3 Methodology

3.1 Mann-Kendall Trend Test

Trends, for all the period, were calculated using the Mann-Kendall test (Mann, 1945; Kendall, 1955). This test detects the presence of a monotonic tendency in a chronological series of a variable. It is a non-parametric method; that is, it makes no assumptions about the underlying distribution of the data, and its rank-based measure is not influenced by extreme values. This method mainly gives three types of information.

- The Kendall Tau, or Kendall rank correlation coefficient, measures the monotony of the slope. Kendall's Tau varies between -1 and 1; it is positive when the trend increases and negative when the trend decreases.
- The Sen slope, which estimates the overall slope of the time series. This slope corresponds to the median of all the slopes calculated between each pair of points in the series.
- The significance, which represents the threshold for which the hypothesis that there is no trend is accepted. The trend is statistically significant when the p-value is less than 0.05.

3.2 Anomaly and Normalization

To compare two periods, we use the probability density function of normalized anomalies. The data of an X variable are exploited as anomalies X' with respect to climatology $\overline{X}$. Here, we take as climatology the whole period of study, the normal of a day d of the year y, with d, ranging from 1 to 365, as the average of this day over the period 1979-2017 (Eq. (1)) as follows:

$$\overline{X}(d) = \frac{1}{N} \sum_{y=1979}^{2017} X(d) \quad (1)$$

with N number of years. To obtain a non-noisy signal, the climatology $\overline{X}$ is smoothed by a LOWESS, i.e., a "LOcally Weighted Scatterplot Smoother", with a spar = 0.3. The spar represents the fraction of data used to smooth the series; it is between 0 and 1. Here, we retain a spar of 0.3 to sufficiently smooth the series by attenuating the residual component, i.e., the noise, while maintaining the appearance of the trend. Once the climatology is obtained, we calculate the daily anomaly (Eq. (2)) as follows:

$$X'(d) = X(d) - \overline{X}(d) \quad (2)$$

Monthly or seasonal anomalies are directly obtained by averaging $\overline{X}(d)$ over months or seasons. Finally, the anomalies $X'(d)$ are normalized over the period 1979-2017 according to the temporal scale studied t, where t ϵ 1,..., Nt (year or season) as follows:

$$\widetilde{X'}_t = \frac{X'_t - \mu_{X'}}{\sigma_{X'}} \quad (3)$$

With

$$\mu_{X'} = \frac{1}{N_t} \sum_t X'_t \quad (4)$$

$$\sigma_{X'}^2 = \frac{1}{N_t - 1} \sum_t (X'_t - \mu_{X'})^2 \quad (5)$$

We normalized the anomalies with respect to the entire 1979-2017 studied period because, according to Huntingford et al., (2013) and Sippel et al., (2015), when anomaly normalization is performed relative to a reference period, then standardization tends to increase the variability and extremes, especially at the global scale.

With normalized anomaly we compute the distributions for two periods (1979-2002, 2003-2017). The choice of separation between these two periods 1979-2002 and 2003-2017 is mainly motivated by the fact that over the period 2003-2017, observations of various meteorological parameters are available at the supersite SIRTA (see Fig. 1) and have been reanalysed to produce the SIRTA-ReOBS dataset at an hourly time scale (Chiriaco et al., 2018). This dataset is not used in this study, but it will be used in a forthcoming paper focused on understanding the processes responsible for the changes detected in the current paper.

3.3 Weather Regimes

In winter and summer, climate variability in Western Europe is controlled by different dynamic states called weather regimes (Cassou et al., 2005, 2011). These regimes are interpreted as quasi-stationary states of daily atmospheric circulation that can persist from a few days to a few weeks. Michelangeli et al., (1995) show that four regimes are relevant for the study of climate variability in the North Atlantic-European basin (NAE). These regimes are defined according to the geopotential height at 500 hPa or the sea level pressure (SLP) by the k-means method. Thus, each day is associated with a preferential regime (Legras and Ghil, 1985; Vautard, 1990; Yiou et al., 2008). Weather regime analysis allows observing climate trends at constant air mass; that is, large-scale circulation is fixed, and thus the variability detected is rather explained by smaller scale processes. This study uses a regime classification, calculated from the SLP over a reference period 1970-2010 and available at the following link https://a2c2.lsce.ipsl.fr/index.php/deliverables (for more details see Cattiaux, 2010; Yiou et al., 2011, 2018). Such classification is efficient for stable seasons such as winter and summer, and less for spring and fall, which are transition seasons and therefore more subject to rapid, large-scale changes. We mainly focused on summer because of the strong local variability related to the thermodynamical processes that affect the summer season and whose changes are more marked in summer than in winter. In summer, there are four preferential regimes, as detailed below (Fig. B1 in the Appendix B represents the anomalies of SPL associated with these four summer regimes).

- The NAO- phase (Fig. B1) is characterized by a weakening of the Icelandic Low. The jet stream is pushed back to the south on its arrival in Western Europe, causing cold conditions over most of Europe. In the Paris area, this regime is marked by cooler and wetter conditions.
- The Atlantic Ridge phase is characterized by high pressures over the Atlantic Ocean and low pressures over the northwest of Europe, favouring cold conditions via the reinforcement of a polar flux. On the other hand, it inflates the Azores Anticyclone in its subtropical part and thus warms the rest of Europe. In the Paris area, this regime is marked by cool temperature and slightly humid conditions.
- The Blocking phase is characterized by a strong anticyclone over the British Isles, which blocks the inflow of maritime air and allows warm conditions to develop in Western Europe. Southeast Europe is rather cold. In the Paris region, this regime favours hot and dry temperature conditions.
- The Atlantic Low phase slows down the polar flow in favour of a southerly flow favourable to warm conditions over all of Western Europe. In the Paris region, this regime favours warmer and drier conditions than other regimes.

Thus, each summer day of our study is associated with one of the four weather regimes above, and we can separate at first order the evolutions of the parameters due to circulation changes to those due to local changes. “