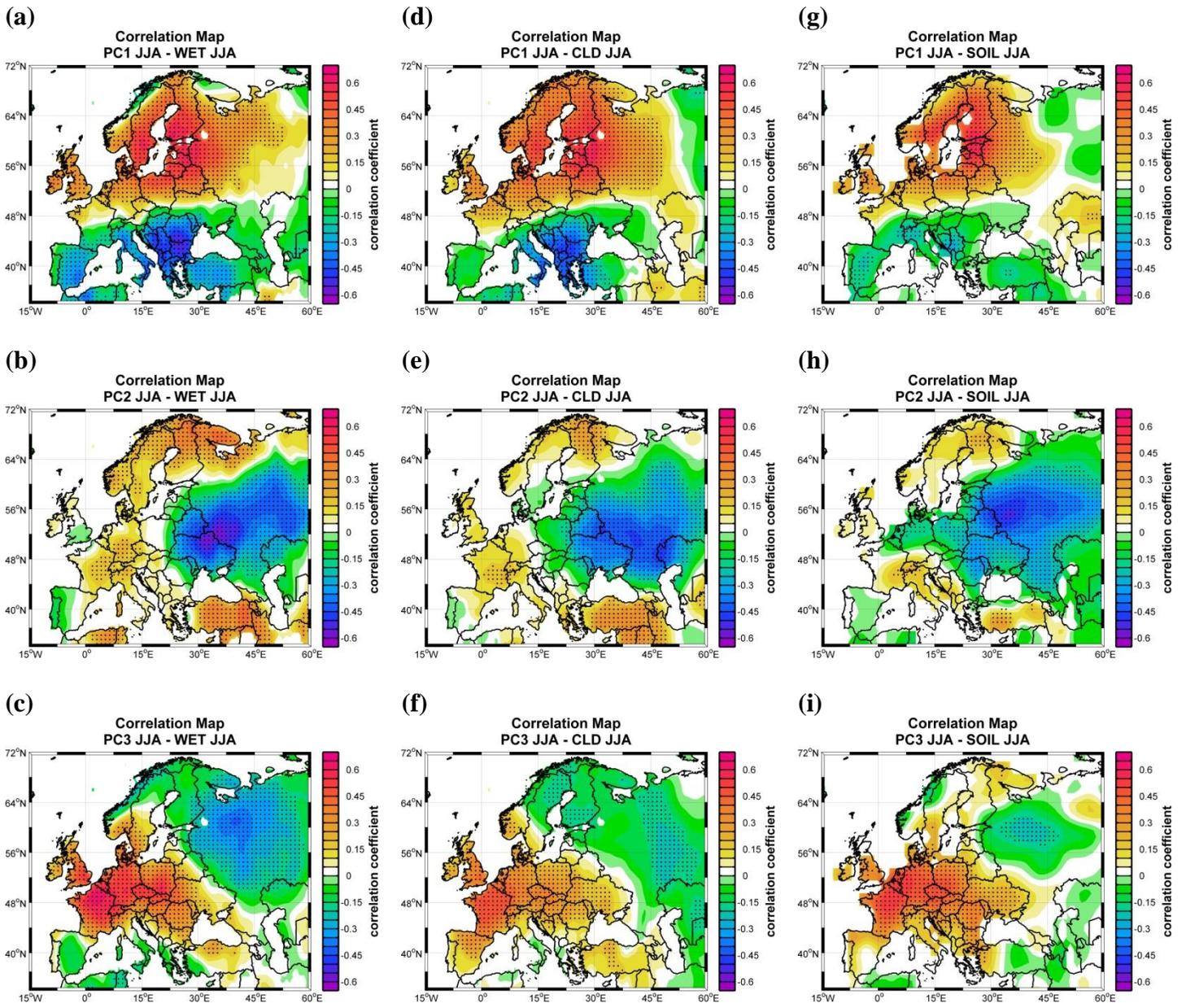


Figure 11. As in Figure 9, but for Summer.

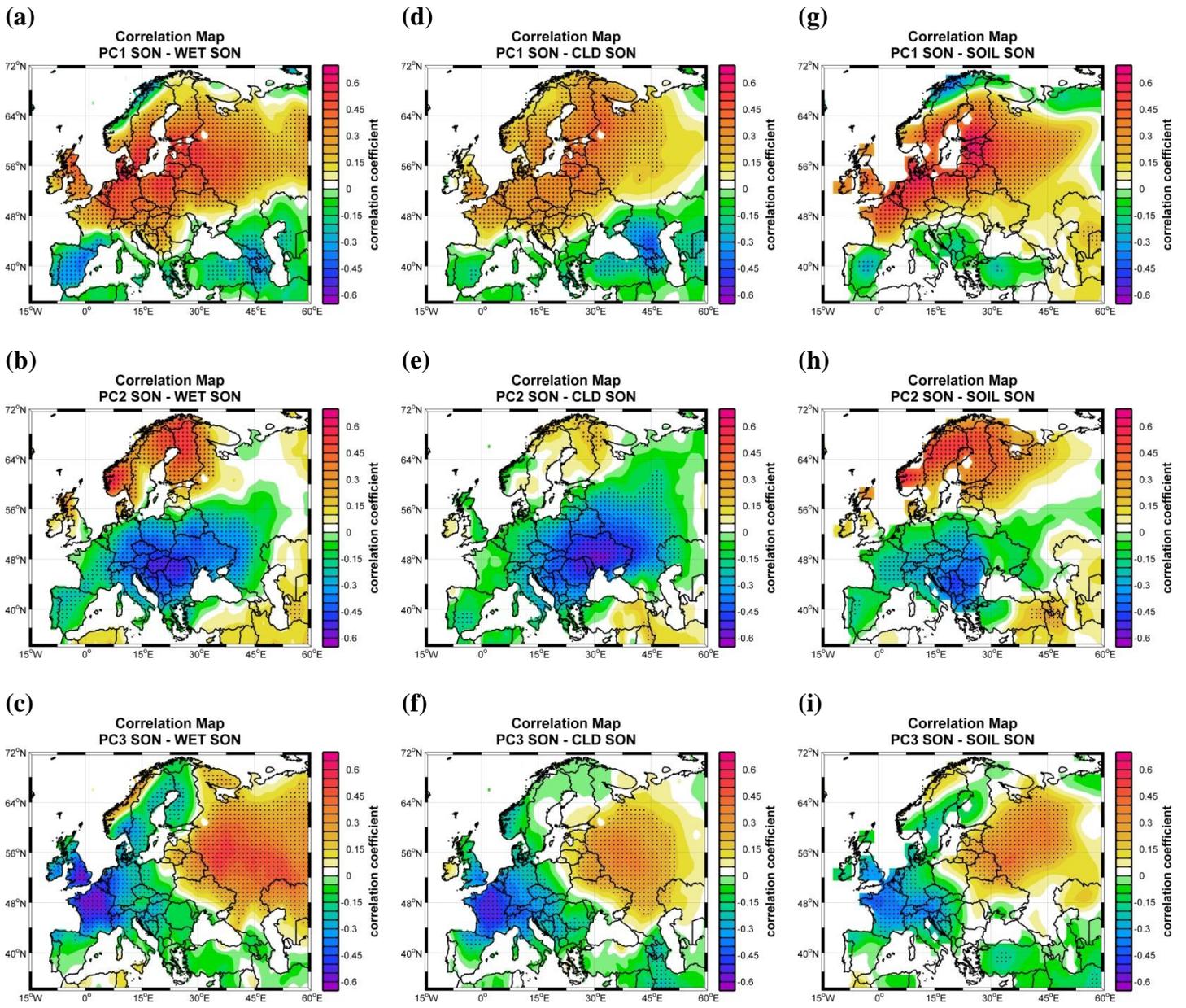


Figure 12. As in Figure 9, but for Autumn.

**Table 1.** The explained variance of the first ten seasonal EOFs. The EOFs highlighted in red, are the seasonal EOFs used in this study.

<b>Explained variance (%)</b>				
<b>No. EOF</b>	<b>Winter</b>	<b>Spring</b>	<b>Summer</b>	<b>Autumn</b>
<b>EOF1</b>	<b>21.2</b>	<b>21.2</b>	<b>612.0</b>	<b>15.0</b>
<b>EOF2</b>	<b>13.6</b>	<b>14.0</b>	<b>4.69.4</b>	<b>12.2</b>
<b>EOF3</b>	<b>8.8</b>	<b>8.6</b>	<b>8.6</b>	<b>8.8</b>
EOF4	5.7	5.1	6.3	6.5
EOF5	4.0	3.8	4.6	4.0
EOF6	3.7	3.0	4.1	3.3
EOF7	3.5	2.9	3.5	3.2
EOF8	3.3	2.0	2.8	2.6
EOF9	2.0	1.9	2.4	2.5
EOF10	1.9	1.8	2.0	2.0

**Table 2.** Teleconnection indices used in this study, time period and their source

<b>Name</b>	<b>Explanation</b>	<b>Period</b>	<b>Data source</b>
AMO	Atlantic Multidecadal Oscillation	1950-2012	<a href="http://climexp.knmi.nl/data/iamo_hadsst2.dat">http://climexp.knmi.nl/data/iamo_hadsst2.dat</a>
NAO	North Atlantic Oscillation	1950-2012	<a href="http://www.cru.uea.ac.uk/cru/data/nao.htm">http://www.cru.uea.ac.uk/cru/data/nao.htm</a>
AO	Arctic Oscillation	1950-2012	<a href="http://www.atmos.colostate.edu/ao/Data/ao_index.html">http://www.atmos.colostate.edu/ao/Data/ao_index.html</a>
SCA	Scandinavian Pattern	1950-2012	<a href="http://www.cpc.noaa.gov/data/teledoc/scand.shtml">http://www.cpc.noaa.gov/data/teledoc/scand.shtml</a>
EAWR	East Atlantic/ Western Russia	1950 - 2012	<a href="http://www.cpc.ncep.noaa.gov/data/teledoc/eawruss.shtml">http://www.cpc.ncep.noaa.gov/data/teledoc/eawruss.shtml</a>
EA	East Atlantic	1950 - 2012	<a href="http://www.cpc.ncep.noaa.gov/data/teledoc/ea.shtml">http://www.cpc.ncep.noaa.gov/data/teledoc/ea.shtml</a>
Niño 3.4	Niño 3.4 index	1950 - 2012	<a href="http://iridl.ldeo.columbia.edu/SOURCES/.Indices/.nino/.KAPLAN/">http://iridl.ldeo.columbia.edu/SOURCES/.Indices/.nino/.KAPLAN/</a>
Niño 4	Niño4 index		<a href="http://iridl.ldeo.columbia.edu/SOURCES/.Indices/.nino/.KAPLAN/">http://iridl.ldeo.columbia.edu/SOURCES/.Indices/.nino/.KAPLAN/</a>
POL	Polar/Eurasia	1950 - 2012	<a href="http://www.cpc.ncep.noaa.gov/data/teledoc/poleur.shtml">http://www.cpc.ncep.noaa.gov/data/teledoc/poleur.shtml</a>
PDO	Pacific Decadal Oscillation	1950 - 2012	<a href="http://jisao.washington.edu/pdo/">http://jisao.washington.edu/pdo/</a>

**Table 3.** Correlation coefficients between the SPEI 3 Principal Components (PCs) corresponding to the first three seasonal EOFs and the seasonal teleconnection patterns (<sup>#</sup> - 90% significance level; \* - 95% significance level; \*\* - 99% significance level).

	PC1				PC2				PC3			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
<b>AMO</b>	0.14	0.19	<b>0.27*</b>	0.15	0.02	0.01	0.01	-0.10	0.03	<b>0.37**</b>	-0.15	-0.08
<b>AO</b>	-0.17	-0.04	<b>-0.31**</b>	-0.14	<b>0.79**</b>	<b>0.52**</b>	-0.11	<b>0.52**</b>	0.16	-0.20	<b>-0.31**</b>	<b>0.31**</b>
<b>EA</b>	0.18	<b>0.35**</b>	<b>0.40**</b>	0.02	0.06	0.08	0.08	0.19	<b>-0.28*</b>	-0.04	<b>0.25*</b>	-0.20
<b>EAWR</b>	<b>-0.24<sup>#</sup></b>	-0.12	<b>-0.47**</b>	<b>-0.25*</b>	<b>0.34**</b>	-0.01	<b>-0.27*</b>	-0.09	<b>0.28*</b>	0.12	-0.10	<b>0.26*</b>
<b>NAO</b>	0.05	-0.16	<b>-0.55**</b>	-0.19	<b>0.64**</b>	<b>0.27*</b>	-0.03	<b>0.37**</b>	-0.03	<b>-0.25*</b>	<b>-0.26*</b>	<b>0.31**</b>
<b>NINO3.4</b>	0.01	0.19	0.09	-0.15	-0.13	0.11	0.06	-0.09	-0.12	0.18	0.16	0.00
<b>NINO4</b>	0.00	0.12	0.03	-0.04	<b>-0.22<sup>#</sup></b>	0.01	0.02	-0.10	-0.07	<b>0.20<sup>#</sup></b>	0.18	0.04
<b>PDO</b>	0.18	0.16	0.07	-0.01	<b>-0.20<sup>#</sup></b>	-0.05	-0.01	-0.14	0.20	0.01	0.07	0.09
<b>POL</b>	-0.17	<b>-0.26*</b>	<b>-0.20<sup>#</sup></b>	<b>-0.34**</b>	-0.16	0.13	0.06	0.05	<b>0.20<sup>#</sup></b>	-0.08	0.08	0.04
<b>SCA</b>	-0.15	<b>-0.42**</b>	<b>-0.46**</b>	-0.12	<b>-0.56**</b>	<b>-0.49**</b>	-0.10	<b>-0.33**</b>	<b>-0.39**</b>	<b>-0.21<sup>#</sup></b>	<b>0.21<sup>#</sup></b>	<b>-0.39**</b>

**Table 4.** The years corresponding to the low values of the seasonal SPEI3 PCs (< -1 std. dev.) and high values (> 1 std. dev.) used for the composite map analysis in Section 4.

DJF						MAM						JJA						SON					
PC1		PC2		PC3		PC1		PC2		PC3		PC1		PC2		PC3		PC1		PC2		PC3	
Low	High																						
1903	1916	1904	1914	1912	1905	1911	1922	1915	1903	1903	1915	1911	1907	1902	1920	1904	1910	1904	1905	1906	1907	1909	1906
1909	1924	1908	1918	1915	1914	1918	1937	1916	1921	1904	1929	1914	1916	1909	1921	1911	1912	1907	1923	1910	1917	1924	1908
1921	1936	1919	1949	1930	1922	1921	1958	1919	1934	1905	1932	1915	1927	1913	1931	1921	1914	1920	1925	1912	1921	1938	1921
1925	1948	1920	1952	1935	1923	1923	1962	1923	1938	1910	1933	1917	1928	1916	1936	1923	1926	1921	1927	1913	1923	1939	1928
1932	1953	1926	1973	1936	1934	1928	1966	1936	1943	1913	1938	1930	1931	1919	1938	1928	1927	1939	1930	1914	1929	1944	1933
1933	1955	1938	1974	1939	1940	1929	1970	1937	1945	1916	1941	1936	1935	1925	1939	1934	1930	1947	1935	1915	1932	1951	1945
1934	1961	1940	1975	1945	1942	1942	1977	1940	1949	1918	1944	1937	1945	1933	1946	1947	1933	1949	1940	1922	1935	1960	1947
1942	1966	1941	1976	1950	1948	1943	1983	1941	1953	1920	1953	1940	1958	1941	1954	1949	1936	1951	1950	1925	1942	1965	1948
1943	1967	1942	1983	1951	1953	1946	1992	1951	1961	1927	1955	1941	1961	1942	1957	1952	1941	1955	1952	1931	1948	1967	1953
1946	1968	1947	1984	1960	1963	1954	1994	1956	1989	1928	1956	1955	1962	1945	1961	1959	1958	1959	1954	1933	1953	1968	1959
1947	1975	1953	1989	1961	1968	1956	1995	1958	1990	1934	1958	1959	1981	1969	1963	1962	1965	1972	1957	1936	1954	1974	1969
1949	1981	1960	1990	1977	1976	1960	1998	1963	1992	1937	1963	1963	1985	1978	1972	1976	1966	1975	1960	1939	1961	1975	1971
1954	1982	1963	1992	1983	1981	1963	2000	1969	1993	1947	1964	1969	1987	1980	1979	1989	1972	1976	1974	1941	1962	1987	1973
1964	2010	1969	1993	1994	1989	1969	2001	1970	1997	1950	1973	1971	1998	1985	1981	1994	1980	2005	1980	1960	1967	1994	1977
1972	2011	1970	1997	2001	1992	1972	2008	1978	2000	1972	1976	1975	2000	1997	1992	1996	1985		1981	1968	1982	2000	1978
1973		1977	2000		2002	1974		1979	2003	1986	1980	1976	2007		1999	2003	1997		1984	1972	1983	2001	1985
1996		1996	2002		2011	1976		1980	2011	1988	1993	1992	2009		2002		1999		1998	1976	1985	2005	1989
		2003	2007			1984			2012	1989	1997	2006	2012		2007		2002			1996	1986		1990
		2010	2008			1996					2002	2004			2010				2002	2011	2012		1997
		2012				2003					2005	2010			2012					2012			2003
<b>17</b>	<b>15</b>	<b>19</b>	<b>20</b>	<b>15</b>	<b>17</b>	<b>21</b>	<b>15</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>22</b>	<b>18</b>	<b>18</b>	<b>15</b>	<b>19</b>	<b>16</b>	<b>18</b>	<b>14</b>	<b>17</b>	<b>19</b>	<b>20</b>	<b>17</b>	<b>20</b>