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Calculation of past and present water availability in the Mediterranean Region and future estimates according to the Thornthwaite water-balance Model

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Master degree thesis, 30 credits in Physical Geography and Ecosystem Analysis

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Abstract

The Mediterranean region is one of the most sensitive regions in the world in the face of climate change. Many studies name this region as a “hot spot”. It is essential to model the water balance of this region in order to better understand the impacts of climate change. The water balance expresses the net result of the flow of water from atmosphere to the surface and vice versa. It is one of the best ways to examine water availability –if the region is dry or wet- in a region. The first input of the model is potential evapotranspiration, which is calculated as a function of temperature and latitude using specific formulae produced by Thornthwaite. The other factors of the water balance are storage, actual evapotranspiration, surplus and deficit. This study spans different time periods which are for the past, present and future. Because of changes that have already occurred in climate, the model produces different results for the three periods. Temperature rise will affect the water balance by enhancing potential evapotranspiration in the Mediterranean Region. Warming-enhanced evapotranspiration will hence increase water stress in the region. It is suggested that this effect will be more severe when combined with the decrease of precipitation. Areas under high stress are mainly in the inlands of North Africa, and mountainous areas such as the Alps. In the region there will not only be enhanced deficits, but also increased surpluses are suggested in some seasons. As has been shown in other studies, this study suggests significant seasonality in the Mediterranean Region. In general, the future Mediterranean Region seems to be exposed to more severe conditions and water availability will be under much greater stress. Most studies suggest a 20% decrease in precipitation and up to 4˚C of temperature rise in the Mediterranean Region by the end of this century. This study only focuses on temperature rise in the future, holding precipitation the same as in the present period. Even so, the model suggests significant changes in the future water balance of the Mediterranean Region.

Acknowledgement

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Abbreviations

IPCC Intergovernmental Panel on Climate Change

SRES Special Reports on Emission Scenarios

AET Actual Evapotranspiration

PET Potential Evapotranspiration

FAO Food and Agriculture Organization of the United Nations

CMIP 3 The Coupled Model Intercomparison Project phase 3

WAI Water Availability Index

NDVI Normalized Difference Vegetation Index

DJF December, January, February

MAM March, April, May

JJA June, July, August

SON September, October, November

1. Introduction

The Mediterranean region is well known for its favorable climate, leading to human settlements going back thousands of years in history. This region has always faced water availability problems, especially during the summer (IPCC, 2007). Despite the difficult conditions, the people of this region have always managed to cope with the harsh conditions, likely by improving their skills in obtaining and conserving water. Nonetheless, this problem continues to grow and in the future it is expected to become more severe because of global climate change (Mariotti et al., 2008).

Climate is changing globally because of human activities and anthropogenic greenhouse gas emissions to the atmosphere (IPCC, 2007; Barkhordarian et al., 2012). For the next twenty years, 0.2 °C warming is expected on average at the global scale. Even if we stop emitting greenhouse gasses and aerosols to the atmosphere now, global temperatures will keep going up (0.1 °C increase through the next two decades) (IPCC, 2007). IPCC (2007) has developed 6 climate change scenarios (SRES) for the future which estimate a temperature rise of between 1.1 and 6.4 °C respectively for the mildest and most severe scenarios (Table 1). This study is based on A1B scenario which is explained in detail below.

Table 1 Climate change scenarios and estimated temperature rises at 2090-2099 relative to 1980-1999 (taken from IPCC, 2007, Summary for Policymakers)

SRES Emission Scenarios	Best Estimate	Likely range
B1	1.8	1.1-2.9
A1T	2.4	1.4-3.8
B2	2.4	1.4-3.8
A1B	2.8	1.7-4.4
A2	3.4	2.0-5.4
A1FI	4	2.4-6.4

Climate change will cause more extreme events in the region, such as extremely high temperatures, serious droughts, water stresses and abrupt flooding (European Commission, 2009). It is affecting some regions more than others. The Mediterranean Region is the one of the most sensitive regions. The reasons for the extreme sensitivity of this region to climate change are insufficient existing resources of water and increasing demand for water (Iglesias et al. 2007). Another reason for this region being highly sensitive is the vulnerability of the region to desertification in the face of considerable climate change (Gao and Giorgi, 2008). According to the IPCC report (2007), temperatures in the region will increase in the future and hence will reduce precipitation and cause a drier climate. Increased temperatures will cause more evaporation from the soil and hence less water will be available for the use of humans (Douville et al. 2002; Wang 2005, IPCC 2007).

There are various ways to estimate evapotranspiration of a region; however it is not very easy to estimate it thoroughly, particularly in terms of spatial and temporal distribution. Actual evapotranspiration can be estimated by field measurements. While there was only one practical method to measure evapotranspiration in the late 1940s, called the “vapor-transfer method” (Thornthwaite, 1948), now it can be measured by an eddy covariance technique, by means of turbulent air (eddies), or directly from soil and vegetation by lysimeter or evaporimeter (Menenti and Choudhury, 1993; Christopherson, 2006). By estimating the evapotranspiration characteristics of a region, with other climate variables such as precipitation and temperature, a water budget can be produced. The Thornthwaite water balance approach (1948) is one methodology, which can easily be applied from the smallest to largest regions located in any part of the world. Thornthwaite found that potential evapotranspiration can be calculated as a function of day length by inputting only monthly mean temperature. This method is fairly easy to implement because it is easier to measure temperature than evapotranspiration, and readily available temperature data can easily be found for most locations. This approach is very useful for creation of a water balance model for the Mediterranean region. This methodology works quite well and gives reasonable results for midlatitude climates, because it does not take into account some parameters for cold climates such as sublimation, permafrost soils and warm or cool movements of air from surfaces. However, there are some positive aspects of the model for application in colder climates, such as counting snow accumulation (Christopherson, 2006). This method is preferred in this study because it can simply be applied to any part on the world and gives quite accurate results, especially for the midlatitudes.

It is expected to see higher evapotranspiration rates during some seasons such as the summer and spring, and lower rates in the autumn and winter in the Mediterranean region. There is more energy to drive evapotranspiration in warmer months (MAM, JJA) than in the cooler months (SON, DJF). Also as it is calculated the function of latitude, more evapotranspiration occurs in the south than the north again because of greater energy availability.

By knowing the precipitation characteristics of a region, the water balance can be estimated by calculating monthly storage, storage change, resulting actual evapotranspiration (AET) and the surplus or deficit produced. All these information can be used to help determine if there already are water shortages in some parts of the region, or surpluses according to what would be expected under climate change scenarios (greenhouse gas forcing). The Mediterranean region is a “hot spot” in the face of climate change (Giorgi, 2006), thus this information will be helpful in order to estimate which parts of the region will suffer from water scarcity and will lead authorities to need to find some solutions starting in the present, because according to the IPCC (2007), in the future, climate change impacts will be more severe in this region.

1.1. Area of interest

This study focuses on the Mediterranean region and modeling climate change impacts upon water availability in this region. The Mediterranean is a region that is surrounded on the border of the Mediterranean Sea. The Region is located within the rectangle delimited by coordinates *27°-47° N* and *10°W-37°E*. 427 million people live in this region and because of its generally favorable environmental conditions (resources, climate, and biological diversity) it has been settled since ancient times. The climate of the region is generally characterized by high evaporation, low precipitation and high salinity. The countries in the region are Albania, Bosnia-Herzegovina, Croatia, France, Greece, Hungary, Italy, Malta, Monaco, Serbia-Montenegro, Slovenia, Spain, Algeria, Cyprus, Egypt, Israel, Lebanon, Morocco, Libya, Palestinian Authority, Syria, Tunisia, and Turkey (FAO, 2003) (Figure 1).

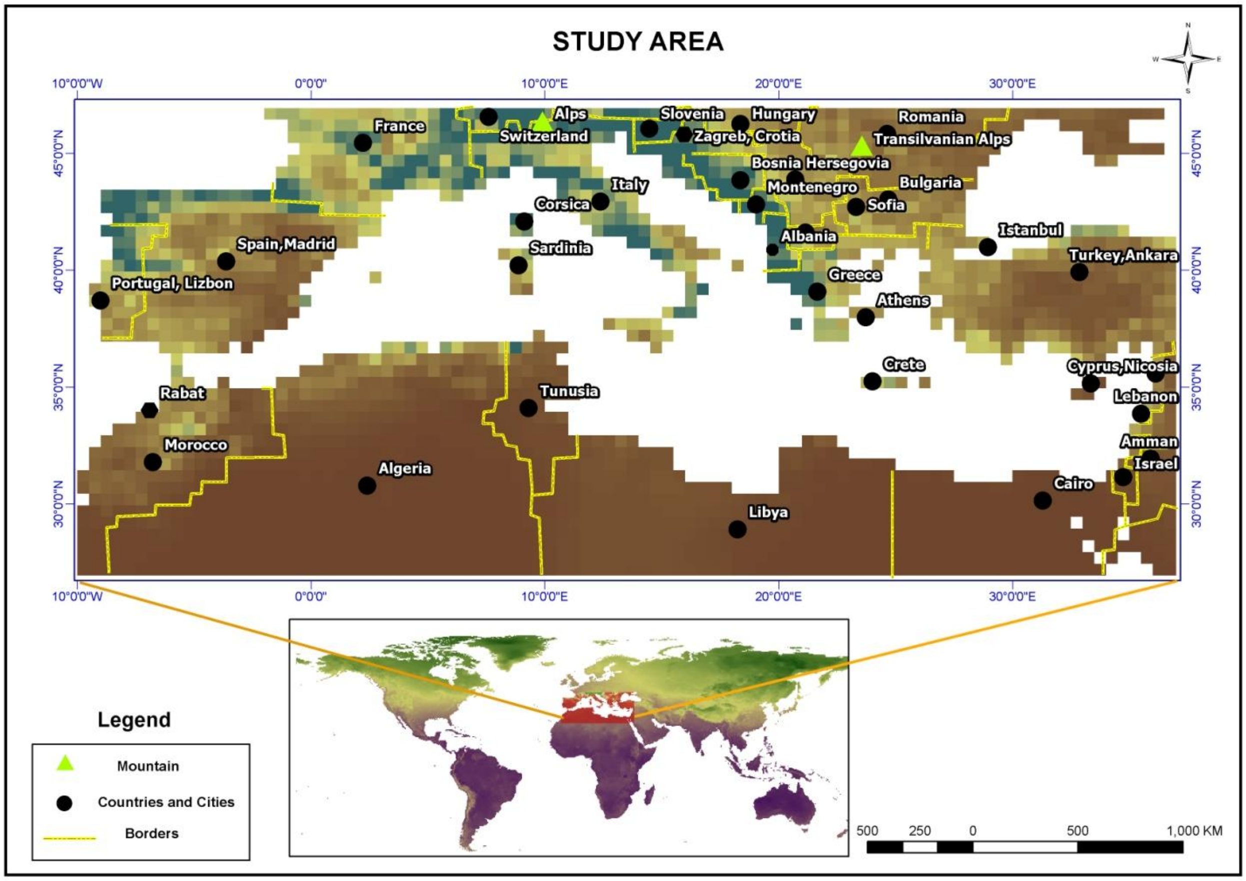

Figure 1 The Mediterranean region with surrounding countries labeled

1.2. Climate of the Mediterranean Region

The climate of the Mediterranean region is defined by warm summers with less precipitation and milder winters with more precipitation in most parts of the region. Temperature differs from south to north; it is warmer in the south and cooler in the north, and the range of mean temperatures is between 3 -15 ˚C. Precipitation has the same pattern as temperature. Monthly mean precipitation is between 50-250 mm and is as high as 500 mm in the mountainous parts of the region (Mitchell and Jones, 2005). However the climate of the region is not evenly distributed because of its complex geomorphological characteristics and transitional location between subtropical and temperate zones (Lionello et al., 2012).

According to Köppen (1900), Mediterranean climate is classified as CSb and CSa; these are temperate climates with dry summers. However the climate of the region not only consists of those two subtypes. There are also other types such as hot and drier or colder (with snow) from the south to the north of the region. All climate types in the region according to the Köppen classification (1900) are; subtropical steppe (BSh), midlatitude steppe (BSk), subtropical desert (BWh), midlatitude desert (BWk), Mediterranean climate with hot/warm summer (CSa/b), humid subtropical with no dry season (CFa), maritime temperate (CFb), humid continental with hot/warm summer (DFa/b), continental with dry hot/warm summer (DSa/b), and tundra (ET) (Figure 2 and Table 2). There are significant climate differences between the north and the south of the region. While the northern part is humid, with permanent glaciers in the Alpine subregion, the southern part is dryer with some desert climates in some parts, especially in Africa (Lionello et al., 2012).

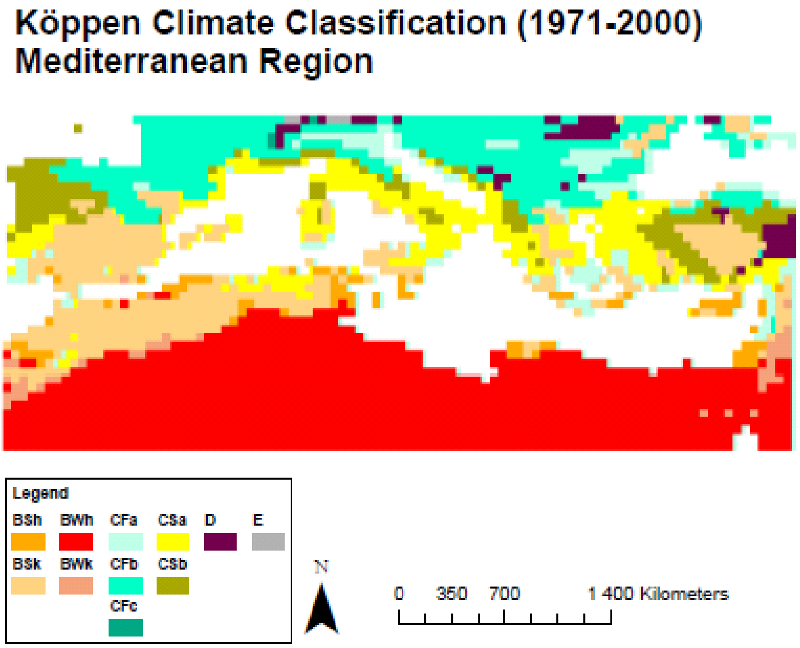

Figure 2 Köppen climate classification in the Mediterranean Region

Table 2 Köppen climate classification for the Mediterranean region

Köppen climate type	Description
BSh	Subtropical steppe
BSk	Midlatitude steppe
BWh	Subtropical desert
BWk	Midlatitude desert
CSa/b	Mediterranean climate with hot/warm summers
Cfa	Humid subtropical with no dry season
CFb	Maritime temperate
Dfa/b	Humid continental with hot/warm summer
Dsa/b	Continental with dry hot/warm summer
ET	Tundra

2. Purpose of the study

A consequence of climate change (temperature increase) in the Mediterranean region is that there will be more evapotranspiration from the ground and vegetation**.** Potential evapotranspiration is an important parameter for the determination of water balance. Since evapotranspiration is part of hydrological cycle, it is important to calculate how much water is going into the atmosphere from soil and vegetation. The aim of this study is to calculate potential evapotranspiration of the Mediterranean region in order to develop a water balance model by using the ArcGIS (created by ESRI, US) Model Builder, which is a tool that allows people to create models, and is used here to calculate storage, storage change, surplus, deficit and actual evapotranspiration, with a model mainly based on the Thornthwaite methodology, applied over modern gridded input datasets. Also, the determination of climate change impacts on the water balance of the Mediterranean region is an aim of this study. One of the IPCC scenarios (A1B) is evaluated to examine the impact of climate change in the region, and to demonstrate and estimate the spatial pattern of impacts it will likely cause. By calculating the water balance it is possible to determine how much water will remain for the use of humans and ecosystems and the adequacy of this water in various locations throughout the Mediterranean Region.

3. Background

3.1. Water Balance Models used in previous studies

The Thornthwaite methodology has seen widespread use since it was first developed. Different researchers have used the model in different studies by modifying the model. The first modification was done by Black (1966) by calculating the water balance using monthly temperature, precipitation and soil water storage capacity as a function of latitude. Other modifications were performed by Grigal and Bloom (1985) for the production of runoff estimations in Minnesota.

Randall and Wolf (1998) created a computer based water balance model in order to calculate Actual Evapotranspiration (ACTET) by modifying Gigal and Bloom's model, which is also a modified version of Thornthwaite. They produced a model for forested sites, which can be used for any temperate climate. They calculated potential evapotranspiration by using Thornthwaite's formula. According to the original model, when precipitation minus potential evapotranspiration (P-PET) becomes negative, it remains negative until the end of dry season. Randall and Wolf's model assumes accumulation of soil water is over the whole year by not looking at whether P-PET is negative or positive. They describe their model more 'natural' than Thornthwaite's. They found their storage simulations never became full (i.e. never reached field capacity) in the spring. They found storage was always decreasing and never reached maximum capacity.

Garcia-Ruiz et al. (2011) used the Thornthwaite methodology to calculate potential evapotranspiration of the Mediterranean region for the period of 1950-2002 in order to analyze climate evolution in the region. As in this study, they also projected the water balance in the region by looking at only precipitation and temperature. Various studies use this method in the estimations of water balance for the Mediterranean region as well.

3.2. Defining the water availability problem in the Mediterranean Region

Studies about the water balance as a function of evapotranspiration are critical for the middle latitude countries in the Mediterranean, especially for the countries that are more sensitive to climate change. This sort of research is necessary in order to find solutions for the management of water resources. Not only is incoming water (precipitation) important, the outgoing water (evapotranspiration) is also important to understand in the hydrological cycles of sensitive regions. Mediterranean climate is one of those sensitive climates because of its lying in between arid and temperate climate where climate is likely to change even under minor changes, such as storm tracks/pressure changes (Giorgi and Lionello, 2008). Increasing of greenhouse gases (GHG) is one of the major drivers of climate change in the region (Ulbrich et al 2006). According to IPCC (2007), semi-arid regions like Mediterranean will experience reductions in water resources under climate change.

3.2.1. Temperature

Increases in the temperatures of the Mediterranean region are a result of human activity, and it is suggested this trend will continue in the future (IPCC, 2007, Barkhordarian et al. 2012, 2013). The region's temperatures have increased since the end of 1970's with a 0.1 ˚C increase and 25 mm decrease per decade (Xoplaki et al. 2004). Piervitalli et al. (1997) suggests temperatures have risen according to their analysis since the 1980s in the Mediterranean region. However this warming trend is not evenly distributed in the east and the west portions of the region (Feidas and Lalas, 2001). Like the spatial differences of the distribution of temperature changes there are also temporal differences. Warming in the region is more pronounced in the summer than the winter and there is high risk of summer drought in the future (IPCC, 2007, Giorgi and Lionello, 2008, Gao and Giorgi, 2008). In warmer seasons while the whole region is experiencing more warming, especially in the southern parts, no warming trend is detected in the eastern and southern parts, in contrast to what is found in the North (Giorgi, 2002, Milano et al. 2013).

For the near future (2001-2020) temperature rise is projected to be 1.2-4.6°C and 0.7-3.1°C for winter (Giorgi and Lionelli, 2008, due to A1B scenario). According to the IPCC's model results for the period of 2011-2030, temperatures will raise 0.64-0.69°C compared to 1980-1999 (for A2, A1B, B1 scenarios-only anthropogenic rise). Until the middle of the century, for the period of 2046-2065 temperature rise is projected to be 1.3°, 1.8° and 1.7° for B1, A1B and A2 scenarios respectively. By the 2050's it is suggested that a 2-3° temperature rise and an up to 30% precipitation decrease will occur in the Mediterranean region. For A1B and A2 scenarios summer temperature increase is projected to be over 4 °C. The same model assumes more summer drought for the period of 2081-2100. According to SRES A1B storyline, temperature rise will be in between 2.2-5.1 ° C for the period of 2080-2099 relative to 1980-1999 (IPCC, 2007).

Global climate changes will not have the same influence on all regions. That means regional temperature and precipitation changes will be different than those found globally. Giannakopoulos et al. (2009) projected future climate changes in the Mediterranean region, considering 2 degrees of global temperature increase for the period of 2031-2060 compared to 1961-1990. Their studies have different results for the different scenarios. For example, for the A2 scenario they found that temperature rise will be higher in the summer (4°), while it is 2° for fall and spring, and 1-2° for winter. Also their results show some differences between coast and inland locations (lower in the coast and higher in the inlands).

3.2.2. Precipitation

One of the most pronounced climate change impacts on the Mediterranean region is the decrease in precipitation, especially in the warm/dry season except for some parts where there will be reductions in the winter in the north such as Alps (Giorgi and Bi, 2005; Giorgi and Lionello, 2006; Mariotti, et al., 2008). The reason for the seasonal diversity of the climate patterns is increased anticyclonic activity –which causes more stable conditions and northward movement of the precipitation due to a shift of the Atlantic storm track. Decreased cyclonic activity will be more severe in winter in the western Mediterranean region (Hurrell and van Loon, 1997, Lionello et al. 2006) while there is increase in the eastern Mediterranean (Guijarro et al. 2006). The region has already experienced a decrease in precipitation, mostly in winter, since the 1970s

(Palutikof et al., 1996,; Piervitali et al., 1997). However, changes in precipitation started earlier (for the last 50 years) in the western and central Mediterranean regions (Piervitali, et al. 1997). Philandras et al. (2011) used CRU TS 3.1 (Climatic Research Unit, time-series) data to analyze the present situation of the precipitation in the region and found that there is a decreasing trend for the period of 1901-2009 in the western, eastern and central Mediterranean. According to the same study in the west Mediterranean there is 28% decrease, while there is a 23% decrease in the central portion, and a 13% decrease in the eastern Mediterranean for the period of 1951-2010. However their results show a greater decrease in the western and central parts during the wet season (30%, 24% 12%). Total decrease in annual precipitation for the period of 1901-2009 is in between 2-6 mmyr^{-1}. On the other hand they found a positive trend in the farther northern parts such as western-northern Iberia, and southwestern France. There are various studies that have results consistent with these for the eastern Mediterranean (Kutiel et al., 1996, Türkes, 1998).

Milano et al. (2013) analyzed the precipitation for the period of 2041-2060 by using GCMs, and all of their simulations suggest a 5-20% decrease in future precipitation. All of the models used in their study shows the greatest decrease will be observed in Spain, Morocco, Algeria and Middle East with a 20-40% decrease. Although there is a general decrease in whole region, in only Libya does one of the models estimates an increase of about 40-60% by 2050.

Future projections for the whole Mediterranean region predict a 20% decrease in the mean annual precipitation during the period 2071-2100 compared to 1961-1990, which agrees with IPCC (2007) estimates (Philandras et al., 2011). This result agrees with the various studies that they also suggest that the precipitation will decrease 20% in the future by the end of 21st century (Schonwiese et al. 1994, IPCC, 2007, Teselioudis et al. 2008). IPCC (2007) has an annual mean precipitation decrease in a range of 4-27% for the period of 2080-2099 relative to 1980-1999. Mariotti et al. (2008) use CMIP3 (Coupled Model Intercomparison Project phase 3) multi model projections to predict the future and suggest a 15.5% (0.17 mm day^{-1}) decrease in the annual mean precipitation (on land surface) while it is 9.7% (0.12 mm day^{-1}) for the wet season and 23.6% (0.21 mm day^{-1}) for the dry season for the period of 2070-2099 relative to 1950-2000. In total it is suggested that 20% decreases will occur all over the region (Mariotti et al. 2008). For the spring and summer season it is assumed that there will be further decreases in precipitation, by up to 28% in 2081-2100, which is lower than in the other seasons (Gao and Giorgi, 2008, Giorgi and Lionelli, 2008). Summer and spring precipitation reductions will hence lead the shift of aridity to the northward till the end of 21st century (Gao and Giorgi, 2008). Precipitation decrease is more pronounced on the sea than land (Giorgi and Lionelli, 2008).

3.2.3. Water availability of the Mediterranean region

Water resources in the Mediterranean region are not evenly distributed in whole region. While some parts have enough water resources, other parts are suffering from scarcity. In total water volume, the freshwater resources of the region are 550 $km^3, which$ is 1.2% percent of the whole earth supply (Milano, et al. 2013). While Italy and Greece share half of all resources, while

Turkey and France have 25% of the resources. On the other hand, the southern part is the most suffers most, with just 2% of the available water resources (Milano, et al. 2013, using data taken from FAO, 2010).

The combined impacts of precipitation decrease and temperature increase will cause bigger problems, such as the reduction of available water in the Mediterranean region. Water resources are mainly based on the runoff from mountains in this region (De Jong et al., 2009). More studies should be done investigating water availability in the region, because while there are various studies about climate change there are relatively fewer studies about the water cycle of the region. Predictions for the water availability of the Mediterranean region suggests an overall decrease all over the Mediterranean, for land-surface water about 20% and for the fresh water content of the Mediterranean sea a 24% decrease (Mariotti et al., 2008). According to the same study, fresh water deficit (0.25-0.55 mm/day) will be very serious in the future, combined with the reduced river discharges in the future, because of decreased precipitation and increased evaporation over the sea.

The current situation of fresh water availability in the region is not evenly distributed. Mainly low fresh water availability dominates the southern parts of the region. While some catchment areas like the Po and Rhone Valleys (Italy and France) have more fresh water, some of other catchments such as Jucar, Tafna and Moulouya (Spain and Morocco) have very limited fresh water (Milano et al. 2013). Temperature increase will enhance evaporation in the region. This will reduce fresh water availability as simulated in future projections. Most of the coastal zones will have 25-50% reductions, and some countries such as Morocco and Spain will have more than 50% reductions in fresh water availability. Fresh water reductions in southern Spain, Morocco, Algeria and the southeastern Mediterranean will occur because of temperature increase-enhanced precipitation decrease and potential evapotranspiration increase, which have important roles in determining water resource availability. However according to model results Libya and Southern Tunisia seem to have an incremental increase in water availability (~10%), even though in the present they are now suffering from poor fresh water availability (Milano et al. 2013).

Water budget changes, e.g. less discharge to the Mediterranean Sea combined with more evaporation will have serious consequences such as changes to the salinity of the sea which will hence affect the thermohaline circulation of Atlantic Ocean, which has already been observed in the Mediterranean region (Mariotti et al. 2008, Elguindi et al. 2011).

The analysis of Gao and Giorgi (2008) shows that by the end of 21st century, the Mediterranean region will face increased aridity and northward movement of dry areas. The Southern Mediterranean will be affected, in locations such as the Iberian, Hellenic, Turkish and Italian peninsulas. According to their study northern Africa, the Middle East coasts and some major islands will be exposed to significant drought.

Any alterations of the patterns of precipitation will affect the amount of water reaching the soil, and hence the behaviors of the rivers as a function of runoff production (Garcia-Ruiz et al. 2011). This will of course affect the water resources by causing decreases. Less precipitation will lead to less evaporation from the soil. However as a result of global warming, precipitation will decrease together with increased temperatures. So, more temperature rise will bring more evaporation from the soil (Garcia-Ruiz et al. 2011) in contrast to precipitation decrease. Precipitation decrease together with temperature rise will increase the total stress on water resources.

According to the Water Stress Index (WAI) -which is the result of combination of observed stream flow for past months and storage in the reservoirs (Randall, 2012)- the Mediterranean region has already been experiencing water shortages in most of its parts. Even now Spain, Morocco, Algeria, Cyprus, Crete and Turkey are under water stress in between 40-80% of the time, and in some locations, more than 80% of the time. In the future (by 2050) because of climate change, water stress will be very severe in those countries. According to the WSI, catchments in France and the Balkans (coastal zones) will be stable under climate change and will not suffer from water stress (Milano et al. 2013).

3.2.4. Land cover and land use change in the Mediterranean and impacts on the water availability

Land cover and land use change has a crucial impact on the water balance of the continents. Vegetation is the main driver of the evapotranspiration, which has vital importance in the water balance of regions (Cosandey, et al. 2005). Humans have changed land cover for thousands of years, and the Mediterranean region is one of those landscapes that has been considerably changed by humans (Carroll et al., 2012, Combourieu-Nebout et al. 2013). Land use change is more pronounced for the last three centuries in the region (Wood and Handley, 2001) and mostly by deforestation of the region (Garcia-Ruiz et al., 2011). An important impact of the change of natural land use into agricultural land is an incremental increase of the irrigation of the lands, which can also increase the pressure on the water resources in some parts of the region (Garcia-Ruiz, et al. 2011). Urbanization is the most severe form of land use change, and often alters the natural vegetation or removing it. On the other hand, increased urbanization is causing more water consumption in the Mediterranean region (Bellot at al., 2007), which is enhancing water stress on limited water resources. The main role of vegetation in the water cycle is its alteration and reduction of runoff, which decreases with increased vegetation, and hence evapotranspiration which is increased inversely (Bosch and Hewlett, 1982). Changes in vegetation are both related to human activities and climate change. Climate change will not only reduce the vegetation cover. In suitable places it will increase the shrubs, forests etc. such as in mountainous areas of the Mediterranean region because of the abandonment of agricultural lands (Garcia-Ruiz et al, 2011). Garcia-Ruiz et al. (2011) used NDVI information to see the changes of the vegetation in the Mediterranean region. According to their interpretation, while there are positive trends (more vegetation) on the Northern Mediterranean mainly in Balkans, Turkey, Italy and Northern Iberian Peninsula, there are negative trends (less vegetation) in the south where North Africa, Iberian Peninsula, the Middle East, Croatia and Montenegro are located.

4. Methodology

4.1. Input Data

My analysis of water availability in the region under the A1B climate change scenario is based on the Thornthwaite methodology. This method is mainly focused upon the calculation of potential evapotranspiration (PET). Since the measurement of temperature is much easier than many other climate variables and one of the most common methods to estimate PET is the Thornthwaite approach, it is preferred for use in this study. According to the PET results water storage, storage change, actual evapotranspiration, deficit and surplus can be calculated. The inputs to the model are temperature, precipitation, day length hours as a function of latitude and available water capacity of the soil (Figure 3).

Data for temperature and precipitation has been obtained from the web site of NOAA (specifically, their Earth System Research Laboratory). Data used includes a monthly gridded time series of mean surface temperature (˚C) and total surface precipitation (mm) from 1900 to 2010 on a monthly time step. Both dataset are covering only the land area. Data for temperature and precipitation are gathered from several meteorological stations and rain gauge measurement stations. Matsuura and Willmott (2012) from the University of Delaware interpolated these data to a 0.5-degree by 0.5-degree latitude/longitude grid by the use of those stations, where the grid nodes are centered on a 0.25 degree increment. In an individual study Matsuura and Willmott (2006) evaluated the measurement errors of their temperature product by using spatial cross-validation and average-error statistics. They gathered the data for temperature from the Global Historical Climatology Network (GHCN) and then interpolated the data globally. They found out that the most of the interpolation errors are less than 2 °C, however there are spatial differences on the interpolation errors such as high errors over the mountainous areas and station-sparse regions (Africa, South America, Asia, Greenland and Antarctica). For precipitation they used the same method which is used for temperature to evaluate the spatial interpolation errors. By removing a station and replacing it with another one they interpolated the value at the location of the removed station by considering nearby stations. Then by looking at the difference between the real and interpolated stations, they evaluated the precipitation interpolation errors (Matsuura and Willmott, 2012). Examples of temperature data used in the study are shown in Figure 8 (for past) and Figure 9 (for present), and examples of precipitation data are shown in Figures 10 and 11.

Required data for the Mediterranean region is extracted from the global time series. The time frame of interest is 30-year duration (for past 1910-1940, for present 1980-2010 and for future

2070-2100) because to define the climate/climate change impacts upon a region, a duration of at least 30 years is appropriate.

Soil data is necessary for the calculation of the storage capacity of water in the soil. AWC (available water content) data is taken from the “Harmonized World Soil Database, Version 1.2” (FAO et al., 2012). This database is created by the combination of analysis from various countries and data sources. Data sources are mainly from 4 databases which are; European soil database (ESDB), 1:1 million soil map of China, various regional SOTER databases (SOTWIS Database) and the Soil Map of the World. Data taken from all those sources are not evenly distributed globally and there were gaps in the data. Also the properties of the places where the soil data are obtained are not well-described in the sources of materials. On the other hand, according to HWSD, there are few missing data, which are replaced by the nearest available information (FAO, 2012). Finally the data used in this study does not have any missing data.

According to this database soil textures are classified as **Coarse** (sand, loamy sand, sandy loams with less than 18% of clay and more than 65% of sand), **Medium** (sandy loams, loams, sandy clay loams, silt loams, silt, silty clay loams and clay loams with less than 35% of clay and less than 65% of sand) and **Fine** textured soils (Clays, silty clays, sandy clays, clay loams and silty clay loams with more than 35% of clay). Available water storage capacity is classified by FAO (1995) according to the texture of soil. Classes consisting of 150, 125, 100, 75, 50, 15 and 0 mm/m of storage have been used in this study. Reference soil is taken at a 100 cm depth. Classes for the Mediterranean region are created in ArcMap, using the soil information from FAO (Figure 3). As shown in Figure 3, water storage capacity is higher over most parts of North Africa except the western part where Morocco, Central Turkey and Bulgaria are located (in between 100-150 mm). Northern and western parts of the region have low water storage capacity (from 0 to 75 mm).

Thornthwaite's water balance model is applicable for any area, from smaller regions to continents, countries etc. In a steady-state world, incoming water (precipitation) should be equal to outgoing water (evapotranspiration) (Christopherson, 2006). However this is not the case in the real world over all durations. There are water deficiencies as well as surpluses in many parts of the world. The first step for calculating water balance is the derivation of potential evapotranspiration (PET). PET is important because actual evapotranspiration (AET) can be calculated from it, by using it together with precipitation, and hence by subtracting AET from PET, water shortages can be determined.

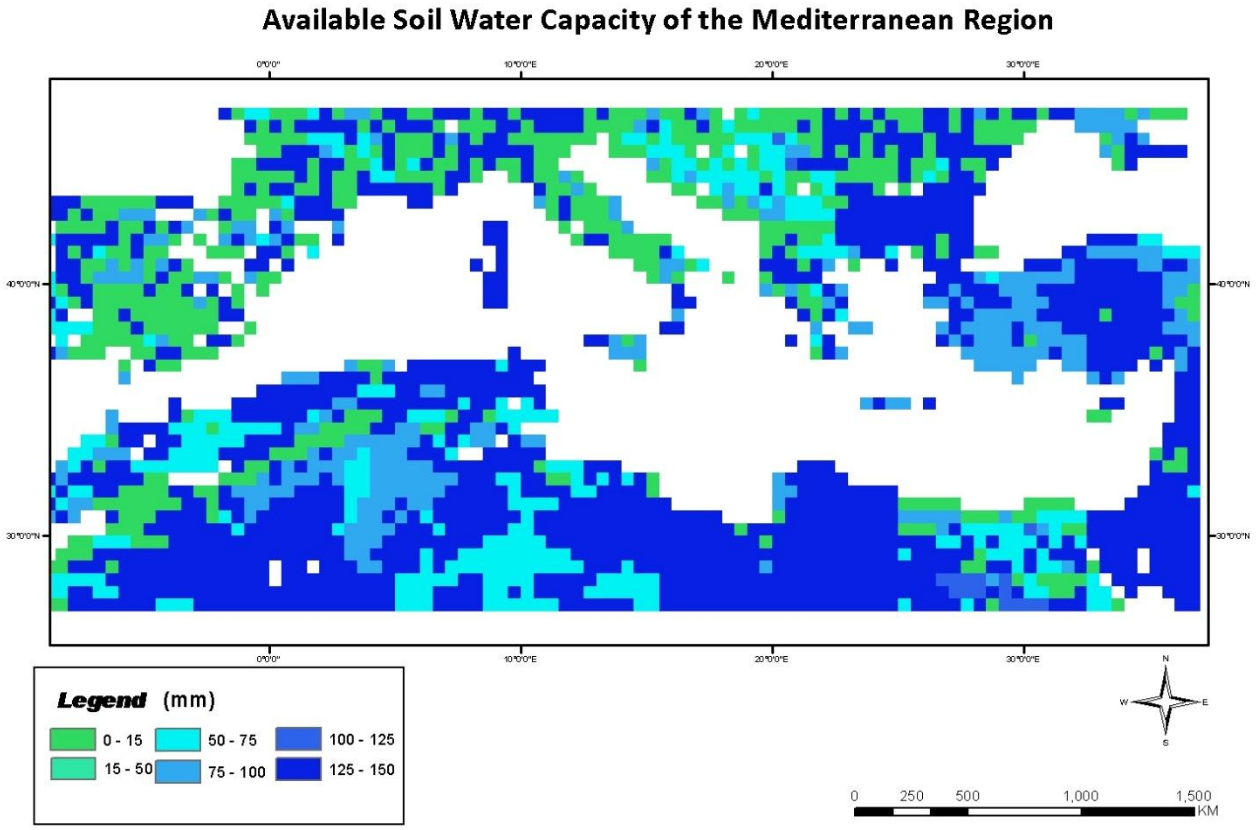

Figure 3 Available water content of the Mediterranean Region (Classified from HWSD, FAO, 2012)

PET is calculated as a function of latitude and day numbers in a month. The most important factors for evapotranspiration are temperature and day length hours (Thornthwaite, 1948) which are also the inputs of the Thorthwaite's formula. This formula is not applicable for temperatures below zero, since PET is expected to be at minimum below zero (Shevenell, 1996). So, under those circumstances, it is accepted as zero in this study. Negative temperatures (which are rare in the region of interest) are thus ignored in this study. The monthly heat (I) index is calculated by summing up 12 months in a specific formula that is shown in Equation 1. Also, exponent a is calculated by using heat index. The I Index varies in between 0 to 160 and a varies in between 0 to 4.25 (Thornthwaite, 1948).

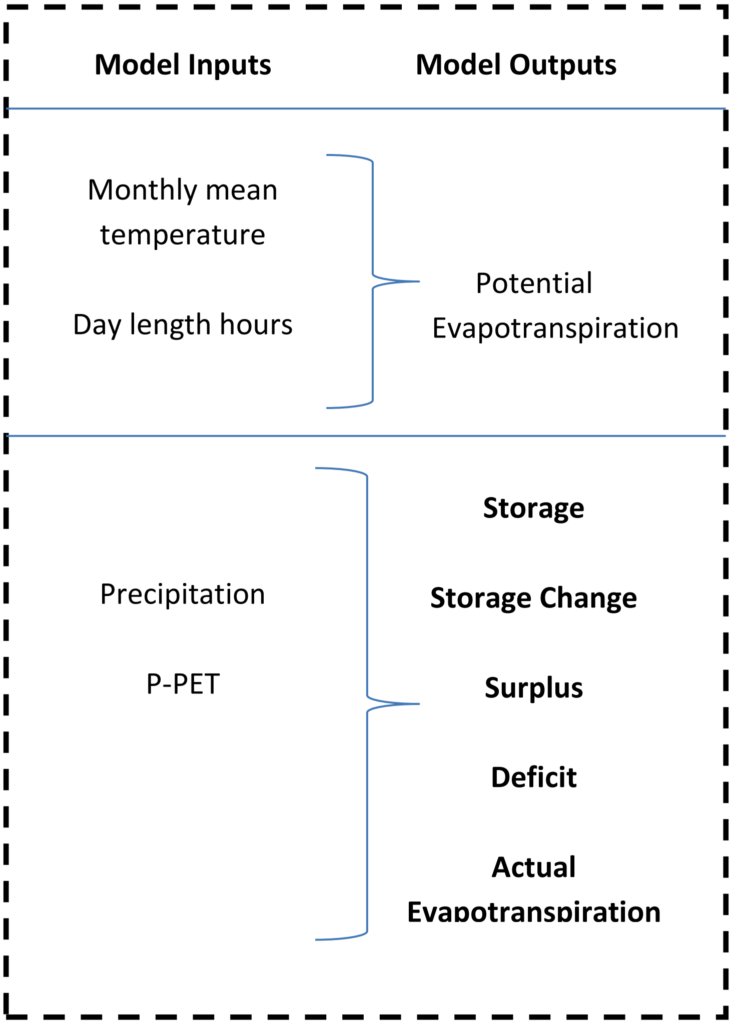

Figure 4 Model inputs and outputs

Potential evapotranspiration is expected to be higher during longer day lengths as well as at lower latitudes. Because in lower latitudes temperatures are higher and the only energy required for PET is net radiation, where there is more sun if the day is long and temperatures are higher in warmer months (May, June, July, August), we expect greater PET. To account for this phenomenon in this model, day lengths at each latitude in the model grid are calculated, as shown in Table 3.

Equation 1. Potential Evapotranspiration calculation by the Thornthwaite Method (mm/mo^{-1})

$$PET = 16.\left(\frac{\mathrm{D}}{12}\right).\left(\frac{\mathrm{N}}{30}\right).\left(\frac{10.\mathrm{Tma}}{\mathrm{I}}\right)^{a}$$

$$I=\sum_{i=1}^{12} \frac{Tma^{1.5}}{5} \qquad (1)$$

$$\mathrm{a}=0.000000675{*}I^{3}-0.000771{*}I^{2}+0.01792{*}\ I$$

PET = Potential evapotranspiration ($mm\ mo^{-1}$)
D = day length hours
N = number of days in the month
Tma = Monthly mean air temperature (°C)
I = annual heat index

Day length hours for any given latitude are calculated by Equation 2. The equation is used to compute the day lengths (D) for given latitude and a given day of year (Forsythe et al. 1995). Forsythe et al. (1995) compared several models in their study (CBM, Brock (Brock, 1981), BGC (Running and Coughlan, 1988), CERES (Ritchie, 1991)) and found that with a smaller range of error, the CBM approach is more accurate than the others. The inputs of the model are; day of year (J), sun's declination angle (Φ), latitude (L) and ρ (day length coefficient). The model allows the use of different ρ values according to various accepted definitions of day length (with/without twilight). In this study definition of day length is taken same as the US government's which is "Sunrise/sunset is when the top of the sun is apparently even with horizon" and according to this definition ρ coefficient is 0.8333 (in degrees).

Equation 2. CBM Equation for the day length calculation

$$\mathrm{D}=24 - \frac{24}{\pi} cos^{-1}\left[\frac{\sin\frac{\rho\pi}{180}+sin\frac{L\pi}{180}.sin\Phi}{cos\frac{L\pi}{180}.cos\Phi}\right]$$

$$(2)$$

$$\Phi = Asin(0.39795.(\frac{2.\pi}{363.25}\ (J-173))$$

Table 3 Maximum and minimum calculated day hours in the Mediterranean region

Months	Maximum day length	Minimum day length
January	10.48	8.78
February	11.06	10.04
March	11.75	11.49
April	13.15	12.55
May	14.60	13.24
June	15.52	13.66
July	15.39	13.60
August	14.28	13.09
September	12.71	12.34
October	11.56	11.10
November	10.83	9.56
December	10.37	8.55

4.2. Terms of Thornthwaite's water balance approach

4.2.1. Potential Evapotranspiration

According to Thornthwaite (1948) potential evapotranspiration (PET) is the ability of soil and vegetation to remove water from the surface by evaporation and transpiration with available energy. It gives an idea about the situation if there would be enough water under available energy (temperature) which is often different from the current situation (Thornthwaite, 1948). PET can be estimated by Thornthwaite's formulae.

4.2.2. Actual Evapotranspiration

Actual evapotranspiration (AET) is the combination of evaporation and transpiration, which is actually moving upwards from soil and vegetation to the atmosphere under current conditions (Christopherson, 2006)..There aremethods in order to determine actual evapotranspiration in a place or a region for instance eddy covariance measurements and satellite data (Garcia et al., 2013). AET has two ways to be estimated which are direct and indirect ways (Garcia et al., 2013). Indirect estimation of actual evapotranspiration can be done via a bulk resistance equation for heat transfer which is mainly based on the difference between surface and air temperatures and the aerodynamic resistance to turbulent heat transfer (Anderson et al., 2007). Direct modeling of AET is possible by the Penman-Monteith equation which is using remote sensing data (Leuning et al., 2008). Combination of gridded meteorological data and vegetation images together with some equations (e.g Penman-Monteith) allows the estimation of AET (Garcia et al., 2013). Another estimation approach for AET is possible by Thornthwaite's water-balance approach which can be estimated by PET and available precipitation data (Thornthwaite,1948). Actual evapotranspiration is calculated by setting a condition; if P – PE < 0, it is the sum of precipitation and storage change. Otherwise it is same as PET (Thornthwaite, 1948).

4.2.3. Storage

Precipitation is an important input to the water balance model in order to determine if the water supply is meeting vegetation demand, resulting in evapotranspiration and some water left over in soil storage (Christopherson, 2006). Precipitation must supply actual evapotranspiration, surplus and soil moisture storage all together. If precipitation is higher than evapotranspiration (P > PET) water is stored in the soil until it reaches it holding capacity. After a while water infiltrates from larger pores and the water that remains in the soil after downward movement, which is for the use of vegetation by means of transpiration and for the soil by means of evaporation, is called “field capacity” or “storage capacity”. This is the water stored in the soil available for the access of plant roots (Christopherson, 2006). Storage is equal to the field capacity if precipitation is higher than evapotranspiration (P > PET). However, storage changes over the whole year. While the storage is charging itself during the wet seasons, it does the opposite in the dry months (mostly in summer) (Thornthwaite,1948).

4.2.4. Storage change

When evapotranspiration exceeds precipitation, soil loses water so storage decreases in the soil until precipitation is higher again and it starts increasing until it is completely refilled again. This change is called the storage change of the soil (Thornthwaite, 1948). Change in storage can be calculated by taking the difference between the previous month’s storage and the current month’s storage (Thornthwaite, 1948).

4.2.5. Surplus

After evapotranspiration is met and storage is full, if there is still water in the soil more incoming precipitation returns to surplus. Surplus can be part of runoff, groundwater or utilization (Christopherson, 2006). In order to see if there is water excess in the region, surplus must be calculated according to Thornthwaite's water balance approach. If soil capacity is saturated with water and further water is added onto the soil, this water will be surplus that can be collected in rivers and lakes or infiltrate to the water table (Christopherson, 2006). If precipitation is higher than evapotranspiration surplus can be found by subtracting storage change from P - PET. If it is lower, surplus is then zero (Thornthwaite, 1948).

4.2.6. Deficit

In a place or a region if there is lesser precipitation than PET that means incoming water is not matching outgoing water (Thornthwaite, 1948). Deficit occurs if the water cannot satisfy the demand of PET (Thornthwaite, 1948). Deficit is one the reasons for the water shortages in a region which hence bring stresses on the water resources. It can be estimated by subtracting PET from AET.

4.3. Modeling the water-balance

All the hydrological measures of Thornthwaite's water balance approach described above are estimated in Model Builder which is a tool available in ArcGIS 10. Model Builder allows iterate runs as well as using outputs as inputs. This capability of the model facilitates the obtaining of results, especially for studies using large time-series datasets. As a result the model created thousands of images which are then reduced to 30-year seasonal maps for winter (DJF), spring (MAM), summer (JJA) and autumn (SON). The main input of the model is P-PET. So, as a first step all of the monthly gridded precipitation data are subtracted from estimated PETs. The model is created by setting the conditions stated in Table 4.

Table 4 Condititons set in the modeling of the water balance

Modeled component (mm)	If	Statement	Result	Otherwise
Storage	Previous month's Storage + P-PET	> AWC < 0	AWC 0	Same as "If" statement
Storage Change			Previous month's storage-Current month's storage	
Surplus	P-PET + Stor change	< 0	0	Same as "If" statement
AET	Precipitation	> PET	PET	P + Storage change
Deficit			PET.AET	

This model is applied for the observed past, present and estimated future conditions. All the units of the model results are in millimeters. For the future, one of the IPCC scenarios is chosen in order to see the impacts of the climate change on the water availability of the region under that specific scenario. The SRES A1B sub-storyline can be accepted as an average scenario for the future projections, and it is preferred in this study because it is one the most realistic scenarios. Only monthly mean temperatures are increased and precipitation is kept same as present (Figure 12) for future scenario. According to the A1B sub-storyline, temperature rise will be up to 4 degrees by the end of the century (IPCC, 2007, Table 1). Temperatures are increased gradually in my representation of this scenario (starting from zero to 4 degrees). Modeled temperature data according to A1B scenario is shown in Figure 10.

5. Results

5.1. Comparison of Present and Past Water Balances in the Mediterranean Region

In this section, past and present water balances of the Mediterranean region are compared in order to see the changes between the two periods. All the maps are obtained by subtracting past (1910-1940) from present (1980-2010) values. While positive values represent increased values in the present, negative values show reductions in the present.

5.1.1. Comparison of Present and Past Potential Evapotranspiration (PET)

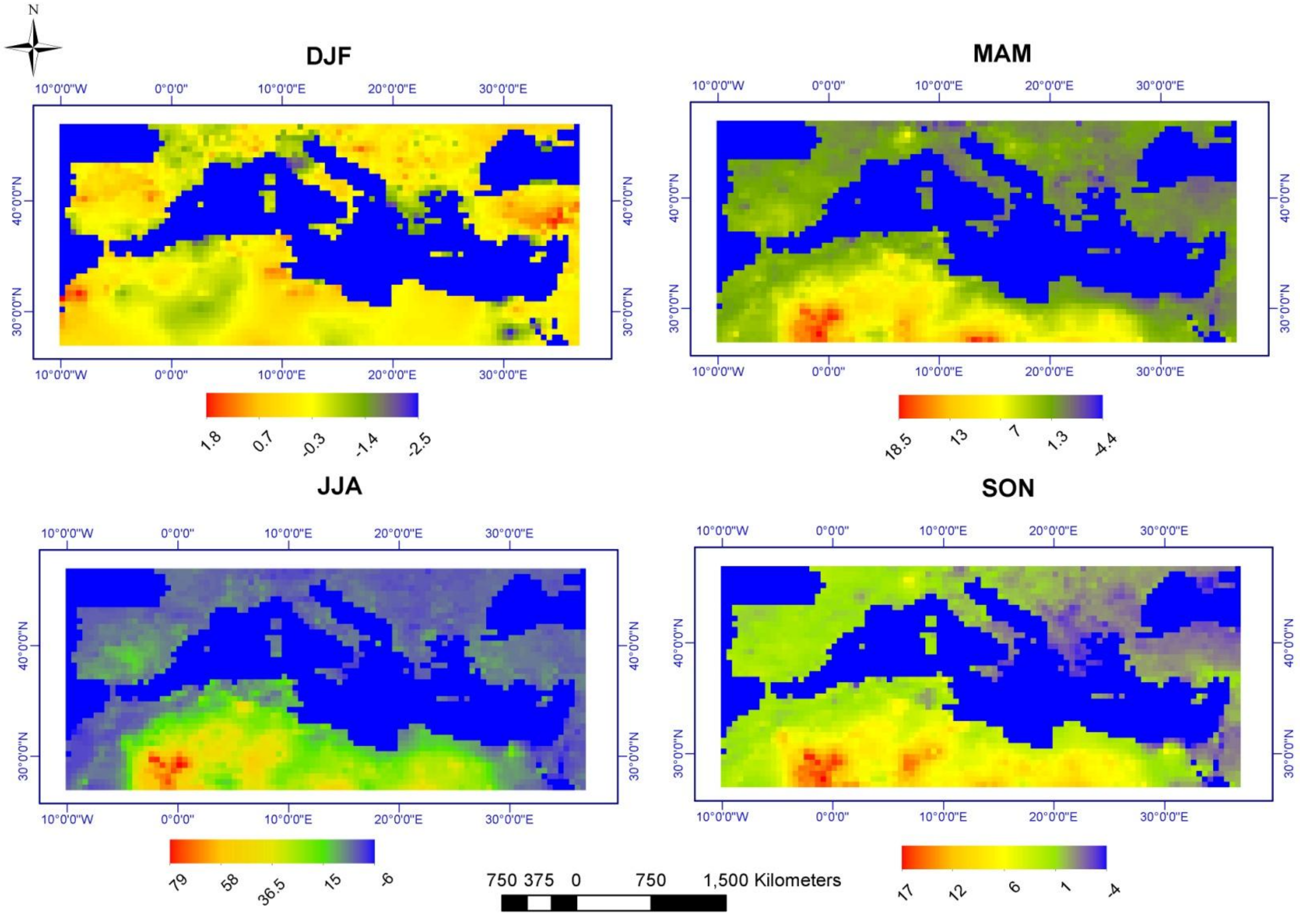

Figure 5 Compared present and past mean PET in the Mediterranean region (1980-2010 minus 1910-1940 in mm)

Calculated PETs are not same in the past and present. Figure 5 shows the difference of PET between the two periods. In general, present PET is higher in most of the seasons, except winter (DJF). In winter only a few places have greater PET. The higher PET values are more visible in a small part of Morocco, Algeria, Spain, the Balkans and central Turkey have a maximum difference of 1.8 mm, which is not very large. The inlands of the North Africa have lower PET than in the past, especially in Algeria and Egypt. Most parts of the Mediterranean region have a slight decrease in the present PET (around -0.3 mm). In spring (MAM) there are mainly increased values in the Mediterranean region, especially in the inlands of North Africa with a maximum value of 18.5 mm. The range varies between 1.3-18.5 mm in North Africa. Lower differences are found in the coastal zone of Italy, north of Turkey, and some coastal parts of Egypt and Israel. The difference is the highest in summer (JJA). Maximum difference is found in the inlands of Algeria, with a maximum 79 mm increase. Also, in the south of Spain there is increase in PET of around 15 mm. The rest of the Mediterranean seems have less of an increase in summer. In autumn (SON), there is decreased PET in the south of Italy, Greece, the east coast of the Balkans and Turkey, of up to -4 mm. Other parts of the region have higher PET in SON.

5.1.2. Comparison of Present and Past Actual Evapotranspiration (AET)

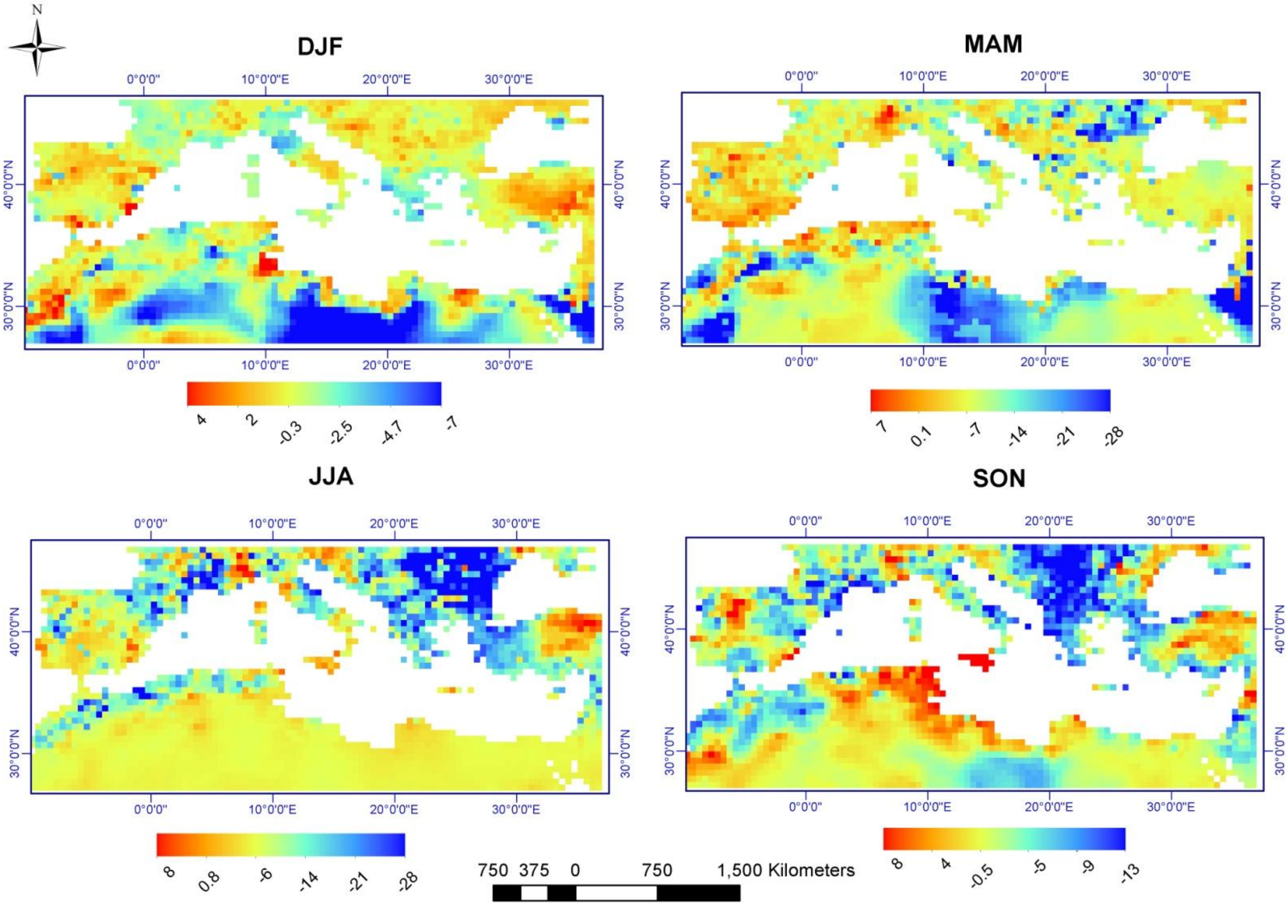

Figure 6 Compared present and past mean AET in the Mediterranean region (1980-2010 minus 1910-1940 in mm)

Comparisons of past and present actual evapotranspiration in the Mediterranean region are shown in Figure 6. In winter, there is lower AET in the present than in the past, especially in the inlands of North Africa with a maximum change of -7 mm. In some very small spots, such as in Morocco, Algeria, and Egypt, AET is higher in the present with a maximum difference of 4 mm. In the north of the Mediterranean, except for some isolated areas, AET is slightly lower than in the past. In Spain and central Turkey, AET is higher in the present than in the past in DJF. In spring, present AET is lower in North Africa, except for some spots in Morocco and Algeria. Other parts have decreased AET values; as much as -28 mm. AET is increased in Spain and in the Swiss Alps, up to a maximum change of 7 mm. Also, Romania has a considerable decrease in the spring, where the maximum change is -28 mm. In Summer (JJA), actual evapotranspiration is mainly lower in the Balkans, Greece, in the west of Turkey, France, and in some parts of Morocco and Algeria; differences are as great as -28 mm. AET is higher in summer in Italy, south Italy, Sicily, Croatia and the north and central parts of Turkey. In Autumn (SON), AET is lower in Morocco, Libya, Israel, coastal zone of Turkey, Bulgaria, Greece, the Balkan Peninsula, south of Italy, France and some parts in Spain. Higher AET are found in Morocco, the coastal zone of Algeria, Sicily, the central part of Spain, the Romanian and Russian coasts of the Black Sea, central and north of Turkey, and Lebanon; values differ up to 8 mm. In some seasons, reductions in AETs are more than small increments, especially in MAM and JJA. The maximum increase is 7-8 mm, which is also found in spring, summer and autumn.

5.1.3. Comparison of Present and Past P-PET

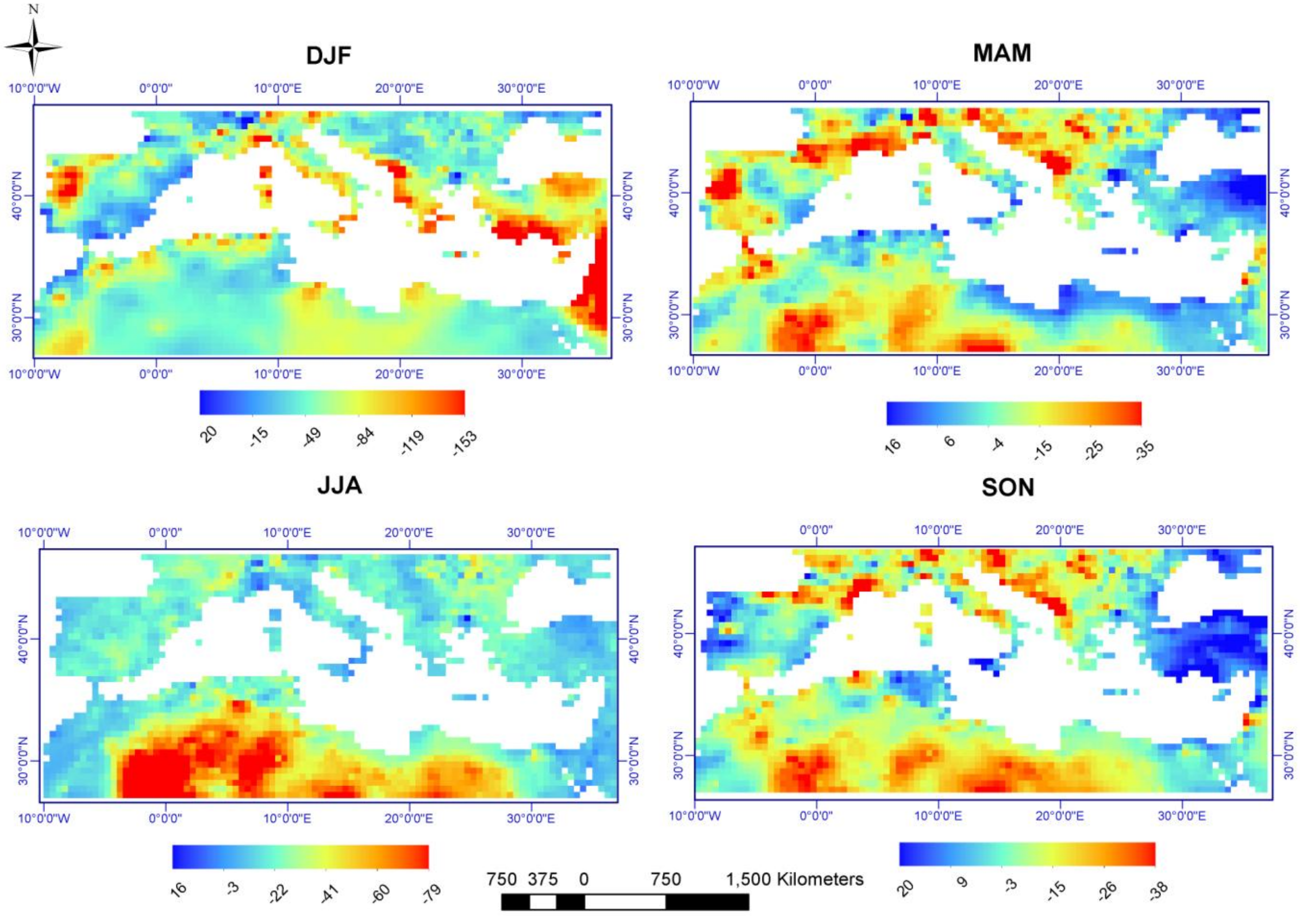

Figure 7 Compared past and present P-PET in the Mediterranean region (1980-2010 minus 1910-1940 in mm)

In Figure 7, past and present P-PET is compared by subtracting past from present. In each season, there are considerable P-PET differences between past and present. Reduced present values are more common than increased ones. The greater reductions are in winter (DJF), which has differences up to -153 mm. The whole of North Africa has lower values in the present than in the past. Some parts have greater reductions than such as in Morocco, Algeria and Libya. The maximum reductions are in Portugal, Italy, Corsica, Sardinia, the west and south coast of Greece, the south of Turkey, the north of Cyprus and the west coast of Middle-East. In general there are smaller P-PET values in present. Some locations, such as south and East of Spain, the Alpine region and a narrow line in the coast of Morocco, have higher values with a maximum of 20 mm. This can be because of increased/decreased precipitation and PET. In spring, P-PET is higher in more parts than in DJF. The coastal zone of North Africa (except the coast of Morocco), some parts in Spain, south Italy, Bulgaria, some parts in Romania and Ukraine, Turkey and Crete have higher values, ranging up to 16 mm. P-PET is lower in the rest of Mediterranean, and the maximum decrease is in Morocco, the inlands of North Africa, Spain, the Alpine region and the west coast of Balkan Peninsula with differences of up to -35 mm. In summer the largest decreased values are in the inlands of North Africa, which is in between -41 and -79 mm. In JJA, the highest increment in P-PET is found only in one grid cell, in Greece on Mount Olympus. North of the Mediterranean Sea and the coastal zone of North Africa have lower values as well, which is range between -3 and -22 mm. In spring, the most significant increase is in Turkey, some coastal parts of the Black Sea, the west of Spain, and Sicily. The largest reductions are in the North Africa, France, Italy and the west coast of Balkan Peninsula.

5.1.4. Comparison of Present and Past Storage

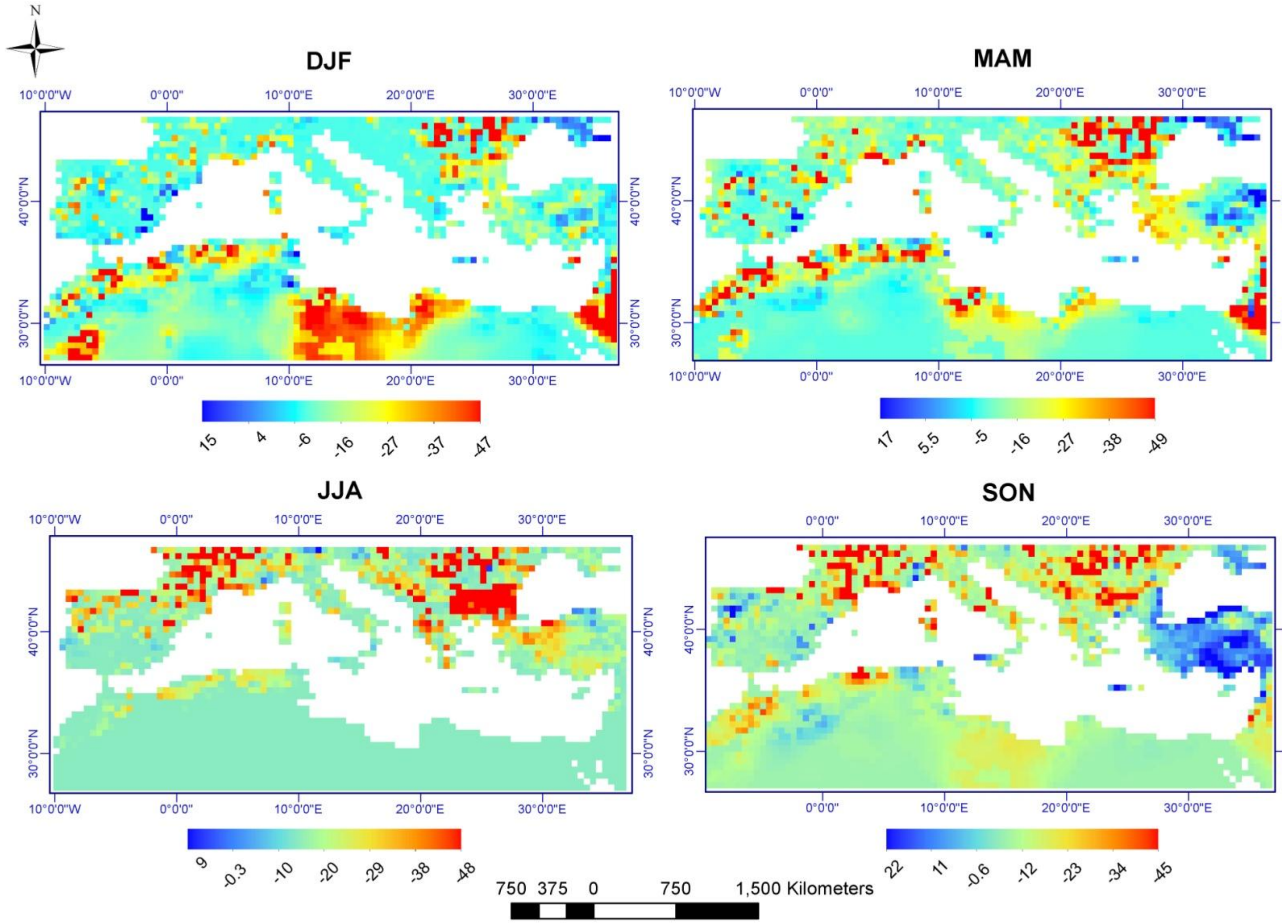

Figure 8 Compared past and present storage in the Mediterranean Region (1980-2010 minus 1910-1940 in mm)

In the Figure 8 past and present seasonal mean storage of the Mediterranean region is compared. Water stored in the soil has a significant decrease in the present, especially in the coastal zones of Morocco and Algeria, Libya, the West coast of Middle-East, Romania and Bulgaria, with a maximum 47 mm decrease. Increases are not very widespread in the winter, only in some limited areas. Only some locations on the coast of Algeria, the west coast of Spain, the Black Sea coast of Ukraine, and Crete have increased storages in DJF with a maximum change of 15 mm. The rest of the Mediterranean region has decreased storage around -6 mm. In spring (MAM), the maximum change is on the Black sea coast of Ukraine and the central and northeast parts of Turkey, with a change of 17 mm. In spring, present storage is less than that of the past in the coastal zone of Morocco, Algeria and Tunisia that is at the maximum, a -49 mm decrease. In the Eastern Mediterranean coast of the Middle East, the decrease in spring is very significant, with a change of -49 mm. Also, a decrease can be seen in the Balkans. In summer, almost the whole Mediterranean region has decreased storage compared to the present. North Africa and the coastal zones of the other countries have reductions in between -10 and -20 mm, except some parts of the coast of Morocco and Algeria. The maximum reductions in JJA are in Spain, France, the Alpine region, Greece, Bulgaria, Romania, and northwest of Turkey with a maximum decrease of -48 mm. In spring, Turkey has more storage in the soil than past, with maximum increase of 22 mm. In general in all seasons there is less storage in the soil, except in some parts of the Eastern and Western Mediterranean.

5.1.5. Comparison of Present and Past Surplus

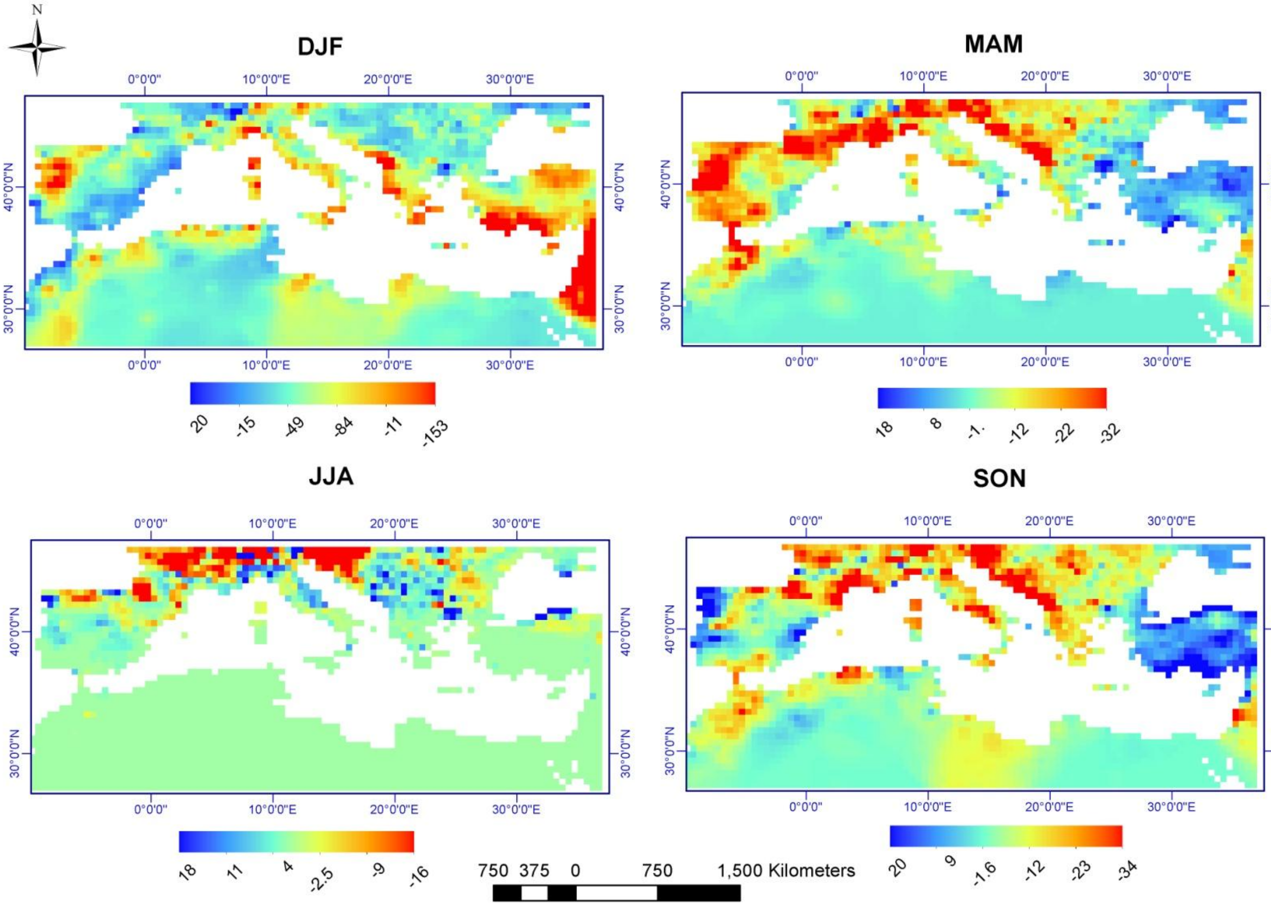

Figure 9 Compared past and present surplus in the Mediterranean region (1980-2010 minus 1910-1940 in mm)

Figure 9 compare past and present mean surplus values in the Mediterranean region. In the present, the largest reductions are seen in winter with a maximum change of -153 mm. Those reductions are located in west Spain and Portugal, Corsica, south Italy, the western and southern coasts of Greece, the north and south of Turkey, and on the Eastern Mediterranean coast of the Middle East. Most of the parts of the region have considerable winter decreases in present surplus except the west coast of Morocco, the south and east coasts of Spain, the Alps, some spots in the Balkans and the Ukraine, and Olympus Mountain in Greece. In spring (MAM) reductions are less than DJF, however there are still decreases in most of the region, except in Turkey, Bulgaria and Ukraine. Those parts have 18 mm more surpluses than in the present. In summer smaller surpluses are mostly found in the north of the Mediterranean region, such as in the north of Spain, France, and the Alpine region, Croatia, Slovenia and in some parts in Balkans, with up to a 16 mm decrease. The rest of the Mediterranean doesn’t have a significant decrease in JJA. Changes are not found in in large areas in summer. Some spots such as in Spain, Italy, the Balkans and north Turkey have increased surpluses of up to 18 mm in present. For

Turkey, SON and MAM are the most efficient seasons for increased surpluses. In SON there are more surpluses in Turkey in everywhere up to 20 mm. IN autumn there are fewer surpluses in the north of Mediterranean compare to summer. There are reductions in between -2 and – 34 mm.

5.1.6. Comparison of Present and Past Deficit

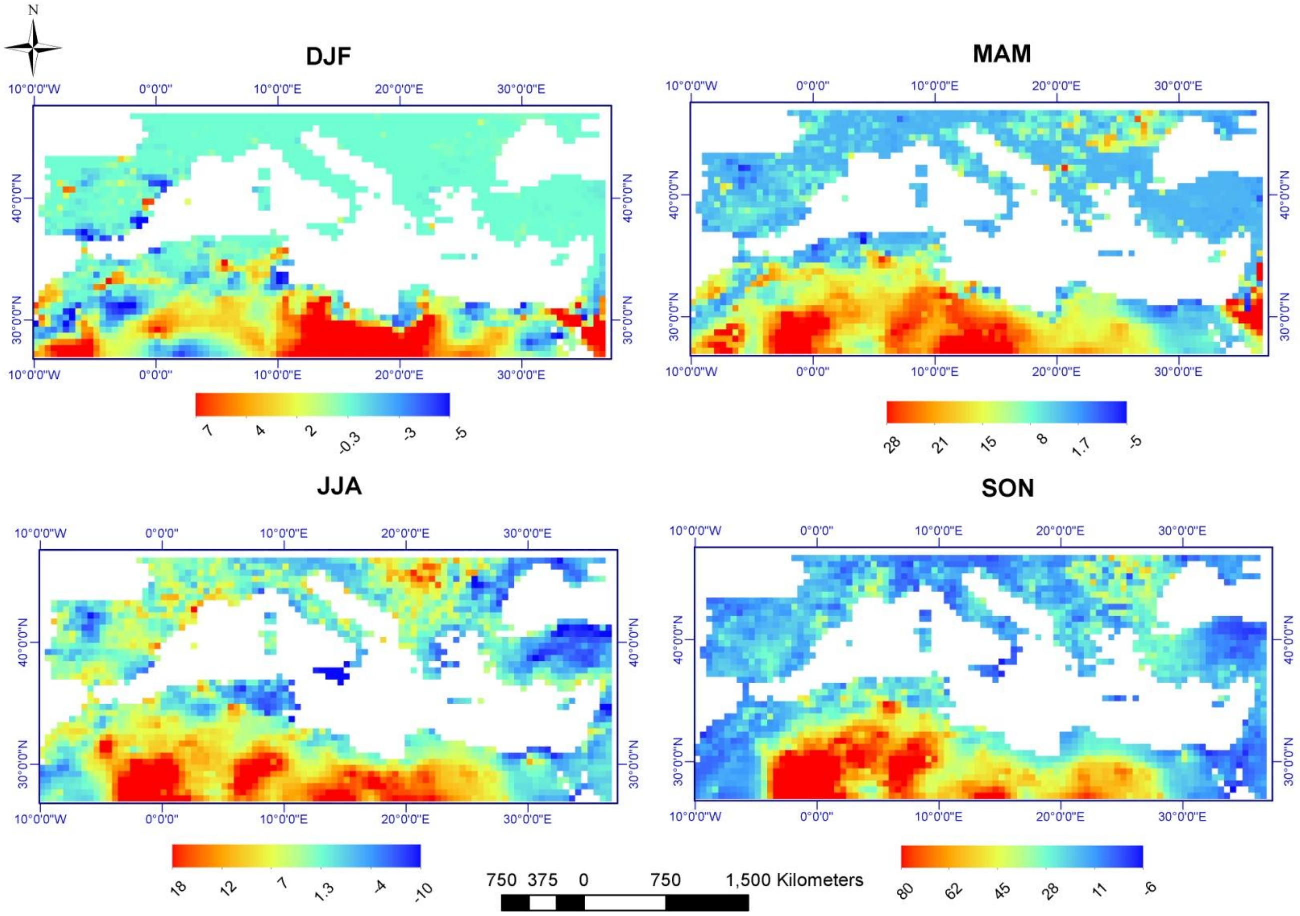

Figure 10 Compared past and present mean deficit in the Mediterranean region (1980-2010 minus 1910-1940 in mm)

In Figure 10 seasonal past and present deficits are compared. In winter, in the north of Mediterranean Sea there is no difference between past and present deficits, except in some spots in the coastal zone of Spain. There are fewer deficits in the east and southern coast of Spain, some places in Morocco, Algeria and Egypt; values range up to – 5 mm. In the inlands of North Africa there are more deficits in the present, up to a maximum of 7 mm. In spring (MAM) there are more deficits in the North of the Mediterranean Sea, in between 1.7 and 20 mm. More deficits are in the inlands of North Africa and Egypt with a maximum value of 28 mm. In summer (JJA) on the coasts of Algeria and Tunisia, Sicily, the east coast of Greece, the coast around the Black Sea, Turkey and the Eastern Mediterranean coast of the Middle East have lower deficits, mostly around values of -10 mm. Deficits have increased from the past to the present in North Africa between 7-18 mm. In autumn (SON) deficit is significantly lower in the south of Italy, the central north of Turkey and in Egypt. In other parts, especially in the central parts of North Africa, there are more deficits up to 80 mm.

5.2. Comparison of Present and Future Water Balances in the Mediterranean Region

All the maps in this section are derived by subtracting present from future.

5.2.1. Comparison of Present and Future Potential Evapotranspiration (PET)

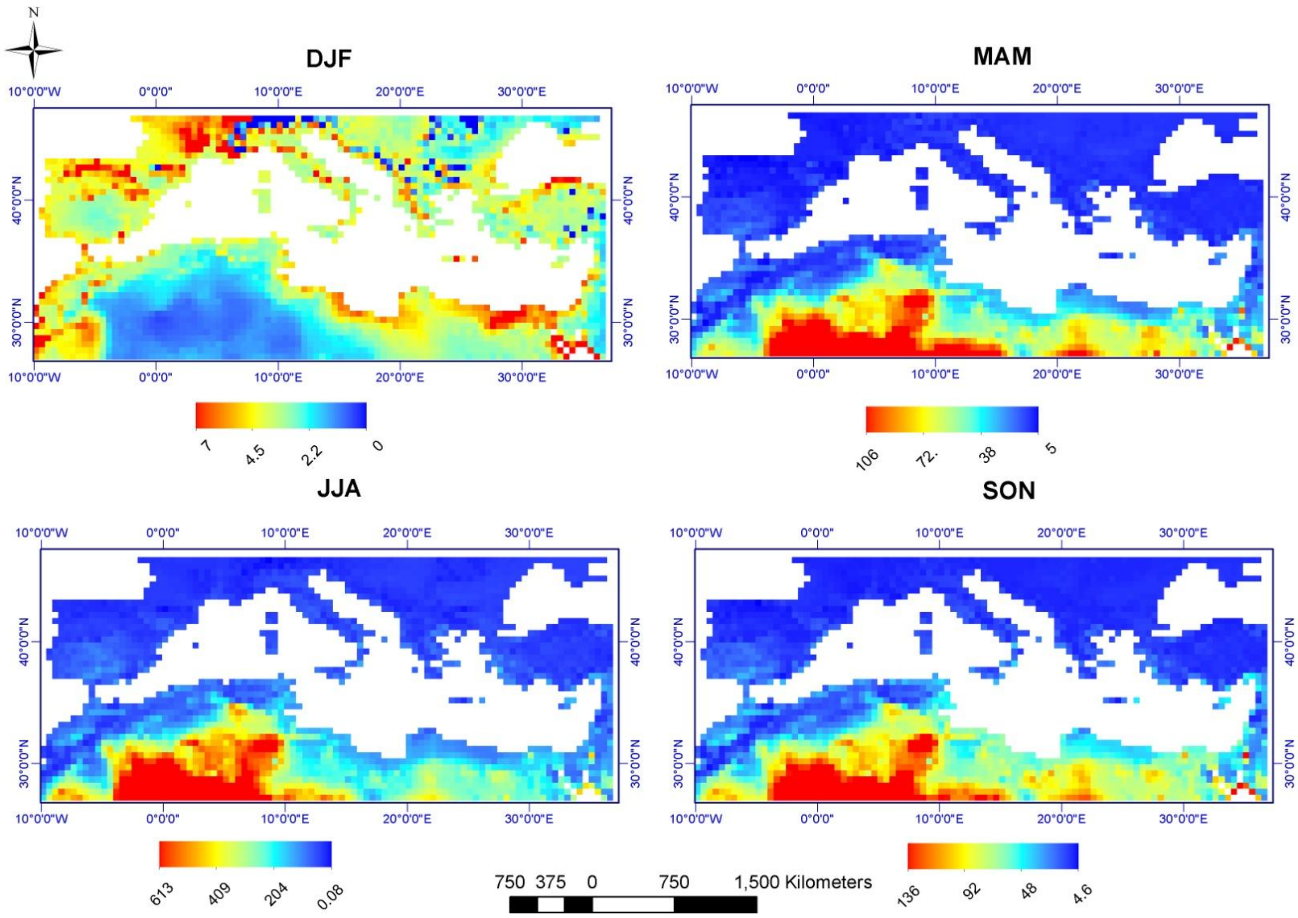

Figure 11 Compared present and future PET in the Mediterranean region (2070-2100 minus 1980-2010 in mm)

In Figure 11, seasonal future and present potential evapotranspiration values are compared. In winter (DJF) PET has slightly increased in the central-west of North Africa. In the Alps, some parts in the Balkans and the South-east of Turkey do not have any changes in the future in the winter. The largest changes are in the western coastal zone of North Africa, northern Spain, France and the central north of Turkey, with a maximum change of 7 mm. In spring, in the North of the Mediterranean Sea we can see higher PET values, around 5 mm, which is also the smallest change in the region. The inlands of Algeria experiences higher PET in the future, with a maximum change of 106 mm. Other parts of North Africa have high PET in the future as well, with values ranging between 38-72 mm. In summer in the north of the Mediterranean Sea and the coastal zone of Morocco, there are very few changes to PET in the future, which are less than 1 mm. On the other hand, in the inlands of the Algeria PET has increased to almost twice its present value in the future, which is 613 mm. In autumn in Algeria, PET is still higher; however it is much less than the change seen in the summer, with a maximum increase of 136 mm. The north of the Mediterranean has increased PET of around 5 mm.

5.2.2. Comparison of Present and Future Actual Evapotranspiration (AET)

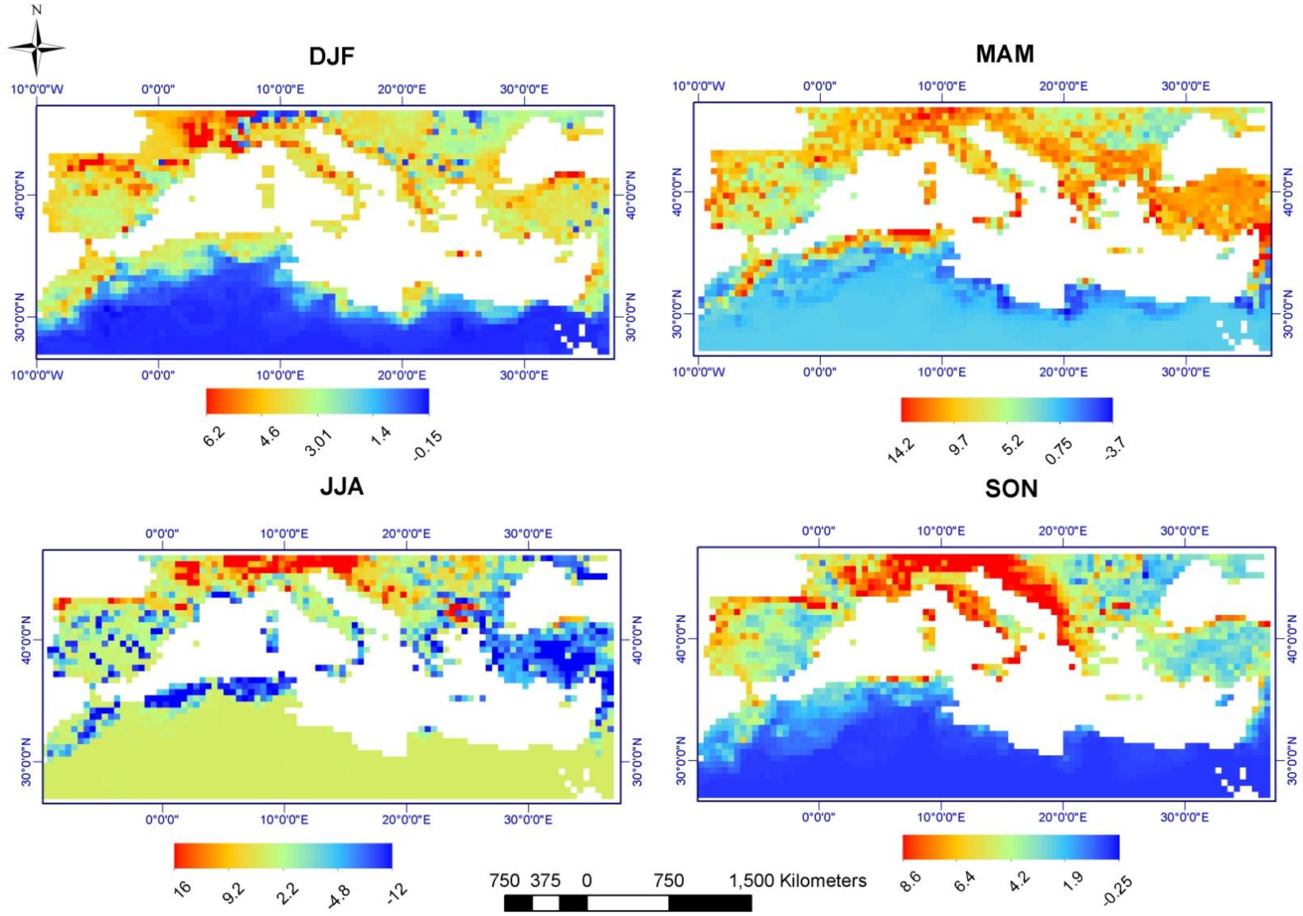

Figure 12 Compared present and future mean AET in the Mediterranean region (2070-2100 minus 1980-2010 in mm).

In Figure 12, future and present mean actual evapotranspiration are compared in order to deduce changes between two periods. According to model results, in the future there will be higher AET values, mainly on the coastal zone of North Africa and north of Mediterranean Sea. The inlands of the North Africa will not have much difference in the future (typically less than 1 mm). The other parts of the region will have changes between 3 and 6.2 mm. The most pronounced increases are in the north of Africa, France, some locations in Italy, the west coast of the Balkan Peninsula and the central north of Turkey. In the Swiss Alps there is almost no change in winter. In spring (MAM) there will be lesser AET in some parts of the coast of North Africa. On the other parts of North Africa, except for the coast of Morocco, Algeria and Tunisia, there is increased AET, with values changing between 5.2 and 14.2 mm. In summer there is more AET in the future in North Africa, except on the coast of Morocco, Algeria and Tunisia -around 12 mm less AET- which is the opposite of what we see in the spring (MAM). In summer some spots in Spain, France, south Italy, Sardinia, Sicily, Greece, Bulgaria, Ukraine, Turkey and the Eastern Mediterranean coast of the Middle East have lower AET, with values decreasing up to 12 mm. Increased AET is mostly found in the Alpine region and a small portion of Greece, with a maximum value of 16 mm. In Autumn (SON) there is not much change in North Africa and the Eastern Mediterranean coast of the Middle East, except in some locations in Morocco and Tunisia. Greater AET is found in the Alpine region, Italy and the west coast of the Balkan Peninsula with a maximum change of 8.6 mm. In general there is greater AET in the north of the Mediterranean Sea in the future, where this amount is in between 1.4 and 6.4 mm.

5.2.3. Comparison of Present and Future P-PET

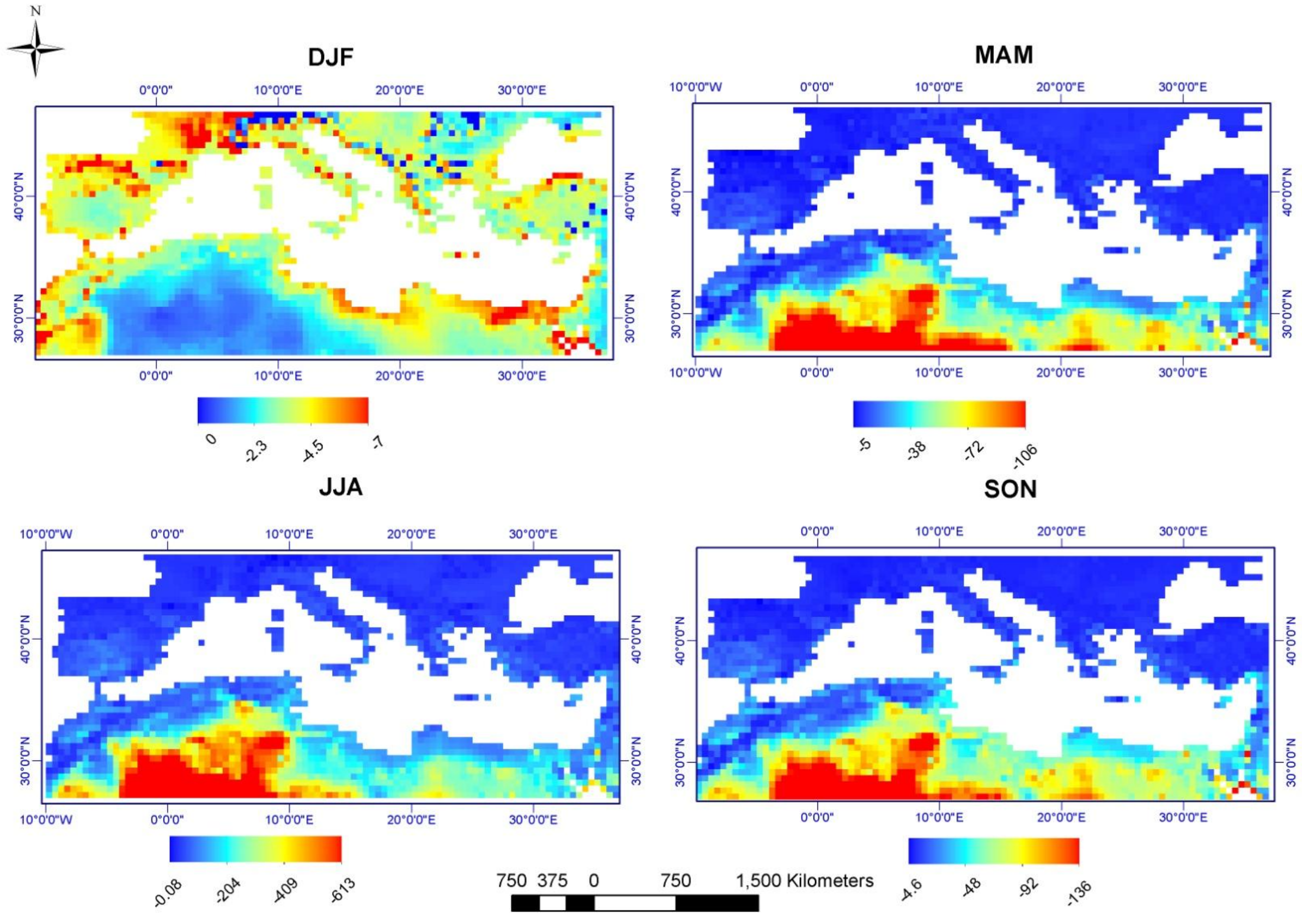

Figure 13 Compared present and future P-PET in the Mediterranean region (2070-2100 minus 1980-2010 in mm)

In Figure 13, present and future P-PET values are compared. The model predicts very few changes in the future P-PET in the inlands of Algeria. The coastal zone of North Africa has lesser P-PET values, between -4.5 and -7 mm. In the north of the Mediterranean Sea the maximum decreases in the winter are in the north of Spain, the Alpine region and the central north of Turkey. In the north of Italy in the Swiss Alps there are almost no changes in P-PET in future. In spring (MAM) in the north of the Mediterranean Sea and the coastal zone of Morocco, Algeria and Tunisia, the decrease is around -5 mm. The maximum decrease in the future spring is -106 mm in the inlands of Algeria, Tunisia and Libya. In the inlands of North Africa, the decrease in P-PET is between -38 and -106 mm. In summer, there is a huge reduction in the inlands of Algeria of about -613 mm. The coastal zone of North Africa has a reduction that is between -204 and -613 mm. In autumn (SON) there is decrease in the north of the Mediterranean Sea of around -4.6 mm. In the north of Africa the greatest decrease is again in the inlands of Algeria with a change of -136 mm. The decrease in North Africa is in between -4.5 and -136 mm, where the smallest decrease is in the coastal zone of Morocco, Algeria and Tunisia.

5.2.4. Comparison of Present and Future Storage

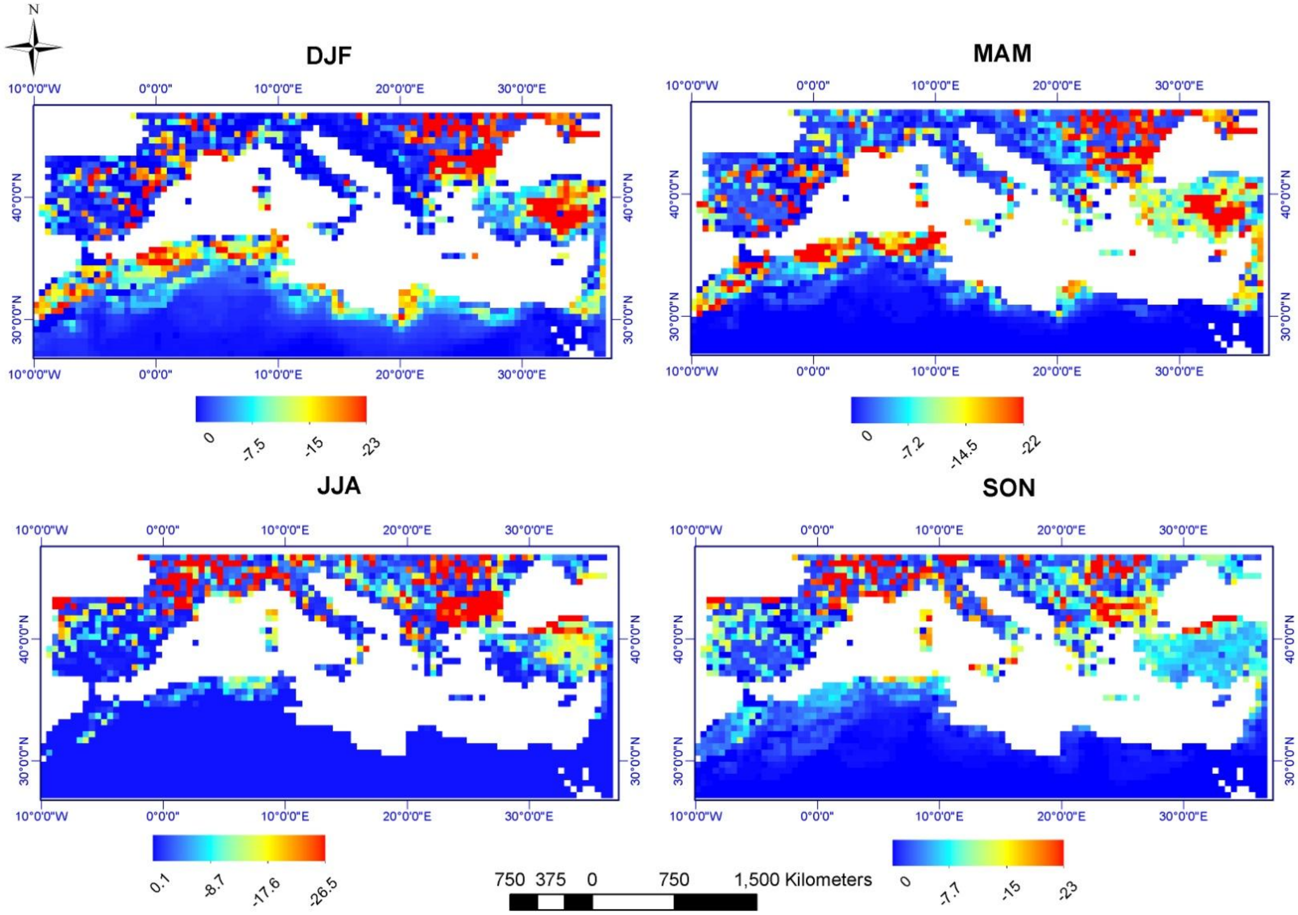

Figure 14 Compared present and future mean storage in the Mediterranean Region (2070-2100 minus 1980-2010 in mm).

Figure 14 compares present and future stored water in the soil, and shows the differences between two seasons. In winter (DJF) in the inlands of North Africa, most of Spain, France, Italy and the west coast of the Balkan Peninsula have no change in future storage. The largest changes are in the coastal zone of Morocco, Algeria and Tunisia, some spots in Spain, in the Black Sea coast and central Turkey, which has a change of -23 mm in winter. Some coastal parts of North Africa and the west of Turkey have decreases of about -7.5 mm in the future. In spring, storage has no change in the inlands of North Africa, Spain, France, Italy (except the south part), and the western coast of Balkans. The largest changes are in the coastal zone of Morocco, some spots in Spain, in eastern parts of the Balkans and central Turkey, which have values between -7.2 and -22 mm. In summer (JJA) storage has not changed much in the most parts of North Africa except the along the coasts of Algeria and Tunisia, which the change is around -9 mm. In the north of the Mediterranean Sea there are some places which have very few changes, such as south Spain, South Italy, South of Greece and the south-west of Turkey. The largest changes are in the Alpine region and Bulgaria and the north of Turkey, with maximum change of -26.5 mm. In Autumn (SON) there are no changes in most parts of North Africa except Morocco, Algeria and Tunisia, which is around -7.7 mm. The largest changes in the future SON are in the Alpine region, Bulgaria and the north of Turkey; up to -23 mm increases. The rest of Turkey has decreased storage in the future SON of around -7.7 mm.

5.2.5. Comparison of Present and Future Surplus

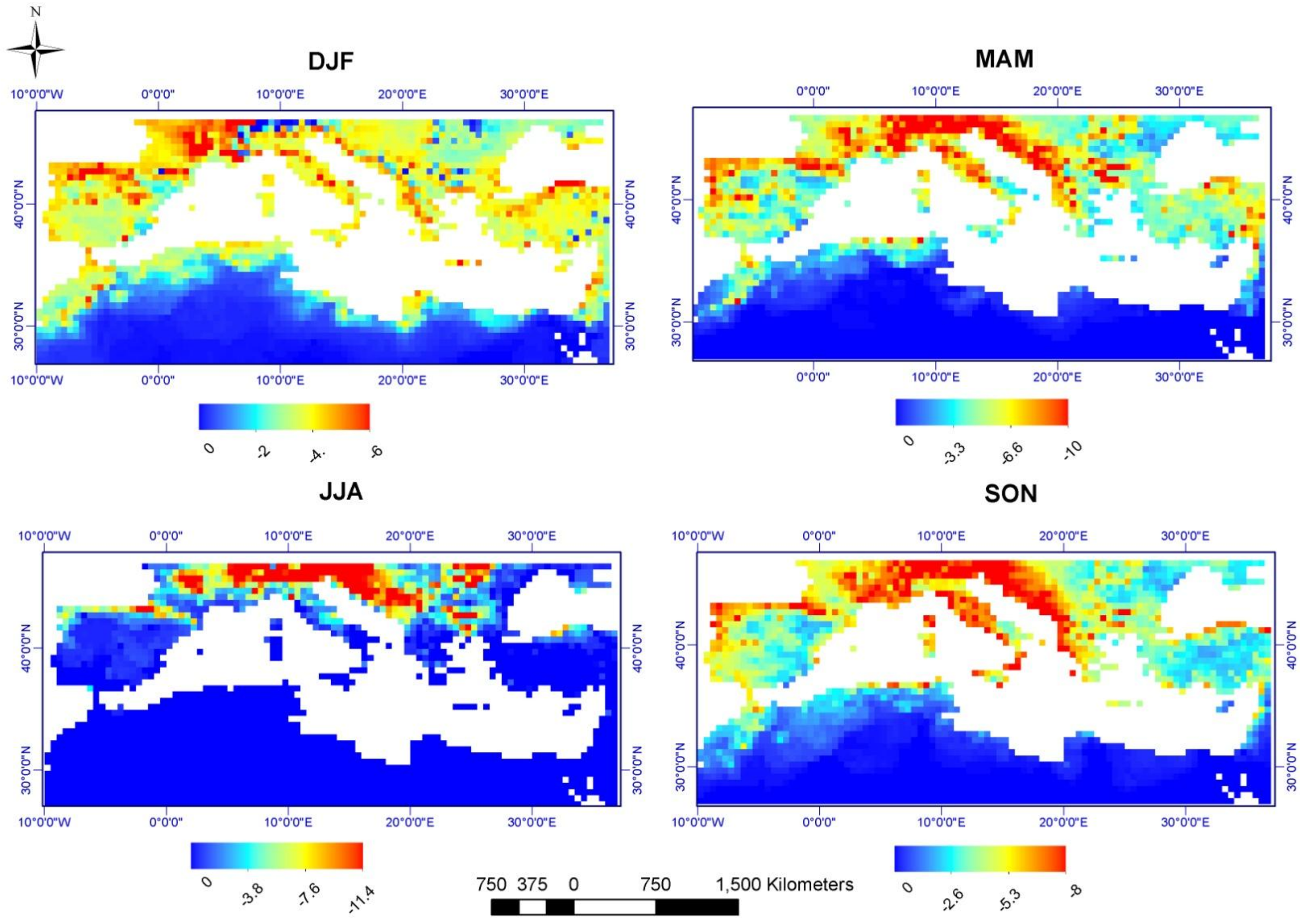

Figure 15 Compared present and future mean surplus in the Mediterranean region (2070-2100 minus 1910-1940 in mm)

Figure 15 shows the comparison of present and future mean surpluses in the Mediterranean region. In winter there is no change in the surplus in the inlands of North Africa. However on the coast of North Africa, changes are between -2 and -4 mm. The north of the Mediterranean Sea has decreases in the future surplus around -4 mm in most locations. However, some parts such as the north of Spain, France, the coastal zone of the Balkan Peninsula and the north coast of Turkey have a maximum decrease of around -6 mm in DJF. In spring, North Africa has no changes in the surplus except along the Moroccan, Algerian and Tunisian coasts. Decrease in surplus is around -2.6 mm in those locations. In Spain there are difference between the north, east and south. While there are -3.3 mm decreases in the east there is a high amount of decrease in the north of around -10 mm. In the central and southern parts the decrease is around 6.6 mm. Also, in the mountainous region of the Pyrenees the decrease is -10 mm. In the Alpine region, Italy, the west coast of the Balkan Peninsula and in some parts in Greece, there is also a maximum decrease (-10 mm) in MAM. In summer the changes in the surplus has moved northwards. The southern Parts of the Mediterranean Sea, Spain, Corsica, Sardinia, South Italy, Sicily, South Greece, Crete, Cyprus and most of the Turkey do not have any changes in summer (JJA). The largest of the changes is in the Alpine region with a maximum -11 mm decrease. In autumn, changes in the surplus have moved to the south again. Except for the North West coasts of North Africa, there are no changes in the surplus of North Africa. The largest changes in future SON are in the north of Spain, France, the Alpine region, Italy and the west coast of the Balkan Peninsula, with a maximum change of -8 mm. The west of Spain, the East of the Balkans and Turkey has a decrease of around -2.6 mm.

5.2.6. Comparison of Present and Future Deficit

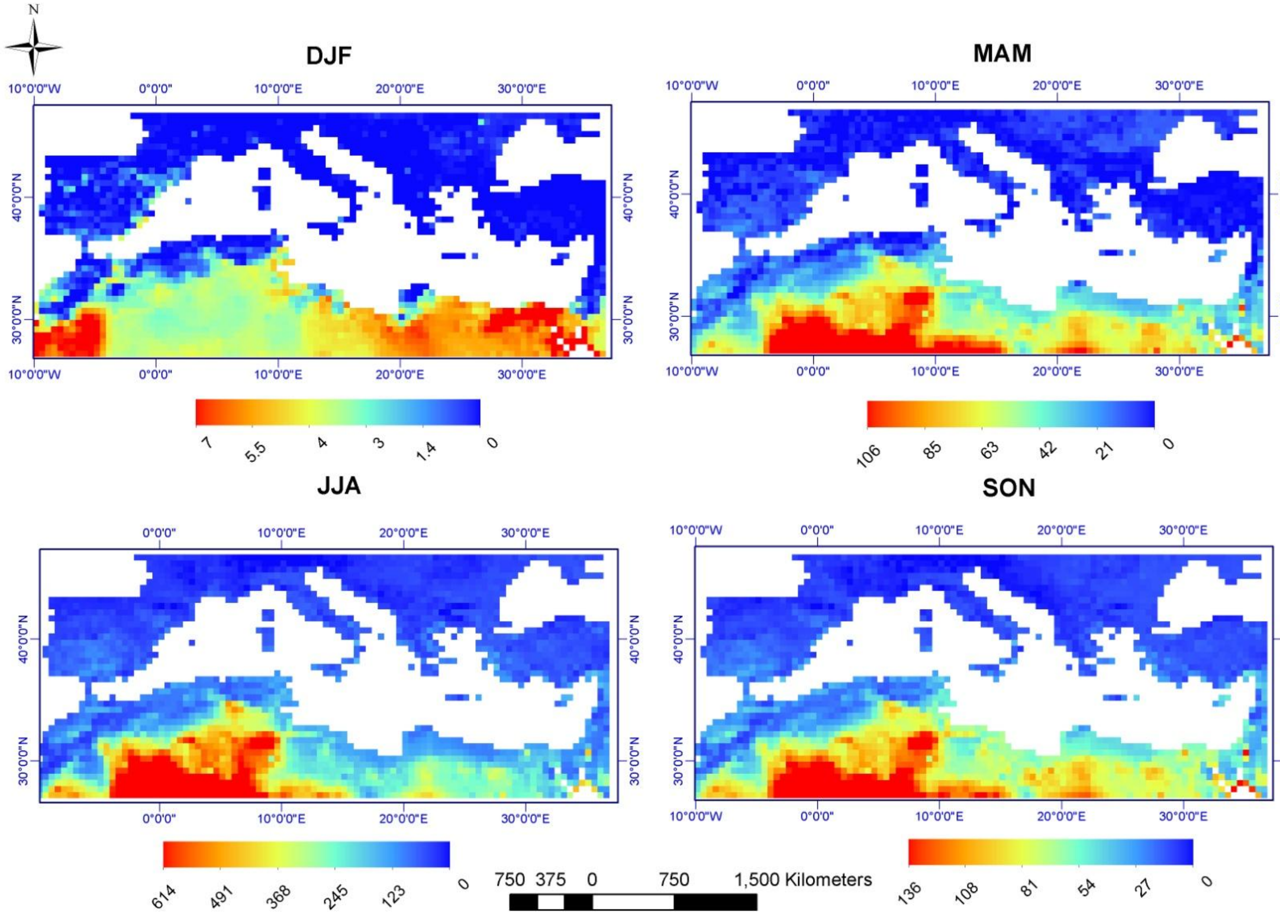

Figure 16 Compared present and future mean deficit in the Mediterranean region (2070-2100 minus 1910-1940 in mm).

In Figure 16, the differences between present and future deficit differences are shown. In winter there is almost no change in the deficit in the North of the Mediterranean Sea and the coastal zone of Morocco, Algeria and Tunisia. The maximum differences are in the inlands of Morocco and the north-west of Africa, which show a maximum of 7 mm of increased deficits. The rest of

North Africa still has increased deficits, between 3 and 5.5 mm. In spring (MAM), deficit is much higher in the inlands of Algeria, increasing 106 mm more in the future. Other parts of North Africa have increased deficits, between 21 and 63 mm. In summer (JJA) deficit is not increased in the north of the Mediterranean Sea and the northwest coast of Africa. The largest difference is in the inlands of Algeria, which is an extreme value of 614 mm. Other parts also have considerable increases, which are between 123 and 491 mm. Deficit has not changed in the north of the Mediterranean Sea in autumn. The only significant changes in the future SON is in North Africa, with a maximum value of 136 mm, again in the inlands of Algeria. The northwestern coast of Africa has increased around 27 mm. In the rest of North Africa, deficit has increased between 54-108 mm.

6. Discussion

6.1. Potential Evapotranspiration

The accuracy of model results is not tested by any statistical methods in this study. However it is still possible to evaluate the validity of results by looking at previous studies' comparisons of computed and observed values. Thornthwaite (1948) compared his study with observed values in order to determine is the quality of his results. His comparisons are not for the Mediterranean region but this can still give an idea about the validity of the empirical formulae used in his study, as well as in this study. For the Eastern United States, Thornthwaite's potential evapotranspiration calculations have differences from the observed values of less than 4%. Also observed and computed surplus values showed high accordance (Thornthwaite, 1948).

Garcia-Ruiz et al. (2011) compared the potential evapotranspiration for past and present by only looking at 1950 and 2002 and found some differences between the two periods. Their calculations and comparisons are similar to this study. Potential evapotranspiration is computed by Thornthwaite's formula and comparisons are done for each season as it is done in this study. According to their study most of the differences are in North Africa. In their study minimum differences are found in winter and maximum differences are found in summer. Those results conform to the results of this study. However the comparison is not completely apt, because of the different periods used in these studies. In Autumn Garcia-Ruiz et al. (2011) found no changes in the most parts of Turkey and the Balkan Peninsula. Although there are similarities in some parts of Turkey and south of the Balkan Peninsula (not in the north) there is no full conformity between the two seasons.

Calculation of PET, using Thornthwaite's approach, is basically dependent on temperature and latitude. PET has a high seasonal variability in the Mediterranean region. PET is minimal for whole region in winter (DJF) in the all periods studied (past, present, future). The main explanation for that is the insufficiency of solar energy during the winter. Another important point for interpreting the PET results is the zero values found only in winter -which is the same in all periods (past, present, future). Zero values are found in the Northern and Eastern Mediterranean especially in the Alps, the Balkans and central Turkey. The explanation for zero PETs from those parts is the negative temperatures in winter. According to Thornthwaite's formulation, negative values are not acceptable for the calculation of PET. Thus, all the negative values are replaced by 0 values in this study.

Temperatures are very high for the inlands of North Africa (in MAM, JJA, and SON), especially in the inlands of Algeria. Because of high temperatures there are very high PETs in those parts. Another reason for high PET results could be the longer day light hours over the North Africa. In summer (JJA), maximum temperature is 37 ^{o}C in Algeria and hence PET is 608 mm in the same region; this is the maximum value of PET found for the period of 1910-1940.

In the period of 1980-2010, potential evapotranspiration increased in some locations, especially in North Africa. On the other hand, decreased PETs are remarkable in some locations. Increases are found in the coastal zone of Morocco and central and East of Turkey, which includes values from 1 to 8 mm in winter. In winter (DJF) there is a general decrease in the region of up to -2.5 mm. In the warmer seasons, the rise in PET is greater. The most pronounced increase is in summer (JJA), which has a maximum value of 79 mm. This increase is in the inlands of Algeria. This must be because of the temperature rise in the present period. North of the Mediterranean Sea and in the coastal zone of Morocco, there seems to be not much of an effect of climate change, because PET has not increased in those regions appreciably in JJA, except in the south of Italy where the increase is around 15 mm. According to the PET calculations, the most sensitive region to climate change in the Mediterranean region is North Africa. Garcia-Ruiz et al. (2011) calculated PET values by using the same methodology in order to estimate the impact of climate change on the water resources of the Mediterranean region. They calculated PET in the same fashion as this study, by using a 0.5° grid (according to Thornthwaite's formulae). They compared past and present changes in PET, by looking at only the years 1950 and 2002. Their results are similar to this study's results. First of all, they found high seasonal differences in the changes of PET between the past and present. They found both positive and negative trends between two periods. According to their results, most of the significant changes are in North Africa, some areas of Iberian Peninsula and the south of Italy. Their results are similar, especially in summer (JJA), because they found 80 mm more PET in the inlands of Algeria, and according to this study the maximum raise is in the same area is up to 79 mm in the present. Still, the comparison is not entirely accurate since the two studies are not spanning the same period. Their results for Turkey and the Balkans are the same as found in this study; they have very few or no PET differences in summer and autumn.

Mariotti et al. (2002) calculated evaporation over the Mediterranean region to determine the hydrological cycle and the water budget there, especially over the sea. This study does not cover the behavior of sea in the water balance model of the Mediterranean region, however it is still important to consider since the main source of water for the hydrological cycle is the sea (Christopherson, 2006). They used different models to calculate evaporation over sea and land. They found high evaporation rates over sea, especially in winter. They found high evaporation over Italy in the period of 1979-1993. Since they did not cover transpiration from vegetation their estimates are lower than those in this study. However, the over sea evaporation rate they use is $1550mm^{-yr}$. Interestingly in their study, summer evaporation is less than in winter over the sea and over land it is much lower. Globally, precipitation is suggested to be raised due to enhanced evaporation and hence results in more moisture in the atmosphere. The reason for this can be understood in terms of the atmosphere physics rule (the Clausius-Clapeyron relation) that for every 1 degree of temperature rise, there is an increase of 7% of the atmosphere's moisture holding capacity. This change is higher over the oceans than land. The reason for the different result in continental settings is because raised temperatures induce surface drying and hence more severe droughts (IPCC, 2007).

According to Mariotti et al. (2002), evaporation is high in the north of the basin. The reason for this could be high precipitation rates over the Alpine region and Northern Mediterranean. PETs are the lowest in general in the same region. This must be because of less energy availability and shorter day lengths.

In the future PETs are increased in all seasons. The seasonal differences are more noticeable in the future. PET is increased to a level of almost twice that of the present in the extreme case (613 mm). Some areas are more sensitive to the temperature rise than others. The Inlands of North Africa are the most sensitive area in the Mediterranean region, and the largest increase is found mainly in Algeria. Except for winter, in all other seasons PET has not increased much. Since temperature rise has been proven to be occurring in the region (Piervitalli et. al, 1997), due to increased energy availability, rises in PET are not surprising in the future. In the future, several studies suggest a global rise in the temperatures (Giorgi and Lionello, 2008; Barkhordarian et al. 2012; 2013) of up to 5°C for the A1B scenario (IPCC, 2007). However, the complicated structure of some regions, such as Mediterranean, will cause different spatial and temporal warming trends (IPCC, 2007, Giorgi and Lionello, 2008; Gao and Giorgi, 2008). Temperature rise will be more pronounced in summer in the Mediterranean region, especially in the southern and northern parts. Other parts will not have a prominent warming trend (Giorgi, 2002; Milano et al. 2013). Another significant difference is the between coasts and inland areas. While there will be a smaller increase in the coastal zone, more temperature rise is expected inland (Giannakopoulos et al. 2005). However, in this study future temperatures are increased evenly everywhere, up to 4 ℃, matching the IPCC A1B scenario. While this is a useful method to show the gross impact of temperature rise on PET, it is obvious that the results will not be absolutely accurate and evenly increased temperatures throughout are not representing the complexities that would occur in the region very well.

For water balance modeling, precipitation is one of the most important inputs. There should be a balance between incoming and outgoing water over longer time periods in a typical system, which operates near steady state over those durations. Precipitation data used for the present water balance modeling has already shown some difference from past data. The reason for that is that the data is based upon observations, and according to some studies there is a remarkable decrease of precipitation in the region since the 1970s (Palutikof et al., 1996,; Piervitali et al., 1997). Most studies suggest a significant decrease in future precipitation, especially in the warm seasons (summer and spring) and in some parts such as Alpine region in winter (Giorgi and Bi, 2005; Giorgi and Lionello, 2006; Mariotti, et al., 2008). For the future, most studies suggest a decrease of around 20% in the Mediterranean region for 2070-2099 (Schonwiese et al. 1994; IPCC, 2007; Mariotti et al. 2008; Teselioudis et al. 2008; Philandras et al., 2011). Unfortunately, the model created in this study does not allow for decreasing the precipitation in different amounts for the different areas of the Mediterranean region, as doing this realistically would introduce a degree of complexity beyond this project’s scope. Since the Mediterranean region has a seasonal pattern on precipitation (Barkhordarian et al., 2013) it would be a problem to change the precipitation seasonally for the wide range of raster images in a realistic fashion. Precipitation is highly affected by topographical patterns (Gao et al. 2006) and the Mediterranean region has diverse morphological characteristics (Sanchez-Gomez, 2009). However, ideally the effect of the topography of a region should be included in a water balance study, in order to assess the impacts on precipitation; this is not included in this study.

Also, it is very well known that Mediterranean precipitation is highly related to NAO with different seasonal patterns (Mariotti and Dell'Aquilla 2011) evident under varying NAO conditions. For the predictions of future precipitation, cyclonic activity in the region should be modeled as well. Different effects of the northern and the southern Mediterranean region on precipitation change can be explained by the seasonal oscillation, with increased anticyclonic activity and the cooling impact on the Alps (Giorgi and Lionelli, 2008) amongst the key phenomena. Trigo and et al. (2000) connected the drought of region to the decadal variability of the North Atlantic Oscillation and resulting decrease of cyclogenesis. While low cyclonic activity is expected for the future, especially in the winter, it would be very difficult to assess the changes of the precipitation in the region (Hurrell and van Loon, 1997). This needs more effort and models of precipitation for more complete examination. Since a 20% decrease is expected by the end of the 21st century (Mariotti et al. 2008) more drought would be prominent in the region in the future. Garcia-Ruiz et al. (2011) analyzed the precipitation pattern for the future according to A1B scenario and found there will be a considerable decrease, especially in Spain, North Africa and the Middle East (up to 15%) and a 10% decrease is projected for south Italy, south Turkey and Greece.

6.2. Actual Evapotranspiration

AET is calculated by using PET along with further information (Randall et al. 1998). However, PET is based on formulae that sometimes overestimate potential evapotranspiration (Thornthwaite, 1948). So, actual evapotranspiration results could be overestimated with a low percentage.

Actual evapotranspiration is not always the same as PET. A location can have a high potential in evapotranspiration however at the same time AET can be very low depending on the vegetation cover and the precipitation of a region. For example, in a desert because of the lack/sparseness of vegetation, even though there is very high energy coming over the surface, evapotranspiration is low because there is not enough vegetation present to access soil water and send it back to the atmosphere by transpiration (Thornthwaite, 1948).

An empirical based model correction of results should be evaluated by looking at other relevant studies or tested by statistical methods. Since the results of the model are all estimated they should be compared with actual conditions. One way to check if the results of actual evapotranspiration in the Mediterranean region are reliable could be by comparing topographical patterns of the region with actual evapotranspiration. Dyer (2009) estimated the water balance in the US by using GIS software and compared his results with topographical patterns of the study site. He found that higher evapotranspiration rates are found over the southern and northern facing slopes, highest points such as valleys and ridges. According to my study most of the evapotranspiration are from the southern coastal zones and mountainous zones such as Alpine zone. My study doesn't directly consider topographical structure of the Mediterranean region during the analysis. However meteorological data based on observations are affected by the topography of the region.

Kosa (2009) compared air temperature and actual evapotranspiration in Thailand in order to find a correlation between those two. Since the study areas are not in the same climate region, and have different topographical and vegetation patterns and their study area is covering a smaller area, comparison of that study with my studies is not very accurate. However it can still give an idea about the relationship between temperature and AET. Their AET calculations depend on satellite images and weather data have a high confidence with their results. They found a linear correlation between temperature and AET with 0.987 R^2. In this study AET is increasing in the warmer seasons with the highest values. However in the Mediterranean region, since the vegetation is sparse over the warmest areas (African desert), where AET is the lowest.

Actual evapotranspiration is highly affected by the vegetation cover. Garcia-Ruiz et al. (2011) analyzed the NDVI (Normalized Difference Vegetation Index) based on remotely sensed data for the period of 1980-2006. Their results show that the sparsest vegetation of the Mediterranean region is over North Africa. The other parts which have higher vegetation cover are the Balkan Peninsula, the Northern Iberian Peninsula, Italy and the coastal zone of Turkey. Their analysis period covers almost the same period presented in this study. Vegetation cover and present AET results have a high correlation with this study. Lowest AETs are from North Africa, except for North-west Africa, which matches with NDVI results. Other higher AETs also match with the vegetation cover, where higher vegetation covers are dominant.

Actual evaporation in winter for the period of 1910-1940 is very low over the Balkans, central and northern Turkey (especially over the Black Sea coast), in the inlands of North Africa and the Alpine region. Nevertheless, PET is very high in North Africa. The reason for low AET in this location is sparse vegetation. Here, AET is low in all seasons. The reason for the low AET over the Balkans and northern Turkey cannot be because of the lack of vegetation. For central Turkey, vegetation is mainly sparse and there is a high amount of water drawn for irrigation because of the scarcity of precipitation there (Dogdu and Sagnak, 2008). Those could be reasons for low AET found over central Turkey. Another possible explanation might be the lower temperatures in those areas during the winter. Topography is also an important factor for AET. Since the Alpine region has high altitudes, temperature is lower over those high mountainous regions. This can be a reason for low AET in the Alpine region. Another reason could be the cooling impact of increased anticyclonic activity over the Alps (Giorgi and Lionelli, 2008) in winter. However the Alps are one of the maximum AET regions in the summer, together with France, some areas in the Balkans and Bulgaria. The reason for the high AET in the Alpine region during the summer could be the relatively higher summer temperatures and more precipitation due to increased evapotranspiration over this area. Seasonal temperature changes in the Alps are more pronounced over the higher elevations in autumn and over lower ones in winter (below 1000 meters) (Schädler and Weingartner, 2010). Since their results include 100 years of data, it is possible to explain the past AET behavior of the Alpine region in autumn by referring to this information. AET is high in autumn over the Alpine region probably due to increased temperatures. For winter it is not very high on the same area it might be because of lower temperatures over the mountains. Also, they found a positive trend on precipitation in winter and autumn. This could be another reason for higher AETs in autumn over the Alpine region. According to the precipitation data used in this study, it is high over the Alps in all seasons except in winter. Even though there is more precipitation in the autumn, it is not as high as other seasons. This explains lower AET values in winter. This has related implications for storage change, PET, precipitation and P-PET. Those factors also affect actual evapotranspiration. Another reason for high AETs in summer and spring is the melting season of ice over the mountains. They are contributing to evapotranspiration too, which has already been observed (Schädler and Weingartner, 2010). The resolution of the model used in this study is not fine enough to explain all the influences of the Alpine region and its contribution to the water balance. More detailed models are required in order to understand the behavior of this region's water balance in the face of climate change. Subsequent to the Little Ice Age, storage has already significantly changed in this region and will keep changing in the future because of climate change (Schädler and Weingartner, 2010). On the other hand, climate change projections for this region -only for temperature- according to the A1B scenario includes a 3.9° temperature increase by the end of this century (Schädler and Weingartner, 2010). According to this study, at the end of this century, temperatures are raised by 4° in the entire region, which is consistent with projections for the Alpine region.

Present AET differs from that found for the past. The decrease in present AET is greater than the increase. In winter there is less actual evapotranspiration over the some areas in North Africa, a decrease of up to - 7 mm. Some areas have low AET, such as central Turkey, the Balkans and the inlands of North Africa; there is a rise in the present AET of up to 4 mm. This should be related to the storage, PET and temperature changes in those areas. In the North African inlands, low AETs are related to the sparse vegetation because of desert climate (Foley et al. 2003). Increased AET values in winter are found in the north and northwest of Spain, where precipitation is high in DJF. Also, winter AETs are increased in the north of Spain and the coastal zone of Africa. The reason for this could be the temperature rise over the North of the Spain in the period of 1972-1994 (Labajo et. al. 1998; Labajo and Piorno 2001). Normally, temperatures are low there in winter; however temperature rise with a considerable amount of winter precipitation could enhance the AET in this area. For the northwest coast of Africa, there are dense shrubs, which are the only significant vegetation in North Africa (Foley et al. 2003). This would be the reason for the higher AET values found over Morocco. In spring there is less AET, especially in Libya. Lower AETs in Libya could be because of increased temperatures in the region. Precipitation does not seem to have changed much from past to present there. Also the vegetation is already very sparse in Libya, where temperature rise could enhance the reductions of vegetation cover. In summer, the largest decrease is over the Balkans. From 1910-1940 to 1980-2010, summer precipitation has decreased over the Balkans and the west of Turkey in between -3 and -22 mm. This would be the reason for decreased summer AET values in the present. On the other hand, precipitation has increased up to 16 mm in the north of Turkey; this could be the reason for enhanced summer AETs here and, the cause of the shown 8 mm increase.

In the future, after temperatures have increased by up to 4 ^{o}C, there is mainly an increasing trend over the north of the Mediterranean Sea, except in spring. While there is more AET in Turkey there are decreases in summer. In spite of the fact that future precipitation is same as that in the present, there is more AET in spring (MAM). This could be because of the combination of high precipitation and increased temperatures over this area in spring. On the other hand, summer is the driest month in Turkey and even though temperatures are high in summer, because of the lower precipitation AET values are lower here. In the western coast of North Africa, there is greater AET than that found inland. According to Droogers et al. (2012) AET is higher in the same region for the period of 2001-2050.

6.3. Precipitation minus Potential Evapotranspiration

P-PET (Precipitation minus PET) is an important factor for assessing moisture condition. Precipitation and evapotranspiration are often unequal. Sometimes more evapotranspiration than precipitation occurs in an area through a year or vice versa. Like the amount, the distribution of both precipitation and evapotranspiration differs temporally and spatially. This is mostly because of the spread of vegetation, latitudinal location and even the geomorphology of a region (Thornthwaite, 1948.). Globally, precipitation is suggested to be higher due to enhanced evaporation and hence more moisture in the atmosphere. This can be understood in terms of the aforementioned atmosphere physics rule (the Clausius-Clapeyron relation), which holds that for every 1-degree temperature rise, there is an increase of 7% of the atmosphere’s moisture holding capacity. This effect is more significant over the oceans than over land. Because oceans are covering more area than continents, it is normal to expect more evaporation from there. On the other hand, the impact of temperature rise on the continents is different than from that upon the oceans, because raised temperatures induce more surface drying and hence severe droughts (IPCC, 2007).

In North Africa, present moisture availability is less than that of the past, with a difference of up to – 79 mm. However moistness reduction is much more pronounced over the north and south of Turkey and the Eastern Mediterranean coast of the Middle East and North West of Spain, with values up to -153 mm in winter. The largest reductions in the moisture availability of the region are found in winter. This could be because of the reduced precipitation over those regions in the present. Since there is more precipitation in spring and autumn, especially over Turkey, the Black Sea coast and the northeast of Africa, there is more moisture in those areas, which includes increases of up to 20 mm.

Future P-PETs are consistent with the results of Mariotti et al. (2008). Their model suggests high P-E (Precipitation minus Evaporation) over South West Spain, South Italy, South Greece, South Turkey and the coastal zone of North Africa for the wet season. According to the results of this study, higher P-PET values are found over South West Spain, Italy, Corsica, the Balkans, Turkey and the coastal zone of North Africa (in DJF, SON). For the dry season, their results are also consistent with those found in this study; P-PET is higher in the north of the Mediterranean Sea almost everywhere, and very low in the inlands of North Africa and the South of Spain, which agrees with the results of the study of Mariotti et al. (2008). However, the amounts are higher in this study because they are potential evapotranspiration values rather than evaporation values. Also their future precipitation is 10% less for wet and 23% less for the dry seasons. As described above, precipitation has not been changed in this study for the future.

6.4. Surplus

If precipitation is greater than evaporation, and even after storage there is still water on the surface, water tends to move towards to rivers and contribute to their flow (Thornthwaite, 1948). All major rivers eventually reach the sea, so finally they mix with the oceans and become part of the water cycle again. Some of the surplus is collected in lakes. Surplus is important to provide water for the use of humans, crops etc. Surplus changes in time and space. When it is larger the area becomes wetter and when it is lesser the area is dry. According to the model results, the largest change in the present surplus is in winter (DJF), which is a decrease of up to -153 mm over Turkey, the Middle East, South Greece, South Italy and South West Spain (Figure 36). This is mainly because of less precipitation in the present. There are more surpluses where present precipitation is increased, especially in Turkey in spring and autumn. Since the surplus is highly related to precipitation, the model assumes less change in the future than in the present because precipitation is assumed to be the same as in the present. Although only temperature is changed in the model, there still will be alterations in surplus in the future. Mainly in the north of the Mediterranean Sea, reductions will occur in the future, but Northern Spain, France, Italy and the Balkans will have smaller surpluses, of up to 11 mm. Other places do not show any changes in the future, and interestingly no excesses are modeled in the future surplus, probably because of not changing the precipitation in our modeled scenario. The condition of seasonal surpluses shows that there is a critical situation, especially in North Africa. There is almost no surplus in the inlands of North Africa during all seasons. Most of the surplus is in the north of the Mediterranean Sea, with values of up to 300 mm in winter. In summer there is a surplus in the region only in a small portion that is mostly over the Alps and some parts of Balkans, with up to 106 mm of surplus in those locations.

In the first place, it is essential to analyze the deficits and surpluses in a region. However, the determination of water shortages cannot be found only by looking at the deficits in a region. We also need to identify the population, associated water demand and the economic activities in a region in order to assess the stress on water resources, how much water is needed and how much of this demand is satisfied. In the North of Africa, because of scarce water resources and the high demand of an increasing population (Droogers et al., 2012), the situation is worse than in the other Mediterranean countries. The Middle East and North Africa are the pioneers in the most severe water-shortages experienced in the world. There are still surpluses in some limited areas of North Africa, which are mainly in the coastal zones of the Maghreb countries (Morocco, Algeria, Tunisia and Libya). The Maghreb countries' climate has a variable structure that ranges from typical Mediterranean to somewhat drier, especially from the shores to the inwards of the continent. The surface hydrology of those countries is very limited and there are rivers present only in Morocco (Droogers, et al. 2012). Some of the Middle East countries, which are also called the Mashreq countries (Lebanon and Syria), have a considerable amount of water resources. Since the climate of the coastal zone of northwestern Africa is milder than that found inlands, and there are relatively more plentiful water resources in Lebanon and Syria (Droogers, et al. 2012), even though the inlands of those countries are very hot and dry, there are water surpluses in all seasons except summer. However future surpluses in those countries are less than those available in the present.

6.5. Storage

Storage and surplus are very important because if the soil is fully saturated with water and there is still water available as a surplus, even though the forthcoming months are dryer, vegetation will use that stored water in the soil (Thornthwaite, 1948). The driest season in the Mediterranean region is summer (JJA). Storage is lowest in this season, except in the North Mediterranean in all periods (past, present, future). The reason for the most pronounced summer drought in the Mediterranean is reduced spring soil moisture, which has the effect of decreasing the summer convection. Different warming behaviors of the land and sea reduce relative humidity and precipitation over the land. Less summer moisture and less precipitation acts as a positive feedback and they both cause additional decreases of each other (Rowell and Jones, 2006).

Especially over the North Africa, storage is very low in all of the seasons in all periods (past, present, future). There is a general decreasing trend in the region from past to present. According to this analysis, some areas have increases in some seasons. Those areas are Turkey and the north coast of the Black Sea, with values up to 22 mm in spring and autumn (present). The largest reductions are found in the Balkans, North Africa (especially in Libya and Moroccan coast), and France. Future model projections assume reductions in storage, especially in the north of the Mediterranean Sea and the coastal zone of North Africa. Since there is no storage in the inlands of North Africa, there isn't any change in the water found in the soil. In the future, the model predicts reductions, particularly in France, Spain, the Balkans, Turkey, and the Moroccan and Algerian coasts.

In Dyer's (2009) study evapotranspiration declines linearly with soil storage. In this study linear correlation is found between soil water storage and actual evapotranspiration. Most of the storage in the region is in winter (DJF) which hence actual evapotranspiration is the lowest over those parts (Turkey, Bulgaria, Alpine region and coastal zone of Morocco). From winter to summer, soil water storage is declining in the region together with evapotranspiration. The water balance approach shows a correlation between topographical and soil moisture patterns of the Mediterranean region.

According to the model results, discharge of soil water starts in March in the past. In a year, water storage is moving from north-to-south and south-to-north depending on the availability of water in the region. From March through September there is discharge and northward movement in the region. In July, North Africa is experiencing its minimum water availability until October. July-August-September is the driest period in Turkey, Spain, Portugal and Italy. In August, water availability is prominent only in the Northern parts of the region (the Alps and the Balkans). In September, refilling of the soil water starts again until February. February is the month with maximum soil water in whole region. Over North Africa most of the water is stored on the west coast and even inner parts of Algeria especially in September. According to the study of British Geological Survey and University of London (UCL) Libya, Algeria and Chad have large water storage in deep aquifers (2011). In February, water availability is considerable in Turkey, Bulgaria and Algeria (FigureA1- Appendix A). The storage pattern is almost same in the future. There is storage during the wet seasons and discharge during the dry seasons, and this shows the model is working properly for the Mediterranean region.

On the other hand, in the future (in 2100) analysis, water starts discharging in March and it reaches its maximum in February (Figure B1- Appendix B). There is a one-month delay in refilling the storage which is in October instead of September. This could be because of the changes in the seasonal patterns of precipitation, however since precipitation remains as it is in the present in our model there must be another reason for that delay. It might be because of more PET in the future scenario. PET is known to be an important factor for determining the moisture content of soil (Zhang et al., 2008). Enhanced PET will hence increase the reduction of water stored in the soil. After removing more water, it probably would take more time to refill the soil.

So, the model predicts a one-month delay for the future storage. Another interesting result for the future storage is almost no storage over Algeria whereas there is high storage in the past (in 1910). Temperature rise would cause drying of the aquifers in this part in the future.

In fact, water availability is relatively limited during all seasons in the Mediterranean region, and this is raising the desire of the humans to abstract water. As a consequence of increased water demand, authorities will have to spend extra money for expensive infrastructure (dams, pumping systems, etc.) to store or obtain the water in order to obtain its benefit during the whole year and transfer it by advanced technological systems from surplus areas to deficit areas (Lopez-Moreno et al. 2008). However some of those infrastructures are not environmental friendly and may affect nearby ecosystems negatively, which would then act as a further feedback upon regional climate change.

6.6. Deficit

It is certain that climate change will cause more deficits in the Mediterranean region. Even now the region is facing significant scarcity problems. In the future, with increased temperatures and decreased precipitation, there will be more problems in the region. According to model results water is not evenly distributed in the region since there are surpluses in some parts, while there are deficits in others at the same time.

If precipitation is less than potential evapotranspiration, the result will be deficits. With high temperatures and a high amount of precipitation, more evapotranspiration will come from the surface. This can reduce the water in the region and with warming-enhanced evapotranspiration, there will be further seasonal deficits in the region in the future (Mariotti et al. 2008).

Dyer (2009) found in his study that the southern slopes are the most sensitive locations for water deficit. In this study most of the water deficit is from the most South part of the region which is the inlands of North-Africa. For more reliable results, a DEM (Digital elevation model) of the Mediterranean region could be overlaid. Garcia et al. (2009) suggests a relationship between vegetation and water vapor deficit which is lower with higher NDVI. By considering this information, the deficit in the Mediterranean region is the highest over the vegetation sparse areas (North Africa) and lowest over the vegetation covered areas (North of the Mediterranean region).

According to the model results, deficit is very high in the inlands of North Africa in all the seasons in all periods. For the present, winter and spring deficits are noteworthy in the north of the Mediterranean region, however in summer and autumn there are deficits in the same region, especially on the southern coast of these countries. However in some countries, present deficit is less than that of the past, which indicates more precipitation, especially over Turkey, the south of Spain and some parts in the coastal zone of North Africa. Present precipitation increase is contributing to reduced deficits in those regions. In the future, since the precipitation remains the same as in the present, the model results suggest more deficits in the inlands of North Africa with values up to 614 mm, which is almost the double that of the present. In the future summer and autumn there are more pronounced deficits in the North of the Mediterranean Sea. Maghreb countries’ shores (Morocco, Algeria and Libya) and some of the Mashreq countries (Lebanon and Syria) are not significantly affected in the future winter and spring. Even those are the least affected North African and Middle East countries in the future, as deficits are suggested to be increased in the summer and autumn.

Since the Mediterranean region has various morphological structures, coarse resolution models are not always very representative for this region, which thus requires higher resolution models for more reasonable detailed results (Sanchez-Gomez, 2009). Climate complexity due to morphological variations, land-sea interactions, location of the region etc. causes difficulties in accurately modeling the region. Ideally, more effective models require high-resolution climate (precipitation and temperature) and morphological data to be able to create more accurate hydrological models (Lionello et al., 2012). According to Sangati and Borga (2009), the resolution of the climate data should be less than 0.2˚ in order to simulate hydrological basins. Also Elguindi et al. (2011) suggest high resolution modeling for the hydrological changes in the Mediterranean region. Another problem for the modeling of the hydrology in the Mediterranean region is the sparse distribution of climate stations and the unequal amount of data from those stations (Lionello et al., 2012). For reliable results, climate data should be taken from as many stations as possible. In this study, climate data is derived by the interpolation of existing stations, which is the best option to regularize non-uniformly distributed data.

6.7. Importance of Land Cover on the Water Balance

Land use and land cover change is another important factor in the determining the water balance of a region over time. Deforestation is a crucial aspect, which affects the water balance directly by affecting evapotranspiration (Lòpez-Moreno and Latron, 2008; Garcìa-Ruiz et al., 2011), soil moisture (Maestre and Cortina, 2004; Garcìa-Ruiz et al. J.M, 2011) and the recharge (Callegari et al, 2003; Garcìa-Ruiz et al. 2011). Thus, in water balance studies, it is important to consider land cover change impacts on water availability (Garcìa-Ruiz et al. 2011).

Bellot et. al. (2007) analyzed the impact of land use change in the future and found that the population will increase in the valleys and coastal zones with new populations introducing urbanization and as well as tourism in these locations. That will increase the stress on the water resources and crop production, which means extra water will be needed for irrigation under climate change (Garciá-Ruiz et al. 2011; Milan et al. 2013). Even now, some analyses (including our own) address the high/severe water stresses in the Mediterranean region. All the scenarios are suggesting more severe conditions in the future (IPCC, 2007; Mariotti et al. 2008; Garcia-Ruiz et al. 2011). If all of the results of these studies are taken into account, the impact of climate change on water resources may be mitigated with suitable management strategies.

Increased PET together with decreased precipitation will enhance the stresses on ecosystems by decreasing moisture availability for vegetation (Garcia-Ruiz et al, 2011). Precipitation decreases, together with excessive agricultural activities, have reduced the vegetation coverage in the south Mediterranean region (Garcia-Ruiz et al. 2011). Reductions in the vegetation cover would cause lower AETs in the future even the energy for that is higher. In this study vegetation cover, has not been taken into account, however, it is very well known that this will affect the water balance, together with temperature increase and precipitation decrease by altering evapotranspiration, runoff and groundwater flow (Foley et. al., 2005). Other forces that change the evapotranspiration are wind, humidity and solar radiation (Garcia-Ruiz et al. 2011) which will change with climate change too. Vegetation cover change has a stronger influence on the water balance than climate change in some cases (Begueria et. al., 2006). Llorens and Domingo (2007) suggest a high correlation between vegetation cover and the water balance in France, Greece, Italy and the Iberian Peninsula. Some studies show that the forest can reduce the availability of water resources in the Mediterranean area (Cosandey et al. 2005; Lopez-Moreno et al. 2008; Garcia-Ruiz et al. 2011).

7. Conclusions

Water balance models can fulfill a crucial need, especially when used for the water availability modeling of sensitive regions such as the Mediterranean Region. Thornthwaite’s methodology is one of the most common and useful model used for this purpose in several studies. Models can be implemented in several environments, including GIS programs such as ArcGIS. ArcMap includes sub-modules like Model Builder, which enable the efficient implementation of a model like Thornthwaite’s with spatial data, and it is used in this study. These kinds of models can give very realistic results, by blending the power if GIS with other methodologies and formulas from other branches of ecosystem science. However it is very important to remember this quote attributed to George P.E. Box: “All models are wrong, but some are useful” (1987).

Thornthwaite’s model estimations can be considered as rough descriptions. However according to Thornthwaite’s (1948) study there are 4% difference between observed and calculated results of PET.

On the other hand data taken from NOAA are not all observed values. Missing data is interpolated from the existing data. It is a reliable method for large areas such as global estimations though have some interpolation errors. For temperature most of the error is less than 2 degrees. Since the missing data is interpolated from long-term observed values data taken from NOAA, this should give more less reliable results because there are no missing values.

This study is helpful to understand the impacts of temperature rise on the water balance and to assess the critically-impacted and favorable locations in the region. Since the data used have some errors and the study doesn’t consider precipitation change for the future estimations, more analysis should be done in order to improve the results.

The main output of Thornthwaite’s water balance methodology is PET, which is significant for the determination of other water balance elements (such as storage, surplus, deficit, and actual evapotranspiration). PET is calculated according to the Thornthwaite’s formulation which is specified in the previous sections. By calculating the potential evapotranspiration of the region other water balance elements (actual evapotranspiration, storage, surplus and deficit) are calculated as well.

According to results in general, PET is the highest in the inlands of the North Africa (especially in summer). In contradiction to this finding, AET’s pattern is not similar to PET in the Mediterranean Region during that period. In North Africa, except for some coastal parts, PET is the lowest. On the other hand, the highest AET values are mainly found on north of the Mediterranean Sea.

There are already impacts of climate change evident in the region. It can be easily seen in the compared results of past and present. In the present, PET has increased, mainly in the inlands of North Africa, probably due to increased energy availability. Energy availability should be increased due to more greenhouse gases in the atmosphere and increased the long wave radiation coming to the surface of the earth. North of the Mediterranean Sea and the west coast of Morocco have slight reductions in the present, especially in JJA.

Significant climate change is expected for the future, especially when looking at the climate change in the present time. According to future projections, with a 4˚C temperature rise, PET is doubled in some areas in the inlands of Algeria. Most of the increases in future PETs are in the summer (JJA). On the other hand, AETs are slightly increased in some parts. Those areas are in the Alpine region, Italy and the west coast of the Balkans. AET reductions in the present are more remarkable than in the future. However, there is still less AET in some locations, such as in the north of the Africa and Turkey.

Storage never reaches its maximum in North Africa, except on the northwest coast. In other parts of the Mediterranean Region, storage differs according to the season. While the lowest storage is in the summer (dry season) the highest is in the winter (wet season). In general the highest storage is found in the Alpine region, Bulgaria and Turkey in all of the periods. However storage amounts are different from the past to the future. In general there is lesser storage over the entire region in the present and the future compared to the past. However, in some seasons, especially in Turkey, there is more storage in the present than the past. In the case of future storage, the difference is more pronounced. Even the areas with the highest storage (the Alpine region, Turkey and the northwest of Africa) have reduced values. Since precipitation change has not been considered in this study, it should be noted that in a realistic scenario with reduced precipitation, storage should be much reduced in the future.

In the Mediterranean Region there are both surpluses and deficits in various locations and seasons. Surpluses are mainly found in the north of Spain, the Alpine region, the west coast of the Balkans, the coastal zone of Turkey and the Eastern Mediterranean coast of the Middle East. On the other hand there are generally deficits found in the inlands of North Africa, and the northern coasts of Mediterranean Sea. Surpluses are not stable and shift from one season to another. In general, most of the surplus occurs in winter. In summer it is very limited, and is only ever found in the Alpine subregion. Climate change has already affected the region; this can be observed by looking at present surpluses and deficits. Present surplus in the region has both decreased and increased at the same time in different locations. While mountainous regions have experienced reductions, there are increases in some parts of the Eastern Mediterranean, such as in Turkey. However, it is very important to mention that the rise is not found in every season, and the amounts shown would not be enough to meet the demand. According to the model results, there are not sufficiently increased surpluses in the region. One possible reason for this result is the use of unchanged precipitation data in the future analysis. With decreased precipitation, there will be more water scarcity and lesser surpluses in the future. Even without the inclusion of this factor, the model predicts more deficits than surpluses in the future.

Appendices

Appendix A

Past yearly storage in the Mediterranean Region (in mm) for 1910

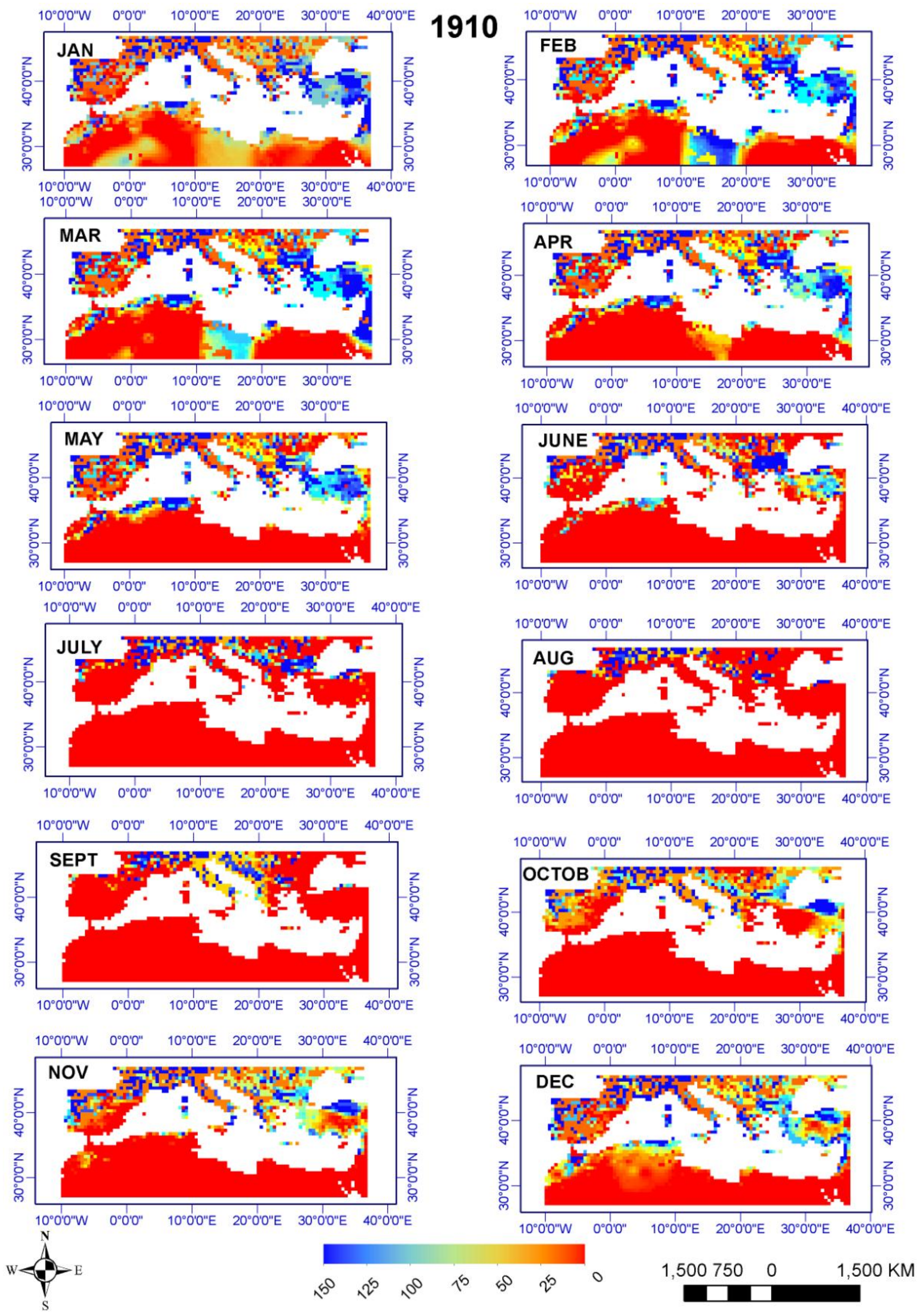

Figure A1 Storage for the year 1910 in the Mediterranean region (in mm)

Appendix B

Future yearly storage in the Mediterranean region for 2100

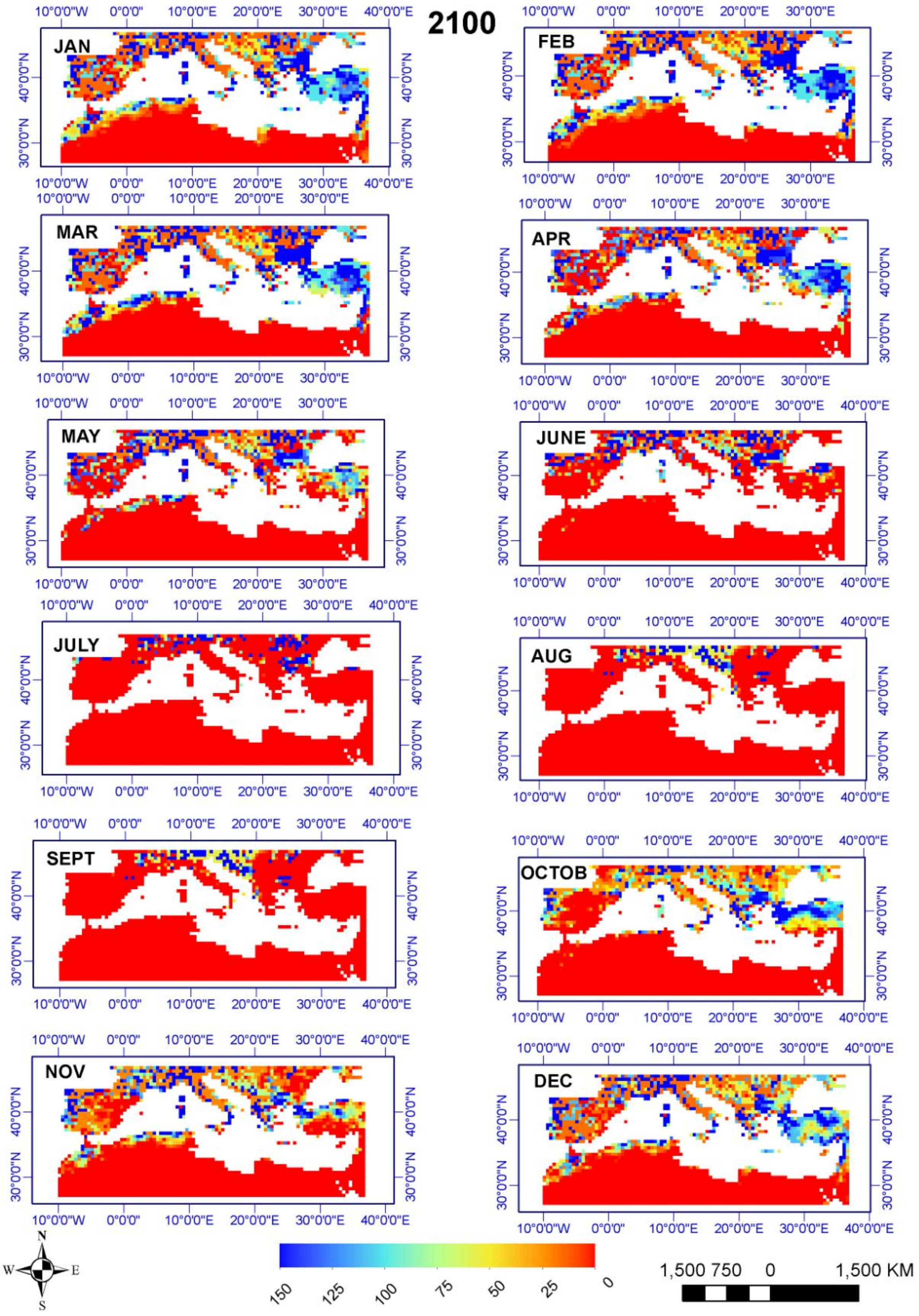

Figure B1 Future storage for the year 2100 in the Mediterranean Region (in mm)

Appendix C

Past, Present and Future climate of the Mediterranean Region

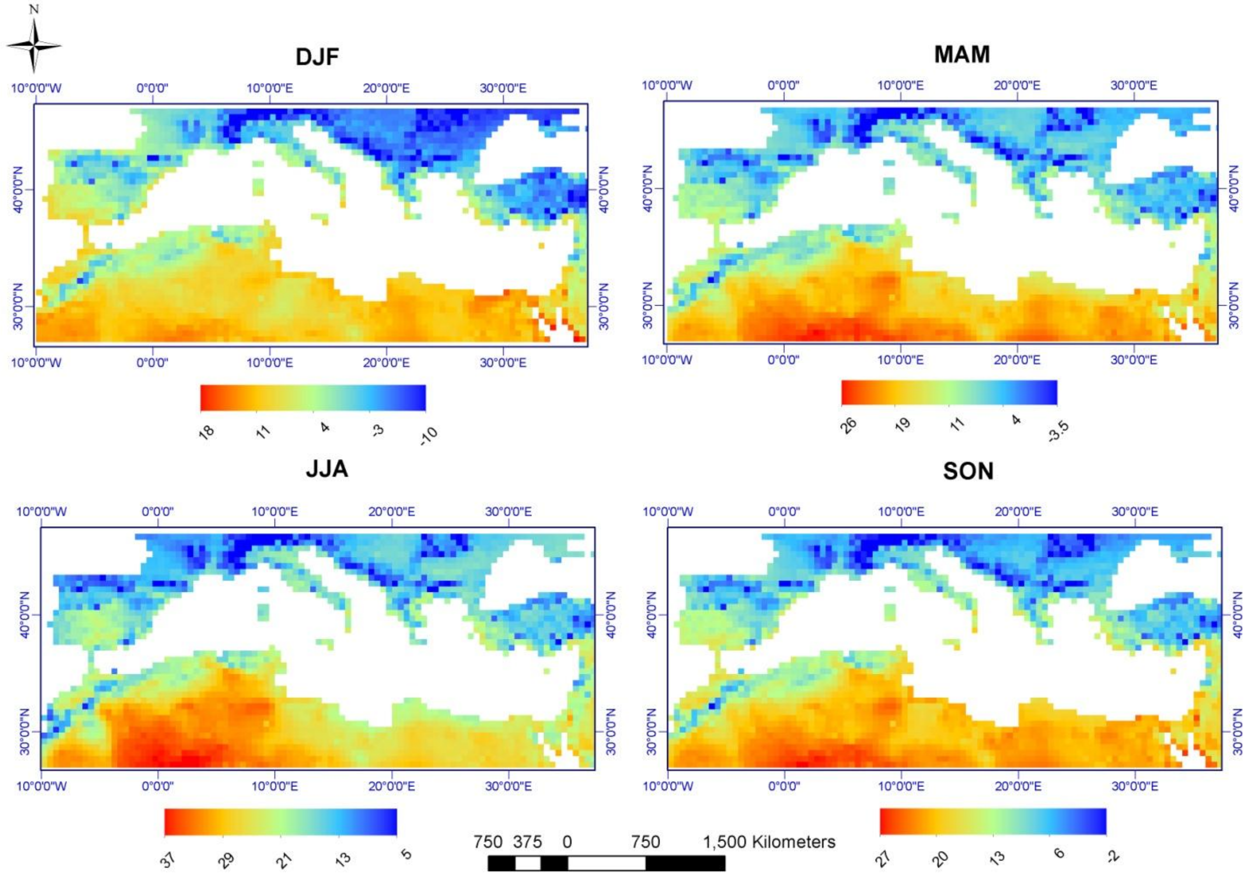

Figure C1 Past seasonal temperatures of the Mediterranean Region for the period of 1910-1940 (˚C)

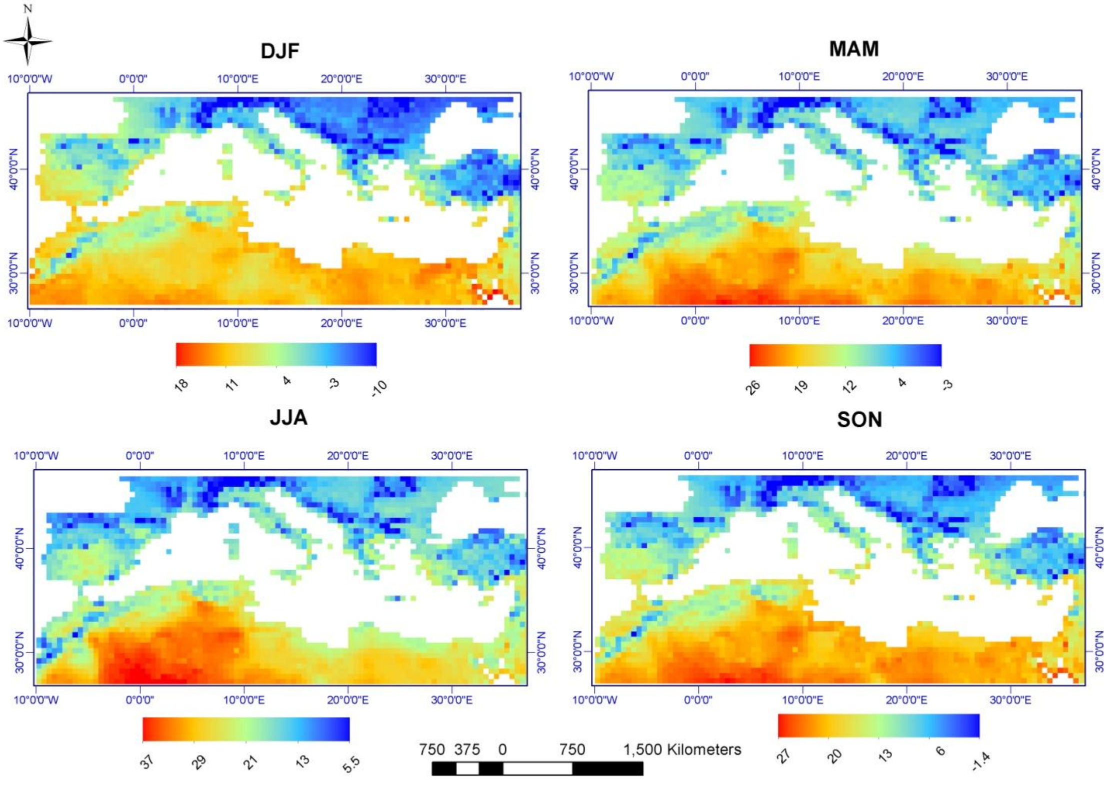

Figure C2 Present seasonal mean temperatures for the period of 1980-2010 (˚C)

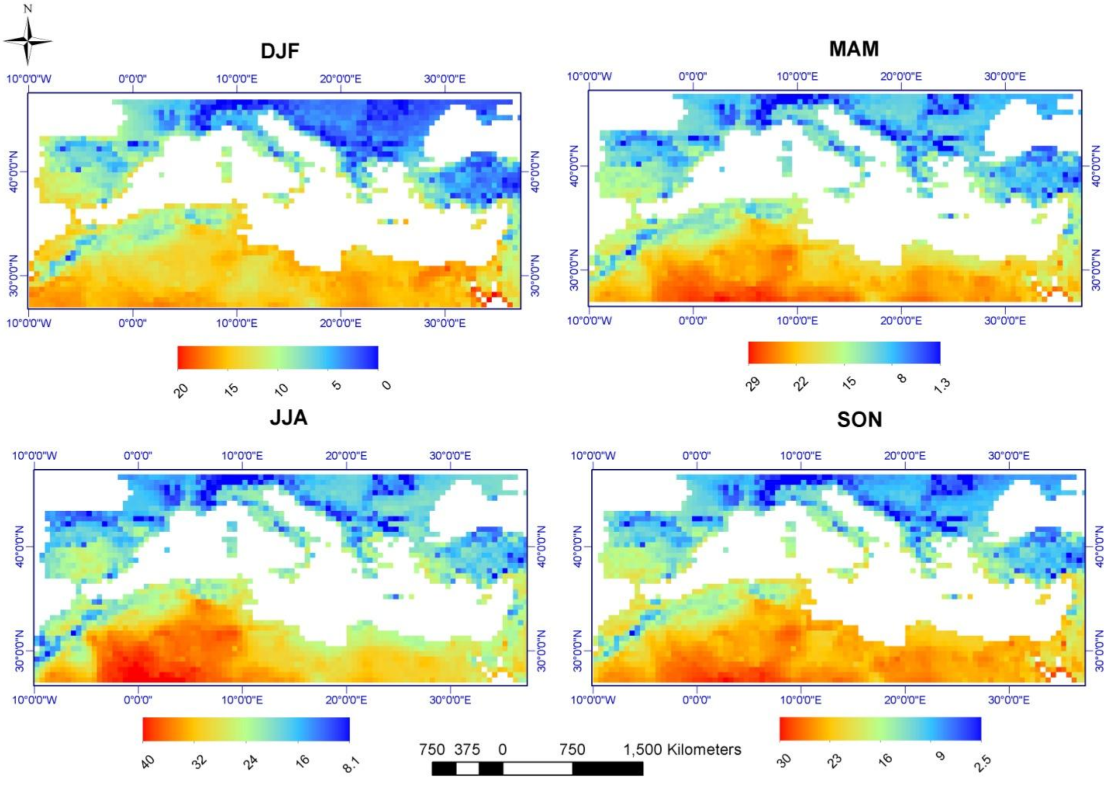

Figure C3 Future seasonal mean temperatures compared to present for the period of 2070-2100 (˚C)

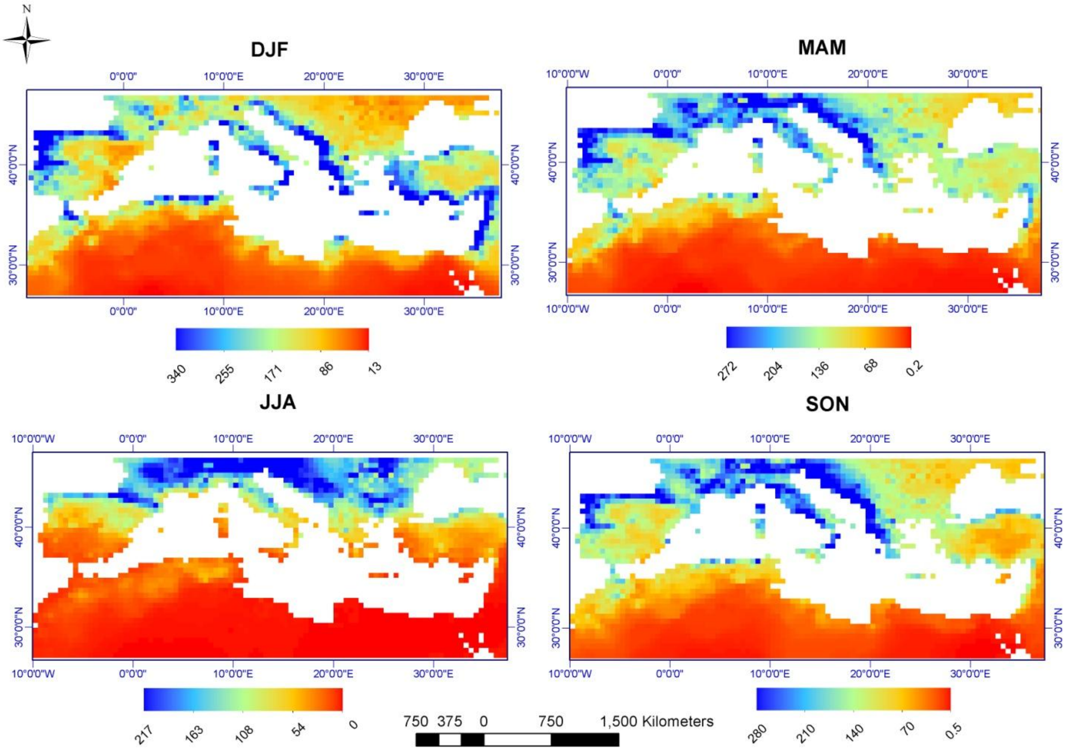

Figure C4 Past seasonal total precipitation of the Mediterranean Region for the period of 1910-1940 (in mm)

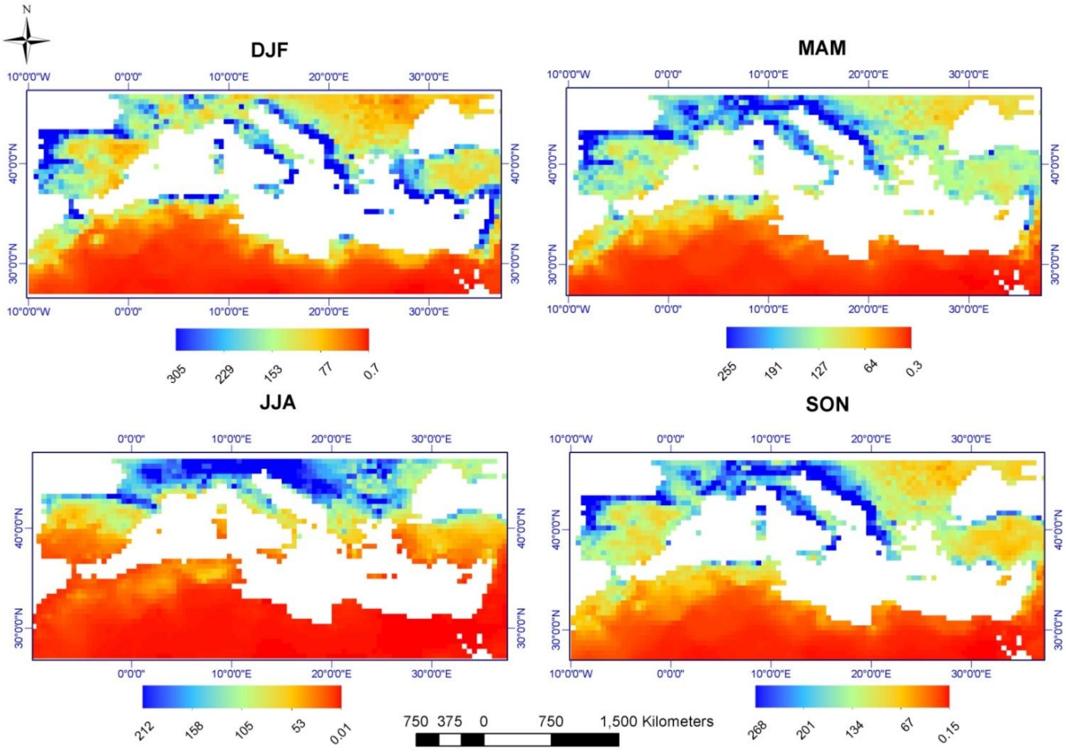

Figure C5 Present seasonal total precipitation of the Mediterranean region for the period of 1980-2010 (in mm)

Appendix D

Past Water-Balance of the Mediterranean Region (1910-1940)

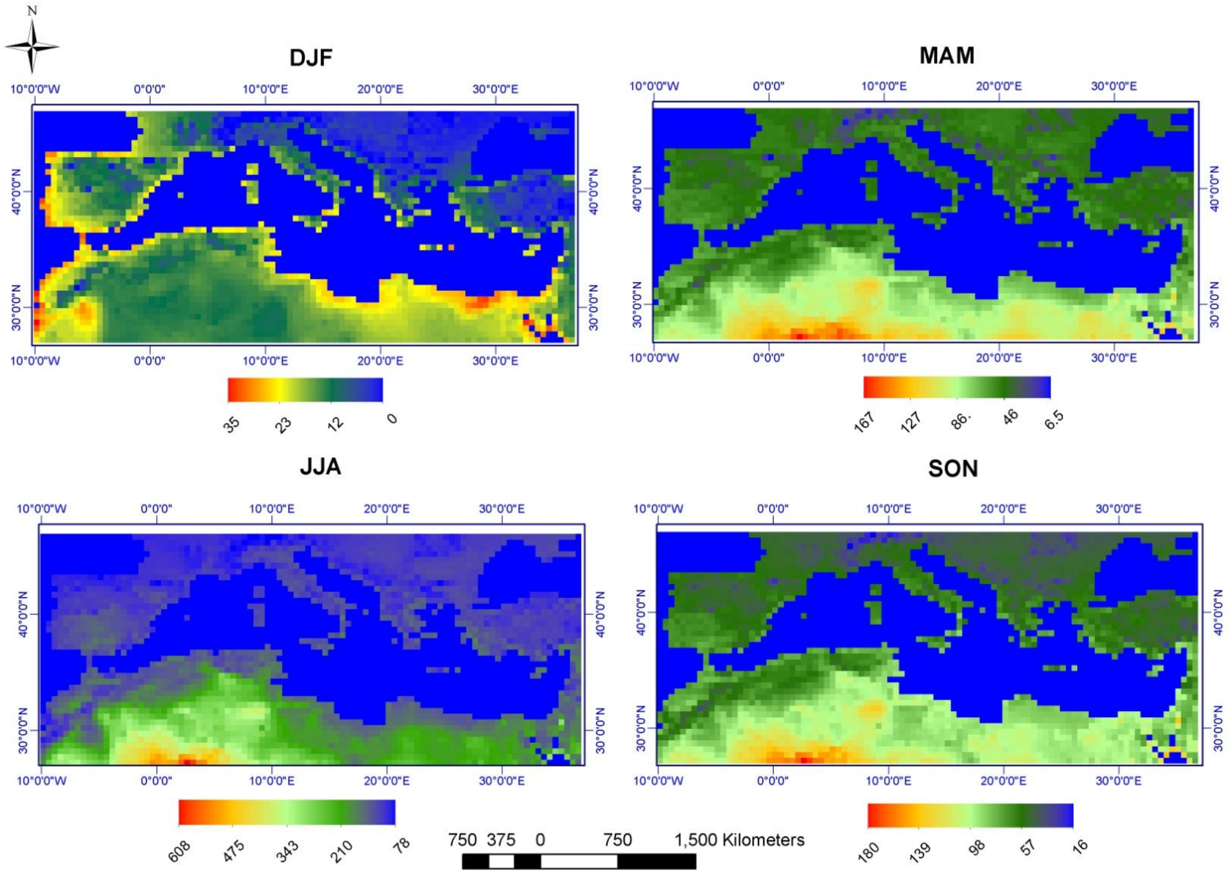

Figure D1 Past seasonal mean PET of the Mediterranean Region for 1910-1940 (in mm)

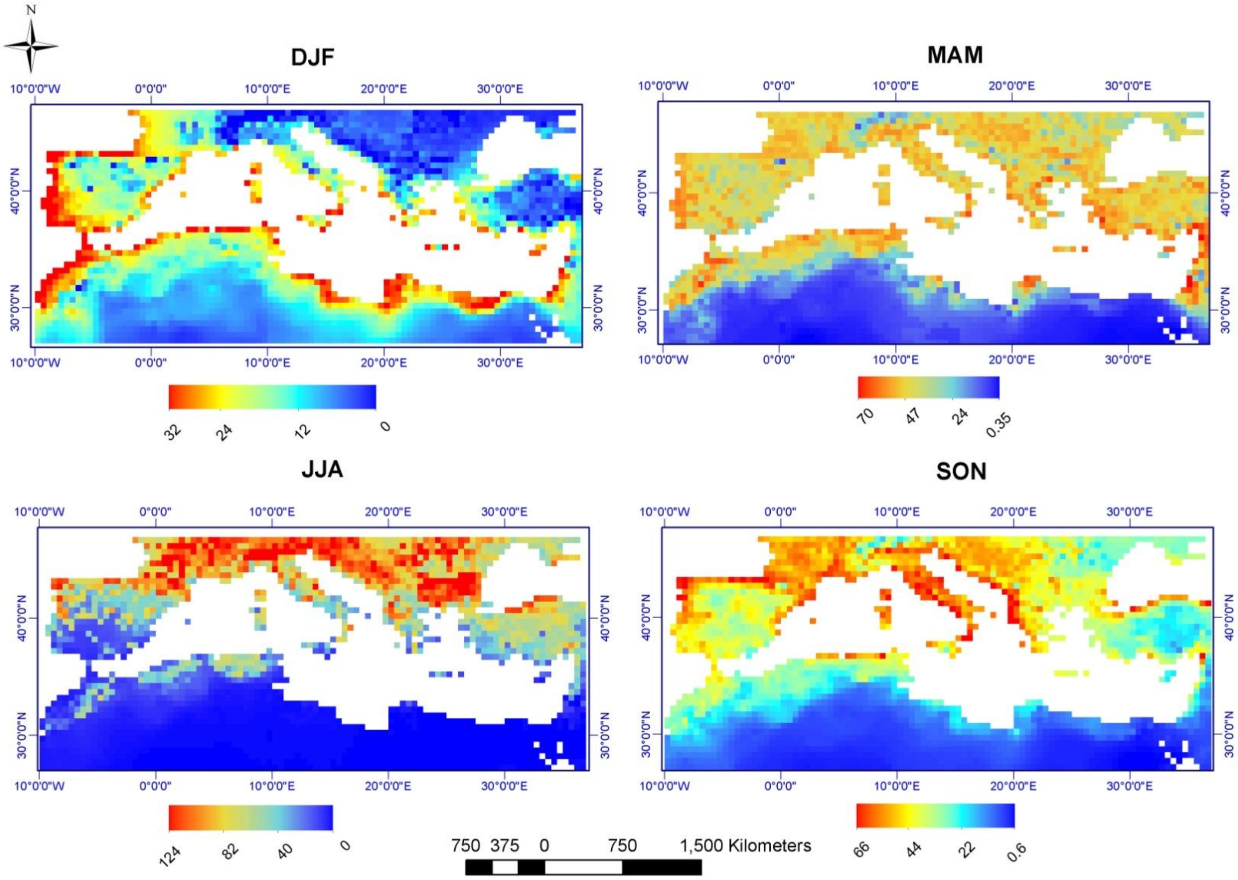

Figure D2 Past seasonal mean AET of the Mediterranean region for 1910-1040 (in mm)

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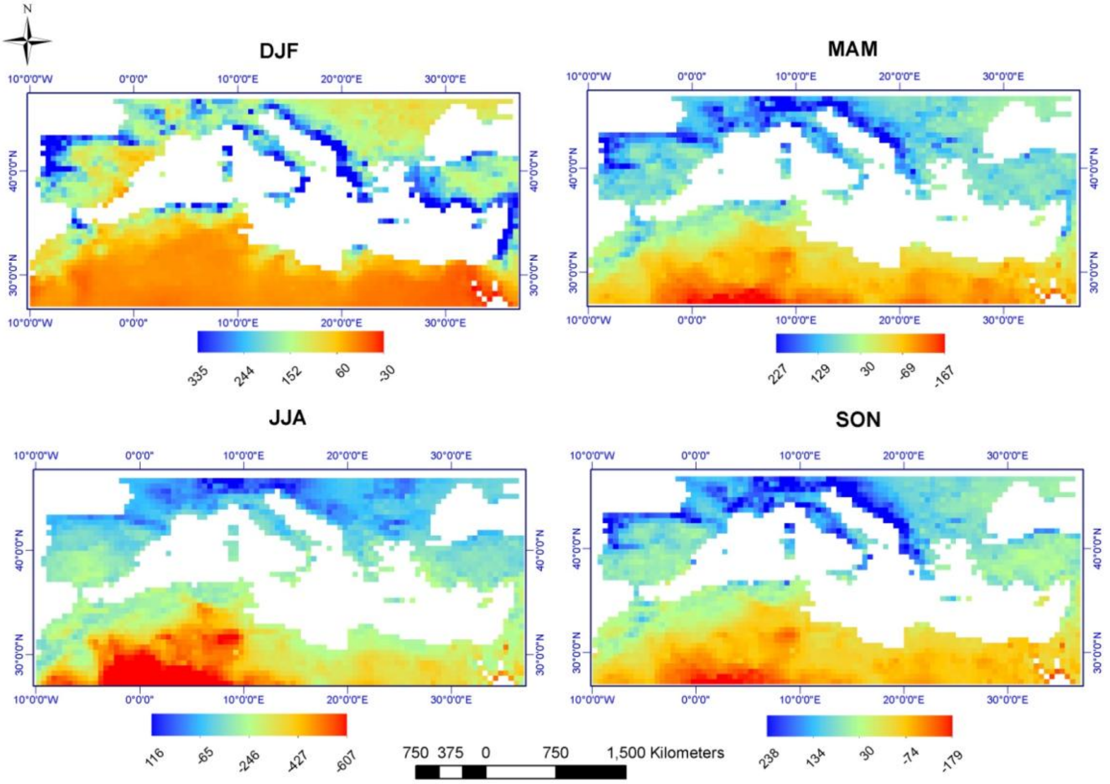

Figure D3 Past seasonal mean P-PET of the Mediterranean region for 1910-1940 (in mm).

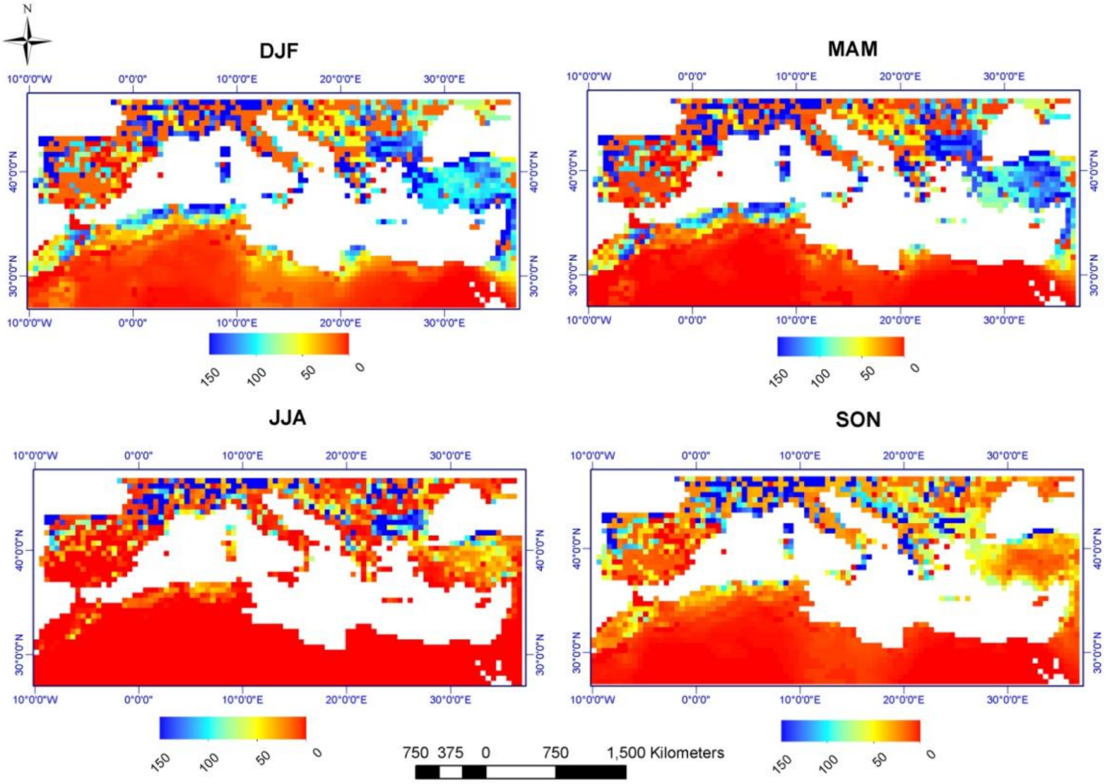

Figure D4 Past seasonal mean storage in the Mediterranean region for 1910-1940 (in mm)

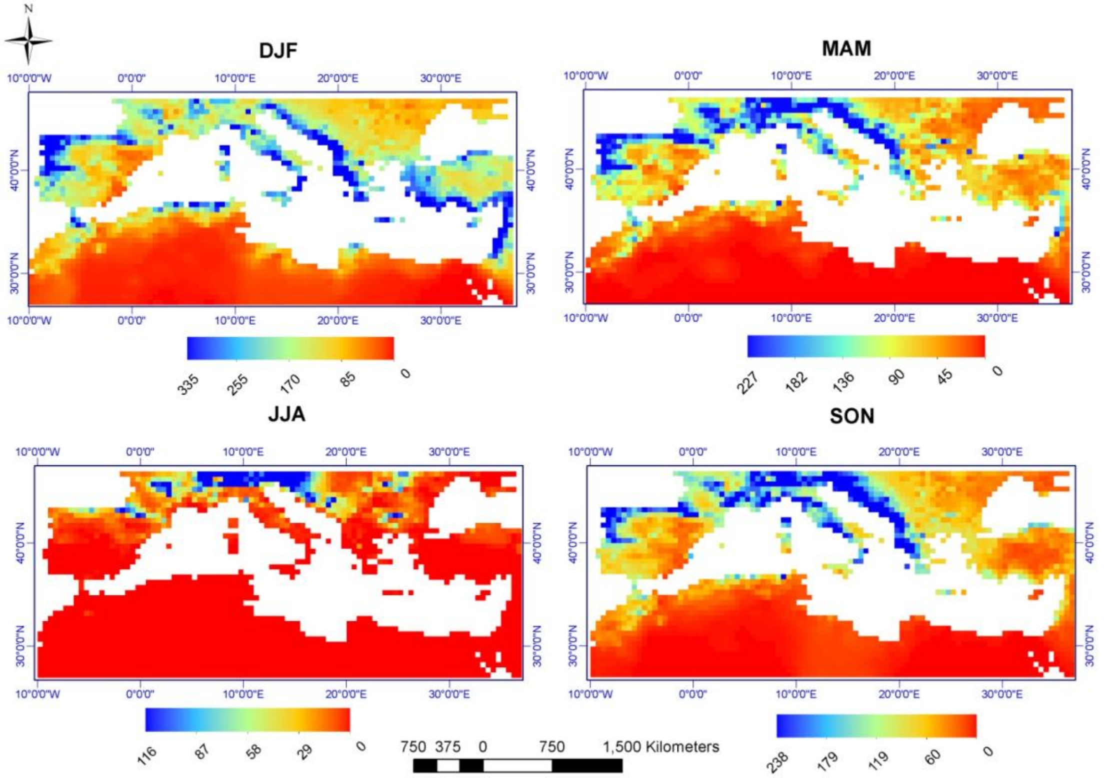

Figure D5 Past seasonal mean surplus of the Mediterranean region for the period of 1910-1940 (in mm)

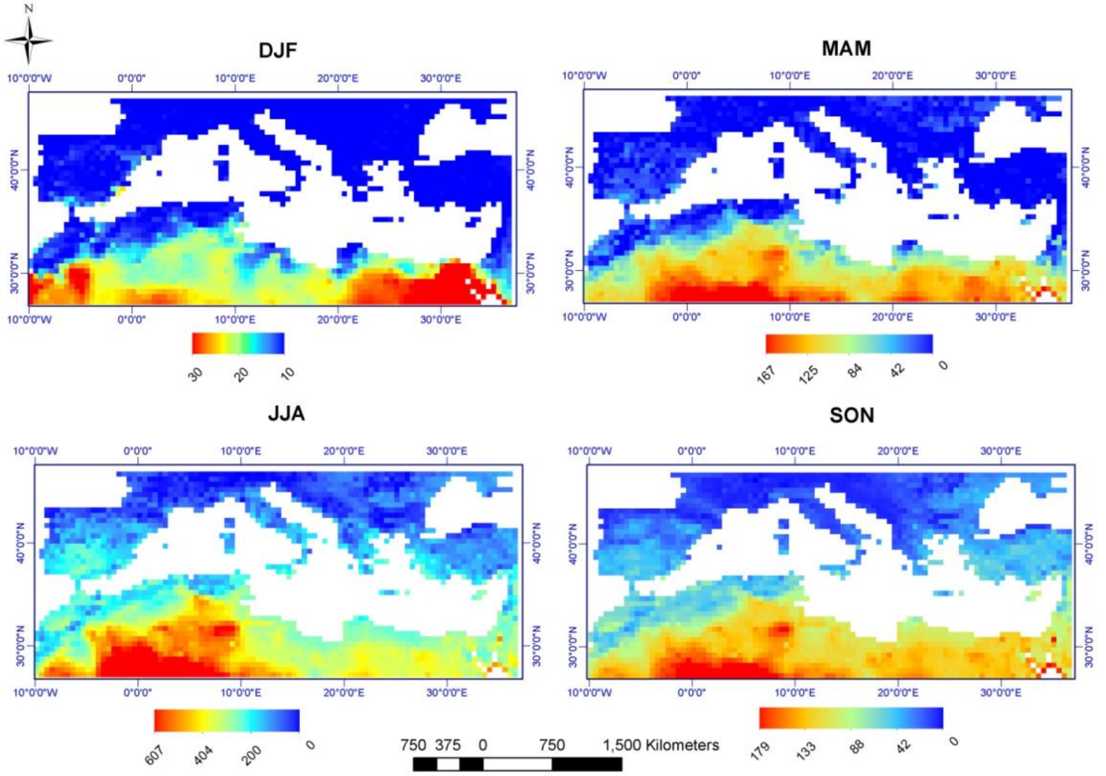

Figure D6 Past seasonal mean deficit in the Mediterranean region for 1910-1940 (in mm)

Appendix E

Present Water-Balance of the Mediterranean Region (1980-2010)

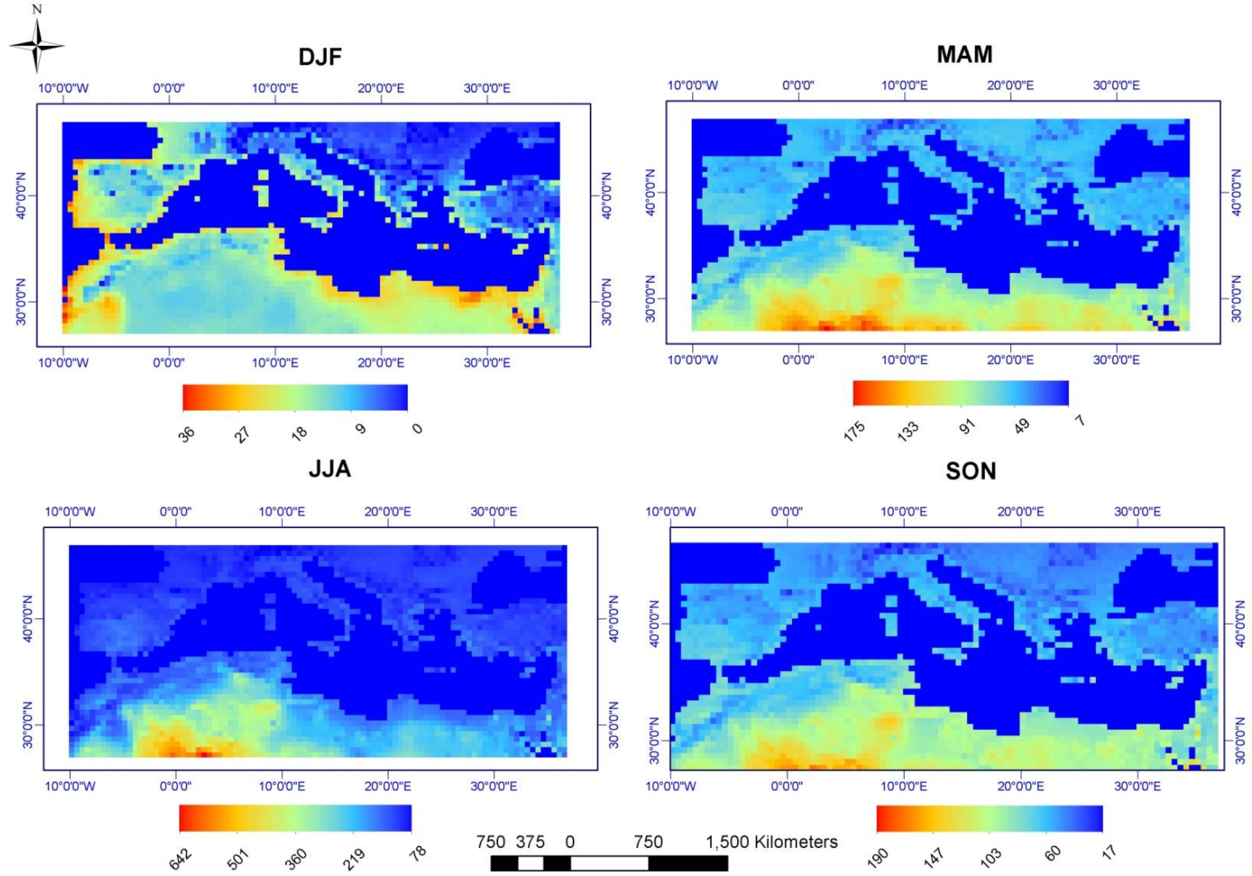

Figure E1 Present seasonal mean PET of the Mediterranean Region for 1980-2010 (in mm).

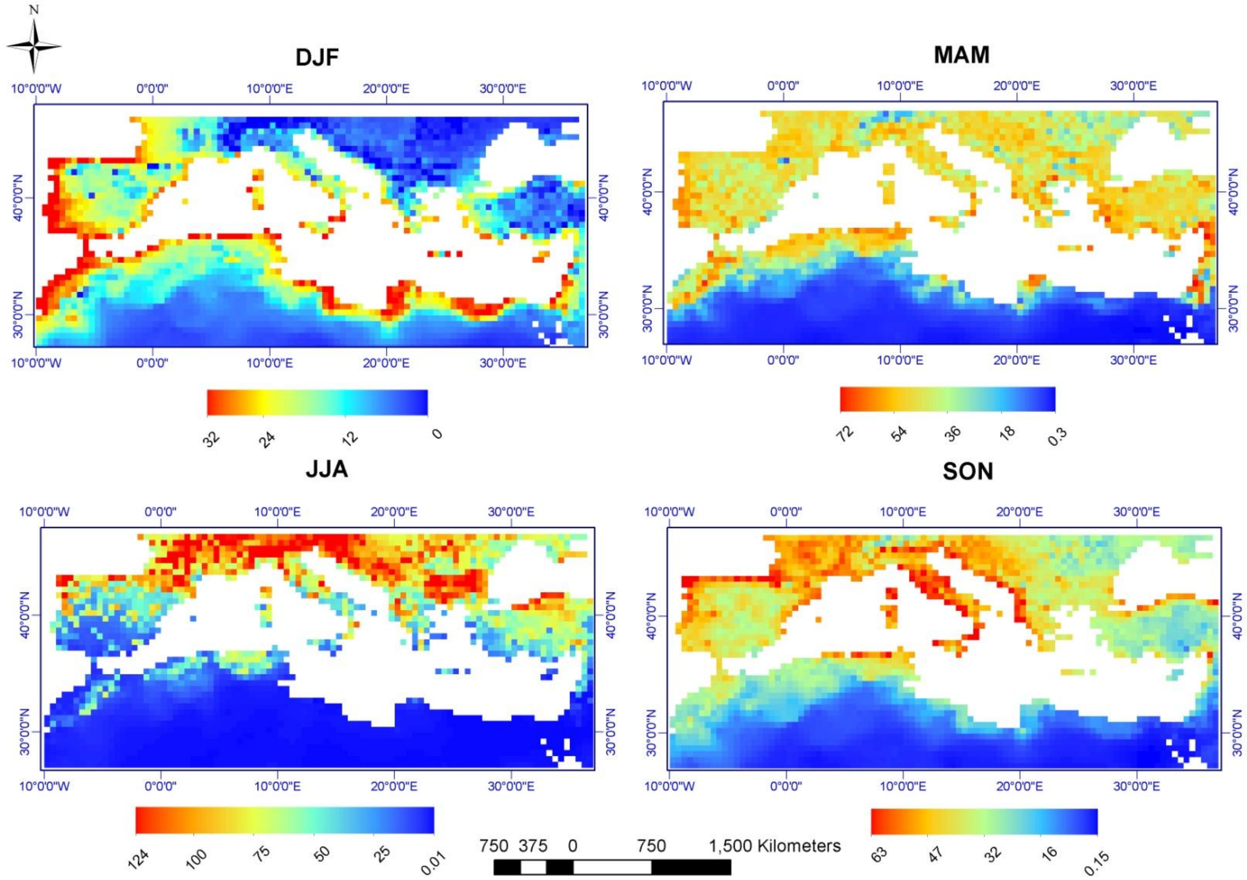

Figure E2 Present seasonal mean AETs in the Mediterranean region for 1980-2010 (in mm)

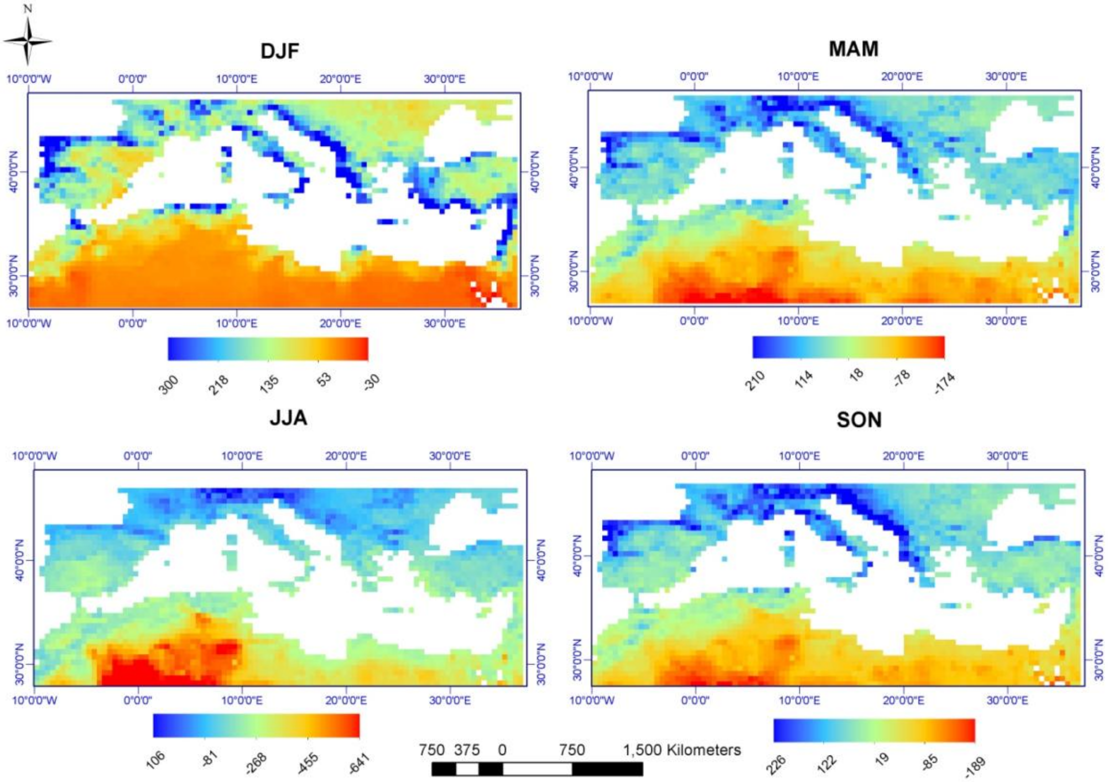

Figure E3 Present seasonal mean P-PET in the Mediterranean region for 1980-2010 (in mm)

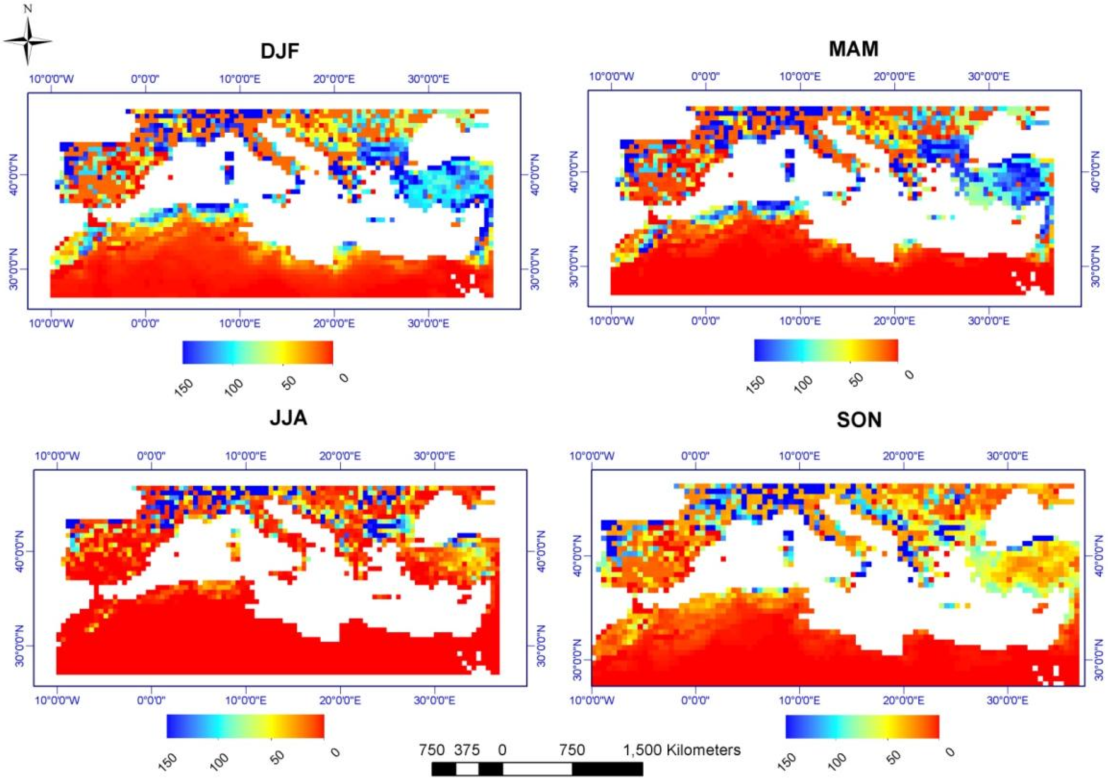

Figure E4 Present seasonal mean storage of the Mediterranean region for 1980-2010 (in mm)

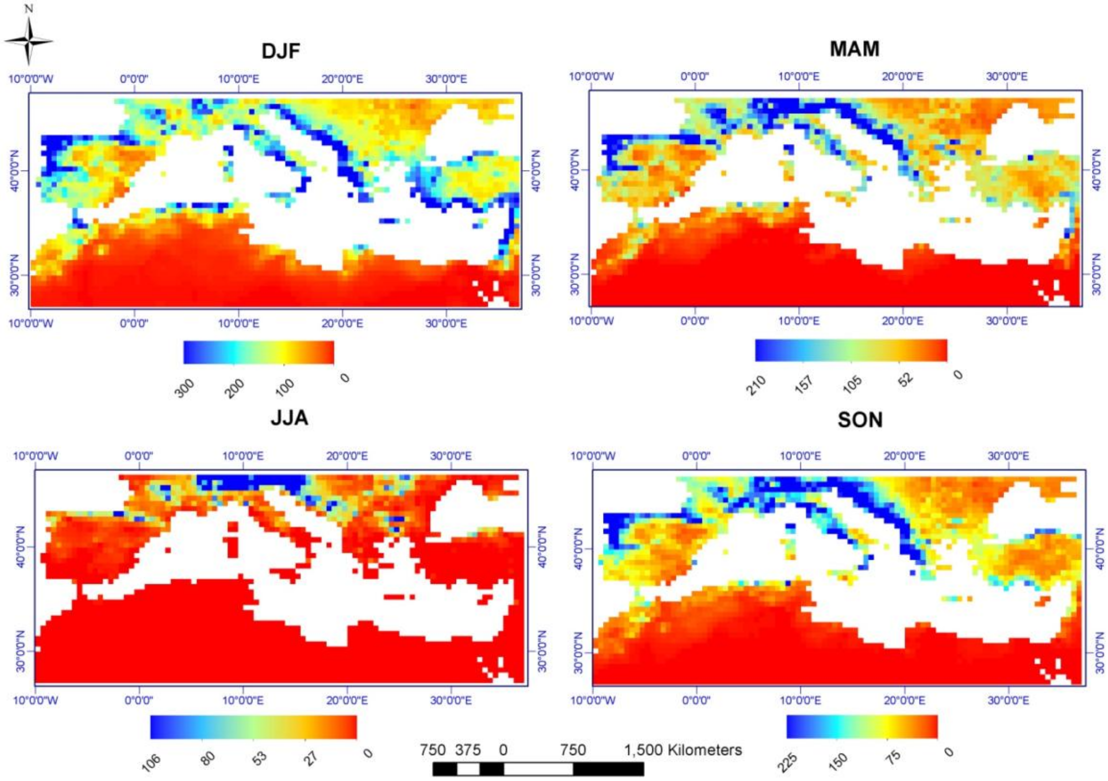

Figure E5 Present seasonal mean surplus in the Mediterranean region for 1980-2010.

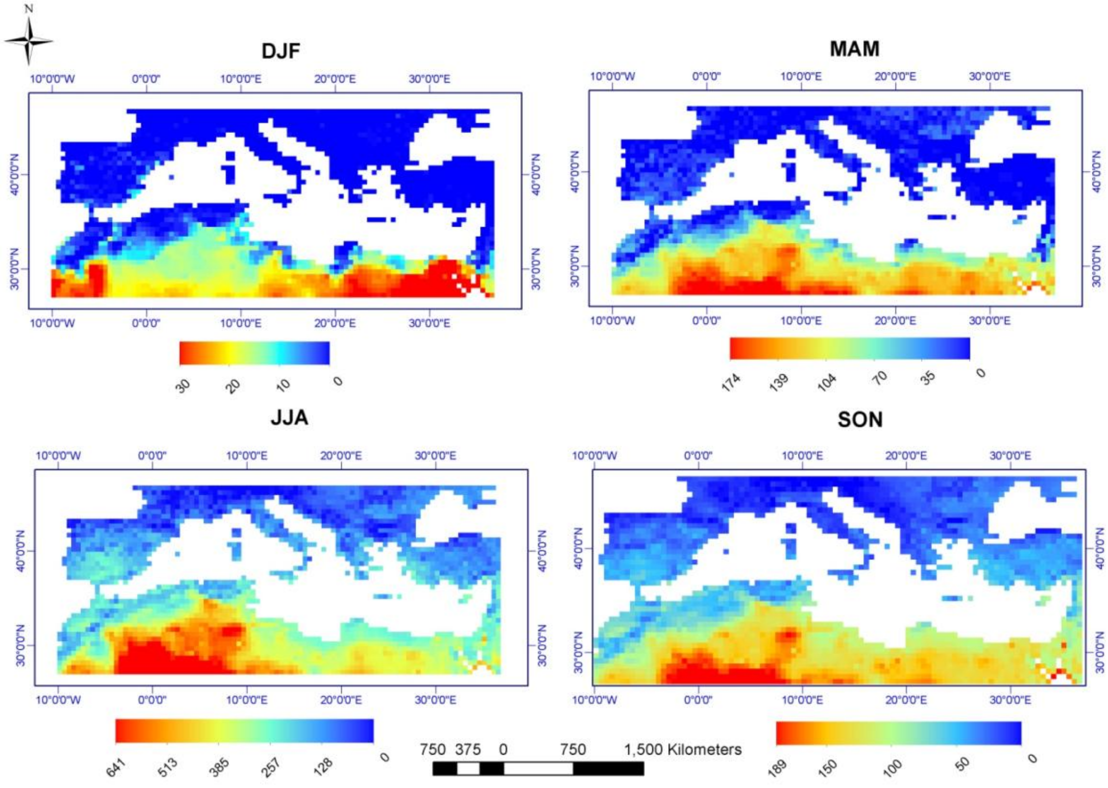

Figure E6 Present seasonal mean deficit in the Mediterranean region for 1980-2010 (in mm).

Appendix F

Future Water-Balance in the Mediterranean Region (2070-2100)

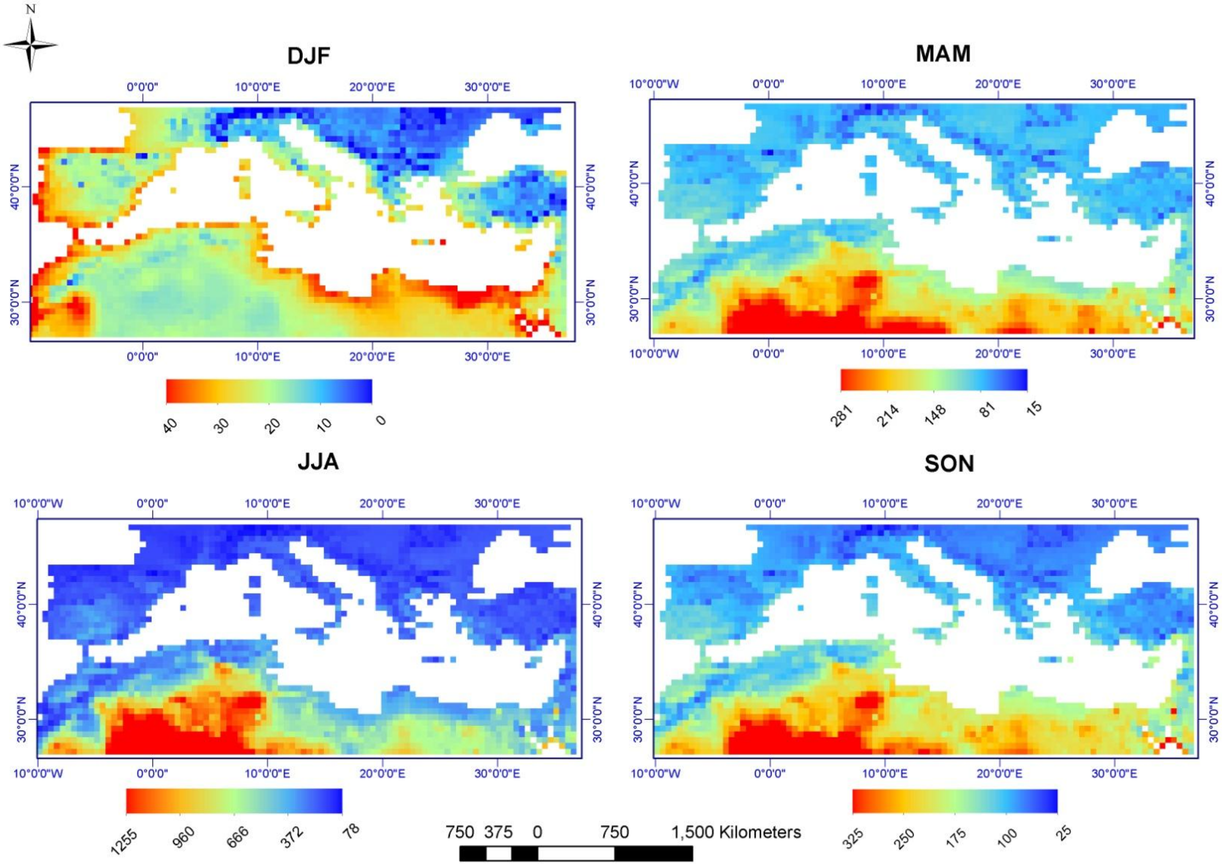

Figure F1 Future seasonal mean PET in the Mediterranean region for 2070-2100 (in mm)

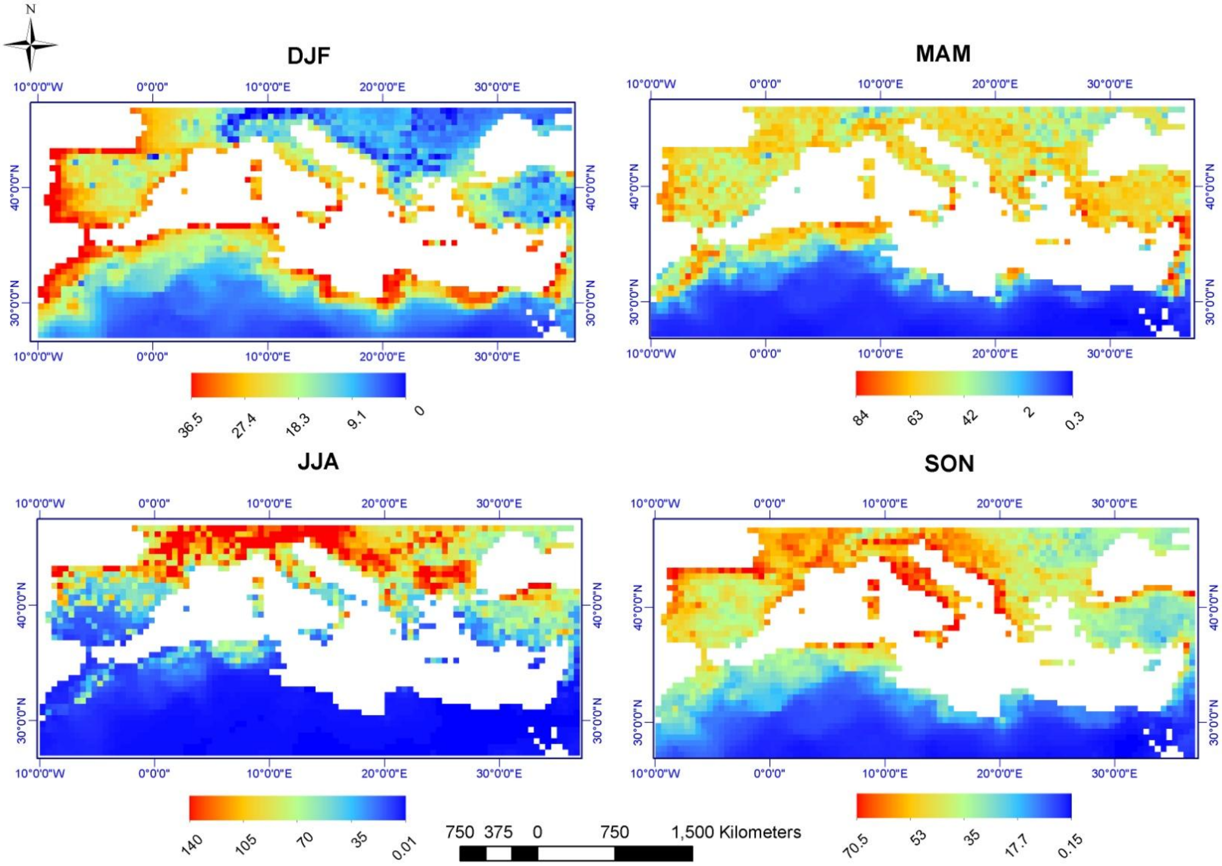

Figure F2 Future seasonal mean AET in the Mediterranean region for 2070-2100 (in mm)

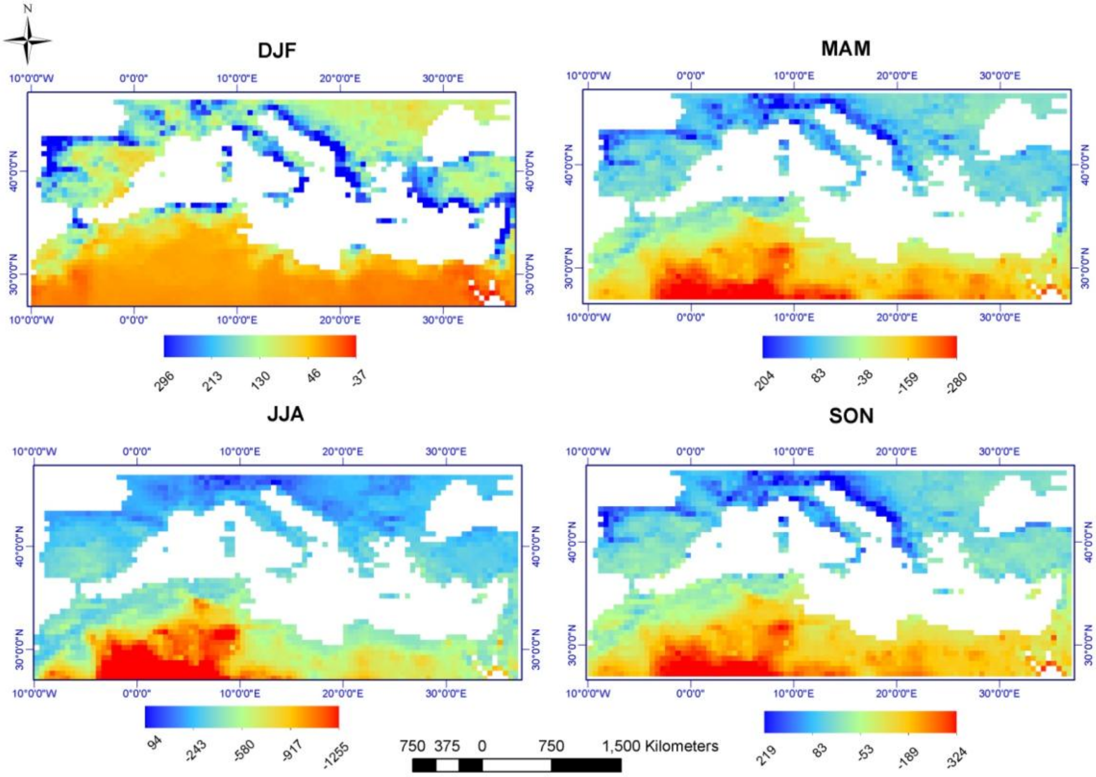

Figure F3 **Future seasonal mean P-PET in the Mediterranean region for 2070-2100 (in mm)**

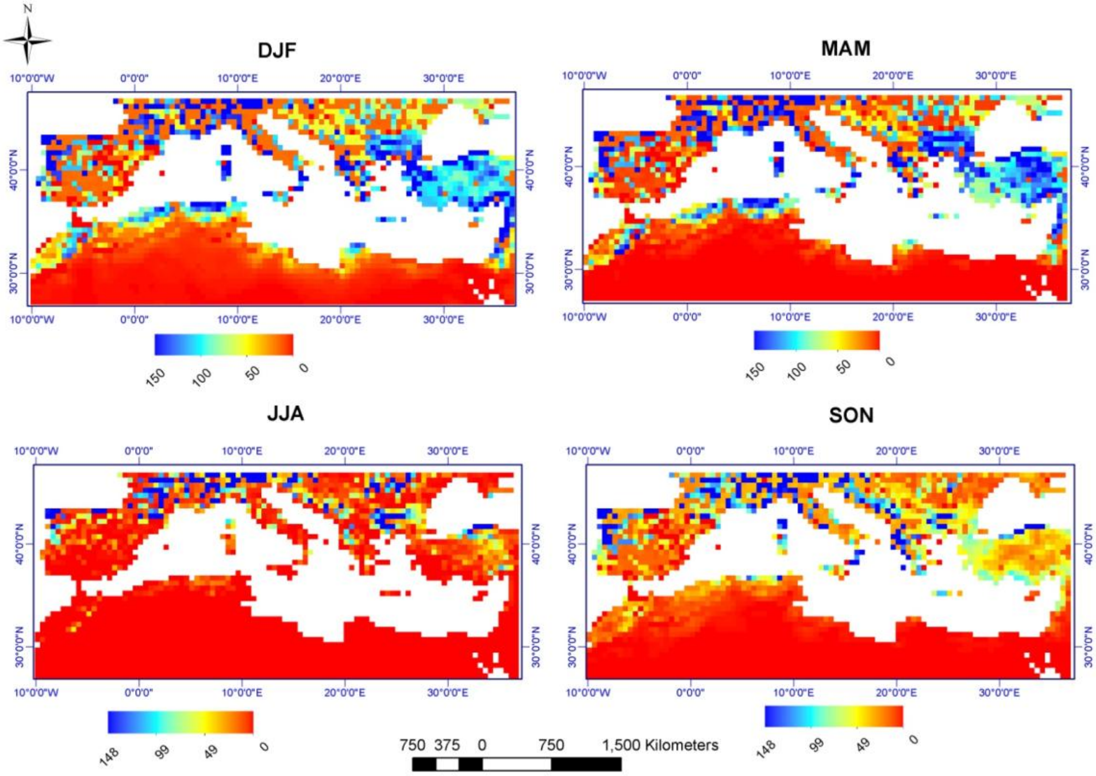

Figure F4 Future seasonal mean storage in the Mediterranean region for 2070-2100 (in mm)

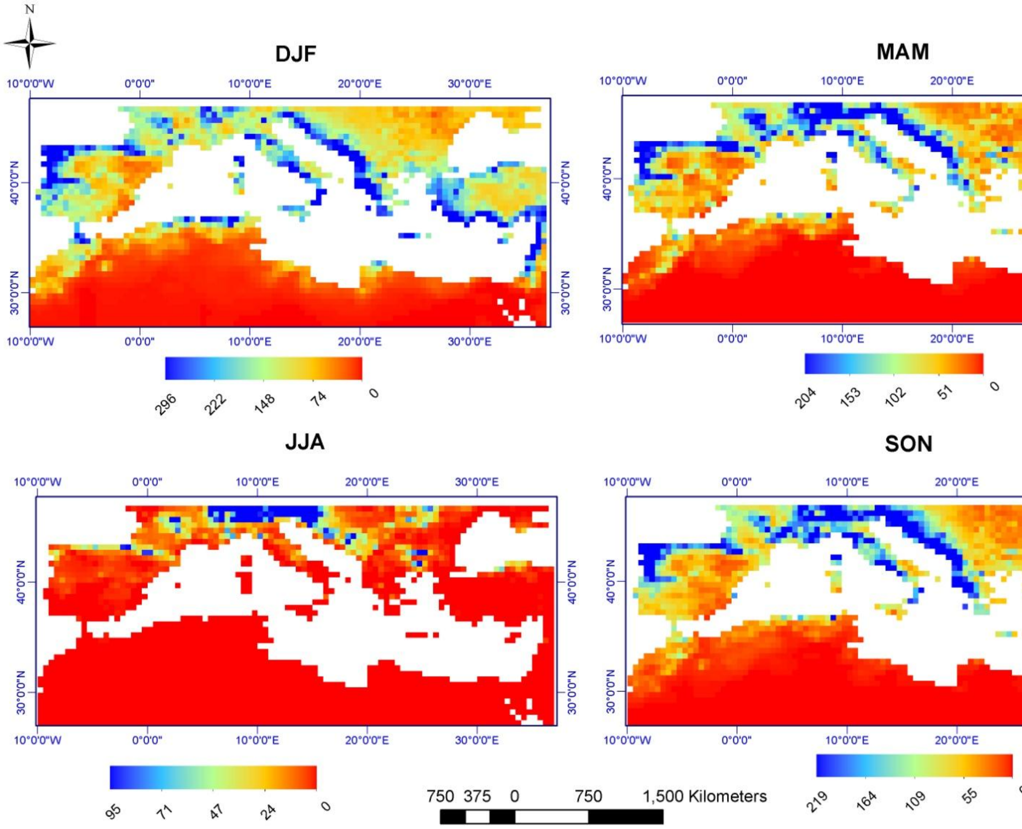

Figure F5 Future seasonal mean surplus in the Mediterranean region for 2070-2100 (in mm)

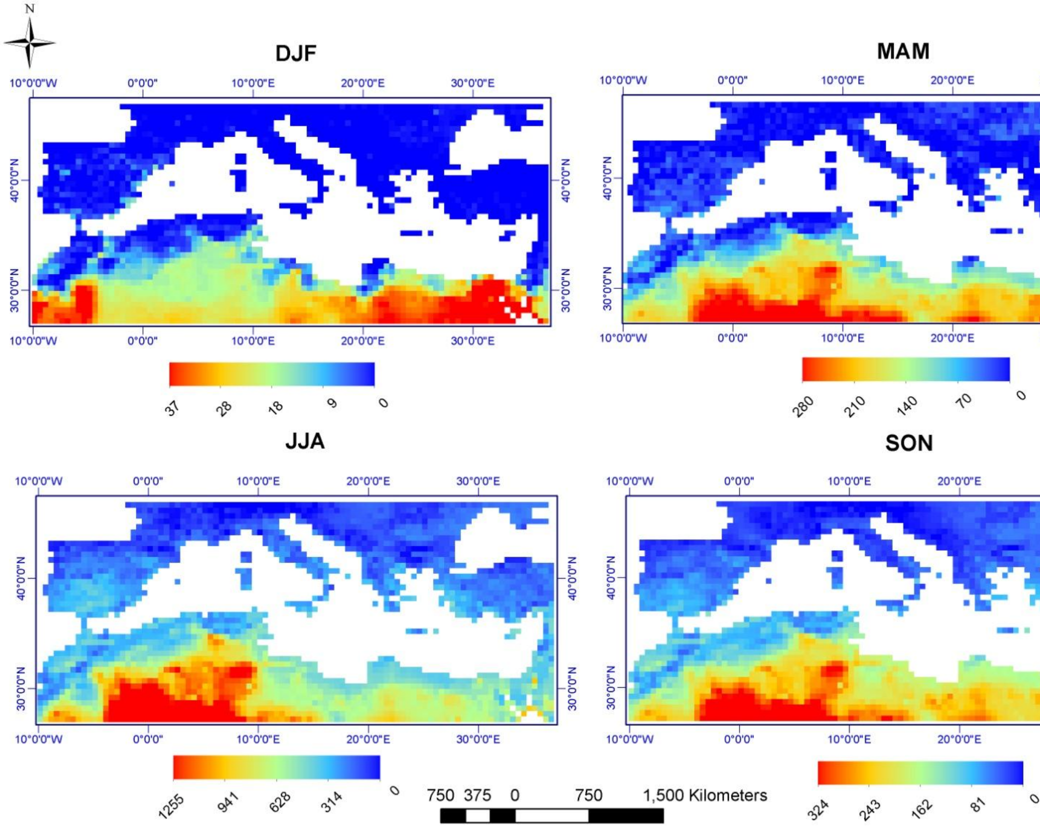

Figure F6 Future seasonal mean deficit in the Mediterranean region for 2070-2100 (in mm)

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