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# Changes in seasonality and magnitude of sub-daily rainfall extremes in Emilia-Romagna (Italy) and potential influence on regional rainfall frequency estimation

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ABSTRACT

*Study region:* The present study focuses on Emilia-Romagna (northern Italy), a densely populated region affected in the last few years by several destructive flood events.
*Study focus:* A rich and detailed regional dataset of annual maximum series (AMS) of sub-daily rainfall is considered with a three-fold aim: to detect possible changes in (1) seasonality and (2) magnitude of sub-daily rainfall extremes, (3) to assess the current reliability and accuracy of a previously developed regional model for rainfall frequency estimation based on the local value of mean annual precipitation (MAP).
*New hydrological insights for the region:* The main findings of the study include: (1) delay (towards Autumn) in the mean timing of sub-daily rainfall extremes, more marked for higher elevations and longer durations; (2) significant increase in the magnitude of sub-daily extreme events for some areas, especially in the Apennine; (3) high sensitivity of the regional predictions of the frequency regime of sub-daily rainfall extremes to local changes in AMS and MAP.

## 1. Introduction

Economic losses and social consequences caused by hydrological extreme events in Italy, as well as in many other European countries, have been steadily increasing over the last three decades (see e.g. Guha-Sapir et al., 2016; Carisi et al., 2017). The literature indicates several possible factors as responsible of such a situation: climate change and the resulting intensification of extreme hydrological events (see e.g. Brunetti et al., 2002; Uboldi and Lussana, 2018), as well as the impact of anthropization on flood-risk changes, as a result of the increase in exposure to flooding due to land-use and land-cover modifications (see e.g. Bouwer et al., 2010; Di Baldassarre et al., 2013; Domeneghetti et al., 2015; Prosdocimi et al., 2015; Requena et al., 2017; Leal et al., 2019). In particular, the frequency of floods caused by extreme rainfall events has increased significantly in recent years (see e.g. Fischer et al., 2019) and urban areas have been shown to be particularly vulnerable to the impacts of these events, triggering the development of fast-processing algorithms for pluvial flood-hazard assessment (see e.g. Safer_RAIN by Samela et al., 2020) as a basis for identifying flood risk mitigation measures and plans under current and future climates.

In this context, the detection of changes in flood behaviour is crucial, yet limited by the knowledge of the processes that control

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magnitude, frequency and timing of flood events (see e.g. Merz et al., 2012). In this respect, within the UPH (Unsolved Problems in Hydrology) initiative of the IAHS (International Association of Hydrological Sciences), Blöschl et al. (2019a) call for a common effort by the scientific community to understand if the hydrological cycle is regionally accelerating or decelerating and to quantify seasonal alterations of flood drivers.

With respect to the intensification of extreme hydrological events, a recent study conducted by Blöschl et al. (2017) on a pan-European database from 4262 observational hydrometric stations for the past five decades finds clear patterns of change in flood timing: earlier spring snowmelt floods in north-eastern Europe (due to warmer temperatures), later winter floods around the North Sea and some sectors of the Mediterranean coast (due to delayed winter storms associated with polar warming), and earlier winter floods in western Europe (due to earlier soil moisture maxima). Furthermore, Blöschl et al. (2019b) show the presence of significant changes in flood magnitudes over large areas in Europe: increasing trends in north-western Europe (due to increasing autumn and winter rainfall) and decreasing trends in southern Europe (due to decreasing precipitation and increasing evaporation) and in eastern Europe (associated with decreasing snow cover and snowmelt, due to warmer temperatures).

A global analysis recently performed by Papalexiou and Montanari (2019) on a dataset of 8730 daily precipitation records in the period 1964–2013 (i.e. characterized by an acceleration of global warming) highlights that the signal of change is not as evident for rainfall extremes over large areas: frequency, not magnitude, is affected for daily maxima worldwide. Also, when it comes to the analysis of sequences of sub-daily rainfall extremes, the assessment of changes becomes even more troublesome due to data availability: most time series are too short, while the long ones are often non-homogeneous (i.e. they may contain variations due to non-climatic factors, such as sensors updates, sensor relocation, changes and anthropization of the surrounding environments, etc.; see e.g. Alexandersson, 1984, 1986). A recent study by Libertino et al. (2019) describes the presence of significant changes in amplitude of sub-daily rainfall extremes (i.e. annual maxima) at specific locations across Italy, yet significant trends do not appear at the whole-country scale: distinct patterns of change emerge in smaller areas with homogeneous geographical characteristics, therefore highlighting the need of developing more systematic and localized approaches for a consistent large-scale trend detection. At the same time, Libertino et al. (2019) do not consider changes in seasonality of sub-daily rainfall extremes. Other recent studies show evidences of statistically significant changes in seasonal and annual rainfall totals across Europe, and in particular in northern Italy (e.g. Antolini et al., 2016; Pavan et al., 2019). Literature shows several examples of regional models of daily and sub-daily rainfall extremes frequency that use long-term mean annual rainfall total (hereafter also referred to as mean annual precipitation, or MAP) as a proxy for

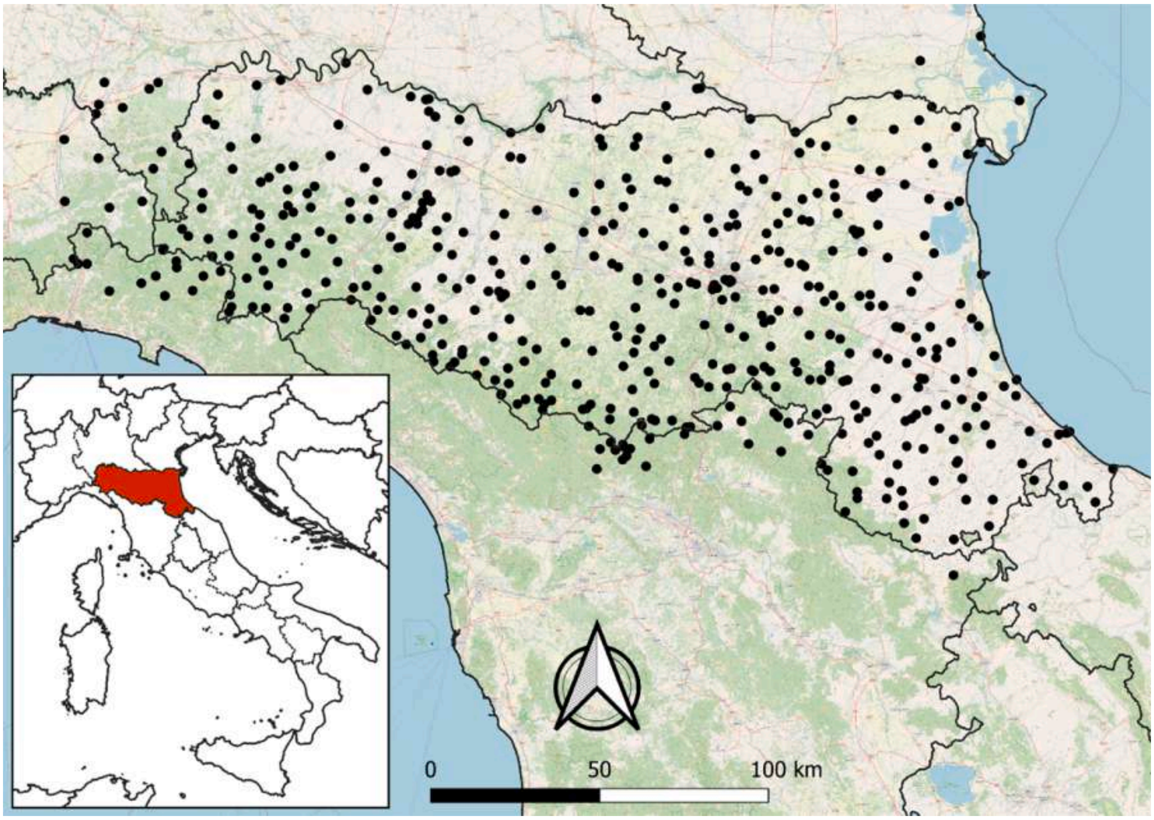



**Fig. 1.** ARPAE dataset of annual maximum series (AMS) of sub-daily (1, 3, 6, 12, 24 h) and sub-hourly (5, 10, 15, 20, 30, 45 min) rainfall depths collected for ~500 stations in Emilia-Romagna and its surroundings over the period 1931–2015.

local climate conditions (Schaefer, 1990; Alila, 1999; Brath et al., 2003; Di Baldassarre et al., 2006; Castellarin et al., 2009). In particular, Di Baldassarre et al. (2006), based on data observed in the period 1935–1989, propose a regional frequency model for estimating the rainfall depth for a given duration and recurrence interval (i.e. return period) based on the dependence of the statistical properties (i.e. L-moments; see Hosking and Wallis, 1997) of rainfall extremes on the value of the MAP. Therefore, changes in local MAP value could imply changes in frequency and magnitude of daily and sub-daily rainfall extremes.

In this context, the present study focuses on Emilia-Romagna, a densely populated region (~200 inhabitants/km$^2$) in the Po Valley (northern Italy), within an area which accounts for more than 40 % of the Italian Gross National Product (GNP). According to the Italian Institute of Environmental Protection and Research (ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale, 2018), ~63.6 % of the population and ~63.1 % of the companies in Emilia-Romagna can be potentially affected by floods with a medium probability (likely return period greater than 100 years). In the past few years, Emilia-Romagna was affected by several destructive flood events: large fluvial flooding (e.g. Secchia and Panaro rivers in January 2014, Enza river in December 2017, Reno river in February 2019, Idice river in November 2019), flash-flooding in mountainous areas (e.g. Alta Val Nure in September 2015), intense pluvial flooding in urban areas (e.g. Rimini in June 2013).

The present study refers to a rich, detailed, complete and recently compiled regional dataset of sub-daily rainfall annual maximum depth for Emilia-Romagna, with a three-fold purpose: (1) to perform a detailed analysis of possible changes in seasonality of sub-daily rainfall extremes, (2) to detect changes in their magnitude, and (3) in the light of regional changes of MAP found by Antolini et al. (2016), to assess the current reliability and accuracy of the regional model developed by Di Baldassarre et al. (2006), that predicts the frequency regime of sub-daily rainfall extremes based on the local value of MAP.

## 2. Study area and dataset

The analyses performed in this study consider a dataset of annual maximum series (AMS) of sub-daily (duration, *d*, equal to 1, 3, 6, 12 and 24 h) and sub-hourly ($d = 5$, 10, 15, 20, 30, and 45 min) rainfall depths, collected at ~500 stations in Emilia-Romagna and its surroundings over the period 1931–2015 (see Fig. 1). Rainfall data are provided by the Regional Agency for Prevention, Environment and Energy (ARPAE).

The present study benefits from the homogeneity analyses of precipitation time series performed for the region by Antolini et al. (2016), who applied the Standard Normal Homogeneity Test (SNHT; see Alexandersson, 1984, 1986) to annual total precipitation time series. Here it is assumed that time series which resulted to be homogeneous in Antolini et al. (2016) in terms of annual total precipitation are homogeneous also in terms of annual maxima. In this way, the original dataset has been filtered to consider only statistically homogeneous time series with at least 80 % of data availability over the considered period. Based on this preliminary investigation on homogeneity and consistence, the sub-hourly dataset shows an inadequacy of the available time series and is regarded as not suitable for assessing the possible presence of changes by means of the non-parametric statistical tests. Therefore, in the following only the sub-daily dataset is considered for assessing changes in seasonality and magnitude.

For the analyses presented here, the dataset of sub-daily extreme rainfall events is rearranged in order to consider two different subsets, in which only the time series covering at least the 80 % of the period are considered: 1931–2015 (85 years) and 1961–2015 (55 years), this latter characterized by greater data availability (see first two rows in Table 1). It is worth highlighting that, based on the above-mentioned filters, the dataset considered for the analyses is characterized by a non-uniform spatial distribution over the study area; in particular, data coverage decreases at lower elevations in the floodplain areas (see e.g. Figs. 1 and 2).

For the analyses focused on seasonality, the subset 1961–2015 is further divided into two subsets having a climatic validity (i.e. nearly 30 years of observation): 1961–1989 (29 years) and 1990–2015 (26 years). The choice of 1989 as a reference year for the identification of these two subsets (instead of the median year 1988) is done to be consistent with the analyses aimed at assessing the current reliability of the regional model developed by Di Baldassarre et al. (2006), which was developed with data collected up to 1989.

Together with the above-mentioned sub-daily dataset, this study also considers a detailed dataset of annual total (i.e. cumulative yearly) rainfall depths for 365 stations in the region, provided by ARPAE. This need is related to the outcomes of the recent study by Antolini et al. (2016), which shows local significant changes in MAP (i.e. mean annual cumulated precipitation) in Emilia-Romagna over the period 1961–2010: a prevailing, locally significant, decrease (attributed mostly to the decrease in winter and spring rainfall

**Table 1**
Data availability (number of stations) in terms of annual totals (AT) and annual maximum series (AMS) of sub-hourly and sub-daily rainfall for each duration, subset and specific analyses applied in the study.

| Data | Subset | 15 min | 30 min | 1 h | 3 h | 6 h | 12 h | 24 h | Yearly | Analyses |
|---|---|---|---|---|---|---|---|---|---|---|
| AMS | 1931–2015 | – | – | 37 | 36 | 36 | 36 | 36 | – | *Trend and Change-point* |
| AMS | 1961–2015 | – | – | 60 | 60 | 60 | 60 | 60 | – | *Trend and Change-point, Seasonality* |
| AT | 1931–2015 | – | – | – | – | – | – | – | 121 | *Change-point* |
| AT | 1990–2015 | – | – | – | – | – | – | – | 92 | *Relationship MAP vs. altitude* |
| AMS and AT | 1990–2015 | 65 | 68 | 74 | 74 | 74 | 74 | 74 | – | *Horton-type relationships* |
| AMS and AT | 1935–1989 | 33 | 39 | 26 | 26 | 26 | 26 | 26 | – | *Regional model* |
| AMS and AT | 1990–2015 | 33 | 39 | 26 | 26 | 26 | 26 | 26 | – | *Regional model* |

totals) was identified over the region, more pronounced in the western mountains, whereas some areas close to the Po river delta show significant increases (mostly explained by the significant positive trends detected in spring and autumn rainfall in the same areas). As the regional model by Di Baldassarre et al. (2006) uses MAP as a proxy for predicting the frequency regime of sub-daily rainfall extremes, the availability of the dataset of annual totals is crucial for describing and understanding changes in the MAP and for assessing the reliability of the model itself. In particular, the analyses regarding the regional model by Di Baldassarre et al. (2006), described in detail in Section 3.3, require the application of selective filters to the available dataset in order to be consistent with the criteria adopted in the original study. For this reason, in order to include the highest number of stations and data for each type of application, the available datasets of AMS and annual totals are further rearranged in different subsets, as summarised in Table 1 (see Section 3.3 for more details about the analyses and the corresponding criteria).

## 3. Methods

### 3.1. Seasonality of sub-daily rainfall extremes

Changes in timing of sub-daily rainfall extremes over the period 1961–2015 are assessed for each station by means of a trend analysis of the date of occurrence (expressed in terms of Julian date) for each duration. This analysis is based on the combined application of the adjusted Theil-Sen slope estimator (i.e. Theil, 1950; Sen, 1968; see also Blöschl et al., 2017) and the Mann-Kendall test (i.e. Mann, 1945; Kendall, 1975) for assessing the statistical significance (a 5% significance level is considered, i.e. statistically significant changes are associated with p-values lower than 0.05).

Moreover, the seasonality of sub-daily rainfall extremes for each station is assessed by means of directional statistics (i.e. Mardia, 1972; Bayliss and Jones, 1993; see also Castellarin et al., 2001), which represent the date of occurrence of the *i*-th extreme rainfall event at a specific station in terms of polar coordinates (i.e. a vector with unit magnitude and direction $\theta_i$; see eq. (9) in Castellarin et al., 2001). Based on this, the average date of occurrence (see eq. (10)-(12) in Castellarin et al., 2001) is represented with a vector, whose direction $\overline{\theta}$ is a measure of the mean timing and whose length $r$ can be seen as a measure of regularity (i.e. seasonality) of the phenomenon (i.e. the closer to 1 the stronger the seasonality, the closer to 0 the greater the dispersion of the dates of occurrence throughout the year). In the present study, the representation in polar coordinates of the dates of occurrence is reproduced by means of the R-packages (R Core Team, 2019) *graphics* (used for representing vectors) and *circular* (Agostinelli and Lund, 2017; used as a basis for computing the relative frequency of occurrence over the year). Results are described and compared for the two periods 1961–1989 and 1990–2015.

### 3.2. Changes in magnitude of sub-daily rainfall extremes

The analysis of the possible presence of changes in the magnitude of sub-daily rainfall extremes is carried out by means of commonly used non-parametric statistical tests, which do not require any assumption on the properties of the statistical distribution of the data. For each considered AMS, the trend is estimated with the Theil-Sen slope estimator (i.e. Theil, 1950; Sen, 1968) and the statistical significance is evaluated with the Mann-Kendall test (i.e. Mann, 1945; Kendall, 1975). Also, the Pettitt test (i.e. Pettitt, 1979) is applied to identify the presence of a shift in the central tendency of the series, i.e. possible abrupt changes (and associated change-point years) in the mean of the AMS. Note that the considered non-parametric tests require the series to be temporally independent, which is a valid assumption when dealing with AMS.

In the present study, the above-mentioned tests are applied by means of the R-packages (R Core Team, 2019) *Kendall* (McLeod, 2011) and *trend* (Pohlert, 2020). Consistent with the trend analyses performed for the date of occurrence (see Section 3.1), a 5% significance level is considered. The analyses are applied to two different subsets: the overall period 1931–2015, and the period 1961–2015.

### 3.3. Assessment of the accuracy of the available regional frequency model

In light of the local significant changes in MAP detected by Antolini et al. (2016), the present study aims at assessing the current reliability and accuracy of the regional model proposed by Di Baldassarre et al. (2006) for estimating the frequency regime of sub-daily rainfall extremes in the study area based on the local value of MAP, which is considered as a proxy for local climatic conditions, in line with several studies (e.g., Schaefer, 1990; Alila, 1999; Brath et al., 2003; Castellarin et al., 2009). The model proposed by Di Baldassarre et al. (2006) allows one to compute the expected rainfall depth $h(d,T)$ associated with given duration $d$ and return period $T$ (i.e. probability of occurrence) in ungauged sites in the regions Emilia-Romagna and Marche (assumed to be climatically homogeneous), based on an index-storm approach (Dalrymple, 1960; Brath et al., 2003):

$$h(d,T) = m_d \cdot h'(d,T) \tag{1}$$

where $m_d$ is the index storm (i.e. scale factor, which is site-dependent), and $h'(d,T)$ is the dimensionless growth factor (valid for the entire homogeneous pooling-group of stations). Di Baldassarre et al. (2006) compute the growth factor by means of a GEV (Generalized Extreme Value) distribution (Jenkinson, 1955), whose parameters can be estimated through the regional procedure based on L-moments (Hosking and Wallis, 1997). With the aim of performing predictions in ungauged locations (where sample L-moments are not available), Di Baldassarre et al. (2006) developed an empirical regional model for estimating the regional L-moments $L-Cv_R$ and $L-Cs_R$ (i.e. L-coefficient of variation and L-coefficient of skewness, respectively) for rainfall annual maxima with the storm duration $d$ of interest as a function of the local MAP value (which is mostly affected by altitude in the study area; see Di Baldassarre et al., 2006). In particular, Di Baldassarre et al. (2006) formalise the relationship between L-statistics of rainfall extremes and MAP through the following Horton-type relationship (Horton, 1939):

$$L-Cx\ (MAP) = a + (b-a)\ e^{-(c\ \cdot\ MAP)} \tag{2}$$

where $L-Cx$ represents a particular regional L-moment (i.e. $L-Cs_R$ and $L-Cv_R$) associated with the AMS of rainfall depth with duration $d$, and $a$, $b$, $c$ (where $0 \leq a \leq b$ and $c \geq 0$) are the parameters of the empirical model, which were properly estimated by Di Baldassarre et al. (2006) through a weighted least-squares optimisation procedure. The regional frequency model (hereinafter also referred to as GEV(MAP), for the sake of brevity) was developed based on a database of AMS of sub-hourly (15 and 30 min), sub-daily (1, 3, 6, 12 and 24 h) and daily rainfall depths observed in the period 1935–1989; in order to incorporate as much information as possible, they considered all available series having at least 30 years of data for daily and sub-daily durations and at least 5 years of data for sub-hourly durations.

As the presence of statistically significant changes in the AMS could affect the capability of the model to reliably predict the design storm, the present study aims at testing the model adequacy in reproducing the observed data using as input AMS and MAP data collected in the period 1990–2015, that follows the period for which the model was calibrated (i.e. 1935–1989). Based on the dataset of cumulative yearly rainfall depths provided by ARPAE, the following preliminary analyses are done:

1) The Pettitt test (Pettitt, 1979; see also Section 3.2) is applied to investigate the presence of abrupt changes in the mean of the cumulative yearly rainfall depths for the period 1931–2015; this analysis considers the 121 stations having at least 80 % of complete years of data (i.e. 68 years) in 1931–2015.
2) Check whether for the period 1990–2015 altitude is the factor that most affects MAP (computed as the average of the cumulative yearly rainfall depths available for each station) in the study region, as shown by Di Baldassarre et al. (2006) for 1935–1989. To this aim, a linear model is fitted between MAP and altitude for the period 1990–2015 to analyse their relationship for the 92 stations having at least 20 years of cumulative yearly rainfall depths over the same period.
3) The Horton-type relationships between L-statistics of extreme rainfall events and MAP considered in Di Baldassarre et al. (2006) (see Eq. (2)) are compared with sample $L-Cs$ and $L-Cv$ observed in 1990–2015; for this period, the stations having at least 20 years of data in terms of both cumulative yearly rainfall and AMS are considered (see also Table 1). The above-mentioned L-statistics are computed by means of the R-package (R Core Team, 2019) *lmom* (Hosking, 2019).

Then, the following procedure is applied by considering the stations with at least 20 station-years of data (in terms of both AMS and cumulative yearly rainfall depths used for computing the MAP) in the period 1990–2015 and, at the same time, complying with the criteria required by Di Baldassarre et al. (2006) for the calibration of the model itself over the period 1935–1989 (i.e. at least 30 station-years of data for sub-daily series and at least 5 station-years of data for sub-hourly series, for which data availability is lower):

4) The GEV(MAP) model is applied by considering the coefficients $a$, $b$, $c$ of Eq. (2) provided by Di Baldassarre et al. (2006) to estimate the regional GEV distribution on the basis of AMS observed in 1990–2015. In particular, in order to assess the influence of changes in cumulative yearly rainfall and AMS, the capability of the GEV(MAP) model is evaluated to reproduce the (a) dimensionless and (b) dimensional at-site rainfall distribution observed at the different sites in the period 1990–2015. In both cases, the growth factor $h'(d, T)$ is estimated based on the L-moments computed as a function of the MAP observed in 1935–1989; for the dimensional case, the index storm for the given station is computed as the mean value of the AMS observed in 1935–1989.

**Table 2**
Number (and corresponding percentage) of stations associated with statistically significant trends in timing for the considered sub-daily durations over the period 1961–2015.

| Duration | No. stations | No. stations with statistically significant trends in timing | |
|---|---|---|---|
| | | Earlier | Delayed |
| 1 h | 60 | 0 (0.0 %) | 2 (3.3 %) |
| 3 h | 60 | 1 (1.7 %) | 7 (11.7 %) |
| 6 h | 60 | 1 (1.7 %) | 7 (11.7 %) |
| 12 h | 60 | 2 (3.3 %) | 6 (10.0 %) |
| 24 h | 60 | 1 (1.7 %) | 6 (10.0 %) |

5) The agreement (i.e. goodness-of-fit) between the GEV(MAP) model and the (dimensionless and dimensional) at-site sample distributions observed in 1990–2015 is assessed by means of the Kolmogorov-Smirnov test (Kolmogorov, 1933; Smirnov, 1939, 1948), which compares the distribution resulting from the model with the at-site sample distribution (evaluated with the Weibull plotting position) for the period 1990–2015.
6) Finally, for each station and duration, the 100-year rainfall quantile is estimated with the GEV(MAP) model based on AMS and MAP observed in 1935–1989; then, to quantify changes, the return period T associated with such a quantile is retrieved by applying the GEV(MAP) model based on AMS and MAP for the period 1990–2015.

The dataset considered for the above-mentioned analyses is composed of 33 and 39 stations for the durations 15 and 30 min, and of 26 stations for the durations 1, 3, 6, 12 and 24 h, in this order (see also Table 1).

## 4. Results

### *4.1. Seasonality of sub-daily rainfall extremes*

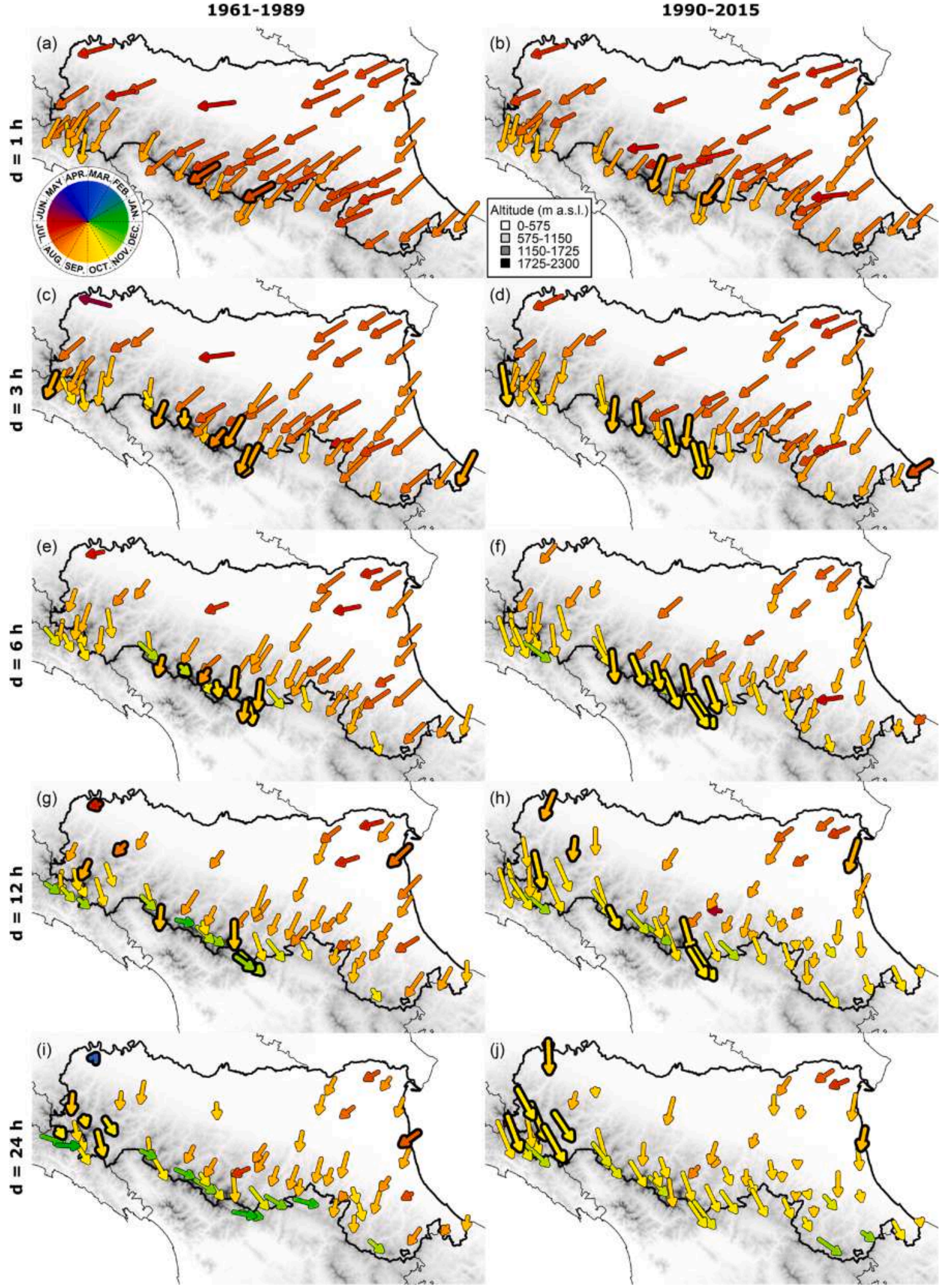
The combined application of the adjusted Theil-Sen slope estimator and Mann-Kendall test (see Section 3.1) highlights the presence of statistically significant (i.e. p-value $< 5\%$) trends in timing over the period 1961–2015 for a few stations, whose number and location depend on the considered duration (see Table 2; see also black-bordered arrows in Fig. 2). Among the detected statistically significant trends, delays in timing are predominant, more evident for longer durations and in the central-western part of the Apennine.

A visual representation of changes in seasonality of sub-daily ($d = 1, 3, 6, 12, 24$ h) rainfall extremes between the two periods 1961–1989 (29 years) and 1990–2015 (26 years) is reported in Fig. 2, where each station is represented with an arrow, according to the polar representation described in Section 3.1. Direction and colour (see the circular colour-scale in Fig. 2a) of each arrow indicate the average timing and the length is an indicator of the regularity of the annual maxima within the year (i.e. the longer the arrow, the higher the regularity).

For each period (i.e. 1961–1989, 1990–2015), Fig. 2 shows that increasing durations (from 1 to 24 h) are associated with lower regularity of annual maxima and a generalized slight delay in the mean timing. Moreover, for a given period and duration, the mean timing presents a slight shift moving from the lower elevations (i.e. flatland and floodplains), where average dates of occurrence are mainly concentrated in Summer (i.e. July and August), to the Apennine, where the average timing is in Autumn and early Winter (i.e. from September to December, depending on the considered duration).

In addition, Fig. 2 highlights the presence of a generalized delay in the mean date of occurrence from 1961–1989 to 1990–2015 for all the considered durations (i.e. 62 %, 67 %, 72 %, 67 % and 65 % of the stations for $d = 1, 3, 6, 12, 24$ h, in this order; see Table 2 for the statistically significant trends), especially in the Apennine area. For 1 h duration (see panels (a) and (b) in Fig. 2), a general shift in the mean date of occurrence (associated with statistically significant trends for two stations only; see Table 2) is observed from late Summer to Autumn in the central-western part of the Apennine, whereas less relevant shifts are detected in the other parts of the region. For durations 3 and 6 h an analogous shift in the central-western Apennine is observed, yet more evident (i.e. 7 stations with statistically significant delays in timing for both durations; see Table 2) and associated with an increase in regularity (i.e. seasonality) from 1961–1989 to 1990–2015 for higher altitudes; a slight increase in variability (i.e. lower seasonality) is also observed in the central plain and in the south-eastern part of the region. Concerning the seasonality for 12 h duration, the above-mentioned general shift is confirmed for the Apennine and observed also along the coastline, yet at higher altitudes some series show the opposite behaviour (i.e. the mean date of occurrence shifts from Autumn - early Winter to early Autumn). Finally, for 24 h the same considerations are valid, yet the central Apennine is characterized by stations with slightly anticipated mean timing (from late Winter to Autumn).

It is worth highlighting here that the average date of occurrence gives a concise description of the mean timing and is not capable of providing a complete indication regarding the temporal distribution of extreme events throughout the year (i.e. some time series could have a multi-modal distribution, with different periods characterized by a higher frequency of occurrence). Therefore, for each station, the present study carries out also an analysis in terms of polar-coordinates diagrams (i.e. Mardia, 1972; Bayliss and Jones, 1993; see Section 3.1 for more details) reporting, together with the mean timing, the temporal distribution of the single extreme events and the corresponding relative frequency of occurrence over the year. As an example, Fig. 3 shows the circular statistics of extreme rainfall events for the station of Ferriere (located in the Apennine in the south-western part of the region, within an area where the delay in mean timing and the increase in regularity have been shown to be more evident). Points represent the single extreme events in the observed AMS and are placed according to their date of occurrence (blue and green points refer to 1961–1989 and 1990–2015, respectively); arrows represent the mean date of occurrence for the considered subsets (1961–2015, red; 1961–1989, blue; 1990–2015, green) and their length varies consistent with regularity. The corresponding curves indicate the relative frequency of occurrence: the more the curve distances itself from the black circle, the stronger the seasonality. As shown also in Fig. 2, Ferriere is characterized by a delay in extreme events and an increase in regularity in the last decades (1990–2015; see green arrow and relative curve in Fig. 3). The increased regularity around the month of October is more evident for durations 12 and 24 h (see panels (d) and (e) in Fig. 3), for which statistically significant trends have been detected in timing over the period 1961–2015, and is associated with a relative frequency of occurrence with unimodal behaviour, different from the bimodal behaviour observed for the previous period (i.e. 1961–1989), when extreme events were frequently detected also in Spring (March and April).




(caption on next page)

**Fig. 2.** Mean date of occurrence of rainfall annual maxima for durations $d = 1, 3, 6, 12, 24$ h and time periods 1961–1989 and 1990–2015. Direction and colour of the arrows indicate the average timing, while their length reflects the regularity of the dates of occurrence within the year. Black-contoured arrows indicate stations where statistically significant trends have been detected in the Julian date of occurrence over the period 1961–2015.

### 4.2. Changes in magnitude of sub-daily rainfall extremes

Concerning the identification of possible trends and abrupt changes in the magnitude of AMS of sub-daily rainfall events (duration 1, 3, 6, 12, 24 h), two different subsets are considered: 1931–2015 and 1961–2015, where the latter has been selected in order to include more stations than the former (see Table 1). The results of the application of all the considered non-parametric statistical tests (i.e. Mann-Kendall, Theil-Sen slope, Pettitt; see Section 3.2) are reported in Fig. 4, where stations are represented with full or empty circles to indicate statistically significant (i.e. p-value < 5%) or non-significant changes, respectively, and with blue or red colours for increasing and decreasing changes, respectively. For stations associated with statistically significant abrupt changes (i.e. Pettitt test), the change-point year is reported within the circle (note that yellow-bordered circles identify stations where significant changes are detected by Pettitt test only). A summary of the statistically significant changes detected in the study is reported in Table 3.

Fig. 4 and Table 3 show for all considered subsets the predominance of significant increasing changes compared to the decreasing ones. Significant decreasing changes are observed in a few cases: two stations in the western Apennine area of the region for 1 h duration and 1931–2015 subset; one station in the central part of the Apennine for 1 h duration and 1961–2015 subset and another one in the same area for 3 h duration and 1931–2015 subset; finally, one station in the south-eastern part of the region for 12 h duration and 1931–2015 subset. Decreasing changes do not appear to follow a clear spatial pattern and in some cases are actually detected for stations located in areas characterised by nearby increasing significant changes. On the other hand, significant increasing changes exhibit a slightly clearer spatial distribution: for both subsets, they are mainly located in the north-eastern plain (nearby the city of Ferrara) and in the Apennine area. This behaviour is particularly evident for the 1961–2015 subset, for which the stations located in the area of the Ligurian Apennines (south-western part of the region) show significant positive trends and abrupt changes, with change-point year mainly located in the period between mid 1980s and mid 1990s (from 1985 to 1997).

At the same time, the empty circles in Fig. 4, which indicate trends resulting from the application of the Mann-Kendall test but

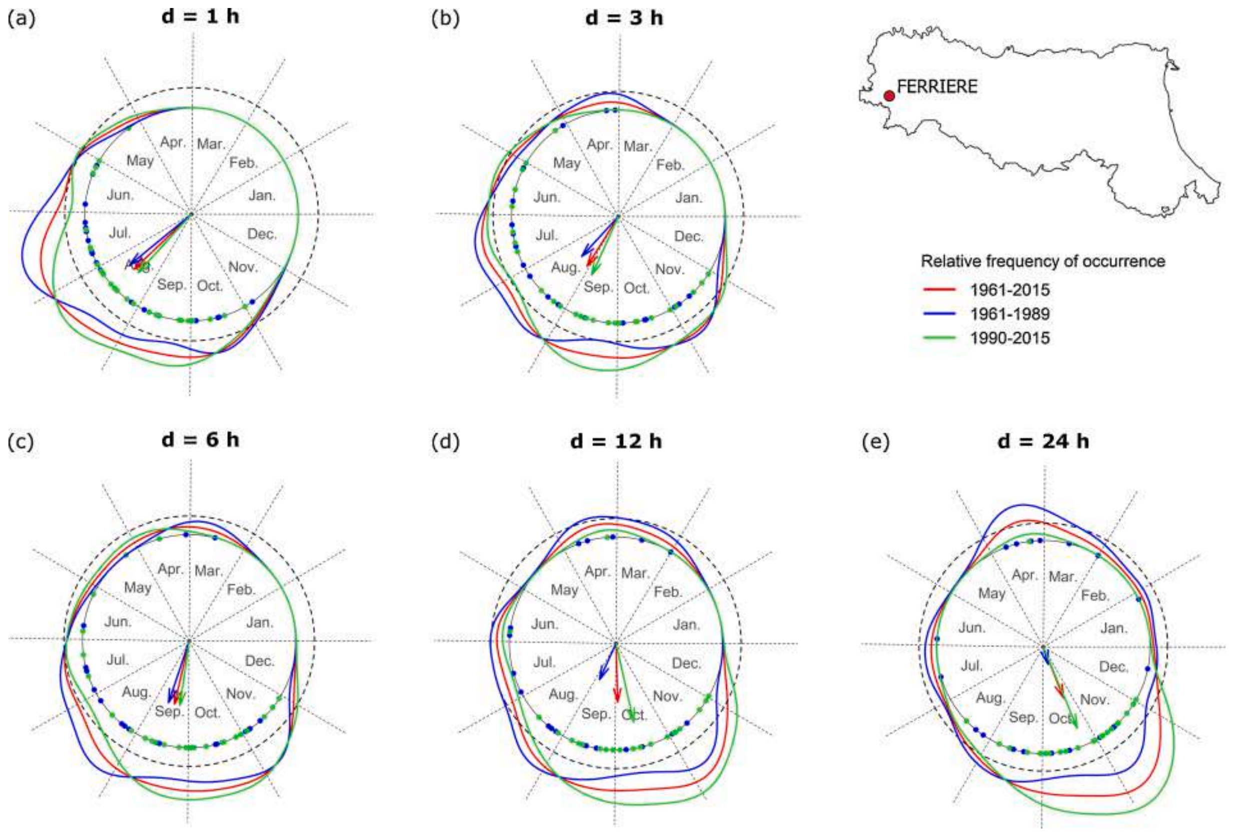



**Fig. 3.** Station of Ferriere. Representation in polar coordinates of the date of occurrence of annual maxima: dates (dots), their relative frequency (lines) and mean timing and regularity (arrows) are indicated for the overall period (1961–2015; red) and for the subsets 1961–1989 (blue) and 1990–2015 (green).

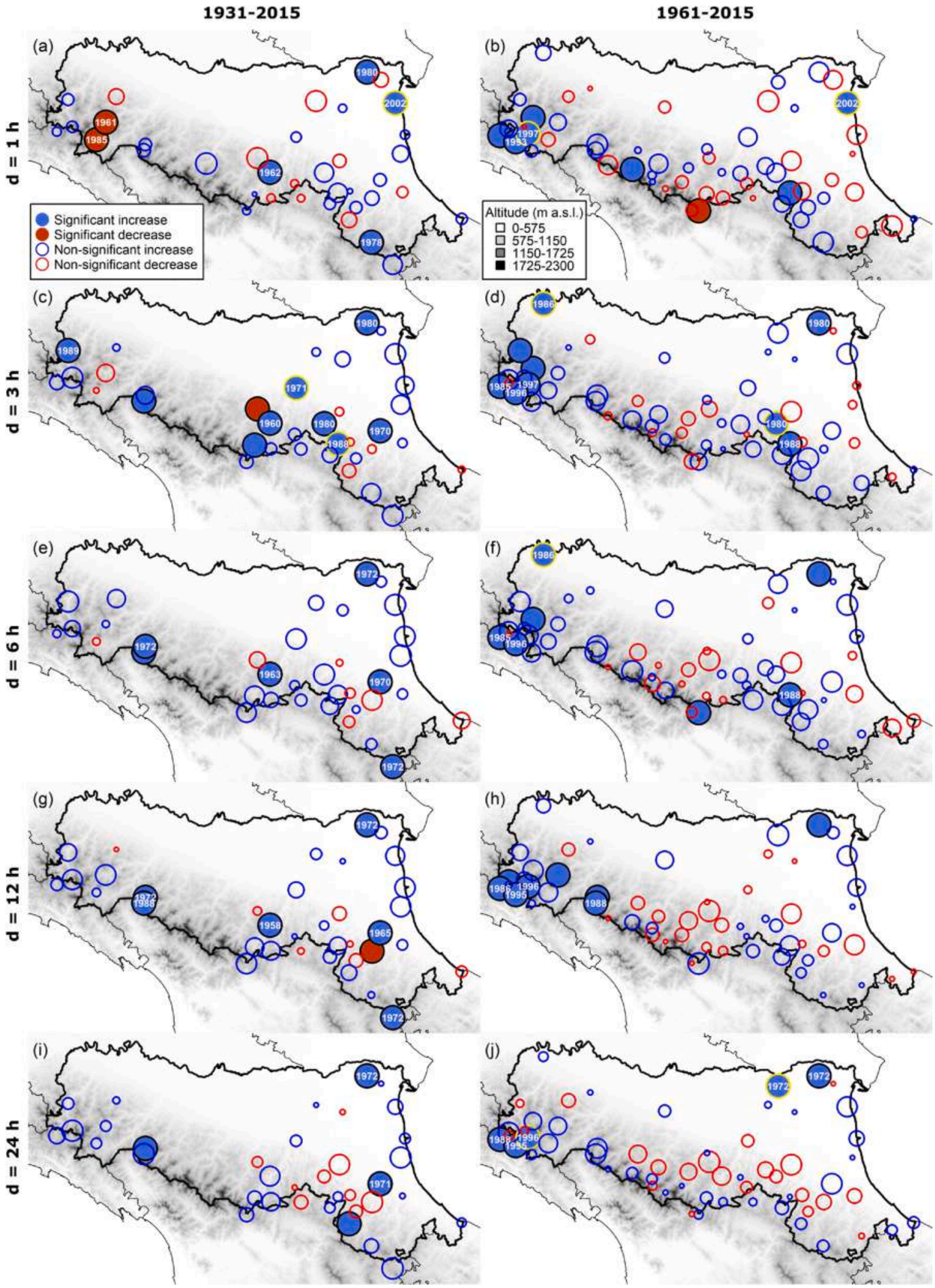



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**Fig. 4.** Results of the application of the non-parametric statistical tests (Mann-Kendall, Theil-Sen slope, Pettitt) for the considered durations (1, 3, 6, 12, 24 h) and periods (1931–2015, 1961–2015). Blue and red colours indicate increasing and decreasing changes, respectively; full and empty circles indicate statistically significant (p-value $< 5\%$) and non-significant (p-value $\geq 5\%$) changes, respectively, according to the Mann-Kendall test (radius of empty circles is proportional to the significance of the trend). For stations with significant abrupt changes (i.e. Pettitt test), the most probable year of change-point is reported (yellow-bordered circles identify stations where significant changes are detected by Pettitt test only).

associated with a p-value $\geq 5\%$ (i.e. statistically non-significant), highlight that some areas characterized by significant changes show also time series for which changes are not statistically significant; moreover, in some cases nearby stations show opposite trends.

### *4.3. Assessment of the accuracy of the available regional frequency model*

The analyses reported in the previous sections highlight the presence of significant changes in both timing and magnitude of sub-hourly rainfall extremes in the study region. These changes could affect the reliability of previously proposed regional models of daily and sub-daily rainfall extremes frequency, which use long-term rainfall depths and MAP as a proxy for local climate conditions (Schaefer, 1990; Alila, 1999; Brath et al., 2003, Di Baldassarre et al., 2006; Castellarin et al., 2009). Among these, the regional model proposed by Di Baldassarre et al. (2006) is based on the idea that MAP can be considered as a proxy of the geographical location, and therefore of the climate conditions. In this context, the present study aims at (1) verifying the reliability of the model, and (2) testing whether the model is capable of reproducing the observed data by considering AMS and MAP data collected in the period 1990–2015.

For the analyses, 121 stations among the 365 available are selected, having at least 80 % years of data in terms of cumulative yearly rainfall depth in the period 1931–2015, and the MAP is computed for them. It is worth noting here that, as Di Baldassarre et al. (2006) estimate the parameters of the regional distribution as a function of the MAP, changes in MAP can affect the shape of the distribution itself. For this reason, the Pettitt test is used here to investigate the presence of abrupt changes in the mean of the cumulative yearly rainfall depths in the period 1931–2015. Fig. 5a shows the statistically significant changes (i.e. blue and red dots for increasing and decreasing abrupt changes, respectively) detected in the study area: an overall decline in the cumulative yearly rainfall is observed, consistent with what detected in Antolini et al. (2016) for the period 1961–2010. The positive changes in the areas close to Ferrara and Piacenza were already observed by Antolini et al. (2016), whereas the ones detected in the Apennines close to Reggio Emilia were not detected before and can be explained with the longer time period considered in the present analyses (i.e. 1931–2015). Change-point years are all before 1989.

Another important aspect is that, for the period 1935–1989, Di Baldassarre et al. (2006) showed that altitude is the factor that most affects the MAP. The analyses performed herein for the 92 stations with at least 20 years of data in the period 1990–2015 highlight that the above-mentioned changes do not affect the increasing relationship between MAP and altitude (see plot and map in Fig. 5b), which is consistent with the one observed in Di Baldassarre et al. (2006), with analogous coefficient of determination $R^2$ (i.e. 0.674, versus 0.696 observed in their study).

As a further preliminary analysis, the Horton-type relationships between L-statistics of extreme rainfall events and MAP provided by Di Baldassarre et al. (2006) are compared with the sample $L-Cs$ and $L-Cv$ observed in the period 1990–2015 for the stations having at least 20 years of data in terms of both cumulative yearly rainfall and AMS (i.e. 65 stations for 15 min, 68 stations for 30 min, and 74 stations for sub-daily durations; see Fig. 6). For the sake of comparison, for each considered duration, the 10-stations window moving average of sample L-statistics is plotted versus the corresponding empirical regional models proposed by Di Baldassarre et al. (2006). Although the dataset considered in the present study is not identical to the one analysed in Di Baldassarre et al. (2006) (i.e. Emilia-Romagna only is included here and the considered stations are not the same considered in their study), the comparison suggests that the empirical relationships properly reproduce the observed $L-Cv$ for all the considered durations but 15 min, for which the sample moving average, though approximately constant, is shifted upward (see panel (b) in Fig. 6). A less coherent behaviour is observed for $L-Cs$, especially for lower durations.

Based on these considerations, to evaluate the influence of changes in cumulative yearly rainfall and AMS on the GEV(MAP) model, the capability of the GEV(MAP) model is assessed in reproducing the (a) dimensionless and (b) dimensional at-site rainfall distribution observed at the different sites in the period 1990–2015. The agreement between the GEV(MAP) model and the at-site sample distributions (i.e. plotted with the Weibull plotting position) is assessed by means of the Kolmogorov-Smirnov test. The analyses highlight

**Table 3**
Number of stations associated with statistically significant changes in terms of trends (Mann-Kendall test and Theil-Sen slope) and change-points (CP; Pettitt test) for the considered sub-daily durations and subsets. The columns "Total" report the number of stations (and the corresponding percentage) where significant changes are detected by at least one test.

| Duration | 1931–2015 | | | | | | 1961–2015 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Increasing | | | Decreasing | | | Increasing | | | Decreasing | | |
| | Trend | CP | Total | Trend | CP | Total | Trend | CP | Total | Trend | CP | Total |
| 1 h | 3 | 4 | 4 (10.8 %) | 2 | 2 | 2 (5.4 %) | 5 | 3 | 7 (11.7 %) | 1 | 0 | 1 (1.7 %) |
| 3 h | 7 | 7 | 9 (25.0 %) | 1 | 0 | 1 (2.8 %) | 7 | 7 | 9 (15.0 %) | 0 | 0 | 0 (0.0 %) |
| 6 h | 6 | 5 | 6 (16.7 %) | 0 | 0 | 0 (0.0 %) | 6 | 4 | 7 (11.7 %) | 0 | 0 | 0 (0.0 %) |
| 12 h | 6 | 6 | 6 (16.7 %) | 1 | 0 | 1 (2.8 %) | 8 | 4 | 8 (13.3 %) | 0 | 0 | 0 (0.0 %) |
| 24 h | 4 | 2 | 4 (11.1 %) | 0 | 0 | 0 (0.0 %) | 3 | 5 | 5 (8.3 %) | 0 | 0 | 0 (0.0 %) |

that the GEV(MAP) model properly reproduces the dimensionless at-site sample distributions for the vast majority of stations; only few stations show a poor match with the model in terms of dimensionless distribution of rainfall extremes (see Table 4).

Concerning the dimensional at-site distribution of rainfall extremes, Table 4 also highlights that the GEV(MAP) model applied to data observed in the period 1990–2015 is not capable of properly reproducing the dimensional at-site distributions for a considerable number of stations. Stations with this behaviour are mostly located in the same areas where statistically significant changes in AMS and MAP have been detected in the analyses reported in the previous sections (see e.g. panel (a) in Fig. 7 for 6 h duration). The outcomes of these analyses suggest that (1) the GEV(MAP) model is capable of properly reproducing the shape of the distribution (i.e. the estimate of the model parameters seems not to be significantly affected by changes in MAP); (2) the mismatch between the GEV(MAP) model

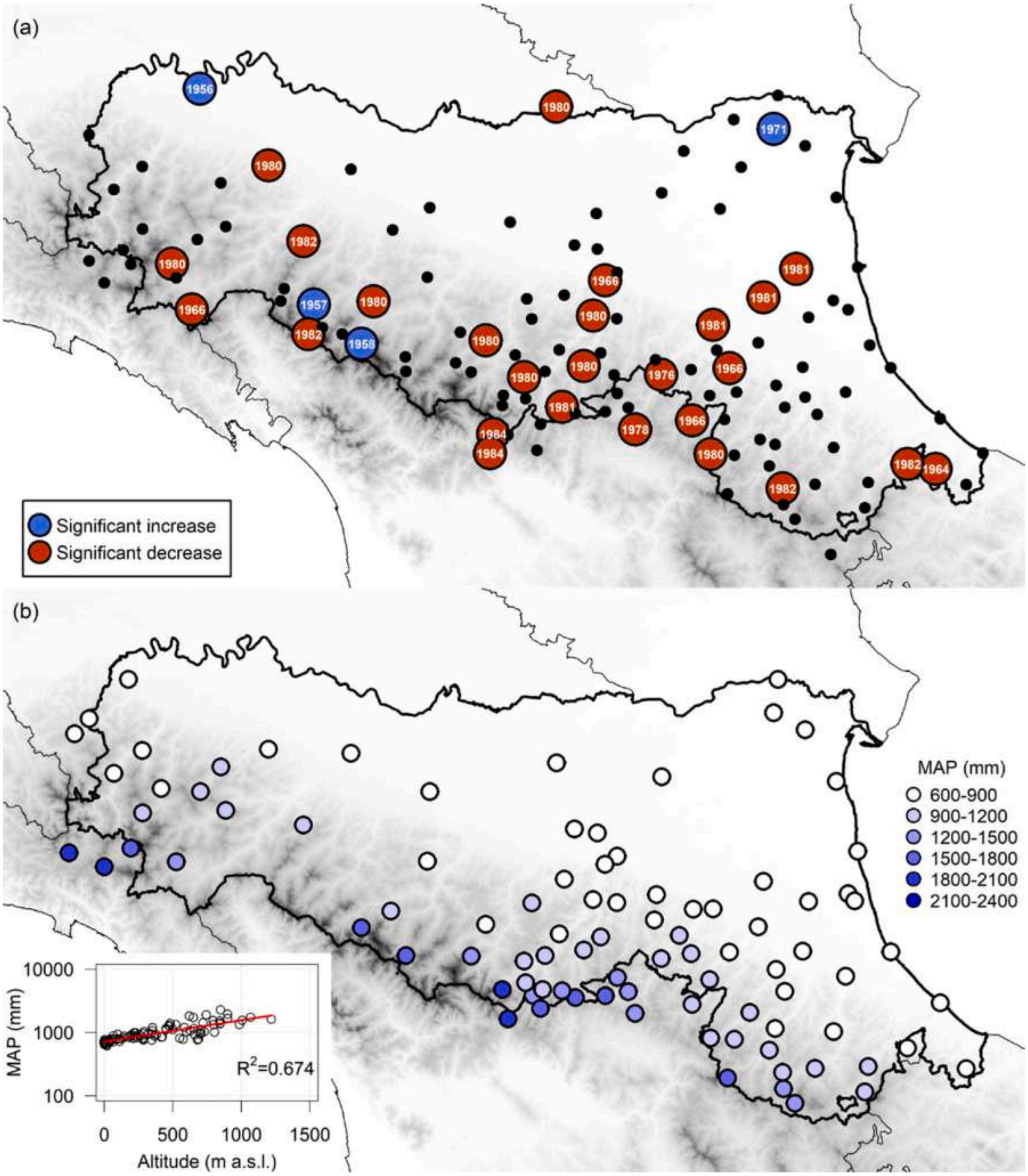


**Fig. 5.** (a) Abrupt changes in the series of annual rainfall totals over the period 1931-2015; blue and red dots indicate increasing and decreasing statistically significant changes, respectively (see also the corresponding change-point year). The other stations are represented with black dots. (b) Relationship between mean annual precipitation MAP (mm) and altitude (m a.s.l.) for the period 1990–2015. See Figs. 2 and 4 for the colour-scale used for altitude.

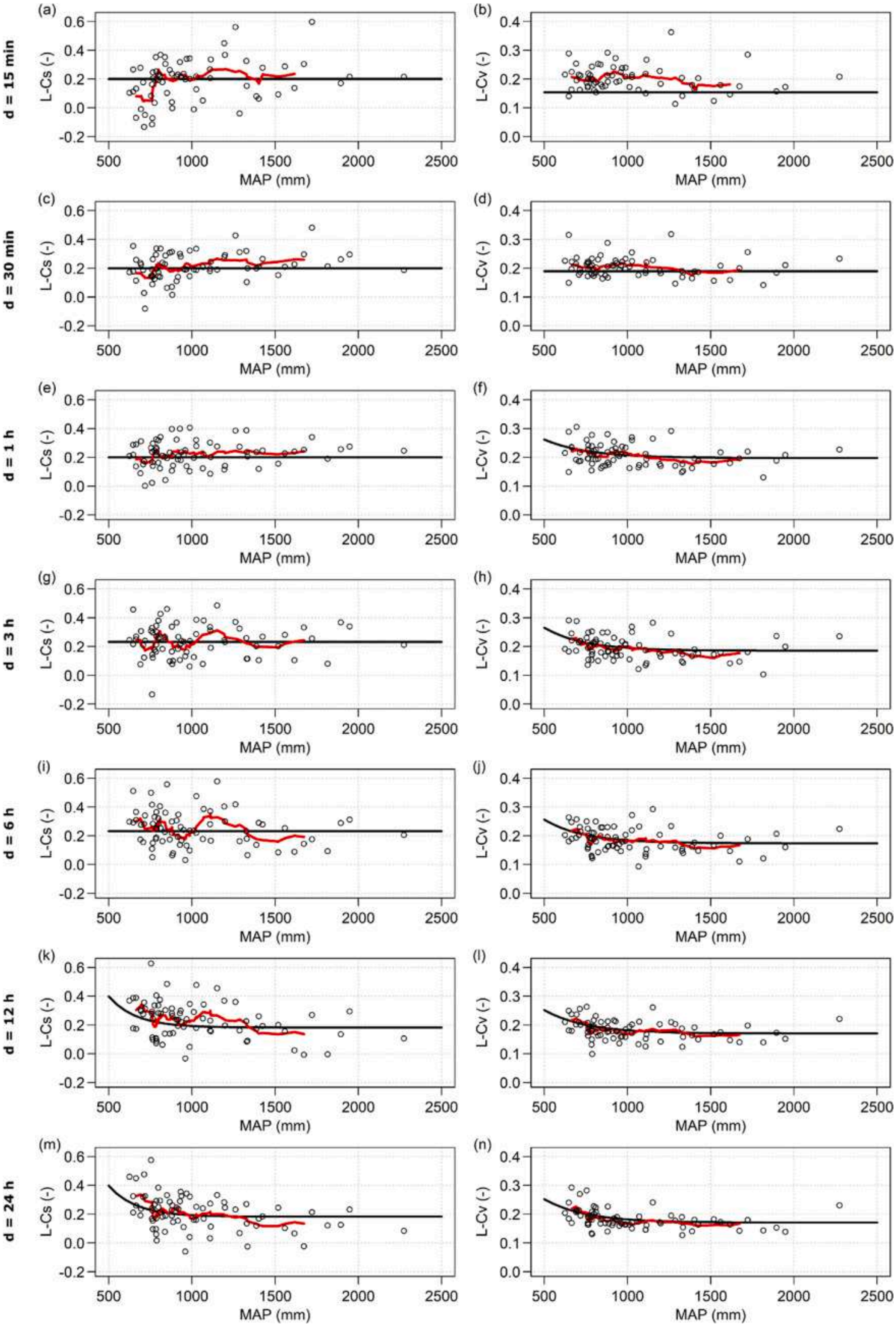


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**Fig. 6.** Sample L-statistics (i.e. L-Cs and L-Cv) versus MAP (mm) for durations between 15 min and 24 h. Red curves represent the 10-stations window moving average for data observed in the period 1990–2015, whereas black curves identify the empirical regional models proposed by Di Baldassarre et al. (2006), developed with data collected in 1935–1989.

and the observed dimensional distributions for the period 1990–2015 is mainly due to the observed changes in the mean of observed AMS.

These considerations are strengthened by plotting the estimated and observed distributions for the considered stations. As an example, panels (b) and (c) in Fig. 7 provide the comparison between the distribution computed with the GEV(MAP) model and the at-site sample distributions (dimensionless and dimensional, respectively) for the station of Cabanne. The shape of the estimated distribution remains the same, but the dimensional one is shifted due to the fact that the index storm considered in the model refers to the AMS collected in the period 1935–1989, whereas the observed dimensional at-site distribution refers to 1990–2015. As a result, the predicted return period obtained by applying the GEV(MAP) model is severely altered. The comparison between the rainfall quantile associated with 100-year return period according to the GEV(MAP) model applied for 1935–1989 and the return period associated with the same quantile obtained by referring to rainfall data observed in 1990–2015 highlights the presence of remarkable differences. Concerning sub-hourly durations, for 15 min there is the general tendency to overestimate the return period (i.e. the 100-year rainfall quantile evaluated for 1935–1989 becomes less frequent for 1990–2015), whereas for 30 min rainfall events both overestimation (mostly located in the eastern part of the region) and underestimation (in the western part, where significant trends in AMS have been detected here for longer durations, see Section 4.2) are observed; this behaviour could be also explained by the short record length for the sub-hourly series available for the period 1935–1989. At the same time, for sub-daily durations (i.e. $d = 1, 3, 6, 12, 24$ h), an overall overestimation of the return period is observed, associated with the presence of an increased frequency of extreme events in the last decades (see Fig. 6(a), as an example for 6 h duration).

## 5. Discussion

The analyses reported in the previous sections highlight the presence of changes in both timing and magnitude of sub-daily extreme rainfall events in the last decades. Concerning seasonality, a generalized shift in the mean date of occurrence is observed from 1961–1989 to 1990–2015 for all the considered durations. A delay in the mean timing of extreme events from late Summer to Autumn is observed for durations up to 6 h, more evident in the central-western part of the Apennine within the study region, where statistically significant trends are detected in timing and where also regularity tends to increase with increasing altitudes. This general tendency confirms the delay observed for the flooding season in the Mediterranean areas by Blöschl et al. (2017) in the last five decades, yet the finer resolution of the dataset considered herein enables to highlight a much richer and more complex figure. In fact, for higher durations (i.e. 12 and 24 h) the behaviour is confirmed, yet some stations in the Apennine area show slightly anticipated mean timing, from Autumn - early Winter to early Autumn. In general, for each duration, the mean timing presents a slight shift moving from the flatland and floodplains (mean timing in Summer) to the Apennine (average timing in Autumn - early Winter, depending on the duration), consistent with the different dynamical characteristics of the underlying atmospheric processes, more linked to convective dynamics over the plains and to orographic amplification of large-scale dynamics over the mountains. Moreover, for all the considered durations, the last decades (i.e. 1990–2015) are characterized by a generalized decrease in regularity at lower elevations (i.e. floodplains) and an increase at higher elevations (i.e. mountainous area), especially in the central-western part of the region. The first result seems to suggest that convective processes are becoming more frequent over the plain in the extended winter season (from October to March), while the second is consistent with the significant changes in the amplitude of intense daily events observed over the northern Apennines by other studies (Antolini et al., 2016; Pavan et al., 2019), i.e. an increase in Autumn and a corresponding decrease in Summer and Spring.

The higher sensitivity of the Apennine area to changes in sub-daily rainfall extremes is observed also in terms of magnitude (i.e. trends and abrupt changes): the western part of the region shows a statistically significant increase in the intensity of sub-daily extreme events. This is particularly clear for the 1961–2015 subset, for which the stations located in the area of the Ligurian Apennines, close to the Tyrrhenian mountainside, present significant positive trends and abrupt changes (change-point years from 1985–1997). This behaviour is in accordance with the already mentioned significant increase in the amplitude of intense daily precipitation events

**Table 4**
Capability of the GEV(MAP) model to reproduce the dimensionless and dimensional at-site rainfall distributions for each considered duration. Results are reported in terms of number of stations (and corresponding percentage) for which the Kolmogorov-Smirnov test indicates a mismatch (rejected).

| Duration | No. stations | No. stations with mismatch | |
|---|---|---|---|
| | | Dimensionless distribution | Dimensional distribution |
| 15 min | 33 | 4 (12.1 %) | 19 (57.6 %) |
| 30 min | 39 | 1 (2.6 %) | 17 (43.6 %) |
| 1 h | 26 | 0 (0.0 %) | 5 (19.2 %) |
| 3 h | 26 | 0 (0.0 %) | 9 (34.6 %) |
| 6 h | 26 | 1 (3.8 %) | 10 (38.5 %) |
| 12 h | 26 | 0 (0.0 %) | 7 (26.9 %) |
| 24 h | 26 | 0 (0.0 %) | 7 (26.9 %) |

observed, especially in Autumn, by Pavan et al. (2019). Other significant increasing changes are observed for the Apennines in the south-eastern part of the region and in the area close to Ferrara (north-eastern part of the study region), consistent with the increase in cumulative yearly rainfall depths observed for the same area in the present study (see Fig. 5(a)) and in other recent studies (i.e. Antolini et al., 2016; Pavan et al., 2019). This said, no clear spatial pattern is observed for the few decreasing changes detected in the study area, which in some cases are actually detected for stations located in areas characterised by nearby increasing significant changes. These results further highlight the variability and complexity of processes and seem to confirm what observed in Libertino et al. (2019), which showed the presence of distinct patterns of change in small domains.

Statistically significant abrupt changes are detected also in the mean of the cumulative yearly rainfall depths over the period 1931–2015, which is characterized by an overall decline of the values, consistent with what observed in Antolini et al. (2016) for 1961–2010. All the above-mentioned changes are shown to affect the reliability of the previously proposed regional model developed by Di Baldassarre et al. (2006), herein termed GEV(MAP), which considers MAP as a proxy of the geographical location (mostly altitude in the study domain), and therefore of climate conditions. The GEV(MAP) model applied with data observed in 1935–1989 is shown to be not capable of properly reproducing the dimensional at-site sample distribution for the period 1990–2015. This behaviour,

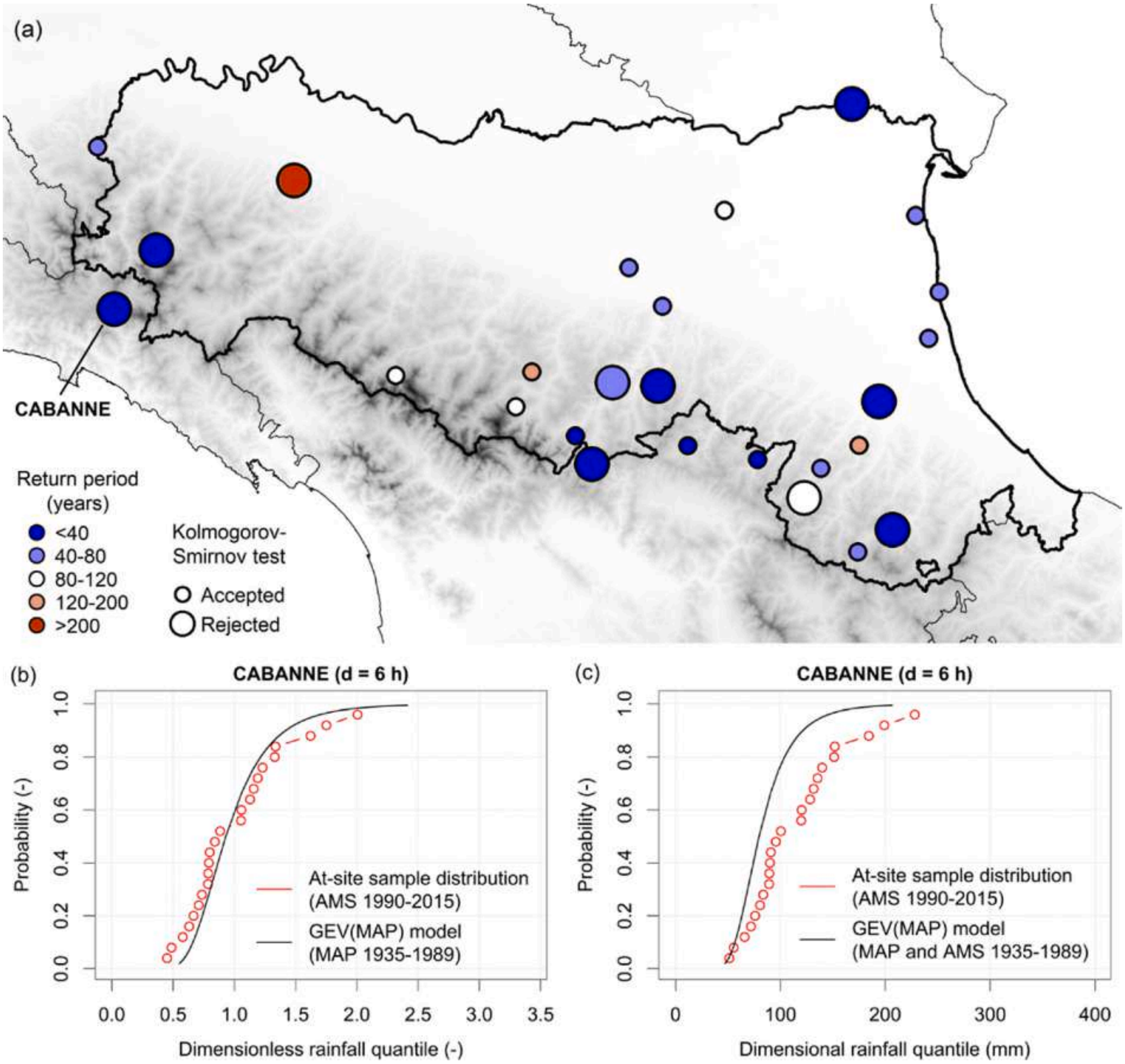


**Fig. 7.** (a) Capability of the 1935–1989 regional GEV(MAP) model to reproduce the dimensional at-site sample distribution of the AMS recorded in the period 1990–2015 for 6 h duration: the radius of the dots indicates if the model is accepted or rejected according to the Kolmogorov-Smirnov test, whereas the colour-scale represents the return period estimated with the GEV(MAP) model 1990–2015 and associated with the 100-year rainfall quantile estimated with the GEV(MAP) 1935–1989. Comparison between (b) dimensionless and (c) dimensional GEV(MAP) and sample growth curves for 6 h extreme events observed at Cabanne.

which is more evident for short durations (especially for sub-hourly ones, i.e. 15 and 30 min; see Table 4), appears to be mainly associated with the changes in AMS detected for the last decades. Indeed, whereas the shape of the estimated distribution properly represents the dimensionless at-site sample, in several cases the dimensional GEV(MAP) curve evaluated over the period 1935–1989 is shifted with respect to the AMS collected in 1990–2015, due to the fact that the index storm considered in the model refers to the AMS collected in 1935–1989. This results in an overall overestimation of the return period in 1990–2015 (see Fig. 7 for 6 h duration) and indicates an increased magnitude of extreme events in the last decades, consistent with the increase observed in the mean of AMS. At the same time, the observed generalized decreasing abrupt changes in MAP seem not to significantly affect the capability of the GEV (MAP) model to properly reproduce the dimensionless rainfall distribution. In this regard, the relationships between MAP and L-statistics proposed by Di Baldassarre et al. (2006) for 1935–1989 are mostly confirmed for the period 1990–2015, yet some differences are observed for lower durations, especially sub-hourly ones (i.e. 15 and 30 min) and for $L-Cs$. In this regard, it is worth highlighting here that estimating the parameters of the GEV(MAP) model as a function of MAP only makes the model easy to apply, but also represents a potential limit of the model itself. Developing a regional model based on indices, which are still easy-to-measure but have stronger dynamical links with AMS, could help to improve the model on a physical basis. This issue is suggested for future studies.

The proper understanding of the potential role and relationships among the above-mentioned changes in rainfall extremes and recent flooding events occurred in Emilia-Romagna requires additional analyses aimed at quantitatively assessing changes in flood hazard. Such analyses are suggested for future studies and must consider that the identification of the possible main drivers of the recent increases in flood damage should account for all the components of flood risk, i.e. also vulnerability and exposure, which are deeply related to the maintenance of territory and infrastructures, as well as to changes in land use due to human activities and population dynamics. For instance, Domeneghetti et al. (2015) show for the floodplain system of the Po river a stable population since the 1950s and yet a dramatic increase in the exposure to floods in residential settlements, which has doubled in the last 7 decades. There are therefore strong evidences of changes in vulnerability of the territory, whose management is a central topic and cannot be neglected when evaluating changes in flood risk over the study region.

## 6. Conclusions

The present study analyses a recently compiled regional dataset of sub-daily and sub-hourly rainfall annual maximum depths collected over the period 1931–2015 in Emilia-Romagna (northern Italy), affected by several destructive flood events in the last years. The aim is to assess the presence of significant changes in the frequency regime of rainfall extremes, in terms of both seasonality and magnitude.

In order to guarantee reliability and robustness of the analyses, the dataset has been preliminary filtered to select the AMS characterized by sufficient record length and statistical homogeneity; the sub-hourly dataset is regarded as not sufficiently robust for assessing changes. Concerning seasonality of sub-daily rainfall extremes in the period 1961–2015, a generalized delay in the mean timing of extreme events from late Summer to Autumn is observed during the last decades, more pronounced in the central-western part of the Apennine, while an opposite behaviour is locally observed for some stations in the same area for higher durations (i.e. 12 and 24 h). Moreover, for the Apennine area, a generalized increase is observed in the regularity of extreme events, more pronounced with increasing altitudes and for the central-western part of the region, and mainly associated with the decreased frequency of annual maxima in Spring and Summer; on the other hand, regularity decreases in the plain area, where annual maxima have become more dispersed throughout the year. Also, statistically significant trends and abrupt changes are detected in terms of magnitude for both the periods 1931–2015 and 1961–2015, with a predominant increase in sub-daily rainfall extremes, more evident in the area of the Ligurian Apennines, close to the Tyrrhenian mountainside of the Apennine (change-point years from 1985–1997), consistent with the statistically significant increase in intense daily rainfall events observed in other studies. Other significant increasing changes are observed in the south-eastern Apennine area within the region and the area of Ferrara, where previous studies (i.e. Antolini et al., 2016; Pavan et al., 2019) detected analogous increases also in cumulative yearly rainfall depths. Few decreasing changes have been detected in the study area, without a clear spatial pattern. The results confirm the outcomes of Libertino et al. (2019) in terms of the presence of different patterns of change in small domains.

Together with the statistically significant generalized decrease in the mean of the cumulative yearly rainfall depths observed over the period 1931–2015 (consistent with the outcomes of Antolini et al., 2016, for 1961–2010), the above-mentioned changes are shown to affect the reliability of the previously proposed regional model developed by Di Baldassarre et al. (2006) for predicting the design storm in the study area. Based on mean annual precipitation (MAP) as a proxy of the geographical location and on data observed in the period 1935–1989, the regional model is shown to properly reproduce the shape of the at-site distribution of AMS observed in 1990–2015, yet to fail in representing its dimensional component, especially for sub-daily durations (i.e. 15 and 30 min), resulting in an overall overestimation of the return period in 1990–2015. This behaviour seems to be mainly associated with changes detected in AMS (which affect the estimation of the index storm), whereas changes in MAP seem not to significantly affect the reliability of the model. At the same time, an update of the regional model is suggested for future studies, accounting also for indices presenting a stronger link with AMS and with atmospheric dynamics, so as to improve the prediction ability of the model.

The proper understanding of the effects of the above-mentioned changes in rainfall extremes on the recent flooding events occurred in Emilia-Romagna requires future additional quantitative analyses, which should consider all the components of flood risk, including vulnerability and exposure.

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## CRediT authorship contribution statement

**S. Persiano:** Software, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **E. Ferri:** Software, Methodology, Formal analysis, Investigation, Data curation. **G. Antolini:** Methodology, Resources, Data curation, Writing - review & editing. **A. Domeneghetti:** Methodology, Resources, Data curation, Writing - review & editing. **V. Pavan:** Conceptualization, Methodology, Resources, Data curation, Writing - review & editing, Supervision. **A. Castellarin:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition.

## Declaration of Competing Interest

The authors report no declarations of interest.

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