Chapter 2
Extreme Rainfalls in the Mediterranean Area

Luigi Mariani and Simone Gabriele Parisi

Abstract A brief survey on the extreme rainfalls in the Mediterranean area has been carried out beginning from the key thermal and pluviometric features of the Mediterranean macroclimate (wet and mild winters – warm and dry summers), passing through the main air masses that influence the basin and coming arriving to the main circulation patterns favourable to extreme rainfall (Atlantic troughs, Mediterranean cyclones, blocking systems). In the final part of the work a statistical climatology of daily extreme rainfall events on the Mediterranean area has been carried out analysing for the period 1973–2010 the extreme events in the whole Mediterranean basin and in the Western and Eastern sub-basins. On the basis of the results, it has been possible to state that the temporal behavior of the relative weight of selected precipitation classes is generally steady on average. Exploring each rainfall class, it has been evidenced only a significant increase of "moderate" events (whole basin) and a meanwhile decrease of "strong" events (West). On the other hand, the observed positive trends of classes "moderate" and "strong" for the East part of the basin should be confirmed by a richer dataset referred to this specific area. Such analysis has highlighted the weaknesses of the historical series currently available in the freely accessible International datasets, pointing up the need of more reliable data sources in terms of time continuity and spatial coverage.

2.1 Introduction

> Change in environmental models may be of properties in time or space.
> Increasingly, models are being developed where both temporal and spatial variation are evaluated, so we need to have techniques that can asses these changes.
>
> Mark Mulligan and Hohn Wainwright, Modelling and Model Building, 2004.

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The Mediterranean climate (Köeppen's Csa) is characterized by a wet-mild winter thanks to the influence of the westerlies and a dry-hot summer under the domination of the subtropical anticyclones. This peculiar climate is the transitional belt between the humid oceanic climate of western and central Europe, ruled by the westerlies (Köppen's Cfb), and the arid North African desert belt, ruled by the subtropical anticyclones (Köppen's BWh) (Köppen and Geiger 1936).

The Mediterranean climate is characterized by the irregular space-time distribution of rainfall events along the year and the relevance of Heavy Precipitation Events (HPEs). This latter aspect is the result of some important driving factors working at different scales, among which the following features will be hereafter discussed:

1. closeness of regions source of peculiar air masses
2. macro and mesoscale circulation patterns favorable to air lift
3. mountain ranges on the coastline or in the nearby inland surrounding the basin, enhancing the air lifting
4. powerful sources of moist air and condensation nuclei into the boundary layer
5. microscale circulations (land-sea and mountain-valley breezes) spreading the energy improving the advective exchanges.

HPEs can be studied by the point of view of (1) causal factors (determinants at different scales approached by means of methods of atmospheric physics), (2) phenomenological features (quantity, intensity and spatial distribution of phenomena approached with the methods of the rainfall meteorology and climatology) and (3) effects on surfaces (soil erosion, river floods and flash floods analyzed with tools of hydrology, geomorphology, geology and soil science). The current analysis of HPEs will be limited to the first two approaches.

2.2 Mediterranean Precipitation and Air Masses

Considerable levels of precipitation are justified only by the presence of suitable clouds that are the result of condensation processes taking place on effective condensation nuclei (Levin et al. 2005; Bougiatioti et al. 2009). A cloud thickness of some thousands of meters and a sufficiently low cloud base are the two premises to trigger and sustain the microphysical mechanisms favorable to the growth of ice crystals or water droplets big enough to reach the soil and induce considerable precipitation (Chen et al. 2011).

Conditions for clouds development are (1) the presence of a dynamic environment favorable to air lift and (2) an air mass rich in water vapor rising from the boundary layer up to the free atmosphere. These two conditions are often satisfied in the Mediterranean basin during the winter semester (from October to March) when weather is periodically affected by westerlies. On the other hand these pre-requisites are rarely verified during the summer semester (from April to September) when weather, often ruled by the subtropical anticyclone, is usually warm and dry.

Table 2.1 Main foreign air masses influencing weather on the Mediterranean. The characteristics are referred to an air mass in equilibrium with its source area.

Air masses	Acronym	Source region	Characteristics
Polar maritime air	Pm	Atlantic Ocean at latitudes greater than 50°	Cool and rather moist
Polar continental air	Pc	Eurasia continent close to the Arctic circle	During winter it is dry and very cold (it is the coldest air mass of the Boreal hemisphere) whereas during summer it is not very different from the Mediterranean air
Arctic air	A	Arctic basin	Cold and dry
Tropical maritime air	Tm	Sub-tropical Atlantic Ocean	Warm and moist near surface and dry above

The theory behind air uplift is based on the dualism between troposphere and air parcels/layers (Mcintosh and Thom 1981). In the presence of an absolutely unstable thermal profile, the ascent of a generic air parcel occurs spontaneously by convection. In case of a potentially instable profile, the ascent usually occurs when the surface layer is bodily lifted up high enough to trigger condensation that provides the energy necessary for further development.

The energy for the ascent of the surface layer comes from thermally forced local phenomena such as the land-sea breezes or upslope flows in mountain valley breezes. At larger scale, air uprising phenomena take place as frontal or orographic air lift or dynamical convergence effects typical of some mesoscale phenomena (van Delden 2001). Typically the ascent leads to cumuliform clouds if quick but local or leads to stratiform clouds if slow but widespread.

In the abovementioned aerological perspective it is important to consider the features (temperature, humidity, lapse rate and so on) of different air masses that come from their long persistence on a given source region with peculiar characteristics. The air mass that dominates the low troposphere in the Mediterranean basin is mild and rich of water vapor due to the evaporation from sea surface. Moreover the main features of the foreign air masses important for weather phenomena in the Mediterranean basin are listed in Table 2.1 (Mcintosh and Thom 1981).

Air masses involved in the Mediterranean weather phenomena are coming from the basin itself or from outer source areas, as known since many decades (Eredia 1941; Haurwitz and Austin 1944) and confirmed by studies on backward trajectories (Argiriou and Lykoutis 2005; Fleming et al. 2012). For instance Duffourg and Ducrocq (2011), working on 10 HPEs occurred over the French Mediterranean region during the autumns of 2008 and 2009, highlighted that the Mediterranean sea is the main source of humidity for HPEs that take place after an anticyclonic phase while the relative contribution of local and remote source regions (Atlantic or African areas) is more balanced when cyclonic conditions prevail before the HPEs.

2.3 Circulation Patterns and Precipitation

The extreme rainfall events in the Mediterranean can be approached in the light of (1) the shapes of the underlying circulation at different geopotential levels (Holton 2004) and (2) the conceptual models that describe the behavior of the underlying weather disturbances (Conway et al. 1996; Zamg 2012).

The two main mid tropospheric patterns able to give precipitations in the Mediterranean basin are Upper Level Troughs (ULT) and Cut Off Lows (COL) (Funatsu et al. 2009).

ULTs are V shaped lows embedded in the westerlies flow and are characterized by cold air in the mid-troposphere and a maximum of potential vorticity (PV) in the upper troposphere, associated with the presence of the polar jetstream.

ULTs are the mid-tropospheric signature of frontal systems whose idealized structure is described in Fig. 2.1 adopting the Harrold-Carlson-Browning conveyor-belt conceptual model (Carlson 1980; Browning 1986), which represents an evolution of the frontal model of the Bergen school (Bjerknes 1919). The Warm Conveyor Belt (WCB) and the Cold Conveyor Belt (CCB) flow together giving birth to a characteristic comma shaped cloud whose sharp western edge is the result of the convergence of a third flow of Dry Cold Air (DCA). Precipitation occurs in a zone parallel to the surface cold front in association to the early ascent of WCB and extends into the region where the WCB ascends ahead of the surface warm front. The distance of the leading edge of precipitation ahead of the surface warm front is determined by the evaporation of precipitation as it falls from the WCB into the initially dry air of the CCB. Moistened by this evaporation, CCB gives rise to an extension of the precipitation area to the west of the WCB.

In many cases ULTs transiting the Mediterranean stretch until their distal part are divided, giving rise to mid tropospheric COLs (Gimeno et al. 2007a, b) that are the typical Mediterranean cyclones (Fig. 2.2).

The characteristic dimensions of ULTs and COLs are substantially different as shown by Alpert and Neeman (1992), which analyzed 192 systems on the period 1982–1986. The authors highlighted distinct features of cyclonic disturbances in Eastern Mediterranean basin as resumed in Table 2.2 which, for example, states that the modal diameters of COLs and ULTs are respectively 1,200 km and 3,200 km long.

Mediterranean cyclones inherit from the source ULTs a “drop” of mid tropospheric cold air and a PV maximum in upper troposphere and are seat of intense stratosphere–troposphere exchange often associated to the descent of stratospheric ozone (Nieto et al. 2008).

The life cycle of a COL (Nieto et al. 2005) can be conceptualized into four stages: the upper-level trough, tearoff, cut-off and final stage. Further details of meteorological properties of COLs can be found in the meteorological literature describing specific case studies (e.g. Emanuel 2005) or in more general studies about upper-level structures (e.g. Palmén and Newton 1969).

The dynamic of the system is the result of three main airstreams that are the Warm Conveyor Belt (WCB), fed by the low tropospheric warm air advected from

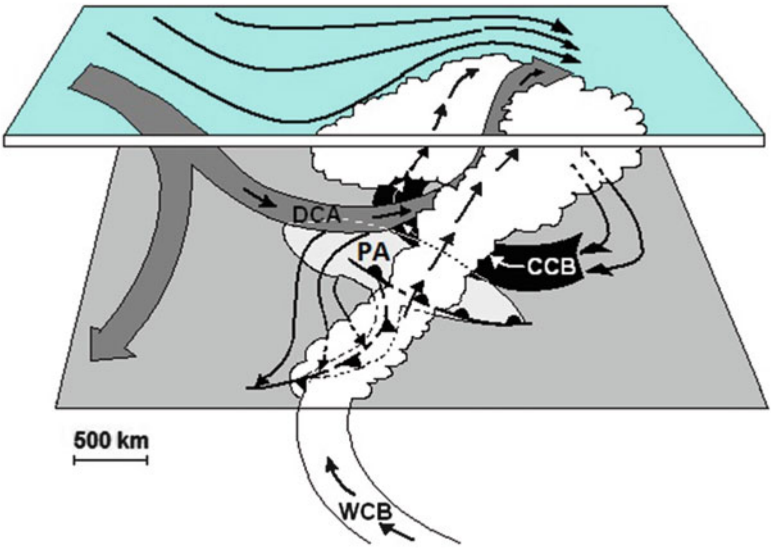

Fig. 2.1 Conceptual model of a fully developed frontal system seen between the marine surface and the 300 hPa surface (about 7,700 m a.s.l.)

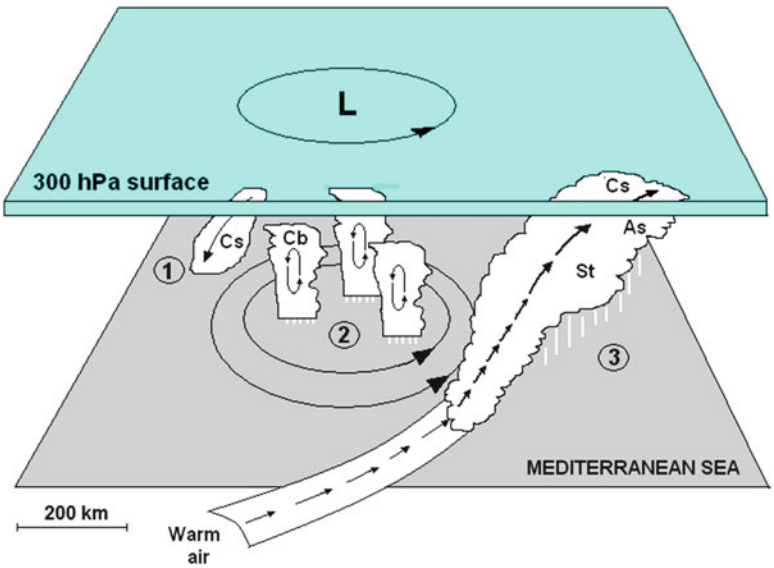

Fig. 2.2 Conceptual model of a fully developed Mediterranean cyclone seen between the marine surface and the 300 hPa surface (about 7,700 m a.s.l.). The symbol (1) is for an upper convergence zone with Cirrostratus cloud (*Cs*) genesis, (2) is a potentially instable area with cumulonimbus clouds and (3) is a warm front like area. In the *lower corner* is shown the indicative scale (Cb clouds are not in scale because their horizontal diameter is about 1 km) (The figure was drawn based on the description of Nieto et al. (2005))

Table 2.2 Main precipitating systems of the Mediterranean (Alpert and Neeman 1992)

Mid tropospheric pattern	Tropospheric system	Characteristic dimension (km)	Temp. at surface (°C)	Reference scale[a]	Mid tropospheric T (°C)
ULT	Frontal system	3,200	19	Beta macroscale	−17
COL	Mediterranean cyclone	1,200	14	Alfa mesoscale	−21

[a]Fujita (1986)

anticyclonic area South-East of the system, the Cold Conveyor Belt (CCB) fed by the low tropospheric cold air advected from the anticyclonic area North-East of the system and the Dry Cold Air (DCA) coming from North-West, which is behind the cold front and send potentially unstable uprising air fluxes overriding the WCB and favoring convection at its top. Lines representing cold and warm front at surface are decorated, respectively, with teeth and crescents. The cloud pattern is comma shaped and the light gray area (PA) represents the extent of precipitation reaching the soil (Browning 1986; Schultz 2001).

2.4 Trajectories, Frequency and Persistence of Upper Troughs and Cut-Off Lows

The mean yearly circulation at 500 hPa over the Euro-Mediterranean area is characterized by a 40–60°N belt ruled by the westerly flow (the so called zonal flow) surmounted by the polar jet stream and embedded between an anticyclonic belt over the Mediterranean area and a cyclonic belt over high latitudes (Fig. 2.3, left side). An analysis of winter and summer periods shows that the mean zonal flow involves the whole Mediterranean area during winter (Fig. 2.3, center), while it is limited to the 50÷60°N belt during summer (Fig. 2.3, right side).

- On the other hand the analysis of circulation on shorter periods (weeks) shows the alternance of two main regimes (Charney and DeVore 1979; Holton 2004): a zonal regime – strong westerly circulation with superimposed low amplitude waves quickly propagating eastwards (ULTs) and vortexes of smaller scale (COLs).
- a blocking regime – weak westerly circulation with superimposed high amplitude waves (ULTs) that show a relatively long persistence on a given area and sometimes tend to detach COLs in their distal zone.

Figure 2.4 shows an example of zonal regime (strong westerlies affecting the western Mediterranean) and some examples of blocking regimes classified within the current taxonomic system (Degirmendzic and Wibig 2007). The area affected by zonal regime is subjected to strong variability with rapid succession of clear and

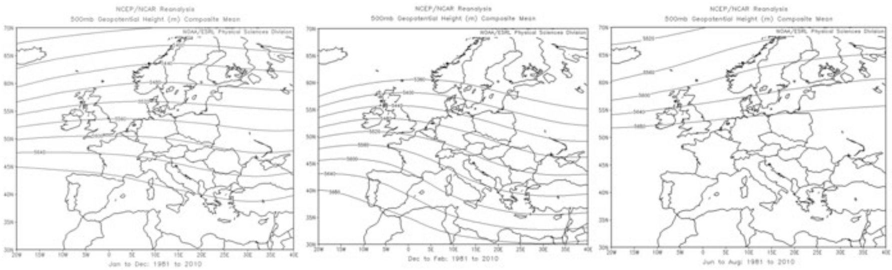

Fig. 2.3 500 hPa topographies showing the mean circulation over the Euro – Mediterranean area for the period 1981–2010. The isolines between 5,360 and 5,680 m have been adopted as tracers of the zonal flow which show a strong seasonality involving on average the whole Mediterranean during winter while during summer it is relegated outside the basin (Data from NOAA – NCEP reanalysis dataset, http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl)

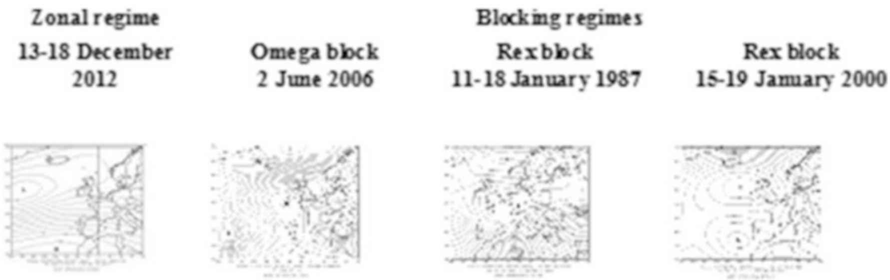

Fig. 2.4 500 hPa topographies showing some examples of zonal and blocking regimes over Europe (Data from NOAA – NCEP reanalysis dataset. http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl)

rainy weather. On the other hand blocking patterns can deeply affect rainfall distribution on different parts of the Mediterranean basin in function of their geographic position. For instance, an omega block with a western trough axis on the Iberian peninsula, an anticyclonic ridge axis over Italy and an oriental trough axis over the Aegean sea leads to a rainfall pattern with maxima on Catalonia, South Western France and Turkey. On the other hand a Rex block with a cyclonic trough axis from Poland towards Sardinia leads to strong rainfall on Southern Italy.

ULTs speed and trajectories are determined by the speed and pathway of the westerlies while COLs motion, once they are disconnected from the westerlies, is not longer controlled by jet stream and becomes more erratic and difficult to predict (Nieto et al. 2005). Generally the predominant component of motion of Mediterranean cyclones (Fig. 2.5) is eastward with exceptions given by systems that (1) remain stationary, spinning for some days until dissipate or (2) may move westward in the opposite direction to the prevailing flow (i.e. retrogression) or

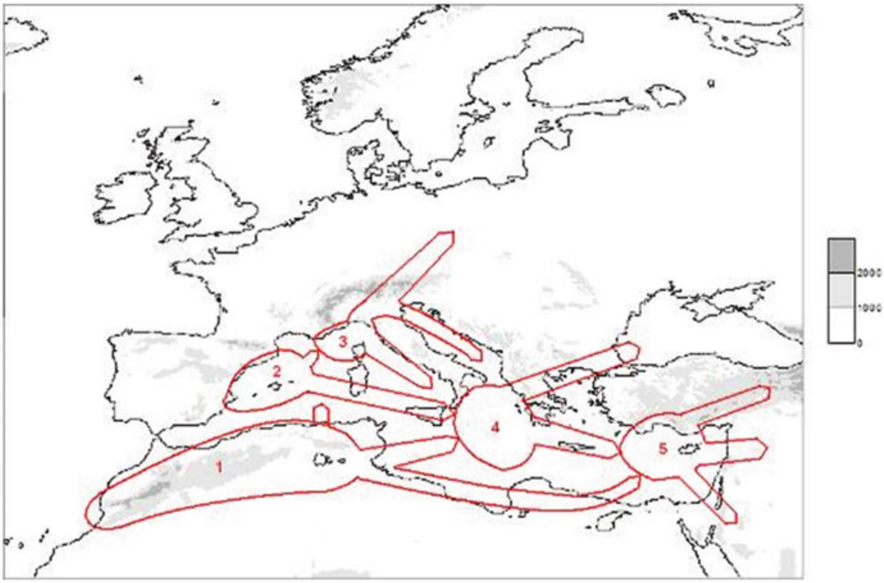

Fig. 2.5 Indicative tracks of Mediterranean COLs radiating form the main genetic centers which are (1) the North West Africa, (2) the Balear, (3) the Gulf of Genoa, (4) the Ionian sea and (5) the Cyprus area

(3) may be reconnected to the main westerly flow. The latter occurs because of the transit of a new trough in the COL area.

Figure 2.5 illustrates birth area and preferential tracks of the systems and is mainly referred to data of UK Metoffice (1963). We can distinguish the following systems and their prevailing trajectories:

1. systems radiating from the North West Africa (Atlas mountains) (Romero 2001; Arreola et al. 2002; Homar et al. 2002; Knippertz and Martin 2007):

   1a: Northwards to the western Mediterranean
   1b: North-eastward across southern Tunisia or the Gulf of Sidra towards the central Mediterranean, reaching South Italy and sometimes Greece
   1c: Slightly North of the Coast towards lower Egypt and the Cyprus area

2. systems radiating from the Balear area (Trigo et al. 2002):

   2a: Towards the central Mediterranean reaching South Italy
   2b: Toward the Gulf of Genoa

3. systems radiating from the Gulf of Genoa (Tibaldi and Buzzi 1983; Federico et al. 2007):

   3a: North-eastwards towards the Po valley and then South-eastwards along the Adriatic sea

3b: North-eastwards towards the Po valley and the Hungary plain
3c: South-eastwards towards South Italy along the Tyrrhenian sea

4. systems radiating from the Ionian sea (Trigo et al. 2002):

4a: North-eastwards trough the Balcans until the Black Sea
4b: Eastwards to the Cyprus area

5. systems radiating from the Cyprus area (Trigo et al. 2002):

5a: East-North-east to North-east
5b: East
5c: South-east.

In a global perspective, the frequency of Mediterranean cyclones in the Mediterranean area, analyzed in its relation with the Polar Vortex behavior, shows that spring and summer COLs located at latitudes lower than 45° are more frequent during the years with early Polar Vortex breakup (Gimeno et al. 2007b). Furthermore, COLs interannual variability is strongly affected by the frequency and persistence of zonal and blocking regime (Nieto et al. 2007).

A COLs climatology for the period 1946–1955 has been presented by Cantù (1977), while data for 1979–1996 have been presented by Trigo et al. (1999, 2002), data for 1992–2001 have been reported by Porcù et al. (2007) and a wider analysis for the large period 1957–2002 (45 years) has been carried out by Campins et al. (2011).

2.5 Mesoscale Precipitation Patterns

The peculiar circulation dynamics of the Mediterranean basin leads to a high variability of precipitation on monthly, interannual and interdecadal time scales with strong effects on regional water resources, water management and land degradation processes.

Mid latitude frontal precipitation is generally organized in mesoscale rainbands with a characteristic horizontal dimension of about 100 km. The convection within rainbands is often organized in Mesoscale Convective Systems – MCSs (Browning and Mason 1981; Ricard et al. 2012). MCSs are clusters of convective cells with a characteristic horizontal dimension of several tens of km.

MCSs are characterized by a continuous renewal of the convective cell and sometimes host heavy precipitation events (HPEs). The meteorological ingredients favoring MCSs are a slow-evolving synoptic environment associated with conditional convective instability, low-level moist air flows from the sea and the effect of orographic barriers. Understanding how these ingredients interact to trigger and sustain HPEs with different timing and location (over the mountains, upstream or downstream, over the plains or the sea) is still an open question.

An analysis of large scale atmospheric circulation patterns that produce daily extreme precipitation events in the Mediterranean basin was carried out by

Giacobello and Todisco (1979), Trigo and DaCamara (2000), Dunkeloh and Jacobeit (2003), Hoinka et al. (2006), Tolika et al. (2007), Yiou et al. (2008), Funatsu et al. (2009) and Toreti et al. (2010).

2.6 Climatology of Precipitation Maxima

2.6.1 Data and Methods

Climatology of the extreme precipitation in the Mediterranean can be established on the base of pluviometric station networks with a suitable spatial and temporal detail. In this context the problem of data availability and quality is a constant drawback for a reliable pluviometric analysis. In the light of these presuppositions the approach adopted has been based on the use of a dataset of daily precipitation obtained from the following main data sources:

– Eca&d non blended data (Klein Tank et al. 2002)
– NOAA GSOD dataset (http://www.ncdc.noaa.gov/oa/gsod.html).

Furthermore, in order to improve the quality and spatial continuity of data, the dataset has been supplemented with data coming from the following data-sources:

– Meteofrance web site on extremes events (http://pluiesextremes.meteo.fr/une-selection-d-evenements-memorables-majeurs_r52.html)
– Dataset of rainfall maxima of Anagnostopoulou and Tolika (2012).

The following selection criteria have been applied in order to obtain the working dataset:

– station location into the 30°/50° North and −20°/−40° East limits
– availability of at least the 95 % of data over the 1973–2010 reference period
– station altitude lower than 400 m a.s.l.

In its turn the working dataset composed by 135 stations (Fig. 2.6) has been submitted to a quality check (with deletion of values judged wrong) based on the following criteria:

1. subjective comparison with neighbors data
2. check of the consistency of daily rainfall data over 200 mm day^{-1} with some daily NCEP-CFS re-analysis maps (500–850 hPa temperature and pressure, 700 hPa relative humidity and last 12 h precipitation) (Saha et al. 2010).

The final dataset was processed to obtain the monthly distribution of daily HPEs exceeding 200 mm for the whole dataset. Furthermore the following indexes have been calculated for each station:

1. yearly mean total rainfall
2. absolute maximum values

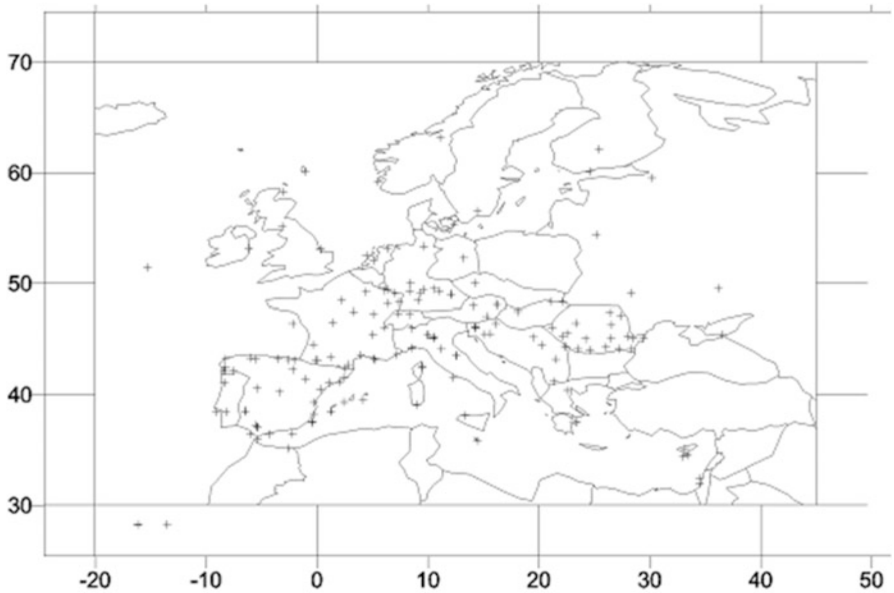

Fig. 2.6 Spatial distribution of the 135 stations adopted for the analysis of extreme precipitation

3. 95th, 90th and 75th percentiles
4. ratio (%) between absolute daily maximum and yearly average
5. ratio (%) between 99th daily percentile and absolute daily maximum.

An ordinary Kriging algorithm has been applied to the above-listed indexes to produce maps for the Mediterranean basin. The spatial representation has been adopted because it is useful to understand the relations of precipitation extremes with synoptic and mesoscale phenomena.

2.6.2 Trend Analysis of Extreme Precipitations

Climate change can be considered as a significant change in the statistical properties of the climate system when considered over periods of decades or longer (WMO 2012). Among statistical properties, particularly important for practical purposes are the indexes of central tendency (e.g. arithmetic mean, median) and dispersion (e.g. standard deviation, interquantile range). This defines the framework of the following study, aimed to obtain for the whole dataset and two subgroups (Western stations located below 10° East and Eastern ones located over 10° East) the mean and standard deviation of the contribution to yearly totals of daily precipitation dropping in pre-defined classes (<20 mm "Weak", 20÷50 mm "Moderate", 50÷100 mm "Heavy", >100 mm "Extreme") (Alpert et al. 2002). The trend analysis on the results has been performed with the Mann – Kendall test and the Sen's slope (Salmi et al. 2002).

2.7 Results and Discussion

A description of the monthly regime of HPEs over the Mediterranean is given by the histogram in Fig. 2.7, which shows that about 70 % of the extreme events happen in the period August-December. This evidence is relevant for management purposes and can be considered as the consequence of the fact that the Mediterranean remains still relatively warm during the autumn, so permitting intense evaporation and, therefore, the production of convective instability (Romero et al. 1997).

The spatial distribution of HPEs has been analyzed by means of a series of maps of precipitation extremes. More specifically the map of precipitation maxima (Fig. 2.8) shows that the highest values spread all over a belt ranging from the North-West Africa (Atlas region) to the Baleares area to the Gulf of Genoa and the North Adriatic. This belt is associated with the tracks of Atlantic troughs and Mediterranean COLs while the precipitation maximum in the Sicily Channel is probably the effect of the storm tracks of North West Africa COLs (Fig. 2.5).

A peak maximum in Genoa Gulf is also notified in 95th and 90th percentiles maps (Figs. 2.9 and 2.10) evidencing that the area is favorable to extreme events because of local factors as the Gulf curvature and the very steep coastal orography that induce air convergence and up-rising. Furthermore, relevant maxima over Gibraltar, Baleares, Malta, Croatia and Israel are clearly detected in all the percentiles maps. Moreover the same pattern of upper percentiles is roughly replicated by the 75th percentile map (Fig. 2.11).

The ratio (%) between 99th daily percentile and absolute daily maximum (Fig. 2.12) is a pluviometric index useful to evaluate the degree of "uniqueness"

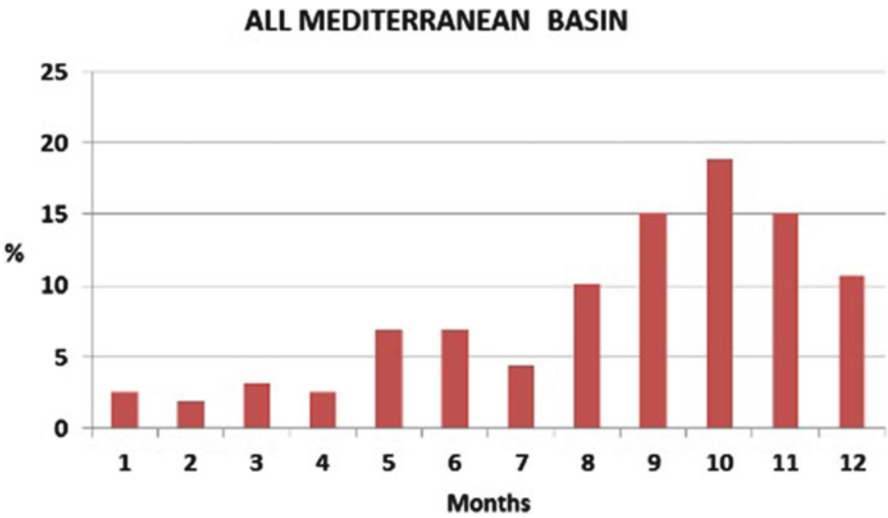

Fig. 2.7 Percentage of the total number of extreme events (rainfall >200 mm day^{-1}) happened in each month of the 1973–2010 period for the whole Mediterranean

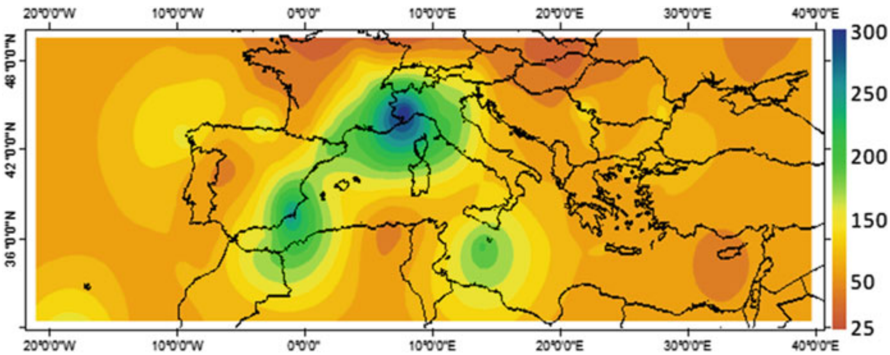

Fig. 2.8 Spatial distribution of maximum precipitation in the Mediterranean area in the period 1973–2010

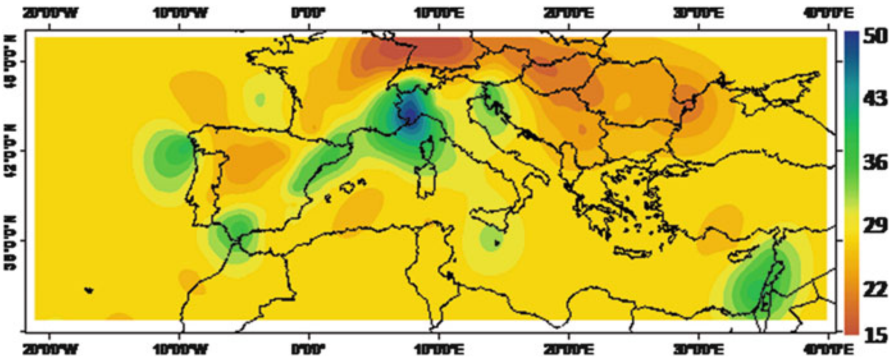

Fig. 2.9 Spatial distribution of 95th precipitation percentiles in the Mediterranean area in the 1973–2010 period

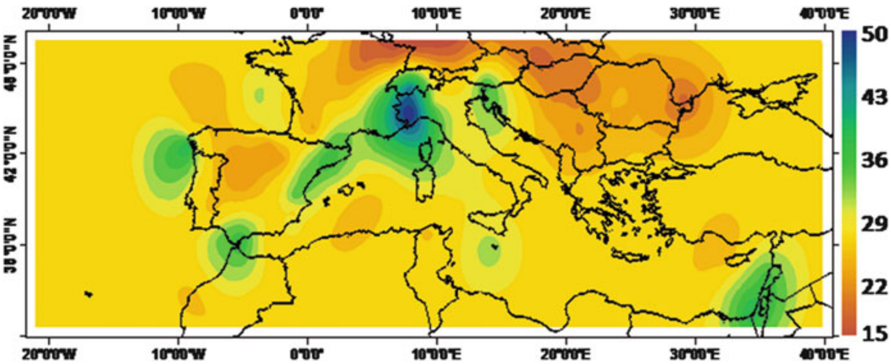

Fig. 2.10 Spatial distribution of 90th precipitation percentiles in the Mediterranean area in the 1973–2010 period

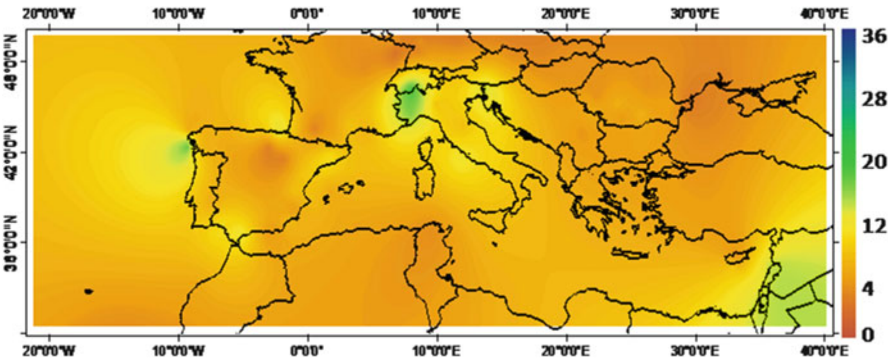

Fig. 2.11 Spatial distribution of 75th precipitation percentiles in the Mediterranean area in the 1973–2010 period

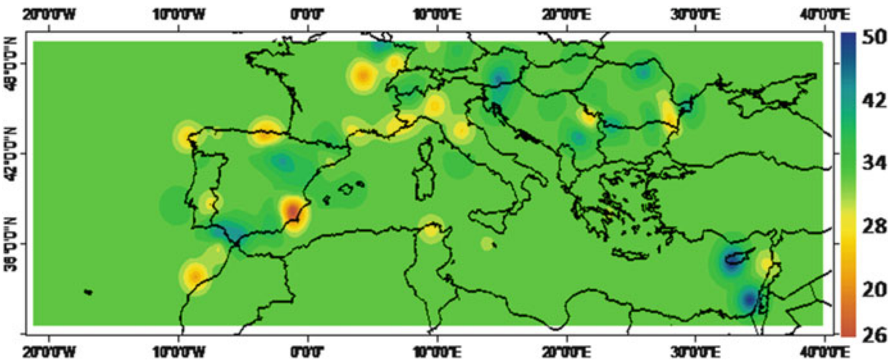

Fig. 2.12 Spatial distribution of the ratio (%) between 99th daily percentile and absolute daily maximum

of absolute daily maximum. More specifically low values of this index indicate that the maximum value is not so far to other higher values registered by the station. High values (>40 %) denote a singular maximum event for that point. The map shows some scattered maxima located on the Spain Mediterranean coast, a line ranging from South France to North Adriatic, channel of Sicily, Greece and Israel.

The spatial distribution of the ratio (%) between absolute daily maximum and yearly average (Fig. 2.13) is useful to evaluate the degree of anomaly of extreme events with reference to the normal pluviometric regime of the area. More specifically a high value of this index shows that an area "accustomed" to low mean rainfall is suddenly exposed to extreme events, which can be important from the point of view of the erosivity. This index shows some nuclei of maximum on Gibraltar, South France, Gulf of Genoa, Corse and Sardinia, Greece and Cyprus with absolute maxima on the Gulf of Genoa and Southern coast of France.

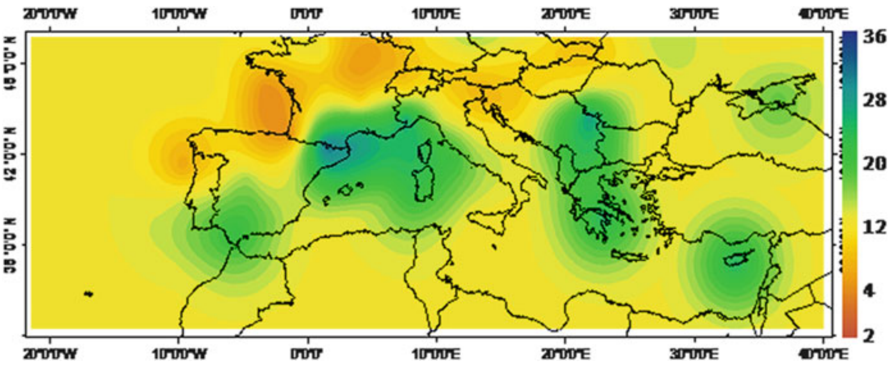

Fig. 2.13 Spatial distribution of the ratio (%) between absolute daily maximum and yearly average

Table 2.3 Mann-Kendall, Sen's test on trend significance of rainfall mean and standard deviation on weight (%) for pre-defined four different classes

				Mann-Kendall trend		Sen's slope estimate
Time series	First year	Last year	n	Test Z	Significance	Q
mean all <20	*1973*	*2010*	*38*	−1.31		−0.055
mean all 20_50	*1973*	*2010*	*38*	2.09	**	0.054
mean all 50_100	*1973*	*2010*	*38*	−0.20		−0.004
mean all >100	*1973*	*2010*	*38*	0.18		0.002
mean west <20	*1973*	*2010*	*38*	0.63		0.028
mean west 20_50	*1973*	*2010*	*38*	0.98		0.024
mean west 50_100	*1973*	*2010*	*38*	−1.66	*	−0.043
mean west >100	*1973*	*2010*	*38*	0.33		0.006
mean east <20	*1973*	*2010*	*38*	−3.24	***	−0.170
mean east 20_50	*1973*	*2010*	*38*	2.29	**	0.093
mean east 50_100	*1973*	*2010*	*38*	3.27	***	0.073
mean east >100	*1973*	*2010*	*38*	−0.83		−0.007
devst all <20	*1973*	*2010*	*38*	−2.26	**	−0.050
devst all 20_50	*1973*	*2010*	*38*	−1.36		−0.021
devst all 50_100	*1973*	*2010*	*38*	−0.18		−0.003
devst all >100	*1973*	*2010*	*38*	−0.03		−0.001
devst west <20	*1973*	*2010*	*38*	−2.11	**	−0.055
devst west 20_50	*1973*	*2010*	*38*	−0.91		−0.017
devst west 50_100	*1973*	*2010*	*38*	−0.78		−0.014
devst west >100	*1973*	*2010*	*38*	0.13		0.013
devst east <20	*1973*	*2010*	*38*	−0.33		−0.005
devst east 20_50	*1973*	*2010*	*38*	0.00		0.001
devst east 50_100	*1973*	*2010*	*38*	1.91	*	0.046
devst east >100	*1973*	*2010*	*38*	−1.23		−0.035

Note: "***" = trend at < = 0.01 level of significance; "**" = trend at < = 0.05 level of significance; "*" = trend at < = 0.1 level of significance

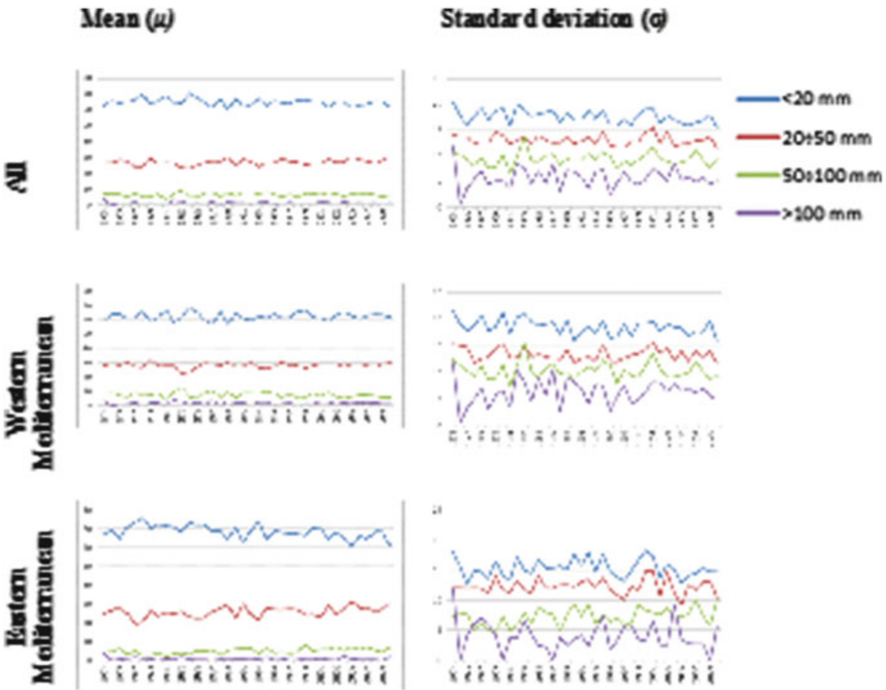

Fig. 2.14 Mean and standard deviation of weight (%) of different precipitation classes on whole West and East side of the Mediterranean basin

Enlarging the analysis to the European area outside the Mediterranean basin and influenced by the westerlies, it's evident that precipitation regime is more stable, with low absolute maxima and low percentiles values. The same can be observed for the Eastern continental Europe.

The analysis of trends of precipitations dropping in the reference classes as been summarized in Table 2.3 and Fig. 2.14.

The results referred to averages show that for the whole dataset and for western stations the trend is not significant for the main part of the rain classes, testifying the substantial stability of phenomena. Exceptions to this general behaviour are given by the class 20–50 (positive trend significant at 95 %) for the whole basin and the class 50–100 (negative trend significant at 90 %) for the western sub-basin. On the other hand eastern stations show significant trends for classes 20–50 (positive and significant at 95 %) and 50–100 (positive and significant at 99 %). Nevertheless it is worthy of note that the number of stations in the eastern part of the basin is quite low at latitudes below 40°N due to low quality of most of the stations analyzed. Hence the highlighted trend results should be confirmed by a analysis extended to a wider dataset.

On the other hand the trends of standard deviations are generally not significant, testifying a substantial stability of the spatial behaviour of the analyzed phenomena. The only exceptions are given by the class <20 (negative trend significant at 95 %) for the whole basin and the west one and by the class 50–100 (positive trend significant at 90 %) for the eastern sub-basin. The above-described behaviour of the whole basin and of the western sub-basin seems to confute the "paradoxical increase of Mediterranean extreme daily rainfall" claimed by Alpert et al. (2002).

2.8 Conclusion

Precipitation is a complex phenomenon because its genesis requires:

– a source of moisture generally represented by the boundary layer
– morphology of the relief, circulatory structures at different scales and vertical thermal profile favorable to the rising of air mass with development of clouds
– microphysical characteristics of cloud environment favorable to magnify droplets or ice crystals to give precipitation.

These aspects have been associated to the Mediterranean environment in order to highlight its peculiarity in terms of precipitation and more specifically its ability to give rise to extreme precipitation events. By this point of view our analysis highlighted the role of weather patterns at macro and mesoscale like frontal systems, Mediterranean cyclones and mesoscale convective systems. The trajectories of these weather patterns are ecologically relevant in order to spread rainfall all over the basin. For instance if rainfall was produced only by frontal systems it would be mainly limited to the part of the basin closest to the areas with oceanic climate, which are more directly affected by the Atlantic Westerlies.

Moreover the analysis of the precipitation time series of the Mediterranean basin was carried out in order to show the areas most exposed to extreme events. Particularly favorable to extreme events are the belt West Africa – Baleares – Gulf of Genoa – High Adriatic and the belt West Africa – Channel of Sicily.

Regarding to the temporal trends of extreme events in the whole Mediterranean basin and the Western sub-basin, it is possible to state that the relative weight of each class has a steady temporal behavior with only a significant increase of "moderate" events (whole basin) with a meanwhile decrease of "strong" events (West). On the other hand the observed positive trends of classes "moderate" and "strong" for the East part of the basin should be confirmed by a richer dataset referred to this specific area.

The standard deviation on different precipitation classes shows a general steadiness apart from the exceptions previously noted.

At the conclusion of our analysis it may be useful to develop some more general considerations on the status and prospects of systems for monitoring precipitation in the Mediterranean and, more generally, globally that are crucial to appreciate the quantity and the space-time variability of a phenomenon so complex to study. By this point of view it is important to state that at present rainfall is measured by pluviometers or remote sensed by ground radars or satellite sensors or lightning monitoring systems. The climatology of precipitation maxima is prone to large errors due to the strong influence of many factors like:

– dimension and shape of rain-gauges
– wind effects on measurements accuracy
– location of pluviometric stations
– length and continuity of time series
– homogeneity of networks.

These drawbacks suggest that the establishment of a premium network, installed and managed with very restrictive criteria, is crucial to gain useful data for updated and improved climatologies of the whole area. More specifically we think at a pluviometric network with mesh size of 10–20 km in plain areas and 5–10 km in hilly regions and managed with attention to ensure quality and continuity of time series. Examples of the reliability of this kind of approach are present in other fields (e.g. Argo project for the establishment of a global buoy network, http://www.argo.ucsd.edu) and should be taken into account in order to overcome the present drawbacks and substantially improve the quality of climatological analysis.

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