Pinardi N, Masetti E (2000) Variability from the large-scale general circulation of the Mediterranean Sea from observations and modeling: a review. Palaeogeogr Palaeoclimatol Palaeoecol 158:153–173

Robinson A, Leslie W, Theocharis A, Lascaratos A (2001) Mediterranean Sea circulation. In: Encyclopedia of ocean sciences, vol 3. Elsevier, New York, pp 1689–1705

Somot S, Sevault F, Déqué M, Crépon M (2008) 21st century climate change scenario for the Mediterranean using a coupled atmosphere-ocean regional climate model. Glob Planet Change 63(2–3):112–126. doi: 10.1016/j.gloplacha.2007.10.003

Chapter 2
Past and Current Climate Changes in the Mediterranean Region

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Abstract Mediterranean climate change during the last 60 years is based on homogenized daily temperature and quality controlled precipitation observational data and gridded products. The estimated changes indicate statistically significant Mediterranean summer temperature increase and a reduction in winter precipitation in specific areas. Reconstructions of Mediterranean sea level suggest a rise of some 150 mm since the beginning of the nineteenth century. A 20 years long reanalysis (1985–2007) was produced, showing long term temperature variability and a positive salinity trend in

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the ocean layers from the surface to 1,500 m depth. A prominent increase in summer temperature extremes is found in the whole Mediterranean region, while warm bias in the mid twentieth century station data is removed by homogenization. No basin-wide trends in precipitation and droughts are found for the second half of the twentieth

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century, while trends in extreme winds are largely negative, as are those of the related cyclones and cut-off-lows. The role of large scale pressure patterns like the NAO for variabilities and trends is discussed for the different parameters considered.

Keywords Station time series • Meteorological Extremes • Weather patterns • Water mass characteristics • Sea level

2.1 Atmosphere

2.1.1 Mediterranean Climatological Data: Station Observations and Gridded Time Series

Reliable regional assessments of climate change require detailed analysis of long, continuous and high-quality instrumental time series with a good spatial distribution and density. Instrumental data sets are of major interest as they are the basis for the analysis of past and present climate changes, detection and attribution of climate trends and a fundamental aspect of modeling future climate scenarios.

In the frame of the CIRCE IP, great effort has been put into the collection of climatological observations and assessment of gridded data in the Greater Mediterranean Region (GMR). Most of the collected observation data (i.e., mainly instrumental temperature and precipitation) are used for the first time with a daily resolution.

2.1.1.1 Observational Station Data

Daily and monthly temperature and precipitation data (Figs. 2.1 and 2.2) in the GMR is available, and in their majority they cover the second half of the twentieth century. The records stem from various sources and databases as the Global Historical Climatology Network (GHCN-Monthly and GHCN-daily, Peterson and Vose 1997), the European Climate Assessment & Data set (ECA&D, Klein Tank et al. 2002), the WMO–Initiative on Mediterranean Climate Data Rescue (WMO-MEDARE, Brunet and Kuglitsch 2008) and most importantly the National Meteorological and Hydrological Services (NMHSs) in the area.

Monthly maximum and minimum temperature series from over 700 stations (Fig. 2.2c) in the GMR show a generally good spatial distribution that for some areas (e.g., Turkey) could be characterized as excellent. Longer time series are primarily located at the northern basin. In North Africa, many time series start early in the twentieth century, however without updates to present and they often cover only a couple of decades at the beginning of the twentieth century.

The Mediterranean daily temperature network (Fig. 2.1) presents a lower density and shorter temporal coverage than the monthly. The 360 stations with daily maximum and minimum temperature records are concentrated mostly over the northeastern Mediterranean basin. The remaining of the area shows a significantly sparser coverage. Especially in North Africa, Alger and Melilla are the only stations

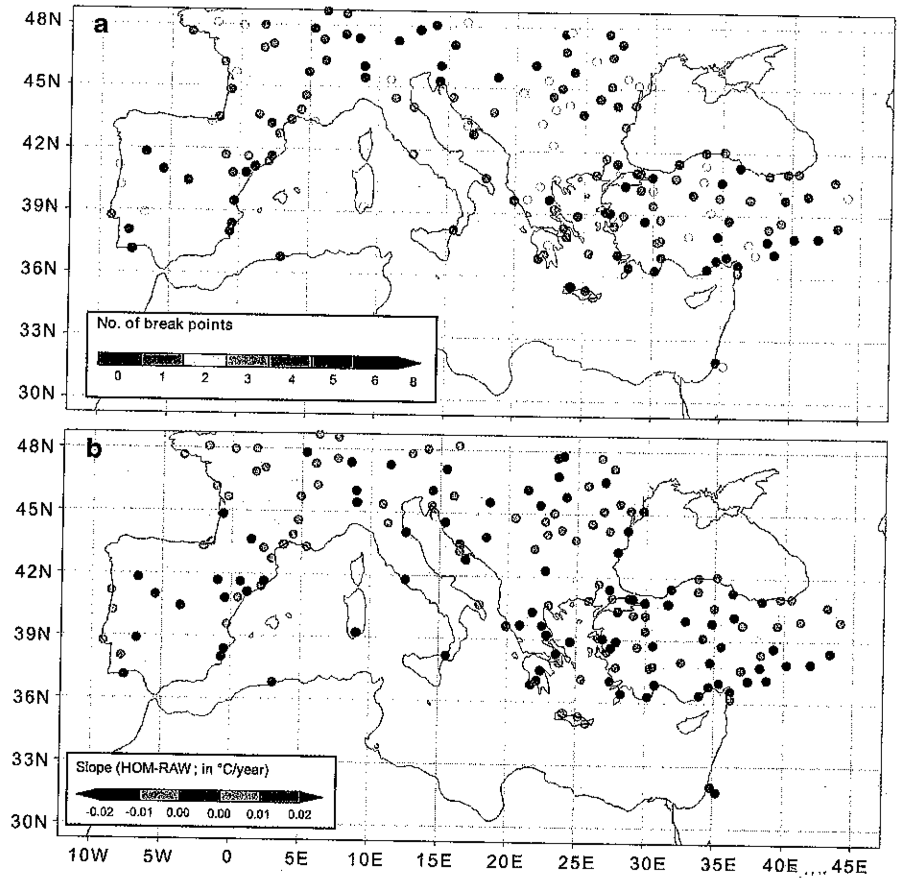

Fig. 2.1 Mediterranean daily temperature data availability and quality: (**a**) Number of detected break points for the daily maximum temperature series; (**b**) Slope differences (homogenized minus raw) for each site. *Light red* areas characterize records with an increased temperature trend after application of PENHOM (From Kuglitsch et al. (2009), Journal of Geophysical Research)

with daily temperature series. Longer series stem in their majority from northern Mediterranean stations.

GMR monthly precipitation time series from 1,115 stations (Fig. 2.2a) best represent Turkey and Italy with sparser distribution over southern Balkans and northeastern Africa. The longest time series are found over western Mediterranean and northern Balkans, while eastern series cover the second half of the twentieth century. Regarding Northern Africa monthly temperature and precipitation series, in many cases the series start at the beginning of the twentieth century and often cover only a couple of decades.

465 daily precipitation time series have been collected. The station density is lower than the one of the monthly dataset and with a different distribution over the area. Turkey is the only country that shows similar distribution and density between the monthly and daily precipitation time series, while in Italy the coverage of daily

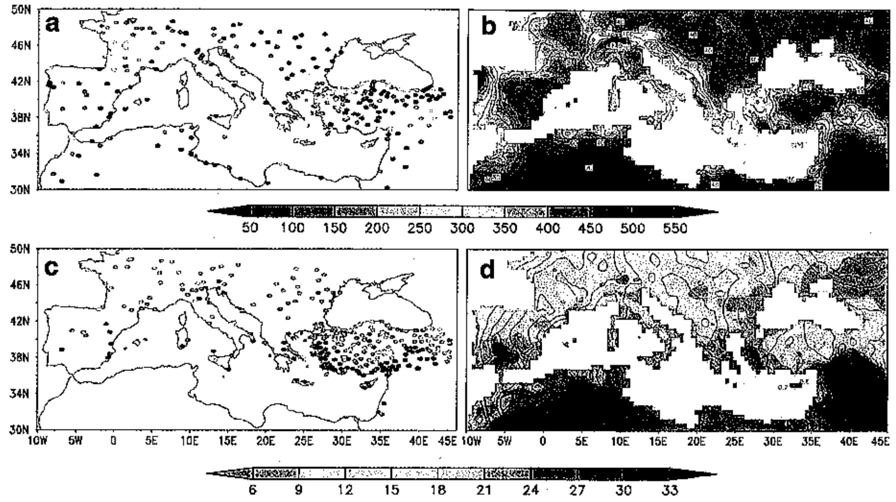

Fig. 2.2 *Upper panel*: winter (DJF) precipitation totals (mm) from (**a**) homogenized monthly series and (**b**) CRU TS 3.0 gridded data; *Lower panel*: mean summer temperature (°C) from (**c**) homogenized monthly series and (**d**) CRU TS 3.0 gridded data

series is significantly sparser than for the monthly series. Alger is the single Northern African station with daily precipitation data. Most of the series begin in the mid-twentieth century. Time series longer than 100 years are primarily located at the northern Mediterranean.

2.1.1.2 Gridded Datasets

Besides observational station data, gridded climate data offer valuable information about the spatial pattern of meteorological elements such as temperature, precipitation or air pressure variables/parameters. The climatology of the GMR is described by numerous gridded data sets in different temporal (sub-daily to monthly) and spatial resolution (0.25°×0.25 to 5°×5°).

Gridded data sets covering the GMR are APRHODITE (E. Mediterranean only, Yatagai et al. 2008), CMAP (Xie and Arkin 1997), CPC GHCN/CAMS (Fan and van den Dool 2008), CRUTEM3 (Brohan et al. 2006), CRU TS 3.0 (Fig. 2.2b,d) (Mitchell and Jones 2005), EMULATE (Ansell et al. 2006), E-OBS (Haylock et al. 2008), ERA-40-Reanalysis (Uppala et al. 2005), ERA-Interim (Dee et al. 2011) GPCC V4 (Schneider et al. 2008), HadSLP2 (Allan and Ansell 2006), JRA-25 Reanalysis (Onogi et al. 2007), NCEP/NCAR-Reanalysis (Kistler et al. 2001), Treberth's NH (Trenberth and Paolino 1980), Twentieth Century Reanalysis (V2) (Compo et al. 2011).

E-OBS is the only dataset based on daily climate observations with daily gridded mean, maximum and minimum temperature as well as precipitation data at 0.25°×0.25° resolution since 1950. The GMR is however not fully covered, especially to the south and east of the area.

The development of spatially highly resolved gridded datasets is a very useful tool for climate and climate change research in highly complex terrains as the GMR. However, the spatial interpolation of daily observations inherits to the gridded output the quality of the input observation time series and is highly dependent on the adopted morphology scheme. Analyses have shown that a large proportion of the GMR station time series are characterized by insufficient quality (Kuglitsch et al. 2009, 2010). In combination to the complexity of the GMR, the gridded datasets have to be used with caution.

2.1.2 *Quality Control and Homogenization of Station Time Series*

The analysis of instrumental climate time series and the achievement of trustworthy results require quality controlled and homogenized data that is, if possible, not affected by break points not connected to climate.

The quality control includes the identification of gross errors, to ensure that data lies in a physically reasonable range, the check of internal consistency and the temporal and spatial coherency (Aguilar et al. 2003) and the replacement of erroneous data by missing values. After the quality control, the time series should be checked for artificial break points in mean and variance due to station relocations, new instrumentation techniques or land-use changes. Both, the detection and correction of artificial break points are based on statistical techniques and the comparison of an investigated, candidate, series with neighboring, highly correlated, series (i.e., reference). For the validation of the detected break points a comparison with several reference series is usually done. Break detection methods are well developed (e.g. Wang 2008; Caussinus and Mestre 2004; Alexandersson and Moberg 1997) and usually applied to mean annual or seasonal data.

The correction of the detected break points is usually carried out on monthly time series (Caussinus and Mestre 2004; Alexandersson and Moberg 1997), with a few recently developed methods at the daily scale (Toreti et al. 2010a; Della-Marta and Wanner 2006; Vincent et al. 2002). It is important to highlight that only the use of metadata informing about the station history (including stations relocations, used instruments, observational practices, station environment changes) can validate statistically detected break points. However, metadata is often not available or difficult to be accessed in archives.

An improved tool for daily temperature homogenization has been developed by Kuglitsch et al. (2009) with a penalized log likelihood homogenization procedure (PENHOM) combining state of art break detection and correction techniques into one procedure. Toreti et al. (2010a) with HOMAD (Higher Order Moments for Autocorrelated Data) further expanded and improved the correction methodology for applications to smaller samples. The application of homogenization procedures on daily summer maximum and minimum temperature series reveals that a majority of the temperature time series is affected by artificial break points, on average by one break point in each 30 years (Fig. 2.1a; Kuglitsch et al. 2010, 2009).

Kuglitsch et al. (2009, 2010) indicated that the 1960s Mediterranean daily temperature time series are warm biased. This is in agreement with other studies for western Europe for the earlier instrumental period. During this period, many station screens were changed in terms of type, size and ventilation, making measured temperatures closer to the ambient temperature (Aguilar et al. 2003). In addition, some of the thermometers are believed to have been more exposed to extremes of sensible heat in the earlier twentieth century decades than in the present (Della-Marta et al. 2007 and references therein). Eventually, the corrections result in a stronger warming from 1960 to present than what was previously reported (Fig. 2.1b).

An advanced correction method for daily precipitation series does not yet exist. The daily correction requires highly correlated reference series and daily precipitation is characterized by high spatial variability, thus the availability of dense data sets is one of the major issues, especially in complex terrain. Therefore, series with too many inhomogeneities are discarded to restrain from unreliable results.

The monthly Mediterranean temperature and precipitation time series are homogenized implementing and applying a method based on the Standard Normal Homogeneity Test (SNHT; Khaliq and Ouarda 2007; Alexandersson and Moberg 1997). The homogenization procedure is validated by using also the method developed by Caussinus and Mestre (2004) for both the detection and correction.

Homogenized temperature series and quality checked precipitation series (at daily and monthly scales) are used for the description of the Mediterranean climate presented in the following section.

2.1.3 *The Mediterranean Climate – Present Knowledge*

The Mediterranean region lies in a transitional zone. The basin and surrounding lands are affected by interactions between mid-latitude and tropical processes and are influenced by some of the most relevant mechanisms acting upon the global climate system (Giorgi and Lionello 2008; Xoplaki 2002). Gridded monthly data (CRU TS 3.0, Mitchell and Jones 2005) and homogenized daily to monthly station time series (Toreti 2010; Kuglitsch et al. 2009) are used for the analysis of the Mediterranean climate.

A main characteristic of the Mediterranean is the high spatial variability in seasonal mean temperature and total precipitation, enhanced by the complex orography of the area (Fig. 2.2).

The Mediterranean winter (DJF) climatic sub-regions comprise from very cold mountainous (Alps, Dinaric Alps, Pyrenees) to mild areas along the coastlines of to the south of the peninsulas, the eastern basin and North Africa (not shown). The total winter precipitation amounts range from 50 to 100 mm (North Africa) to over 500 mm (along western coasts of the peninsulas enhanced due to orographic forcing and land-sea interactions). Higher variability characterizes the areas with high winter precipitation amounts. For winter precipitation (Fig. 2.2a, b), the station time series along the southern Black Sea coast and those of three individual stations at the Strait of Gibraltar show higher totals, likely connected with the station density, the area morphology and the interpolation scheme of the gridded data.

Mean summer (JJA) temperatures (Fig. 2.2c, d) show a gradient from north (cool) to south (warm) and exceed 30°C in the southeast. Large areas receive no rain during summer, while in mountainous areas precipitation totals can reach 400 mm (associated with high variability, not shown). The lower station density over areas with complex topography, as the Alpine regions, is related with an underestimation of precipitation variability.

The Mediterranean climate is influenced (among other factors of smaller and larger scale) by both tropical and mid-latitude climate dynamics (Trigo et al. 2006; Barry and Chorley 2003, and references therein). The eddy-driven jet stream and the subtropical jet stream (e.g., Barry and Carleton 2001) contribute to the weather characteristics of the region. A key feature for the GMR is the Mediterranean Sea itself. It represents an important source of energy and moisture to the atmosphere. The local evaporation largely exceeds precipitation during all seasons and the characteristics of the local water budget influence the amount of moisture available for the surrounding land areas, especially northeast Africa and the Middle East. Sea Surface Temperature (SST) anomalies govern, at least partly, precipitation and air temperature anomalies in neighboring continental regions.

During winter, the western Mediterranean is influenced by a mid-tropospheric (500 hPa geopotential height, Z500; NCEP/NCAR reanalysis, Kistler et al. 2001; not shown) northwesterly flow, associated with moisture transport from the North Atlantic. Over the eastern basin a mid-tropospheric westerly flow is prevalent. High variability characterizes the Z500 field over the northern North Atlantic and the western Mediterranean. The Sea Level Pressure (SLP; NCEP/NCAR reanalysis, Kistler et al. 2001; not shown) pattern reveals the characteristic dipole structure over the North Atlantic (comprising the Icelandic low and the subtropical high pressure systems), the high pressure system to the east and the cyclogenetic area of the Gulf of Genoa. In addition to these centers of action, cyclonic disturbances influence the winter Mediterranean weather. Low pressure systems that originate from North Atlantic synoptic systems, and the cyclogenetic character of areas in the Mediterranean (the lee of the Alps, the Gulf of Lion and Genoa, the Aegean Sea and the Cyprus area, among others; Lionello et al. 2006; Xoplaki 2002) influence the winter climate. The low pressure systems moving along the basin are regenerated above the warmer sea and precipitate over the western coasts of the peninsulas. The winter Mediterranean SST (°C, HadISST, Rayner et al. 2003; not shown) pattern presents a west-east (cooler-warmer) gradient. The lowest mean winter SSTs are observed in the Gulf of Lion, the northern Adriatic Sea (13°C) and the Black Sea (10°C), related to local air temperature field, the wind system and connected upwelling as well as the local oceanic circulation. Highest values are recorded in the eastern basin (19°C).

In summer, the atmospheric circulation over the area, both at surface (SLP) and mid-troposphere (Z500) (not shown), is characterized by reduced circulation variability and a weak gradient. The northward shift of the subtropical ridge that leads to enhanced stability over the entire basin, and the expansion of the anticyclonic area from the Atlantic to the western and central Mediterranean dominate the surface circulation. The thermal low pressure system, that is located over the Arabian Peninsula and expands towards the eastern Mediterranean, is linked to the Asian summer monsoon (Zhang et al. 2004). The summer Mediterranean SST pattern (not shown), as in

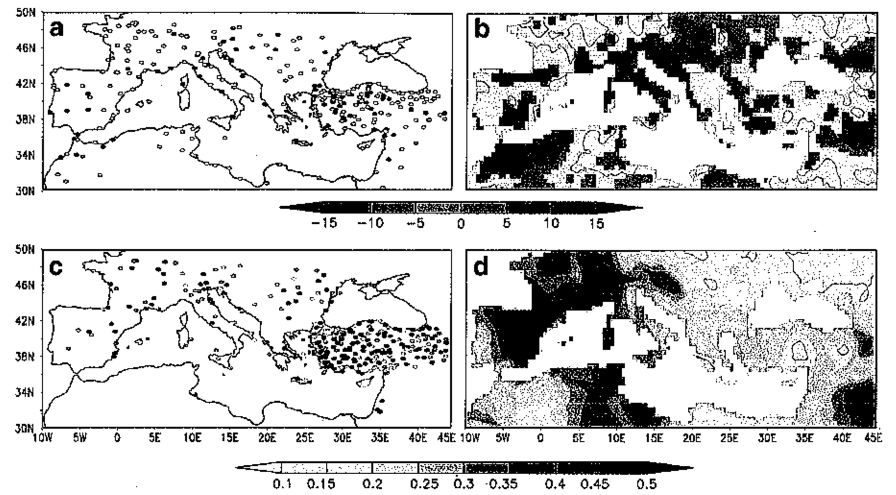

Fig. 2.3 *Upper panel*: Trends of winter (DJF) total precipitation (mm/decade), 1951–2005, from **(a)** station and **(b)** CRU TS 3.0 gridded data. *Lower panel*: Trends of summer (JJA) seasonal temperature (°C/decade), 1951–2005, from **(c)** station and **(d)** CRU TS 3.0 gridded data. *Gridded maps*: *contour lines* represent the 0-line and the *gray* areas non-significant changes (<90%). Station data: *full circles* denote statistically significant changes (From Toreti 2010)

the winter, shows a west-east gradient with a warmer eastern and a cooler western basin, though with regional modifications that are connected to atmospheric fluxes, the wind system and the oceanic circulation. The SSTs range from 20 to 26°C.

2.1.4 Mediterranean Climate Change in the Instrumental Period

The Mediterranean area is considered a 'hotspot' whose climate is especially responsive to global change and where potential climate change impacts are particularly strong (Giorgi 2006). In this section, we assess Mediterranean past and recent trends (1951–2005) of seasonal (winter, DJF and summer, JJA) temperature and precipitation. For the trends detection and estimation, a modified Mann-Kendall test (Yue et al. 2002) and the Theil Sen method (Sen 1968) are applied. The two methods are nonparametric and are characterized by robustness.

Winter precipitation in the Mediterranean is characterized by a drying both for the station series and the gridded data (Fig. 2.3a, b). Differences in the statistical significance of trends between the observations and the gridded data could be attributed to the homogenization process. Currently, other homogenization procedures are validated and additional methodologies are employed. The CRU TS 3.0 gridded winter temperature data pattern (not shown) reveals a significant increasing trend over the western Mediterranean with highest values for Iberia and France and a remarkable cooling over the southern Balkans and Turkey. In contrast, station series (except for few sites over northern Italy) do not show statistically significant changes.

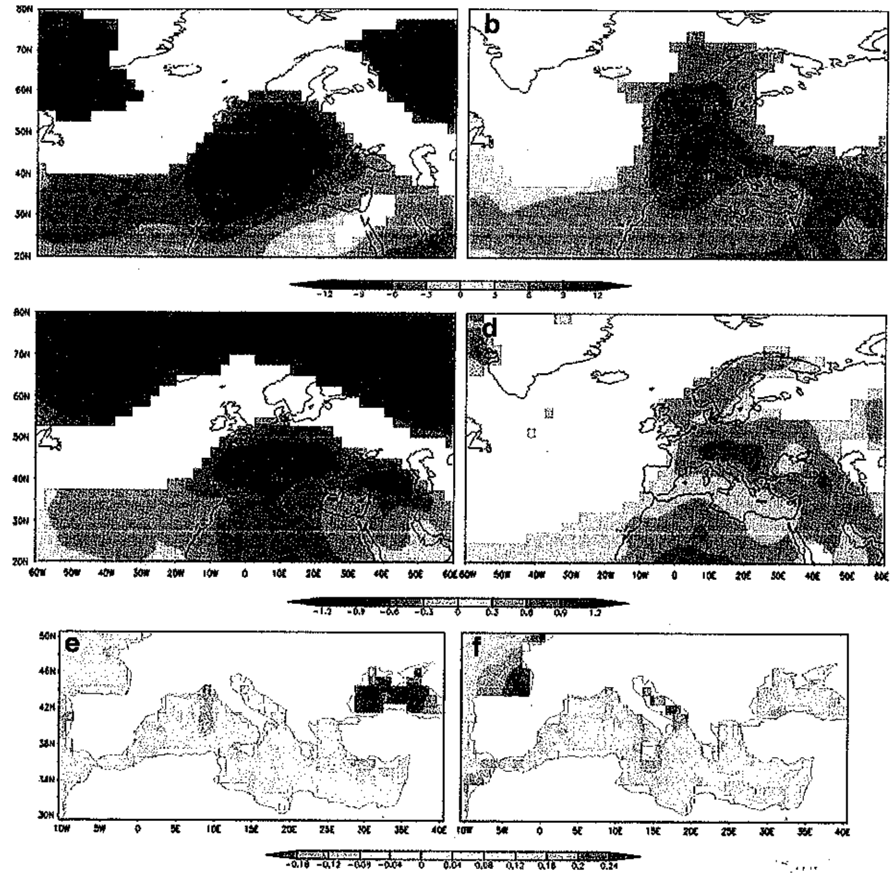

Fig. 2.4 Trends of winter (DJF; *left*) and summer (JJA; *right*), 1951–2005, (**a**, **b**) Z500 (gpm/decade), (**c**, **d**) SLP (hPa/decade) and (**e**, **f**) SST (°C/decade). *White areas*: no-significant trends (From Toreti 2010)

A strong and statistically significant increase of mean summer temperature is identified for both gridded and station data (Fig. 2.3c, d). However, over Turkey the temperature trend from gridded data is weaker than the one estimated from the station time series. For summer precipitation (not shown), large areas, as the Iberian Peninsula and northern Italy and the Alpine areas, reveal a statistically significant summer precipitation decrease. The observed differences in statistical significance between the gridded and station data could be related to the quality of the station time series (e.g., time continuity) and/or to the fact that gridded data are derived with a procedure optimized in space rather than in time (Mitchell and Jones 2005).

Both the Z500 and the SLP fields present statistically significant trends during the period 1951–2005 (Fig. 2.4a–d). The winter Z500 field (Fig. 2.4a, b) presents a strong positive trend over the Atlantic and the Mediterranean area, with highest

values over western Europe and the Mediterranean. Conversely, negative trends are prevalent over Greenland and western Russia. At the sea level (Fig. 2.4e, f), an area of negative trends extends over large part north of 55° N. In addition, highly significant positive areas are found across the western and central Europe, the Mediterranean and south of the Black Sea. In summer, an area with weaker but positive trend is detected over the whole Mediterranean region, most parts of Europe, the Middle East and North Africa. These results highlight a changing atmospheric circulation over the Mediterranean, leading to a northward shift of the Atlantic storm track and an increased stability over the basin. Similar results were reported by Giorgi and Lionello (2008) using global model scenarios. The Mediterranean SST trends (Fig. 2.4e, f) are in good agreement with the seasonal air temperature of the surrounding land areas. Increasing SSTs for both seasons are detected in the central and western Mediterranean, with the exception of the Ligurian Sea. In winter, significant downward trends are identified in the Eastern Mediterranean and the Black Sea.

2.1.5 Links Between Large Scale Atmospheric Circulation and Mediterranean Climate

Several studies have investigated the relationship between the Mediterranean climate and the large scale atmospheric circulation modes in the Northern Hemisphere (e.g., Toreti 2010 and references therein, Xoplaki et al. 2004, 2003; Dünkeloh and Jacobeit 2003; Jones et al. 2003; Quadrelli et al. 2001; Hurrell and van Loon 1997; Corte-Real et al. 1995, among others). During winter, the most relevant atmospheric circulation modes for the Mediterranean region (Trigo et al. 2006) are: the North Atlantic Oscillation (NAO), the East Atlantic pattern, the East Atlantic/Western Russia pattern (EA/WR) and the Scandinavian pattern (Barnston and Livezey 1987). The NAO is significantly correlated with Mediterranean winter precipitation (Xoplaki et al. 2004), especially in the western basin (Trigo et al. 2004). Studies pointed out that the Mediterranean climate is statistically linked to the El Niño Southern Oscillation (ENSO) and the South Asian Monsoon (Alpert et al. 2006). The ENSO has been connected to increased rainfall in Israel (Price et al. 1998; Yakir et al. 1996) and to monthly precipitation variability over Turkey (Kadioglu et al. 1999). In the western Mediterranean, Mariotti et al. (2002) found a significant correlation between ENSO and autumn precipitation. Brönnimann et al. (2007) identified anomalous winter temperature and precipitation in Europe associated with El Niño events. However, the relationship between ENSO and the Mediterranean climate is highly nonlinear and not stable because it is influenced by natural noise, ocean-atmosphere interactions and numerous feedback mechanisms. The linkage between summer regimes in the eastern Mediterranean and the Asian Monsoon was attempted and analyzed by Rodwell and Hoskins (1996), Ziv et al. (2004) and Tyrlis et al. (2012).

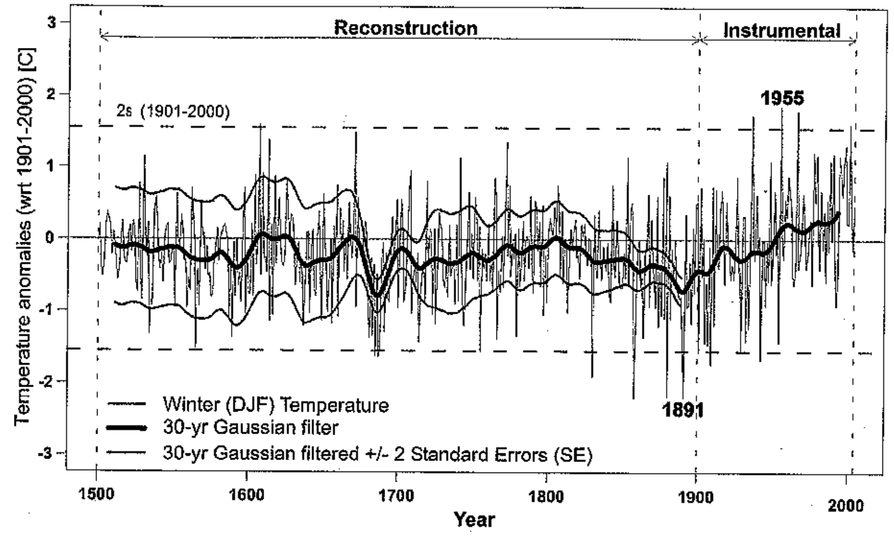

Fig. 2.5 Winter (DJF) averaged-mean Mediterranean temperature anomalies (with respect to 1901–2000) from 1500 to 2005, defined as the average over the land area 10°W to 40°E and 35°N to 47°N (*thin black line*). The values for the period 1500 to 1900 are reconstructions; data from 1901 to 2005 are derived from CRU TS 3.0 gridded instrumental data. The *thick black line* is a 30-year smoothing. *Grey lines*: ±2SEs of 30-year Gaussian filtered reconstructions. The dashed horizontal lines are the 2 standard deviations of the period 1901–2000. The warmest and the coldest Mediterranean winter are denoted (Adapted from Luterbacher et al. (2006), in: Mediterranean Climate Variability, Elsevier)

2.1.6 Analysis of Climate Variations from the Pre-instrumental Period to the Past Half Millennium Using Climate Proxies

The reconstruction and interpretation of spatial and temporal patterns of climate change in earlier centuries is a necessary task for assessing the degree to which the instrumental period is unusual against the background of pre-industrial climate variability. The Mediterranean area offers a high quantity and quality of long instrumental station series, a wide range of documentary evidence (i.e. reports from chronicles, daily weather reports, ship logbooks, the time of freezing and opening up of waterways, religious ceremonies, etc., see Brázdil et al. 2005 for a review) as well as high and low spatio-temporal resolved natural proxies (tree-rings, tropical and non-tropical corals, speleothems, lake sediments, vermetid reefs (reefs composed of vermetid gastropods, a family of marine snails), etc.; see Luterbacher et al. 2006, 2012 for extended reviews).

Numerous, seasonally resolved, proxy information has been used to reconstruct Mediterranean winter temperature (Fig. 2.5) back to AD 1500 and analyze associated uncertainties, trends and extremes. The Mediterranean area experienced several

cold relapses and warm periods as well as dry and wet intervals on decadal timescales, on which shorter-period quasi-oscillatory behavior was superimposed. Substantial winter warming started at the end of the nineteenth century. In the context of the last half millennium, the last winter decades of the twentieth/twenty first century were among the warmest. Seasonal Mediterranean scale precipitation reconstructions (Luterbacher et al. 2006, 2012) are less certain but also point to rather dry winter conditions in recent decades.

The relationship between large-scale atmospheric circulation patterns and Mediterranean winter climate anomalies during the last 500 years revealed that warm and dry winters are linked with a positive NAO mode, whereas cold and wet Mediterranean winters are connected with Scandinavian blocking. However, Mediterranean sub-regions might react differently in terms of temperature and precipitation anomalies to different circulation modes. Running correlation analyses between the leading atmospheric circulation modes and the regional averaged Mediterranean temperature and precipitation over the past centuries indicate that the NAO (EA/WR) has a robust signal on Mediterranean mean land precipitation (temperature), whereas the influence on Mediterranean mean land temperature (precipitation) is fluctuating and depends on the time window (Luterbacher et al. 2006, 2012). Results also indicate that sub-regional processes provide different signals which can cancel (i.e., not-significant connection between atmospheric circulation and climate over the last centuries).

2.2 Ocean

2.2.1 General Structure of the Mediterranean Circulation

The Mediterranean Sea can be approximately divided into three vertical layers with different water mass characteristics (Robinson et al. 2001). The first layer occupies the top 150 m of the water column and is characterized by the inflow of the Atlantic waters with the low salinity. The second layer extends from the depth of 150 to 600 m and is occupied by warm and salty Levantine Intermediate Waters (LIW). The layer below 600 m has cold dense waters (DW) formed both in the western and eastern parts of the Mediterranean. Furthermore, the circulation in the Mediterranean may be described by major circulation belts (Pinardi and Masetti 2000). The first is positioned in the top 500 m and connects the Atlantic waters with the LIW. The other belts are meridional. They are connected to the formation sites of DW in the Gulf of Lion, the Adriatic Sea and the Aegean Sea.

The surface circulation is dominated by large scale cyclonic gyres that occupy the northern parts of the western and the eastern basins (Fig. 2.6). Along the southern coast of the Western Mediterranean there is a jet-like Algerian Current, formed mainly by the density gradients between the fresh Atlantic and salty Mediterranean

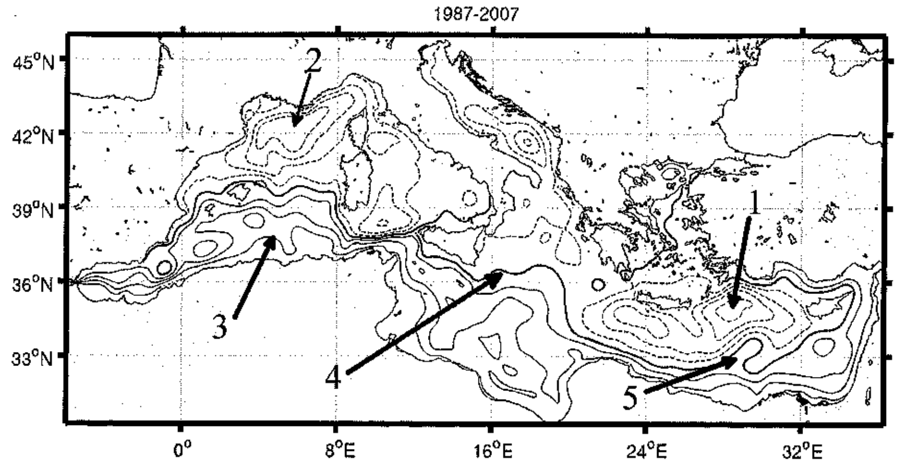

Fig. 2.6 Mean sea level in the Mediterranean in the period 1987–2007 (m) estimated by Circe reanalyses. The contour interval is 3 cm, 0 cm isoline is *bold*, and negative values are *dashed*. Major surface circulation features are shown: *1* Rhodes Gyre, *2* Lion Gyre, *3* Algerian Current, *4* Atlantic Ionian Stream and *5* anticyclonic gyres in the Levantine.

waters. It detaches from the coast and forms a complex structure of anticyclonic eddies that extend to the north to the central parts of the Western Mediterranean. The Algerian Current extends further eastward into the central part of the Mediterranean as the Atlantic Ionian Stream (AIS). The southern part of the Levantine is dominated by large anticyclonic gyres.

Ongoing changes in the Mediterranean have been estimated using the 20 years long reanalyses (1985–2007) made in the project CIRCE (Adani et al. 2011).

2.2.2 *Sea Level Changes*

Sea level changes pose the highest risk for coastal areas. Globally, sea level rise is expected due to climate change through mass addition (by melting of inland ice sheets and glaciers) and through thermal expansion of the water column. However sea level is not expected to rise uniformly around the globe. Thus for each and every coastal location understanding the expected changes in mean sea level by reference to the land is crucial for coastal planning purposes. Moreover, knowledge of the extremes in sea level (Sect. 2.1.3) is equally important because the extreme events are the events causing the damage.

Observations of sea level change based on tide gauges partly go back to the late nineteenth century. They have high temporal sampling but only measure locally. Satellite altimetry, available since about 1993. is of lower accuracy and sampling rates but provides complete coverage of the Mediterranean for areas further than around 40 km from the shore.

A few long sea level records spanning to the beginning of the 1900s exist at the northern coasts of the Western Mediterranean (Marseille and Genoa) and at the northern coasts of the Adriatic Sea (Trieste and Venice) (Tsimplis and Spencer 1997; Tsimplis and Baker 2000). The records of the gauges of Venice and Trieste are consistent with each other after corrections for the local subsidence have been taken into account (Woodworth 2003). The sea level trends for the three stations with longer records are in the range 1.1–1.3 mm/year, that is lower than the estimated global value for sea level rise which is closer to 1.8 mm/year (Church et al. 2004). New data for Trieste extending the record for this tide gauge 15 years back to 1875 leave the above estimates unaffected (Raicich 2007).

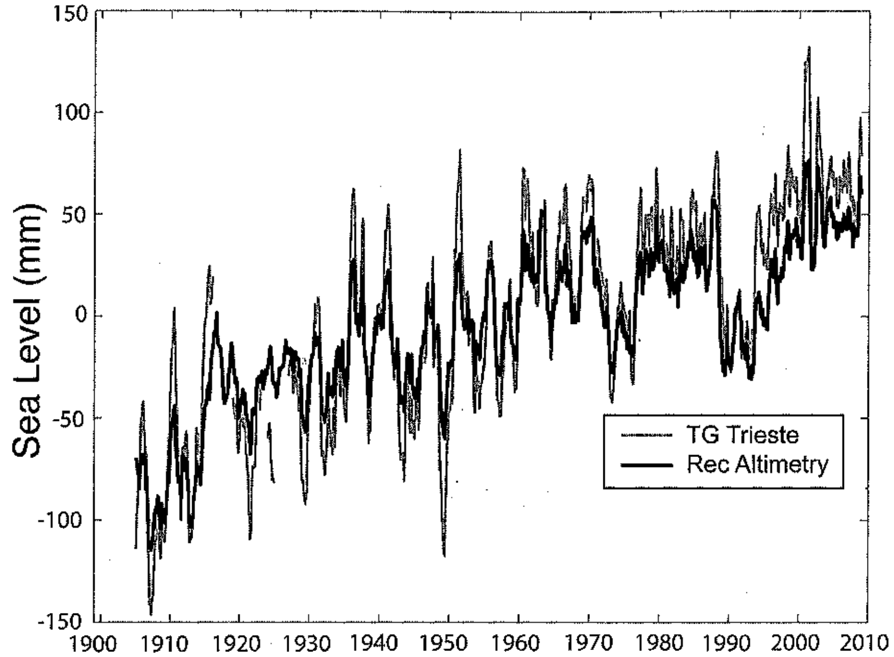

Fig. 2.7 Sea level rise in the Mediterranean from the tide-gauge in Trieste (corrected for atmospheric pressure and glacio-isostatic rebound) (*gray line*); and reconstruction of basin wide sea level from altimetry and tide gauges (*black*)

Assuming that the sea level changes in the Mediterranean basin are represented by the observations of the three long tide gauges at the northern coasts (Fig. 2.7) there were positive trends equivalent to those at the open ocean stations before about 1960 (Tsimplis and Baker 2000). Between 1960 and the beginning of the 1990s sea level was either not changing or decreasing (Tsimplis and Baker 2000; Orlic and Pasaric 2000), mainly due to increased atmospheric pressure changes during the winter period (Tsimplis and Josey 2001; Woolf et al. 2003). According to the analyses of the TOPEX/POSEIDON dataset (Cazenave et al. 2001; Fenoglio-Marc 2002), however, sea level is not coherently varying in the basin. After 1993, a period of fast sea level rise was observed at the Eastern Mediterranean Sea (Cazenave et al. 2001; Fenoglio-Marc 2001, 2002) and was linked with changes in observed sea surface temperature (Cazenave et al. 2002). Recently, on the basis of altimetric data, Vigo et al. (2005) confirmed an abrupt reduction of sea level rise rates (Fenoglio-Marc 2002) as well as negative trends in parts of the eastern Mediterranean Sea after 1999.

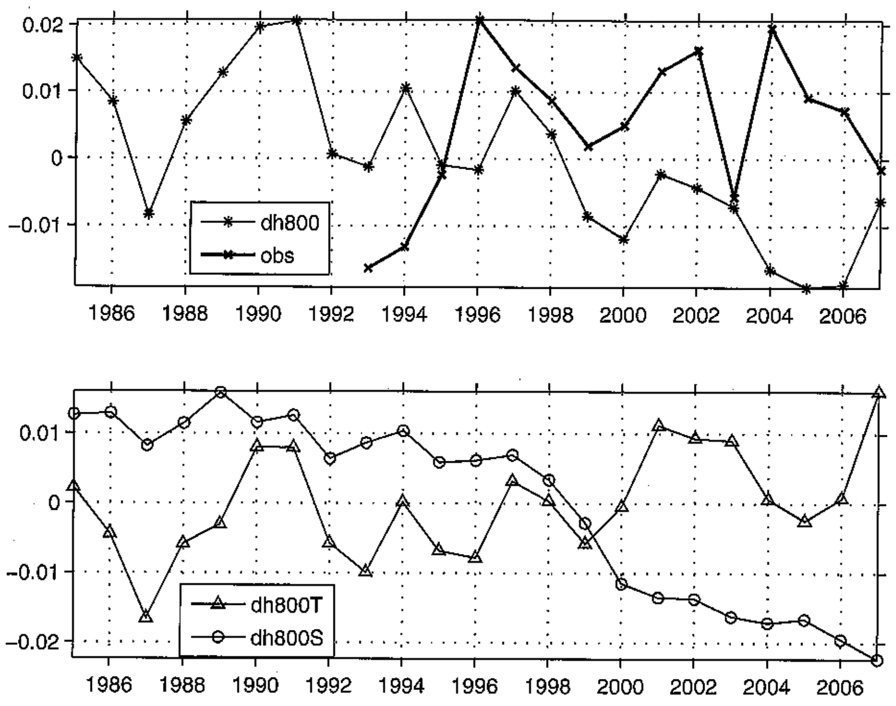

Fig. 2.8 Temporal change of the yearly averaged mean Mediterranean dynamic topography with respect to 800 m (dh800) in CIRCE reanalyses (m) (*top panel*), and separate contribution by temperature and salinity (*bottom panel*). The *top panel* also shows the estimate by SLA observations assimilated by the reanalyses

There are both contributions to Mediterranean sea level rise from local processes and from processes in the nearby Atlantic. Mass addition must surely be coming through the Strait of Gibraltar but thermosteric changes may be partly due to changes in the inflowing Atlantic water but also due to changes in the heat fluxes within the Mediterranean basin (Castellari et al. 1998). In addition changes in the basin and sub-basin circulation can also be important as well as changes in the local atmospheric forcing.

Changes in both atmospheric pressure and wind imposed a negative contribution to the sea level trends by between 0.3 and 0.8 mm/year from the 1960s to 1993 (Tsimplis et al. 2005; Gomis et al. 2008). Surface circulation changes occurring during the Eastern Mediterranean Transient (EMT) period Theocharis et al. (1999) have been identified as responsible for some of the regional sea level changes between 1993 and 2002. During the same period very good correlation between SST and sea level as well as oceanic temperature and sea level indicated that at least part of the sea level rise had a thermosteric expansion origin. Tsimplis et al. (2008) combined three dimensional and two dimensional models and estimate that there is a residual contribution of 1 mm/year after the mid 1970s which they argue is due to an incoming signal from the Atlantic. There is significant uncertainty involved in the separation of the steric signal from the mass component.

The top panel in Fig. 2.8 shows the estimate of the interannual change of mean Mediterranean dynamic topography with respect to 800 m in the CIRCE reanalyses. Below 800 m there is significant uncertainty due to lack of measurements thus the values are not included. In the same figure the basin mean SLA from satellite altimetry is shown as observations. Observations of mean SLA are completely independent of the mean dynamic topography, because when assimilating SLA the along track mean was subtracted from the misfits. The two signals do not appear correlated: the mean observed SLA appears stable after 1996 while the dynamic topography from the reanalyses has a downward trend. If the changes below 800 m could be ignored then one could argue that the difference between the two curves would be an estimate of mass addition to the basin. In fact by adding a constant trend of mass addition of about 1 mm/year (Tsimplis et al. 2008) or the global estimate of land ice melting of 1.2 mm/year (Nerem et al. 2006) the dynamic topography from the reanalyses would also become steady (not shown).

However, the lack of a larger number of observations below 1,000 m and the existence of deep water formation periods in the Mediterranean Sea introduce additional uncertainty in the interpretation of the temporal change of the sea level estimated only by the dynamic height above 800 m. The bottom panel in Fig. 2.8 partitions the temporal change of mean dynamic height with respect to 800 m on temperature and salinity components. The temperature component shows a marked interannual variability with a weak positive long term trend, while there is an almost linear negative trend in the salinity component with a large acceleration in the second part of the 1990s that fully suppresses the positive temperature trend and forms the overall decrease of the mean dynamic height shown in the top panel.

2.2.3 Changes in Surface Circulation

The temporal changes in surface circulation in the Mediterranean are mainly driven by the changes in the density gradients due to the inflow of low saline Atlantic water through the Gibraltar Strait and by the changes in the atmospheric forcing (e.g. Pinardi et al. 2005). After entering the Mediterranean, the Atlantic water is spread along the African coast forming anticyclonic gyres and slowly mixes with the surrounding waters with a higher salinity. Therefore, the impact of salinity gradients on the surface circulation becomes less important eastwards from the Gibraltar. The anticyclonic circulation along the southern coasts and the cyclonic circulation along the northern coasts are further sustained by the north-south gradients in the atmospheric heating and the curl of the wind which in winter blows from the north-west to the south-east (Pinardi et al. 2005).

Figure 2.6 shows the mean sea level from CIRCE reanalyses (1987–2007) indicating the intensity and the directions of the gestrophic currents at the surface. Some variation of the surface circulation can be found, for example a noticeable intensification of the anticyclonic eddies along the Algerian coast in the 1990s and their weakening after 2001.

During the first pentad the general picture of the surface circulation in the Ionian Sea is similar to that observed by in situ data in the Mediterranean in the second half of the 1980s and the first part of the 1990s. There is a clear intrusion of the Atlantic

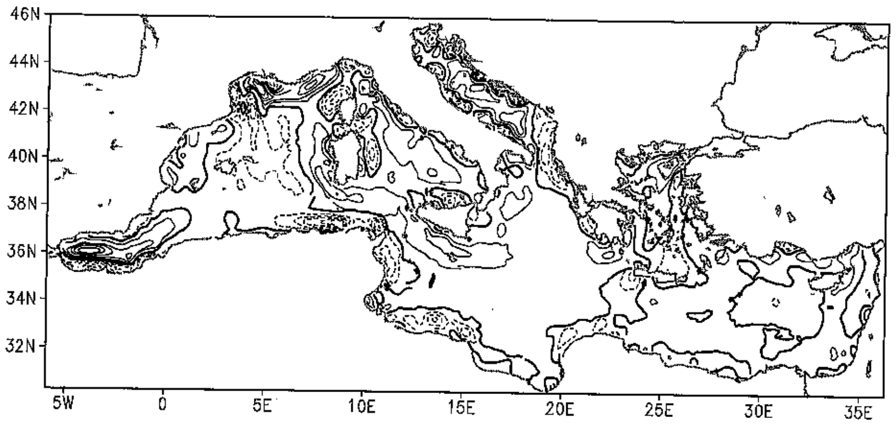

Fig. 2.9 The December-January-February wind stress curl anomaly in 1994 and 1995 with respect to the mean from 1985 to 2007 (Nm^{-3}). Contour interval is 2×10^{-7} Nm^{-3}, zero isoline is *bold*, and negative values are *dashed*

Ionian Stream (AIS) into the Northern Ionian Sea forming the Western Ionian Anticyclonic Gyre. The anticyclonic gyre extends over the whole Ionian Sea and the AIS flows to the entrance of the Adriatic Sea, and then turns southwards along the coast of Greece. A similar flow structure in the Northern Ionian Sea is estimated in the pentad 1992–1996, except that the anticyclonic Pelops Gyre vanishes, and the circulation next to the coast of Greece becomes cyclonic. On the other hand, the direction of the circulation in the Northern Ionian Sea is completely reversed in the pentad 1997–2001 with a large cyclonic gyre occupying the whole Northern Ionian Sea. The anticylonic gyre is limited to the Southern Ionian Sea, and the AIS flows directly from the southern edge of the Sicily to the Northern African coast. However, the anticyclonic Pelops Gyre reappears close to the Greek coast. In the pentad 2002–2006 the anticyclonic gyre propagates towards the Northern Ionian Sea, and the Pelops Gyre is intensified, but the largest part of the Northern Aegean Sea is still occupied by a large cyclonic gyre. In the first pentad the Iera-Petra Gyre is connected to the Mersa-Matruh Gyre, while it weakens in the pentad 1992–1996. It has a strong signature in the pentad 1997–2001, but this time it is disconnected from the Mersa-Matruh anticyclonic Gyre system.

The large scale change of the circulation in the Northern Ionian Sea between pentads 1992–1996 and 1997–2001 has already been observed by SLA observations, as a large scale change in sea level anomaly in 1997 (e.g. Pujol and Larnicol 2005). It has been shown that the change in the surface circulation in the Northern Ionian Sea may be connected to the variability of the surface forcing (Demirov and Pinardi 2002). Indeed it is shown in Fig. 2.9 that the wind stress curl in the Ionian has a significant positive anomaly in winters preceding the event, and for several years it has opposed the anticyclonic circulation in the Northern Ionian Sea. It is reasonable to assume that as a consequence in 1997 the AIS stopped to

penetrate into the Northern Ionian Sea. Also intensity of the Pelops, the Iera-Petra and the Mersa-Matruh gyres is strongly influenced by the wind stress curl intensity (e.g. Pinardi and Masetti 2000) and, therefore, they have a large interannual variability during the period of the reanalyses.

The eddy kinetic energy in the Mediterranean has not temporal trend between 1987 and 1995, but increases subsequently until the end of the reanalyses (2007) in agreement with the estimates only from SLA observations by Pujol and Larnicol (2005). However, the trend of the EKE is very different in the two basins: Although there is a significant interannual variability in the Western Mediterranean, there is no significant trend in EKE, and the total Mediterranean trend is exclusively due to the trend in the eastern basin where the EKE almost doubles in the 15 years long period.

2.2.4 Changes in Water Mass Characteristics

By analyzing historical data sets in the Mediterranean, provided by the MEDAR Group (2002), Rixen et al. (2005) find that in the period 1950–2000 the changes of water mass properties in the Mediterranean were different in the Western and the Eastern basins. The data set shows that from 1950 till 1990 in the Western basin there was a small decrease of the temperature in the near-surface layer followed by a faster increase until the 2000, while in the Eastern Mediterranean there was a noticeable cooling from 1970 until the 1985 and the heating onwards. On the other hand in the intermediate and deep layers, the temperature changes similarly in the Western and the Eastern Mediterranean throughout the period 1950–2000. However, while intermediate layers show only a decadal oscillation, the deep layers show a marked increase in the temperature from the mid 1980s.

The salinity in the surface layers has a decadal variability and shows a small increase in the Western Mediterranean, while there is no significant change in the eastern basin. In intermediate layers the salinity almost linearly increases from 1950 till 2000 in the Western basin, while in the Eastern basin there is a weak increase until the 1970s followed by a steady behavior. In deep layers the salinity increases in the Western basin, especially after the mid 1970s, while there is a decadal oscillation in the eastern basin with a significant increase after the mid 1980s.

It has been proposed that temperature and salinity changes in the different layers arise from both anthropogenic and natural changes. In surface layer and intermediate layers it has been found that the temperature and salinity changes are correlated with the larger scale changes in the atmospheric forcing related to the North Atlantic Oscillation (NAO) (Demirov and Pinardi 2002; Tsimplis and Rixen 2002). Probably, changes in deep layers of the western basin were linked to the anthropogenic global warming (Bethoux et al. 1990), the anthropogenic reduction of river runoff (Rohling and Bryden 1992), and the reduced amount of the precipitation in the second half of the twentieth century (Krahmann and Schott 1998). In the Eastern Mediterranean the significant increase of temperature and salinity in deep layers happens after the occurrence of the EMT (Roether et al. 1996). In this event the traditional source of Eastern Mediterranean deep waters in the southern Adriatic was substituted by the Aegean Sea in which warm and saline waters were formed in the first half of the 1990s and spread across the deep layers of the Eastern Mediterranean (Theocharis et al. 2002). Recently it has been found that the Aegean was once again substituted by the southern Adriatic Sea as the production site for the deep waters (Manca et al. 2003).

Figure 2.10 (top 3 panels) shows estimates of temperature anomalies in the CIRCE reanalyses from the surface to the depth of 1,500 m. In the reanalyses of the Western basin the temperature in the surface layers increases in the 1990s, in intermediate layers shows the decadal variability, and in deep layers the figure shows a weak increase in the 1990s. These processes are in agreement with observations except that the temperature increase in the deep layer seems to be somewhat slower than that estimated from observations. From 2000 till 2003 the temperature increases in surface layers, and in the following years it decreases. However, there is the increase of temperature in the intermediate layer starting from 2003, either due to the mixing with the surface layer or due to the advection of LIW from the Eastern Mediterranean. Also in deep layers there is an increase of temperature above 1,200 m. In the Eastern basin the temperature increase during 1990s in agreement with observations continues until 2003 and then there is a decrease of temperatures. In the intermediate layer the temperature changes weakly during the 1990s and starts to increase from 2000. It seems that the warm waters accumulated in surface layers until the 2003 penetrate into the intermediate layer showing a lag of several years between the heating of the surface and intermediate layers. The heating is further extended down to 1,200 m.

In the Western Mediterranean, the near surface salinity (Fig. 2.10, lower 3 panels) shows a decrease in the beginning of the 1990s in agreement with observation. It does not change significantly until a sudden increase in the surface layers occurs in 2004, coinciding with the deployment of several Argo floats in the Western Mediterranean in the EU project MFSTEP. It may be that the increase of the salinity in the surface layers was more gradual, but it was detected by observations only in the second half of 2004. In the intermediate layer the salinity changes only slightly until the 2000, and it increases onwards. The increase in intermediate layer eventually may be explained by the advection of LIW from the Eastern Mediterranean, because it can be seen in the top panels of the Fig. 2.10 that at the same time the temperature increases. On the other hand the increase of salinity in the deep layer happens jointly with the decrease of temperature indicating that it could be due to the deep convection. However, it should be noticed that the reanalyses assimilated observations only above the depth of 1,000 m and therefore the changes below this level estimated by the reanalyses are less reliable. In the Eastern Mediterranean the surface salinity starts to increase at the end of the 1990s. From 2000 it is significantly higher than in the earlier period. In the deep layer, the salinity has the maximum value in 2003 and afterwards starts to decrease.

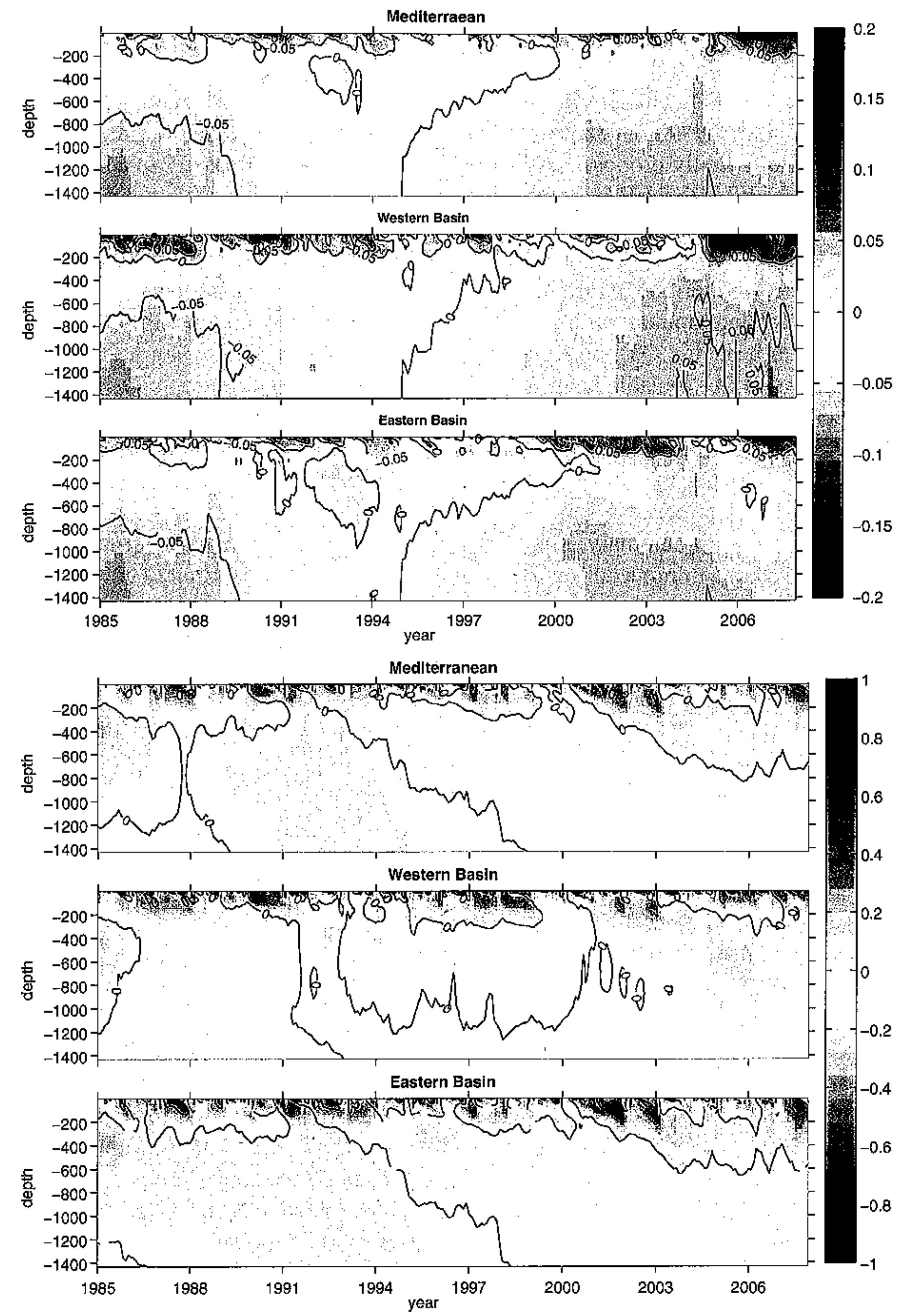

Fig. 2.10 *Top 3 panels*. The temperature anomaly (°C) in the Western (*top*) and the Eastern (*bottom*) basins. The anomaly is calculated by subtracting the monthly mean value in the period 1985–2007. *Bottom 3 panels*: The salinity anomaly (in practical salinity units) in the Western (*top*) and the Eastern (*bottom*) basins. The anomaly is calculated by subtracting the monthly mean value in the period 1985–2007

2.2.5 Changes in Ocean-Atmosphere Fluxes

Estimates of ongoing changes in ocean-atmosphere heat fluxes have been presented in a recent study by Pettenuzzo et al. (2010) that adapted for the Mediterranean Sea a methodology firstly proposed by Large and Yeager (2008) for the Global Ocean. In this study, ECMWF ERA-40 reanalysis for the period 1958–2001 (Uppala et al. 2005) were corrected to compute ocean-atmosphere fluxes in concordance with recent satellite observations and the observations of the heat content of 6 W/m^2 entering the Mediterranean through the Gibraltar Strait (Bethoux 1979). The study estimated the interannual variability of the basin average of the monthly mean of the net total heat flux QT and its four components: shortwave radiation Q_S, longwave radiation Q_L, sensible heat flux Q_H, and latent heat of vaporation Q_E. The Q_S time series is dominated by a strong seasonal cycle with a small interannual signal mostly due to cloud coverage. The series has a summer cool anomaly during the years 1970–1973 due to anomalous high cloud coverage. However, the cloud coverage has the opposite effect of a summer warm anomaly in Q_L time series that largely compensates the Q_S anomaly. The Q_H flux is the smallest of the four terms and it presents five large minima during the years 1967, 1969, 1980, 1991 and 1999, which are related to strong wind regimes and air temperature anomalies. The Q_E time series is always negative, and represents the second largest term of the total heat flux. In conclusion the Q_T time series has a smooth signal dominated by Q_S and is interannually modulated by Q_E and Q_H.

Several historical datasets of evaporation and precipitation have been analyzed in CIRCE (Mariotti 2010). All datasets show an increase in Mediterranean Sea evaporation since 1996 that, however, varies significantly among them. Only two datasets are available back to the 1970s. They both show the increase of the evaporation in the 1970s, but their trends somewhat differ in the 1980s. However, the two datasets give an overall increase of evaporation for the period 1979–2006 of 0.1–0.2 mm/d per decade. Only a single data set is available in the 1960s. Its evaporation rates in the 1960s are comparable to those of the late-1990s, and subsequently decrease until the mid-1970s. Considering the whole 1958–2006 period, the interdecadal variations have amounted to an equivalent linear mean evaporation increase of 0.06 mm/d per decade. All historical data sets show that the precipitation over the Mediterranean Sea and surrounding land region during 1979–2006 is mainly characterized by decadal variations. There is a substantial decrease of 0.2–0.3 mm/d in the 1980s, followed by an increase of 0.2 mm/d until the mid-1990s, and a decrease until the turn of the twentieth century, with a recent tendency to increase. Overall, in the period 1958–2006 available datasets suggest that these decadal variations were superimposed on a long-term negative trend of 0.03–0.04 mm/d per decade, whilst since 1979 there is no significant precipitation trend.

The importance of the severe wind regimes driven fluxes anomalies for the closure of the heat budget in the Mediterranean Basin is confirmed by the fact that the heat which is gained through the Strait of Gibraltar by advection, is lost exclusively in the area affected by the major northerly continental winds in winter. In order to understand what defines main continental wind regimes that drive the variability of

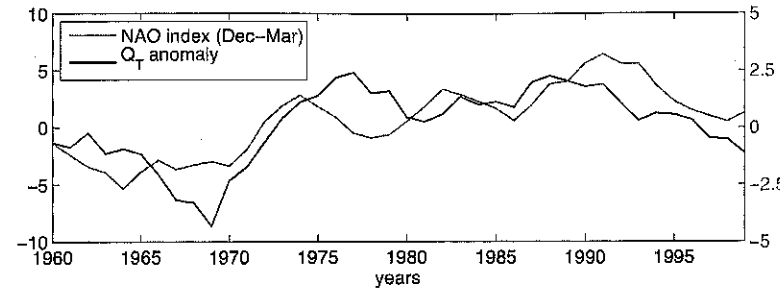

Fig. 2.11 5-year running mean of net surface heat flux (*black line*; *left axes*) and Winter (December through March) NAO index based on the difference of normalized sea level pressure between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland (*grey line*; *right axes*) (After Pettenuzzo et al. 2010)

heat fluxes, it is useful to examine the correlation between the surface heat flux and the North Atlantic Oscillation (NAO) index. The winter (December through March) NAO index (Hurrell et al. 2001) may be compared with the annual mean Q_T anomaly time series. Figure 2.11 shows high correlation (about 0.7) between the two fields. It is at least partially due to the wind regimes induced by the NAO itself: a positive index implies lower winds with lower latent heat flux, which is the largest modulation factor of Q_T. Conversely, a negative index is accompanied by stronger winds that imply a low Q_T anomaly. Similarly the observed evaporation rate in Mariotti (2010), which is directly proportional to Q_E and therefore also strongly influenced by northerly winds in winter, is also correlated to the NAO index with a minimum in the 1970s and a maximum in the 1990s.

2.3 Extremes in the Mediterranean Region During the Last Decades

2.3.1 Introduction

The objective of this section is twofold: to provide a view of the long term variability of extremes and to identify their links to large scale atmospheric circulation patterns.

Understanding changes in climate extremes is a difficult task because (a) high resolution (at least daily, often hourly) data are often required, (b) the causes of variations of extremes and their links to large scale atmospheric circulation patterns are not adequately known, (c) current global (and also regional) models have limitations in simulating extreme events, (d) the intensity of extreme events has a large intrinsic variability and it is therefore often difficult to identify statistically significant trends or changes and (e) extremes are, by definition, rare and thus the probability to detect changes is even lower. Because of these difficulties, assessments of trends in CIRCE have often been based on indices of rather 'moderate' extremes, such as those defined by the 90th or 95th percentiles in the distribution of daily observations, following a common research practice.

The characterization of the relations between the occurrence of extremes and large-scale patterns and indices is based on the simultaneous availability of high resolution regional sets of data and global data. The influence of large scale patterns on the climate of the Mediterranean region shows links that are complex both in space and time, because of the presence of strong regional features affecting them, such as orography and land-sea distribution. Particularly large-scale mid latitude atmospheric patterns such as NAO (North Atlantic Oscillation), the EA (East Atlantic), the EA/WR (Eastern Atlantic/Western Russia) and the Scandinavian (SCAND) patterns (Barnston and Livezey 1987) play an important role on the variability of precipitation, temperature (Xoplaki et al. 2012), ocean waves and affect the formation and evolution of cyclones (Trigo et al. 2006; Ulbrich et al. 1999; Lionello et al. 2006; Lionello and Galati 2008).

2.3.2 *Extreme Temperature*

A Mediterranean-wide study of changes in temperature extremes over the last 50 years was undertaken for CIRCE (Efthymiadis et al. 2011) using two daily high-resolution gridded data sets (E-OBS, Haylock et al. 2008, and ERA-40/interim reanalysis, Uppala et al. 2005; Simmons et al. 2006). The focus is on 'moderate' extremes generally defined by the 5th and 95th percentiles of the distributions of daily observations. 15 indices of extremes were calculated encompassing three different characteristics of extremes: intensity, frequency and duration.

Figure 2.12 shows changes for 1958–2008 in the frequency of very hot days for both gridded datasets. In summer, a prominent increase is found almost everywhere and especially over the sea. Increasing trends are particularly strong over the last 20 years (1989–2008) over the Central and Eastern Mediterranean and in the Black Sea region. Hot extremes in winter also increase in the western Mediterranean, whereas in the eastern Mediterranean, some decrease is observed. Analysis of all 15 indices shows a wide-spread increase of hot extremes, not only in the Mediterranean but also in the greater European area. At the same time, a general (but less strong) decreasing trend of cold extremes is found.

The CIRCE grid-based analysis is complemented by independent station-based analyses for the Eastern Mediterranean and Italy. Homogenization of data from a network of 246 Eastern Mediterranean stations (see Sect. 2.1.1.1) tends to remove the mid-twentieth century warm biases that have also been found by others (Kuglitsch et al. 2009, 2010). After correcting these biases, the hot day and night indices are found to have increased significantly – more so than for the raw data. While the dominant pattern of summer warming is consistent with the Mediterranean-wide analysis, more sub-regional variability is seen in the station-

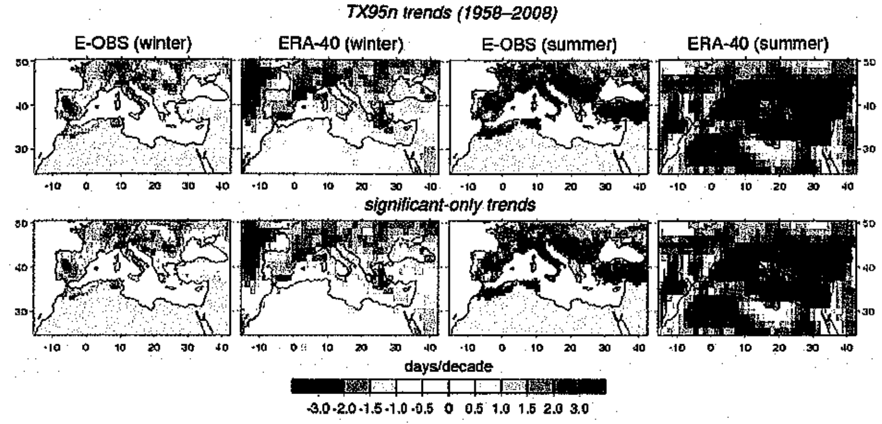

Fig. 2.12 Trends of winter and summer very hot days (TX95), over the period 1958–2008, from E-OBS and ERA-40/interim data. The lower panel shows only statistically-significant trends (Adapted from Efthymiadis et al. (2011) Natural Hazards and Earth System Sciences)

based analysis. For example, while the hot day increase is highest in continental areas (Central Balkans and Anatolia), the maximum increase of cold nights occurs in the coastal areas of eastern Mediterranean Europe. The homogenized series also show a significant increase in heat wave number, length and intensity with "hot spots" of change along eastern parts of the Turkish Black Sea coastline, in western, southwestern and central Turkey, and across the western Balkans (Kuglitsch et al. 2010). Quality control and homogenization was also undertaken for a network of 100 Italian stations. All Italian regions considered show a statistically significant increase in hot spells/events and a significant decrease of cold spells/events, confirming the results of Baldi et al. (2006). In addition, a slight, but not statistically significant, increase of daily temperature range is found.

In accordance with the wide-spread increase of hot extremes the first decade of the twenty-first century has been characterized by frequent heatwaves within the Mediterranean-European region. The outstanding summer 2003 heatwave struck western Europe, including France, Spain and Portugal while the recent 2010 heatwave affected the Black sea area, Ukraine and western Russia. The CIRCE comprehensive comparison of these two major heatwaves shows that the 2010 event exceeded the amplitude and spatial extent of the previous hottest summer of 2003 (Barriopedro et al. 2011). The results also indicate that the temperature maxima observed during these heatwave episodes were associated with the simultaneous occurrence of outstanding anticyclonic blocking patterns. 'Mega-heatwaves' such as the 2003 and 2010 events broke the 500-year long seasonal temperature records over approximately 50% of Europe, including all the northern Mediterranean sector. Moreover, according to state-of-the-art regional multi-model experiments, the probability of a summer experiencing 'mega-heatwaves' will increase by a factor of 5–10 within the next 40 years. However, the magnitude of the 2010 event was so extreme that despite this increase, the occurrence of an analogue remains fairly unlikely until the second half of the twenty-first century (Barriopedro et al. 2011).

The CIRCE analyses of temperature extremes are generally consistent with earlier studies of the Mediterranean and are generally in accordance with the global picture of trends: i.e., fewer cold extremes and more warm/hot extremes (Frich et al. 2002; Kostopoulou and Jones 2005; Alexander et al. 2006; Brunet et al. 2007). Understanding of these trends has been advanced by investigating links with large-scale circulation patterns such as the Arctic and Mediterranean Oscillations and with sea surface temperature anomalies including those associated with the West Africa Monsoon. These studies provide a robust foundation for investigating how temperature extremes which are of major concern with respect to their potential impacts on natural and human systems may change in the future.

2.3.3 *Extreme Precipitation*

Water management is a key issue for the Mediterranean. Changes of the hydrological regime affect crop productivity and are of higher importance than changes in seasonal totals (Iglesias et al. 2009). Hydrological regimes are, further, related to extreme precipitation events, as changes in their statistics, e.g., frequency and intensity, perturb the hydrological regime of the area (Trenberth et al. 2007). Extreme precipitation events can, thus, affect water availability, quality or access, posing a threat to human populations (Semenza and Menne 2009). Mediterranean extreme precipitation events considerably contribute to seasonal totals and can reach about 60% of the wet season (October to March) precipitation (Toreti 2010).

Extreme precipitation studies with applied indices have reported spatial incoherence along the Mediterranean (Alpert et al. 2002; Klein Tank and Können 2003; Haylock and Goodess 2004; Moberg et al. 2006), mainly due to the influence of local factors (Xoplaki et al. 2004). Haylock and Goodess (2004) reported a decrease of winter very wet days in 1958–2000, while no significant changes were reported by Moberg et al. (2006) for the western Mediterranean in 1901–2000.

Further features are derived applying tools from Generalized Extreme Value Theory (GEV, Coles 2001) that provide a complete characterization of extreme precipitation events. Studies have analyzed with GEV the precipitation behavior in selected areas (eastern Mediterranean, Tolika et al. 2007 and France, Yiou et al. 2008). In this context, Toreti (2010) analyzed a dataset of 286 daily, quality controlled wet season precipitation series. They followed a Generalized Pareto approach for modeling precipitation peaks over a station dependent threshold and found that the majority of the series is characterized by a high likelihood of severe events. No significant changes were detected in the occurrence of these events for most stations. Only in specific areas (e.g., Greece) a significant decrease (without changes in intensity) was identified.

The 25-year return levels for each series (Fig. 2.13) showing the daily precipitation totals of extreme events that could recur every 25 years were also estimated.

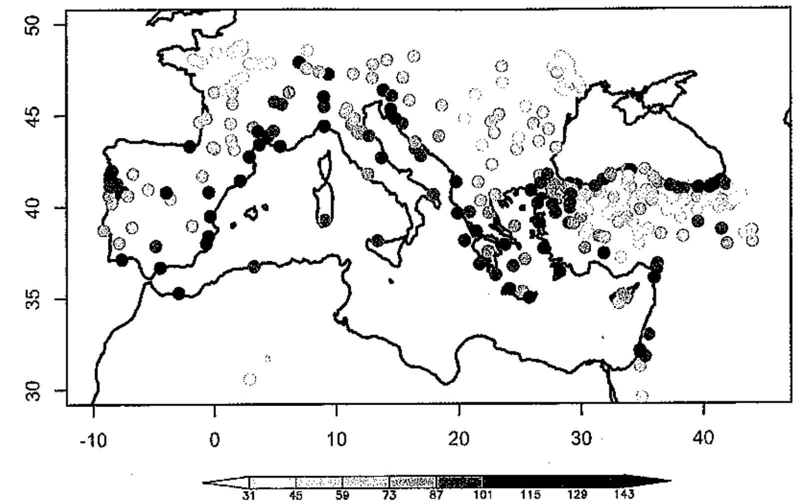

Fig. 2.13 25-year return levels of daily precipitation. Values are in mm

Maximum values appear around the Gulfs of Genoa and Lion, the northern Adriatic and the southern and eastern Aegean.

Better understanding of extreme precipitation events and identification of the drivers of these events was attempted with an analysis of the associated atmospheric circulation by Toreti et al. (2010b), applying a new 2-step classification procedure based on Self Organizing Maps and Genetic K-means. The extremes of 20 wet season precipitation series (selected according to quality, length and completeness), during the period 1950–2006, equally distributed along the Mediterranean, were investigated and linked to large scale atmospheric circulation at the 500 hPa and sea levels over the North Atlantic-European area. The atmospheric fields associated with extreme precipitation events were classified for each station, and western and eastern Mediterranean anomaly patterns were derived. A nearly barotropic lower to mid-troposphere dipole structure, associated with southwesterly flow, favoring intensified moisture transport of Atlantic origin, is connected with western Mediterranean extreme precipitation. At the eastern basin, warm air advection and anomalous vertical motion, affecting the lower troposphere moisture budget are related with severe precipitation. Noteworthy, the detected atmospheric patterns are significantly different from the clusters associated with non-extreme wet days (Toreti et al. 2010b).

2.3.4 *Droughts*

Mediterranean droughts are driven both by lack of precipitation and high evaporation rates. Thus it is important to use an index like the PDSI (Palmer Drought Severity Index, (Palmer 1965)) which corresponds to a measure of regional moisture availability. It is based on water supply and demand using a relatively simple water budget system, computed from records of precipitation and temperature and the soil characteristics of the considered area, allowing the classification of relative moisture conditions within 11 categories. The PDSI was originally developed for the USA and used in many other regions. Application of the PDSI to Europe results in an exaggerated frequency of extreme dry or wet spells (Schrier et al. 2006), Thus a new formulation was introduced by Wells (2004), called self-calibrated PDSI (scPDSI), reducing the excessive frequency of extreme events, when compared to the original PDSI. The scPDSI data used in CIRCE employ the original severity scale where episodes with values above 4 (below -4) corresponding to extremely wet (dry) events. The inter-annual variability of the scPDSI averaged for the entire Mediterranean basin can be seen in Fig. 2.14 (top). Taking into account the severity scale for the scPDSI, Fig. 2.14 (bottom) shows the temporal evolution in the percentage of the Mediterranean that is under dry (very dry) or wet (very wet) conditions as proposed by Schrier et al. (2006). Since the region presents so much spatial variability, a large spatial average will inevitably tend to smooth large inter-annual variations. In any case, Fig. 2.14 shows that some periods of the twentieth century were characterized by fairly generalized dry or wet spells in the Mediterranean basin. Periods where wet areas exceed dry areas appear to be as frequent as those characterized by predominance of dryness over wet periods. However, some long-lasting episodes with extreme drought conditions cover a wider spatial range, such as those during the 1940s and at the end of the 1980s. Concerning the wet spells, they appear to last also for long periods but with relatively smaller amplitude. A more comprehensive analysis performed separately for several sub-domains can be seen in Sousa et al. (2011).

Table 2.1 shows the impact of the most relevant atmospheric circulation modes on the interannual variability of the seasonal scPDSI index for the entire basin. Statistically significant correlation values are highlighted (bold) whenever significant at the 5% level, after taking into account the auto-correlation effect of the scPDSI index (Wilks 2006). The winter NAO presents the highest impact on the corresponding winter scPDSI series ($r = -0.62$), that is persistent to the following spring ($r = -0.68$) and summer ($r = -0.64$). Similar behavior is found for the winter SCAND index, but with positive correlation values with the average Mediterranean winter scPDSI series ($r = 0.50$), in spring ($r = 0.52$) and summer ($r = 0.54$). The remaining modes of circulation considered (SOI, Southern Oscillation Index, EA/WR and EA) do not achieve statistically significant correlation. These results are useful to construct seasonal forecast models, or drought warning systems for different Mediterranean sectors, since the values of NAO and SCAND indices provide significant information on the drought conditions during the next 6 months (Sousa et al. 2011).

2.3.5 *Extreme Ocean Wave Conditions*

A careful assessment of extreme wave conditions and of their possible change is important for the long coastline of the Mediterranean and the large population living

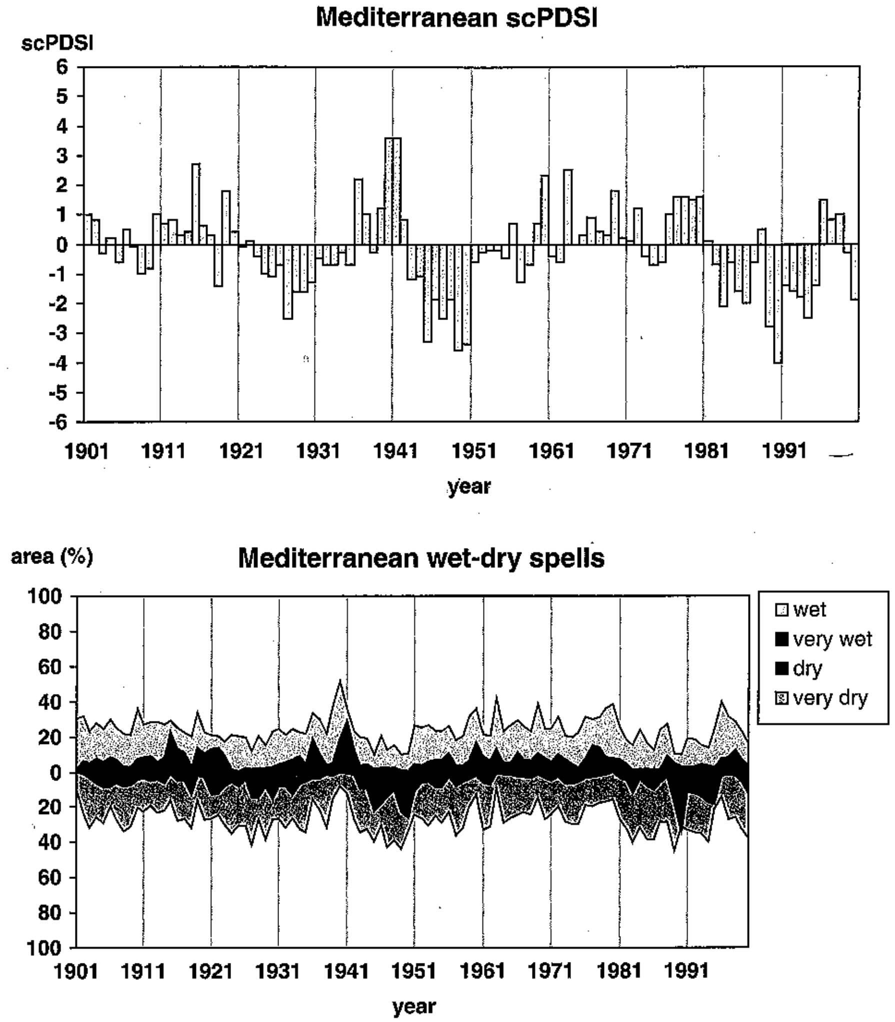

Fig. 2.14 (*top*) Inter-annual variability of the average scPDSI for the entire Mediterranean basin; (*bottom*) corresponding percentages of area under wet (*blue*) and dry (*orange*) conditions (Adapted from Sousa et al. (2011) Natural Hazards and Earth System Sciences)

along it. On one hand, high sea waves pose a hazard for shipping, offshore activities and structures, and can produce large damage to coastlines and ports. On another hand, persistent extremely low wave height can be suggestive of environmental stresses, such as reduced surface mixing and anoxia.

This analysis is based on the significant wave height (SWH), which is a statistical parameter that is proportional to the total variance of the sea surface and a good representation of the visual estimate of wave height at sea. The indicators discussed in this subsections are SWHx95p (95th percentile of SWH daily maxima, extreme

Table 2.1 Correlation coefficient values between Mediterranean mean scPDSI time series and the considered large-scale atmospheric indices – non-lagged, 3-month and 6-month lagged correlations

Mediterranean	Winter scPDSI			Mediterranean	Spring scPDSI		
Teleconnection	No log	3	6	Teleconnection	No log	3	6
NAO	**−0.62**	−0.06	0.00	NAO	−0.36	**−0.68**	0.08
EA	−0.10	−0.04	0.17	EA	−0.15	−0.15	−0.08
EA/WR	−0.37	−0.07	0.11	EA/WR	0.08	−0.37	−0.07
SCAND	**0.40**	−0.01	0.32	SCAND	0.37	**0.50**	−0.06
SOI	0.08	0.15	0.13	SOI	0.22	0.12	0.05
Mediterranean	Summer scPDSI			Mediterranean	Autumn scPDSI		
Teleconnection	No log	3	6	Teleconnection	No log	3	6
NAO	−0.04	−0.30	**−0.64**	NAO	−0.03	0.02	−0.26
EA	−0.20	−0.23	−0.19	EA	−0.19	−0.33	−0.27
EA/WR	0.17	0.01	−0.21	EA/WR	0.01	0.15	0.10
SCAND	**0.43**	0.31	**0.52**	SCAND	0.23	0.39	0.25
SOI	0.10	−0.04	−0.04	SOI	−0.04	0.01	0.09

Values in *bold* are considered statistically significant taking into account the auto-correlation of the scPDSI index. A 3 (6) months lag implies that the teleconnection is leading by 3 (6) months the corresponding scPDSI value

SWH threshold), SWHm5p (5th percentile of SWH daily minima, dead calm SWH threshold), SWHg50p (median of the SWH daily average).

Since instrumental wave records are too sparse and satellite time series are too short for the identification of climate trends, CIRCE results are based on a WAM (Wave Model, WAMDI 1988) simulation forced by the REMO-HIPOCAS regional model wind fields (Soares et al. 2002) and validated using the TOPEX-POSEIDON satellite observations.

In general, high SWH values are caused by strong winds with a long fetch. Simulations show the highest values in the western Mediterranean under the effect of the Mistral wind. Other maxima are located in the southern Ionian Sea and Levantine basin. The northern Aegean and the whole Adriatic are the basins where SWH are lowest.

Trends have been computed for each month in the period 1958–2001 splitting the basin in western and eastern part. The results denote progressively milder conditions, with a decrease of all three indicators (SWHx95p, SWHg50p, SWHm5p), which represents a shift of the whole SWH distribution towards small values. Reduction of high SWH (SWHx95p) is particularly significant during the cold season and in the western Mediterranean, but there is also a significant decrease in the eastern basin, most significant in July. Note that the decrease of median SWH values in winter is consistent with the decrease of winter SWH found in a previous study (Lionello and Sanna 2005) and with future projections (Lionello et al. 2008, 2010).

The links between the north Hemisphere teleconnection patterns and the mean SWH fields have already been explored (Lionello and Sanna 2005, Lionello and Galati 2008). The analysis extended to the occurrence of extreme SWH conditions at the monthly scale considering the NAO, SCAND, EA/WR and the EA patterns, on one hand, and swhx95p and swhm5P, on another hand, for the intensity of very high and low SWH conditions, respectively. Results show that large SWH values are modulated by several patterns, with an important variability in space and at monthly level. No single pattern can be attributed a dominant role along the whole annual cycle. All the mentioned patterns are important for at least few months in the year and none of them is important for the whole year. The SCAND is anti-correlated with extremely low wave conditions in February, March and October, with extremely high wave conditions in January, August and October. NAO is important mainly for high SWH extreme values in winter with significant correlation in December, January and March. EA phases strongly affect the mean value of SWH extremes over the whole basin, especially in winter. EA/WR is important mainly for high SWH extremes in late winter and spring with significant correlation in March and April.

2.3.6 *Extreme Sea Levels*

Sea level extremes are caused by various forcing factors or their combination. Though also Tsunamis should be included among the catastrophic events, because of their rarity very little can be done in terms of statistical or physical assessment of their occurrence. Thus we concentrate on sea level extremes caused mainly by the combination of tides with storm surges.

Hourly values from tide gauges have been used in the analysis. The time series are available through ESEAS website (www.eseas.org) and the web sites of various national services. The records span different time periods, from a few months to 68 years, and were found to be of varying quality. Robust and detailed quality checks were performed on the data. The tides were estimated and removed from the records on a yearly basis. The analysis was based on years starting on September 1st until August 31st. This way the winters, when most of the storm surges causing the extremes are expected, are not split into subsequent years.

The values of the observed sea level extremes in the Eastern Mediterranean are generally less than 60 cm with the exception of N. Halkis (at the west coast of the Greek island of Euboea) where particularities of the tidal signal cause local amplification (Tsimplis 1997). In the Western Mediterranean the maxima are highest (about 80 cm) near the Strait of Gibraltar where the incoming tidal signal from the Atlantic significantly contributes to the creation of extremes and it reduces to less than 65 in the other stations. The Adriatic Sea is the area where the highest extremes are found. At the northern part of the basin the values found exceed 1.5 m, that is, more than twice the values found in the other areas of the Mediterranean Sea. When the tidal signal is removed from the sea level records the tidal residuals are primarily determined by the storm surge component (Marcos et al. 2009).

The maxima found in the tidal residuals follow in essence the same geographical pattern. The maximum values are less than 60 cm in most areas except the Adriatic Sea where values in excess of 1.5 m are found. Basin oscillations within the Adriatic are significantly contributing to the higher tidal residuals (Marcos et al. 2009, Lionello et al. 2005).

The six time series which are longer than 35 years have been used to explore the changes in time of the extreme values. Linear trends for the yearly 99.9 percentile of tidal residuals have been estimated by means of a robust linear fit for percentile time series of observations at tide gauge sites. Negative trends were found in the Adriatic and slightly positive at Ceuta near the Strait of Gibraltar. However all trends, apart from one in the Adriatic (Koper) disappear when the yearly median value is removed from the data indicating that the changes in extremes are caused by changes in mean sea level (Marcos et al. 2009).

The 99.9th percentiles of tidal residuals and the Climate Research Unit's winter NAO Index (http://www.cru.uea.ac.uk/cru/data/nao.htm) are negatively correlated. The NAO is known to affect mean sea level (Tsimplis and Josey 2001) in the Mediterranean primarily through its atmospheric pressure effects. The subtraction of the yearly median value, from the 99.9th percentile, removes the correlation with the NAO in most stations (Marcos et al. 2009). The changes in the extremes are dominated by changes in the autumn and winter seasons. However, at all seasons the changes observed are in line with changes in the mean sea level. (Tsimplis and Shaw 2010).

2.3.7 Cyclones and Wind Storms

Extreme cyclones in the Mediterranean climate can cause hazardous weather conditions. Here, cyclones causing wind storms in the Mediterranean region (MR) are considered with respect to spatial distribution of their frequencies, their relation with large scale variability patterns, and with respect to observed long term trends.

Cyclones in the ERA40 (1957–2002) dataset were identified and tracked using an objective method (Murray and Simmonds 1991). The intensity of cyclones is defined via their Laplacian of pressure ($\nabla^2 p$). Extreme cyclone events are defined on a 6 hourly basis using the 95th percentile of the climatological $\nabla^2 p$ -distribution for the MR as the threshold. A pronounced annual cycle is found both in terms of mean values and frequency of extremes, with more intense cyclones and higher numbers of extreme cyclone events occurring during the winter season. While the total number of detected cyclones in winter is comparable between the eastern and western MR, the number of extreme cyclones is three times higher over the western than over the eastern MR.

Though extreme cyclones are assumed to have a stronger impact potential, the relationship between the intensity of cyclones and their impact is not linear (Lionello et al. 2006). It is, therefore, not possible to infer on the strength, nature and location of a cyclone's impact from the intensity. Thus, the impact relevant effects must be quantified directly. With respect to wind storms this can be achieved by a scheme for the identification and tracking of extended extreme wind storm events (based on the local 98th wind percentiles, see Leckebusch et al. 2008). The wind tracks are then assigned to the responsible cyclone as described in Nissen et al. (2010).

For the extended winter season of the ERA40 period, 2,508 cyclones causing extreme wind events in the MR have been found. 69% of the wind storms affecting the region are associated with cyclones that have entered the area at least once during their life time, while the remaining 31% can be attributed to North Atlantic/Central European cyclones. 28% of all identified cyclones crossing the MR during the extended winter seasons are associated with an extreme wind event. The extreme wind tracks are not evenly distributed throughout the MR. The highest number of wind events occurs over Sardinia, Sicily and southern Italy, i.e., south of the Golf of Genoa, the region of highest cyclone activity over the Mediterranean Basin. In the eastern part of the MR a secondary maximum in extreme wind track occurrence is located south of Cyprus, apparently associated with Cyprus lows.

Cyclones that have caused extreme wind events in the MR tend to have higher values of $\nabla^2 p$ than cyclones that have not caused a storm, but they are not necessarily extreme: 77% of the extreme wind events have been attributed to cyclones never exceeding the Mediterranean 95th quantile of $\nabla^2 p$ in their lifetime.

Two of the main atmospheric variability patterns relevant for the MR, the NAO and the EA/WR pattern, also affect cyclone occurrence and intensities. During the positive phase of the NAO, cyclones associated with wind tracks over the MR increased frequency north of 50°N. At the same time, fewer cyclones are found in western and northern MR, partly caused by the decrease of North Atlantic cyclones entering the western Mediterranean during this NAO phase. The corresponding reduction in extreme wind events is found at the south western edge of the MR. As a counter-intuitive effect, the frequency of extreme wind tracks over the central and eastern MR is increased during the positive NAO and is associated with a higher percentage of cyclone tracks producing wind events.

The EA/WR also exerts a significant influence on the number of extreme wind tracks and extreme wind producing cyclones. In its positive phase both numbers decrease over the central MR, while an increase can be noted over the Levant region.

Linear trends have been analyzed for the extended winter season. Over the ERA40 period a decrease in the number of cyclones responsible for extreme wind is found over the western Mediterranean, while cyclone numbers in the Levant region have increased. Correspondingly, trends in extreme wind tracks are negative over the south western MR and positive east of the Sinai Peninsula. A significant increase can also be found over northern Europe extending as far south as the Golf of Genoa. A regression analysis reveals that two thirds of the trends can be attributed to the NAO variability, while EA/WR does not contribute to the trends.

2.3.8 *Cut-Off-Lows*

A cut-off low pressure system (COL) represents a closed low in the upper troposphere that has become completely detached (or "cut off") from the characteristic westerly current of the jet stream (Gimeno et al. 2007), and which is usually advected towards the equatorial side of the mid-latitude westerlies. Systems related to COLs are capable of affecting the weather conditions at the earth's surface to a considerable degree for periods of several days at a time. The instability of the troposphere beneath the COL can lead to the occurrence of severe convective events, depending on surface conditions. COLs yield significant precipitation when the air mass below the COL is very moist and generates a potentially unstable condition. Such weather systems are among the most severe that affect the Mediterranean and are responsible for some of the most catastrophic events in terms of their precipitation rate, especially during warm months (Kotroni et al. 2006), but only the more extreme COLs are responsible for severe weather events. Studies in the region where the occurrence of COLs is common (Nieto et al. 2005) show that the highest intensity of cyclonic-related precipitation is located at a distance of 300–400 km from the center of the COL (Porcù et al. 2007). Convective rainfall occurs within about 300 km of the COL center, with a pronounced peak close to the center of the COL that is displaced marginally eastwards (i.e. in front) of it. At the same time, large-scale precipitation is distributed along the east–west axis that passes through the COL. In about 50% of cases, it is this precipitation that dominates. It has also been shown that in around 25–30% of cases (mainly those that occur during the autumn months), COLs do not induce any rainfall at all, and that only 25% are dominated by convection.

Table 2.2 Summary of the significant trends in the extreme COL indices

Annual/seasonal occurrence of COLs	EM	Annual	1958–2002	Negative
Annual/seasonal occurrence of COLs	EM	JAS	1958–2002	Negative
Annual/seasonal occurrence of COLs	WM	JFM	1958–2002	Positive
Annual/seasonal occurrence of COLs	WholeM	JAS	1979–2002	Negative
Annual/seasonal occurrence of COLs	WM	JAS	1979–2002	Negative
Occurrence of the most intense COLs	WholeM	Annual	1958–2002	Negative
Occurrence of the most intense COLs	WholeM	Annual	1958–1978	Negative
Occurrence of the coldest COLs	WholeM	Annual	1958–1978	Positive
Occurrence of the coldest COLs	WholeM	JAS	1979–2002	Negative
Occurrence of the largest COLs	WholeM	Annual	1958–2002	Negative

The most intense COLs are those having a 200 hPa geopotential lower than the 10th percentile in the complete series, and the largest COLs are those with 4 or more grid points matching the criteria of Nieto et al. (2005). Areas were defined as *WM* Western Mediterranean region, *EM* Eastern Mediterranean region, and *WholeM* whole Mediterranean region. Seasonal periods are JAS (July–September) and JFM (January–March)

By using the same method as Nieto et al. (2005), COL systems have been identified for the whole Mediterranean area, (30°W–40°E; 30°N–50°N), and for two subareas according to frequency of occurrence (Western region (WM): 30°W–5°E; 30°N–44°N, and Eastern region (EM): 12°E–35°E; 36°N–48°N). The analysis was carried out for the period 1959–2002 using ERA40 reanalysis as raw data (2.5° grid resolution).

Trends in the annual and seasonal variation of extreme indicators were calculated using linear regression. Table 2.2 summarizes the results. Values significant at the 95% level after a Pearson test are shown.

2.4 Conclusions

Mediterranean climate variability, both in the atmosphere and the ocean, was studied in the framework of the CIRCE project. Available instrumental station datasets and gridded products, mainly temperature and precipitation, were collected and homogenized. Many of the data were used for the first time on a daily resolution. It was noted that data availability for the northern part of the Mediterranean Basin is still much better than for the southern part, resulting in a larger uncertainty in the gridded data products over the southern Mediterranean Basin. The homogenization of temperature data revealed a warm bias in the 1960s assigned most likely in instrumentation. Thus, the warming trend in the second half of the twentieth century has before been underestimated in several sub-regions. The warming during the twentieth century is particularly evident when comparing the instrumental period data with re-constructed winter temperatures during the period 1500–1900. Strong negative trends in both summer and winter precipitation were found over many parts of the basin, apparently related to positive trends in Mean Sea Level Pressure over the area during the same period.

Both the current state and past changes of the Mediterranean Sea have been studied. A 20 years long reanalysis (1985–2007) was produced, showing long term temperature variability and a positive salinity trend in the ocean layers from the surface to 1,500 m depth. Some features of the surface circulation were also found to change during this period, notably the anticyclonic eddies at the Algerian coast which intensified until the end of the twentieth century and then weakened again. Evidence for Sea level rise was found for the last century, but strong decadal variations were detected considering sub-regions of the basin. Trends in extreme winds are largely negative, as are those of the related cyclones and cut-off-lows. The role of large scale pressure patterns like the NAO for variabilities and trends is discussed for the different parameters considered.

The temporal variability of extreme events in the Mediterranean reveals a few common basin-wide features. Apart from the recent tendency towards drier and hotter conditions in most of the basin, no general patterns can be identified. In fact the detected trends of several climate variables show different signs in sub-areas, partly, which are only partly significant.

The two major heatwaves of 2003 (western Mediterranean/Europe) and 2010 (eastern Mediterranean/Europe) were outstanding in amplitude, spatial extension and temporal extent. However, it was shown that the 2010 event largely exceeds the amplitude and spatial extent of the 2003 episode at different temporal scales. Moreover, both events were firmly associated with the simultaneous occurrence of record-breaking blocking patterns.

Simultaneously, no basin-wide features are found related to the influence of teleconnection patterns, i.e., the links of the extremes to the large scale circulation. There is a dominant role of the NAO for the Western and Northwestern Mediterranean, however the influence of main circulation patterns, namely NAO, SCAND, EA and EA/WR that is producing high spatial variability is evident in sub-basin scales. The analyses undertaken for CIRCE confirm and extend a number of the relationships between Mediterranean temperature extremes and large-scale circulation and SST patterns previously identified or postulated in the literature.

The available results on extremes may leave the impression of a high spatial fragmentation, thus requiring additional a focus on local behavior and characteristics. They reflect, however, our advances in the quantification of their occurrence, and the understanding of the processes relevant for producing extremes. The complexity of these relationships (both in terms of spatial and temporal variability), together with the relative weakness of many of the statistical relationships, still poses ongoing challenges for understanding in detail the nature and the causes of the observed changes in Mediterranean extremes.

In general (and thus not restricted to the issue of extremes), the identification of mechanisms and approaches capable of describing/understanding the spatially differing response to the large scale forcing taking also into consideration the important role of smaller scale factors and feedbacks is an important issue that requires further analysis and is vital for climate research and related impacts in the Mediterranean and subregions. The results shown in this chapter also highlight the need of improving the atmospheric and marine observational networks by increasing their density and when possible their length controlling their quality.

References

Adani M, Dobricic S, Pinardi N (2011) Quality assessment of a Mediterranean Sea 1985–2007 re-analysis. J Atmos Ocean Technol 28:569–589. doi:10.1175/2010JTECHO798.1

Aguilar E, Auer I, Brunet M, Peterson TC, Wieringa J (2003) Guidance on metadata and homogenization, Report WMO-TD 1186, World Meteorological Organisation, Geneva, Switzerland, 51 pp

Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AMG, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L, Stephenson DB, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111:D05109. doi:10.1029/2005JD006290

Alexandersson H, Moberg A (1997) Homogenization of Swedish temperature data. Part 1: Homogeneity test for linear trends. Int J Climatol 17:25–34

Allan R, Ansell TJ (2006) A new globally-complete monthly historical gridded mean sea level pressure data set (HadSLP2): 1850–2004. J Climate 19:5816–5842

Alpert P, Ben-Gai T, Baharad A et al (2002) The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. Geophys Res Lett 29:1536–1539

Alpert P, Baldi M, Ilani R et al (2006) Relations between climate variability in the Mediterranean region and the tropics: ENSO, South Asian and African monsoons, hurricanes and Saharan dust. In: Lionello P, Malanotte-Rizzoli P, Boscolo R (eds) Mediterranean climate variability. Elsevier, Amsterdam, pp 149–177

Ansell TJ, Jones PD, Allan RJ et al (2006) Daily mean sea level pressure reconstructions for the European – North Atlantic region for the period 1850–2003. J Climate 19:2717–2742

Baldi M, Dalu G, Maracchi G, Pasqui M, Cesarone F (2006) Heat waves in the Mediterranean: a local feature or a larger-scale effect? Int J Climatol 26(11):1477–1487. doi:10.1002/joc.1389

Barnston AG, Livezey RE (1987) Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. Mon Weather Rev 115:1083–1127

Barriopedro D, Fisher E, Luterbacher J, Trigo RM, García-Herrera R (2011) The hot summer of 2010: redrawing the temperature record map of Europe. Science 322:220

Barry RG, Carleton AM (2001) Synoptic and dynamic climatology. Routledge, London

Barry RG, Chorley RJ (2003) Atmosphere, weather and climate. Routledge, London

Bethoux JP (1979) Budgets of the Mediterranean Sea. Their dependence on the local climate and on the characteristics of the Atlantic waters. Oceanologica Acta 2:157–163

Bethoux JP, Gentili B, Raunet J, Tailiez D (1990) Warming trend in the western Mediterranean deep water. Nature 347:660–662

Brázdil R, Pfister C, Wanner H et al (2005) Historical climatology in Europe-the state of the art. Clim Chang 70:363–430

Brohan P, Kennedy JJ, Harris I et al (2006) Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. J Geophys Res Atmos 111:D12106

Brönimann S, Xoplaki E, Casty C et al (2007) ENSO influence on Europe during the last centuries. Clim Dyn 28:181–197

Brunet M, Kuglitsch FG (eds) (2008) Proceedings of the international workshop on rescue and digitization of climate records in the Mediterranean Basin. WMO-TD 1432, World Meteorological Organization, Geneva, Switzerland

Brunet M, Jones PD, Sigró J, Saladié O, Aguilar E, Moberg A, Della-Marta PM, Lister D, Walther A, López D (2007) Temporal and spatial temperature variability and change over Spain during 1850–2005. J Geophys Res 112:D12117. doi:10.1029/2006JD008249

Castellari S, Pinardi N, Leaman K (1998) A model study of air-sea interactions in the Mediterranean Sea. J Mar Syst 14:89–114

Caussinus H, Mestre O (2004) Detection and correction of artificial shifts in climate series. Appl Stat J Roy Stat C 53:405–425

Cazenave A, Cabanes C, Dominh K, Mangiarotti S (2001) Recent sea level changes in the Mediterranean Sea revealed by TOPEX/POSEIDON satellite altimetry. Geophys Res Lett 28(8):1607–1610

Cazenave A, Bonnefond P, Mercier F, Dominh K, Tomazou V (2002) Sea level variations in the Mediterranean Sea and Black Sea from satellite altimetry and tide gauges. Glob Planet Change 34:59–86
Church JA, White NJ, Coleman R, Lambeck K, Mitrovika JX (2004) Estimates of the regional distribution of sea level rise over the 1950–2000 period. J Climate 17:2609–2625
Coles S (2001) An introduction to statistical modeling of extreme values. Springer, London, 228 pp
Compo GP, Whitaker JS, Sardeshmukh PD et al (2011) The twentieth century reanalysis project. Q J R Meteorol Soc 37:1–28
Corte-Real J, Zhang X, Wang X (1995) Large-scale circulation regimes and surface climatic anomalies over the Mediterranean. Int J Climatol 15:1135–1150
Della-Marta PM, Wanner H (2006) A method of homogenizing the extremes and mean of daily temperature measurements. J Climate 19:4179–4197
Della-Marta PM, Haylock MR, Luterbacher J, Wanner H (2007) Doubled length of western European summer heat waves since 1880. J Geophys Res 12:D15103. doi:10.1029/2007JD008510
Demirov E, Pinardi N (2002) Simulation of the Mediterranean Sea circulation from 1979 to 1993: Part I: The interannual variability. J Mar Syst 33–34:23–50
Dünkeloh A, Jacobeit J (2003) Circulation dynamics of Mediterranean precipitation variability 1948–98. Int J Climatol 23:1843–1866
Efthymiadis D, Goodess CM, Jones PD (2011) Trends in Mediterranean gridded temperature extremes and large-scale circulation influences. Nat Hazard Earth Syst Sci 11:2199–2214
Fan Y, Van den Dool H (2008) A global monthly land surface air temperature analysis for 1948–present. J Geophys Res 113:D01103
Fenoglio-Marc L (2001) Analysis and representation of regional sea-level variability from altimetry and atmospheric–oceanic data. Geophys J Int 145:1–18
Fenoglio-Marc L (2002) Long-term sea level change in the Mediterranean Sea from multi-satellite altimetry and tide gauges. Phys Chem Earth 27:1419–1431
Frich P, Alexander LV, Della-Marta P, Gleason B, Haylock M, Klein-Tank AMG, Peterson T (2002) Observed coherent changes in climatic extremes during second half of the twentieth century. Clim Res 19(3):193–212. doi:10.3354/cr019193
Gimeno L, Trigo RM, Ribera P, García JA (2007) Editorial: special issue on cut-off low systems (COL). Meteorol Atmos Phys 96:1–2. doi:10.1007/s00703-006-0216-5
Giorgi F (2006) Climate change hot-spots. Geophys Res Lett 33:L08707
Giorgi F, Lionello P (2008) Climate change projections for the Mediterranean region. Glob Planet Change 63:90–104
Gomis D, Ruiz S, Sotillo MG, Álvarez-Fanjul E, Terradas J (2008) Low frequency Mediterranean sea level variability: the contribution of atmospheric pressure and wind. Glob Planet Change. doi:10.1016/j.gloplacha.2008.06.005
Haylock MR, Goodess CM (2004) Interannual variability of European extreme winter rainfall and links with mean large-scale circulation. Int J Climatol 24:759–776
Haylock MR, Hofstra N, Klein Tank AMG, Klok EJ, Jones PD, New M (2008) A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. J Geophys Res 113:D20119. doi:10.1029/2008JD010201
Hurrell JW, van Loon H (1997) Decadal variations in climate associated with the North Atlantic Oscillation. Clim Chang 36:301–326
Hurrell JW, Kushnir Y, Visbeck M (2001) The North Atlantic Oscillation. Science 291:603–605
Iglesias A, Garrote L, Quiroga S et al (2009) Impacts of climate change in agriculture in Europe. PESETA-Agriculture study. Joint Research Centre EUR- Scientific and Technical Report series:doi 10.2791/33218
Jones PD, Osborn TJ, Briffa KR (2003) Pressure-based measures of the North Atlantic Oscillation (NAO): a comparison and an assessment of changes in the strength of the NAO and in its influence on surface climate parameters. In: Hurrell JW, Kushnir Y, Ottersen G et al (eds) The North Atlantic Oscillation: climatic significance and environmental impact, vol 134, Geophysical monograph. AGU, Washington, DC

Kadioglu M, Tulunay Y, Borhan Y (1999) Variability of Turkish precipitation compared to El Nino events. Geophys Res Lett 26. doi:10.1029/1999GL900305
Khaliq MN, Ouarda TBMJ (2007) On the critical values of the standard normal homogeneity test (SNHT). Int J Climatol 27:681–687
Kistler R, Kalnay E, Collins W et al (2001) The NCEP-NCAR 50-year reanalysis: monthly means CD-Rom and documentation. B Am Meteorol Soc 82:247–267
Klein Tank AMG, Können GP (2003) Trends in indices of daily temperature and precipitation extremes in Europe, 1946–99. J Climate 16:3665–3680
Klein Tank AMG, Wijngaard JB, Konnen GP et al (2002) Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int J Climatol 22:1441–1453
Kostopoulou E, Jones PD (2005) Assessment of climate extremes in the eastern Mediterranean. Meteorol Atmos Phys 89(1–4):69–85. doi:10.1007/s00703-005-0122-2
Kotroni V, Lagouvardos K, Defer E et al (2006) The Antalya 5 December 2002storm: observations and model analysis. J Appl Meteorol Climatol 45:576–590
Krahmann G, Schott F (1998) Longterm increases in Western Mediterranean salinities and temperatures: anthropogenic and climatic sources. Geophys Res Lett 25:4209–4212
Kuglitsch FG, Toreti A, Xoplaki E, Della-Marta PM, Luterbacher J, Wanner H (2009) Homogenization of daily maximum temperature series in the Mediterranean. J Geophys Res 114:D15108. doi:10.1029/2008JD011606
Kuglitsch FG, Toreti A, Xoplaki E, Della-Marta PM, Zerefos CS, Türkeş M, Luterbacher J (2010) Heat wave changes in the eastern Mediterranean. Geophys Res Lett 37:L04802. doi:10.1029/2009GL041841
Large WG, Yeager SG (2008) The global climatology of an interannually varying air-sea flux data set. Clim Dyn 33:341–364
Leckebusch GC, Renggli D, Ulbrich U (2008) Development and application of an objective storm severity measure for the northeast Atlantic region. Meteorol Z 17:575–587
Lionello P, Galati MB (2008) Links of the significant wave height distribution in the Mediterranean Sea with the North Hemisphere teleconnection patterns. Adv Geosci 17:13–18
Lionello P, Sanna A (2005) Mediterranean wave climate variability and its links with NAO and Indian Monsoon. Clim Dyn 25:611–623
Lionello P, Mufato R, Tomasin A (2005) Sensitivity of free and forced oscillations of the Adriatic Sea to sea level rise. Clim Res 29:23–39
Lionello P, Bhend J, Buzzi A, Della-Marta P, Krichak S, Jansà A, Maheras P, Sanna A, Trigo I, Trigo R (2006) Cyclones in the Mediterranean region: climatology and effects of the environment. In: Lionello P, Malanotte-Rizzoli P, Boscolo R (eds) Mediterranean climate variability. Elsevier, Amsterdam, pp 325–372
Lionello P, Cogo S, Galati MB et al (2008) The Mediterranean surface wave climate inferred from future scenario simulations. Glob Planet Change 63:152–162
Lionello P, Galati MB, Elvini E (2010) Extreme storm surge and wind wave climate scenario simulations at the Venetian littoral. Phys Chem Earth 40:86–92. doi:10.1016/j.pce.2010.04.001
Luterbacher J, Xoplaki E, Casty C et al (2006) Mediterranean climate variability over the last centuries: a review. In: Lionello P, Malanotte-Rizzoli P, Boscolo R (eds) Mediterranean climate variability. Elsevier, Amsterdam, pp 27–148
Luterbacher J, García-Herrera R, Akcer-On S, Allan R, Alvarez-Castro MC, Benito G, Booth J, Büntgen U, Cagatay N, Colombaroli D, Davis B, Esper J, Felis T, Fleitmann D, Frank D, Gallego D, Garcia-Bustamante E, Glaser R, González-Rouco JF, Goosse H, Kiefer T, Macklin MG, Manning S, Montagna P, Newman L, Power MJ, Rath V, Ribera P, Riemann D, Roberts N, Sicre M, Silenzi S, Tinner W, Valero-Garces B, van der Schrier G, Tzedakis G, Vannière B, Vogt S, Wanner H, Werner JP, Willett G, Williams MH, Xoplaki E, Zerefos CS, Zorita E (2012) A review of 2000 years of paleoclimatic evidence in the Mediterranean. In: Lionello P (ed) The climate of the Mediterranean region: from the past to the future. Elsevier, Amsterdam, pp 87–185

Manca B, Budillon G, Scarazzato P, Orsella L (2003) Evolution of dynamics in the eastern Mediterranean affecting water structures and properties in the Ionian and Adriatic Seas. J Geophys Res 108:101029–101046
Marcos M, Tsimplis MN, Shaw AGP (2009) Sea level extremes in southern Europe. J Geophys Res 114:C01007
Mariotti A, Zeng N, Lau K-M (2002) Euro-Mediterranean rainfall and ENSO-a seasonally varying relationship. Geophys Res Lett 29. doi:10.1029/2001GL014248
Mariotti A (2010) Recent changes in Mediterranean water cycle: a pathway toward long-term regional hydroclimatic change? J Clim 23:1513–1525
MEDAR Group (2002) Mediterranean and Black Sea database of temperature, salinity and biochemical parameters and climatological atlas (4 CD-ROMs), Ifremer Ed. Plouzane, France. Available at http://www.ifremer.fr/sismer/program/medar
Mitchell TD, Jones PD (2005) An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int J Climatol 25:693–712
Moberg A, Jones PD, Lister D et al (2006) Indices for daily temperature and precipitation extremes in Europe analyzed for the period 1901–2000. J Geophys Res 111:D22106
Murray RJ, Simmonds I (1991) A numerical scheme for tracking cyclone centres from digital data. Part I: Development and operation of the scheme. Aust Meteorol Mag 39:155–166
Nerem RS, Leuliette E, Cazenave A (2006) Present-day sea-level change: a review. C R Geoscience 338:1077–1083
Nieto R, Gimeno L, de la Torre L, Ribera P, Gallego D, García-Herrera R, García JA, Núñez M, Redaño A, Lorente J (2005) Climatological features of cut-off low systems in the Northern Hemisphere. J Climate 18:3085–3113
Nissen KM, Leckebusch GC, Pinto JG, Renggli D, Ulbrich S, Ulbrich U (2010) Cyclones causing wind storms in the Mediterranean: characteristics, trends and links to large-scale patterns. Nat Hazard Earth Syst Sci 10:1379–1391
Onogi K, Tsutsui J, Koide H et al (2007) The JRA-25 reanalysis. J Meteorol Soc Japan 85:369–432
Orlic M, Pasaric M (2000) Sea-level changes and crustal movements recorded along the east Adriatic coast. Nuovo Cim C 23:351–364
Palmer WC (1965) Meteorological drought. Office of Climatology. US Weather Bureau Research paper no 45
Peterson TC, Vose RS (1997) An overview of the Global Historical Climatology Network temperature data base. B Am Meteorol Soc 78:2837–2849
Pettenuzzo D, Large WG, Pinardi N (2010) On the corrections of ERA-40 surface flux products consistent with the Mediterranean heat and water budgets and the connection between basin surface total heat flux and NAO. J Geophys Res 115:C06022. doi:10.1029/2009JC005631
Pinardi N, Masetti E (2000) Variability from the large-scale general circulation of the Mediterranean Sea from observations and modeling: a review. Palaeogeogr Palaeoclimatol Palaeoecol 158:153–173
Pinardi N, Coppini G, Grezio A, Oddo P (2005) Ocean climate variability in the Mediterranean Sea: climate events and marine forecasting activities. In: Flooding and environmental challenges for Venice and its lagoon: state of knowledge. Cambridge University Press, Cambridge
Porcù F, Carrassi A, Medaglia CM et al (2007) A study on cut-off low vertical structure and precipitation in the Mediterranean region. Meteorol Atmos Phys 96:121–140. doi:10.1007/s00703-006-0224- 5
Price C, Stone L, Rajagopalan B et al (1998) A possible link between El Nino and precipitation in Israel. Geophys Res Lett 25. doi:10.1029/1998GL900098
Pujol M-I, Larnicol G (2005) Mediterranean Sea eddy kinetic energy variability from 11 years of altimetric data. J Mar Sys 58:121–142
Quadrelli R, Pavan V, Molteni F (2001) Wintertime variability of Mediterranean precipitation and its links with large-scale circulation anomalies. Clim Dyn 17:457–466
Raicich F (2007) A study of early Trieste sea level data (1875–1914). J Coast Res 23(4):1067–1073
Rayner NA, Parker DE, Horton EB et al (2003) Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. J Geophys Res 108:4407. doi:10.1029/2002JD002670

Rixen M et al (2005) The western Mediterranean deep water: a proxy for climate change. Geophys Res Lett 32:L12608
Robinson A, Leslie W, Theocharis A, Lascaratos A (2001) Mediterranean Sea circulation. In: Encyclopedia of ocean sciences, vol 3. Elsevier, New York, pp 1689–1705
Rodwell MJ, Hoskins BJ (1996) Monsoons and the dynamics of deserts. Q J R Meteorol Soc 122:1385–1404
Roether W, Manca BB, Klein B, Bregant D, Georgopoulos D, Beitzel V, Kovacevic V, Lucchetta A (1996) Recent changes in eastern Mediterranean deep waters. Science 271:333–335
Rohling E, Bryden H (1992) Man-induced salinity and temperature increases in the western Mediterranean deep water. J Geophys Res 97:11191–11198
Schneider U, Fuchs T, Meyer-Christoffer A et al (2008) Global precipitation analysis products of the GPCC. Global Precipitation Climatology Centre (GPCC). DWD. Internet Publication. 1–12. Updated version of Rudolf B (2005) Global Precipitation Analysis Products of the GPCC. DWD, Klimastatusbericht 2004. 163–170. ISSN 1437-7691. ISSN 1616-5063 (Internet www.ksb.dwd.de). ISBN 3-88148-402-7
Schrier G, Briffa KR, Jones PD et al (2006) Summer moisture variability across Europe. J Climate 19:2818–2834
Semenza JC, Menne B (2009) Climate change and infectious diseases in Europe. Lancet ID 9:365–75
Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc 63:1379–1389
Simmons A, Uppala S, Dee D, Kobayashi S (2006) ERA-Interim: new ECMWF reanalysis products from 1989 onwards. ECMWF Newsletter 110:25–35, European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading, Berkshire RG2 9AX, UK
Soares CG, Weisse R, Carretero JC et al (2002) A 40 years hindcast of wind, sea level and waves in European waters. In: Proceedings of the 21st international conference on offshore mechanics and arctic engineering, Oslo, Norway
Sousa P, Trigo RM, Aizpurua P, Nieto R, Gimeno L, Garcia-Herrera R (2011) Trends and extremes of drought indices throughout the 20th century in the Mediterranean. Nat Hazard Earth Sys Sci 11:33–51
Theocharis A, Nittis K, Kontoyiannis H, Papageorgiou E, Balopoulos E (1999) Climatic changes in the Aegean Sea influence the eastern Mediterranean thermohaline circulation (1986–1997). Geophys Res Lett 26:1617–1620
Theocharis A, Klein B, Nittis K, Roether W (2002) Evolution and status of the Eastern Mediterranean transient (1997–1999). J Marine Syst 33–34:91–116
Tolika K, Anagnostopoulou Chr, Maheras P, Kutiel H (2007) Extreme precipitations related to circulation types for four case studies over the Eastern Mediterranean. Adv Geosci 12:87–93
Toreti A (2010) Extreme events in the Mediterranean: analysis and dynamics. PhD thesis, University of Bern, Switzerland
Toreti A, Kuglitsch FG, Xoplaki E et al (2010a) A novel method for the homogenization of daily temperature series and its relevance for climate change analysis. J Climate 23:5325–5331
Toreti A, Kuglitsch FG, Xoplaki E et al (2010) Characterization of extreme winter precipitation in the Mediterranean and associated anomalous atmospheric circulation patterns. Nat Hazard Earth Sys 10:1037–1050
Trenberth KE, Paolino DA (1980) The Northern Hemisphere sea level pressure data set: trends, errors, and discontinuities. Mon Weather Rev 108:855–872
Trenberth KE, Jones PD, Ambenje P et al (2007) Observations: surface and atmospheric climate change. In: Solomon S, Qin D, Manning M et al (eds) Climate change 2007: the physical science basis. Contribution of WG 1 to the fourth assessment report of IPCC. Cambridge University Press, UK/USA
Trigo RM, Pozo-Vázquez D, Osborn TJ et al (2004) North Atlantic Oscillation influence on precipitation, river flow and water resources in the Iberian Peninsula. Int J Climatol 24:925–944
Trigo R, Xoplaki E, Zorita E et al (2006) Relations between variability in the Mediterranean region and mid-latitude variability. In: Lionello P, Malanotte-Rizzoli P, Boscolo R (eds) Mediterranean climate variability. Elsevier, Amsterdam, pp 179–226

Tsimplis MN (1997) Tides and sea level variability at the strait of Euripus. Estuar Coast Shelf S 44:91–101
Tsimplis MN, Spencer NE (1997) Collection and analysis of monthly mean sea level data in the Mediterranean and Black Sea. J Coast Res 13(2):534–544
Tsimplis MN, Baker TF (2000) Sea level drop in the Mediterranean Sea: an indicator of deep water salinity and temperature changes? Geophys Res Lett 27(12):1731–1734
Tsimplis MN, Josey SA (2001) Forcing of the Mediterranean Sea by atmospheric oscillations over the North Atlantic. Geophys Res Lett 28:803–806
Tsimplis MN, Rixen M (2002) Sea level in the Mediterranean Sea: the contribution of temperature and salinity changes. Geophys Res Lett 29(23):2136. doi:10.1029/2002GL015870
Tsimplis MN, Shaw AGP (2010) Seasonal sea level extremes in the Mediterranean Sea and at the Atlantic European coasts. Nat Hazard Earth Sys 10:1457–1475
Tsimplis MN, Álvarez-Fanjul E, Gomis D, Fenoglio-Marc L, Pérez B (2005) Mediterranean Sea level trends: separating the meteorological and steric effects. Geophys Res Lett 32:L20602. doi:10.1029/2005GL023867
Tsimplis M, Marcos M, Somot S, Barnier B (2008) Sea level forcing in the Mediterranean Sea between 1960 and 2000. Glob Planet Change 63:325–332
Tyrlis E, Lelieveld J, Steil B (2012) The summer circulation over the eastern Mediterranean and the Middle East, influence of the South Asian monsoon. Clim Dyn. doi:10.1007/s00382-012-1528-4
Ulbrich U, Christoph M, Pinto JG, Corte-Real J (1999) Dependence of winter precipitation over Portugal on NAO and baroclinic wave activity. Int J Climatol 19:379–390
Uppala SM, Kållberg PW, Simmons AJ, Andrae U, da Costa Bechtold V, Fiorino M, Gibson JK, Haseler J, Hernandez A, Kelly GA, Li X, Onogi K, Saarinen S, Sokka N, Allan RP, Andersson E, Arpe K, Balmaseda MA, Beljaars ACM, van de Berg L, Bidlot J, Bormann N, Caires S, Chevallier F, Dethof A, Dragosavac M, Fisher M, Fuentes M, Hagemann S, Hólm E, Hoskins BJ, Isaksen L, Janssen PAEM, Jenne R, McNally AP, Mahfouf J-F, Morcrette J-J, Rayner NA, Saunders RW, Simon P, Sterl A, Trenberth KE, Untch A, Vasiljevic D, Viterbo P, Woollen J (2005) The ERA-40 reanalysis. Q J R Meteorol Soc 131:2961–3012. doi:10.1256/qj.04.176
Vigo I, García D, Chao BF (2005) Change of sea level trend in the Mediterranean and Black Seas. J Mar Res 63(6):1085–1100
Vincent LA, Zhang X, Bonsal BR et al (2002) Homogenization of daily temperatures over Canada. J Climate 15:1322–1334
WAMDI Group (1988) The WAM model – a third generation ocean wave prediction model. J Phys Oceanogr 18:1776–1810
Wang XL (2008) Penalized maximal *F* test for detecting undocumented mean shift without trend change. J Atmos Ocean Technol 25:368–384
Wells N, Goddard S, Hayes MJ (2004) A self-calibrating Palmer Drought Severity Index. J Climate 17:2335–2351
Wilks DS (2006) Statistical methods in the atmospheric sciences, International Geophysics series. Academic Press, San Diego, 648 pp
Woodworth P (2003) Some comments on the long sea level records from the northern Mediterranean. J Coast Res 19(1):212–217
Woolf DK, Shaw AGP, Tsimplis MN (2003) The influence of the North Atlantic Oscillation on sea-level variability in the North Atlantic region. Glob Atmos Ocean Syst 9(4):145–167. doi:10.1080/1023673031000163380 3
Xie P, Arkin PA (1997) Global precipitation: a 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. B A Meteorol Soc 78:2539–2558
Xoplaki E (2002) Climate variability over the Mediterranean. PhD thesis, University of Bern, Switzerland
Xoplaki E, González-Rouco JF, Luterbacher J et al (2003) Mediterranean summer air temperature variability and its connection to the large-scale atmospheric circulation and SSTs. Clim Dyn 20:723–739

Xoplaki E, González-Rouco JF, Luterbacher J et al (2004) Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends. Clim Dyn 23:63–78
Yakir D, Lev-Yadun S, Zangvil A (1996) El Nino and tree growth near Jerusalem over the last 20 years. Glob Change Biol 2:97–101
Yatagai A, Alpert P, Xie P (2008) Development of a daily gridded precipitation data set for the Middle East. Adv Geosci 12:1–6
Yiou P, Goubanova K, Li ZX et al (2008) Weather regime dependence of extreme value statistics for summer temperature and precipitation. Nonlinear Processes Geophys 15:365–378
Yue S, Pilon P, Cavadias G (2002) Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. J Hydrol 259:254–271
Zhang Z, Chan JCL, Ding Y (2004) Characteristics, evolution and mechanisms of the summer monsoon onset over Southeast Asia. Int J Climatol 24:1461–1482
Ziv B, Saaroni H, Alpert P (2004) The factors governing the summer regime of the eastern Mediterranean. Int J Climatol 24:1859–1871