

# Assessing the Crop Growing Period According to the Climate Change Forecasts for Marina Baixa (SE Spain)

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## Abstract

The present work aims to assess the likely effects of climate change on the length of growing period (LGP) of crops in Marina Baixa (SE, Spain). LGP can be assessed by a balance between precipitation and reference evapotranspiration. Less rainfall and an increased evapotranspiration, forecast by Global Climate Models (GCMs), are considered as a high risk for agriculture. This area is located in a semiarid climate region where water is a very limited resource. It is a typical example of areas where the agricultural sector has to compete for water with the tourism industry. In this context, by using observed and projected precipitation data set (model HadCM3, Scenario A2), calculating reference evapotranspiration (ET<sub>o</sub>), and applying the frequency analysis of a probability-type method, we estimated the growing period length in the observed period (1961-1990) and three 30-year future periods (2011-40, 2041-70 and 2071-99) in the study area. The results show a drop in annual precipitations (−30%) and an increased ET<sub>o</sub> (+18%) towards the end of this century with respect to the observed period (mean annual rainfall: 356 mm; mean ET<sub>o</sub>: 1476 mm). The results also show a decrease in the number of decades (10 days) when precipitation exceeds half of the ET<sub>o</sub>, which means shorter growing periods as the 21<sup>st</sup> century advances. This expected reduction in growing period length towards the end of the present century will imply that many rainfed crops, like olives, almonds and cereals, will require a higher irrigation water supply to maintain suitable growth and performance levels. The results are an early warning to manage water resources in Marina Baixa in a sustainable way.

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## Keywords

Climate Change, Growing Period, Frequency Analysis, Semiarid, Mediterranean

## 1. Introduction

Global climate change is an unquestionable process. From the 1950s to the present day, it has been scientifically demonstrated that the atmosphere and ocean have warmed, volumes of snow and ice have decreased, the sea level has risen, and concentrations of greenhouse gases have increased. On a global scale, an increase of  $0.6^{\circ}\text{C} \pm 0.2^{\circ}\text{C}$  in the mean air temperature has been observed since 1861 and forecasts predict an increase of  $2^{\circ}\text{C} - 4^{\circ}\text{C}$  over the next 100 years. More frequent intense and extreme weather events (including drought and floods) are also expected [1] [2]. The scientific community has reached a broad consensus about the impact and consequences of climate change on plant biodiversity [3]-[5], especially on agriculture. Climate change will produce changes in the spatial plant distribution on a regional scale as a result of changes in rainfall and air temperature. Long-lasting climatic changes are likely to cause geographical shifts of the main plant species and even of the ecosystems [6].

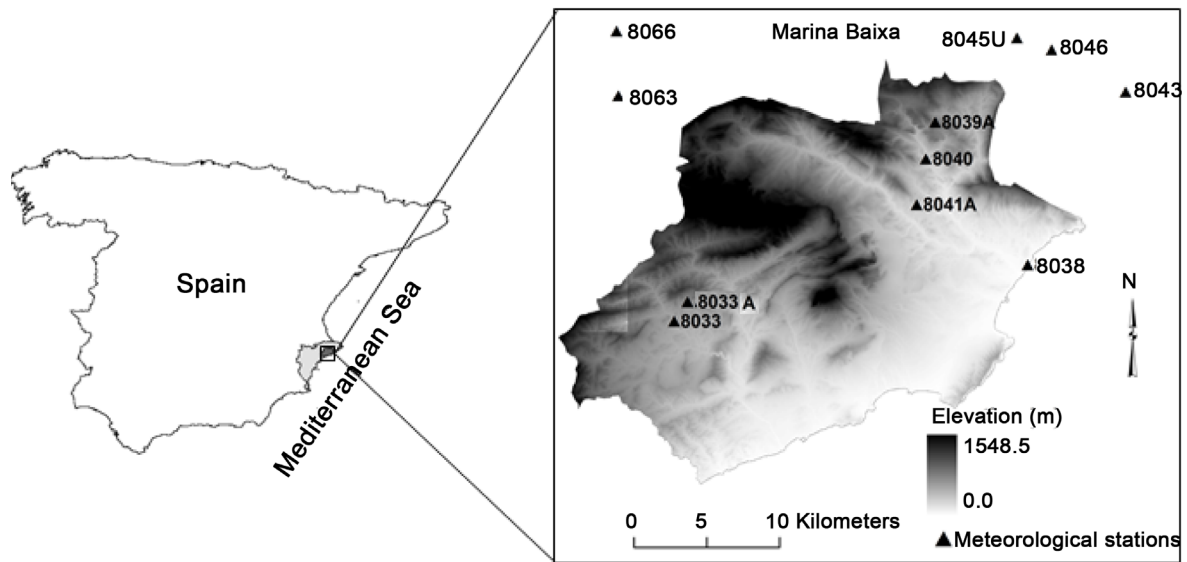
In the Mediterranean region, an increase of  $2^{\circ}\text{C}$  in mean air temperatures in the second half of this century is expected [7] [8]. A decrease in precipitations and more frequent long-lasting extreme weather events including severe droughts, heat waves and heavy rainfall events are also expected in this region. These changes in the climatic conditions will affect the agricultural production which is one of the main economic activities in the Mediterranean area. Indeed, prolonged periods of time with less precipitation and high reference evapotranspiration (ET<sub>o</sub>) rates, due to rising temperatures, will affect the crop growing period. Shorter growing period means reduced crops productivity. Studies and programmes of adaptation to climate change will be an adequate way to mitigate the damage that climate change could cause. For this purpose, assessments of future climatic changes based on Global Climate Models (GCMs) can help to define early warning systems to prevent climate change effects. The Intergovernmental Panel on Climate Change (IPCC) provides a set of GCMs (e.g., HadCM3, ECHAM4, CGCM2, etc.) with a well standardised group of scenarios (e.g., A1B, A2, B1, B2, etc.) for climate impact studies. The database of these models presents certain levels of uncertainty due to multiple factors.

A change in the variance of a distribution will have a larger effect on the frequency of extremes than a change in the mean [9]. An analysis of climatic data dedicated to detect trends on extreme events may not be the appropriate analysis due to the fortuitous behavior of these events. Therefore, it is recommended to establish the frequency of occurrence of these events and to correlate it with their observed variability, instead of adopting the mean values of climatic variables. In this context, the objectives of this study are: 1) to assess the temporal and spatial variation of the climatic conditions in the Marina Baixa region from the observed period (1961-1990) to the end of the 21<sup>st</sup> century, using the Agroclim-Map<sup>®</sup> software; 2) to assess the potential effect of climate change forecasts on the crop growing period length (LGP) in the study area.

## 2. Materials and Methods

### 2.1. Study Area

The study was conducted in the Marina Baixa region in the province of Alicante, SE Spain (Figure 1). This region covers an area of 578.7 km<sup>2</sup> and encloses 18 municipalities. Climate is characterised by high inter-annual variability of rainfall. The predominant soil type in the region is the Entisol which shows erosion processes and insufficient vegetation cover affected by torrential rain [10]. Altitudes in the region go from more than 1500 (Sierra Aitana: 1558) to 0 m.a.s.l. in the coastline. This topography produces strong climatic contrasts between continental inland and the Mediterranean coastal areas. This region includes three watersheds (Algar River, 216.2 km<sup>2</sup>, Guadalest River, 122.5 km<sup>2</sup> and Amadorio River, 205.2 km<sup>2</sup>) and three aquifer systems (Sierra Bernia, 90 km<sup>2</sup>, Serrella-Aixorta, 40 km<sup>2</sup> and Sierra de Aitana, 255 km<sup>2</sup>). Agriculture and tourism have been the main economic activities in the region for decades. Farmlands in Marina Baixa cover 8582 ha and more of the half of this area is covered by rainfed crops (4775 ha), where non-citrus fruit trees, olives and cereals cover 3093 ha, 1400 ha and 282 ha respectively. Irrigated crops (3807 ha) are dominated by citrus (1820 ha) and non-citrus fruit trees (1550 ha.).



**Figure 1.** Location of the study area and the meteorological stations.

## 2.2. Data

To conduct this study, we used daily precipitation data, and the maximum and minimum temperatures, of eleven weather stations located inside (6 stations) and outside (5 stations) the study area (**Figure 1**). These data derive from a database of climate forecasts available on the Spanish State Meteorology Agency website (<http://escenarios.aemet.es/>), which collects data from different GCMs. However, only three GCMs have regionalised data in weather stations. These data, generated by three GCMs (ECHAM4 (the atmosphere-ocean-coupled model of the Max Plan Meteorology Institute (Germany), version 4), CGCM2 (the atmosphere-ocean-coupled model of the Canadian Climate Centre, version 2), HadCM3 (the atmosphere-ocean-coupled model of the Hadley Centre (UK), version 3), have been regionalised by two empirical methods: the FIC analogues (method of Climate Research Foundation) to regionalise the data of models ECHAM4 and CGCM2, and the SDSM (Statistical Down Scaling Method) regression method for the HadCM3 model data [11]. It was considered sufficient to use only HadCM3 model data because it presents similar simulation data as the ECHAM4 model. CGCM2 model was discarded given the worse fit that it provided to reconstruct the observed period climate data in Marina Baixa. Indeed, a recent study carried out in a nearby area [12] concluded that from the above cited CGMs the HadCM3 model presented the most similar database (precipitation and air temperature) when the same years selected from the observed period were compared. Another former study carried out in Iran came to a similar conclusion [13].

The impact of climate change forecasts on the Marina Baixa region was assessed for emission Scenario A2. Scenario A2 forecasts high population growth and slow economic and technological development, where local solutions prevail with a moderate employment of energy for future time series (2011-40, 2041-70 and 2071-99). Scenario A2 was selected based on the assumption that the demographic development and growth model to follow, and its relation with the natural environment would continue with no significant changes, especially as far as the sustainability of ecosystems is concerned.

## 2.3. Data Analysis

In order to study the change dynamics of precipitations in Marina Baixa, a temporal and spatial analysis was done for the observed and projected periods. The mean annual precipitation during each projected period was calculated and compared to the observed period (1961-1990). The same analysis was done with the reference evapotranspiration (ET<sub>o</sub>) calculated by Hargreaves-Samani method [14], using observed and projected air temperature data.

To complete the analysis of precipitations in the study area, an analysis of the probability of exceedance of a threshold was done. The probability of exceedance ( $P_e$ , %, Equation (1)) was calculated according to the dis-

tribution of Weibull [15] and Gulinova [16]:

$$Pe = \frac{m}{n+1} * 100 \quad (1)$$

where  $m$  is the order number of each observed value, with  $m = 1$  for the higher value and  $m = n$  for the lower one, and  $n$  is the number of observations. The study of probability of exceedance considered the 400 mm threshold (70% of the mean annual precipitation of the observed period 1961-1990).

In order to assess the likely effects of climate change on agriculture, the crop growing period length (LGP) for each climatic period was estimated. The growing period is the period of the year when both moisture and temperature conditions are favorable for crop growth [17] [18]. LGP can be assessed by a simple moisture balance of precipitation (P) and reference evapotranspiration (ET<sub>o</sub>) when the temperature is not a limiting factor ( $T > 5^{\circ}\text{C}$ ) [17]. In Marina Baixa crops are grown in low altitudes where temperatures rarely go down  $5^{\circ}\text{C}$ . The growing period (GP) is the period of consecutive decades (10-day periods) when P is higher or equal to the half ET<sub>o</sub>. The choice of 10-day periods as a time base for analysing water balance derives from the ability of a soil to hold rainwater and to have it available to the crop [18]. New decadal (10-days) time series of precipitation and ET<sub>o</sub> were computed to carry out this analysis. Climate model data have only 360 days; it is why only 36 decades were computed by year. Besides the decadal analysis, an exploratory analysis of LGP at a daily basis was done.

To analyse this information, applying probability methods like a frequency analysis (FA) [18] (Equation (2)) was prioritised. This method evaluates the probability of precipitation exceeding half the ET<sub>o</sub> of each decade as a percentage. With the obtained results, the growing period was obtained, and was defined as the time interval in which precipitation exceeded half the ET<sub>o</sub> for a probability of 75% or more.

$$FA(\%) = \frac{n}{N} * 100 \quad (2)$$

where  $n$  is the number of times that  $\geq \frac{ET_o}{2}$ ;  $N$  is the number of years in the data series.

The attributes of the LGP lie in precipitation acquiring ecological properties since its performance relates to being able to meet the water requirements of crops. A risk assessment is also indicated when conditioning the period to meet the conditions of exceeding 75% of probability, which is a guarantee for the crop in question. Frequency over 30% in any of the scenarios is taken as a comparison measure.

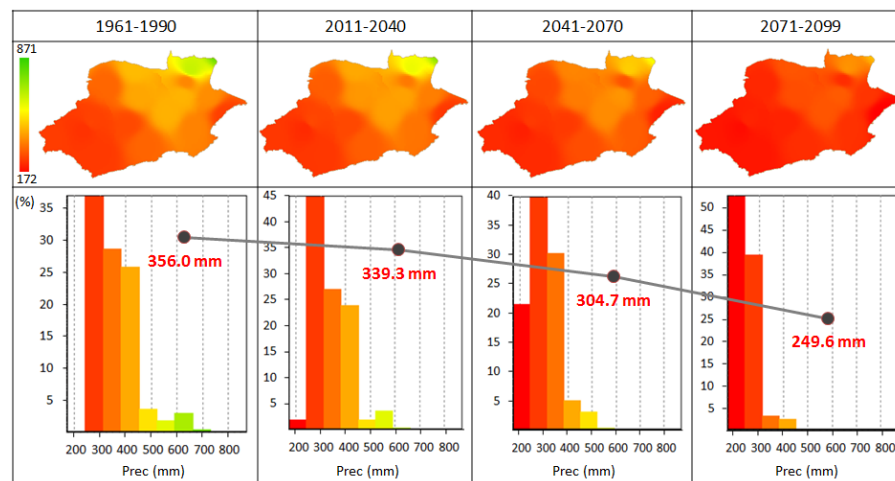
The whole database was processed by the Agroclim-Map<sup>®</sup> software [19]-[21], which allowed the computation of various agroclimatic models and indices. The output variables of these models were used as input variables for post-processing methods (statistic and geostatistic processing). The final products were tables, graphs and maps created using the Inverse Distance Weighted (IDW) interpolation method, which provided a better interpretation of the results.

### 3. Results and Discussion

#### 3.1. Temporal and Spatial Dynamics of Precipitations

The spatial distribution of precipitations in Marina Baixa shows a NE-SW gradient. High precipitation values (green and yellow areas on the map) are observed in the NE of the study area and low values (red and orange areas) in the SW (Figure 2). The temporal dynamics analysis of precipitation from the observed period to the end of the present century showed a negative trend. The reduction in the mean annual precipitation, for the entire region, expected in the first projected period is less marked (-5% with respect to the observed period). However, the decrease is expected to be more evident in the 2041-70 and 2071-99 periods (-14% and -30% with respect to the observed period respectively). Frequency histograms show the percentage of the Marina Baixa territory with precipitations in a given range (Figure 2). In the observed period 20% of the territory showed precipitation values above 400 mm, with areas reaching values above 600 mm near the town of Altea located in the NE. During the 2041-70 and 2071-99 periods, these areas are expected to be reduced to 10% and only 2% of the territory, respectively. These results coincide with those reported by Tatarinov [22] in Central Europe and at a global scale by IPCC [23].

The spatial analysis of precipitation in Marina Baixa and its expected changes in the future showed that the rate of change is space-dependent. Actually, despite the fact that the mean rates of change were -5%, -14% and



**Figure 2.** Temporal and spatial distribution of the mean annual precipitations during the observed and projected periods. Frequency histograms (X-axis: annual precipitation mm); Y-axis: observed frequency (%)). Grey line shows the decrease of precipitations over time.

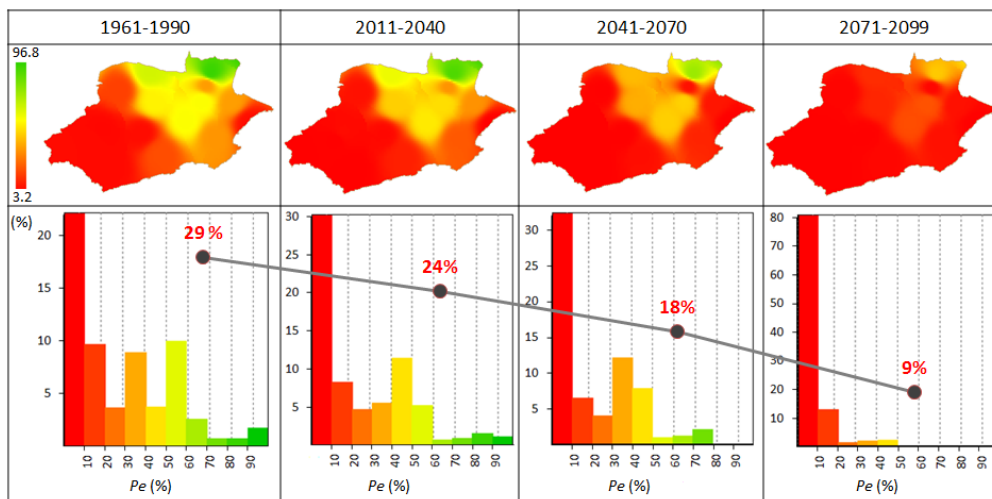
–30% in the 2011-40, 2041-70 and 2071-99 periods with respect to the observed period respectively, these rates were different depending on the space. Few differences found between the observed period and 2011-40 exceeded 60 mm; however, the most frequent differences were concentrated between 0 and 30 mm. The differences found in the 2041-70 period exceeded 210 mm, although 90% of the area showed differences below 100 mm. In the period 2071-99 infrequent differences reached values above 300 mm in reduced areas while in the major part of the territory these differences fluctuated within the 50 - 250 mm range. Between the period 2041-70 and the period 2071-99 the areas affected by high change rates passed from 10% to 40% which coincides with results reported by Jones [24] and Whetton [25], who reported more shortages in precipitations and changes in their annual distribution. The resulting reduction in precipitations became a factor that can have serious effects on the growth of different species, as reported by several authors [3] [26] [27]. In some regions, as is the case crop growing regions of Russia, the frequency of food production shortfalls could triple by the 2070s [28].

### 3.2. Probability of Exceeding the 400 mm Threshold of Annual Precipitation

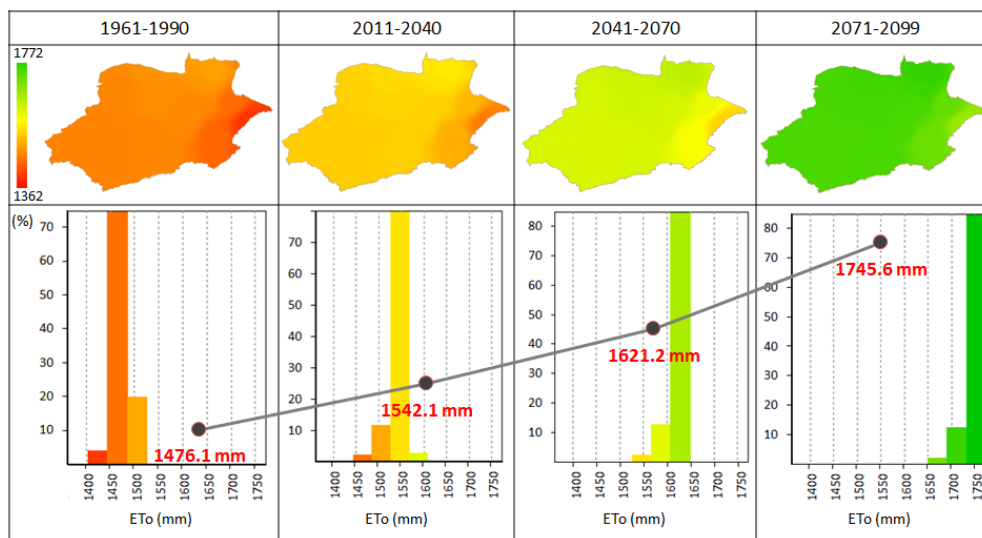
The mean probability of exceeding the 400 mm threshold ( $Pe_{400}$ ) of annual precipitation in Marina Baixa was 29% in the period 1961-1990. This probability is expected to decline to 9% by the end of the 21<sup>st</sup> century (Figure 3). The maps in the Figure 3 show the spatial distribution of the  $Pe_{400}$  where green and yellow indicate high values and red and orange low values. The histograms show the percentage of the territory with a given probability. The results of the comparison of the  $Pe_{400}$  in the projected periods with the observed one indicate that there will be more areas with little  $Pe_{400}$ , while the areas with a great probability tend to lower by the end of the 21<sup>st</sup> century (Figure 3). Probability that equalled or exceeded 60% were only significant during the observed period 1961-90 and the first projected period, whereas areas that reached this threshold was negligible in the 2041-70 period, and null in the last period 2071-99 (Figure 3). Similar results were reported by Alcamo *et al.* [28]. The spatial analysis of the territorial distribution of the probability of exceedance in the study area is essential. If not, extreme values can be confusing when making comparisons because they can obtain higher or lower values, but in small areas. This became evident when comparing the observed period with the period 2011-2040, where the distribution of the values provided a more exact image of the true effect of territory, even when values appeared with similar magnitudes.

### 3.3. Temporal and Spatial Dynamics of Reference Evapotranspiration (ETo)

The spatial distribution of the reference evapotranspiration follows the same distribution as temperature, low values in the northern and coastal areas and high values in the southern and inland areas (Figure 4). Over time the ETo showed inverse trends in comparison with precipitation. In fact, the expected increment in air temperature will cause an increase in ETo (Figure 4). The observed mean value of ETo for the entire region is about



**Figure 3.** Temporal and spatial distribution of probability of exceeding 400 mm of annual precipitation during the observed and projected periods. Frequency histograms (X-axis: Probability of exceedance (%)); Y-axis: observed frequency (%)). Grey line shows the decrease of probability of exceeding 400 mm of annual precipitation over time.



**Figure 4.** Temporal and spatial distribution of the mean annual ETo during the observed and projected periods. Frequency histograms (X-axis: annual ETo mm); Y-axis: observed frequency (%)). Grey line shows the increase of ETo over time.

1476 mm. This value is expected to rise more slightly in the first projected period (+4% with respect to the observed period) and with higher rates in the second and third projected periods (+10% and +18% with respect to the observed period respectively). These changes are expected to show some homogeneity throughout the study area where no contrasts are obtained in the obtained in the reference evapotranspiration values shown in the maps. These results are similar to those obtained by Whetton [28], who considered that lack of humidity would increase, along with a rise in temperatures, a trend that is related with increased evapotranspiration. In some experiments, the increase of 3.5°C found by some models could determine an increase in evapotranspiration of 13.8% [29].

### 3.4. Analysis of the Length of the Growing Period (LGP)

#### 3.4.1. Balance between Precipitation and ETo at a Daily Basis

The LGP can be computed as the consecutive periods of time when P exceeds half the ETo with a probability of 75%. As an exploratory analysis we analysed the balance between P and ETo at a daily basis computing the

days when P exceeds half the ETo with a probability of 75%. The balance showed very low values, which ranged from 0 to 10 days. The resulting balance between precipitation and reference evapotranspiration was negative for more than 90% of the days of the year. Although rainfall a certain number of years was higher than the ETo, it does not exceed the probability of 75% of the population ( $30 \times 0.75 = 22.5$  years) due the torrential regime of precipitation and their high inter-annual variability in the region [30]. The spatial and temporal analysis of the balance between P and ETo in Marina Baixa showed low values varying between 0 and 10 days in the observed period with high values in the north part and very low values in the south part. In the periods 2011-40 and 2041-70 the balance showed values between 1 and 2 days, whereas in the last projected period (2071-99) there were null days throughout the study area.

### 3.4.2. Analysis of the Length of Growing Period (LGP) and Its Projected Evolution

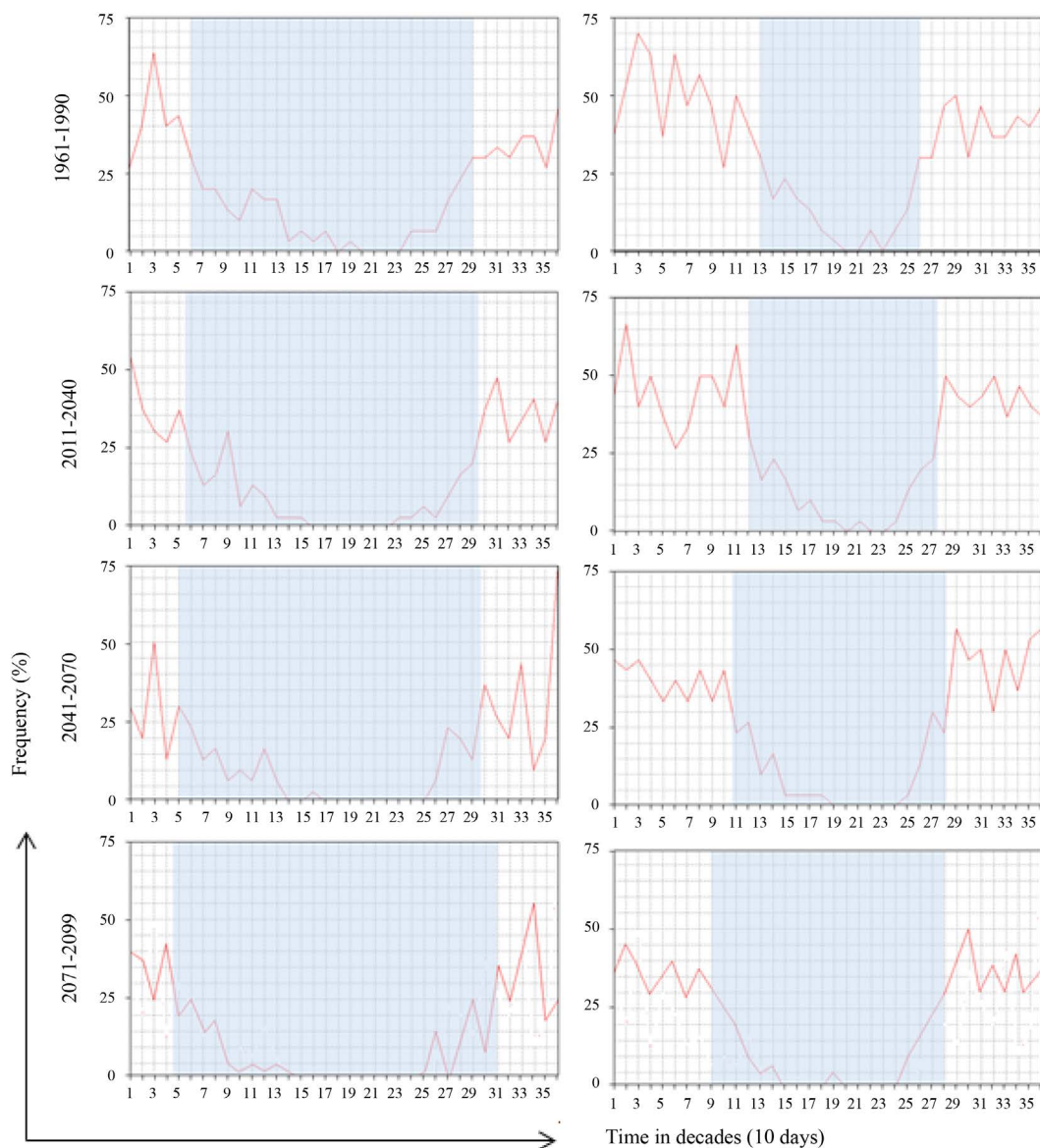
In this section the LGP was computed as the consecutive decadal periods (10-day periods) when P exceeds half the ETo. However, as in the case of the daily basis, the probability that P exceeds half the ETo reached the 75% threshold only in very few decades in just one of the eleven meteorological stations used. Therefore, the use of the 75% probability threshold to assess LGP in Marina Baixa was not feasible. After exploring the use of other threshold, we chose the 30% threshold because it marks the beginning and end of the rainy season in the region. On the one hand, when the probability that P exceeds, half the ETo starts going up 30% between the 26<sup>th</sup> and 29<sup>th</sup> decade (September to October), this marks the start of the autumn rainfalls. On the other hand when this probability starts going under 30% between the 7<sup>th</sup> and 13<sup>th</sup> decade (March to May), it marks the end of the spring rainfalls. The growing period starts in a year and end in the next year in the Mediterranean region which coincide with hydrological year.

**Figure 5** presents the *FA* graphs in two weather stations inside Marina Baixa limits, 8033 and 8041 A for the observed and projected periods. These two stations, situated in the SW and NE respectively, are representative of the regional climatic conditions. In the two stations the probability that P exceeds half the ETo never reaches the 75% threshold in the four periods. Station 8033 showed a large interval of time with low frequencies in general and very low frequencies (<30%) between the 6<sup>th</sup> decade and 29<sup>th</sup> decade in the observed period which means a shorter LGP (blue area in the left graphs in **Figure 5**). Station 8041A, in comparison with station 8033, showed a short interval of time with low frequencies (<30%) in the observed period (from the 13<sup>th</sup> decade to the 26<sup>th</sup>) which means a larger LGP (blue area in the right graphs in **Figure 5**). This interval of time is expected to increase in the projected periods in both stations with a slight high rate of change in station 8041A in comparison with the station 8033. This means that the LGP is expected to be shorter by the end of the 21<sup>st</sup> century.

**Table 1** summarises all the *FA* results and the LGP at the six stations inside the study area limits, and for all the simulation periods. The observed LGP starts in the beginning of the last quarter of a year (26<sup>th</sup> to 29<sup>th</sup> decades) and end in the next year (7<sup>th</sup> to 13<sup>th</sup> decade) taking into account that in this work the year has 360 days and 36 decades. In the observed period the mean value of LGP varies between SW and NE (150 and 230 days respectively). The LGP is shorter (150 - 180 days) in SW and coastal stations and larger (220 - 230) in the NE stations with the exception of station 8040. The LGP is expected to decrease by the end of the 21<sup>st</sup> century in the six stations. Indeed, in the SW and coastal stations the LGP is expected to decrease by 60 to 70 days in the last projected period (2071-99) while in NE stations the reduction will be about -40 to -50 days. The contrast between NE and SW is due the differences in precipitations and ETo between the two regions. Precipitations are higher and temperatures are lower in the NE and changes in LGP will be proportional to change in these two climatic variables.

## 4. Conclusion

The results show that a decrease in the annual total precipitation is expected towards the end of this century (-30% in the period 2071-99 with respect to the observed period (1961-1990)). Besides this change in the mean, the probability of exceeding the 400 mm threshold of annual precipitation is expected to decrease from 29% in the observed period to 9% in the last projected period. In contrast, an increase of +18% in the ETo is expected. Therefore these forecasts in the climatic conditions will produce a reduction in the crop growing period length assessed by a balance between precipitation and ETo. This result indicates that the region of Marina Baixa will face a big challenge in terms of water insufficiency in the future, which can only be overcome through mitigation and adaptation actions. A possible alternative could be to consider the use varieties of crops with short growing season and to design infrastructures for irrigation to meet the water needs of crops of interest.



**Figure 5.** Frequency analysis of P exceeding half the ETo in the stations 8033 (left) and 8041A (right) during the observed and projected periods. (Blue area shows the decades when the frequency goes down 30%).

**Table 1.** LGP in Marina Baixa using the 30% threshold of probability that P exceeds half the ETo. Start and end decades and duration in days. LGP start in a year and end in the next year.

Meteorological Stations	LGP start and end decades and duration in days			
	1961-90	2011-40	2041-70	2071-99
8033	29 - 8 (150)	30 - 6 (120)	30 - 6 (120)	31 - 4 (90)
8033A	28 - 10 (180)	26 - 12 (220)	28 - 6 (140)	29 - 5 (120)
8038	28 - 7 (150)	29 - 10 (170)	28 - 6 (140)	32 - 4 (80)
8040	28 - 9 (170)	27 - 10 (190)	28 - 6 (140)	28 - 7 (150)
8039A	26 - 13 (230)	26 - 14 (240)	28 - 12 (200)	27 - 10 (190)
8041A	26 - 12 (220)	27 - 12 (210)	28 - 9 (170)	28 - 9 (170)



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