Extreme temperature events in the Mediterranean

Master's Thesis

Faculty of Science
University of Bern

presented by

Loredana Politano

2008

Supervisor:

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Institute of Geography and Oeschger Centre for Climate Change Research
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Abstract

The Mediterranean is an area of large interest due to unique geographical, historical, societal and morphological characteristics. The semi-arid Mediterranean environment is regarded as a “Hot Spot” of climate change (Giorgi, 2006), that suffers from more temperature extreme events and an increase of summer heat wave frequency and duration (e.g. Della-Marta et al., 2007). As well as, rising variability combined with a decrease in water resources can have an unprecedented impact on ecology, economy and society (IPCC, 2007).

This thesis analyzes trends in daily maximum (TX) and minimum temperatures (TN) based on the assessment of five temperature indices. 80 stations distributed across the whole Mediterranean region were selected and used for calculating temperature based climate indices.

The results showed statistically significant changes in minimum and maximum temperature extremes between 1950 and 1999. An increase of consecutive heat days (HWDI: +14.3 days/decade), summer days (SU: +6.7 days/decade) and warm days (WD: +5.7 days/decade) was detected. In parallel the number of frost days (FD: -5.5 days/decade) and cold nights (CN: -5.5 days/decade) has been reduced. Most significant changes of -10.4 days/decade and +10.8 days/decade occurred for summer CN and winter WD, respectively. Changes in TX related indices were stronger and more significant in the Western Mediterranean (Portugal, Spain, France) compared to the Eastern Mediterranean.

Between 1950 and 1970 an overall temperature decrease accompanied by lower maximum temperatures and fewer TX related events (HWDI, SU, WD) was detectable in Central and the Eastern Mediterranean. In contrast, between 1971 and 1999, TX related events in winter increased more (winter WD: +10 days/decade) than TN related events in summer decreased (summer CN: -8.5 days/decade). Overall, significant changes of TX and TN related indices occurred in the western part. Only the HWDI showed rising significant trends of similar magnitude in both, the Western and Eastern Mediterranean.

The large-scale atmospheric circulation pattern is related to temperature extreme events and therefore is able to explain the severe temperature extremes found at different levels (200hPa, 500hPa, 850hPa). The cool summer in 1972 (on average 22 cool nights) revealed low geopotential anomalies in both the geopotential heights (500hPa and 200hPa). We assumed that cold anomalies in summer months are linked to advance of cold-humid polar or artic air masses. In contrast, in 1998 the warm winter (on average 19 warm days) showed positive geopotential anomalies at different levels. We supposed that warm-dry winter anomalies are linked to air flow from west to south-west.

The present thesis shows that there are differences in the annually and seasonally distribution of maximum or minimum temperature extremes between the entire (1950-99) and the two sub-periods (1950-1970; 1971-1999), particularly in the spatial distribution of the indices, which affected the regions in the Mediterranean differently. Outcomes could be used for the analysis of extremes in future climate scenarios. Nevertheless, it is still of interest to include also the importance of soil moisture feedbacks and sea surface temperatures when working with seasonal or annual temperature variability. Though, the analysis of the role of human (e.g. land-use changes) and future climate scenarios is of great interest to understand daily temperature variability.

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Abbreviations

CIRCE	Climate change and Impact Research : the Mediterranean Environment
CN	Cold Nights
EA	East Atlantic
ECA&D	European Climate Assessment & Dataset
EMULATE	European and North Atlantic daily to MULtidecadal climATE variability
ENSO	El Niño/Southern Oscillation
ETCCDMI	Expert Team on Climate Change Detection, Monitoring and Indices
FD	Frost Days
GCOS	Global Climate Observing System
GHCN	Global Historical Climatology Network
HWDI	Heat Wave Duration Index
IPCC	Intergovernmental Panel on Climate Change
NAO	North Atlantic Oscillation
SAM	South Asian Monsoon
SAT	Surface Air Temperature
SO	Southern Oscillations
SU	Summer Days
TN	daily Minimum Temperature
TX	daily Maximum Temperature
WD	Warm Days
WMO	World Meteorological Organisation

1. Introduction

1.1 Motivation

The impact of human activities on the atmospheric chemical composition has become more evident since the industrial revolution. This warming, mainly caused by burning fossil fuels, land use changes and other man made activities started in the mid- to late Holocene and has induced modifications of the global energy balance leading to positive and negative radiative forcings (IPCC, 2007; Ruddiman, 2003). One of the positive radiative forcings for temperature is the rise of greenhouse gas concentrations such as carbon dioxide, methane and nitrous oxide amongst others. In contrast, aerosols, such as black carbon, have a negative forcing leading rather to decreasing temperatures (IPCC, 2007).

The general consensus of the Fourth Assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC) is that *“most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gases concentrations. It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)”*. Indeed, the global greenhouse gases emissions caused by human activity have risen dramatically during the last two centuries (e.g. the atmospheric CO_2 concentration has risen from 180ppm to 385ppm; Methan from 715ppb to 1790ppb) with an increase of 70% between 1970-2004 (IPCC, 2007).

It is assumed that the human impact induced an increase of the global mean surface air temperature of approximately 0.74°C during the twentieth century. The temperature increase between 1950 and 2000 (+0.13°C/decade) nearly doubled compared to the previous 100 years. Hence, the global warming trend due to anthropogenic activities corresponds to an increase in energy flux of +1.6 Wm^{-2} since 1750 (IPCC, 2007).

However, the human factor is not the only one which changes and influences the energy balance of the earth system. Also natural forcings such as solar activity, volcanic eruptions or changes in orbital characteristics can cause climate change and climate variability. Fischer et al. (2007) and Robock (2000) point out that volcanic eruptions represent an important natural radiative forcing because it is large and short lived, giving like this the opportunity to test climate response.

Besides increasing average temperatures, also more extreme events, modified wind patterns and sea level rise are consequences of the climate change. Temperature findings are sustained from instrumental observations over the last 150 years (IPCC, 2007). Overall, the IPCC (2007) predict hotter temperature extremes, more intensive heat waves, stronger precipitation events, a decrease in snow cover and a reduction in sea ice as potential consequences of climate change. This implies that we will be exposed to more extreme events with potential severe consequences on natural and anthropogenic ecosystems, health and economy (IPCC 2007). Thus, it becomes more important to analyze extreme events, such as heat waves, floods and droughts.

Climate change is a global phenomenon which affects not all areas to the same extend. The highest vulnerability is shown by polar to sub-polar zones and semi-arid areas (IPCC, 2007). The Mediterranean is one of the European regions with highest anthropogenic impacts. It is a region with large interest due to its geographical, historical, societal and geomorphological characteristics (Lionello et al., 2006). This area is climate-sensitive, stressed by limited water resources and often very high temperatures leading to socio-political tensions and conflicts. Further, the Mediterranean region is a “hotspot” whose climate is especially responsive to global change and where potential climate change impacts are particularly strong (Giorgi, 2006; Diffenbaugh et al., 2007). In the countries around the Mediterranean Sea live more than 420 million people, approximately one third at coastal areas. The largest fraction of the total coastline (46,000km) is in Greece, followed by Italy, Croatia and Turkey (http://www.planbleu.org; Lionello et al., 2006).

For the Mediterranean, the study by Pal et al. (2004) identified that the central Mediterranean and the central/Western Europe are particularly vulnerable to the increase in both summer flood and drought. Gao et al. (2006) found over a number of regions of the Mediterranean area (e.g. Balkan regions, the Iberian) changes in extreme events exhibit by topographically induced fine scale structure. Della-Marta et al. (2007) showed that the climate of Western Europe has become more extreme and that the hypothesized increase in variance of future summer temperature has in fact been a reality over the last 126 years. Moreover, the study of Diffenbaugh et al. (2007) argues that the increased heat stress risk in the Mediterranean region is caused by dramatically elevated greenhouse gas concentrations. Finally, recent work by Goubanova and Li (2006) has shown that all scenarios suggest an increase in both, annual minimum and maximum temperature. The largest warming for the minimum temperature occurs over Northeast Europe, on the other hand for the maximum temperature warming was found over Southern Europe. In addition changes in temperature extremes are mainly due to the shift of the whole distribution to warmer values. All these findings denote that changes in extremes are essential in the framework of anthropogenic climate change.

Extreme events, such as heat waves are often accompanied by large damages and losses. The 2003 heat wave and drought in Europe for instance caused more than 30,000 fatalities (at least 15,000 in France), the destruction of large forested areas by fires and a monetary damage of around US$ 14 billion from crop losses (Nicholls and Alexander, 2007; WHO, 2003; Koppe et al., 2004; García-Herrera et al., 2008). Moreover, the drought in Italy induced an increase of air pollution in all major cities. In contrast, in January 2002 southeastern Europe suffered from a very cold period accompanied by snow and severe frost damages even at the southernmost areas as Crete (Bolle, 2003).

Although daily climate data are essential for societally-sensitive extremes, most analyses have focused on changes in mean values due to the lack of the availability of high quality daily resolution data required for monitoring, detecting and attributing changes in climate extremes (Jones, 1999). Unfortunately, the availability of a globally complete and updated daily data set is still missing. Especially for the Mediterranean region, there is still a scarcity of available digitized daily data. Nevertheless, detecting, monitoring and attributing changes in climate extremes require high quality, continuous and long daily data (e.g. ECA&D, ETCCDMI) (Jones, 1999).

Beside the data availability, the quality and homogeneity of climate series are a prerequisite for detailed and trustworthy climate studies. However, most long-term time series are affected by inhomogeneities caused by changes in instrumentation, site displacements, changes in the local environment such as urbanization, or the introduction of different observing practices (Wijngaard, 2003). If these inhomogeneities are not accounted for properly, the results of climate analyses using these data can be erroneous (Peterson et al., 1998). The homogeneity adjustments of atmospheric climate data make possible to consider temporal variations as caused by climate processes (e.g. Della-Marta and Wanner, 2006). In order to improve predicting models it is essential to have a reliable set of observations.

However, the detection of trends in weather extremes remains a challenge because of the rare occurrence of extreme events. Moreover, the detection likelihood decreases with increasing rarity of the event (Frei and Schär, 2001; Klein Tank and Können, 2003; Schär et al., 2004). Therefore, the assessment of trends is often based on indices describing extreme events. To notice if changes are already evident and to reduce the climate variability it is of remarkable interest to analyze the occurrence of past extremes (Moberg et al., 2006).

A number of studies dealing with trends of climate extremes during the last decades have been performed for different regions (e.g. Alexander et al., 2006; Della-Marta et al., 2007; Easterling et al., 2003; Klein Tank and Können 2003; Kiktev et al., 2005; Luterbacher et al., 2004; Moberg et al., 2005, 2006; Tebaldi et al., 2005; Xoplaki et al., 2003). The study by Alexander et al. (2006) is the most current assessment of changes in observed daily temperature and precipitation extremes which has been made world-wide. They argued that considerable changes in temperature extremes occurred for the period 1951-2003, mainly those linked to daily minimum temperatures. More than 70% of the global land areas showed a significant rise in the annual amount of warm nights and a decreasing amount of cold nights between 1951 and 2003. Moreover, Seneviratne et al. (2006) and Fischer et al. (2007) have shown that in the Mediterranean the high greenhouse gas concentrations contribute to an elevated heat stress risk region.

So far, the climate debate has focused on the detection of spatial and temporal patterns of climate change during the last few decades and answered questions related to the causes of such changes. A better understanding of natural climate variability is essential to assess the detection of any anthropogenic signals and to quantify the human impact even if it is difficult to get this information from relatively short instrumental record (Lionello et al., 2006).

1.2 Mediterranean region and Mediterranean climate

1.2.1 Mediterranean region and characteristics

This chapter focuses on the main characteristics of the Mediterranean area to provide an overall image of the region and its climate.

The Mediterranean region extends over three continents namely Europe, Africa and Asia. It covers an area of about 1.35 million km^2 landmasses and 2.5 million km^2 sea surface (without the Black Sea). The Mediterranean Sea is a semi-enclosed basin and has a west-east extension of more than 3,700 km and a north-south extension of approximately 1,600 km. The average depth of sea is 1,500 m, the maximum of 5,150 m is located in the Ionian Sea (Rother, 1993).

Climatologically the region is situated in a transitional zone where atmospheric variability of the mid-latitudes and the tropics are the main driving forces for the special characteristic of the regional climate. The high energy input and the large water body are an important source for a high number of cyclones (Lionello et al., 2006).

The interaction of the atmospheric circulation, the latitude, the terrain, the land-sea distribution and smaller scale processes due to temperature differences are the main factors controlling the climate conditions of the Mediterranean region and determine a large spatial variability leading to the presence of many sub regional and mesoscale climate characteristics (Lionello et al., 2006). The Mediterranean basin is unique because of its geographical position. Other marginal seas like the Japan Sea have much smaller extent and depth or they are connected through much wider openings to the ocean (Roether and Klein, 2003). Critical coastal areas could be heavily affected by changes of marine storminess, extreme storm surges and wind waves events (e.g. the northern Adriatic Sea; Lionello et al., 2003; Lionello, 2005) with large impacts on societies in the Mediterranean region.

1.2.2 Mediterranean climate

The Mediterranean area is a region where the dynamics of the mid latitude circulation and the tropics are intimately linked. The topography (e.g. Pyrennees, Alps, Dinaric Alps), the unique distribution of land and sea (Figure 1) play an important role in steering air flows. The meridional gradient visualized from hot and arid regions to humid mountain climate is a key feature affecting the atmospheric circulation (Lionello et al., 2006).

The classification of Koeppen (1936) defines the northern part of the Mediterranean region as a Maritime West Coastal Climate, while the Southern part as a Subtropical Desert Climate (Figure 2).

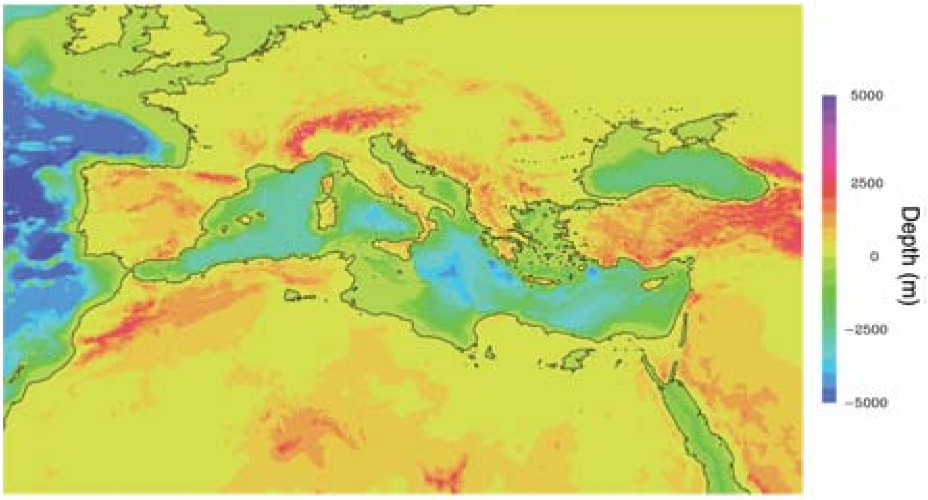


Figure 1*: Orography and sea-depth of the Mediterranean region (Lionello et al.,2006)*

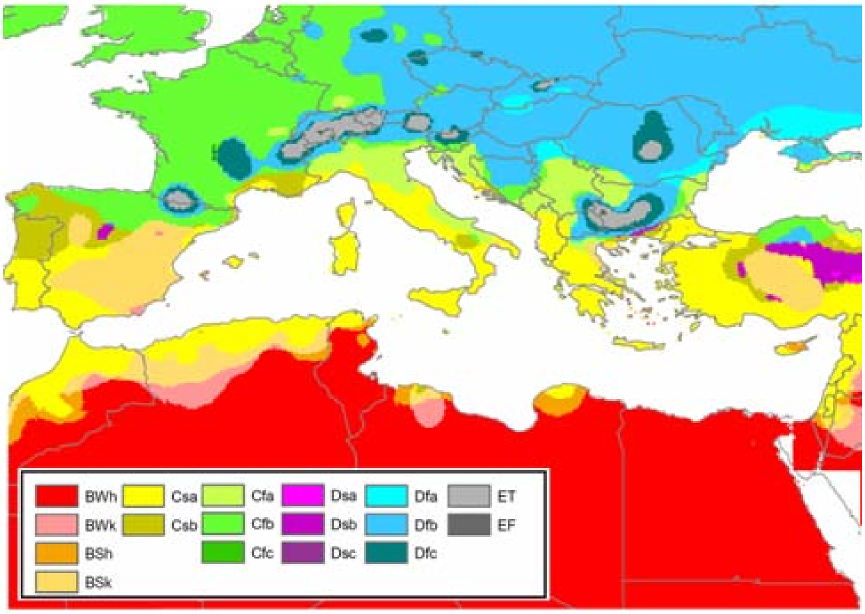


Figure 2*: Modified Köppen-Geiger climate map of the Mediterranean (after Peel et al.,2007)*

The winters are characterized by cyclonic disturbances and low pressure systems whereas subtropical high pressure system are prevalent for the summers. The formation of cyclones is partially determined by the polar Front Jet Stream and the European trough. These processes are modified by the land-sea temperature contrast and therefore favor cyclogenesis over the area (Xoplaki, 2002).

1.3 Aims of the thesis

This master thesis is part of the interdisciplinary integrated project CIRCE (Climate change and Impact Research: the Mediterranean Environment) initiated by European Commission’s Sixth Framework Programme. CIRCE has started in spring 2007 with the goal to provide an overview of climate change and impacts in the Mediterranean area. The major aims of CIRCE are:

- The prediction and the quantification of the physical impacts of climate change in the Mediterranean area
- The evaluation of the consequences of climate change for the society and the economy of the population located in the Mediterranean area
- The development of an integrated approach to understand combined effects of climate change
- The identification of adaptation and mitigation strategies in collaboration with regional stakeholders
- Analysis of extreme events based on the definition of extreme event indexes, identification of thresholds, and analysis of links with large scale patterns. Outcomes will be used for the analysis of extremes in future climate scenarios

This master thesis was written within the framework of Research Line 6 on extreme events. This Research Line focuses on 1) understanding of the current space-time distribution of extreme events over the Mediterranean 2) to analyze sets of climate simulations with several models to understand how the intensity of extremes could change in the 21 first century and 3) providing information for “focused” impacts analysis.

The aim of this study is to improve of the understanding of the Mediterranean climate by using daily temperature data, analyzing extreme events and their connection to the large-scale circulation patterns during the second half of the twentieth century.

To address this aim we studied temperature extreme events by using a selection of five climate indices. Trends in different percentiles of daily data distribution were analyzed for winter and/or summer which allowed us to study how the distribution of daily maximum and minimum temperature has changed seasonally. This work gives more detail information about the development of these five indices in the Mediterranean area and which region is more affected by these changes. The following research questions are addressed:

- **How are the selected indices distributed in space and time in the Mediterranean area and what are the limitation factors?**
- **How relevant is the selection of indices for climate change studies?**
- **Is the large-scale atmospheric circulation pattern related to temperature extreme events?**

The thesis is structured as follow: Section 2, “Data and Methods”, explains the methods used in the study. In Section 3, “Results”, presents the results obtained, section 4, “Discussion”, compares and discusses the results with similar studies and findings. Finally, conclusions and an outlook is given.

2. Data and Methods

2.1 Daily Data

This study aims to provide a better understanding of changes in extreme temperature in the Mediterranean area for the second half of the twentieth century. By analyzing daily maximum and minimum temperature data, it is possible to detect, monitor and attribute changes in extreme events. In contrast to changes in the mean values, high resolution daily data filter out detailed information about meteorological events and make available more trustfully information.

There are three international climate databases available offering daily resolved data for the research community: (1) the GCOS Surface Network (GSN) data set (Peterson et al., 1997), (2) the European Climate Assessment (ECA&D) data set (Klein Tank et al., 2002) and (3) the daily Global Historical Climatology Network (GHCN-Daily) data set (Gleason et al., 2002). For a better spatial coverage of the Mediterranean region, daily data of ECA&D (http://eca.knmi.nl/) and a number of unpublished station time series provided by collaborators (Elena Xoplaki, Franz G. Kuglitsch pers., regional National Hydrological and Meteorological Services) were analyzed.

The ECA&D database distinguishes between blended and non-blended series. Blended series are series which integrate data of several surrounding stations to complete a candidate time series best. Non-blended series contain only data recorded by one candidate station. For our analysis we used quality controlled non-blended series. The ECA&D has been initiated by the European Climate Support Network (ECSN) and it is supported by the Network of European Meteorological Services (EUMETNET). The main goals of this project are to join collections of daily series of observations at meteorological stations, the quality control of those series, the analysis of their extremes and the dissemination of both daily data and analysis results. Today, the ECA&D has 53 participants from 41 countries and their dataset contains 7033 series of observations at 2317 meteorological stations throughout Europe and the Mediterranean (http://eca.knmi.nl).

Complete daily data series from 14 countries (Albania, Algeria, Bosnia and Herzegovina, Croatia, France, Greece, Italy, Portugal, Romania, Serbia, Slovenia, Spain, Switzerland (Lugano), and Turkey) covering the time period between 1950 and 1999 were collected in the frame of CIRCE (Franz G. Kuglitsch and Elena Xoplaki, pers com). A station network of 80 representative stations (Table 1, Figure 3) across the Greater Mediterranean area were examined to calculate a set of climate change indices (Table 2). However, there are still areas, such as the central- and southern part of Italy or Northern Africa where the station density is low. Moreover, many data only exist in form of written information which has not been digitized yet. To cover this problem the WMO-MEDARE on Mediterranean Data Rescue was initiated in 2007 (Brunet and Kuglitsch, 2008), while in the frame of CIRCE efforts are continuously occurred for the collection of data from these areas (Research Line 1).

Table 1: *List of stations used for the calculation of the indices*

Country	Stations	Start year	End year	Lat (°)	Lon (°)
Albania	Tirana	1950	1999	42.6	19.32
	Shkodra	1950	1999	41.20	19.47
Algeria	Alger	1950	1998	36.43	3.15
	El-Golea	1950	1998	30.34	2.52
	Tamanrasset	1950	1998	22.48	5.26
Bosnia and Herzegovina	Bjelasnica	1952	1971	43.43	18.16
	Sarajevo	1950	1999	43.51	18.23
Croatia	Gopsic	1950	1999	44.43	15.22
	Hvar	1950	1999	43.10	16.27
	Lastovo	1950	1999	42.46	16.54
	Osijek	1950	1999	45.32	18.38
	Rijeka	1950	1999	45.19	14.25
	Zagreb	1950	1999	45.49	15.59
France	Besancon	1950	1999	47.15	6.1
	Biarritz	1956	1999	43.28	-1.32
	Bordeaux	1950	1999	44.50	0.40
	Bourges	1950	1999	47.5	2.24
	Carcassonne	1950	1999	43.13	2.21
	Cognac	1950	1999	45.50	0.19
	Deols Chat.	1950	1999	46.52	1.43
	La Rochelle	1950	1999	46.9	-1.9
	Langres	1950	1999	47.52	5.20
	Lyon	1950	1999	45.43	4.56
	Marseille	1950	1999	43.18	5.24
	Mont-Aigoual	1950	1999	44.11	3.34
	Montelimar	1950	1999	44.34	4.45
	Nancy	1950	1999	48.41	6.13
	Nimes	1950	1999	43.50	4.21
	Orleans	1950	1999	47.54	1.54
	Paris	1950	1999	48.49	2.20
	Perpignan	1950	1999	42.44	2.52
	Rennes	1950	1999	48.4	-1.44
	Sete	1950	1999	43.24	3.42
	Strasbourg	1950	1999	48.33	7.38

	Toulouse	1950	1999	43.37	1.23
	Vichy-Charmeil	1950	1999	46.8	3.26
Greece	Corfu	1955	1999	39.37	19.55
	Hellinikon	1955	1999	37.54	23.45
	Heraklion	1955	1999	35.20	25.11
	Larissa	1955	1999	39.39	22.27
	Methoni	1956	1999	36.50	21.42
Italy	Bologna	1950	1999	44.29	11.15
	Brindisi	1951	1999	40.38	17.56
	Cagliari	1951	1999	39.14	9.3
	Milan	1950	1999	45.28	9.0
	Rome	1951	1999	41.53	12.29
	Verona	1951	1999	45.26	10.59
Portugal	Braganca	1950	1999	41.48	-6.44
	Coimbra	1950	1994	40.12	-8.28
	Lisboa	1950	1999	38.43	-9.9
	Porto	1950	1999	41.8	-8.36
Romania	Arad	1950	1999	46.8	21.21
	Bucuresti	1950	1999	44.26	26.6
	Buzau	1950	1999	45.8	26.51
	Calarasi	1950	1999	44.12	27.20
	Drobeta T.S.	1950	1999	44.38	22.38
	Tg Jiu	1950	1999	45.2	23.16
	Turnu M.	1950	1999	43.45	24.54
Serbia	Beograd	1950	1999	44.49	20.28
	Nis	1950	1999	43.20	21.54
Slovenia	Kredarica	1955	1999	46.23	13.51
	Ljubljana	1950	1999	46.4	14.31
Spain	Alicante	1950	1950	38.21	0.28
	Badajoz T.	1955	1999	38.53	-6.48
	Barcelona	1950	1999	41.25	2.7
	Madrid	1950	1999	40.25	-3.39
	Navacerrada	1950	1999	38.47	-4.4
	Salamanca	1950	1999	40.58	-5.40
	San Sebastian	1950	1999	43.19	-1.58
	Torrevieja	1950	1999	37.59	-0.41
	Tortosa	1950	1999	40.49	0.31
	Valencia	1950	1999	39.29	0.21
	Zaragoza	1950	1950	41.39	0.54
Switzerland	Lugano	1950	1999	46.0	8.58
Turkey	Isparta	1950	1999	37.45	30.33
	Istanbul	1950	1999	40.58	29.5
	Kastamonu	1950	1999	41.23	33.47
	Rize	1950	1999	41.01	40.31
	Sivas	1950	1999	39.45	37.1

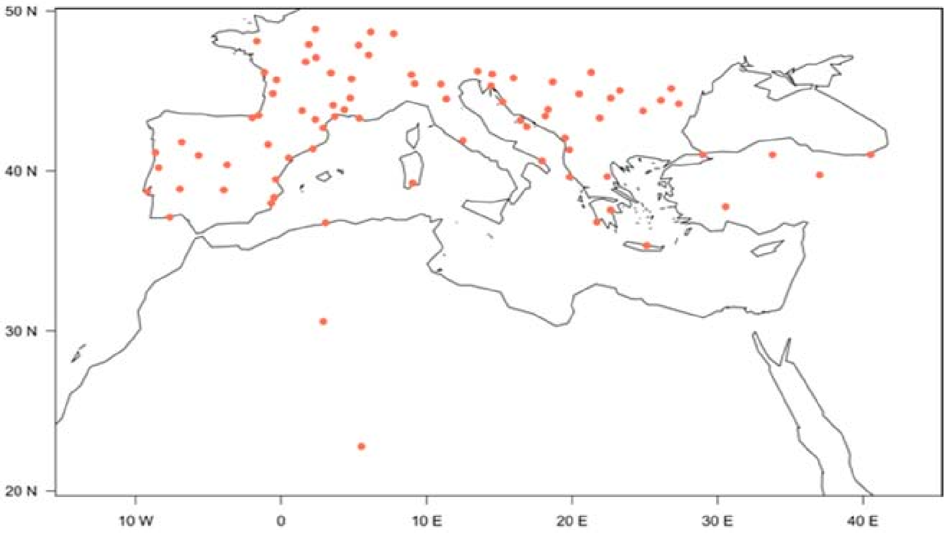


Figure 3: *Location map of stations with continuous daily records of air temperature for the period 1950-1999 (see also Table 1)*

2.2 Data quality

The quality of the data collected differs from country to country, but an effort was made to use the best possible data sources. Nevertheless to get nearly complete time series all stations were quality controlled. For the quality control, the open source program RClimDex developed by the Climate Research Branch of the Meteorological Service of Canada was used (see http://cccma.seos.uvic.ca/ETCCDMI/software.shtml for further details). The main goal of this procedure was to reduce errors in data recording and processing such as errors in manual keying. Daily maximum and minimum temperature were set to missing values if the daily maximum temperature was lower than the daily minimum temperature. Outliers in daily maximum and minimum temperature exceeding +/- four standard deviation were also identified and replaced.

The stations were selected based on the general criteria used by the ECA&D (Klein Tank et al. 2002b): (i) data must be available for at least 40 years, (ii) missing data must not be more than 10% of the total, (iii) missing data from each year must not exceed 20%, (iv) more than 3 months consecutive missing values are not allowed.

2.3 Climate Indices

Climate indices are based on daily data and they are suitable for analysing extreme events. Extreme events occur several times per year or per season giving them more robust statistical properties. Indicators, such as the frequency of extreme temperatures and heating degree days, are quantities that tend to be noticed by people and have economic significance. The climate index is the mean of several climate change indicators (Hansen et al., 1998).

The detection probability of weather extremes decreases the rarer the event is (Klein Tank and Können, 2003). The advantage of using Indices for climate change detection is that (1) they can be applied to different climate parameters such as TX, TN, RR… , (2) they enable an easy comparison of trends between different climate regions and (3) they are easily understandable and manageable for impact studies.

A total of 27 core indices are suggested by the ETCCDI (CCI/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices) with primary focuses on extremes to reflect changes in intensity, frequency and duration of events. The software "RClimDex" offers a suitable template to compute these indices efficiently.

In the frame of the European 6th Framework programme EMULATE (European and North Atlantic daily to MULtidecadal climate variability) 64 climate indices were defined, deriving from daily temperature and/or precipitation series (http://www.cru.uea.ac.uk/projects/emulate/). The calculation of the extreme indices was made with a self-programmed Fortran routine "EMULATE-Seas-Extremes.f90". The indices can be divided into five different categories:

1.) Percentile-based indices giving information about the temperature (°C) of cold nights (TN05p), warm nights (TN95p), cold days (TX05p) and warm days (TX95p). They sample the coldest and warmest deciles for both maximum and minimum temperatures.
2.) Absolute indices (°C) represent maximum or minimum temperature values (°C) within a given time period (season, year) such as highest maximum temperature (TXx), highest minimum temperature (TNx), lowest maximum temperature (TXn) or lowest minimum temperature (TNn).

3.) Threshold indices are defined as the number of days exceeding or dropping below, respectively, a fixed temperature threshold such as the number of frost days (FD), ice days (ID), summer days (SU) or tropical nights (TR). The fixed thresholds used in the definitions may not be applicable everywhere on the globe because these indices are not necessarily meaningful for all climates.

4.) Periods of excessive heat or cold can be defined as duration indices (in days). They include the cold wave duration indicator (CWDI), the warm spell duration indicator (WSDI) and the heat wave duration index (HWDI).

5.) Other indices include the diurnal (DTR) and extreme temperature range (ETR) in °C.

A full descriptive list of the indices can be downloaded from http://eca.knmi.nl/indicesextremes/indicesdictionary.php#5.

One of the methods, also used in this study for the definition of temperature extreme climate events, is the calculation of temperature based indices (Frich et al., 2002; Moberg et al., 2005; Peterson, 2005; Alexander et al., 2006). The selection of the temperature indices allows the assessment of changes in both the cold and the warm tails of the distribution for both daily maxima and minima. The study of the extreme events was done for annual and seasonal time scales. The investigated seasons are summer (June to September; JJAS) and winter (December to February; DJF). Finally, we focused only on seasonal scale because it is essential to detect differences in trends between annual and seasonal scale.

Based on the recommendations of EMULATE and ETCCDI, 18 temperature indices, listed in Table 2, were computed on an annual basis. The preliminary calculation of all the selected indices was needed to outdraw the five most representative for the region of interest (Table 2). The first screening shows these five indices as the most suitable for the study because of visible annual changes reported by them. The selected indices were then calculated on a seasonal basis (winter and/or summer) to provide a better measure of extreme temperature variability (Klein Tank and Können, 2003).

Table 2: *List of all temperature indices calculated in this study. Indices in bold are considered in detail in this thesis*

ID	Indicator Name	Definitions	Units
	Threshold Indices		
SU30	**summer days**	**Summer days (No. days TX>30°C)**	**Days**
FD	**Frost days**	**Frost days (No. days TN<0°C)**	**Days**
ID	ice days	Ice days (No. days TX<0°C)	Days
TR	tropical nights	Tropical nights (No. days TN>20°C)	Days
	Percentile-based		
CD(TX05n)	cold days	Percentage of days when TX<05th percentile	Days
WD(TX95n)	**warm days**	**Percentage of days when TX>95th percentile**	**Days**
CN(TN05n)	**cold nights**	**Percentage of nights when TN<05th percentile**	**Days**
WN(TN95n)	warm nights	Percentage of nights when TN>95th percentile	Days
	Absolute indices		
TXx	max Tmin	Annual max value of daily min temperature	°C
TXn	min Tmin	Annual min value of daily min temperature	°C
TNx	max Tmax	Annual max value of daily max. temperature	°C
	min Tmax	Annual min value of daily max. temperature	°C
TNn	***Duration indices***		
	Warm spell duration index	Warm spell duration index (No. of consecutive days (at least6)with TX>90thp)	Days
WSDI90			
WDI	cold wave duration indicator	Cold wave duration index (No. consecutive days with TX<5thp)	Days
HWDI	**heat wave duration index**	**Number of consecutive (at least 3) days exceeding TX95thp**	**Days**
	Others indices		
DTR	diurnal temperature range	Diurnal Temperature Range (TX [on basis of whole time series])	Days
ETR	annual temperature range	Extreme temperature range (Diff. between highest TX & lowest TN during the year)	Days

2.4 Analysis of Temperature Indices

In these thesis study referring to the ETCCDMI and EMULATE definitions, we used five climate indices related to temperature. As statistical cut off we set the 5th and the 95th percentile (Table 2). The selected indices refer to cold and warm extremes.

Although the SU and the FD indices may not provide really global spatial coverage or be really extreme, previous studies (e.g. Frich et al., 2002; Kiktev et al., 2003) have shown that these temperature indices, defined as the number of days when minimum temperature falls below the 0°C, exhibit coherent trends over the mid-latitudes during the second half of the twentieth century. For this reason they were included in the study. The heat wave duration index (HWDI), defined by Frich et al. (2002), is not to be statistically robust as it had a tendency to give to many zero values (Kiktev et al., 2003). Frich et al. (2002) used a fixed threshold of 5°C above climatology to compute the index. This threshold is too high in many regions where the variability of daily temperature is low. Therefore we used for the computation of this index a percentile based threshold, the number of consecutive days exceeding TX95th percentile. Moreover, the assessments of percentile based indices require a centered 5-day window.

The others indices (warm days and cold nights) are threshold based indicators that give information about the frequency of an event. On the other hand HWDI gives information about the length and the SU and the FD indices about the magnitude of an event. The indices were calculated with RClimDex software package, as well as with the free available language R (http://www.r-project.org). As base period, for indices representing count of days crossing climatolological percentile thresholds at a station, was chosen the 1961-1990. The temperature indices based on percentile, such as WD, CN and HWDI, are calculated as percentage of days above or below the 95th or 5th percentile.

2.5 Trend calculation

The study by Moberg and Jones (2005) demonstrated that with two different methods, the ordinary least square (OLS) and a robust non parametric test, the estimated trends were very similar. These findings are also confirmed by the studies of Cohn and Lins (2005) and Kiktev et al. (2003). However, because of the smaller variance of the estimator the significance was generally reached more easily with the OLS method. Although there are different methods for trend estimation and significance testing, there is no universally accepted best technique. From the indices series a linear trend is computed using the OLS method. The significance of the trend is determined using Kendall’s tau test, a non parametric test, which does not assume an underlying probability distribution of the data series (Moberg et al., 2006). The 5% level was chosen to determine the statistically significant trends. We also provided estimates of the uncertainties in these trends, by calculating 95% confidence intervals; these are obtained by using the individual trend estimated at each station and for each index. The trend calculations were performed for two consecutive sub-periods (1950-1970 and 1971-1999) as well as for the entire 50-yr period 1950-1999.

2.6 Seasonal climate composites

To understand some seasonal extreme events occurred between 1950 and 1999 it is crucial to look at the large-scale atmospheric circulation. Thus, changes between different atmospheric altitudes and sea level pressure features are the main interesting factors. We plotted seasonal climate composites analysis for winter and/or summer for different atmospheric levels (200hPa, 300hPa, 500hPa, 850hPa geopotential height) and sea level pressure (SLP). This allowed us to detect circulation anomalies for each highlighted extreme events.

Taking advantage of a public tool (Climate explorer), disposed by the KNMI (http://climexp.knmi.nl/start.cgi?someone@somewhere), we plotted climate composites analysis for three seasonal indices (CN, WD and SU) (Oldenborgh and Burgers, 2005). The representative year of the three indices was selected by choosing for each station a year with the highest amount of days/nights for the period 1950-1999. This filtering permitted to find for each index the year with the most recurrences. The base period of the seasonal composites analysis (1961-1990) correspond to ours utilized in the assessment of the fives climate indices (see section 2.4).

3. Results

3.1 Annual results

3.1.1 Percentile-based Temperature Indices

The analysis of daily temperature data revealed a variety of changes in extreme values in the Mediterranean area during the period 1950-1999. Trends in temperature indices reflect an increase in both maximum (Tmax) and minimum temperatures (Tmin) (see Table 3).

Most remarkable trends were found for the period 1950-1999 showing significant increases of Tmax related indices (e.g. Warm Days) and significant decreases in Tmin related indices (e.g. Cold Nights). Overall there are somewhat more significant positive trends for Tmax than negative trends for Tmin for this period. Similar trends but weaker for Tmax indices and stronger for Tmin indices also apply for the period 1971-1999. However, more than half of the stations (approximately 60%) does not show any significant changes between 1950 and 1999. Approximately a 50-70% of the stations show not statistically significant changes in the two sub-periods.

Table 3: *1950-1999*: *Number of stations with significant negative and positive and non significant trends for the annual temperature indices (5 % level). In bold at least the 25% of the stations shows significant trends.*

Indicator name	Negative	Nonsignificant	Positive
Frost Days	**26**	47	3
Cold Nights	**27**	42	4
Heat Wave Duration Index	6	48	**25**
Summer Days	4	53	17
Warm Days	4	48	**28**

In the period 1950-1999 27 out of 80 stations show a significant decrease of CN (-5.5 days/decade), whereas 28 out of 80 show a significant increase of WD (+5.7 days/decade) (Table 3). The significance of the CN index is distributed in the western part of the Mediterranean area with values between -10 to 0 days/decade. A decrease in significance is even observable from the west to the east of the Mediterranean (Figure 4). However, for Istanbul which has a trend >-10 days/decade the urban heat island could be considered as an important factor for this behavior due to the strong population growth of the city (2.6%/year) (http://iussp2005.princeton.edu/download.aspx?submissionId=50487). On the other hand, the WD index (Figure 4) reveals differences in changes between the western, central and eastern Mediterranean, whereas the highest concentrations of significant trends are observed to the western basin.

Table 4: *1950-70 and 1971-99: Numbers of stations with significant negative and positive and non significant trends for the annual temperature indices (5 % level). In bold at least the 25% of the stations shows significant trends.*

Indicator Name	**Negative**		**Nonsignificant**		**Positive**	
	1950-70	**71-99**	**1950-70**	**71-99**	**1950-70**	**71-99**
Frost Days	1	5	73	65	0	3
Cold Nights	4	**25**	67	43	1	4
Heat Wave Duration I.	14	1	62	54	2	**23**
Summer Days	15	0	57	33	2	**41**
Warm Days	18	0	59	22	2	**57**

Dividing the entire period in two sub-periods (1950-1970 and 1971-1999) a different spatial distribution of the indices could be found (Table 4). In the period 1950-1970, approximately 80% of the stations showed not significant trends in CN (see Figure 25, chapter 7). In contrast, WD shows decreasing and often significant trends (-2.7 days/decade) in the central and eastern part of the Mediterranean (from Italy to Greece), with Spain bearing a slightly increasing trend pattern (Figure 5). Therefore, the slight cooling for this period has to be refered to significant changes in WD.

When considering the second sub-period the CN pattern is similar to those described in Figure 4; namely a stronger significant decreasing trend (between 0 and -10 days/decade) is visible in the western Mediterranean but not in the eastern part (-5 to 5 days/decade). Nevertheless, a notable finding is the particularly slightly significant increasing trends of WD (+4.14 days/decade) throughout the Mediterranean area (Figure 6).

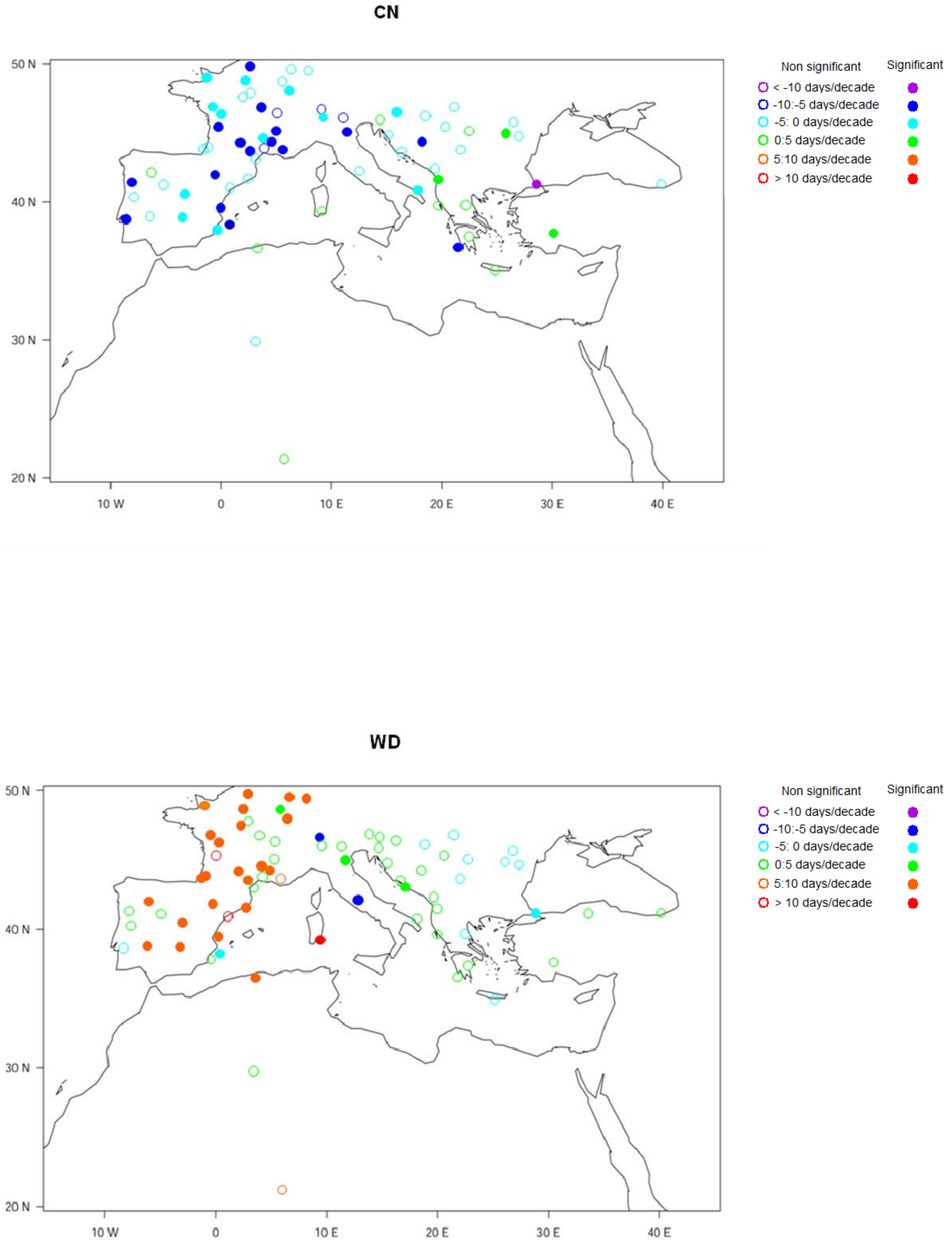


Figure 4: *CN (top) and WD (bottom) annual trends for the period 1950-1999. Colors represent the trends values estimated with the OLS (Ordinary Least Square) method.* ***.*** *Filled dots indicate significant trends at 5% level*

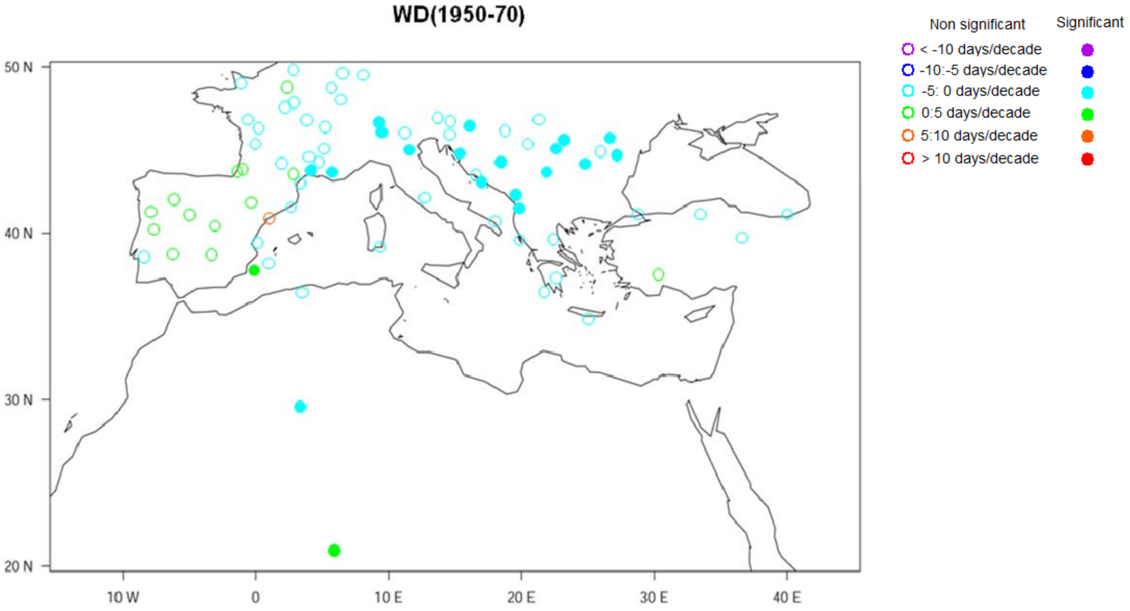
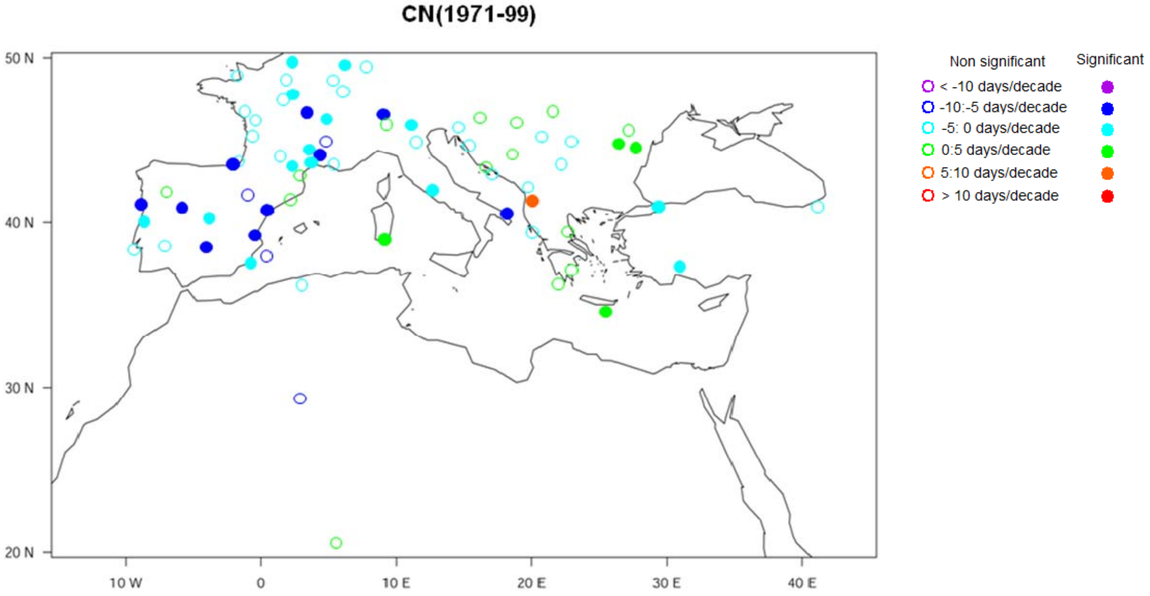


Figure 5: *WD annual trends for the period 1950-1970. Filled dots indicate significant trends at 5% level.*

The findings in this section illustrate the significant increase of WD (70% of stations) in the period 1971-1999 (+4.1 days/decade) and non significant decreasing trends between 1950 and 1970 (Table 4). In general changes for the entire 50 years period in Tmax (+9 days/decade) are greater than those of Tmin (-8.1 days/decade).



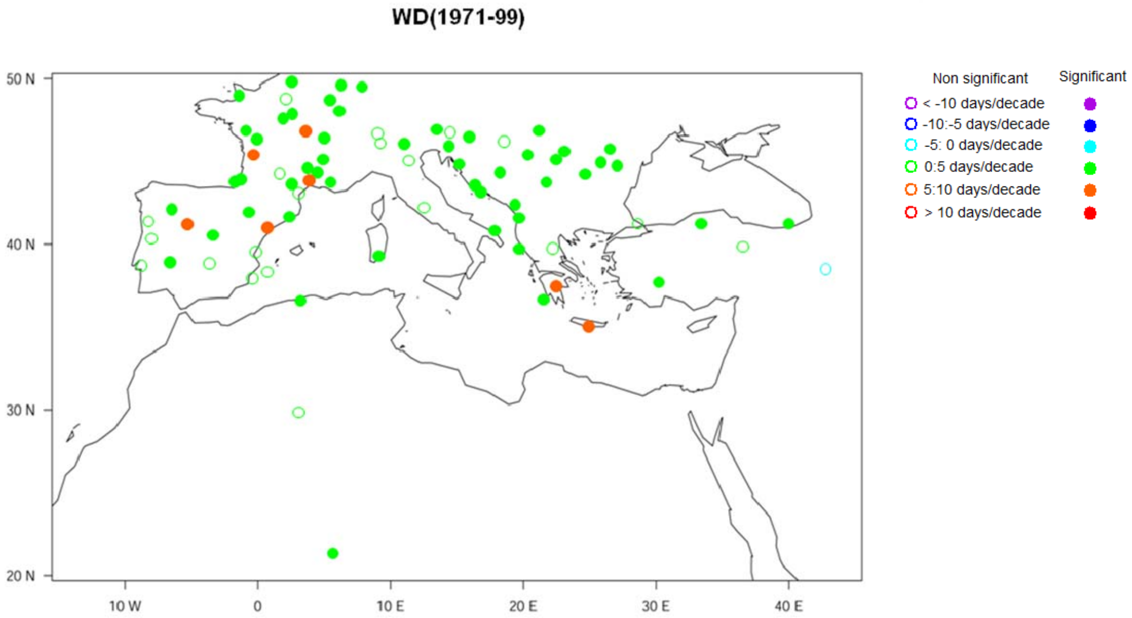


Figure 6: *CN (top) and WD (bottom) annual trends for the period 1971-1999. Filled dots indicate significant trends at 5% level.*

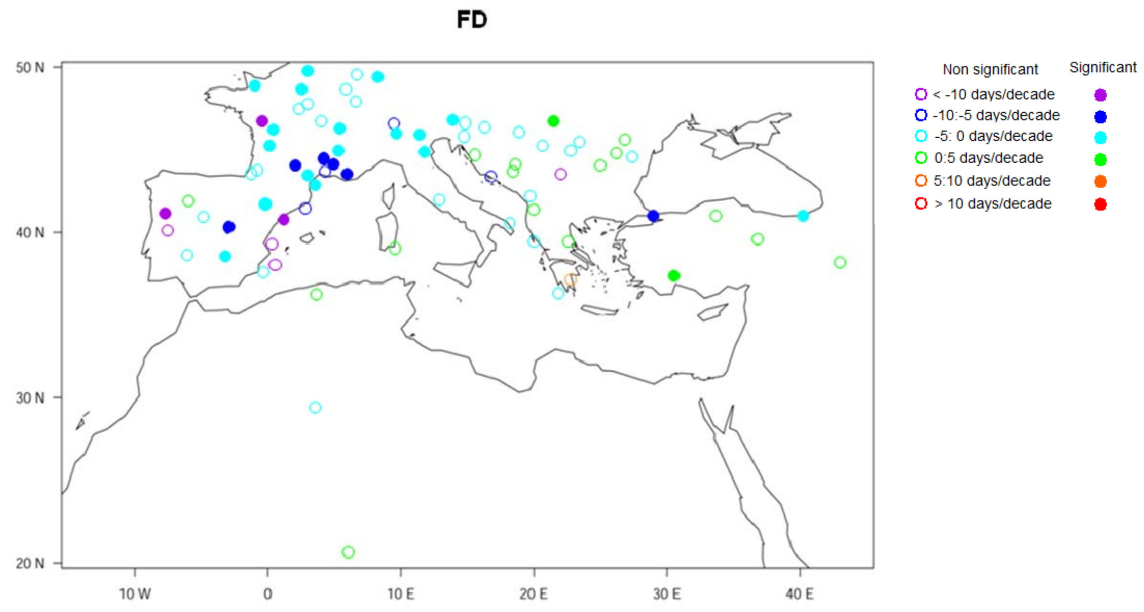
3.1.2 Other Temperature Indices

This section gives an overview of extreme trends and their distribution on threshold and duration based indices in the Mediterranean area (Tables 3 and 4). For the period 1950-1999 significant increases of HWDI and SU and a significant decrease of the FD index was found. Overall, more significant positive trends for Tmax than negative trends for Tmin have been found, most notably for the second sub-period (1971-1999). Nevertheless, more than half of all sites (approximately 60%) do not show significant changes between 1950 and 1999. For the two sub-periods the amount of non-significant changes is 40% for the first and 70% for the second sub-periods.

Maps for FD, SU and HWDI trends are shown in Figures 7-9. The Tmin related index (FD) indicates for the entire 50-year period a strong and significant negative trend (-5.5 days/decade) for the Western Mediterranean with highest values in France. Non significant trends are characteristic for the whole eastern Mediterranean with the exception of Istanbul (Figure 7; see also above (section 3.1.1)). The warming trend is significant at the 5% level for 26 out of 76 stations. In contrast, for the two sub-periods there is not a remarkable change in trends for the whole region (Table 4). The assessment of HWDI was undertaken to show which region is more affected by heat waves. For the entire 50-year period, a high and significant increase of +14.3 days/decade was found. The strongest increase occurred in the Western (Spain) and Eastern Mediterranean (Balkans) (Figure 7). Even though, more non significant changes are located in the North-eastern Mediterranean (Slovenia and Romania). However, a significant homogeneous increase of + 9.2 days/decade (Figure 8) with the exception of central and south-Italy coins the image for the second sub-period. For the first sub-period there is a strong significant negative trend in Romania whereas the Western and Central Mediterranean are rather characterized by non significant trends (Figure 9).

Beside the HWDI index, the threshold based index (SU) exhibits summer days (TX>30°C) which also play a crucial role for the Mediterranean region. Slightly non significant negative and positive trends are found for the entire 50-year period in the eastern part. At the same time a high number of stations show significant trends in the western part of the Mediterranean. For the period 1950-1970 (see Figure 25, chapter 7), a large decrease of approximately -2.6 days/decade was detected in the Central and Eastern Mediterranean. Only, in Spain a slight increase in SU of less than 5days/decade can be observed. However, the second sub-period (Figure 9) shows an overall homogeneous positive trend pattern (+4.2 days/decade) with some higher values in south-west France.

These findings show that the warming of the Western Mediterranean between 1950 and 1999 is mostly associated with an increase of Tmax related indices (HWDI and SU). Over the Balkan area only the HWDI increased. In contrast, the decreasing of Tmin related indices (e.g. FD) has smaller trend magnitudes (-5.5 days/decade) for both periods. As well as, the slight cooling in the 1950-1970 period is characterized by significant Tmax decreasing trends (e.g. for SU -2.6 days/decade).



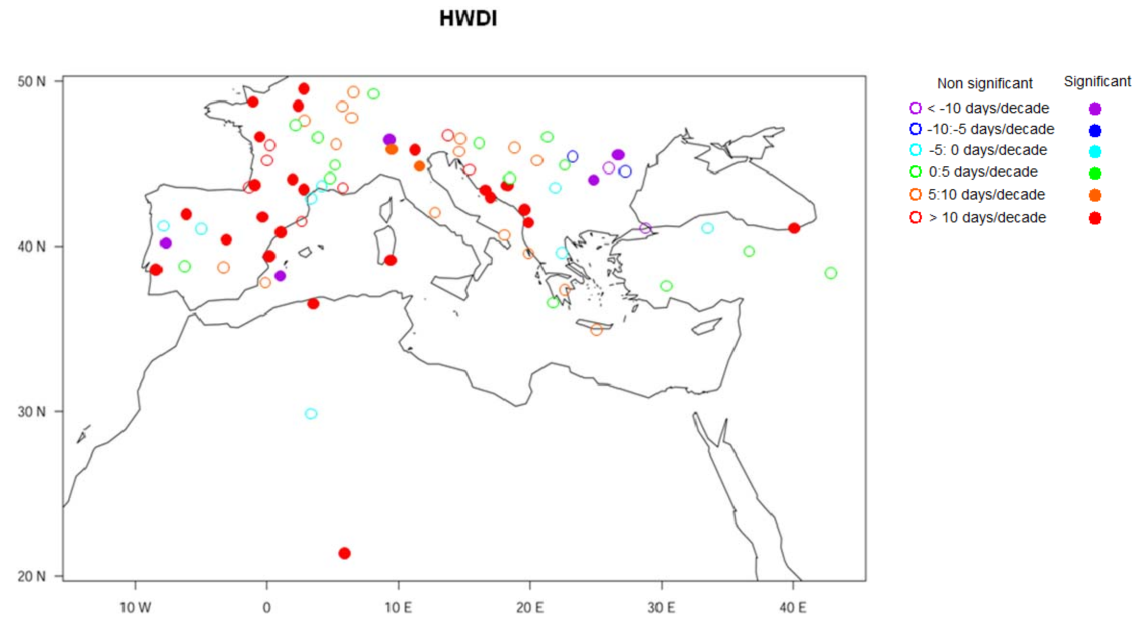


Figure 7: *FD (top) and HWDI (bottom) annual trends for the period 1950-1999. Filled dots indicate significant trends at 5% level.*

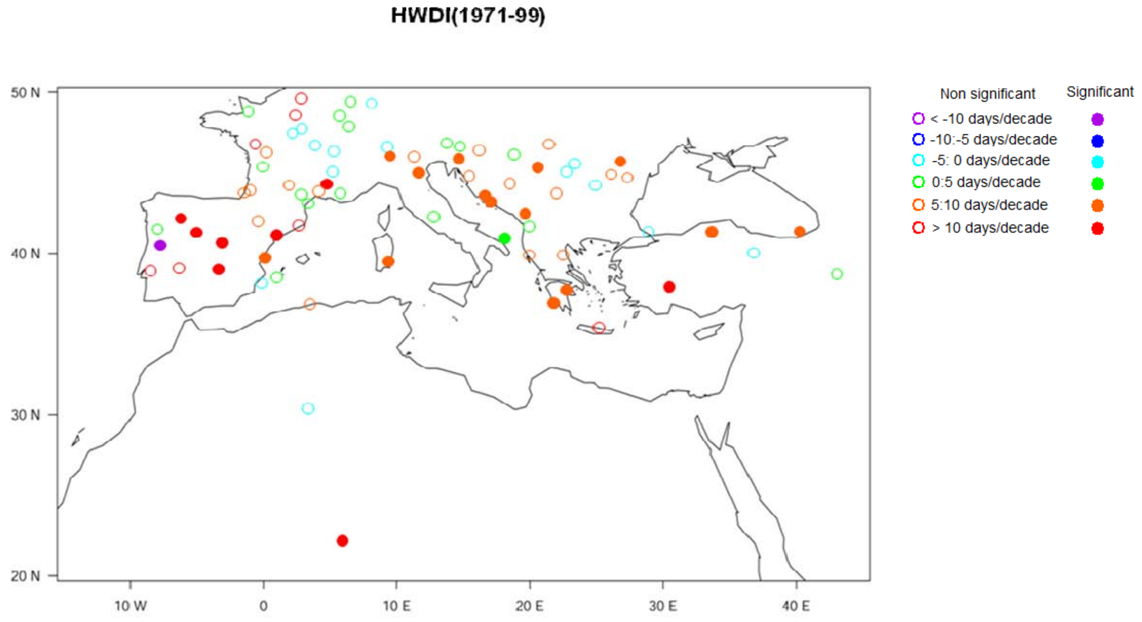


Figure 8: *HWDI annual trends for the period 1971-1999. Filled dots indicate significant trends at 5% level.*

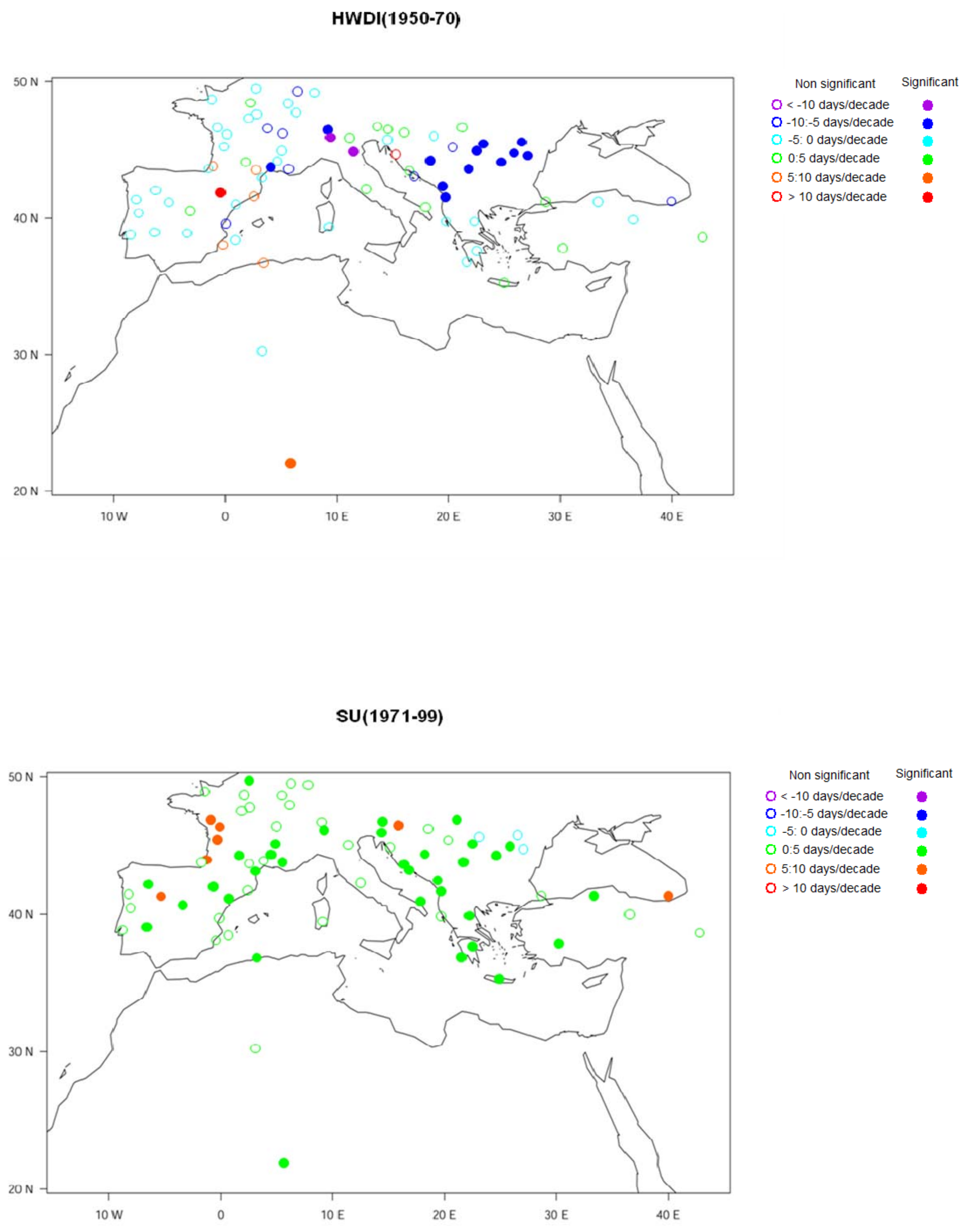


Figure 9: *HWDI (top) and SU (bottom) annual trends for the period 1950-1970and 1971-1999. Filled dots indicate significant trends at 5% level.*

3.2 Seasonal results

3.2.1 Percentile-based Temperature Indices

In the following section the same indices as shown above are introduced on seasonal scale (winter or/and summer). Hence, for the entire 50-year period, the seasonal changes in CN and WD do not reveal differences between winter and summer. In contrast to the annual results, in both seasons there are more negative trends for Tmin than positive trends for Tmax (Table 5). Though, when considering the second sub-period (Table 6), summer (winter) has more significant negative (positive) trends in CN (WD). However, more than half of all sites (approximately 60%) do not show any significant changes between 1950 and 1999. For the two sub-periods the amount of non-significant changes is 40% for the first sub-period and 70% for the second one.

Table 5: 1950-1999: *Number of stations with significant negative and positive and non significant trends for the seasonal temperature indices (5 % level). In bold at least 25% of the stations show significant trends.*

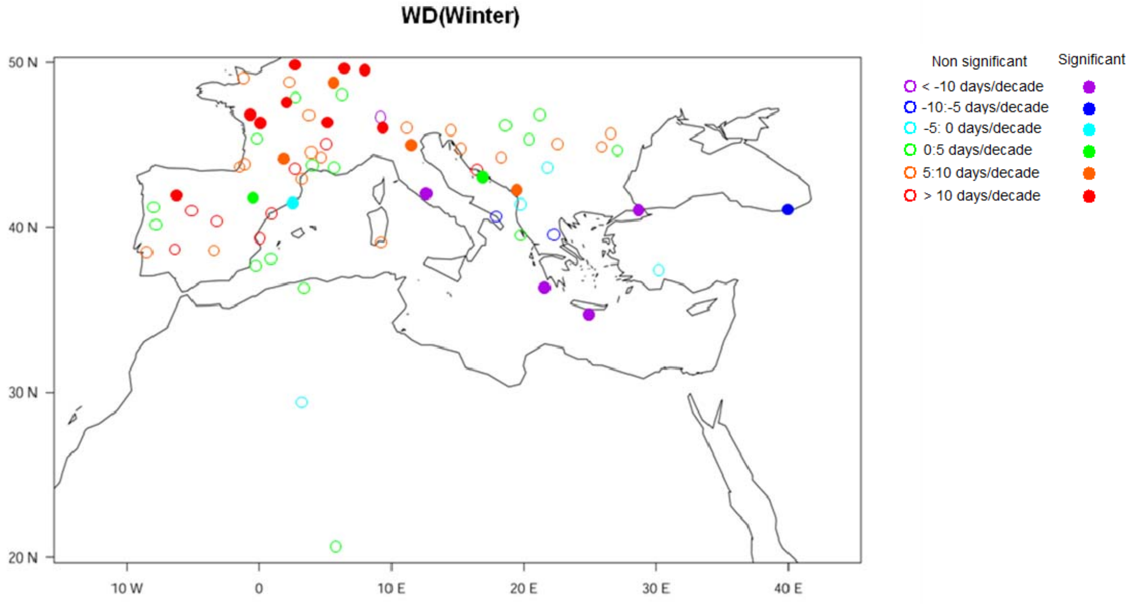
Indicator name	Negative	Nonsignificant	Positive
Frost Days *(FD)*	**25**	53	1
Cold Nights *(CN)* (winter)	**26**	44	0
Cold Nights *(CN)* (summer)	**26**	51	3
Heat Wave Duration Index *(HWDI)*	5	63	12
Summer Days *(SU)*	3	60	13
Warm Days *(WD)* (summer)	3	52	15
Warm Days *(WD)* (winter)	6	58	15

Most striking trends were found for the period 1950-1999 (Figure 10) showing significant decreases of CN for both seasons (winter and summer) though with a higher trend magnitude for summer (-10.4 days/decade) than for winter (-7.8 days/decade). Similar trends were found for WD in winter; significant and non significant increasing trends in the Western Mediterranean (northern Spain and France) and at the same time non significant changes in the Eastern part with some exceptions (e.g. Heraklion, Methoni and Rome). Compared to CN, WD has warmed more in winter (+10.8 days/decade) than in summer (+9.2 days/decade) (see Figure 26, chapter 7).

When looking at the first sub-period (1950-1970) the main contributors of this slight cooling are significant decreasing summer WD trends (-3.2 days/decade), in the central and eastern parts (from Italy to Greece) (Figure 11). In contrast to summer, winter returns non significant trends for large areas. On the other hand, in winter non significant CN changes (Table 6) were detected whereas the summer showed increasing trends in Central and in the Eastern Mediterranean (Figure 11).

Table 6: *1950-70 and 1971-99: Number of stations with significant negative and positive and non significant trends for the seasonal temperature indices (5 % level). In bold at least 25% of the stations show significant trends*

Indicator Name	**Negative**		**Nonsignificant**		**Positive**	
	1950-70	**71-99**	**1950-70**	**71-99**	**1950-70**	**71-99**
Frost Days	2	5	75	69	0	1
Cold Nights (winter)	2	5	68	65	15	0
Cold Nights (summer)	2	**43**	62	27	15	1
Heat Wave Duration I.	9	3	58	64	12	12
Summer Days	18	0	58	44	0	**32**
Warm Days (summer)	16	0	53	53	1	**17**
Warm Days (winter)	3	0	65	43	3	**28**



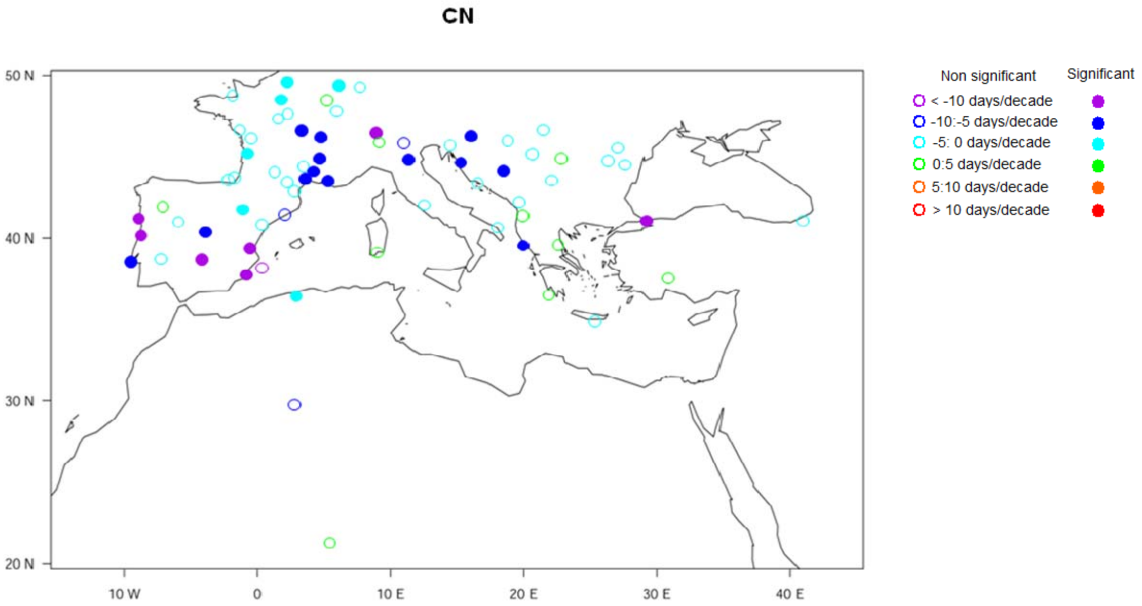
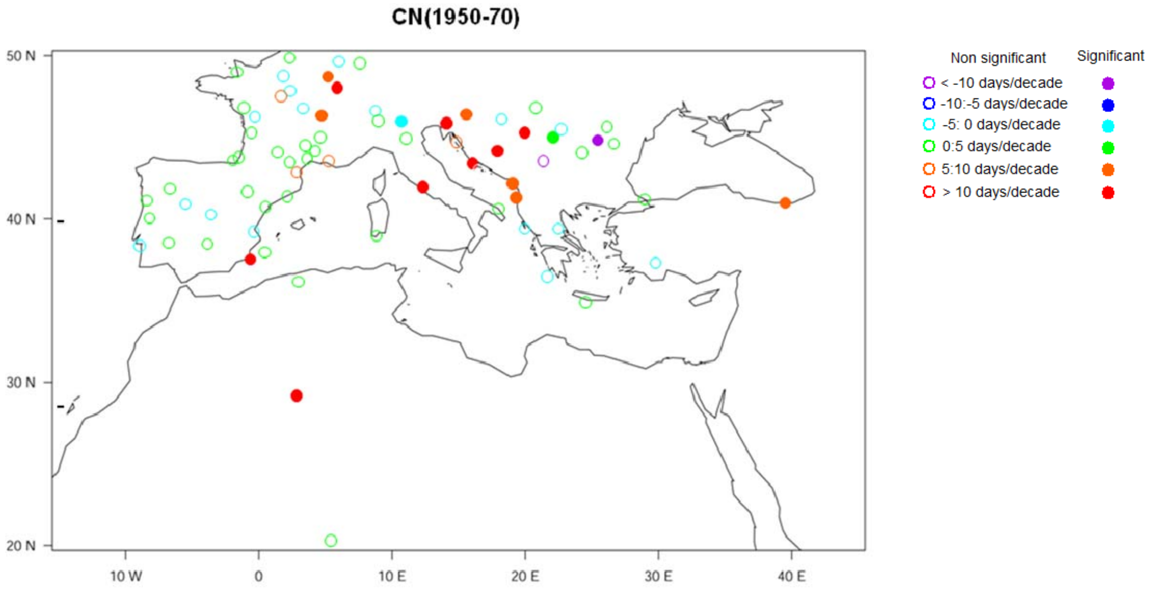


Figure 10: *WD (winter, top) and CN (summer, bottom) seasonal trends for the period 1950-1999. Filled dots indicate significant trends at 5% level.*



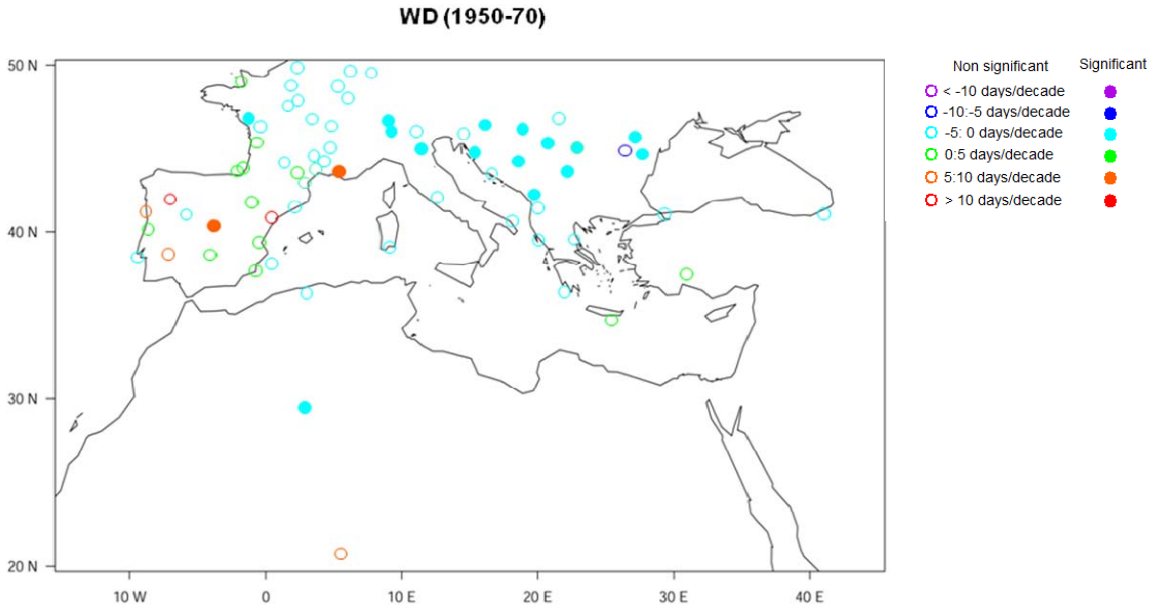


Figure 11: *CN (summer, top) and WD (summer, bottom) seasonal trends for the period 1950-1970. Filled dots indicate significant trends at 5% level.*

However, in the period 1971-1999 winter CN has a similar behavior as those of the first sub-period with exceptions of some stations (e.g. Alicante, Valencia and Tamanrasset). As already shown before, significant decreasing trends (-8.5 days/decade) in the Western Mediterranean and mostly non significant changes in the eastern parts characterize the CN in summer (Figure 12). Nevertheless, the WD in winter (+10.0 days/decade) characterizes foremost this warming period, particularly in the Western and Central Mediterranean (Figure 12). Compared to winter, summer is biased in large areas by slightly increasing and often significant trends (+ 0-10 days/decade).

For both indicators (CN and WD) a strong change in trends around the mid 1970s is detected. These results point to a significant increase of WD in summer (+5.9 days/decade) and particularly winters (50% of stations) has warmed between 1971 and 1999 (+10.0 days/decade). In contrast, the CN (40% of stations) has decreased mainly in summer (-8.5 days/decade). As already detected for the annual results (see section 3.1.1) also for the seasonal findings changes for the entire 50-year period in Tmax (+13.6 days/decade) are greater than those of Tmin (-7.7 days/decade).

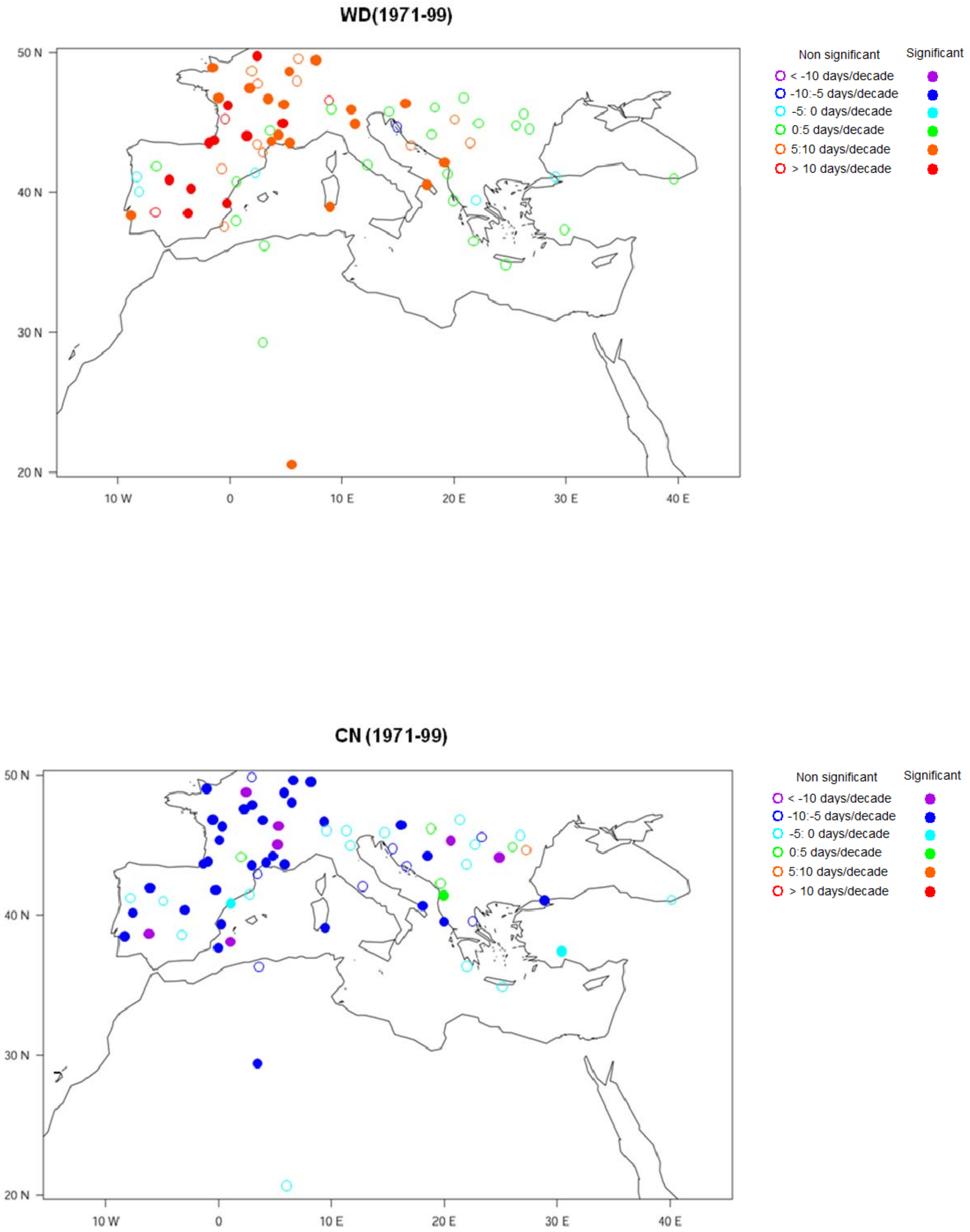


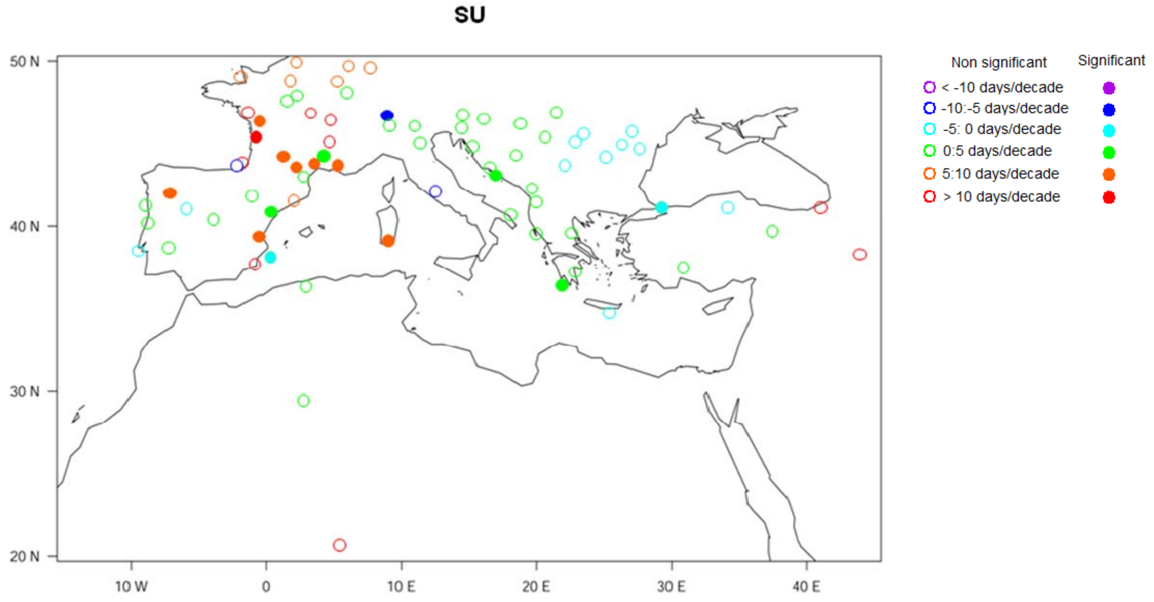
Figure 12: *WD (winter, top) and CN (summer, bottom) seasonal trends for the period 1971-1999. Filled dots indicate significant trends at 5% level.*

3.2.2 Other seasonal Temperature Indices

The seasonal findings demonstrate that more than the half of significant trends can be attributed to FD in winter and to HWDI and SU in summer (Tables 5 and 6).

When looking at the Tmax related index SU, very different trends were found in the Western, Central and Eastern Mediterranean between 1950 and 1999. The increase declines from west to east and reaches its maximum with >+ 10 days/decade in southern France. Weaker trends of + 0-5 days/decade were observed in the Adriatic Sea area and even slightly negative trends in the Eastern Balkans and the Aegean region. Statistically significant trends seem to follow a trajectory from the Bay of Biscay via Sardinia towards Greece and western Turkey (Figure 13). The SU trends within the two sub-periods are comparable to the WD changes in summer. The period 1950-1970 is also characterized on the seasonal scale by a slight cooling episode. The Tmax related index SU (summer), demonstrates a large-scale and significant decrease of approximately -2.6 days/decade in the central and eastern parts. Small but non significant SU increases of less than 5 days/decade can be found only in Spain. In contrast, the period 1971-1999 shows an overall increasing trend of + 0-5 days/decade (+3.9 days/decade) across the whole area with some higher trend values in Bordeaux, Heraklion, La Rochelle and Rize (Figure 13).

The other Tmax related index HWDI (summer), reveals for the periods 1950-1999 and 1950-1970 positive trends across the Western and Central Mediterranean whereas in the eastern parts show slightly increasing trends. At the same time in Romania a slightly decreasing trend is observable (Figure 14). In addition, the trend pattern changes when we consider the second sub-period: decreasing trend of -1.8 days/decade in the Central Mediterranean (north and central France) while the eastern part of the Mediterranean displayed a rising trend (Figure 14).



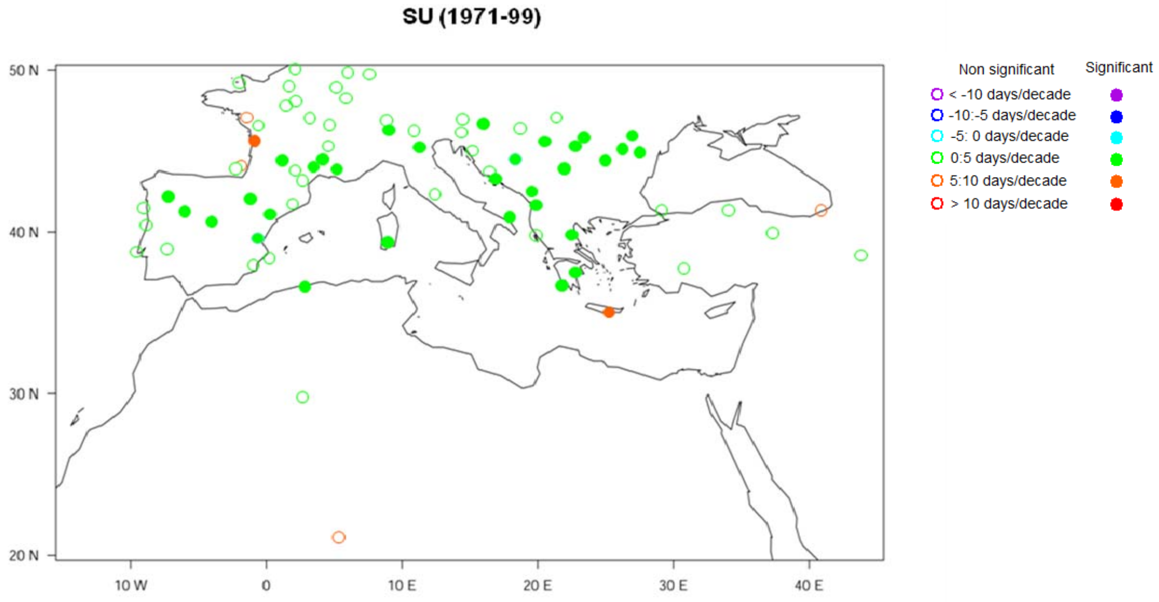


Figure 13: *SU (summer) trends for the period 1950-1999 (top) and 1971-1999 (bottom). Filled dots indicate significant trends at 5% level.*

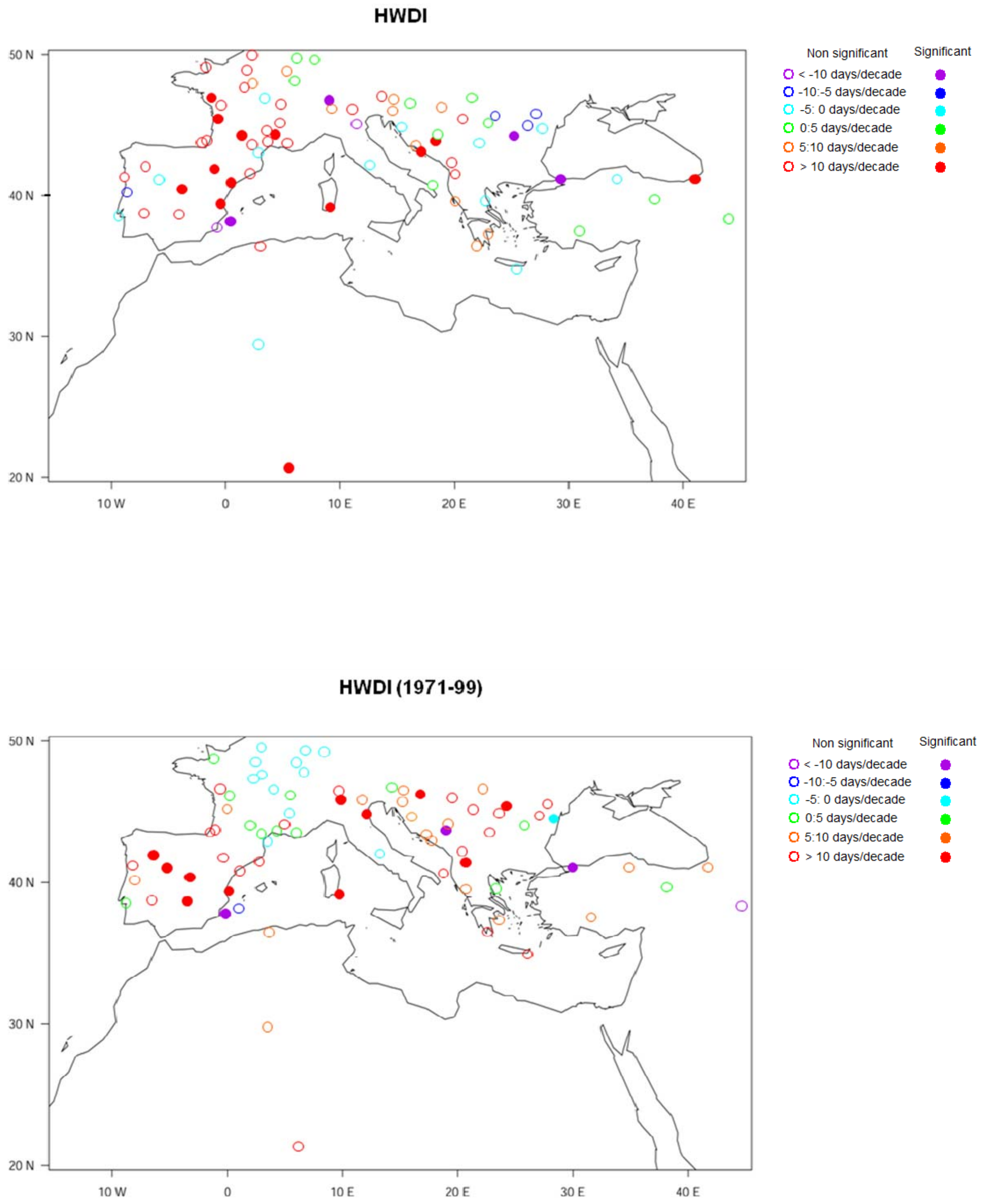


Figure 14: *HWDI (summer) trends for the period 1950-1999 (top) and 1971-1999 (bottom). Filled dots indicate significant trends at 5% level.*

The Tmin related index, FD (winter), shows a similar behavior for 1950-1999 as the CN index. Strong decreasing trends of up to 10 days/decade were detected in the western and central parts of the Mediterranean area with highest concentrations of significant trends in Spain and France (Figure 15). However, most trends situated in the eastern Mediterranean are not statistically significant, except for Ljubljana. In addition, the two sub-periods showed a similar behavior as it does the annual scale (see section 3.1.2).

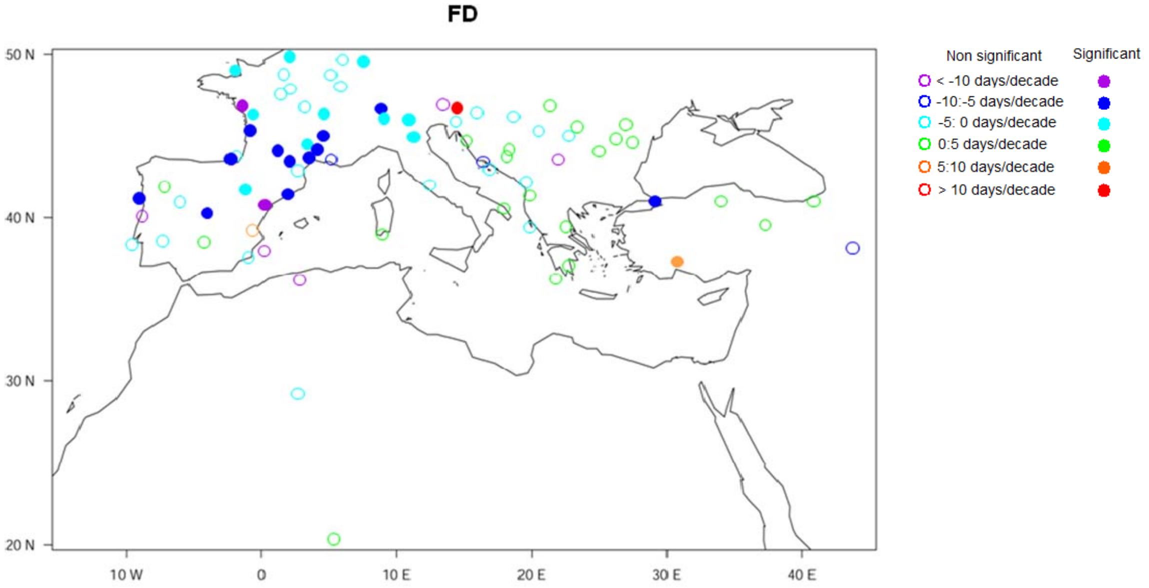


Figure 15: *FD (winter) trends for the period 1950-1999. Filled dots indicate significant trends at 5% level.*

To give an overview over the main findings presented in section 3.1 and 3.2, table 7 summarizes Tmax and Tmin related temperature indices and their statistically significant distribution in the Mediterranean area. Further, a review of the indices related trends magnitudes are shown in table 8. The calculation of these trends is based on a simple average formula of the statistical significant trends values of the stations.

Table 7: *A summary of Tmax and Tmin related temperature indices and their statistically significant distribution in the Mediterranean area (Med.) over the period 1950-1999 and the sub-periods.*

Indicator name	**Increasing(+) Decreasing (-) Days**	**Period**	**Locality**
Tmax-related			
WD (winter), SU and HWDI	+	1950-1999	Western Med.
WD (summer), SU and HWDI	-	1950-1970	Central & Eastern Med.
HWDI (seasonal)	+	1950-1970	Throughout the Med.
WD (winter), HWDI	+	1971-1999	Western & Eastern Med.
WD, SU and HWDI (annual)	+	1971-1999	Throughout the Med.
Tmin-related			
CN (summer) and FD	-	1950-1999	Western Med.
CN summer	+	1950-1970	Central & Eastern Med.
CN (summer)	-	1971-1999	Western Med.

Table 8: *A summary of Tmax and Tmin related trend magnitudes (days/decade) for the annual and seasonal (JJAS and DJF) scale for the Mediterranean area over the 1950-1999 period and the two sub-periods.*

Indicator Name	**1950-1999 Annual Trends (days/decade)**	**JJAS**	**DJF**	**1950-1970 Annual Trends (days/decade)**	**JJAS**	**DJF**	**1971-1999 Annual Trends (days/decade)**	**JJAS**	**DJF**
Warm Days (WD)	+5.7	+9.2	+10.8	-2.7	-3.2	-	+4.14	+5.9	+10
Summer days (SU)	+6.7	+7.4	-	-2.6	-2.6	-	+4.2	+3.9	-
Heat wave duration Index (HWDI)	+14.3	+3.1	-	-2.6	+1.4	-	+9.2	+1.85	-
Cold Nights (CN)	-5.5	-10.4	-7.8	-5.5	+9.0	-	-5.0	-8.5	-7.7
Frost Days (FD)	-5.5	-	-5.5	-	-	-	-	-	-

3.3 Seasonal climate composite analysis for subregions

To obtain a more detailed insight in the temporal development of the indices, we looked at the large-scale atmospheric circulation which can explain temperature extreme events. The anomaly of the atmospheric circulation in different altitudes and the Sea Level Pressure (SLP) are key factors in order to better explain some of the extreme events in sub-regions of the Mediterranean area. Hence, we focused on three seasonal indices: CN (summer), WD (winter) for the period 1950-1999 and SU (summer) for the period 1971-1999 (Tables 9 and 10). The representative year, for these three indices, has been selected by choosing for each station the one with the highest amount of days/nights. This filtering has shown the years with the most recurrences: 1972, 1994 and 1998, respectively. The Year 1972 had on average 22 cold nights in summer distributed in the Western Mediterranean while the amount of warm days (on average 10) was significant less (not shown). A high amount of warm days, on average 19, was detected in winter 1998 in the western and eastern part of the Mediterranean while the number of cold days was small (on average 2.3, not shown). Moreover, the trend magnitude in winter is greater than those of the two other seasons. Further, the highest quantity of summer days (on average 56) had been in 1994.

Table 9: *Left: Cold Nights in summer for the year 1972. Right: Warm Days in winter for the year 1998. Both based on the entire 50 years seasonal period.*

Stations	**CN in 1972 (days)**	**Stations**	**WD in 1998 (days)**
Besancon	20	Arad	16
Biarritz	31	Biarritz	15
Bordeaux	31	Bordeaux	18
Bourges	23	Braganca	17
Cagliari	18	Cognac	23
Cognac	27	Deols Ch.	19
Deols Ch.	27	Langres	26
Langres	18	La Rochelle	19
La Rochelle	21	Marseille	17
Lyon	16	Mont A.	16
Marseille	25	Nancy	16
Milan	21	Rennes	18
Mont A.	20	Rijeka	22
Orleans	22	Shkodra	20
Rennes	21	Toulouse	14
San Sebastian	27	Vichy Ch.	20
Sete	17	Verona	19
Strasbourg	16	Zagreb	22
Toulouse	19	*Average*	*19*
Vichy Ch.	22		
Average	*22*		

As mentioned above the highest number in CN was in 1972, particularly concentrated in the Western Mediterranean (Table 9), namely in France, Portugal and Spain. As well as the high number of cold days (CD), which is not listed in Table 8, is also apparent for this summer which underlines that this summer was rather cold. Figure 16 reveals the geopotential height (500hPa) anomaly for summer (June-September) of this year. Hence, there is a low mid tropospheric anomaly with center over the Western Mediterranean (between -30 and -50 gpm). Moreover, when considering other geopotenial height (e.g. 200hPa, 700hPa or 850hPa) a similar low geopotential anomaly is observable as already seen by the 500hPa, just with different values (between -40 and -100 gpm) (Figure 17). However, the Sea Level Pressure in Figure 18 shows for the whole Southern Mediterranean, with focus over the eastern part, a negative anomaly (between -0.5 and -1.5 hPa).

Table 10: *SU index for the year 1994. Based on the period 1971-99.*

Stations	**SU(days)**		
Arad	58	Nimes	64
Besancon	24	Nis	70
Beograd	49	Osijek	42
Buzau	51	Roma	64
Brindisi	61	Rijeka	45
Carcassonne	39	Valencia	61
Calarasi	66	Verona	52
Cagliari	72	Zagreb	32
Corfu	80	*Average*	*56*
Hellinikon	98		
Hvar	63		
Istanbul	33		
Larissa	107		
Lastovo	58		
Lugano	18		
Lyon	35		
Madrid	75		
Montelimar	50		

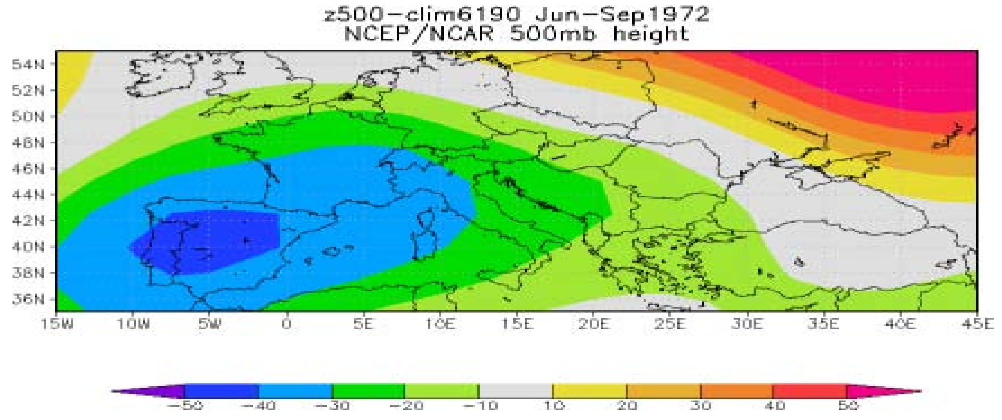


Figure 16: *500hPa geopotential height anomalies (gpm) for summer (June-September) 1972 based on the base period 1961-1990. NCEP/NCAR,(http://climexp.knmi.nl)*

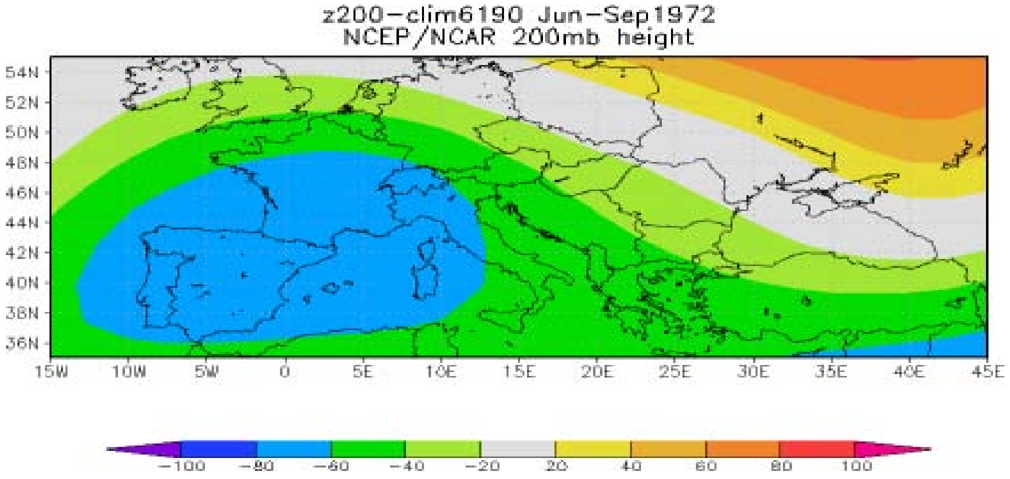


Figure 17: *200hPa geopotential height anomalies (gpm) for summer 1972 based on the base period 1961-1990.(http://climexp.knmi.nl)*

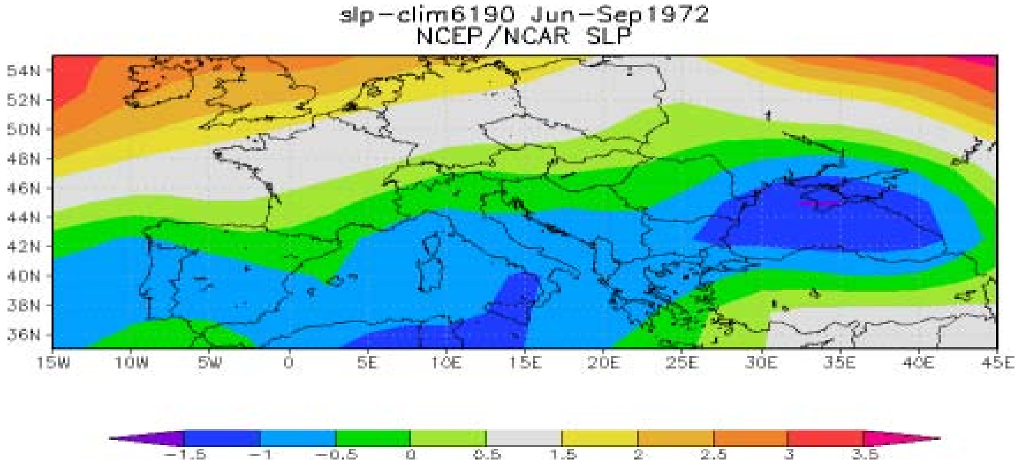


Figure 18: *Sea Level Pressure (hPa) for summer 1972 based on the base period 1961-1990. (http://climexp.knmi.nl)*

In contrast to 1972, 1998 characterizes the year with the highest number of WD in winter across the Northern Mediterranean from France to Albania (Table 9). Besides, the highest number of WD also the maximum of HWDI and one of the highest numbers of WN (not shown) was detected for this season. For example, the HWDI shows 8 stations (on average 12.5 days) across the central and eastern part of the Mediterranean. Figure 19 and 20 present the geopotential height for 500hPa and 850hPa for this winter. Both Figures have a strong positive geopotential anomaly stretching from France to Albania: >50gpm for the 500hPa and >25gpm for the 850hPa level. Looking at others geopotential levels (e.g. 200hPa and the 300hPa level) a similar strong pattern is visible. Furthermore, Figure 21 exhibits a positive SLP anomaly over a large area of the Mediterranean region (between +3 to 4 hPa).

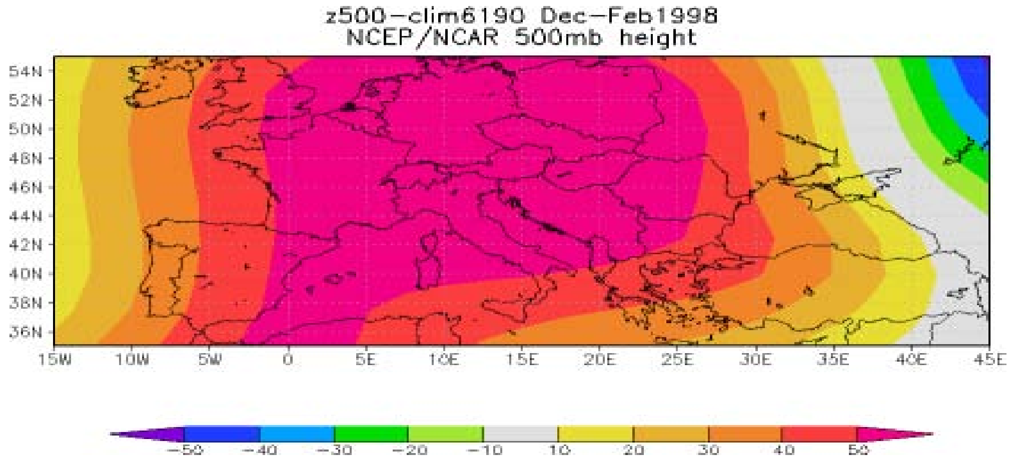


Figure 19: *500hPa geopotential height anomalies (gpm) in winter (December-February) 1998 based on the base period 1961-1990. (http://climexp.knmi.nl)*

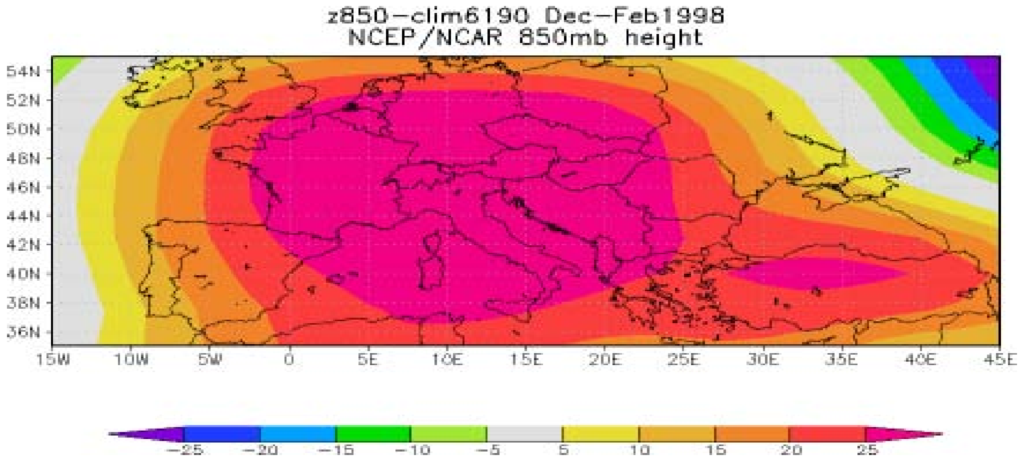


Figure 20: *850hPa geopotential height anomalies (gpm) in winter 1998 based on the base period 1961-1990. (http://climexp.knmi.nl)*

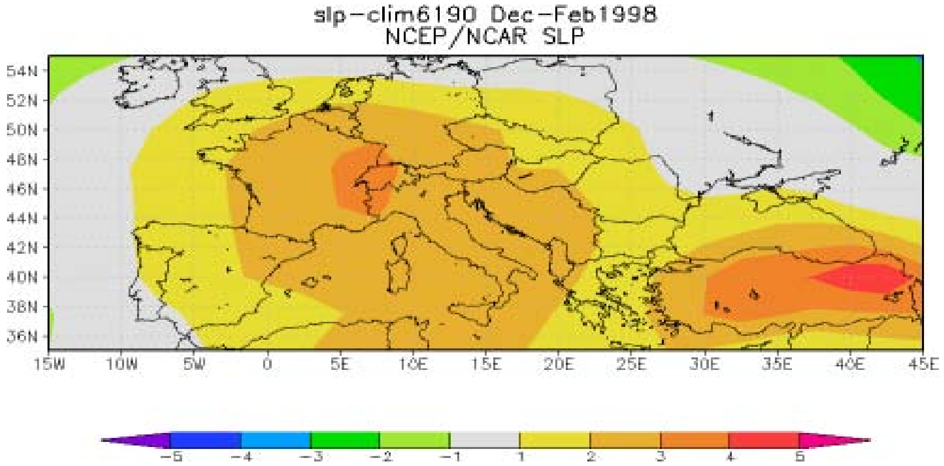


Figure 21: *Sea Level Pressure (hPa) for winter 1998 based on the base period 1961-1990. (http://climexp.knmi.nl)*

As mentioned before, the summer of 1994 was pretty warm. On average 56 summer days and 23 warm nights (not shown) across large areas (from France to Greece) were detected (Table 10). This summer was characterized by a strong positive geopotential anomaly (between +10 and 25 gpm) with a maximum over the Northeastern Mediterranean (Figure 22). When looking at the 850 geopotential height in Figure 23 it is clearly visible the maximum of this positive anomaly. In contrast, the Sea Level pressure (SLP) (see Figure 24) shows a slight positive pressure anomaly (up to +1.0 hPa) in Central to Eastern Mediterranean (from east France to north Greece). On the other hand, a slight negative SLP anomaly (between 0 and -0.5 hPa) is concentrated in the southern part of the Mediterranean.

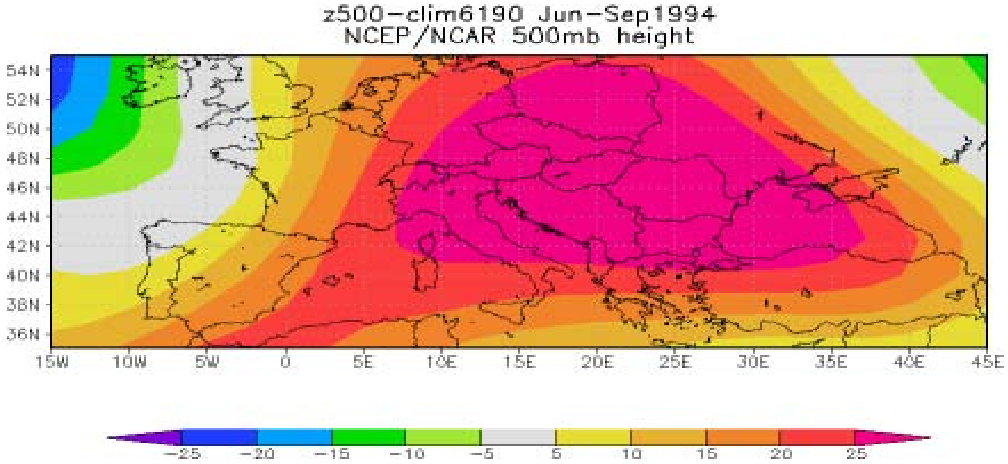


Figure 22: *500hPa geopotential height anomalies (gpm) for summer 1994 based on the base period 1961-1990. (http://climexp.knmi.nl)*

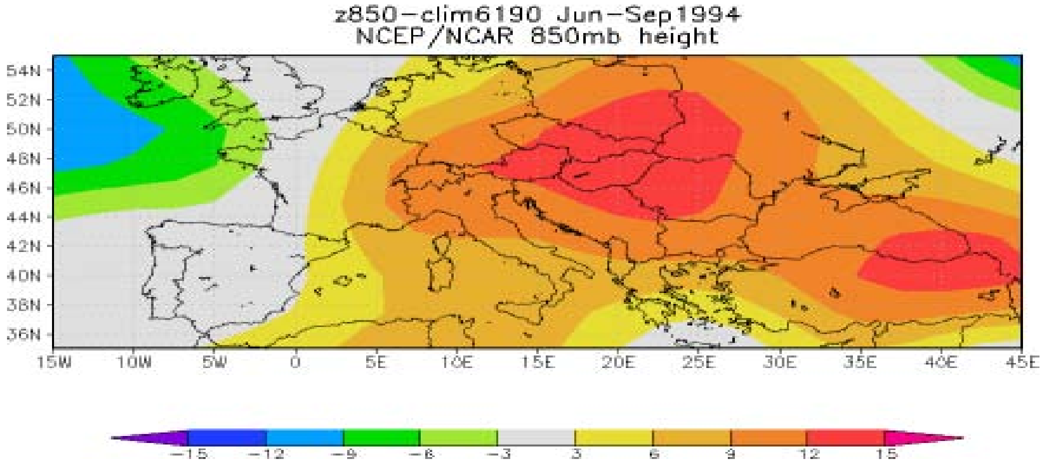


Figure 23: *850hPa geopotential height anomalies (gpm) for summer 1994 based on the base period 1961-1990. (http://climexp.knmi.nl)*

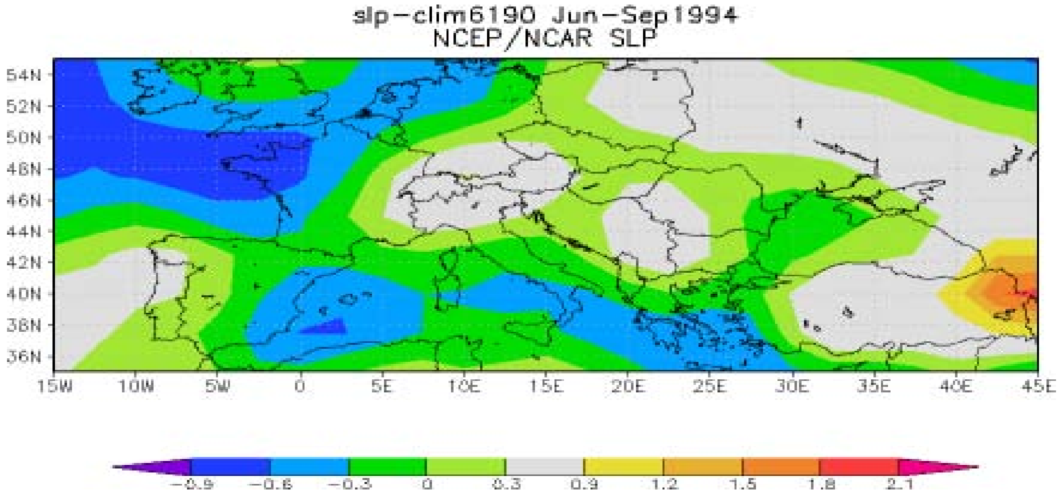


Figure 24: *Sea Level pressure (hPa) for summer 1994 based on the base period 1961-1990. (http://climexp.knmi.nl)*

4. Discussion

In this chapter the results and the findings obtained in this work are discussed and interpreted. Chapter 4.1 discusses the percentile-based temperature indices, 4.2 all other temperature-based indices.

4.1 Percentile-based Temperature Indices

The main purpose of this study was to find changes in the annual and seasonal distribution of extreme maximum and minimum temperature events in the Mediterranean area based on the assessment of five climate indices. The results reveal for the entire 50-yr period (1950-1999) that significant changes have been occurred in the maximum and minimum temperature extremes for both (annual and seasonal) scales (Tables 3 and 5). For the annual scale, the number of warm days (WD) shows an overall increase of +5.7 days/decade while a decrease of approximately -5.6 days in cold nights (CN) was detected (Figure 4). Changes at seasonal scale show similar pattern but more significant Tmin trends and less significant Tmax trends (Table 5). Most significant changes were detected with -10.4 days/decade (summer CN) and +10.8 days/decade (winter WD).

The changes in temperature extremes for the entire 50-year period documented here reasonably agree with findings of previous studies (e.g. Alexander et al., 2006; Moberg et al., 2006; Kostopoulou and Jones 2005). A Mediterranean climate change accompanied by more warm extremes and less cold extremes is obvious. Following Alexander et al. (2006) changes in Tmin are greater than those of Tmax for the period 1951-2003. As already noted by the findings in Table 5, our seasonal results (numbers of stations) agree with those. This can be partially attributed to the utilization of the same data set. However, the small differences between our results and those of Alexander et al. (2006) are likely due to different spatial domains (global versus Mediterranean area).

For this reason, the presented findings need to be discussed in relation to some limitations caused by the inhomogeneity of the data and the analysis. In this study only data quality control procedures (see section 2.2) but no data homogenization was applied. Methods to homogenize annual and monthly climate data are well-known (e.g. Vincent, 1998;

Wang, 2003; Caussinus and Mestre, 2004; Della-Marta and Wanner, 2006). In contrast, only few methods for the homogenization of high resolution daily data are established (e.g. Demaree et al., 2002; Vincent et al., 2002; Brandsma and Koennen, 2006; Della-Marta and Wanner, 2006). Even if the homogenization method RHtest (Wang, 2003), was applied in the study of Alexander et al. (2006) the method has to be reconsidered due to the fact, that the method used by Della-Marta and Wanner (2006) is the most reliable technique for correcting extreme daily temperatures at present. Overall, the disadvantages when dealing with daily temperature measurements are that they vary on relatively small spatial scales (Jones and Trewin, 2002). The challenge remains that small scales are influenced by local processes, which are complex and nonlinear and therefore difficult to capture (Della-Marta and Wanner, 2006).

Further difficulties appeared by owing to the number of stations (80 in this study) and the length of the period (50 years). The studies from Alexander et al. and Moberg et al. (2006) worked with longer periods (approximately 100 years), more temperature stations (between 75 and 200). The lack of stations in our study, in central- and southern part of Italy and Northern Africa, is caused by non available digitized data and restricted data exchange policies. Besides, data of other countries like Cyprus, Egypt, Israel or Moldova are available but the length of the period was less than 50 years and therefore not suitable to analyze. In addition, many stations could not be used after the data quality control because they showed too many non reliable or missing values (see section 2.2).

Although the seasonal changes agree with some studies (e.g. Moberg et al., 2006), we found an asymmetric warming for the period 1950-1999. The significant Tmax trends (WD) are of greater magnitude (+9.2 and +10.8 days/decade) than their cold (CN) counterparts (-7.8 and -10.4 days/decade), suggesting that the warm tails of the daily temperature distributions are warming faster than the cold tails. This assumption has to be reconsidered by drawing comparisons after a homogeneity control due to the fact that other studies (e.g. Alexander et al., 2006; Moberg et al., 2006) show the opposite trend. This applies to errors due to the fact that extreme temperatures are more sensitive to relocations and local environmental than mean extremes (Tuomenvirta, 2001). For example, growing cities such as Alicante (populations growth: +1.9%/year) and Istanbul (+2.6%/year) induce artificial warming of temperature records from city locations.

During the second sub-period the temperature changes were accompanied by asymmetric changes in temperature extremes for both scales (annual and seasonal). Earlier regional studies (e.g. Klein Tank and Können 2003; Moberg et al., 2005; Zhang et al., 2005) detected a warming period caused by stronger decreases of Tmin related extremes since the 1970s. Even if there are some *limitations* as shown above, our seasonal results (Table 6) agree with these findings as well as for the annual CN trend magnitudes (-5 days/decade) for Tmin temperatures. A similar issue concerning the investigation period was discussed in Klein Tank and Können (2003). Indeed, they argued that Tmax trends increased faster than Tmin trends. This implies an extension of the distribution of maximum temperature and consequently a higher temperature variance (Houghton et al., 2001). Our seasonal results in Figure 12 indicate that the temperatures rise in the Western Mediterranean is basically associated with a strong increase of warm extreme events (e.g. WD). Particularly the warming of TX in the winter period was more remarkable for the warm tails (+10 days/decade) than for the cold tails (+5.9 days/decade) and therefore agree with the findings of Klein Tank and Können (2003) and Moberg et al. (2006). Indeed the study of Moberg et al. (2006) demonstrates that winter has warmed on average more than summer for both tails but with a maximum for the warm tails. However, winter (-7.7 days/decade) of Tmin (CN) has not warmed more than the summer (-8.5 days/decade) which dissent with their findings (Table 6). On the other hand for the first sub-period (1950-1970), an episode of slight cooling is characterized by a decreasing trend of WD and an unchanged situation for CN for both scales (annual and seasonal). These findings agree with other studies and are therefore useful.

For this purpose, the open questions remain: (1) why this recent warming occurred asymmetrically, (2) why this asymmetry is not apparent in the long period and (3) what are the driving forces of temperature extremes. Extreme temperature events are associated with specific atmospheric circulation pattern and changes in air flow. Cold extremes can be linked to airflows from the snow-covered continent and the northern Atlantic Ocean in winter (Klein Tank and Können, 2003). It is also to remark that cold extremes are less sensitive to large-scale warming than warm extremes due to the latent heat of snow and the thermal inertia of water. Small changes in the frequency of atmospheric circulation patterns in a warming scenario may be capable to stabilize or increase the number of cold extremes. Due to the fact that the asymmetry of the sub-periods is obscured in the long period may then be due to averaging of two opposite tendencies (Klein Tank and Können, 2003).

For this reason, one of the goals of this study was to find changes in atmospheric circulation pattern at different levels, which are able to explain the most severe temperature extremes during the last 50 years in a better way. Of course the strong influence by the large-scale mid-latitude atmospheric circulation varies across the region and depends on the period under consideration. Section 3.3 presents the seasonal climate composite analysis for two percentile-based indices. For the entire 50-year period, the highest amount of CN were detected in summer 1972. On the other hand the winter in 1998 showed a maximum in WD.

The first example discusses the cold summer 1972. In this year the highest number of CN (on average 22; see Table 9) with a maximum over the Western Mediterranean (France, Portugal and Spain) was detected. In addition, a great amount of cold days (CD; on average 15) was also detected while the amount of warm days was less (on average 10). One possible explanation can be related to the seasonal climatic composite analyses (see section 2.6). Figure 16 and 17 demonstrate for both levels (500hPa and 200hPa) a similar low geopotential anomaly pattern with a minimum over the western parts. Besides, negative geopotential anomalies increase with height. They show a higher frequency of cold air advection in the upper levels. This implies instability, enhanced cloud formation and precipitation, as well as higher frequency of short-wave duration. Also the Sea Level Pressure (Figure 18) shows a slightly negative pressure anomaly across the western parts. The stations, listed in Table 8, are widespread distributed over France which makes it difficult to identify some typical climatic sub-regions. We assume that cold anomalies in summer months are linked to the advance of cold-humid polar or arctic air masses. This takes place mostly at the eastern ridge of a strong anticyclone situated quite northward. Therefore, daily sea level pressure and geopotential height anomalies composites were plotted for few days for each summer month (June-September) as confirmation (also from http:// climexp.knmi.nl/start.cgi?someone@somewhere; not shown).

The second example for the seasonal climate composite analysis was the warm winter 1998 with the highest number of WD (Table 9). One possible reason for this extreme warm winter season can be explained by the positive geopotential anomaly with a maximum over the Central Mediterranean (Figures 19 and 20). Moreover, a small amount of heat wave days (particularly in the eastern part, not shown) and warm nights have occurred in winter too. The Sea Level Pressure (SLP) at surface demonstrates also a slight positive anomaly (between +2 and 4hPa) over a large area of the Mediterranean region. Daily sea level pressure reconstructions were plotted for a time period of few days for each winter month (December-February; not shown), as well as precipitation anomalies. We supposed that warm-dry winter anomalies are linked to mild air flow from west to south-west. Another possible explanation for this warm winter can be linked to the positive North Atlantic Oscillation (NAO) or the South Asian Monsoon (SAM). This could be a further step to analyze if NAO effectivly influenced this winter. Another question can be related to the SAM (South Asian Monsoon). The study by Ziv et al. (2004) argued that the SAM is a key factor influencing the climate of the Eastern and Central Mediterranean due to high variability in SLP over Arabia and the Middle East. As showed above, we found in the central Mediterranean a positive sea level pressure anomaly suggesting a role played by the SAM. However, this should be proved in further research activity. The difficulty to classify climatic sub-regions by reason of the topography is also here remarkable. However, the station Langres (France) which had the highest amount of warm days in this winter (Table 9) is located at the foothills of the plateau of Langres.

Several studies have contributed in the past to important findings. For example the study by Fischer et al. (2007b) argued that the anticyclonic circulation anomaly is not the only factor leading to extreme hot event. Hence, they suggest to study important role the land surface-atmosphere feedback mechanisms. The study by Black and Sutton (2006) demonstrated for the European heat wave of 2003 that the sea surface temperature anomalies of both, the Indian Ocean and the Mediterranean have crucial impact on temperature and precipitation. Overall, both percentile-based indices show the strongest warming trends on annual and seasonal scale over the Western Mediterranean between 1950 and 1999.

4.2 Other temperature indices

The changes in absolute (SU and FD) and duration(HWDI) based indices are discussed in this section. The changes in temperature extremes have been occurred for both (annual and seasonal) scales in a similar way. The whole investigation period was characterized by a strong increase of SU, HWDI accompanied by a weaker decrease of FD (Tables 5-6). Overall, the maximum temperature extremes (SU and HWDI) show higher trend magnitudes than it does the Tmin related index (FD) for annual and seasonal scales. As already noted, our findings (Figures 7-9 and Figures 13-15) agree well with findings of previous studies (e.g. Alexander et al., 2006; Klein Tank and Können, 2003; Kostopoulou and Jones, 2005). They also found an increasing trend in SU and HWDI and a decreasing trend in FD for the entire 50-year period. For example the study by Kostopoulou and Jones (2005) found more significant changes in FD for the annual than for the seasonal scale. They mentioned an assessment of four seasons but they did not present in detail their seasonal results what it makes difficult to compare. We calculated the FD index only for winter given that it is the most relevant season. Besides, our annual trend changes are not greater as the seasonal. One possible explanation for this difference could be the spatial domain (Eastern Mediterranean versus entire Mediterranean area) as well as the time period they used (1958-2000) versus 1950-1999 in our study. Kostopoulou and Jones (2005) also show coherent changes in the Eastern Mediterranean. On the other hand, we found mainly significant changes in the Western Mediterranean and non significant changes in the eastern part (Figure 7). The small discrepancy can probably be ascribed to the different methods utilized to analyze trends and their significance (see section 2.5).

However when considering the two sup-periods, the FD index does not show any significant changes. Only in the study by Zhang et al. (2005) an assessment of the sub-period, 1970-2003, was undertaken. For this period, they found a significant seasonal trend of about +2.8 days/decade. Unfortunately their study is based on trends in the Middle East which is not appropriate for comparisons to our results. Overall, neighboring studies with the same investigation area did not present threshold indices for sub-periods which makes it difficult to compare our results with them. Nevertheless our findings seem to be reasonable and suitable.

As mentioned before, also the Tmax related indices agree well with the findings of Alexander et al. 2007, Kostopoulou and Jones (2005), and Klein Tank and Können 2003. Accordingly, Kostopoulou and Jones (2005) argued that the HWDI rose on the annual and seasonal (summer) scale in the period 1958-2002, particularly over the central Balkan and northern Italy. We also found an increasing trend in the annual (+14.3 days/decade) and seasonal (summer) (+3.1 days/decade) scale for the entire 50-year period (Table 5). According to this, a strong warming in the western and eastern part of the Mediterranean (Figure 7 and 15) was detected. For the two sub-periods (Tables 4 and 6) not any comparison can be undertaken due to the fact that regional studies have not presented their outcomes for this index. Nevertheless, our findings seem to be still useable due to the fact that the first and second sub-periods are affected by changes for both, Tmax and Tmin related indices. This is in agreement with few studies (e.g. Klein Tank and Können, 2003; Moberg et al., 2006).

However, for the SU index the study from Alexander et al. (2007) and Klein Tank and Können (2003) can be considered. They demonstrated a significant increase of SU in Western Europe in the periods 1951-2003 and 1946-1999 for the annual scale, respectively. Hence, the annual (+6.7 days/decade) and seasonal (+7.2 days/decade) findings presented in Figure 13 and Tables 5 and 6 agree well with their outcomes. As mentioned before, the reason for these agreement can be the utilization of the same data set. Though, their studies do not provide any information about changes in sub-periods for annual and seasonal scales. As pointed out above, the results for the two sub-periods are still useable.

As aforementioned in section 4.1, the atmospheric circulation plays a crucial role when dealing with extreme temperature events. For this issue we provided also in our results (section 3.3) an example for the threshold based index SU. The summer 1994 was characterized by the maximum number of summer days (on average 56) across a large area (from France to Greece). In addition, a great amount of warm nights (on average 23, not shown) was detected in this year. One possible explanation can be found by a seasonal climate composite analyses (see section 2.6). Figure 22 and 23 present for both levels (500hPa and 850hPa) a similar positive geopotential anomaly pattern with a maximum over the Central and Eastern Mediterranean. Also the Sea Level Pressure (Figure 24) shows a slight positive pressure anomaly at the same locations. We assumed that the Central Mediterranean was largely influenced by effects of the Azores high, as well as high bridges up to the Eastern Mediterranean. This implies to subsidence and stability. In addition, the study by Cassou and Philips (2005) identified the summer 1994 as one of the warmest in the period 1950-2003 due to two regimes, blocking and Atlantic low in France. The stations, listed in Table 9, are widely distributed from France to Greece.

Overall, nearly in all maps there are only few stations with anomalous trends compared with neighboring stations. Nevertheless, our results (see chapter 3) in this study seem to reflect real climate changes, although the exact numerical values of trends may be distorted because of some *limitations*, such as inhomogeneity of the data and analysis. Other difficulties appeared when working with seasonal climate composites. They have the disadvantages that different monthly processes would be missed. This implies to misinterpretation if the weather development within the months is high variable.

5. Conclusion and Outlook

The present thesis examines the changes in the annual and seasonal distribution of daily maximum and minimum temperatures extremes for the Mediterranean area. A better understanding of the ongoing changes in extremes based on the assessment of fives climate indices was the primary objective. Further aims involve the analysis of large-scale atmospheric circulation patterns at different geopotential levels as well as the Sea Level pressure based on seasonal climate composites analysis to quantify the driving forces of temperature related extremes events.

(1) How are the selected indices distributed in space and time in the Mediterranean area and what are the limitation factors?

We conclude that both, annual and seasonal indices, exhibit a significant change between 1950 and 1999. However, changes were more obvious for the Western Mediterranean (Portugal, Spain and France) than for the eastern parts. The warming period 1950-1999 is characterized by increasing Tmax trends (HWDI, SU and WD) and decreasing number of FD and CN. In addition, trends in Tmax extremes are of greater magnitudes than Tmin extremes. These findings agree with other studies (e.g. Alexander et al., 2007; Klein Tank and Können 2003; Kostopoulou and Jones 2005; Moberg et al., 2006). Significant increases of WD (28 out of 80 stations) and decreases of CN (28 out of 80 stations) appeared on the annual scale. Furthermore, decreasing FD and rising SU and HWDI trends were detected in this period. These warming trend mainly emerge from the decreasing of CN, particularly those of cold summer nights (-10.4 days/decade). On the other hand the major changes in Tmax related indices (e.g. WD) occurred in winter (+10.8 days/decade). For example, the high amount of CN (on average 22 nights) in 1972 was caused by low geopotential anomalies at different levels over the Western Mediterranean. In contrast, a high amount of WD (on average 19 days) was detected in winter 1998 caused by strong positive geopotential anomalies over the Central Mediterranean. Only the HWDI shows more significant trends in the eastern part of the Mediterranean than the others (Kostopoulou and Jones 2005).

To detect changes in temperature extremes we splitted the investigation period into two sub-periods (1950-1970 and 1971-1999). The first sub-period (1950-1970) is characterized by a slight cooling episode due to significant decreases of Tmax related extremes. In contrast, the second sub-period (1971-1999) is characterized by warming trends accompanied by decreasing FD and CD and increasing SU and HWDI. On the annual scale significant decreases of approximately -10days/decade (CN) and rising WD trends (+4.14 days/decade) appeared. Most significant changes of +9.2 days per decade (HWDI in summer), -8.5 days/decade (CN in summer), +4.2 days/decade (SU in summer) and +10 days/decade (WD in winter) mainly biased this period. For example, the highest average number of SU (56 days) was detected in 1994 and induced by positive geopotential anomalies over the Central and Eastern Mediterranean.

Nevertheless, the presented results need to be considered with some *limitations* due to data inhomogeneities. Even if many of the ECA series were subjected to homogenization by the National Meteorological and Hydrological Services (NMHSs), there are certainly still non-climatic influences and artificial shifts in the time series that have to be corrected. Hence, with the information available it is not possible to draw any accurate conclusions to what extent inhomogeneities affected the trends in the investigated extreme indices. Moreover, there is a need for more and longer daily observational records (e.g. Northern Africa, Middle East) to allow a better spatial analysis covering the whole Mediterranean region. The main impediment is that many NMHSs have not digitized much daily data, yet.

(2) How relevant is the selection of indices for climate change studies?

Our findings demonstrate that the use of percentile based climate indices is adequate for climate change finding on a continental scale. For example, 28 out of 80 stations show significant trends in annual WD for the 5%level. On the other hand threshold based indices (e.g. FD, SU) are defined as the number of days when temperature exceeds or falls below a fixed threshold. They can also be related to observed impacts, in particular if the threshold refers to values of physical, hydrological or biological significance. Even though they are less suitable for the comparison of direct impacts, they may provide useful indirect information relevant to climate changes studies (Bonsal et al., 2001). In addition to the two categories above, also the duration indices (e.g. HWDI characterizing the number of consecutive heat days) play a crucial role for climate change detection. Even if a minority of stations shows statistically significant trends (25 out of 80 stations) the maps in Figure 7 and 15 show a clear warming pattern in the Eastern Mediterranean.

(3) Is the large-scale atmospheric circulation pattern related to temperature extreme events?

We found that the large-scale atmospheric circulation pattern is related to temperature extreme events. The first example was the highest number (on average 22) of cold summer nights in 1972. We assumed that cold anomalies in summer months are linked to advance of cold-humid polar or arctic air masses. This takes place at the eastern ridge of a strong anticyclone situated in the north. In the second example we found a maximum amount of warm days (on average 19) in winter. The geopotential anomalies revealed for different levels (e.g. 200hPa, 500hPa and 850hPa) strong positive pattern over the Central and Eastern Mediterranean. We supposed that warm-dry winter anomalies are linked to air flow from west to south-west. This implies warm and sunny weather with little snow fall and few frost days. On the other hand, in 1994 was detected the highest amount of summer days (SU: on average 56). We believe that the Central Mediterranean was highly influenced by strong Azores high, as well as high bridges up to the Eastern Mediterranean. This creates subsidence and stability.

Within the EU-IP CIRCE, the research activities in the Mediterranean area will continue until 2010. The project will analyze a number of climate parameters including: temperature, precipitation, wind, waves, sea-level rise, surface radiative forcing, humidity etc. for the development of specific modeling scenarios. For example, for a better understanding of extreme weather events and their impact in the Mediterranean area consistent quality controls and homogenization methods have to be applied (Research line 1). Furthermore, climate change impacts on environment, society and economics will be analyzed and evaluated at different dimensions (e.g. meteorological, oceanographic). Moreover, it is important to find new approaches of adaptation to the climate impacts and strategies of mitigation. Focusing on three selected categories (urban, rural and coastal), the studies represent a practical method to test adaptation and mitigation strategies.

However, it could be of interest in further research studies, when working with seasonal or annual temperature changes, to clarify the linkage of: soil moisture feedbacks, sea surface temperatures anomalies and the role of human (e.g. land-use changes). Though, the analysis of the role of human (e.g. land-use changes) and future climate scenarios is of great interest to understand daily temperature variability.

For example the study by Fischer and Schär (2008) demonstrated that the projected warming of uppermost percentiles of daily summer temperature is larger over France than in the others Mediterranean regions. Moreover, the study by Ogi et al. (2005) argued that the summer Northern Hemisphere annular mode (NAM) can describe aspects of anomalous summers, such as the summer of 2003.

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7. Supplementary Figures

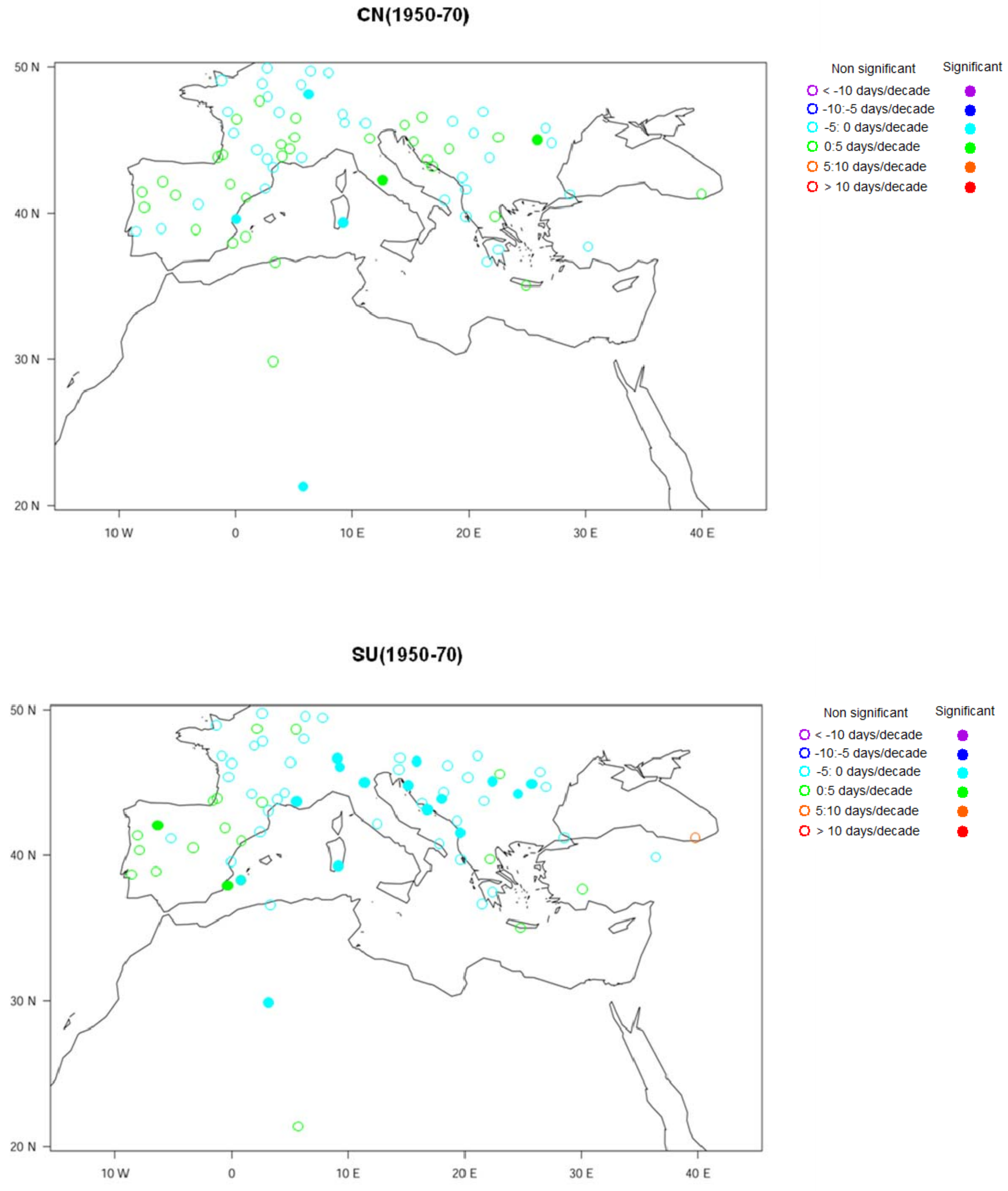

Figure 25: *CN and SU annual trends for the period 1950-1970. Filled dots indicate significant trends at 5%level.*

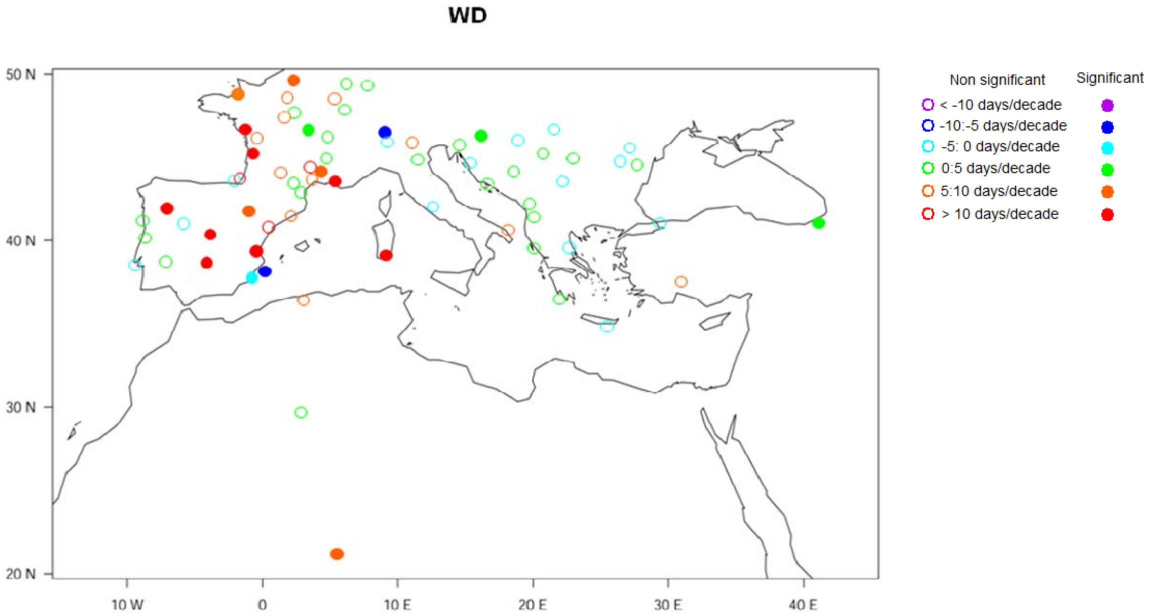

Figure 26: *WD (summer) seasonal trends for the period 1950-1999.Filled dots indicate significant trends at 5% level.*

Declaration

under Art. 28 Para. 2 RSL 05

Last, first name:	Politano Loredana
Matriculation number:	02-051-209
Programme:	Master of Science in Climate Sciences

Bachelor ☐ Master ☐ Dissertation ☐

Thesis title:	Extreme temperature events in the Mediterranean
Thesis supervisor:	PD. Dr. Jürg Luterbacher, Prof. Dr. Heinz Wanner and Dr. Elena Xoplaki

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, except where due acknowledgement has been made in the text. In accordance with academic rules and ethical conduct, I have fully cited and referenced all material and results that are not original to this work. I am well aware of the fact that, on the basis of Article 36 Paragraph 1 Letter o of the University Law of 5 September 1996, the Senate is entitled to deny the title awarded on the basis of this work if proven otherwise.

....

Place, date

....

Signature