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Assessment of Climate Change Impacts on Cork Oak in Western Mediterranean Regions: A Comparative Analysis of Extreme Indices

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Abstract

Mediterranean regions have a growing number of extreme weather events due to rapid change of climate. Cork oak, which is located in the western Mediterranean area, has become a very valuable resource within the western Mediterranean forests. Therefore, assessment of the impacts of climate extremes upon cork oak can help us produce better forest management practices for coping with future climate change, and to achieve the purpose of sustainable development of the ecosystems and societies within the Mediterranean area in the future. In order to have a comprehensive understanding of how climate affects cork oak, climate extremes are investigated for western Mediterranean regions, especially Portugal and Northwest Africa.

15 indices of frequency and intensity indicators were derived from daily maximum temperature and daily precipitation data of the period from 1979 to 2009, and used in this investigation. Overview maps of the annual maximum temperature and annual precipitation sum distribution were plotted. Exploratory Factor analysis (EFA) was applied to find out the underlying temporal variance for those indices. And on this basis, 15 indices were simplified into several variables. Correlation analysis is adopted to identify the relationship between those climate variables that generated by EFA and cork production. Burned area was also involved in this analysis as a special case in Portugal. A Regression model was developed to make a prediction of cork production by viewing those climate factors as dependent variables.

The results of those analyses show that as annual rainfall and maximum temperature changes, distribution of cork oak stands may have a potential of moving to the northwest. Northwest Africa is the recipient of climate extremes, especially hot and dry extremes, with higher frequency and intensity compared to Portugal. Summer dry extremes rather than rainfall extremes, can have considerable effect upon cork production, while burned area shows no correlation with cork production.

Keywords: climate extremes; cork oak; western Mediterranean; EFA; regression.

Content

1. Introduction

There are lots of serious assumptions regarding the future climate conditions in Mediterranean area according to numerical climate extremes studies. The Mediterranean region is vulnerable to climate extremes through limited water resources, extremely high temperature and intensive solar radiation in the summer (Xoplaki et al 2005). Therefore, assessing the vulnerability of forest stands in the Mediterranean regions to climate extremes is important for sustainable development of the environment as well as society. Although the climate extremes used in this paper are defined according to statistical reference, which are different from the weather extremes events that refer to hazardous weather conditions such as droughts and floods, it is very likely that climate extremes and weather extreme events have a similar systematic change (Klein Tank 2004).

Cork oak forest, which has limited distributed in western Mediterranean regions, has an uncertain future. Land use changes driven by local conditions in North Africa and Europe (Eric et al. 2003; Bhere 1988), agriculture policies implemented by the European Union (Common Agriculture Policy), global climate changes and market trends have all contributed to the serious circumstances facing cork oak (Aronson et al. 2009). With regards to future climate change, even though cork oak can survive well in Mediterranean regions, it will be a severe test for the cork oak surviving hotter and drier climate conditions. According to the report of Intergovernmental Panel on Climate Change (IPCC 2007), in the Mediterranean area, mean air temperature is expected to rise by 2°C to 4.5°C above the present average. Total precipitation may decrease as much as 20% in summer and up to 10% in winter by the end of twenty-first century. Compared to global levels, the Mediterranean region is like a hotspot with a larger magnitude of climate changes than the rest of the world (Giorgi 2006). Furthermore, the pace of climate change today is faster than in past episodes (IPCC 2007).

From the historical records of changing cork oak distribution, which is primarily proved by fossil pollen and chlorotype identity studies, climate change played a very important role (Carrion et al 2000). The shift of cork oak woodland distribution has a rather close relationship with climate change in temporal scale, which can be characterized by the expansion to the northwest of Mediterranean region in the warm period and to the southeast in the cold period such as glacial periods (Aronson et al. 2009). Due to these specialties of cork oak forest, assessing the impacts of climate change on them in form of extremes within this specific Mediterranean area is something worth expecting.

This study of climate change impacts on cork oak forest has focused on both direct and indirect influences. Cork oak forest is chosen because of its economic importance to the whole western Mediterranean regions (Luis and Maria 2002). Besides, its production and growth are closely connected to a number of factors (biotic and abiotic) directly or indirectly related to the climate (Pausas 2004). The starting point for this research considers how droughts as well as wildfires, which affect the landscape, growth and production of cork oak, are related to the climate change. In addition, the Mediterranean area is a space of distinguished climatic type and severe climate extremes. Thus, the impacts of climate changes on cork need to be widely studied.

In this investigation, analysis methods are focused on a statistical way of first finding inner relationships between climate extremes indices within 31 years (January 1979 to December 2009). 15 indices of climate extremes in each subregion within the study area were derived from daily temperature and precipitation data. In order to better correlate impacts with different types of climate extremes instead of single indices, those indices were reduced into few big groups by factor analysis of detecting their underlying temporal variance. Pearson correlations and multiple and simple linear regression are used for the purpose of illustrating the impacts.

1.1. Objectives

No aspect of the environment can escape from the complex feedbacks from climate change impacting land use, ecosystem, atmosphere and humankind. Cork oak is not an exception. Recent studies show that climate changes do have an effect on cork oak forest in terms of growth (Costa et al. 2001). Therefore, the main purpose of this paper is to find out how climate change, in terms of climate extremes affecting cork oak, in terms of its forest landscape and production, by using a series of statistical methods.
The main points that will be addressed in this paper are:

- Both Southwest Europe and Northwest Africa belong to west Mediterranean region, but the climate extremes may have large differences. What are the characteristics of climate extremes respectively in different regions?

- Are forest fires in Mediterranean area largely dependent of climate extremes? Is cork production influenced by forest fire?

- 33% of world cork forest is located in Northwest Africa with only 9% cork production contributed when compared with its extensive resource of cork oak forest. Does it mean that in Northwest Africa, climate extremes are more frequent and intensive than in Portugal, which has the same percentage of cork oak coverage but much larger percentage of production?

- When facing climate change, what will happen to cork oak in the future through extreme climate change?

1.2. Structure of this paper

In this paper, there are 7 chapters. Chapter 1 presents the motivation, purpose and the structure of this paper. Chapter 2 outline the basic information on cork and climate conditions in west Mediterranean regions, pointing out the recent study reports related to climate changes and its impacts on cork oak. Chapter 3 and Chapter 4 briefly describe observed data, indices of extremes and the analysis methods used in this research. Results and analysis are given in Chapter 5. Chapter 6 illustrates further discussion related to this study. Conclusions are presented in Chapter 7.

In this investigation, the programs that were applied to enable the analysis were: ArcMAP, which is the main component of ESRI's (Redland NewYork) ArcGIS suite of geospatial processing programs. SPSS (Statistical Product and Service Solutions) is a computer program for statistical analysis belonging to IBM (Wacker Drive, Chicago). Matlab stands for Matrix Laboratory, was developed by The Mathworks (Apple Hill Drive, Natick), and is used for numerical computation. The main scripts of mat lab content, as well as some supplementary documents are listed in the Appendix.

2. Background

2.1. *Basic information about cork oak*

Cork oak (Quercus suber L.) is an evergreen broad-leave tree that is known for producing cork. Thanks to its ability to withstand the long, dry and hot summer of the Mediterranean region, this species mainly grows in its original habitat (WWF report 2006). Although attempts have been made to introduce cork oak to areas outside of the western Mediterranean region, these attempts have had limited success (William M. C. 2002).

As Figure 2.1 shows, Cork is formed by phellogen and located in the outer bark of the cork oak (Oliveira et al. 2001). It is also the part for producing stoppers in wine industry, which is the most important product of cork (Giles 1948). Four special characteristics, including low density, high elasticity, excellent impermeability and low conductivity to heat, also give it a wide range of uses; from constructing material to gaskets. (Jelinek Cork group). However, it is the most important characteristic of sustainable utilization, which indicates a process like periodical stripping of the cork layer can be repeated every 9~12 years when the outer bark layer is ready to make a stopper (Pereira &Tome, 2004), it provides very important economic value of cork oak for the whole western Mediterranean communities

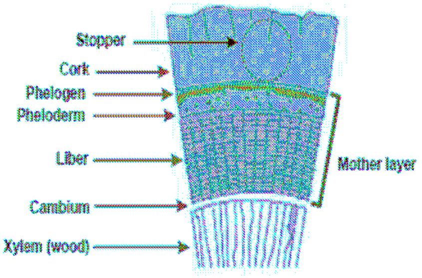

Figure 2.1. cross section of a cork oak stem , showing the different layers. Source: http://www.preteux-bourgeois.com/mise/pourg/htm

The growing season for cork oak starts from spring to late autumn (Costa et al. 2002). During this period, water and nutrient availability, as well as climatic condition, are important growth factors (Montenegro 1987). Like other evergreen Mediterranean oaks, cork oak has an extensive and deep root system. This may have evolved as root growth priority during the early stages of cork oak life (Maroco et al. 2002). Thanks in part to this root system, cork oaks survive droughts by taping water from the deeper soil or subsoil (Pereira et al. 2006). In this case, cork oak may have a healthy and long life with deep soil and adequate rainfall. In other words, the tree must protect crucial organs and tissues from dehydration during the summer droughts periods. In areas with a Mediterranean-type climate, most trees reduce their water loss or preserve access to soil water during water deficits (Walter 1973; Pereira et al.2006), especially in summer. To maintain the water status of plants, stomatal functioning (closure) and leaf shedding are assumed be instrumental in controlling water losses (Jackson et al. 2000) while deep roots systems provide access to water. Hydraulic lift is an important mechanism during the process, which can contribute to an increase in plant transpiration.

2.2. *Typical Mediterranean-type climate and cork oak*

The Mediterranean climate is a typical climate condition for a part of the world which is characterized by cold winter and hot summers, along with sporadic precipitation (Boscolo 2005). As the ‘climate diagram’ of the study area shows in figure 2.2, the highest temperature occurring in summer when precipitation is lowest. Moreover, a deficient hydrological balance (summer droughts stress), mostly happened from June to September, is driven by the high rates of evaporation, which are resulting from high temperature and high light, and the low runoff, which are corresponding to low precipitation (Arnell 1999). This can cause the drainage of the soil in the region. As the figure 3.1 shows in the "study area" section, the cork oak forest is mainly distributed along the coast, which may partly indicate that cork oak can survive well in hot places rather than dry places.

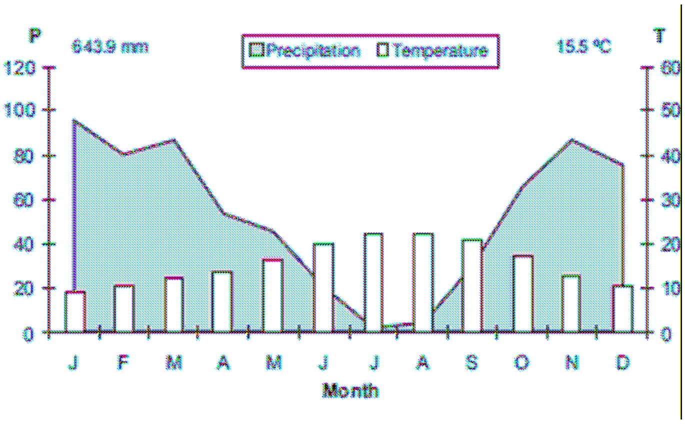

Figure 2.2 mean anuual patterns of temperature and precipitation for the study period for the study area

The ideal climate conditions for cork oak to grow include an annual rainfall of between 400 mm to 800 mm, an average temperature around 15 °C and an elevation lower than 800 meters (Aronson et al. 2009; Blanco et al.1997). In other words, plant production under Mediterranean climates, in general, is limited by cold temperature and low irradiance during wintertime and high temperatures combined with increasing water stress as the summer drought progresses. These requirements push cork oak to survive in a relatively narrow band along the western coastal area of Mediterranean (William 2002).

The Mediterranean region is one of the foremost regions in the world in terms of climate extremes; especially the frequency and intensity of droughts, which has a dramatically increase in the last twenty –five years (Pausas 2004). As the dry period continues, firstly, water deficits resulting from dry extremes, combined with the high temperature and high light, can lead to permanent impacts upon leaf tissues by affecting photosynthesis and transpiration, and therefore affecting the growth of cork oak (Breda et al. 1995). Secondly, water deficit can bring problems to wood growth: i), after previous stripping, dry periods can extend the 9 year harvest cycle by influence cork oak not forming annual ring of wood for one or even two years from inhibition of phellogen activity (Gourlay & Pereira 1998). ii), leading to large trunk damage or even tree death by separating cork and bark through a wrong layer instead of phellogen, because only phellogen can be regenerated (Costa and Oliveira 1999). In addition, cork production is largely influenced by water deficits, since cork production takes precedence of wood growth of cork oak.

Increasing temperatures is another risk for cork oak as well as some other species in Mediterranean regions. First of all, the carbon balance of the tree would be negatively changed by high temperatures through an increase in plant respiration relative to carbon uptake (Aronson et al. 2009). In addition, evapotranspiration would be also restricted by stomato closure, which causes overheating and functioning damage in leaves (Jackson et al. 2000). Secondly, the severity of plant water stress would be further increased due to the high evaporation under extremely hot temperatures. At last, high temperatute would also longer the active period of pethogen and lead to a potential expansion of the disease risk zone for oaks along the Atlantic coast(Bergot 2004).

2.3. Distribution of cork oak

It is very important to give a description of the historical distributions of cork oak, which clarifies the relationship with climate change. After the first cork oak was identified millions years ago, the geographical distribution of cork oak was affected by several episodes of climate change, especially during the Pleistocene. It was forced to take refuge and make its territorial expansions relative to the alternating periods of extreme cold glacial eras with warmer inter-glacial periods (Huntly and birks

1983; Aronson et al. 2009). The present distribution in Europe, which is quite far west of its origin distribution area, was recolonized by the end of last glacial period, around 10,000 years ago (Lumaret et al 2002; Aronson et al. 2009).

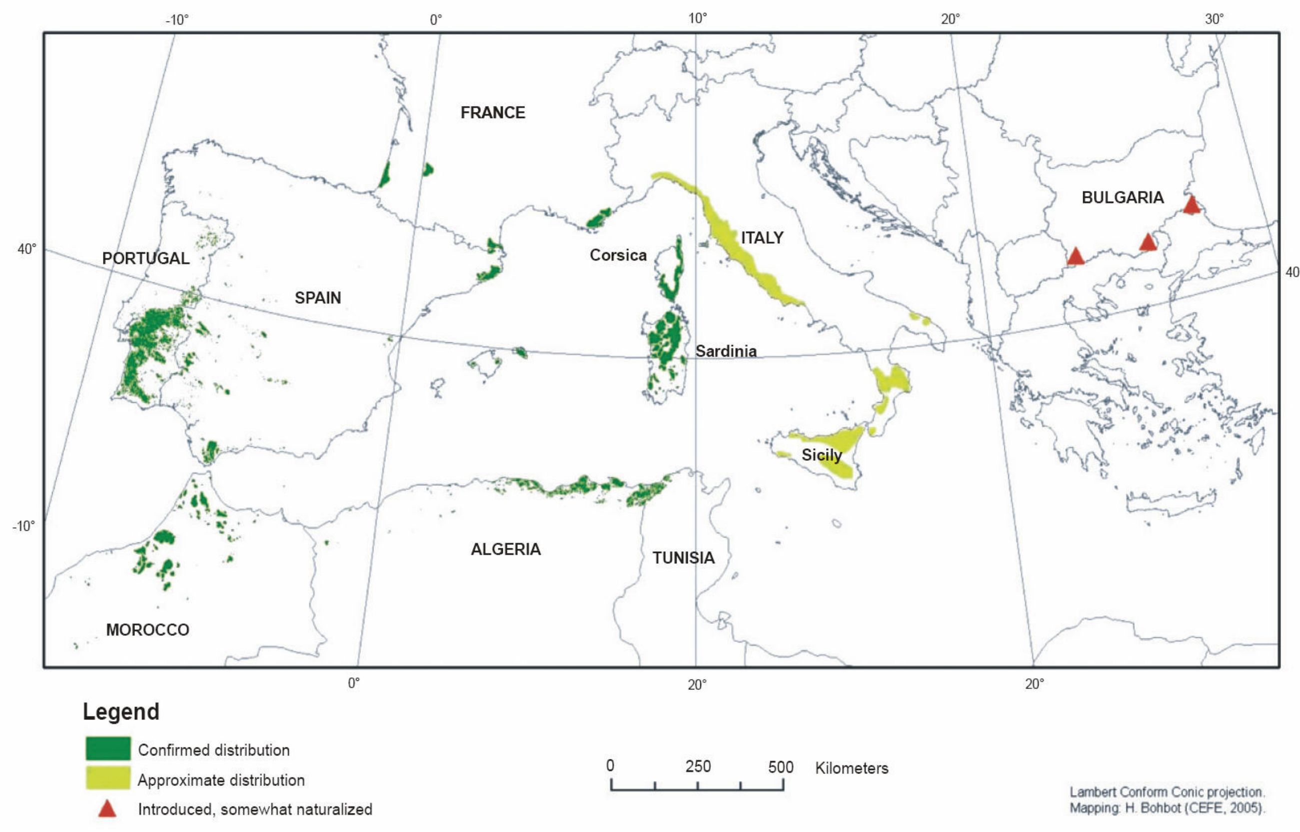

Figure 2.3. The distribution area of cork oak forest landscape in western Mediterranean regions

The present cork oak distribution is in Southwest Europe and Northwest Africa in seven countries (Portugal, Spain, Algeria, Morocco, France, Tunisia, and Italy) with a Mediterranean climate influenced by Atlantic Ocean, mainly contributing present cork oak distribution. In each country, special names are given to the cork oak woodland landscape; for example, in Portugal they are called respectively “montado” which benefited from cork oaks on its biodiversity (APCOR year book 2009) and “dehasa” respectively for Spain (Pereira and Tome 2004).

As figure 2.3 above shows, the confirmed distributions of cork oak forest are mainly located along the coast of the western Mediterranean region. It is clear to see from the map, Cork oak can be the most common indigenous trees in the southern Portugal since its coverage is centralized in the southern part. In Spain, the coverage of cork oak is more dispersed than Portugal. Two particular locations are the provinces of southwestern and northeastern Spain. Historically, northeastern Spain was first exploited for cork oak around 1790 (William 2002). In France, the mainland has little coverage of cork oak, and the French island of Corsica (an island to the left of Italy) has certain forests containing this tree. In Italy, the islands of Sardinia and Sicily have the major cork oak distribution, with only small areas of cork oak located in mainland Italy. Note that the yellow areas on the map are only approximate distributions. However, in some studies this part is actually counted as a distribution area (Aronson et al. 2009). In this study, the yellow part in Italy is treated as approximate (not counted as real) distribution; this will be explained further in the paper.

On the African continent, cork oak can be found in Algeria, Morocco and Tunisia. Algerian cork oak forests are confined to the coastal regions. For Tunisia, it is obvious and interesting to see from the map that the cork oak forest is an extent of the Algerian coastal strip. In Morocco, the cork oak covers most of the Mediterranean coast as well as the Atlantic coast.

The red triangles indicate places where cork oak was introduced. Some countries including Russia, United States, Argentina, Australia, Israel, Japan, South Africa, Turkey and Uruguay, have had cork oak plantations with limited success (William 2002).

As the Table 2.1 shows, about one third of world cork forest is located in Portugal with the same proportion of world cork production, which is the highest among those seven countries. The cork oak can be seen throughout the country, especially from the middle to the southern part. The second largest cork country is Spain. The cork production of Northwest African countries includes Algeria, Morocco and Tunisia, which have very low production with no proportion to their cork forest coverage. 33 percent of world cork forest located in Northwest Africa with only 9 percent cork production contributed, even with its extensive resource of cork oak forest.

Table 2.1. Cork oak forest area in each country. Source: APCOR yearbook 2009.

Countries	AREA (Hectares)	Percentage (%)	Cork Production (Tonnes)	Percentage(%)
Portugal	736.700	32.4	157.000	52.5
Spain	506.000	22.2	88.400	29.5
Algeria	414.000	18.2	15.000	5.2
Morocco	345.000	15.2	11.000	3.7
France	92.000	4	3.400	1.1
Tunisia	92.000	4	7.500	2.5
Italy	92.000	4	17.000	5.5
TOTAL	2.277.000	100	299.300	100

2.4. *The values and services of cork oak forest*

As mentioned in previous paragraphs, cork oaks are important for western Mediterranean economies and the biodiversity of woodland landscapes, but the values of cork oak are far beyond that. It is said that cork oak forest landscapes have been one of the best examples in Mediterranean for sustainable development (Montero and Torres，1993).

- Biodiversity value
  The Mediterranean area has a high level of species diversity (Myers et al., 2000; Acacio et al., 2008). Coincidentally, cork oaks, which survive particularly well in the harsh Mediterranean climate, can not only support high biodiversity levels (lots of species can coexist in cork oak woodland), but also increase them. This is good for sustainable development (APCOR year book 2009). To further explain this, the cork oak forests can be the ideal habitats for different kinds of local birds and the places for migratory birds from northern Europe (APCOR year book 2009). In addition, other tree species such as Holm oaks, pine, ash and small species like

strawberry trees can integrate well with cork oak (Massoura 2005; WWF report 2006). That means both flora and fauna have high diversity in cork oak landscape.

- Environmental services
  Forest can always play a vital role in protecting the environment. Cork oak is not an exception. As a unique forest type of limited distribution in the Mediterranean area, it performs functions such as soil conservation from erosion and landslides in steeply sloping watersheds by its deep roots (Pereira et al. 2006), water protection from droughts, excellent carbon sequestration by harvested cork oak (3 to 5 times more than one is not harvested) (Gil et al., 2005) and energy conservation.

- Economic values
  Cork is one of main Non Wood Forest products (NWFP) in Southern Europe and Northwest Africa. It generates approximately €1.5 billion in revenue annually (Natural Cork Quality Council, 1999). Bottle stoppers required by the wine industry, as the main final products of cork, play a very important role in export trade area for its habitat country (Barker B 2004). Other valuable goods and services from cork oak landscape such as providing grazing, hunting games, fire wood, charcoal and rural tourism also have benefits for the local economy (Aronson et al. 2009).

- Social and cultural values
  Cork oak woodlands provide employment and guarantee the survival of local communities. More than 100,000 people in the seven Mediterranean cork-producing countries depend directly and indirectly on cork economies (WWF report 2006). Its industry employs an estimated 30,000 workers in a variety of jobs such as debarkers, cutters and water suppliers for harvesting and agents for industrial processing (Parker 2004). In northwest Africa, the current primary roles of forests are environmental protection and poverty alleviation (Daly-Hassen et al. 2007).

2.5. Threats

Cork oak forests are increasingly threatened by the inter-related threats. Economic factors like global cork markets, often attract the interest of researchers. However, forest fires, changing climate conditions as well as associated diseases are starting to lead to increasingly damaged cork (WWF report 2006; Aronson et al. 2009), a situation that cannot be ignored any longer. The biotic factors such as pests and diseases seem to be associated with the mortality and regeneration of cork oak forest. Nevertheless, the effects of such biotic agents depend on abiotic factors, such as drought and poor soil drainage, as well as alternating drought and wet periods in poorly drained soils (Aronson et al. 2009). Rising temperature and declining precipitation might result in extended dry seasons, which will affect the photosynthetic capacity, leading to reduced primary production (Medlyn et al. 1999). In addition, the abiotic factors are further influenced by the increasing frequency of climate extremes. Though cork oak forest is not in the situation of being endangered as long as it has economic value (Luis and Maria 2002), however, those small and scattered stands are at risk of disappearing (Luis and Maria, 2002).

2.6. State-of –the-art of cork research

Research on the state of cork oak is rather limited. Since Portugal owns largest percentage of cork oak forest as well as cork production, most research is related to the situation of Portugal. Although the artificial restoring is carried out (WWF-Mediterranean Programme), the decline of cork oak forest, especially when some small-scaled stands are facing the edge, is still a big problem for Mediterranean cork oak landscapes. Indeed, increased mortality of cork oak in western Mediterranean has been shown in recent reports (William 2002). Despite all the recent studies, the exact causes of the cork oak forest decline is still not clear, because of the complex ecosystem, biotic stress and changing climate conditions together with land use changing coupled to socioeconomic and population changes, all drive cork oak into an aggravated situation (Aronson et al. 2009).

Nowadays, the research on the impacts of climate change on cork oak is mostly in terms of daily changes or mean values rather than extreme analysis. For example, some studies show that rainfall and temperature, which are studied through the approach of dendrology, have significant effects on the growth of cork oak; especially the mean precipitation in the growing season (Costa et al 2001). In Mediterranean regions, apart from human influences, drought is the most severe nature problem for the growth of cork oak (Acacio V. et al. 2008), which triggers a lot of damage to cork oak forests and also its cork production.

3. Data

3.1. *Study area*

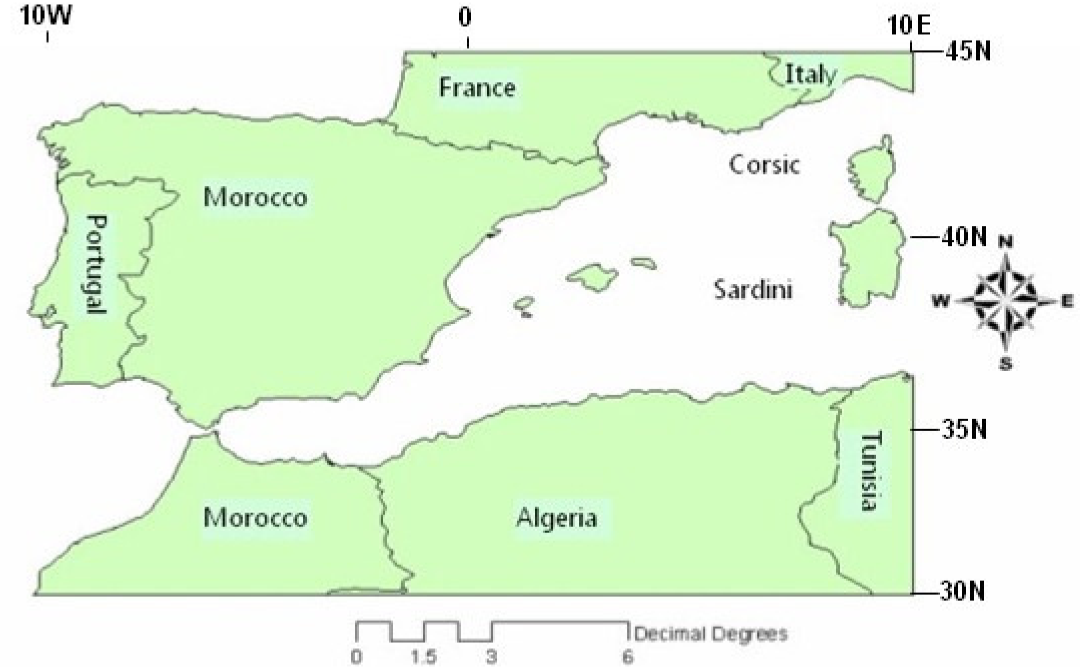

Figure 3.1. study area of western Mediterranean ranges from +30° to +45° in latitude and -10° to +10° in longitude.

In this study, the main study area ranges from +30° to +45° in latitude and -10° to +10° in longitude, which is the centralized location of cork oak forest (see Figure 3.1). On the other hand, focusing on this area means abandoning the approximate distribution area in Italy. According to the statistics of cork oak forest area obtained from Portuguese Cork Association (APCOR) for each year, the cork oak coverage in Italy was only a few percent of the world distribution (see Table 2.1 for example). In this case, it is reasonable to only focus on the confirmed distribution.

3.2. *Climate Data*

3.2.1. Stations

The small dots in Figure 3.2 denote the meteorological stations involved in this research. The process of choosing stations is based on the European Climate Assessment (ECA) datasets that consist of daily series of temperature and precipitation of a large number of meteorological stations throughout whole of Europe as well as some subregions in Africa. 197 stations were first selected within the study area. And a further selection of stations was processed according to data quality, which is explained in chapter 3.2.2. There are relatively more stations covering in Southwest Europe than in Northwest Africa as one can see from the figure 3.2, since Algeria, Morocco and Tunisia are included in the European datasets as subregions to Europe. In addition, there are much less stations with daily precipitation data in Northwest Africa, which may contribute to possible differences between two series of variables in data analysis.

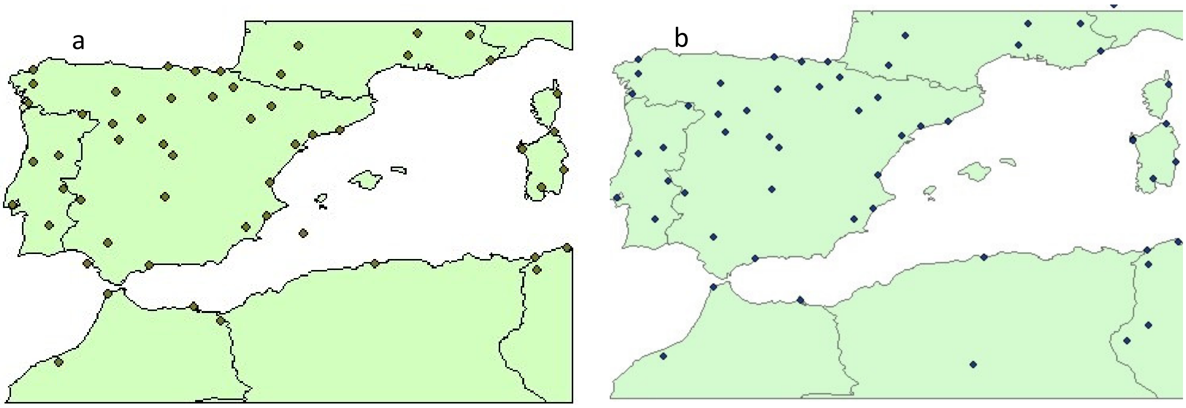

Figure 3.2. a) The stations in study area with daily precipitation data in period from 1979 to 2009. b) The stations in study area with daily maximum temperature data from 1979 to 2009. Source: http://eca.knmi.nl/utils/mapserver/stations.php

3.2.2. Daily data

As with the selection of stations, obtaining daily data is basically from ECA datasets and all the data can be directly downloaded from the ECA website. Historical daily maximum temperature (TX) and daily precipitation (RR) data are available from 1979 to 2009 within seven countries in the western Mediterranean region. Daily-observed station data were used for all the analyses in the study instead of gridded/interpolated data in order to present well the extreme climate, and blended series (series that are near-complete by in filling from nearby stations) were selected for the analysis. Annualized data with the criteria that an individual year would be considered missing if more than 10% of the daily data were missing in a given year throughout the period 1979 to 2009 study period. Finally, 81 stations left (coordinates of stations is attached in Appendix AI) are located throughout study area with elevations averaging 388m, ranging from 1m to 1890m. The nearest-neighbor index is also calculated for the network and found the value to be 1.06, which indicates a properly (p<0.1) dispersed distribution of the stations. Averaged across the study area, both the mean annual maximum temperature and the annual precipitation sum show considerable variability from year to year with a range from 34.3ºC in 1997 to 30ºC in 2003 for maximum temperature and a range from 550mm in 1998 to 820mm in 1996 for precipitation. There is a slight upward trend in the mean maximum

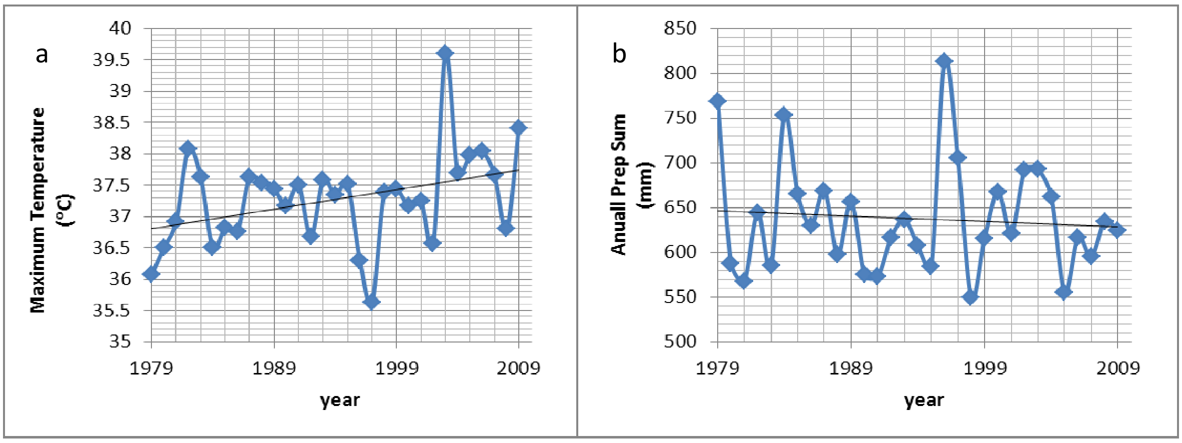

Figure 3.3. a) Annual precipitation sum during the period of 1979 to 2009.
b) Annual maximum temperature over period of 1979 to 2009.

temperature of 0.04ºC per year and a downward trend in the mean annual precipitation sum of 0.67 mm per year (see Figure 3.3).

3.2.3. Data quality control

It is always difficult to find complete and high quality data series. Minimizing the missing value is an important but troublesome task to do before analyzing. Since the data from ECA datasets are automatically quality checked, several types of errors including anomalous values (e.g. precipitation value exceeding 300 mm per day or even negative values), repetitive values (i.e. repetitive precipitation data over more than 10 days of non-zero values), outliers (i.e. temperature that exceed a certain z-score in the normal distribution of that calendar day) and inconsistencies (minimum temperature that exceed the daily maximum) are detected through the quality check, and only 0.5% of all the values in the ECA datasets are currently considered as suspect (Klein Tank 2009). However, prior to creating the daily database for this study, individual time series were evaluated for irregularities through time: stations with 30% or more missing daily data were eliminated. In addition, stations with gaps of three or more years in between series were also discarded, as well stations with erroneous precipitation and temperature values. Of the data used for this study are 0.03% of all the maximum temperature values and 0.65% of all the precipitation values (mainly contributed by Northwest Africa) considered as suspect or missing. Pchip interpolation (Piecewise cubic Hermite interpolation) method is used for solving the missing and suspect data in this study. Scripts of Matlab contents of pchip interpolation are showed in Appendix AII.

3.3. Indices of extremes

Precipitation and temperature indices are calculated from daily datasets. 2 indices of annual maximum temperature and annual precipitation sum, which are intensity indicators, are used for plotting a spatial distribution of climate in study area. This is because intensity indicator, rather than frequency indicator, has characteristic of geographic distribution. Annual Precipitation sum, which in itself is a kind of extremes, also expresses information of general climate. In order to better analyze the climate extremes conditions in one location and compare the differences between different regions, 15 indices of extremes indices were used for statistical analyzing with replacing annual precipitation sum by spring precipitation sum. These indices generally fall into two broad categories: frequency indicators and intensity indicators.

3.3.1. Frequency indicators

For each station, 11 frequency indicators were determined including the no. of summer days (TX> 25ºC), wet days (RR>=1mm) and dry days (RR<1 mm). Maximum number of consecutive dry/wet days was also determined to find out how dry/wet period affect the growth and production. Rainfall extremes with different fixed thresholds and percentile thresholds were determined to examine which level has the largest affection on cork oak. When calculating the threshold for the 95th percentile of precipitation extremes and 90th percentile of temperature extremes, the value based on the data for all the years from 1979 to 2009 should be used and then determine the very wet days for each year. Similarly, the threshold for the 90th percentile calculated for a 5 days window centered on each calendar day in the 1979-2009 periods was determined to obtain warm spell duration index, which can result in a harsh period for cork oak to grow. Table 3.1 shows the calculation methods of frequency indicators of extremes

3.3.2. Intensity indicators

The intensity measure for temperature extreme is the maximum value of daily maximum temperature for each year. And three other intensity measures are precipitation extremes: total precipitation sum in springtime, which was determined for assessing if rainfall in growing season affects production, highest 5-day precipitation amount, which was determined for checking the role of wettest amount, simple daily intensity index, which was determined for detecting the contribution of mean precipitation amount at wet day in affecting cork oak. Table 3.2 shows the calculation way of intensity indicators of extremes.

Table 3.1. 11 Frequency indicators and their explanations

Frequency indicators	Explanations
Summer days (SU)	The No. Of days where TX>25°C
Extremely hot days (SU41)	The No. Of days where TX>41°C
Warm spell days (WSDI)	The No. Of days where, in intervals of at least 6 consecutive days, TX is larger than the calendar day 90th percentile calculated for a 5 days window
Very warm days (TX90p)	The No. Of days where TX is larger than the 90th percentile of maximum temperature during the period of 1979 to 2009
Heavy rain days (R10mm)	The number of days where: RR >= 10 mm
Very heavy rain days (R20mm)	The number of days where: RR>= 20 mm
Moderate wet days (R75p)	The No. Of days where RR is larger than the 75th percentile of precipitation at wet days in the 1979-2009 period
very wet days (R95p)	The No. Of days where RR is larger than the 95th percentile of precipitation at wet days in the 1979-2009 period
Maximum NO. of Consecutive wet days (CWD)	The largest number of consecutive days where: RR>=1 mm
Dry days (DD)	The number of days where: RR< 1 mm
Maximum NO. of Consecutive dry days (CDD)	The largest number of consecutive wet days where: RR < 1mm

Table 3.2. 4 intensity indicators and their explanations

Intensity indicators	Explanations
Max value of TX (TXX)	The maximum value of daily maximum temperature of each year in 1979-2009 period
Spring time prep sum (SPS)	The total precipitation sum for each springtime in period of 1979-2009
Highest 5-day prep amount (Rx5days)	The maximum value of the precipitation amount for the 5-day interval
Simple daily intensity index(SDII)	The mean precipitation amount at the wet days

Scripts of mat lab contents for calculating these indices are listed in Appendix BI.

The reason for using these 15 extreme indices as the study indices is that they are closely related to the growth of cork oak. For instance, a temperature threshold of 41ºC is chosen because it can be considered as a maximum temperature for plant growth. Springtime precipitation (SPS) has considerable influence on root development (Costa et al 2002: Oliveria et al 1994), which provides a long-term strategy for cork oak growth. Wood growth, fundamental for cork production, has been studied showing a considerable pronounced inter annual variation (Costa et al 2002), marked as one of typical characterizations of the climate, which suggest that a link between cork production and climate. Some of them could even be ‘proxies’ for something else that cannot be qualified directly with the available climate data: high frequency of dry days (DD) and long period of consecutive dry days (CDD) proxy for droughts, which poses a great threat to water availability of the tree. Maximum temperature is ‘proxy’ for evaporation, since higher evaporation is mostly attributed by higher temperature. As indicated in the explanation, during a cork production cycle of the tree, both raidial increments and wood are relevant with general climatic conditions. With reference to these results, consecutive dry days may have negative relationship with cork production. Extremely hot days would also show its incongruous change compared to cork production. Heavy rain days may closely relate to cork production.

In the investigation, an intention of dividing rainfall extremes into several groups by factor analysis is expected, for instance, very heavy rain days (R20mm), very wet days (R95p) and highest five day precipitation (Rx5days) belong to largest rainfall extremes, whist moderate wet days (R75p) and heavy rain days (R10mm) are moderate rainfall extremes, these two groups could be distinguished by some certain underlying temporal variance. Thus, 8 out of 15 extremes are rainfall extrems.

3.4. Production data

A Part of the annual production data, such as 17 years ranging from 1990 to 2007 for Portugal, can be directly obtained from the website of APCOR. After contacting the organization, other production data were obtained such as such as 17 years production for Northwest Africa and change of cork production per decades. Cork production among the seven countries can vary a lot, which has been also showed in Figure 3.4.

Figure 3.4 shows the decades cork production in seven western Mediterranean countries during the period if 1880 to 2000, as one can see Portugal and Spain has very similar cork oak production change, reaching their highest levels in the 1960s. There is a decline trend during the period of 1960 to 1990, prior to an increase. Other countries except Algeria and Italy have similar changes to Portugal with less magnitude. For Algeria and Italy, cork production reached their highest levels around the 1940s.

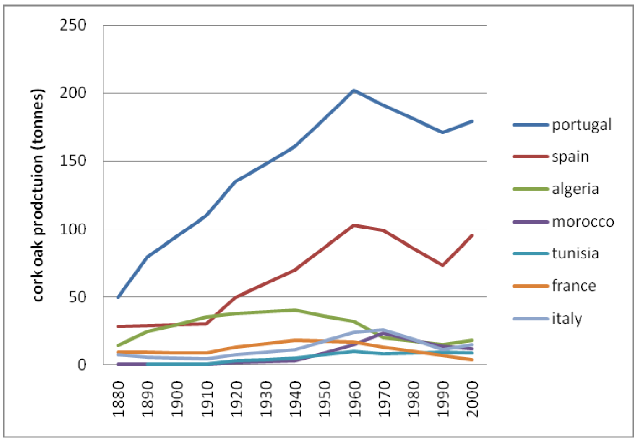

Figure 3.4. Decades Change of cork production in seven western Mediterranean countries during the period of 1880 to 2000.

3.5. Burned area data

Analysis of the relationship between burned area and climate extremes and cork production in Portugal is a further study in this project. Burned area data rather than numbers of forest fire data was used in this analysis. According to the paper written by Silva & Catry in 2006, the burned area is referred to as burned cork oak stand (*in ha*). As the graph (figure 3.5) below shows, burned area is mostly not totally coinciding with No. Of forest fire, since intensity of fires is not considered in No. of forest fire. And in 2003, largest area is burned due to the heat wave.

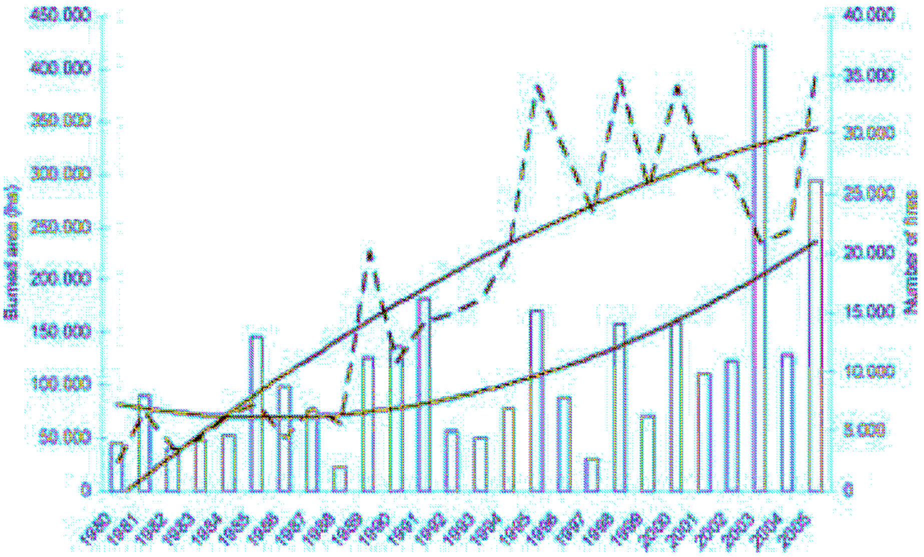

Figure 3.5. Number of fires (dashed line) and burned area (histogram) in Portugal between 1980 and 2005 (provisional data for 2005). Solid lines represent main trends given by a second order polynomial adjusted to the data (source: Silva & Catry 2006).

4. Methodology

15 indices of extremes were calculated from daily series including both frequency and intensity indicators to explain the climate extremes in 7 countries through a comparative analysis. To achieve this object, first, spatial interpolation is used to generate the surface of climate intensity extremes over the study area. Grid overlay calculation is used to illustrate the changes of those extremes during the period of 1979 to 2009. Statistical methods are applied to analyze impacts and climate extremes. Factor analysis is used in this study. After applying factor analysis, 11 indices will be regrouped to several large components due to the inner connection among these indices. Correlation analysis is adopted to detect the relationship between the large components and the numbers of wildfire in cork oak forest as well as cork production. For the future prediction, regression analysis is applied. In the following part, briefly explanations are given for these analysis methods.

4.1. Interpolation

In this study, interpolation was used for indices of extremes, especially intensity indicators, rather than daily data, since observation data can present better climate extremes. But regional study of extremes analysis is required, for this purpose, it is better interpolate indices of extremes in study area; change them into gridded data (0.25º × 0.25º sized cell is used in this study). The gridded data are plotted on a map and the natural borders of climate are included. This can give a first image of how climate extremes differ from region to region. The results derived from this method are the basis of the statistical method. As mentioned in the previous paragraph, there are less station data in Northwest Africa than Southwest Europe; which lead to relatively larger errors for Northwest Africa extremes.

Interpolation is a method for dealing with discrete data by making up a continuously function, which creates a continuous curve through all the given discrete data. It is very popular and it is useful to use interpolation for dealing with a lot of types of data. In geostatistics, it means using sample points taken at different locations in a landscape and creating (interpolate) a continuous surface (ESRI education services).

There are two main groups of interpolation techniques: deterministic (relies on mathematical functions for interpolation) and geostatistical (relies on both mathematical methods and statistical models including autocorrelation). Geostatistical interpolation techniques were used in this study.

Ordinary kriging was used as interpolation method, which is a basic method of surface interpolation, (Meyer and Thomas 2004; Bailey 1994). It weighs the surrounding values to facilitate a prediction for each location (Kumar et al. 2007). The weights are based on not only the distance between the sample points and the prediction location, but also the overall spatial arrangement among the sample points. The ordinary kriging model is

$$Z(S_o) = \mu + \varepsilon(s)$$

Where $s=(x, y)$ is a location of one of sample points, and $Z(S_o)$ is the estimated value (temperature or precipitation) at that location. The model is based on constant mean μ for the data and random errors $\varepsilon(s)$ with spatial dependence. Assume that the random process $\varepsilon(s)$ is intrinsically stationary. The predictor is formed as a weighted sum of data,

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

Where $Z(S_i)$ is the known value at the *i*th location.
λ_i is an unknown weight for the known value at the *i*th location.
S_0 is the prediction location. And N means the number of known values.
Kriging tries to choose the optimal weights that produce the minimum estimation error, which are obtained by solving a set of simultaneous equations:

$$\begin{vmatrix} \gamma_{11} & \cdots & \gamma_{1n} & 1 \\ \cdots & \cdots & \cdots & \cdots \\ \gamma_{n1} & \cdots & \gamma_{nn} & 1 \\ 1 & \cdots & 1 & 0 \end{vmatrix} \begin{vmatrix} \lambda_1 \\ \cdots \\ \lambda_n \\ \mu \end{vmatrix} = \begin{vmatrix} \gamma_{01} \\ \cdots \\ \gamma_{0n} \\ 1 \end{vmatrix}$$

Where $\gamma_{i,j}=\gamma(x_i, x_j)$ is the variogram function value between x_i and x_j; μ is the fouth variable called Lagrange multiplier. Once the individual weight coefficient λ_i is known as well as the Lagrange multiplier μ after resolving the Kriging equations, the best appraisal value $Z(S_o)$ can also be estimated (Tang, 2007).

4.2. Grid overlay analysis

Math composite method which refers to the corresponding grid values of two or more layers by adding, subtracting operation, and receive a new grid data system, is used to analyze the average difference of annual precipitation and maximum temperature in the study period of 1979 to 2009. The map calculations were used for analyzing how the extremes changes over the period for study area. The process is carried out first by obtaining the difference between two close years according to

$$D_{j-i}= L_j-L_i$$

Where, L_i is the layer of one year from the study period of 1979 to 2009. L_j is the layer of the next year after year i of the study period. D_{j-i} is their difference. Make an average operation to get the final map after finishing all the differences throughout the study period.

Gird overlay analysis is a method to overly sets of spatial layers (maps), and generate new properties on corresponding position in the overlay map (Bonhan – Carter 1994). The following equation can indicate the computing of new properties:

$$U= f\,(A, B, C\ldots\ldots\ldots)$$

Where, A, B, C are the confirmed properties from the know raster layers. The value of U depends on the requirements of overlay.

4.3. Factor analysis

15 climate extreme indices are calculated for this study. Although each indices may bring different information, generally, some of them could have similar pattern of changes. Thus, doing separate analysis between every indices and dependent value would not be an efficient use of time. To provide a solution for this situation, factor analysis is introduced to divide them into larger groups.

In this study, for each station in study area, a matrix is produced. Each matrix has the structure of 31 rows for each year from 1979 to 2009 and 15 columns for each indices of extremes. Another 31 × 15 matrix has one row for each year from 1979 to 2009 and 15 columns containing the mean z-score averaged across the network of stations; there are no missing data in the matrix. The goal in constructing this matrix was to capture the temporal variance in each of the 15 extremes indices averaged across the station network. Each column is converted into z-scores at each station, and averaging the z-score for each row and column across the entire work. The resulting matrix is analyzed to determine the underlying temporal variance structure in the extreme indices by factor analysis

Factor analysis is a collection of methods used to examine how underlying variance influences the responses on a number of measured variables and create indexes with variables that measures similar things (Kim 1978). This analysis is based on the Common Factor Analysis Model, illustrated in figure 4.1. This model is based on the assumption that each observed response (variable 1 through variable 5) is influenced partially by underlying common factors (factor 1 and factor 2) and partially by underlying unique factors (E1 through E5). In this factor analysis would be the climate extreme indicies. The strength of the link between each factor and each variable varies, such that a given factor influences some variables more than the others.

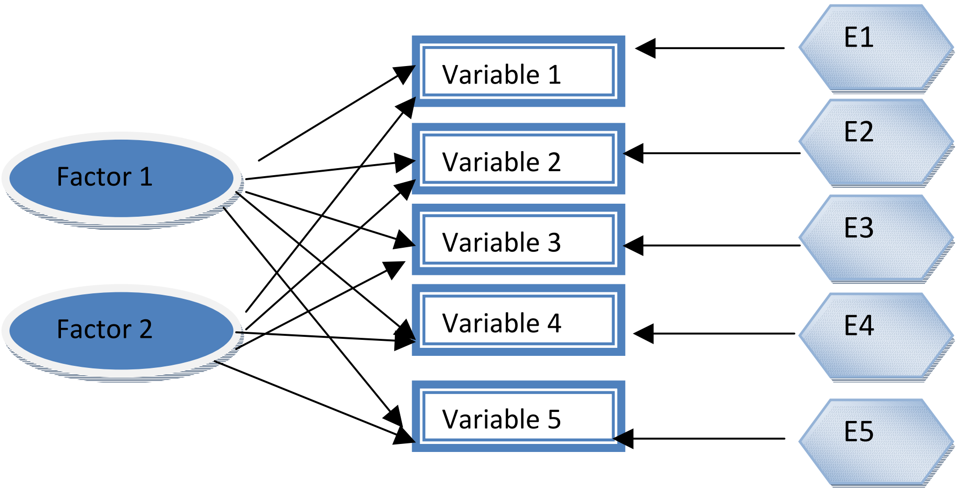

Figure 4.1 the common factor model. Variable 1 ~ 5 are observed responses. Factor 1 and factor 2 are underlying common factors. E1 to E5 are underlying unique factors.

To sum up, factor analysis is performed by examining the pattern of correlations between known variables. Variables that have strong correlations (either positive or negative) are grouped into one factor, while those that are relatively unrelated are likely grouped into another factor.

Selecting EFA as the method in this study is motivated by the fact that not only the simple data reduction is of interest, but there is also interest in making statements about factors that are responsible for a set of observed variables. There are five basic steps to perform EFA:

- *Selecting the variables and obtain the correlation matrix*
  It is very important to know the variables that chosen for the study do have significant correlations; otherwise, they won't get any common factors. Variables used in this study do have clear relationships between each other. For example, summer days and warm spell days are affected by temperature. It is a troublesome task to obtain the correlation matrix, because more than one matrix with 31 rows and 15 columns should be constructed.

- *Select the number of factor s for inclusion*
  According to Kaiser Criterion, one should use a number of factors equal to the number of the eigenvalues (represents the explanatory importance of the factors with respect to all the variables) of the correlation matrix that are greater than 1, since the ones less than 1 may have very low contributions to the explanation of variances in the variables and can be ignored.

- *Extract the initial sets of factors*

  This step is too complex to be reasonably done by hand. Several different extraction methods, including maximum likelihood, alpha, unweighted least squares, principle component and principle axis extraction (refers to MatLab manus), can be chosen. Generally, the best method is maximum likelihood extraction that is also the one applied to realize analysis for this study.

- *Rotation and interpretation*
  Factor analysis requires a series of steps to reduce the data and make them more understandable; because only a small subset of factors in the first extraction is kept for further consideration, determining the remaining factors as either irrelevant or nonexistent. To search the best explanation of patterns of data, rotation is a vital step that should be taken. The goal of rotation is to simplify and clarify the data structure. As figure 4.2 shows on left, Green dots have better directions on rotated coordinate (red one). After rotation, define the factor a name by considering what the underlying inner relationships for the observed pattern of positive and negative loadings. In this study, rotation is used for all the cases to get better understanding of each factor.

  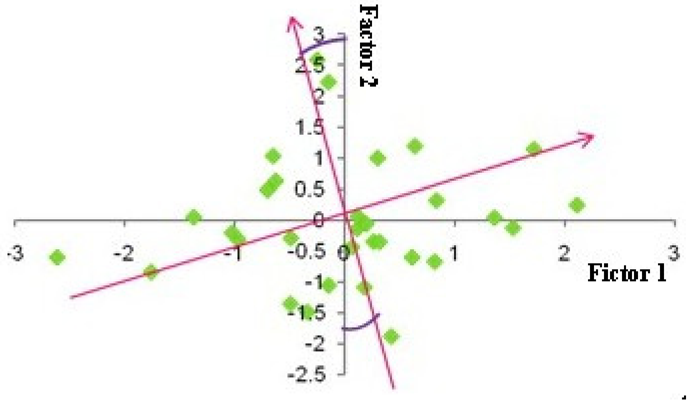

  Figure 4.2 rotation of factors in two dimention space. Black coordinate is original one (before rotated). Red coordinate is rotated one.

- *Construct factor scores*
  Constructing factor scores aims to perform additional analyses by treating the factors as variables. The score for a given factor is a linear combination of all of the measures, weighted by the corresponding factor loading. Then, the factor scores can be used such as variables in cluster analysis or regression factors in regression analysis (Christine et al. 2009).

All the steps of factor analysis are performed by SPSS

Z-score

More than one matrix was constructed for the analysis. It would be a very large task to do factor analysis for all the matrices in this study. Thus, z-score was introduced to construct a comprehensive matrix for each subregion. For calculating z-score for each matrix, equations are used as follows:

$$z_1 = \frac{x_1 - \overline{x}}{s}, z_2 = \frac{x_2 - \overline{x}}{s}, \ldots, z_n = \frac{x_n - \overline{x}}{s}$$

Where $z_1 \; z_2, \ldots\ldots, z_n$ are z-scores for each value in one column, $x_1 \; x_2, \ldots\ldots, x_n$ are values from the column. $\overline{x}$ is the column mean. S is the standard deviation for the column, which calculated as:

$$s = \sqrt{\frac{1}{n-1}\sum_{1}^{n}(x_n - \overline{x})^2}$$

Apply the same equation for rest columns to get z-scores for the whole matrix and the rest of matrices in a region as well.

Z-scores for the final matrix is calculated as:

$$\overline{z} = \frac{1}{n}\sum_{1}^{n} z_i$$

Where, z_i is the z-score of certain column and row from each matrix. $\overline{z}$ is the corresponding z-score for certain column and row in the comprehensive matrix. *n* is the number of matrix.

Adopting z-score is to minimize the discrepancies between different stations' value, since centralized indices can have standardized distribution.

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4.4. Correlation analysis

Correlation analysis is applied to study the relationship between climate extreme factors, which obtained from factor analysis and cork production and forest fire. The research is operated in two cases including Portugal case and Northwest Africa case in order to further compare their different impacts of varied climate extreme changes.

To carry out this correlation analysis, especially for analysis between cork production and climate factors, a 9-year moving average of every climate factor is calculated first, since cork oak has the 9-year harvest cycle. The range of cork production datasets is from year 1990 to 2007, which means a moving average value for climate factor should be calculated from 1982 to 2007.

A great deal of geographical analysis involves studying the relationships between two or more variables, either through time or in different place. There are several types of correlation analysis methods, and the values of correlation coefficients, derived by any of the methods, can vary only between -1.0 and 1.0. These extremes represent respectively the perfect negative and positive relationship between the two variables. In the former case the value of one variable increases as the other decrease, in the latter case the two increases in concert. If the values are 0.0, that indicates there is no any statistical relationship. Figure 4.3a and c show how perfect positive (r=1.0) and negative correlations (r= -1.0) might look, while figure 4.2b indicates the scatter of points that might arise when there is no correlation (r=0.0).

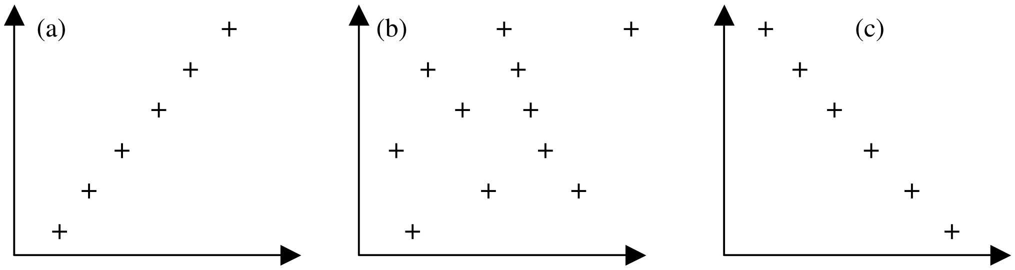


Figure 4.3 Scatter grams showing the differences between perfect positive (a) And negative (c) correlations. Zero correlation might plot as in diagram (b)

Between zero and perfect negative or positive associations there exists a range of less distinct correlation.

4.5. Regression analysis

A correlation analysis is, mathematically, a subset of a regression analysis. Choosing to do both within the study is motivated by the need to show not only the form of linear association that best predicts cork production or burned area from the value of climate extreme indices, but also the strength of the linear association between them. In addition, a relatively good model could be obtained by determining variables with strong correlations (Whitley et al. 2002).

In regression analysis, climate extreme factors are viewed as dependent values to predict the independent value of cork production and burned area as well. Both multiple linear regression models and simple linear regression models are used for predicting cork production in order to find the best model by comparing them.

Regression analysis is a famous statistical tool for the investigation of relationships between two groups of variables, which is applied almost in every field (Gareth & Dennis 1996). And the fitted model may then be used to describe the relationship between two groups of variables as well as to predict the new value. Generally, there are two data matrices denoted by X and Y involved in regression, and the purpose of regression is to explaining the link between them by building a model Y=*f(X).*

4.5.1. Simple linear regression model

When there is only one predictor value and one knows it is linear correlation between variables the simple linear regression model is used to predict the dependent variable. If the regression function is linear, the response variable Y is modeled as:

$$y = \beta_0 + \beta_1 x + \varepsilon$$

Where, β_0、β_1 Are unknown parameters, and ε is random noise that assumed to have normal distribution N (0, σ^2) is averagely equal to zero.

4.5.2. Multiple linear regression models

The multiple regression models are a direct extension of the simple linear form. It attempts to predict and to explain the variation of a single dependent variable (Y) from a number of predictor terms (Garenth & Dennis 1996). The latter may, or may not, be correlated between themselves; it is generally better, however, if they are not. The multiple regression equation takes the form:

$$Y= a + b_1X_1 + b_2X_2 + \ldots\ldots b_jX_i \pm e$$

Where, a is intercept value; b_1 to b_j is partial regression coefficients; e is error term (random noise). And each of the X termed and their associated regression coefficients represent the individual predictor variables.

The concept of least squares is still mathematically valid and used to obtain the best-fit 'surface' through multi-dimensional space rather than best-fit lines in two-dimensional space. This can be illustrated in figure 4.4.

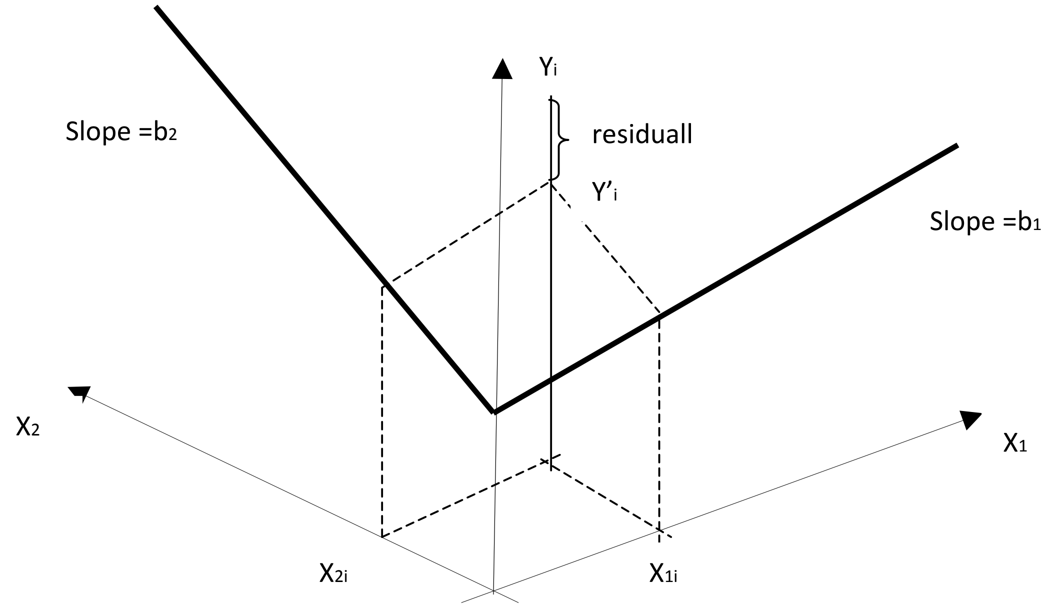


Figure 4.4. Representation of regression plane in three-dimensional space. Any point (*Yi*) can be located by references to its value by the two variables (represented by axes), for example *X1i* and *X2i*. The residual value is the degree to which the latter point lies above or below the regression 'surface' at the location. Source: Gareth & Dennis 1996.

5. Analysis and Results

5.1. An overview of intensity extremes in Mediterranean area

5.1.1. Annual precipitation sum

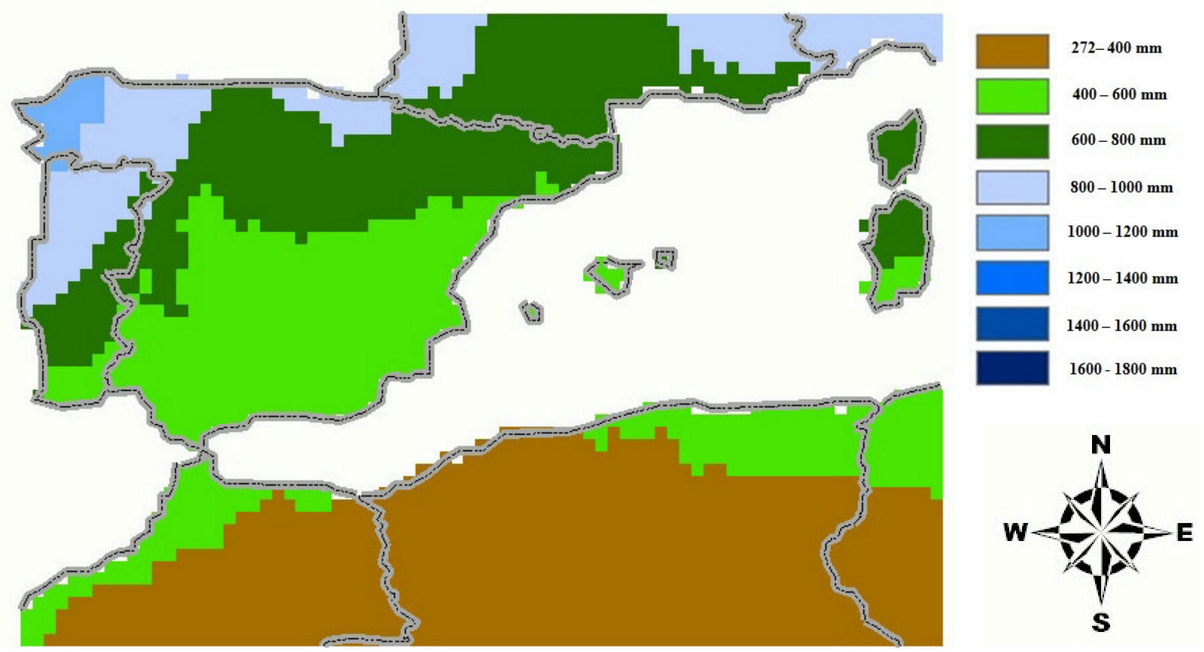
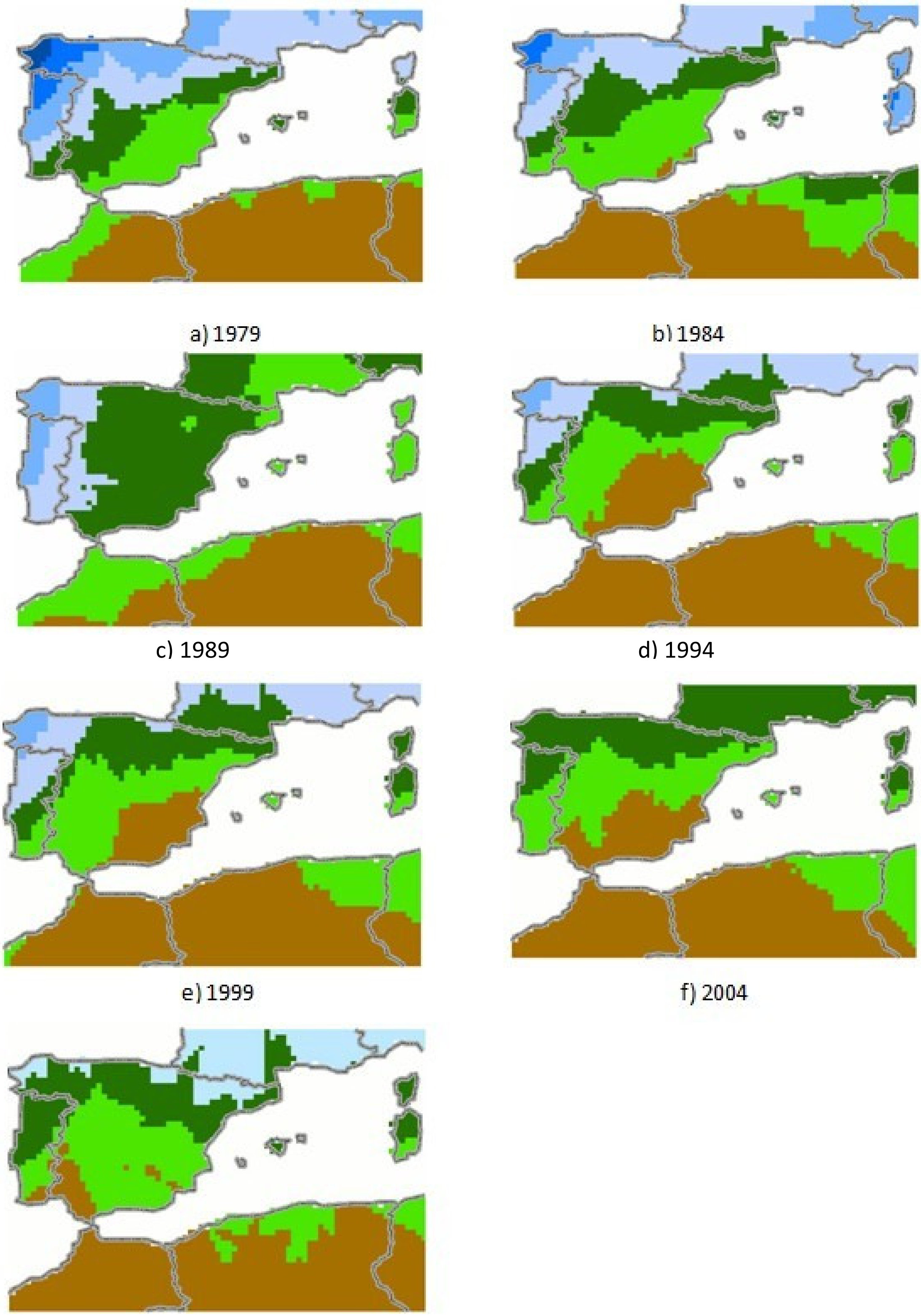


Figure 5.1 Spatial distribution of average annual precipitation sum over period of 1979 to 2009. The unit in legend is 1 mm.

The map of average annual precipitation sum over the period of 1979 to 2009 (Figure 5.1) serves to demonstrate where the cork oaks are. As mentioned in the background, the ideal annual precipitation condition for cork oaks' growth ranges from 400mm to 800mm. in figure 4.1, brown color indicates the area with less than 400mm yearly precipitation. Green color series (both dark and light green) represent the area with the ideal range of 400mm ~ 800mm yearly precipitation. The series of blue color shows the area with more than 800mm yearly precipitation. Associated figure 5.1 with figure 3.1, one can see that the area classified by series of green color (ideal rainfall condition) in figure 5.1 is exactly the confirmed cork oak forest distribution in figure 3.1. Secondly, although the green color area is the present region where cork oak forests are located, the bands showing distribution of precipitation reveals that there is 200mm difference of average annual precipitation sum between South Europe and Northwest Africa. However, in the same latitude, the middle part of western Mediterranean area has relatively less precipitation than both side parts, since the precipitation bands have convex parts in the middle. Features of bands distribution and middle convex can be also seen from the most of annual map in the following Figure 5.2.



a) 1979

b) 1984

c) 1989

d) 1994

e) 1999

f) 2004

g) 2009

Figure 5.2. a-g) Annual precipitation sum in every 5 year from 1979 to 2009.

From the 7 maps shown in figure 5.2, the notable changes that one can observe are the color shifts (seven maps are applied the same color and value in classification):

1. The numbers of subitems in blue series decreases from 4, which indicates range of 1400mm~ 1600 mm in year 1979 (Figure 5.2a), to 1, which indicates range of 800mm ~ 1000mm in year 2009 (Figure 5.2g). This change demonstrates that an evident decrease of precipitation in north part of western Mediterranean regions is staging.

2. The brown area with less than 400mm is somehow expanding, particularly in year 1994, 1999 and 2004, with a little bit fallback in 2009. The line graph of spatial average precipitation sum over the period, which was shown in figure 3.3a, illustrates a larger amount of precipitation in 2004 than in 2009. However, it is difficult to figure out in Figure 5.2f & g.

3. The area with range of 400mm ~ 800mm is expanding over the study period due to the decreasing precipitation in north part from these 7 maps. Especially in 2004, it occupied half of the study area. However, because of the same expansion of brown area, what one can conclude is that the area with ideal precipitation condition ranges from 400mm to 800mm is shifting to the higher latitude of western Mediterranean.

Figure 5.2 a-g only covers 7 years out of 31 study period. Results could be different with picking up other years. To further illustrate and prove the precipitation sum changes over western Mediterranean regions, the differences in average annual precipitation over the period of 1979 to 2009 are given in figure 5.3, which contains all the information from the whole study period.

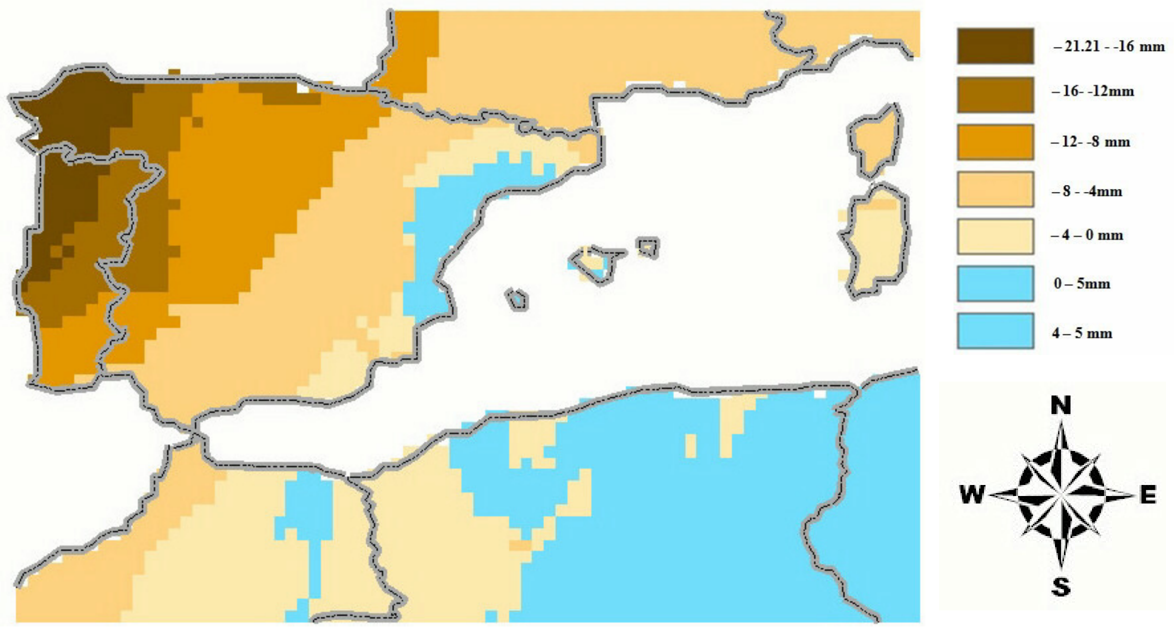


Figure 5.3 The annual precipitation change over period of 1979 to 2009

As the series of -21.21mm~0mm shown in figure 5.3 demonstrates, most places of western Mediterranean area are experienced a decline of annual precipitation; especially the north part. The most severe decline reaches 21mm per year per area. Nevertheless, a slight increase in annual precipitation (in blue) 0~5mm is found in southeast part of study area and eastern part of Spain, with a peak of 5mm per year per area. Further explanation for the increasing annual precipitation is given in discussion part. What should be pointed out here is that even in some parts of North Africa, especially in Tunisia, are going through an increase in annual precipitation, the total amount is still quite low (see Figure 5.1).

5.1.2. Annual maximum temperature

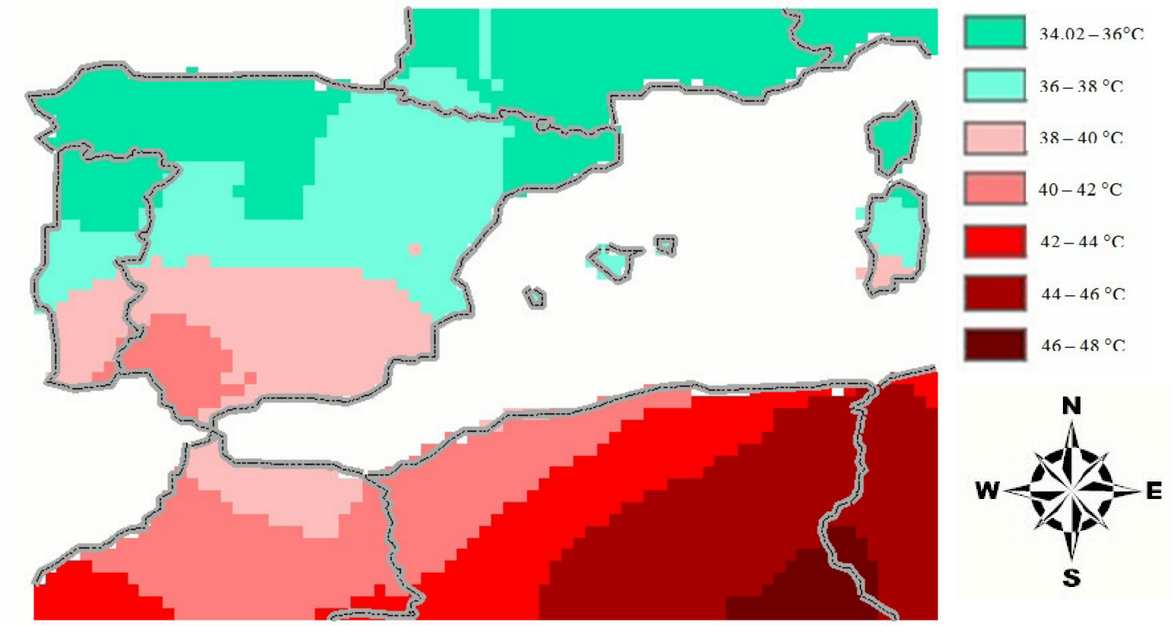
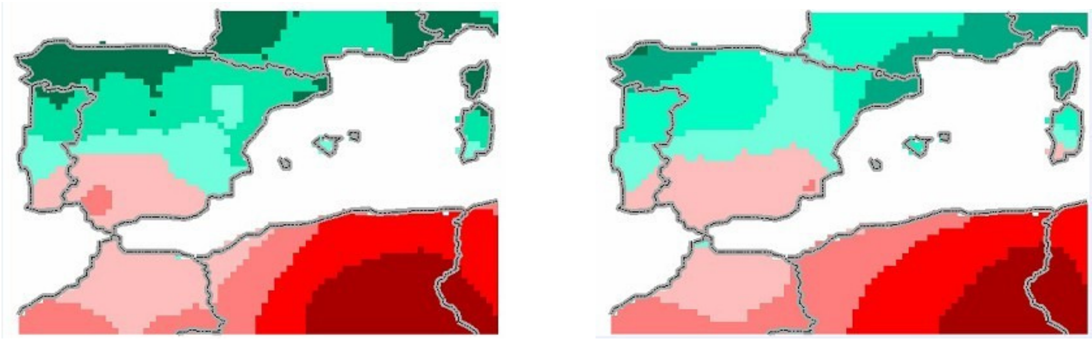


Figure 5.4. Average of annual maximum temperature over period of 1979 to 2009

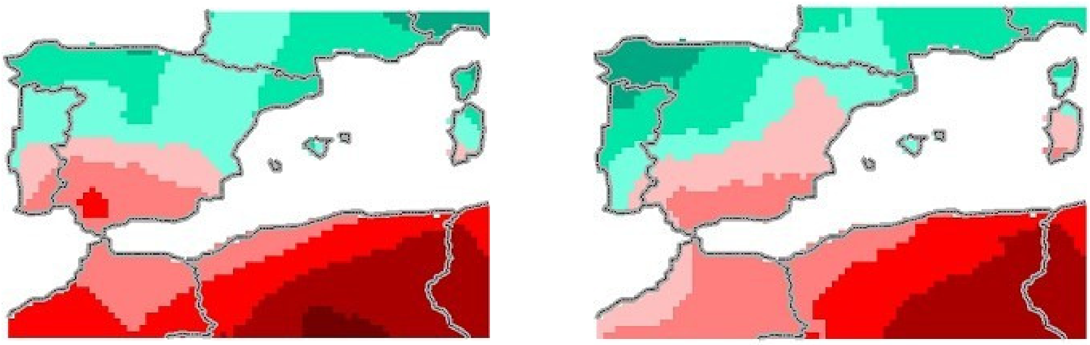
As the map (Figure 5.4) shows above, a relatively large spatial variance of maximum temperature can be discerned in the western Mediterranean area, which increases from 32.7°C in northwest to 47°C in southeast. It is obvious to find out that almost the whole of northwest Africa is covered with series of red color (except the lightest one) with the maximum temperatures higher than 40°C. No straightforward reports are given about the highest temperature for cork oak's survival, but the area distributed with cork oak has the range of 35°C ~ 42°C. Besides, the bands feature of maximum temperature has pointed out a notable maximum temperature border between south Europe and northwest Africa. Compare it with annual precipitation map (Figure 5.1), instead of ridges; hollows emerged in the middle parts of bands. This indicates a tender temperature covers the middle part of western Mediterranean regions.

Associated average annual maximum temperature distribution map (figure 5.4) with average annual maximum precipitation distribution map (figure 5.1), northwest Africa can be defined as an area with extremely high temperature (hot) and extremely low precipitation (dry). The southern Europe area can be treated as an area with moderate high temperature and particularly ideal annual precipitation for cork oak.



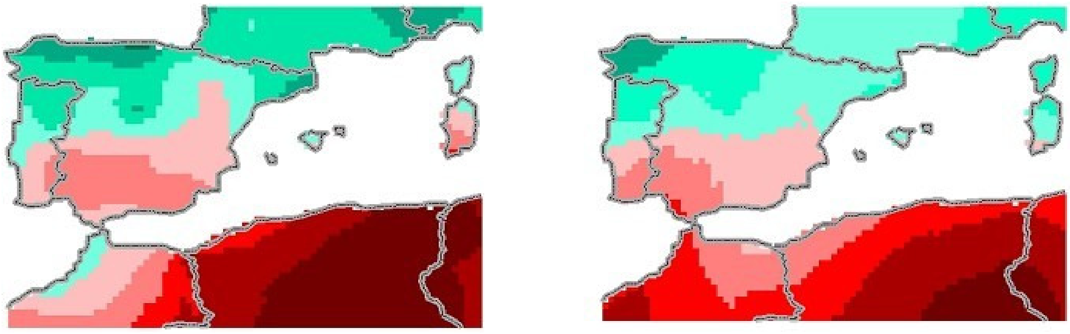
a) 1979

b) 1984



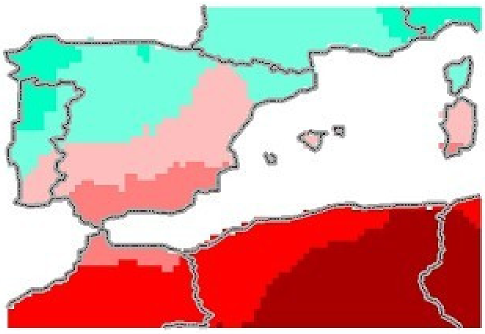
c) 1989

d) 1994



e) 1999

f) 2004



g) 2009

Figure 5.5. a-g) Annual maximum temperature in every five year from 1979 to 2009.

The 7 maps plotted in figure 5.5 show partly dynamic of maximum temperature change during the study period. To conclude the characteristics in those maps:

1. The area with 38° C ~ 48° C (red color), which is spreading from the southeast corner to both north and west parts, intends a trend of occupying the whole area in the future. Such consequence has occurred in 2003 (see Appendix CI).
2. The area in blue-green series, which represents the range of 34°C to 38°C, is shrinking to the northwest corner in these 7 yesrs. The temperature range of 34° C ~ 36° C (darkest blue-green) is completely disappeared in 2009.
3. One can conclude by highlighting the general warmer trend from figure 5.5, whilst acknowledging that large variability exists in some parts of Northwest Africa. For example, cooler climate is found in 1994 rather than in 1989; 2004 is warmer than 2009.

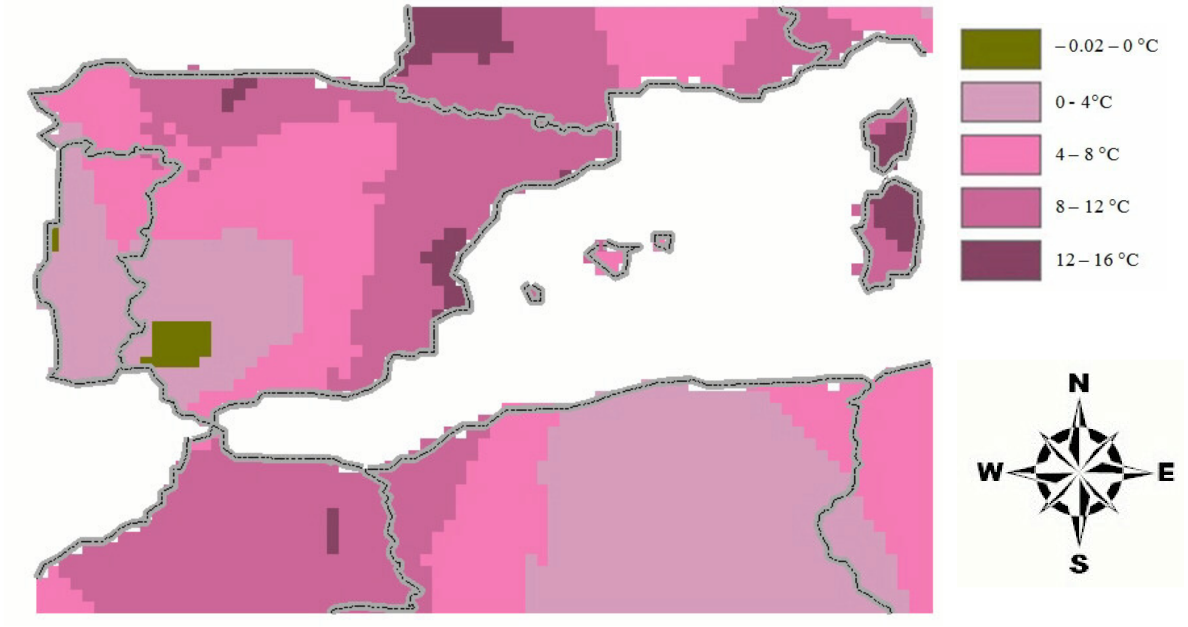


Figure 5.6 the average difference of maximum temperature over the period of 1979 to 2009.

These changes are further proved by the average difference of maximum temperature over 31 years map (Figure 5.6), which shows that almost everywhere in western Mediterranean area is experiencing an increase in maximum temperature up to 0.16°C per area per year in the middle and northern parts. A slight rising trend can also be seen in the east part of Northwest Africa.

To sum up, the north part of western Mediterranean is cooler than the south part whilst the western part of western Mediterranean area has a milder temperature than the eastern part. When it comes to cork oak countries, Portugal, Spain, Italy and two islands are located in the same climate band with only very few differences, while Morocco, Algeria and Tunisia are located in the most aggravated climate bands. And these findings are the basis of the performed statistical analysis.

5.2. Comparison of Climate extremes events

The whole study area is divided into 3 subregions for the analysis. Region 1 refers to Portugal. Region 2 refers to Algeria, Morocco and Tunisia. Region 3 refers to Spain, Italy and France. The principle for the division is according to their percentage of cork oak forest coverage. All these three regions have the approximately equal percentage that is one third of word coverage (see table 1.1). The reason for adopting this principle is for the purpose of better related to cork production in the coming analyses. Previous results from GIS analysis show that subregion 3, which contributes reasonable cork production, has similar extreme conditions as subregion 1. So, two main study regions in this study are region 1 and 2.

5.2.1. Characterization of extreme indices in Subregion 1

The resulting matrix for subregion 1 is processed by the method showed in section 4.3. The unrotated and rotated solutions are similar and showed four basic dimensions in our dataset (each with an eigenvalue >=1), as seen in figure 5.7. The loadings (Table 5.1) revealed a first component that explained 33.78% of the variance in the Portugal wide matrix with absolute highest loadings (>=0.9) on the moderate wet days (R75p), very heavy rain days (R20mm), with relatively higher positive loadings (>=0.5) on very wet dys (R95p), heavy rain days (R10mm), consecutive wet days (CWD), highest 5-day rainfall amount (RX5days), simple daily intensity index (SDII) and high negative loadings on dry days (DD) (indicates a negative relationship with this factor), which are emphasized in with bold in table 5.2. The first factor summarizes temporal variance in rainfall extremes events, and as seen in figure 5.8a, the factor score show a significant downward trend over the period of 1979 – 2009 with a dramatic decreasing after 2005.

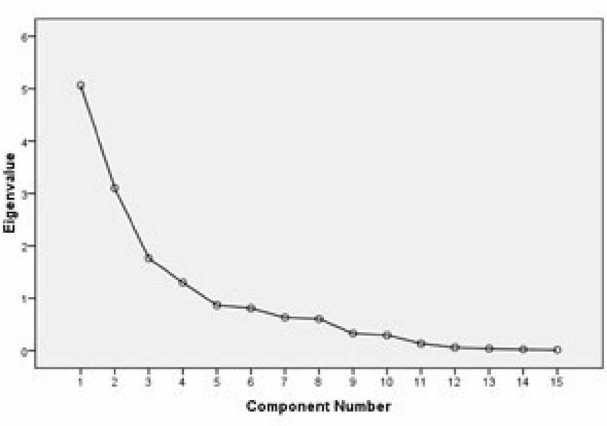


Figure 5.7. Factor eigenvalues plot for Portugal climate extreme indices

Table 5.1. Cumulative percentage of eigenvalues

Component	**Initial Eigenvalues**			**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	5.066	33.772	33.772	3.337	22.244	22.244
2	3.099	20.662	54.434	3.310	22.067	44.311
3	1.761	11.741	66.175	2.537	16.916	61.227
4	1.296	8.642	74.817	2.038	13.590	74.817

Table 5.2. Climate factors after factor analysis with climate extremes indices for Portugal

	COMPONENT				
	FACTOR1	**FACTOR2**	**FACTOR3**	**FACTOR4**	**CUMULATIVE%**
SU	.083	.638	-.176	.028	.446
SU41	-.002	.478	.694	.123	.725
TX90P	.052	.786	-.291	.424	.885
WSDI	.046	.817	-.305	.387	.911
R75P	.920	.120	-.012	-.113	.874
R95P	.795	.311	.048	-.307	.825
R10MM	.891	-.186	-.126	.273	.919
R20MM	.930	-.039	-.166	.148	.916
CWD	.557	-.227	.470	.216	.629
DD	-.711	.466	.022	-.395	.880
CDD	-.178	.118	.618	.076	.434
TXX	-.217	.661	.478	.067	.717
SPS	.421	-.259	.410	.330	.521
RX5DAY	.538	.196	.155	-.483	.585
SDII	.746	.456	-.003	-.439	.956

The second factor explained 20.67% of the variance in the composite matrix and had high positive loadings of the hot extremes on SU, TX90p, WSDI, TXx, with a step-like jump in late 1990s. As one can see from figure 5.8b there is a strong increasing trend for factor 2 scores. Moreover, the third factor, which explained 11.74% of the total variance, also had a strong upward trend with high positive loadings on the two variables related to the summer dry period including CDD and SU41. There is a big jump of factor 3 in the early 1990s. Finally, the fourth factor explained 8.6% of all the variance with no obvious high loadings on any of them. All these four factors explained 74.8% of all variance in the Portugal wide climate extremes.

Take a closer look at factor score changes in figure 5.8, the overall trends of deceasing precipitation and increasing temperature are agreed with the results got from GIS analysis. Scores of factor 3 have the similar changes as factor 2 from figure 5.8 b, c, but less magnitude compared with factor2. In addition, no significant increase is found in hot extremes from factor 2 scores in 2003, when a heat wave occurred in Europe. And also there is no significant rising of precipitation extremes from factor 1 in 1995, when a peak is found in figure 3.3a of annual precipitation sum. However, according to signal to noise ratio, the trends from these factor scores are very uncertain in the future, since large variability can also be seen between years.

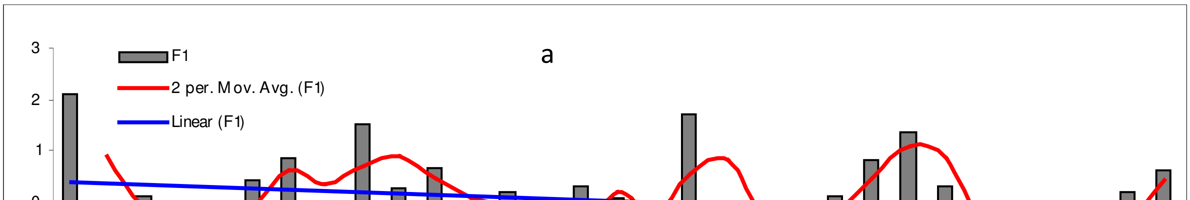


Figure 5.8. a) Changes of scores of factor 1 (rainfall extremes) from 1979 to 2009 in Portugal. . b) Changes of scores of factor 2 (hot extremes) from 1979 to 2009 in Portugal. c) Changes of scores of factor 3 (summer dry extremes) from 1979 to 2009 in Portugal.

5.2.2. Characterization of extreme indices in Subregion 1

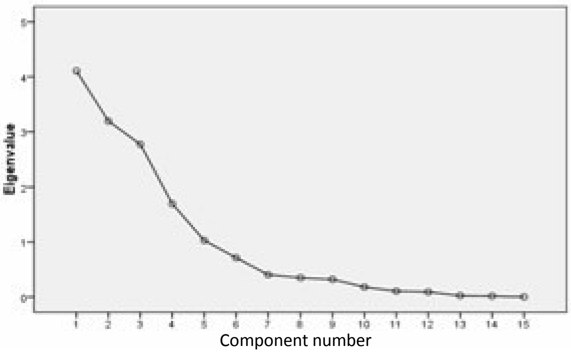


Figure 5.9. Factor eigenvalues plot for NW Africa climate extreme indices

For each of the 11 stations in subregion 2, the same matrix with 31 rows and 15 columns containing the mean z-score averaged across the network of stations is produced as the one in subregion 1. The results for subregion 2, as figure 5.9 on the right shows, demonstrates that there are 5 factors rather than 4 factors with their eigenvalue larger than 1. Table 5.3 shows both single and cumulative percentages for those factors explaining all the variance in northwest Africa wide climate extremes. These five factors explained totally 85.3% of all variance.

Table 5.3. Cumulative percentage of eigenvalues for NW Africa climate factors

Component	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.106	27.374	27.374	3.164	21.094	21.094
2	3.193	21.289	48.663	3.033	20.221	41.315
3	2.770	18.465	67.128	2.392	15.947	57.262
4	1.697	11.312	78.440	2.161	14.409	71.671
5	1.030	6.865	85.305	2.045	13.634	85.305

Table 5.4. Climate factors after factor analysis with climate extremes indices for NW Africa

	COMPONENT					
	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5	CUMULATI
SU	.062	-.137	.066	-.199	-.770	.660
SU41	-.032	.065	.611	.512	.167	.668
TX90P	-.048	-.110	.965	.029	-.110	.958
WSDI	-.052	-.111	.964	.024	-.106	.955
R75P	.323	.847	-.152	-.002	-.110	.858
R95P	.019	.775	.062	.253	.403	.832
R10MM	.965	.110	-.056	-.024	.114	.960
R20MM	.896	.333	-.019	.041	.127	.932
CWD	.650	-.290	-.063	.392	-.502	.916
DD	-.882	.344	.056	-.160	.185	.960
CDD	-.383	.260	.108	.595	-.469	.800
XX	.115	.120	.228	.818	.285	.831
SPS	.311	.445	-.115	-.085	.685	.784
RX5DAY	.079	.609	-.189	.558	.161	.750
SDII	-.348	.830	-.072	-.030	.339	.931

Unrotated component matrix and rotated solution for subregion 2 are not similar to one another. Rotated solution is shown here. Factor 1 in subregion 1 is divided into 2 factors (factor 1 and factor 2) by underlying reasons in subregion 2. The high loadings from factor 1 here, which explained 21.1% of all variance, are seemingly more characterized by frequency of rainfall extremes, while the high loadings in factor 2, which expained 20.2% of all variance, seemingly indicate the intensity rainfall extremes. Scores for factor 1(Figure 5.10) indicate a decreasing trend during the study period, but scores for factor 2 (Figure 5.10) is showing an upward trend.

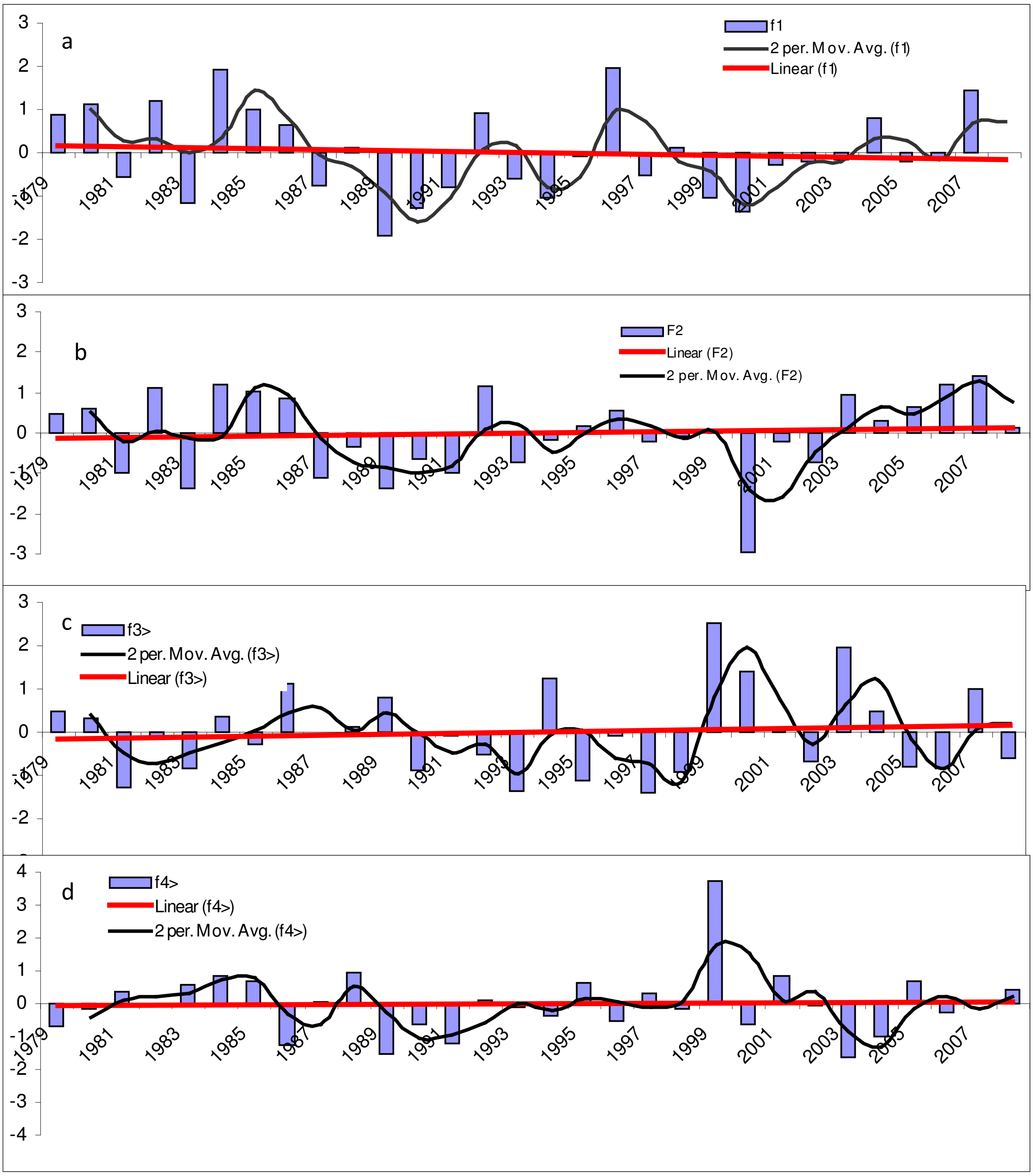


Figure 5.10. a) Changes of scores of factor 1 (frequency rainfall extremes) from 1979 to 2009 in NW Africa. b) Changes of scores of factor 2 (intensity rainfall extremes) from 1979 to 2009 in NW Africa. c) Changes of scores of factor 3 (hot extremes) from 1979 to 2009 in NW Africa. d) Changes of scores of factor 3 (summer dry extremes) from 1979 to 2009 in NW Africa

The third and fourth factor in subregion 2 is quite similar as factor 2 and 3 in subregion 1. The high loadings in factor 3, which explained 15.9% of all variance in subregion 2, indicate hot frequency, while the high loadings in factor 4, which explained 14.4 % of all variance in subregion 2, indicate summer dry extremes. Both of their scores are showing an increasing trend in the study period of 1979

– 2009. Finally, factor 5 explained 13.6% of all variance with high positive loading on SPS and high negative loading on SU. This may demonstrate a seasonal shift is the underlying reason for this factor.

Taking a closer look at the score changes for subregion 2 in figure 5.10, it is even harder to tell the future trends of these climate extreme factors in northwest Africa, since even larger variability can be found between years. More discussions about variability and trend of climate extremes are presented in Chapter 6. In addition, a negative relationship might exist between temperature extremes and precipitation extremes, which will be further proved in correlation analysis.

5.2.3. Subregion comparison

From factor analysis for subregion 1 and 2, all the changes of climate extremes indices in subregion 1 (Portugal) are more in concert than in subregion 2 (Northwest Africa), because 4 factors are extracted in Portugal but 5 factors are extracted in Northwest Africa. All the precipitation extremes are showing a decrease in Portugal, while in North Africa, rainfall intensity indicators (Factor 2) have an increase. This is consistent with previous results demonstrating that there is an increasing trend in annual precipitation sum in Northwest Africa.

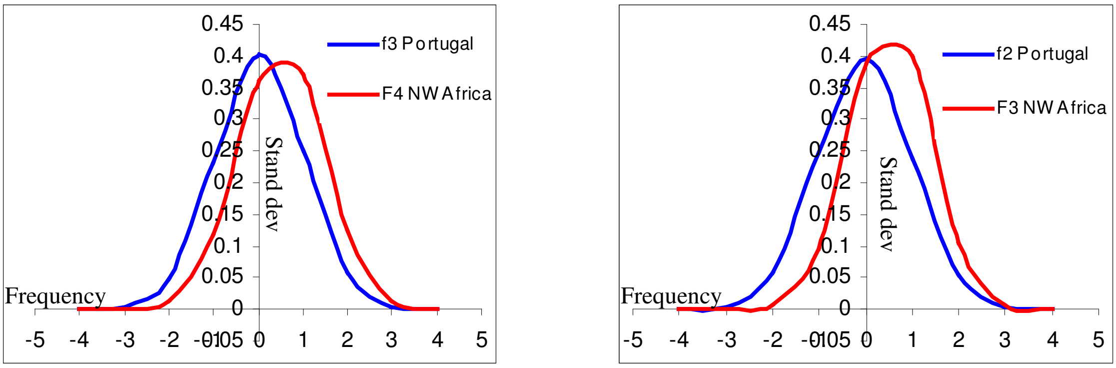


Figure 5.11. a) Normal distribution of summer dry extremes in Portugal and NW Africa. b) Normal distribution of hot extremes in Portugal and NW Africa.

Due to the similarity of the hot extremes factor and summer dry extremes factor in both regions, a normal distribution is plotted to compare their mean and standard deviation. One can see clearly from figure 5.11 that there are significantly more summer dry extremes and hot extremes in Northwest Africa than in Portugal over the period of 1979 to 2009. This indicates, in Northwest Africa, the situation of hot and dry is considerably more severe than in Portugal, which can result in more damage for cork oak stands as well as cork production.

5.3. Correlation between climate extremes and impacts

5.3.1. Case study subregion1, Portugal

Correlation between extremes and cork production

In general, there are no significant correlations between cork production and climate extremes in Portugal, with the only exception being the negative correlation (p= 0.024) between summer dry extremes (factor 3) and cork production, respectively (Table 5.5). And the negative relationship between cork production and summer dry extremes implicates that the increasing of drought events may bring damage to cork oak forest.

Table 5.5. Correlation between climate factors and cork production in Portugal *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

		Cork production	factor1	factor 2	factor 3	factor 4
Cork production	Pearson Correlation	1	.234	-.449	**-.560***	.033
	Sig. (2-tailed)		.350	.062	.024	.895

Though there is no statistically significant correlations between hot and rainfall extremes and cork production. However, what one can confirm from Table 5.5 is that positive relationships are detected between each other. It is easy to understand the positive relationship between rainfall extremes and cork production, since rain can be beneficial for the growth of cork oak in semi-arid Northwest Africa. But the reason for the positive relationship between hot extremes and cork production is maybe that the temperature range is still suitable for cork oak to survive.

Correlation between extremes and burned area

Table 5.6. Correlation between climate factors and burned area in Portugal. *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

		BA	Factor1	Factor2	Factor3	Factor4
BA	Pearson Correlation	1	.022	**.664****	**.561***	.182
	Sig. (2-tailed)		.935	.005	.024	.499

Statistics in bold and red color from Table 5.6 are showing the significant correlations between these parameters. An absolutely high statistically significant (p=0.005<0.01) positive correlation is found between burned area and hot extremes (factor 2), and summer dry extremes (factor3) are also found highly statistically significant (p=0.024 <0.05) positively correlated with burned area. Burned area has extremely low correlation (p= 0.935) with rainfall extremes, which can be viewed as no correlation. There is no statistically significant correlation among those climate factors themselves in Portugal climate extremes.

These correlations first indicate that burned area is largely related to climate extremes, especially hot extremes and summer dry extremes, which may provide natural preconditions for forest fires. Secondly, they indicate that the forest fires mostly occur in summer time rather than the other seasons, since hot and dry extremes usually occur in summer in the Mediterranean area. From this highly significant correlation between hot and dry extremes and burned area, we should pay more attention or be more careful towards cork oak stands when summer comes

Correlation between burned area and cork production

Table 5.7. Correlation between cork production and burned area in Portugal.

		BA	Cork production
BA	Pearson Correlation	1	.004
	Sig. (2-tailed)		.987
Cork production	Pearson Correlation	.004	1
	Sig. (2-tailed)	.987	

The statistics (Table 5.7) here are showing no statistically significant correlations between burned area and cork production in Portugal.

To sum up, in Portugal, the burned area still have considerable correlation with climate extremes even though intensive protection policy is carried out in Portugal forest stands. And the cork production is somehow related to the summer dry extremes. Because there is no correlation between burned area and cork production due to the high resistance to fire of cork oak itself, the summer dry extremes may affect cork production in terms of affecting their growth rather than contributing forest fires in Portugal.

5.3.2. Case study subregion 2, Northwest Africa

Correlation between extremes and cork production

Table 5.8. Correlation between cork production and burned area in NW Africa.*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

		CP	Factor1	Factor 2	Factor 3	Factor 4	Factor 5
CP	Pearson Correlation	1	.509*	.225	**-.531***	**-.683****	-.032
	Sig. (2-tailed)		.031	.369	**.023**	**.002**	.899

Better results (Table 5.8) were obtained from the correlation analysis between cork productions and climate extremes for Northwest Africa. There is absolutely highly statistically significant (p= 0.002) negative correlation between summer dry extremes, which is the same as in Portugal. In addition, high statistically significant (p=0.023) negative correlation was also found between hot extremes and cork production in Northwest Africa. A statistically significant (p= 0.031) positive correlation is detected between rainfall extremes and cork productions.

5.4. The future challenge

5.4.1. Cork oak stands distribution

The average maximum temperature and annual precipitation sum in the study period are still suitable for cork oak to survive at present. From annual precipitation sum plot in chapter 3, the green bands (400mm ~ 800mm) are continuously shifting to the northern part of the western Mediterranean region. And the average maximum temperature shows that the threshold temperature of 41°C for plants to survive also start to spread to the north and west parts, which shows the potential of the northwest movement of cork oak distribution. In other words, future scenarios seem to steer cork oak migration to higher latitudes where is not abundant today (Penuelas & Boada 2003). Moreover, the capacity of cork oak for migration cannot catch up with the rate of climate change and lead to local extinction, especially in fragmented landscapes, where the distance between original stands and new suitable habitats exceed natural migration distances (jump and Penuelas 2005).

5.4.2. Cork production prediction

Table 5.9 shows that, the multiple regression model provides better predictions for Portugal's cork production, while in Northwest Africa, simple linear regression models have higher statistically significant results for cork production.

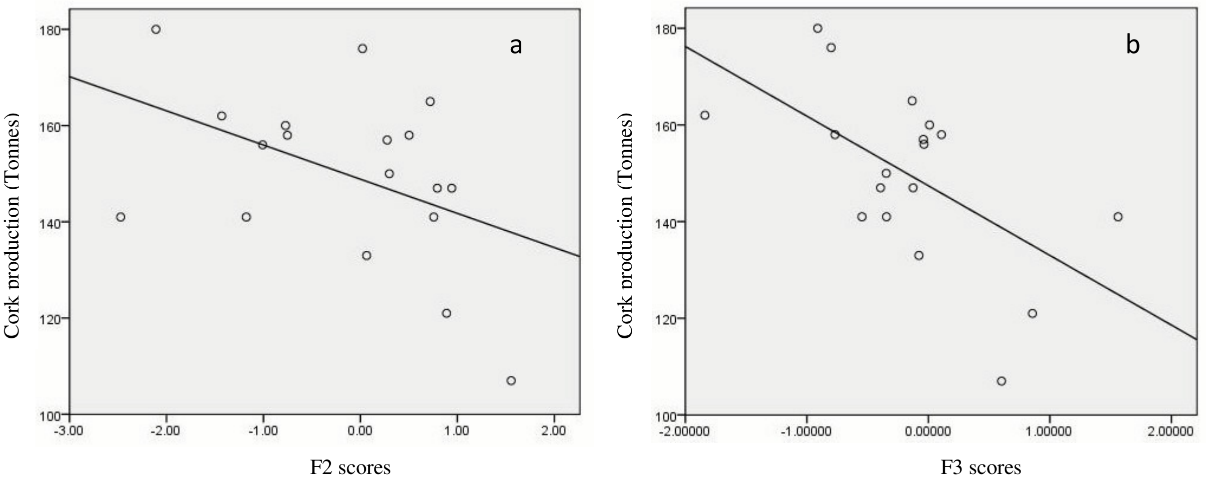


Figure 5.12 a) regression plot between Cork production and hot extremes (F2) in Portugal.
b) regression plot between Cork production and summer dry extremes (F3) in Portugal

For Portugal, it is particularly useful to build a multiple regression model (model 1), as R^2 equals to 0.549, which means the quality of the model is satisfactory. Table 5.9 shows the coefficients of all the climate factors in this model. One can see from the table that, factor 2 ($p= 0.041$) and factor 3 ($p=0.013$) have high statistically significance in this model. This indicates that cork production has a cause and effect relationship with hot extremes and dry extremes. As figure 5.12 shows above, cork production has a negative affection when hot extremes and dry extremes lead to a positive phase. And summer dry extremes with larger slope have greater impacts on cork production than hot extremes do. In this case, the model can be described as:

$$CP= 146.535 + (-6.715)\ F2 + (-13.277)\ F3\ (tonnes)$$

Where *CP* is cork production, *F2* is hot extremes in Portugal; *F3* is summer dry extremes in Portugal.

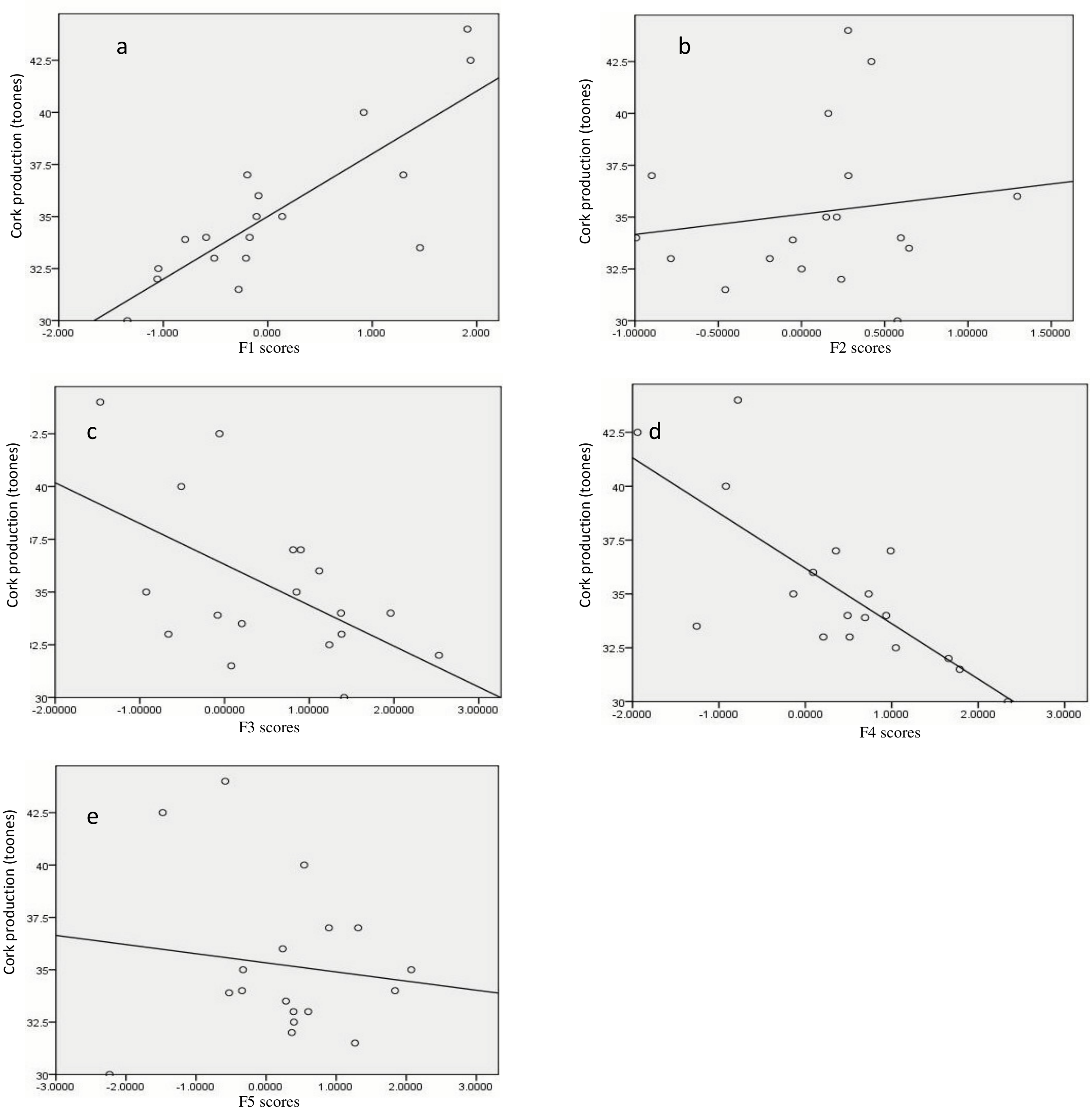


Figure 5.13. a) regression plot between Cork production and rainfall frequency extremes (f1) in NW Africa b) regression plot between Cork production and rainfall intensity extremes (f2 in NW Africa. c) regression plot between Cork production and hot extremes (f3) in NW Africa. d) regression plot between Cork production and summer dry extremes (f4) in NW Africa. e)regression plot between Cork production and f5 in NW Africa.

As figure 5.13 and Table 5.9 show, factor 1, factor 3 and factor 4 have a highly statistically significant (p=0.028, p = 0.033, p=0.002) cause and effect relationship with cork production in multiple regression model of Northwest Africa, while factor 2 and factor 5 show no statistically significant (p= 0.442, p=0.416) relationships.

In this model, R² equals 0.683, which express an efficient fit with small standard error of estimate value. The positive cause and effect relationship with cork production demonstrates that precipitation is good for the growth of cork oak located in arid or semi-arid regions such as Northwest Africa. The same as in Portugal, hot and summer dry extremes play a negative role in affecting cork production in Northwest Africa. In addition, summer dry extremes have the strongest influence, which can be seen from its highest slope in figure 6.2. In this model, their relationships can be described as:

CP= 35.587+ *(2.137) F1 + (-1.821) F3 +(-2.598) F4 (tonnes)*

Where *CP* is cork production, *F1* is rainfall extremes in NW Africa. *F3* is hot extremes in NW Africa. *F4* is summer dry extremes in NW Africa.

5.4.3. Burned area

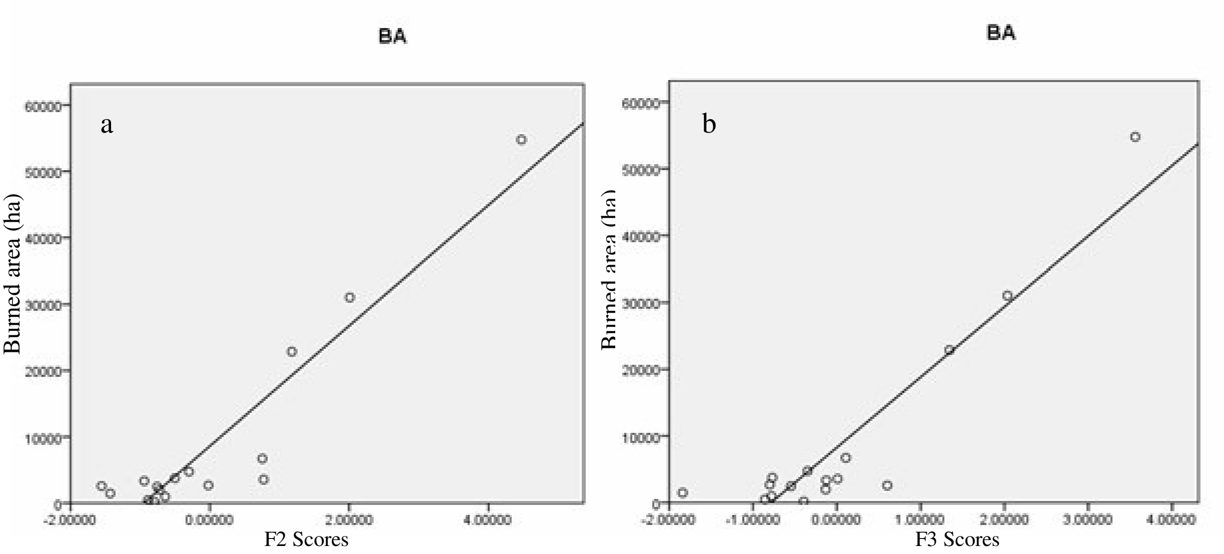


Figure 5.14. a) Partial regression plot between burned area and hot extremes (f2) in Portugal. b) Partial regression plot between burned area and summer dry extremes (f3) in Portugal

For predicting burned area in Portugal, a multiple regression model is more effective than the simple linear model (see Table 5.9). Regression plots (Figure 5.14) above show a fairly good quality regression model (ANOVA P= 0.000, R² = 0.711) is built between burned area and climate factors (hot extremes and summer dry extremes) in Portugal. And the model can be shown as equation:

BA = 6577.69 + 9984.99 f3 + 8392.53f2 (ha)

Where *BA* is burned area, *F2* is hot extremes in Portugal; *F3* is summer dry extremes in Portugal.

Table 5.9. Regression models for adjusted cork production and burned area by using climate factors as independent variables.

DEPENDENT VARIABLES	**Mult**					**Simple linear regression**				
	R²	ANOVA	Independent variables	Coefficients		R²	ANOVA	Independent variables	Coefficients	
				B	sig				B	sig
Cork production in Portugal	0.549	0.026	(Constant)	146.535	.000	0.055	0.350	(Constant)	149.957	.000
			f1	2.793	.374			f1	3.775	.350
			f2	-6.715	.041	0.201	0.062	(Constant)	148.853	.000
								f2	-7.103	.062
			f3	-13.277	.013	0.354	0.010	(Constant)	147.417	.000
								f3	-14.411	.010
			f4	.109	.974	0.001	0.895	(Constant)	150.164	.000
								f4	.575	.895
Cork production in NW Africa	0.683	0.025	(Constant)	35.587	.000	0.669	0.000	(Constant)	35.004	.000
			f1	2.137	.028			f1	3.01	0.041
			f2	0.3700	.442	0.051	0.369	(Constant)	35.196	.000
								f2	1.604	.369
			f3	-1.821	.033	0.302	0.018	(Constant)	36.308	.000
								f3	-1.936	0.69
			f4	-2.598	.002	0.567	0.001	(Constant)	36.186	.000
								f4	-2.567	0.01
			f5	.666	.416	0.032	0.899	(Constant)	35.360	.000
								f5	-.124	.899
Burned area in Portugal	0.711	0.000	(Constant)	8577.69	.001	0.314	0.024	(Constant)	9249.83	.011
			f3	9984.99	.004			f3	10748.8	.024
			f2	8392.53	.001	0.441	0.005	(Constant)	7129.12	.024
								f2	8829.86	.005

6. Discussions

6.1. Explain the variance in extremes

For the whole Mediterranean area, the results obtained from both interpolation and factor scores show a general increase in temperature extremes and a general decrease in precipitation extremes. In particular, the changes of temperature extremes are quite homogeneous over the study area and period due to global warming trends. However, for precipitation extremes, there is large variability over temporal and spatial, such as the increase of annual precipitation sum in North Africa and some parts of Spain, and the rising of rainfall frequency extremes in northwest Africa.

There are several variables that could explain the variance of rainfall extremes in the western Mediterranean area. As is often discussed, the Mediterranean climate is influenced by teleconnections with some major climate variability modes.

6.1.1. ENSO

The relationship between El Niño–Southern Oscillation (ENSO) and Western Mediterranean precipitation is an opposite signs in Autumn and in Spring (as figure 6.1 shows below), and also it varies at the multidecadal time scale (Rodo et al, 1997). This can explain the negative values and positive values for rainfall extremes in every 10 years (see Figure 5.8 & 5.10). Large negative precipitation values indicate periods of El Nino while large positive values indicate periods of La Nina spatially, coherent correlation patterns are found within western Mediterranean region in all seasons

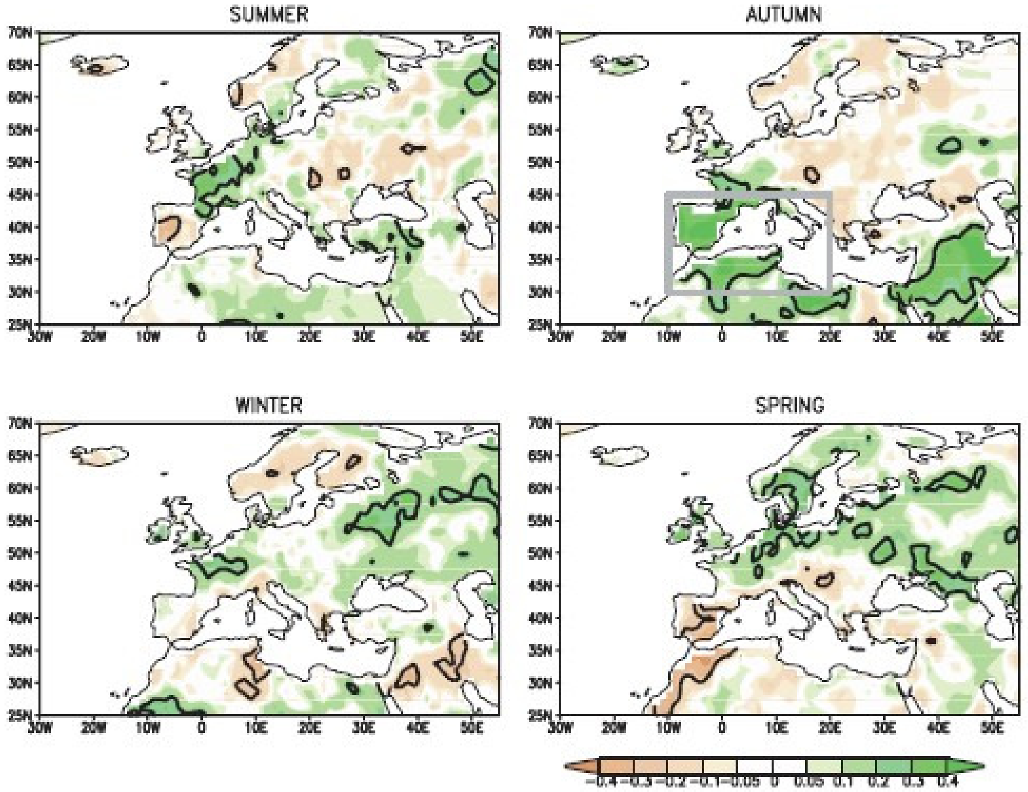


Figure 6.1. Seasonal correlation of rainfall in Europe-Mideterranean region and the ENSO index for the period 1948-1996. correlations coeficients enclosed by contour are statistically significant at the 95% level. The grey box defines the region considered to compute western Mediterranean area-averages. Source: Mariotti et al 2002.

except summer (see figure 6.1). Moreover, the correlation between ENSO and rainfall in the western Mediterranean area has increased towards the end of the present century (Park 2004). A negative correlation in Portugal could erase quite a bit water stress there. Temporally, a study by Mariotti concluded that there is a rainfall reduction in the Mediterranean area according to the analysis of the large-scale climatic phenomenon ENSO (Mariotti et al, 2002).

6.1.2. NAO

When the positive phase of North Atlantic Oscillation (NAO) occurs, negative anomolies in precipitation result (Hurrel et al 2003). The typical Mediterranean climate of dry summer and wet winter is shaped mainly by NAO, especially the winter. NAO has been modelled likely influencing the observed change of the frequency of above 90th percentile winter precipitation between the 1960s and 1990s over Europe and extratropical North Africa (Adam et al. 2007). But the influence of NAO in Mediterranean area is not the same over temporal and spatial scales, because there are reports showing that any correlations of precipitation amounts with large-scaled index including NAO and ENSO should properly consider stations (portugal or NW Africa), locations (costal or inland) and response to the precipitation types (frequency or intensity) (Millan et al.2005). In this case, different precipitation extremes change over temporal and spatial scales in this study is offers further proof for this conculusion.

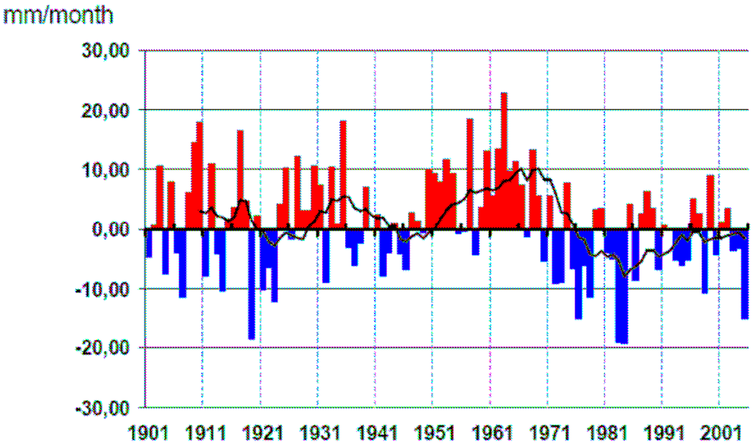


Figure 6.2. Mean precipitations over the western Mediterranean domain (GHCN NCDC dataset). Source: Mediterranean-HyMEX workshop, 9-11 Jan. 2007

Other reasons, such as the northerly replacement of the Mediterranean front can also ensure a decrease in the mediterranean area, especially in southern europe (Quereda et al. 1996). And African moonsoons which can transport moisture in hot summers may contribute to the increasing of Northwest Africa's precipitation.

The selection of the study period can be an additional reason for the precipitation increase in some parts of western Mediterranean area. A graph (Figure 6.2) above which was generated by GHCN (Global Historical Climate Work) NCDC (National Climate Data Center) datasets shows a decline trend over the period from 1901 to 2001. however, the period of 1981 – 2001 has noticable trend of increased summer precipitation in Western Mediterranean domain. Besides, most literature shows that changes in precipitation are more difficult to identify than temperature changes, and also no clear trends of declining rainfall in North Afrcia have been studied (DePauw 1999; Yacoubi et al. 1998).

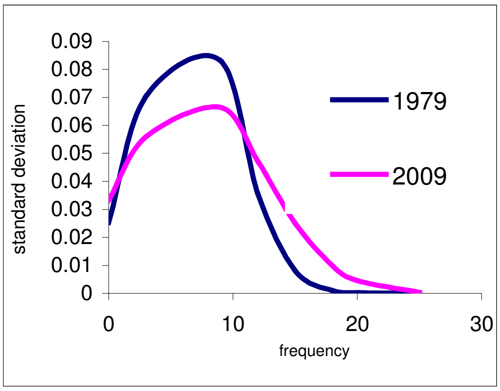


Figure 6.3. Distribution of rainfall in 1979 and 2009

It is easy to understand the increase of summer dry extremes with decreasing rainfall extremes in portugal. The rising of summer dry extremes is still happened when increasing trends of part of rainfall extremes in NW Africa are found, this phenomenon probably contributed by the change of rainfall distribution, as figure 6.3 showed on the right. There was more precipitation in 2009, but also more days with no precipitation.

6.2. Climate extremes and cork oak

As the results in Chapter 5 demonstrate, cork prodution in portugal is somehow dependent on hot extremes and summer dry extremes, but production has nothing to do with rainfall extremes. From dendrochoronological techniques used for studying cork oak, the growth of cork oak shows strong correlations with rainfall instead of temperature (Costa et al 200). However, this is not the case when it comes to extremes, because when precipitation levels are gennerally suitable for cork oak to survive, the temperature and dry extremes rather than rainfall extremes have more pronounced effects, as previously discussed in section 2.2, high temperature could induce carbon balance change and extend the active period of pethogen on them (Aronson et al. 2009). In other words, they can bring long-term effects as well as instant effects to cork oak in both landscape and production. But the situation in Northwest Africa is different in that the annual precipitation sum is often lower than ideal precipitation conditions for cork oak to grow well. So the higer intensity of precipitation would promote efficient conditions for growth of local cork oak.

For Portugal and Northwest Africa, cork production shows large correlations with, and dependencies on, summer dry extremes. What makes summer dry extremes play such an important role in affecting cork production? Explanations can be found in section 2.2 and all these results suggest that when hot summer comes, the combination of water deficits with high light intensity and high temperature as well as high evaporation rate can make life difficult for plants (Pereira et al. 2004).

Climate extremes seemingly have large effects on cork oak in this study. However, it is interesting to know that in reality if it is the general climate that covaries with the extremes or extremes themselves affect the production. To clarify this, covariability is checked between the factors that got from factor analysis and two parameters that used to describe a general climate of study area in chapter 5.1 and 5.2. Large correlations ($p=0.000$, $p=0.029$) are found between rainfall extremes and annual precipitation sum during the period of 1979 to 2009 in both Portugal and NW Africa. Hot extremes have no significant correlation with annual maximum temperature in study area. Summer dry extremes also showed nothing to do with either annual precipitation sum or annual maximum temperature during the study period. This means that hot and dry extremes do have such large influence on growth and production as it seems.

The positive trends of heat and dry extremes from this study, though not significant due to the large variability, coincide with the results from the KNMI (Koninklijk Netherlands Meteirilogisch Instituut) regional climate model based on A1B senerio. The majority of the Mediterranean regions will frequently experience temperatures of up or greater than 40°C and dry spells are approaching 90 days due to the persistent absence of rainfall by the end of 21 century (Konstantia 2008). Therefore, although cork oak tolerates the present Mediterranean climate conditions, it is negatively affected by extremes of hot and dry weather episodes, which may become more and more common in the future (Ulbrich et al. 2006). Even at present, new planting is being undertaken (in Portugal), cork oak will not face extinction, but some small mosaic of cork oak stands are disappearing.

6.3. Forest fire

From the special case in Portugal, burned area is found to distinctly positive depending on hot and dry extremes in the summer. Although it is reported that only 20% or even less percentage of forest fires are natural, with the remaining percentage of fires contributed by human actions (European forest fire report 2007). Furthermore, forest fires tend to happen in summer. This indicates that dry and hot climate extremes are kind of preconditions for creating forest fires, whether natural or human-caused. In other words, wild fires can be directly or indirectly caused by hot and dry climate extremes. However, in the analyzing of the correlation between burned area and cork production, nothing is found. There are three reasons which may contribute to this result: first, cork oak has exceptional resistance to wildfire, because it is the only species in Europe that can sprout above the ground after fire (Pausas 1997). Second, as discussed, cork oak production is weakly related to climate extremes in Portugal, thus, human influence can have a more important role in affecting cork production. Thus, the unrelated correlation between burned area and cork production can further prove this view. Third, the frequency and intensity of forest fire varied from location to location. It is hard to find relations in a general whole region. However, the surprisingly strong positive linear relationship between burned area and climate extremes, which means greatly increasing wildfire hazard (Perira and Santons 2003; Pausas 2004) that generated by gradually longer rainless period combining with hotter weather (Paredes et al. 2006), will be a big threat for cork oak stands in the future (Silva and Catry 2006).

6.4. Other causes

No certain factor is found to be the main factor for influencing cork oak because of their complex relationships (Aronson et al.2009). Human influence is another big factor as well as climate change that affecting cork oak. The way people think and act in different Mediterranean cultures can result in different consequences for cork oak. Poor forest management policies and measures can raise the mortality of cork oak. Overexploitation of cork oak forest can result in decline (Aronson et al. 2009). An incorrect method of cork harvest such as separating cork and bark from wrong layer rather than phellogen, not being able to harvest before summer comes in one year can both push cork oaks to death (Fialho et al 2000). Replacing use of stoppers made from cork by other materials such as plastic can shrink the cork trade market (WWF Market Analysis Report 2009). Human imprudence and climate extremes can bring big damage to cork oak. However, the worst situation is the combination of these two big factors. For example, severe summer dry extremes occurred after the bark-stripping can become a serious test for cork oak tree survival (Pausas 1997). Increasing dry extremes in overgrazed land can result in permanent destroying of the soil that cork oak rely on. This further affects the survival of cork oak.

There is not enough evidence to conclude here that if people in Northwest Africa can cherish cork oak or provide more attention to the development of cork oak as people do in Portugal, that the situation can be eventually improved, but more benefits can be obtained from focusing on the four values (ecosystem, environmental, economic, social) of cork oak.

6.5. Other impacts

6.5.1. Ecological consequences

Due to its outstanding characteristics, cork oak plays a key role in the ecological communities where they are located. Regardless of the behavior of cork oak or the rest species has had the change, they can both result in effects on ecosystem level (Terradas 1999). As mentioned before, rising hot extremes can induce the shifts in the phenology of cork oak by influencing the growing season, and this is also the case for the other organisms in the ecosystem. In this situation, changes of community composition and food web changes might occur. Moreover, warmer climate conditions can raise the rate of pathogen attacks, which brings high disease risk to the whole ecosystem.

6.5.2. Economic and social consequences

The straightforward analysis of the economic and social consequences of climate extremes in the western Mediterranean region's cork oak has not yet been attempted, since it is hard to identify with a lack of available data and too many uncertainties. The different kinds of economic and social consequences can be estimated as follows:

1. As the results show in previous chapters, rising climate extremes can result in the reduction of cork production owing to the loss of trees at different ages or extending the 9- year harvest cycle. This may cause the instant loss of income on cork trade for each cork oak country.
2. The disappearance of cork oak stands that in a small scale may lead to unemployment for the local people, since, in the different stage of the production chain, cork oak forest are a sector responsible for thousands of jobs
3. For the damaged cork oaks affected by climate extremes, costs have to be paid for recovery and rehabilitation. And quantities of work also need to be done for them.

6.6. Uncertainties and limitations

6.6.1. Distribution of stations

Due to the limitation of data availability from ECA datasets, more meteorological stations are distributed in southwest Europe than northwest Africa. Thus, greater error can be generated through interpolation in northwest Africa. In addition, there are more stations with daily maximum temperature distributed in the whole study area than stations with daily precipitation data, which can contribute a different accuracy for the spatial analysis. According to the report written by Klein Tank 2009 there are two uncertainties existing in ECA daily datasets: i), between countries and even within countries between stations, the observation time for maximum temperature or precipitation amounts sometimes may have differences. ii), the same observation rules sometimes cannot be kept all the times within a series. These may bring about some problems for data analysis

6.6.2. Data and extreme indices

Over the period 1960 – 1990, the data had the best quality in ECA datasets (Klein Tank 2009), yet data quality for the study period of 1979 – 2009 is of lesser quality, especially the stations located in the Northwest Africa. More suspect and missing values have to be processed before they are analyzed. It is possible to have more rain days after the pchip interpolation, which used for minimizing the missing data. This might be another reason contributing to the increasing trend of rainfall extremes in Northwest Africa. Cork production data used in the study might relate to industrial production instead of biological production, which is hard to confirm. If it is industrial data, economic causes may play a larger role in affecting cork production.

15 climate indices are derived from daily precipitation data and daily maximum temperature data， as it has mentioned in section 4.4, correlation matrix is needed to build before operating factor analysis. The different dependence of all the indices could result in big differences in corresponding results. Correlation matrix of chosen indices for both Portugal and Northwest Africa are showed in Appendix CII. Statistical significant correlations are found within same datasets, which coinciding with the results from factor analysis. moreover, 15 indices may not cover all the possible factors that affecting

the growth of cork oak as well as cork production. For example, cold days or minimum temperature may shorter the growing season. Thus, slow the cork oak growth.

6.6.3. Ordinary Kriging

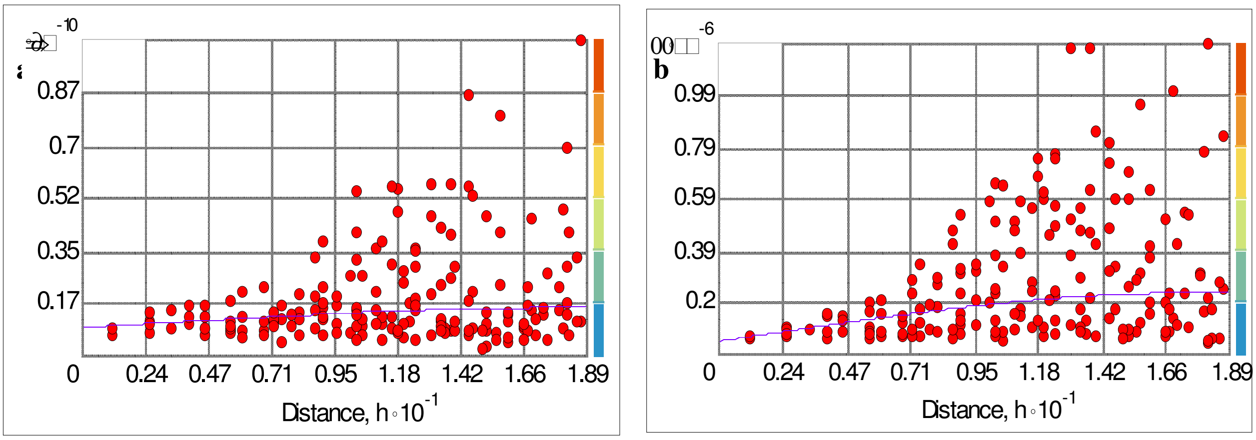


Figure 6.4 a) semivariogram of average annual precipitation. b) semivariogram of average max temperature. Red dots are coordinates of stations. Blue line is trendline

In this study of regionalized interpolation, ordinary kriging rather than universal kriging is used. Because there is no obvious trend that can be seen in figure 6.4a & b., it could be that small errors could be contributed by ordinary kriging without removing trends before interpolation.

6.6.4. Factor analysis

Factor analysis can help us find out the underlying temporal variance for those indices. It is the best method for dividing indices into groups. Since, generally, circumstances are contributed to by multiple factors rather than one. However, dividing all the climate extreme factors into several big groups means, to some extent, losing separately direct information between climate indices and cork production. The coefficients of correlation analysis might be different in separate analysis, either increased or reduced. In addition, the factors are only extractions of all the variables, which do not represent the 100 percent of original data. Moreover, factor scores are the estimated values that are generated from common factor models. They are not observed value as original data. When using them as variables to correlate or to build regression models with other observed data, it may contain errors. Another problem of the factor analysis in the study is the invisibility of weaker underlying factors, which is caused by stronger factor of the different datasets themselves. The author would like to see if there is an underlying factor affects largest extremes and moderate extremes, which has been mentioned in section 3.3.2. However, no relevant results could be seen. The problem could be solved by doing factor analysis for one dataset in one time.

6.6.5. Regression models

The accuracy of prediction enabled by using linear regression models is affected both by the quality of training data and the model itself. Errors can be generated by even using data free of errors, when the latter data points to be predicted cannot follow the generated linear trend line of earlier data point, imperfect data may tilt the regression line, which in turn affects the accuracy of prediction.

Due to considerable uncertainties within society, economy, environment and humanity, the validity of regression models for cork production in the study would go through suspicions. As a result, there would not be, either less or more, 19.992 (tonnes)(see Equation 5.1) of cork production and 8377.52(ha) (see Equation 5,4) of burned area reduced and increased by raising up 1 unit of both hot extremes and summer dry extremes in the future. However, the directions of their relationship are far more useful for future forest management decisions.

6.7. Further study

From this study, one can derive a general overview of how climate extremes affect cork oak in western Mediterranean regions as well as different regional scales over the period of 1979 – 2007. But the local studies are hard to carry out due to the limitation of getting higher resolution data of cork oak production and burned area. It will be interesting to have a look at very local impacts on cork oak of climate extremes changes such as making a comparison between cork oak forests located in coastal area and inland areas; or between higher altitude and lower altitude areas.

It is also very important to study the measures and practices of cork oak forest management in the future study when facing climate changes, since most policies are solutions for human imprudence at present. New management practices will not only concern the simply restoration, but also promoting the natural regeneration, selecting the droughts-tolerant genotype and assisting finding a new favorable environment for them to live (Lindner M, 2000). And how to put these thoughts into reality is a crucial problem for us to study in the following decades.

7. Conclusions

In this investigation, interpolation is used to plot the overview map of the distribution of annual maximum temperature and annual precipitation sum. Factor analysis is applied to find out the underlying temporal variance for those indices as well as dividing them into proper groups. Correlation analysis is adopted to find the relationship between those climate factors and cork production as well as burned area. A regression model is built to make a prediction of cork production by view those climate factors as dependent variables.

Conclusions from this paper can be concluded as follows:

1. There is the potential of cork oak distribution to move northwest in the future. Because generally, increasing maximum temperature and decreasing annual precipitation is shifting the ideal climate conditions (annual precipitation ranges from 400mm – 800 mm, maximum temperature lower than 41°C) for cork oak growth to the northwest.
2. There are more climate extremes in the Northwest Africa than in southwest Europe, especially hot and summer dry extremes. And large variability exists in Northwest Africa’s rainfall extremes, which might contribute by complex climate variability modes.
3. Cork production has considerably strong correlations with climate extremes in Northwest Africa, but relatively weak correlations are found in Portugal, which indicates that climate extremes, especially summer dry extremes can have really close relationships with cork production in the place where there is a lack of positive human influences. Moreover, as discussed in chapter 6.2, hot and dry extremes affect cork oak without covarying with general climate. However, as soon as human intervention begins to show its power, this connection between climate extremes and cork production is no longer evident. In this situation, if people in Northwest Africa still take this for granted, cork might not bring any economic value for them due to the rapid change of climate.
4. No correlations are found between burned area and cork production in Portugal from this study. This may be evidence that human action plays a larger role in affecting Portugal’s cork production. Nevertheless, forest fires are still serious issues for cork oak in the future, since they are largely correlated with climate extremes.
5. When facing future climate change, cork oak stands in NW Africa are more fragile than ones in Portugal under circumstances of more dry extremes. As an individual effect of climate extremes, threats are waiting for cork oak in the future with no doubts. However, Too many uncertainties exist for us to know exactly how cork oak will change; since active cork market can generate the production, humans can give more efficient protections.

Climate extremes, though perhaps not the most important factor, do play a vital role in affecting cork oak. And the delayed reactions of cork oak trees may not catch up with the rapid rate of climate change; proper practices for forest management can still be feasible for concerning our collective future.

Hoping this paper can help promoting the best practices for cork oak in the future.

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Appendix AI: Locations of stations

id	Station	country	LatDD	LongDD
753	AGEN	FR	44.1800	0.6000
755	EMBRUN	FR	44.5600	6.5000
756	TARBES	FR	43.1867	-0.0050
757	NICE	FR	43.6500	7.2000
758	BASTIA	FR	42.5500	9.4800
786	MONTELIMAR	FR	44.5817	4.7381
788	NIMES	FR	43.8581	4.4067
1664	ALGHERO/FERTILIA	IT	40.6700	8.2797
1666	TORINO/BRIC DELLA CR	IT	45.0300	7.7300
1709	TORINO CASELLE	IT	45.2167	7.6500
1712	MILANO MALPENSA	IT	45.6167	8.7331
1725	MONDOVI	IT	44.3831	7.8167
1727	ALBENGA	IT	44.0500	8.1167
1742	ALGHERO	IT	40.6331	8.2831
1748	DECIMOMANNU	IT	39.3500	8.9667
2107	GUARDIAVECCHIA	IT	41.2200	9.4000
2109	CAPO BELLAVISTA	IT	39.9300	9.7200
278	ALGER-DAR EL BEIDA	DZ	36.7167	3.2500
2285	ANNABA	DZ	36.8300	7.8200
2286	BEJAIA	DZ	36.7200	5.0700
2287	CONSTANTINE	DZ	36.2800	6.6200
2288	TEBESSA	DZ	35.4797	8.1300
2289	ORAN	DZ	35.6300	-0.6000
2164	TABARKA	TN	36.9500	8.7500
2165	BIZERTE	TN	37.2500	9.8000
2168	JENDOUBA	TN	36.4800	8.8000
2171	GAFSA	TN	34.4200	8.8200
2173	TOZEUR	TN	33.9200	8.1000
2144	TANGER	MA	35.7297	-5.9000
2145	AL HOCEIMA	MA	35.1800	-3.8500
2146	OUJDA	MA	34.7800	-1.9300
2148	TAZA	MA	34.2200	-4.0000
2150	FES-SAIS	MA	33.9300	-4.9800
2151	MEKNES	MA	33.8800	-5.5300
2152	CASABLANCA	MA	33.5700	-7.6700
2153	NOUASSEUR	MA	33.3697	-7.5800
211	BEJA	PT	38.0167	-7.8667
212	BRAGANCA	PT	41.8000	-6.7331
213	COIMBRA	PT	40.2000	-8.4167
214	LISBOA GEOFISICA	PT	38.7167	-9.1500
215	PORTO	PT	41.1331	-8.6000
216	TAVIRA	PT	37.1167	-7.6500
295	AGUIAR DA BEIRA	PT	40.8100	-7.5400
296	ALMEIDINHA	PT	40.6	-7.13
1062	PEGOES	PT	38.6300	-8.6500
1063	ALVEGA	PT	39.4600	-8.0397
1064	MORA	PT	38.9300	-8.1600
1065	PENHAS DOURADAS	PT	40.4100	-7.5500
1066	PORTALEGRE	PT	39.2800	-7.4100
229	BADAJOZ TALAVERA	ES	38.8831	-6.8292
230	MADRID - RETIRO	ES	40.4108	-3.6781

232	NAVACERRADA	ES	40.7806	-4.0103
233	SALAMANCA AEROPUERTO	ES	40.9456	-5.4958
234	SAN SEBASTIAN - IGUELDO	ES	43.3075	-2.0392
236	TORTOSA - OBSERVATORIO DEL EBRO	ES	40.8206	0.4914
237	VALENCIA	ES	39.4806	-0.3664
238	ZARAGOZA AEROPUERTO	ES	41.6617	-1.0081
414	BURGOS-VILLAFRIA	ES	42.3600	-3.7200
416	CIUDAD-REAL	ES	38.9831	-3.9167
419	HUESCA	ES	42.0831	-0.3331
420	LA CORUNA	ES	43.3667	-8.4167
421	MURCIA	ES	38.0000	-1.1667
422	PAMPLONA	ES	42.7667	-1.6331
423	SEVILLA	ES	37.4167	-5.9000
425	VALLADOLID	ES	41.6500	-4.7667
412	ALICANTE	ES	38.3667	-0.4942
1389	MELILLA	ES	35.2800	-2.9500
1392	SANTANDER CENTRO	ES	43.4500	-3.8200
1393	BILBAO AEROPUERTO	ES	43.2800	-2.9000
1394	SANTIAGO COMPOSTEL	ES	42.8800	-8.4200
1395	VIGO PEINADOR	ES	42.2200	-8.6197
1397	LEON VIRGEN DEL CAMINO	ES	42.5800	-5.6300
1398	LOGRONO-AGONCILLO	ES	42.4500	-2.3200
1399	ZAMORA	ES	41.5200	-5.7300
1401	REUS BASE AEREA	ES	41.1300	1.1500
1402	PRAT DE LLOBREGAT	ES	41.2800	2.0697
1404	MURCIA/SAN JAVIER	ES	37.7800	-0.8000
1405	JEREZ DE LA FRONTERA	ES	36.7300	-6.0500
2969	BARCELONA/AEROPUERTO	ES	41.2800	2.0694

Appendix AII: Scripts of interpolating datasets

```
function InterpolationForPortugal()
    close all;
    matrix = xlsread('TX_STAID000212.xls');
    interpMatrix = [];
    [row, col] = size(matrix);

    disp(matrix(1, :));
    fprintf('row = %d, col = %d\n', row, col);

    for i = 1:row
        if (matrix(i, 4) ~= 0)
            matrix(i, 3) = NaN;
        end
    end

    day = 1:row;
    interpMatrix = [interpMatrix interp1(day, matrix(:, 3), day, 'pchip')];
    matrix(:, 3) = round(interpMatrix);

    d = {'SOUID', 'DATE', 'TX', 'Q_TX'};
    xlswrite('O:\JING THESIS\PORTUGAL\TX_STAID0002121NTERPOLATED.xls', d,
'Sheet1', 'A1');
```

```
    xlswrite('O:\JING THESIS\PORTUGAL\TX_STAID0002121NTERPOLATED.xls',
matrix, 'Sheet1', 'A2');
end
```

Appendix BI: Scripts of abstracting indices of extremes

An example from Morocco 2160

```
function IndexGenerator()
    close all;
    [ndata, headertext] = xlsread('P_PROCESSMorroco2160.xls');

    [row, col] = size(ndata);

    SUIndex = SU(ndata);
    DDIndex = DD(ndata);
    TXxIndex = TXx(ndata);
    CWDIndex = CWD(ndata);
    CDDIndex = CDD(ndata);
    SPSIndex = SPS(ndata);
    SDIIIndex = SDII(ndata);
    R95pIndex = R95p(ndata);
    RX5daysIndex = RX5days(ndata);
    WSDIIndex = WSDI(ndata);
    SU41Index = SU41(ndata);
    TX90pIndex = TX90p(ndata);
    R75pIndex = R75p(ndata);
    R10mmIndex = R10mm(ndata);
    R20mmIndex = R20mm(ndata);

    year = ndata(1, 4):ndata(row, 4);

    outputMatrix = [year' SUIndex SU41Index TX90pIndex WSDIIndex R75pIndex
R95pIndex R10mmIndex R20mmIndex ...
                    CWDIndex DDIndex CDDIndex (TXxIndex .* 0.1)
(SPSIndex .* 0.1) ...
                    (RX5daysIndex .* 0.1) (SDIIIndex .* 0.1)];


    d = {'YEAR', 'SU', 'SU41', 'TX90p', 'WSDI', 'R75p', 'R95p', 'R10mm',
'R20mm',...
        'CWD', 'DD', 'CDD', 'TXx', 'SPS', 'RX5day', 'SDII'};
    xlswrite('MORROCO2160.xls', d, 'Sheet1', 'A1');

    xlswrite('MORROCO2160.xls', outputMatrix, 'Sheet1', 'A2');
end
```

CDD extraction

```
function [output] = CDD(ndata)
    close all;

    [row, col] = size(ndata);

    vector = zeros(ndata(row, 4) - ndata(1, 4) + 1, 1);

    for i = ndata(1, 4):ndata(row, 4)
```

```
        tempValue = 0;
        for j = 1:numel(ndata(:, 4))

            if (ndata(j, 4) == i && ndata(j, 3) < 1)
                tempValue = tempValue + 1;
            elseif (ndata(j, 4) == i && ndata(j, 3) >= 1)
                if (vector(i - ndata(1, 4) + 1) < tempValue)
                    vector(i - ndata(1, 4) + 1) = tempValue;
                end
                tempValue = 0;
            else

            end
        end
    end
    output = vector;
end
```

CWD extraction

```
function [output] = CWD(ndata)
    close all;

    [row, col] = size(ndata);

    vector = zeros(ndata(row, 4) - ndata(1, 4) + 1, 1);

    for i = ndata(1, 4):ndata(row, 4)
        tempValue = 0;
        for j = 1:numel(ndata(:, 4))

            if (ndata(j, 4) == i && ndata(j, 3) >= 1)
                tempValue = tempValue + 1;
            elseif (ndata(j, 4) == i && ndata(j, 3) < 1)
                if (vector(i - ndata(1, 4) + 1) < tempValue)
                    vector(i - ndata(1, 4) + 1) = tempValue;
                end
                tempValue = 0;
            else

            end
        end
    end
    output = vector;
end
```

DD extraction

```
function [output] = DD(ndata)
    close all;

    [row, col] = size(ndata);

    vector = zeros(ndata(row, 4) - ndata(1, 4) + 1, 1);

    for i = ndata(1, 4):ndata(row, 4)
        for j = 1:numel(ndata(:, 4))
            if (ndata(j, 4) == i && ndata(j, 3) < 1)
```

```
                vector(i - ndata(1, 4) + 1) = vector(i - ndata(1, 4) + 1) +
1;
            end
        end
    end
    output = vector;
end
```

R10mm extraction

```
function [output] = R10mm(ndata)
    close all;

    [row, col] = size(ndata);

    vector = zeros(ndata(row, 4) - ndata(1, 4) + 1, 1);

    for i = ndata(1, 4):ndata(row, 4)
        for j = 1:numel(ndata(:, 4))
            if (ndata(j, 4) == i && ndata(j, 3) >= 10)
                vector(i - ndata(1, 4) + 1) = vector(i - ndata(1, 4) + 1) +
1;
            end
        end
    end
    output = vector;
end
```

R20mm extraction

```
function [output] = R20mm(ndata)
    close all;

    [row, col] = size(ndata);

    vector = zeros(ndata(row, 4) - ndata(1, 4) + 1, 1);

    for i = ndata(1, 4):ndata(row, 4)
        for j = 1:numel(ndata(:, 4))
            if (ndata(j, 4) == i && ndata(j, 3) >= 20)
                vector(i - ndata(1, 4) + 1) = vector(i - ndata(1, 4) + 1) +
1;
            end
        end
    end
    output = vector;
end
```

R75p extraction

```
function [output] = R75p(ndata)
    close all;

    [row, col] = size(ndata);
```

```
    vector = zeros(ndata(row, 4) - ndata(1, 4) + 1, 1);

    tempVeryWetDays = [];
    indexFor75 = 0;
    rrFor75 = 0;

    for i = 1:numel(ndata(:, 3))
        if (ndata(i, 3) >= 1)
            tempVeryWetDays = [tempVeryWetDays ndata(i, 3)];
        end
    end
    tempVeryWetDays = sort(tempVeryWetDays);
    indexFor75 = round(numel(tempVeryWetDays) * 0.75);
    rrFor75 = tempVeryWetDays(indexFor75);

    for i = ndata(1, 4):ndata(row, 4)
        tempVeryWetDays = [];

        for j = 1:numel(ndata(:, 4))
            if (ndata(j, 4) == i && ndata(j, 3) >= 1)
                tempVeryWetDays = [tempVeryWetDays ndata(j, 3)];
            end
        end

        for k = 1:numel(tempVeryWetDays)
            if (tempVeryWetDays(k) > rrFor75)
                vector(i - ndata(1, 4) + 1) = vector( i - ndata(1, 4) + 1)
+ 1;
            end
        end
    end
    output = vector;
end
```

R95p extraction

```
function [output] = R95p(ndata)
    close all;

    [row, col] = size(ndata);

    vector = zeros(ndata(row, 4) - ndata(1, 4) + 1, 1);

    tempVeryWetDays = [];
    indexFor95 = 0;
    rrFor95 = 0;

    for i = 1:numel(ndata(:, 3))
        if (ndata(i, 3) >= 1)
            tempVeryWetDays = [tempVeryWetDays ndata(i, 3)];
        end
    end
    tempVeryWetDays = sort(tempVeryWetDays);
    indexFor95 = round(numel(tempVeryWetDays) * 0.95);
    rrFor95 = tempVeryWetDays(indexFor95);

    for i = ndata(1, 4):ndata(row, 4)
```

```
        tempVeryWetDays = [];

        for j = 1:numel(ndata(:, 4))
            if (ndata(j, 4) == i && ndata(j, 3) >= 1)
                tempVeryWetDays = [tempVeryWetDays ndata(j, 3)];
            end
        end

        for k = 1:numel(tempVeryWetDays)
            if (tempVeryWetDays(k) > rrFor95)
                vector(i - ndata(1, 4) + 1) = vector( i - ndata(1, 4) + 1)
+ 1;
            end
        end
    end
    output = vector;
end
```

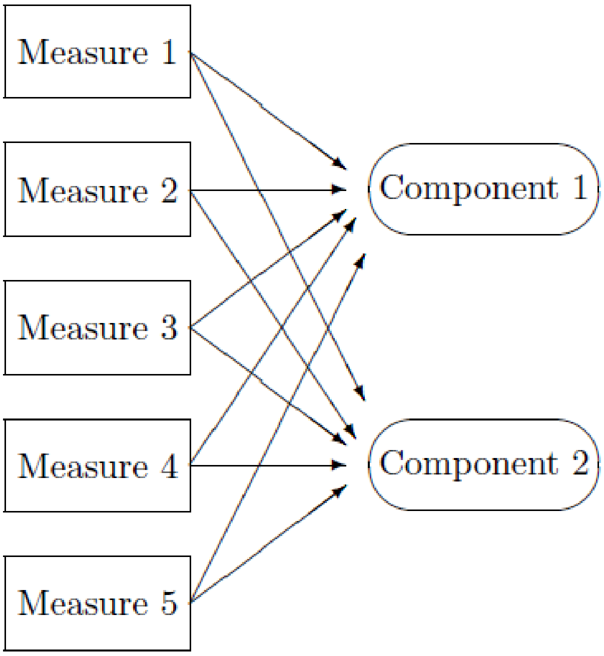
RX5days extraction

```
function [output] = RX5days(ndata)
    close all;

    [row, col] = size(ndata);

    vector = zeros(ndata(row, 4) - ndata(1, 4) + 1, 1);

    for i = ndata(1, 4):ndata(row, 4)
        tempMaxFiveDaysPrecipitation = [];

        for j = 1:numel(ndata(:, 4))
            if (ndata(j, 4) == i)
                tempMaxFiveDaysPrecipitation =
[tempMaxFiveDaysPrecipitation ndata(j, 3)];
            end

        end

        for k = 1:numel(tempMaxFiveDaysPrecipitation)
            if (k <= numel(tempMaxFiveDaysPrecipitation) - 5)
                if (vector(i - ndata(1, 4) + 1) <
tempMaxFiveDaysPrecipitation(k) +  tempMaxFiveDaysPrecipitation(k + 1) +
tempMaxFiveDaysPrecipitation(k + 2) +  tempMaxFiveDaysPrecipitation(k + 3)
+  tempMaxFiveDaysPrecipitation(k + 4))
                    vector(i - ndata(1, 4) + 1) =
tempMaxFiveDaysPrecipitation(k) +  tempMaxFiveDaysPrecipitation(k + 1) +
tempMaxFiveDaysPrecipitation(k + 2) +  tempMaxFiveDaysPrecipitation(k + 3)
+  tempMaxFiveDaysPrecipitation(k + 4);
                end
            end
        end

    end
    output = vector;
end
```

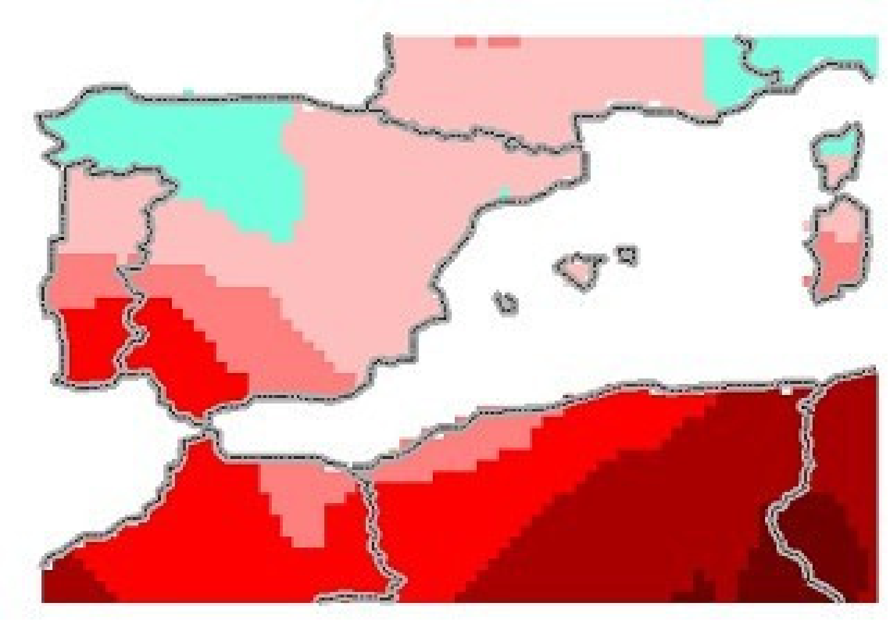
SDII extraction

```
function [output] = SDII(ndata)
    close all;

    [row, col] = size(ndata);

    vector = zeros(ndata(row, 4) - ndata(1, 4) + 1, 1);

    for i = ndata(1, 4):ndata(row, 4)
        tempValue = [];
        for j = 1:numel(ndata(:, 4))
            if (ndata(j, 4) == i && ndata(j, 3) >= 1)
                tempValue = [tempValue ndata(j, 3)];
            end
        end
        vector(i - ndata(1, 4) + 1) = round(mean(tempValue));
    end
    output = vector;
end
```

Appendix BII: Model of PCA



Appendix CI: Interpolation of maximum temperature in 2003



Appendix CII: Correlation matrix between each climate extreme indices

Portugal

		SU	SU41	TX90p	WSDI	R75p	R95p	R10mm	R20mm	CWD	DD
SU	Pearson	1	.151	.338	.426(*)	.183	.164	-.059	.095	-.113	.353
	Sig. (2-tailed)		.427	.068	.019	.333	.386	.757	.619	.552	.056
	N	30	30	30	30	30	30	30	30	30	30
SU41	Pearson	.151	1	.213	.207	.060	.156	-.131	-.095	.184	.147
	Sig. (2-tailed)	.427		.257	.271	.753	.411	.492	.618	.331	.438
	N	30	30	30	30	30	30	30	30	30	30
TX90	Pearson	.338	.213	1	.962(**)	.123	.178	-.032	.016	-.204	.171
	Sig. (2-tailed)	.068	.257		.000	.517	.347	.867	.933	.281	.366
	N	30	30	30	30	30	30	30	30	30	30
WSDI	Pearson	.426(*)	.207	.962(**)	1	.129	.184	-.036	.019	-.261	.214
	Sig. (2-tailed)	.019	.271	.000		.498	.330	.850	.922	.164	.255
	N	30	30	30	30	30	30	30	30	30	30
R75p	Pearson	.183	.060	.123	.129	1	.810(**)	.795(**)	.876(**)	.375(*)	-.571(**)
	Sig. (2-tailed)	.333	.753	.517	.498		.000	.000	.000	.041	.001
	N	30	30	30	30	30	30	30	30	30	30
R95p	Pearson	.164	.156	.178	.184	.810(**)	1	.560(**)	.677(**)	.253	-.302
	Sig. (2-tailed)	.386	.411	.347	.330	.000		.001	.000	.177	.104
	N	30	30	30	30	30	30	30	30	30	30
R10m	Pearson	-.059	-.131	-.032	-.036	.795(**)	.560(**)	1	.946(**)	.516(**)	-.846(**)
	Sig. (2-tailed)	.757	.492	.867	.850	.000	.001		.000	.004	.000
	N	30	30	30	30	30	30	30	30	30	30
R20m	Pearson	.095	-.095	.016	.019	.876(**)	.677(**)	.946(**)	1	.488(**)	-.718(**)
	Sig. (2-tailed)	.619	.618	.933	.922	.000	.000	.000		.006	.000
	N	30	30	30	30	30	30	30	30	30	30
CWD	Pearson	-.113	.184	-.204	-.261	.375(*)	.253	.516(**)	.488(**)	1	-.518(**)
	Sig. (2-tailed)	.552	.331	.281	.164	.041	.177	.004	.006		.003
	N	30	30	30	30	30	30	30	30	30	30
DD	Pearson	.353	.147	.171	.214	-.571(**)	-.302	-.846(**)	-.718(**)	-.518(**)	1
	Sig. (2-tailed)	.056	.438	.366	.255	.001	.104	.000	.000	.003	
	N	30	30	30	30	30	30	30	30	30	30
CDD	Pearson	.059	.287	-.041	-.014	-.149	.001	-.219	-.275	.051	.095
	Sig. (2-tailed)	.757	.124	.830	.941	.432	.996	.245	.141	.790	.617
	N	30	30	30	30	30	30	30	30	30	30
TXx	Pearson	.360	.631(**)	.374(*)	.358	-.156	-.033	-.261	-.213	.017	.454(*)
	Sig. (2-tailed)	.050	.000	.041	.052	.412	.864	.164	.259	.928	.012
	N	30	30	30	30	30	30	30	30	30	30
SPS	Pearson	-.121	.104	-.099	-.093	.329	.166	.383(*)	.353	.428(*)	-.464(**)
	Sig. (2-tailed)	.524	.586	.602	.624	.076	.381	.037	.055	.018	.010
	N	30	30	30	30	30	30	30	30	30	30
RX5d	Pearson	.086	.066	.096	.083	.462(*)	.538(**)	.252	.345	.299	-.210
	Sig. (2-tailed)	.651	.727	.614	.664	.010	.002	.179	.062	.109	.266
	N	30	30	30	30	30	30	30	30	30	30
SDII	Pearson	.426(*)	.139	.203	.243	.817(**)	.864(**)	.474(**)	.637(**)	.210	-.104
	Sig. (2-tailed)	.019	.464	.281	.195	.000	.000	.008	.000	.266	.583
	N	30	30	30	30	30	30	30	30	30	30

- Correlation is significant at the 0.05 level (2-tailed).
- ** Correlation is significant at the 0.01 level (2-tailed).

Northwest

SU	Pearson	1	-.018	.076	.073	-.113	-.437(*)	-.081	-.094	.262	-.194
	Sig. (2-		.926	.689	.703	.551	.016	.669	.621	.162	.304
	N	30	30	30	30	30	30	30	30	30	30
SU41	Pearson	-.018	1	.478(**)	.470(**)	-.056	.188	-.061	.057	.091	.064
	Sig. (2-	.926		.008	.009	.769	.319	.749	.764	.633	.738
	N	30	30	30	30	30	30	30	30	30	30
TX90p	Pearson	.076	.478(**)	1	.999(**)	-.247	-.049	-.126	-.128	.060	.014
	Sig. (2-	.689	.008		.000	.189	.799	.508	.500	.751	.942
	N	30	30	30	30	30	30	30	30	30	30
WSDI	Pearson	.073	.470(**)	.999(**)	1	-.251	-.047	-.130	-.132	.056	.016
	Sig. (2-	.703	.009	.000		.181	.804	.493	.485	.767	.932
	N	30	30	30	30	30	30	30	30	30	30
R75p	Pearson	-.113	-.056	-.247	-.251	1	.574(**)	.388(*)	.531(**)	-.047	-.014
	Sig. (2-	.551	.769	.189	.181		.001	.034	.003	.804	.940
	N	30	30	30	30	30	30	30	30	30	30
R95p	Pearson	-.437(*)	.188	-.049	-.047	.574(**)	1	.134	.296	-.219	.264
	Sig. (2-	.016	.319	.799	.804	.001		.481	.113	.244	.158
	N	30	30	30	30	30	30	30	30	30	30
R10mm	Pearson	-.081	-.061	-.126	-.130	.388(*)	.134	1	.938(**)	.254	-.774(**)
	Sig. (2-	.669	.749	.508	.493	.034	.481		.000	.176	.000
	N	30	30	30	30	30	30	30	30	30	30
R20mm	Pearson	-.094	.057	-.128	-.132	.531(**)	.296	.938(**)	1	.188	-.625(**)
	Sig. (2-	.621	.764	.500	.485	.003	.113	.000		.320	.000
	N	30	30	30	30	30	30	30	30	30	30
CWD	Pearson	.262	.091	.060	.056	-.047	-.219	.254	.188	1	-.666(**)
	Sig. (2-	.162	.633	.751	.767	.804	.244	.176	.320		.000
	N	30	30	30	30	30	30	30	30	30	30
DD	Pearson	-.194	.064	.014	.016	-.014	.264	-.774(**)	-.625(**)	-.666(**)	1
	Sig. (2-	.304	.738	.942	.932	.940	.158	.000	.000	.000	
	N	30	30	30	30	30	30	30	30	30	30
CDD	Pearson	.059	.218	.193	.194	.116	.120	-.366(*)	-.257	.386(*)	.272
	Sig. (2-	.758	.248	.307	.305	.540	.527	.047	.171	.035	.146
	N	30	30	30	30	30	30	30	30	30	30
TXx	Pearson	-.265	.620(**)	.159	.152	.109	.461(*)	.111	.216	.361(*)	-.091
	Sig. (2-	.157	.000	.402	.424	.565	.010	.558	.252	.050	.632
	N	30	30	30	30	30	30	30	30	30	30
SPS	Pearson	-.475(**)	.000	-.247	-.238	.380(*)	.568(**)	.409(*)	.489(**)	-.371(*)	.009
	Sig. (2-	.008	.998	.187	.206	.038	.001	.025	.006	.044	.964
	N	30	30	30	30	30	30	30	30	30	30
RX5day	Pearson	-.317	.253	-.222	-.227	.469(**)	.633(**)	.151	.301	.130	.017
	Sig. (2-	.088	.177	.239	.228	.009	.000	.426	.106	.492	.927
	N	30	30	30	30	30	30	30	30	30	30
SDII	Pearson	-.351	.090	-.189	-.189	.530(**)	.748(**)	-.208	.027	-.545(**)	.653(**)
	Sig. (2-	.057	.637	.316	.317	.003	.000	.271	.888	.002	.000
	N	30	30	30	30	30	30	30	30	30	30

- Correlation is significant at the 0.05 level (2-tailed).
- ** Correlation is significant at the 0.01 level (2-tailed).

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