Chapter 2

Relations between Climate Variability in the Mediterranean Region and the Tropics: ENSO, South Asian and African Monsoons, Hurricanes and Saharan Dust

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2.1. Introduction

The Mediterranean climate is affected by several tropical and subtropical systems as illustrated by some evidence presented in this chapter. These factors range from the El Niño Southern Oscillation (ENSO) and tropical hurricanes to the South Asian Monsoon and Saharan dust. This leads to complex features in the Mediterranean climate variability. In the following sections, we review some tropical and subtropical teleconnections to the Mediterranean climate in the following order: El Niño Southern Oscillation is elaborated in Section 2.2, the South Asian Monsoon is discussed in Section 2.3, Section 2.4 is dedicated to African monsoon, tropical cyclones are discussed in Section 2.5 and finally Red Sea Trough intrusions into the Eastern Mediterranean and the Saharan dust are discussed respectively in the last two Sections 2.6 and 2.7.

2.2. ENSO Impact on the Mediterranean Climate

[1]The El Niño Southern Oscillation (ENSO) phenomenon is recognized as a major source for global climate variability (Halpert and Ropelewski, 1992) either via standing modes over the entire Tropics or via coherent large-scale low-frequency spatial patterns referred to a as ‘‘teleconnections’’ over midlatitudes (see Wallace and Gutzler, 1981; Allan et al., 1996; Diaz et al., 2001 for reviews on ENSO).

Several studies have dealt with the underlying physics of the phenomenon and with the worldwide implications for climate (e.g. van Loon and Madden, 1981; Kiladis and Diaz, 1989; Ropelewski and Halpert, 1992; Trenberth et al., 1998; Diaz et al., 2001). The impact of ENSO on the climate of extra-tropical regions, as well as the mechanism responsible for anomalies in the tropical Pacific sea surface temperatures (SST) having worldwide impacts are poorly understood and documented (Pozo-Vázquez et al., 2001).

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The El Niño phenomenon is related to the warming of the eastern Pacific sea surface temperatures (SST) for an extended period of 6–12 months, and sometime longer. The SST distribution is directly linked to the atmospheric pressure patterns over the Pacific, with a low pressure cell being located above the warm pool in the western Pacific during normal conditions, while moving eastward with the warm pool in El Niño years. The atmospheric pressure oscillation between the west and central Pacific is known as the Southern Oscillation (SO). Positive pressure anomalies over Australia and Indonesia are associated with the warm El Niño conditions in the eastern Pacific, while negative pressure anomalies over Australia are associated with the cold La Niña conditions in the eastern Pacific. Due to the strong link between the SSTs and the atmospheric pressure, the phenomenon is often referred to as the El Niño/Southern Oscillation.

During warm (El Niño) episodes, the normal patterns of tropical precipitation and atmospheric circulation become disrupted. The abnormally warm waters in the equatorial central and eastern Pacific give rise to enhanced cloudiness and rainfall in that region, especially during the boreal winter and spring seasons. At the same time, rainfall is reduced over Indonesia, Malaysia and northern Australia. Thus, the normal Walker Circulation during winter and spring, which features rising air, cloudiness and rainfall over the region of Indonesia and the western Pacific, and sinking air over the equatorial eastern Pacific, becomes weaker than normal, and for strong warm episodes, it may actually reverse.

The increased heating of the tropical atmosphere over the central and eastern Pacific during warm episodes affects global atmospheric circulation features, such as the jet streams in the subtropics and in the temperate latitudes of the

[1]Much of the preface of this section is based on Xoplaki (2002) and the Climate Prediction Center (CPC) website http://www.cpc.ncep.noaa.gov/

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winter hemisphere. The jet streams over the eastern Pacific Ocean are stronger than normal during warm episodes. Also, during warm episodes, extra-tropical storms and frontal systems follow paths that are significantly different from normal, resulting in persistent temperature and precipitation anomalies in many regions. Significant departures from normal conditions, for the Northern Hemisphere (NH) winter and summer seasons, can be found at the Climate Prediction Center (CPC) site: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/index.html).

According to the general descriptions of ENSO above, there is no El Niño/La Niña impact in either season visible for the European/Mediterranean area.

It has been proposed that ENSO exerts a positive forcing on tropical North Atlantic SSTs and this effect is strongest in boreal spring (Enfield and Mayer, 1997). However, it has been argued that only when tropical SST anomalies are large (strong ENSO events), the ENSO signal can be found in the extra-tropics (Huang et al., 1998; Trenberth et al., 1998). On the other hand, tropical forcing is stronger during the northern winter, coinciding with the mature stage of El Niño events (Trenberth et al., 1998). It appears that the possible influence of ENSO in the North Atlantic-European area is more likely to be found during extreme events of ENSO and during the winter (Pozo-Vázquez et al., 2001). The perturbation can be propagated downstream, as a wave train, to other longitudes in the form of Rossby waves, eventually affecting locations far away from the Pacific, particularly the North Atlantic region. Consequently, the eventual propagation of such events to other longitudes takes place with a lag of around three months (Pozo-Vázquez et al., 2001).

Several papers have related ENSO to weather and climate variability over Europe and Africa as well as over specific countries at the Mediterranean Sea (e.g., Fraedrich and Müller, 1992; Fraedrich, 1994; Rodó et al., 1997; Laita and Grimalt, 1997; Moron and Ward, 1998; Rodriguez-Puebla et al., 1998; Price et al., 1998; Türkeş, 1998; Kadioğlu et al., 1999; Rocha, 1999; van Oldenborgh et al., 2000; Compo et al., 2001; Diaz et al., 2001; Pozo-Vázquez et al., 2001; Giorgi, 2002; Lloyd-Hughes and Saunders, 2002). A compilation of their findings together with some others is summarized below.

2.2.1 ENSO and Eastern Mediterranean (EM) Rainfall

Yakir et al. (1996) and Price et al. (1998) showed significant connections between ENSO events and winter rainfall in Israel, both indicate increased rainfall occurring in El Niño winters. Price et al. (1998) also demonstrated that La Niña years were associated with below normal rainfall. The 2003–2004 rainy winter in Israel, coinciding with an El Niño event, supports the above. The analysis

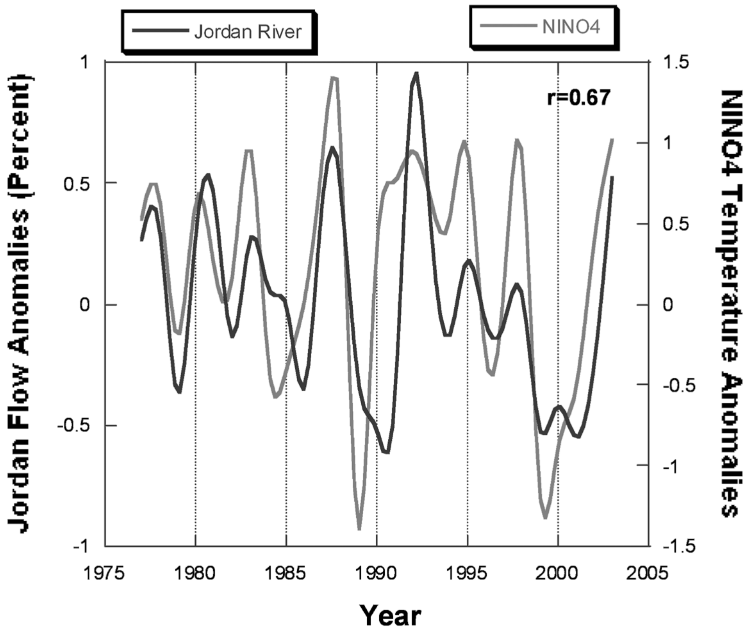

Figure 45: The winter streamflow in the Jordan River and the winter NINO4 SSTs in the tropical Pacific. Adapted from Price et al. (1998).

in Israel was extended to the Jordan River discharge, used as a proxy for regional rainfall, since the stream flow entering the Sea of Galilee is dominated by regional rainfall. The seasonal stream flow in the Jordan River is significantly correlated ($r \sim 0.67$) with the seasonal NINO4 temperatures (Fig. 45). This implies that the tropical Pacific temperature oscillations can explain approximately 45% of the inter-annual variability in winter rainfall in northern Israel. It is hypothesized that the reason for this strong connection is related to the position of the winter jet over the Eastern Mediterranean (EM). Israel is located at 30°N, exactly the mean latitude of the winter jet. Small shifts, in the order of ~1 deg, in its mean position can have a major impact on the storm tracks, and hence on the rainfall amounts. Fig 46 shows that indeed in a composite of El-Niño years, the jet over the EM moves further south by about 50–100 km.

During El Niño/La Niña years, meridional shifts of the jet in the EM have been observed. However, the intensity of the ENSO events is not directly related to the intensity of the rainfall anomalies in Israel. This is one of the reasons the correlation coefficient is only 0.67. However El Niño/La Niña years have been wet/dry for 75% of the ENSO events in the last 30 years. Stream flow data in the Jordan River are only available since the end of the 1960s. However,

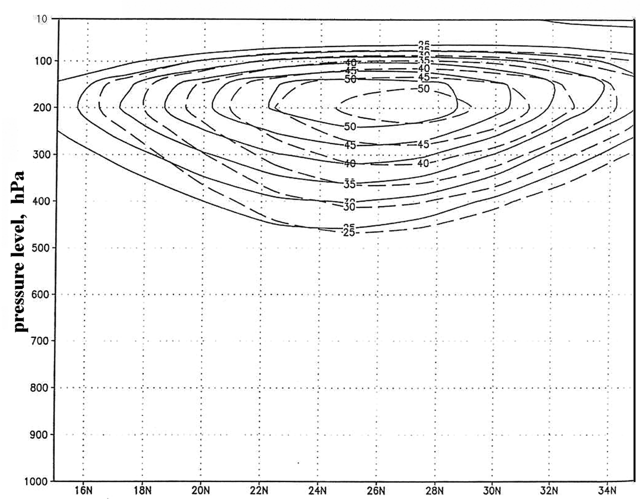

Figure 46: Zonal means (30°E – 40°E) of west wind (m/s) in the winter period (December, January and February). The dashed lines correspond to the winters from 1982/83 to 1993/94, while the solid ones, to the El-Nino winters 1982/83, 1986/87 and 1991/92.

since individual rain gauge measurements in the watershed are highly correlated ($r \sim 0.9$) with the catchment's integrated stream flow, it is possible to extend the time series back to 1922. However, the ENSO signal appears in the rainfall/streamflow data only after the mid-1970s. It is puzzling as to why these correlations are observed only in the recent record. This may be a result of the changes in the frequency and intensity of ENSO events since the mid-1970s. Trenberth and Hoar (1997) have shown that since the mid-1970s, there has been a significant increase in the frequency of El Niño events relative to La Niña events, and the intensity and period of these events has also changed. It has also been suggested that there may have been a shift in the global climate system during the 1970s, which may have resulted in a stronger Pacific-mid-latitude link during the past three decades (Wuethrich, 1995).

Kadioğlu et al. (1999) investigated the Turkish monthly total precipitation variation at 108 meteorological stations between 1931 and 1990. They found that much of the month-to-month variability is related to El Niño events. El Niño events, as classified by high ENSO index, seem to produce both depressions and enhancements in the southern and northwestern parts of Turkey, respectively. During El Niño years, the cyclones move towards the north. This may be the reason why there is a decreasing trend in precipitation around the southwest of Turkey (Kadioğlu et al., 1999).

2.2.2 ENSO and the Western Mediterranean Relationship

Rodó et al. (1997) investigated the signatures of ENSO in Spanish precipitation and stated a coherent decrease in March/April/May following El Niño events, in accordance with that stated in the pioneering studies (Ropelewski and Halpert 1987, Kiladis and Díaz 1989), and later confirmed and extended by van Oldenborgh et al. (2000) and Mariotti et al. (2002). This coherence appeared to increase in the second half of the twentieth century.

Mariotti et al. (2002) also found that western Mediterranean-averaged rainfall is significantly correlated with ENSO variability during autumn, with the sign being opposite to that found in spring. A composite analysis reveals an approximate 10% increase (decrease) in seasonal rainfall for El Niño (La Niña) events in September/October/November, preceding the mature phase of ENSO, with an early (late) arrival of the rainy season in these regions. This relationship appears to have been stationary starting from the late 1940s (Fig. 47).

Mariotti et al. (2005) investigate the Mediterranean autumn ENSO-signal in the context of the impact that ENSO events have on a larger domain extending from southwest Europe/ northern Africa into parts of southwest Asia, as also

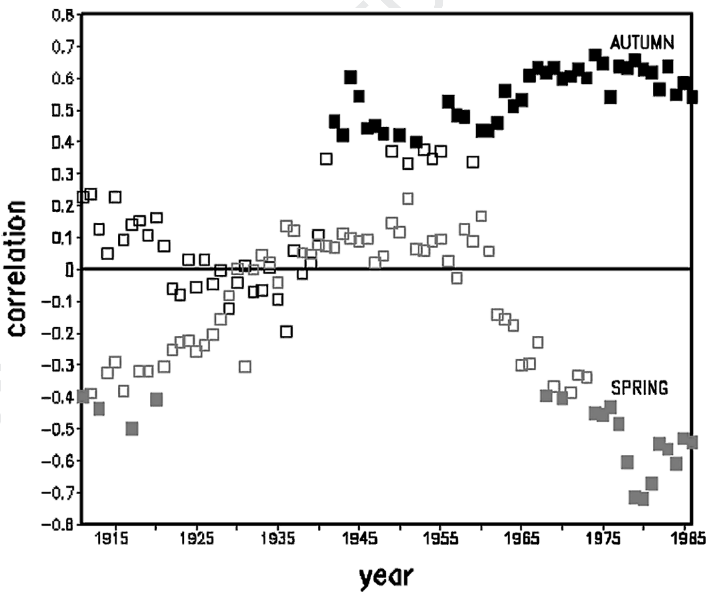

Figure 47: Correlations between western Mediterranean rainfall (from the data base of the Climate Research Unit (CRU), University of East Anglia, UK) and Nino3.4 indices in autumn (SON, black) and spring (MAM, grey). Each value refers to the correlation in a 20-year window centered at the symbol. Full symbols are for values at least 95% significant (After Mariotti et al., 2002, Fig. 6 therein).

found by the early work of Kiladis and Díaz (1989) and Mason and Goddard (2001). The observational evidence suggests a link between southwest Europe rainfall anomalies and circulation anomalies in the North Atlantic/European sector, while a more direct connection to the Indo-Pacific region and Middle-Eastern jet-stream variability for the rainfall anomalies in southwest Asia. The teleconnection mechanisms for warm and cold ENSO events appear to be different, with a prevailing signature of PNA/NAO-like variability in the former case and a more relevant role for tropical Atlantic SST anomalies in the latter (Fig. 48).

Regarding ENSO signatures in the North Atlantic/European sector by using common statistical techniques, Rodó (2001) highlighted the difficulty in isolating ENSO signals mainly due to their spiky nature with respect to the dominating mid-latitude dynamics. Their importance for the Mediterranean climate might be high, though only for selected intervals and vanish elsewhere. Rodó (2001) showed this occurrence for SST anomalies in the western Mediterranean basin. The possibility of an ENSO influence through perturbations of the Atlantic Walker circulation was also highlighted by Rodó (2001), who stated the importance of a weak Atlantic Hadley cell as a response to anomalous warming in the eastern tropical Pacific. This is in accordance with Sutton et al. (2000), Saravanan and Chang (2000) whose results suggest that a fraction of the inter-hemispheric variability in the tropical Atlantic is forced by way of a tropical atmospheric bridge (Lau and Nath, 1996, Klein et al., 1999).

Correlation between ENSO and Iberian rainfall has increased in the second half of the 20th century (Rodó et al., 1997), but the only relevant (significant) area is confined to the eastern part of the peninsula. Later studies confirm these connections and suggested possible mechanisms responsible for those

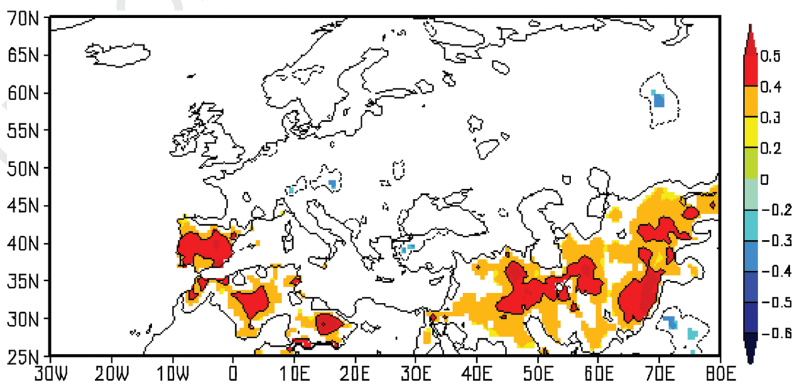

Figure 48: Correlations between Euro-Asian autumn rainfall and Nino3.4 indices for the period 1948–2000. Shading depict region where the correlation is at least 95% significant. Data is from CRU. (After Mariotti et al., 2005, Fig. 1a therein).

associations (Rodó, 2001; van Oldenborgh et al., 2000; Mariotti et al., 2002), which appear to involve a typical bipolar seesaw between the Mediterranean region and northern Europe.

Correlations between ENSO and Iberian rainfall are maximum in autumn before a mature El Niño phase and in the spring following the El Niño peak. Sign of the correlations points to an increase in autumn rainfall in the year 0 and a decrease in spring precipitation in the year + 1.

ENSO-Iberian rainfall correlations may account for up to 50% of springtime decrease in rainfall in certain areas while slightly lower values, showing a converse association with El Niño, were estimated for autumn. These values mostly concentrated in the second half of the last century, a time when correlations appear to have intensified (Rodó et al., 1997; Mariotti et al., 2002), particularly after the 1960's.

The ENSO influence appears most relevant at inter-annual timescales than the NAO effect. At inter-annual timescales the NAO effect shows no clear signature on Iberian rainfall, except for small selected areas. Conversely, ENSO accounts for half of the total annual variance in southeast Spain and parts of Morocco. The potential for future predictability needs to be further assessed in the light of the lack of current predictors for Mediterranean climate at inter-annual timescales and provided there is a sufficient time lag of some months between the two processes here involved. A gain of the inter-annual predictability potential would be mostly relevant for agricultural systems and other economic activities with the high impact on population in the Mediterranean region (Rodó and Comín, 2000)

2.2.3 ENSO and Extreme Mediterranean Rainfall

Alpert et al. (2002) calculated relative contributions of 6 daily rainfall intensity categories to the annual rainfall amounts between 1951 and 1995 over Spain, Italy, Cyprus and Israel. Both the linear and the monotone non-linear (Spearman's) time tests show significant increases in heavy daily rainfall in spite of decreases in annual totals. For instance, torrential rainfall in Italy, above 128 mm/day, increased percentage wise by a factor of 4 between 1951 and 1995. It is interesting to note that the torrential rainfall peaks were observed in the El-Niño years.

2.2.4 Transient and Stationary Waves Approach

Previous work has shown an ENSO-impact during boreal winters, with a trough (ridge) over southern Europe during El Niño (La Niña) events, accompanied by more (less) cyclones reaching the Mediterranean region. That is, both the mean flow and the sub-seasonal variations of the flow are affected by ENSO. In particular, the sub-seasonal variations tend to feedback on the anomalous mean flow. However, the impact in the Atlantic and Europe, and, in particular, in the Mediterranean region, appears to be more robust during La Niña events than during El Niño ones. Previous work from the Interannual and Decadal Climate Variability: Scale Interaction Experiments (SINTEX) EU project (Gualdi et al., 2003) indicated that the dominating mode of interaction – resembling the NAO – is only related to La Niña but not to El Niño events. Further, these modes – though defined in the Atlantic and Europe – appear to be connected to the North Pacific and North America. This suggests that transient eddies are also important in "transporting" the ENSO-response from the latter regions to the Atlantic and Europe. This insight gained may improve the prospects of seasonal prediction in the Atlantic/European region. Modelling experiments could cope with a complex response to ENSO through the alteration of mid-latitude internal modes of variability (e.g., NAO, East Atlantic/West Russian (EATL-WRUS), etc.), in particular with respect to future scenarios (e.g. Timmermann et al., 1999).

2.2.5 Possible Coupling Mechanism of ENSO and the Mediterranean

The search for the physical mechanisms that might be responsible for the connection between the tropical Pacific and the North Atlantic European region was initiated through the exploration of ENSO signatures in different regions of the tropical Atlantic. Lanzante (1996) and Enfield and Mayer (1997) explored remote forcing of the tropical Atlantic and noted a significant correlation with ENSO. They suggested that a fraction of the inter-hemispheric variability in the tropical Atlantic is forced by way of a tropical atmospheric bridge (Lau and Nath, 1996; Klein et al., 1999). Other studies have suggested such a link along a zone from 10°N to 20°N (Curtis and Hastenrath, 1995; Nobre and Shukla, 1996; Mestas-Nuñez and Enfield, 2001). In addition, Sutton et al. (2000) and Saravanan and Chang (2000) suggest an influence through perturbation of the Atlantic Walker circulation. This possibility was also highlighted by Mestas-Nuñez and Enfield (2001) and Rodó (2001), who stated the importance of a weak Atlantic Hadley cell as a response to anomalous warming in the eastern tropical Pacific. Finally, Sutton et al. (2000) suggested that a variety of competing mechanisms might be responsible for the weakening of the Atlantic cell during boreal winters. Recently, Ruiz-Barradas et al. (2003) with the aid of model simulations and the NCEP–NCAR reanalysis data for the period from 1958 to 1993, showed how anomalous ENSO-related diabatic heating influences near-surface winds in the tropical Atlantic. This remote influence directly induces changes in the intensity of both the Atlantic Walker and Hadley circulations.

The simulation of Mediterranean climate as influenced by some major modes of atmospheric variability appears to have improved in the recent years (see also Luterbacher et al., this book; Trigo et al., this book). In particular, the simulation of NAO responses to ENSO was improved. However, the nature of NAO prospects for predictability are limited to a few months and do not offer much field for predictability studies in the seasonal/interannual range. In this respect, a notable portion of the NAO predictability potential for future studies lies at scales longer than decades (Griffies and Bryan, 1997).

Several reasons may account for the limited ability of the GCM to simulate the ENSO responses at mid-latitudes. Among those, note, for instance:

- ENSO transmission to mid-latitudes appears to operate through a complex teleconnection pattern that interacts with strong internal mid-latitude atmospheric dynamics. This transition further complicates its observational identification with techniques that need study of aggregates or ‘‘composite’’ events. This fact may also result in a serious limitation of its predictability potential. For instance, occasionally different events have been documented to have yielded different responses.
- The coarse resolution of global models over the Mediterranean region does not yet yield credible simulation scenarios.
- The nesting of regional models in global models is not yet developed enough for the Mediterranean sector, though together with downscaling techniques provides a promising area to investigate in the future.
- The Mediterranean sea is not adequately integrated in most model simulations. In addition, boundary responses coming from adjacent oceanic and terrestrial regions surrounding the Mediterranean area are not fully covered in regional experiments, yielding a poor representation of Mediterranean conditions.
- Processes of the previous four items may be responsible for some difference in ENSO sensitivity detected by observational and modelling studies. The latter usually yields weaker responses to ENSO out of the tropical regions (Rodó, 2001). A deficient integration of transients and transitory couplings might account for a significant portion of the residual variability left, as proved by recent observational studies.

Recent modelling studies show new areas for exploration in ENSO teleconnections, which might be of use in the future, in the search for increasing predictability of the Mediterranean climate. This is, for instance, the case with experiments seeking to simulate the atmospheric forcing in regions of the tropical North Atlantic during ENSO events (Lau and Nath, 2001). Another possibility is increasing horizontal resolution to obtain more reliable responses.

This is the case for a recent study by Merkel and Latif (2002), illustrating that an increase of the horizontal resolution (from T42 to T106) causes significant changes in sea level pressure (SLP), temperature and precipitation over the Mediterranean as well as in the transient/ stationary wave activity. A southward shift of the North Atlantic low pressure systems in the winter season during El Niño was also noticed.

2.3. South Asian Monsoon Variability and the Mediterranean Climate

The South Asia Monsoon (SAM) is a key factor influencing the climate of the eastern and central Mediterranean (Reddaway and Bigg, 1996; Rodwell and Hoskins, 1996, Ziv et al., 2004a, b). It causes high variability in SLP over Arabia and the Middle East with high pressures in winter and low pressures in summer. The adjustment to the SAM couples the falling pressure and land temperature over the Indian subcontinent/ Asia Minor, with rising pressure and temperature over the Persian Gulf and Iraq.

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Another possible explanation for the different climatic behaviour of the eastern and western Mediterranean basins is derived from the gradual delay, of up to two weeks, of the onset of the monsoon in the 1980s, as compared with that in the early 1950s (Subbaramayya et al., 1990). This places the period of monsoon low pressure firmly in the summer months (JJA), whereas, previously, it was partly in May. On an average, this potentially lowers the summer pressure along with the temperature by shifting the monsoonal cloud cover, later in the season (Reddaway and Bigg, 1996). In accordance with Kripalani and Kulkarni (1999), this monsoonal delay could be attributed to the prolongation of the winter snow cover over Eurasia. They reported on a significant negative (positive) relationship between the wintertime snow depth over western Eurasia (eastern Eurasia and central Siberia) and subsequent Indian monsoon rainfall. This correlation structure is indicative of a mid-latitude longwave pattern with an anomalous ridge (trough) over Asia, during the winter prior to a strong (weak) monsoon.

Rodwell and Hoskins (1996) showed that the Asian Summer Monsoon dominates not only Central Asia, but also the Eastern Mediterranean (EM). By using numerical simulations, they pointed at the linkage between the appearance of the semi-permanent subsidence structure over the EM and the onset of the Monsoon. The climatic regime and the dynamic factors governing the EM in the summer season, and their relationships with the Asian Monsoon, were analyzed by Ziv et al. (2004a), who found significant correlation on the interdiurnal time-scale. They identified a circulation connecting the upward motion maximum over the Himalayas with the downward motion over the EM. Raicich et al. (2003) studied the relationship between the Asian and African Monsoon systems and found a high correlation between the intensity of each of them and the pressure distribution over the Mediterranean on the interannual time-scale.

The monsoon–desert mechanism presented by Rodwell and Hoskins (1996) may not be confined to the Asian monsoon alone. In a similar way, it could explain the relationship between the observed summertime strengthening of the oceanic sub-tropical anticyclones and the existence of western continental deserts and of "Mediterranean type" climate regions. They showed that the monsoon could force a remote descent to its west and northwest. The very dry summertime climate of the Mediterranean and the surrounding lands may be strongly related to this. They also showed that this descent is highly dependent on the latitude of the monsoon heating; a southward shift, for example, may lead to wetter weather, for southern Europe.

2.3.1. Mediterranean Climate and South Asian Rainfall

The Indian summer Monsoon index has been recorded for almost 200 years, while records of the subsequent winter rain in Israel are relatively "younger"; the longest record used is the one kept in Jerusalem, for the past 118 years. The overall correlation between these two indices was found to be only −0.3 (for the past 118 years). However, in 73 years (62%), the indices sign were the opposite. For extreme summer seasons, in which the index deviates by over 1.3 standard deviations, the correlation increases to −0.56 (Alpert et al., 2003). Similar results were found for other relatively long-record of rainfall stations in Israel. This illustrates the potential of the Indian Monsoon as a predictor for Israeli rainfall in the subsequent winter season.

An important index of monsoon precipitation is the All-India Rainfall Index (AIR; Parthasarathy et al., 1995). It is an areal average of rainfall for 29 sub-divisions, which come from areally averaged district rainfalls. Rainfall amounts are totals for June, July, August and September (Parthasarathy et al., 1995). The AIR data are available online at: http://grads.iges.org/india/allindia.html. Liu and Yanai (2001) found significant positive correlation between June–September AIR and JJAS tropospheric temperature from 1949 to 1998, over the entire Mediterranean and northern Africa, within pressure levels from 200 and 500 hPa levels. Similar results have been revealed for the southern and eastern Mediterranean in June and for the eastern Mediterranean in August (Liu and Yanai, 2001).

While the role of the Tropical Atlantic Variability (TAV), ENSO and associated changes in SST over the tropical Pacific and Atlantic oceans have been widely investigated, the effect of the Indian Ocean on monsoon rainfall is not well understood. The existence of the Indian Ocean Dipole (IOD) mode was demonstrated by Saji et al. (1999) Webster et al. (1999) and Andersen (1999). A respective index was determined, though no statistical relationship between the index and the monsoon rains has been established. It is suggested that the variations in distribution and intensity of the EM rainfall, during the last decade, are associated with variations in the characteristics of the air mass over the Indian Ocean via its transport toward the EM. However, recent findings of idealized SST anomaly experiments by Hoerling et al. (2004) and Hurrell et al. (2004), indicate that SST variations have significantly controlled the North Atlantic circulation, related to the NAO, with the warming of the tropical Indian and western Pacific Ocean being of particular importance.

When the winter regime over the entire Mediterranean is considered, the focus is given to the Rossby waves and other extra-tropical factors (such as the NAO) as the dominating features. However, some attention should be given to continental polar outbreaks associated with the South Asian Monsoon (e.g. Saaroni et al., 1996).

2.4. African Monsoon Impact on the Climate of the Mediterranean

The climatic variables in the various parts of the Mediterranean are correlated with each other as well as with external circulations. For instance, the Mediterranean SLP oscillation (MO), i.e., the difference between its western and eastern parts, is correlated with precipitation. In winter, a fundamental role is played by the NAO index, whereas in summer, the regional Hadley cell was found to be correlated with climatic conditions over parts of the Mediterranean (see Trigo et al., this book). There is also some evidence for teleconnections with the South Asian Monsoon and with the Sahel precipitation. The correlation between the precipitation indices of these two systems and the MO is negative over the EM and positive over the western Mediterranean. The relevant governing mechanisms have been studied by several authors (see Baldi et al., 2002 for an extended bibliography), as well as the influence of the position and the strength of the Hadley cell (Dima and Wallace, 2003).

Focusing on the summer season, Chen et al. (2002), showed evidence for strengthening of the tropical general circulation in the 1990s, and in particular the West Africa monsoon, reaching its northernmost extension in August, when the ITCZ, after the abrupt shift at the end of June and further slow northward migration, reaches its northernmost location (Sultan and Janicot, 2000, 2003). Important mechanisms, such as heat and moisture advection in

North America and Asia and anomalously high values of the surface albedo in northern Africa, limit a further extension towards northern latitudes (Chou and Neelin, 2003; Rodwell and Hoskins 1996, 2001). The two regimes, the dry and hot summers in the Mediterranean and the monsoon regime over West Africa, are highly correlated; interactions and feedback mechanisms between the two are not only possible, but also evident (Rowell 2003, Baldi et al., 2002, 2003a, b).

Ziv et al. (2004a), in their study of the summer regime, found a signature of the Hadley cell over eastern North Africa, connecting the EM with the African Monsoon. The relationship between them is manifested by a significant correlation between the ascent at 15°N –20°N latitudes and the descent at 30°N –40°N latitudes. The correlation between the EM subsidence and the Asian Monsoon was further validated through correlating the inter-diurnal variations of the vertical velocities of the two Monsoon systems, yielding $r = 0.33$, in spite of the ~6000 km distance.

2.5. Tropical Cyclones' Impact on the Mediterranean Climate

Reale et al. (2001) showed that several cases of severe floods over the western Mediterranean could be traced back to hurricanes. Also, Hoskins and Berrisford (1988) related the severe 1987 storm in South England to hurricanes. Next, we review a first study showing the relationship between flooding in Israel and hurricanes (Fig. 49). Over the period from 3–5 December, 2001, there were heavy rains in northern Israel reaching 250 mm in some areas. The rains were associated with a relatively weak cyclone system approaching the area from the north-west. Atmospheric developments that produced the unusually intense rainfall and flash floods in Israel during 3–5 December 2001 were associated with upper-tropospheric jet stream activity. This activity was stimulated by the potential vorticity (PV) streamer conditions in the upper troposphere and by the intense intrusion of cold stratospheric air masses into the troposphere over the Mediterranean Sea area. Local topography and geography of the EM region also played a role of an additional triggering factor in the process. The intense synoptic processes of December 2001 were initiated by the development of a tropical storm, which subsequently developed into hurricane Olga (from 25 to 29 November) accompanied by intense ascent motions in the tropical Atlantic. Convergence of huge amounts of atmospheric water vapour took place during the first stage of the hurricane development. Both the rise of large amounts of warm and moist tropical air and the subsequent release of latent heat caused an additional intensification of the hurricane.

This process also induced development of an anticyclone to the north-east of Olga. The ascending moist air from Olga was later transported to Europe and

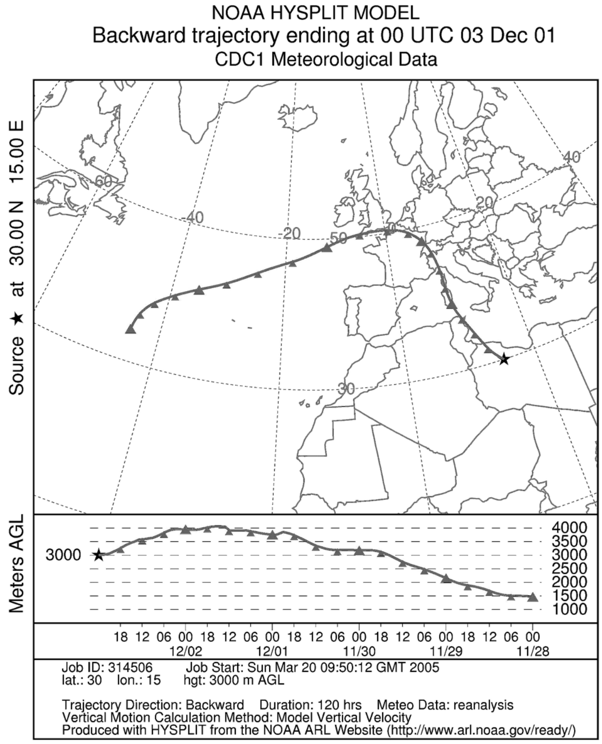

Figure 49: The back-trajectory from Mediterranean to Hurricane Olga3 - December - - > 28 November 2001.

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finally to the Mediterranean region by the high intense clockwise atmospheric circulation in the process of Olga's decline. This process led to the southward propagation of the polar jet and to the establishment of a situation characterized by the tropopause fold PV streamer with an extrusion of cold upper-tropospheric and stratospheric air over the south Alpine and the central Mediterranean areas. Formation and intensification of the EM cyclone of 3–5 December 2001 was additionally stimulated by the interaction of the polar and subtropical jets over the region (Krichak et al., 2004).

2.6. Tropical Intrusions into the Mediterranean Basin

Rains in the Mediterranean basin take place mainly during winter, most of which is associated with Mediterranean baroclinic cyclones. Winter Mediterranean cyclones have their origin in the North Atlantic synoptic systems, in secondary lows formed when upper troughs interact with local orography, and/or with low level baroclinicity over the northern Mediterranean coast. However, processes originating from tropical regime are also significant in its eastern part (Krichak et al., 1997a,b; Krichak and Alpert 1998; Dayan et al., 2001; Kahana et al., 2002; Ziv et al., 2004b) and along its western part, in north western Africa (Knippertz et al., 2003). The Red Sea Trough (RST) is one of the impressive manifestations of mid-latitude–tropical interactions in the EM especially during autumn and spring. The intensity and duration of the EM rain-spells highly depend on the interactions between the upper and lower-tropospheric jets as well as their positioning and orientation. Specific jet characteristics stimulate development of meso-scale convective complexes and cyclogenesis. Due to turbulence associated with strong wind shear, tropopause folding may allow intrusions of the stratospheric air into the troposphere. It was recently shown that frequencies of RST intrusions into the EM, have nearly doubled since 1970 from about 50 d/y to about 100 d/y (Fig. 50) (Alpert et al., 2004a,b)

Another type of rainstorms originating from the tropics is associated with ‘‘tropical plumes’’. This is a long cloud band that extends from the ITCZ down to 30°N–40°N latitude, accompanied by a pronounced trough in the Subtropical Jet to its west combined with a ridge to the east, while no common distinct system

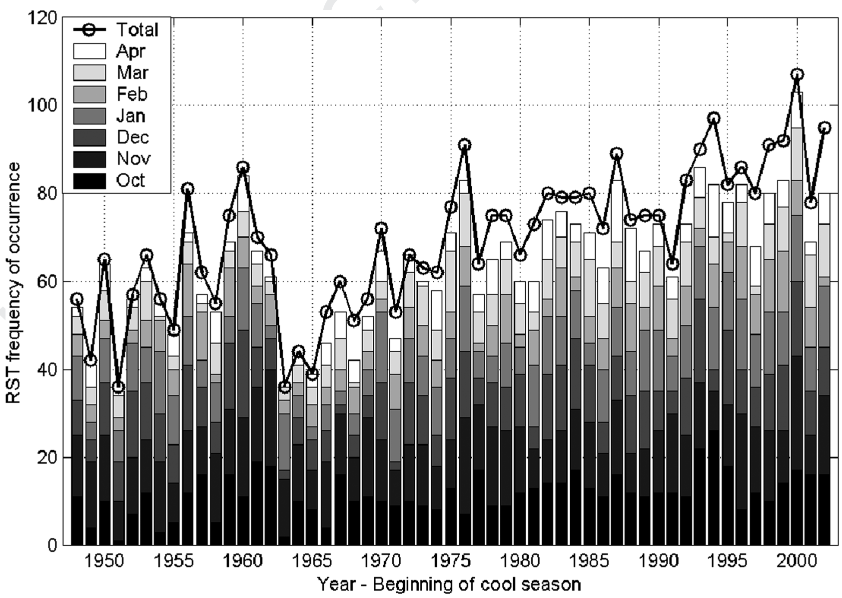

Figure 50: The Red Sea Trough frequencies as totals per hydrological year (August to July) and cumulative monthly contributions (October to April).

at the surface or at the 500hPa level, was found. Ziv (2001) found that prior to such type of a rainstorm the "tropical plume" is generated. It extends toward the subtropics, injects moisture of tropical origin that is captured by the Subtropical Jet, and if a pronounced trough develops there, extensive stratified cloudiness and widespread rains result. Zangvil and Isakson (1995) found in a rainstorm of the same type that the vertically integrated moisture convergence reached 1.8 mmh^{-1} over Israel, mostly above the 750 hPa level. Dayan and Abramski (1983) found an abnormal feature in the Subtropical Jet structure, i.e. a reversed position of its axis that leads to the formation of a large and humid warm air mass up to very high levels in the atmosphere above the Middle East.

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2.7. Mediterranean Dust Transport from Sahara

The role of atmospheric aerosols on the climate system is found to be most significant (IPCC, 2001). The dust radiative effect strongly depends on its vertical location. Daily model-based forecasts of 3D-dust fields could be used in order to determine the dust radiative effect in climate models, because of the large gaps in observations of dust vertical profiles (Alpert et al., 2004c). The averaged dust vertical distribution, based on the 3-year database of 48-hour dust forecasts, shows significant differences between the Atlantic and the Mediterranean dust transport. As a whole, the Mediterranean dust is found to be within a wider range of altitudes, penetrating high into the troposphere (Fig. 51).

Supporting evidence for this characteristic feature of the Mediterranean dust transport was obtained from the analysis of lidar dust profiles over Rome

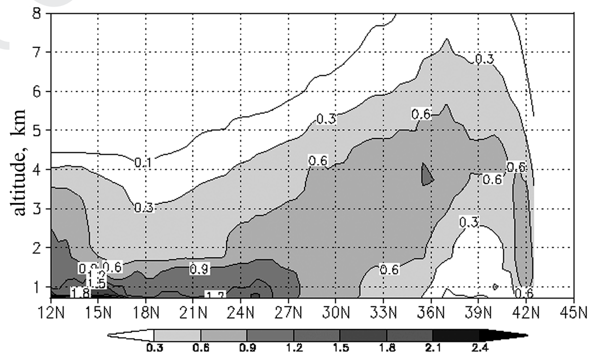

Figure 51: Latitudinal cross-sections of averaged dust concentrations (10^{-7} kg/m^3) for the months of April, zonal averaged within the longitudinal zone 30°E–40°E. Adapted from Alpert et al. (2004c).

(Italy), collected in the 3-year period 2001–2003 during the high dust activity season from March to June (Kishcha et al., 2005). Based on the data set of dust-affected lidar profiles (206), Fig. 52 presents histograms of the main parameters of these dust layers. In particular, the bottom boundary was found to range from 0.5 to 5 km, with the mean value BT $= 1.6 \pm 0.8$ km; the top boundary ranges from 2.4 to 8 km, with mean value TP $= 5.1 \pm 1.1$ km, and the thickness of dust layers ranges from 0.4 to 7.5 km, with mean value TH $= 3.6 \pm 1.5$ km. Hence, on an average, dust over Rome is distant from the surface and penetrates high into the troposphere. Moreover, as shown in Fig. 52, the Gaussian fitting curves suit the histograms of lidar-derived data. In seasons other than March – June, some indication of the mean vertical distribution of dust over Rome can be found in Gobbi et al. (2004), based on lidar data collected in the year 2001.

The lidar vertical profiles collected in the presence of dust over Rome were also used in order to validate the TAU dust model. A quantitative comparison of model vertical profiles against lidar soundings was made and the model was found good in about 70% of the cases (Kishcha et al., 2005).

Saharan dust is generally transported over the Mediterranean by southerly winds generated by cyclones (Alpert and Ziv, 1989; Bergametti et al., 1989; Alpert et al., 1990; Moulin et al., 1998). In particular, Alpert and Ziv (1989) found that spring and early summer are the most favourable periods for the development of Saharan lows (also called Sharav cyclones) south of the Atlas Mountains. Usually, such cyclones move eastward and cross Egypt, Israel and the eastern Mediterranean basin. As shown by Bergametti et al. (1989) and Moulin et al. (1998), dust outbreaks to the western and central parts of the Mediterranean are linked with two depression centres: Saharan lows and a high over Libya. The high over Libya prevents Saharan lows from following an eastward direction. This synoptic situation, having a peak in spring and in early summer, induces strong south and southwestern winds between the two systems and is characterized by dust intrusions from North Africa to the Mediterranean basin. Moreover, complex wind fields associated with frontal zones under those atmospheric conditions could be one of the causal factors for dust over the Mediterranean being within a wide range of altitudes, penetrating high into the troposphere, as mentioned above.

The mean synoptic situation associated with dust outbreaks from Sahara into the central Mediterranean was examined on a daily basis for the month of July from 1979 to 1992 (Barkan et al., 2004). It was found that the strength and position of two essential features of the circulation patterns, such as the trough emanating southward from the Iceland low and the eastern cell of the subtropical high, are the governing factors in making suitable flows for the Saharan dust transportation toward Central Europe. The typical composite pattern of wind in the case of five days of great quantity of dust in the atmosphere

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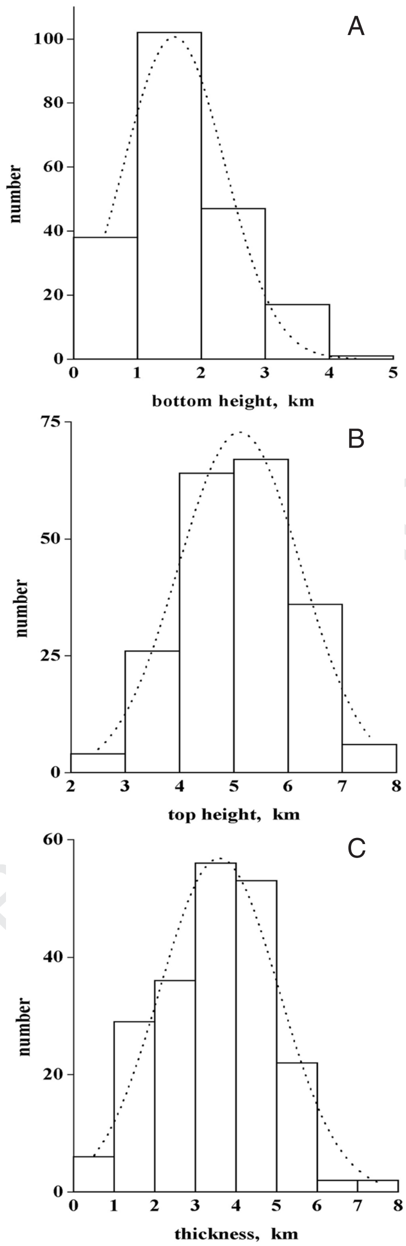

Figure 52: Statistical distributions of lidar-derived parameters of the dust layer over Rome from March to June based on the data set of dust-affected lidar profiles (206) between 2001 and 2003: bottom (A) and top (B) heights (km), and thickness, km (C). Fitting curves of the Gaussian distribution are shown by dotted lines. From Kishcha et al. (2005).

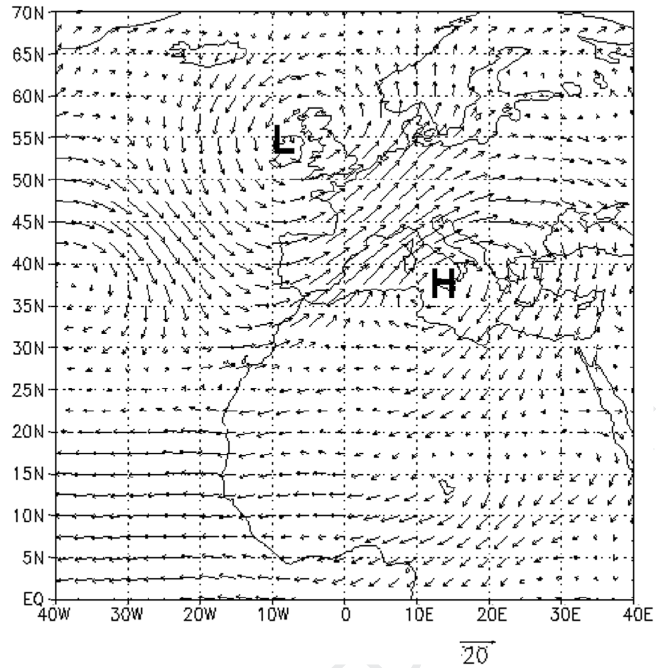

Figure 53: Average wind flow of the dusty period 5–9 July 1988 at 700 hPa. Adapted from Barkan et al. (2005).

above Italy between 5 and 9 July 1988 is shown in Fig. 53. A deep low over Ireland with a strong trough emanating from it southward and splitting the subtropical high into two separate cells is apparent. The eastern high pressure centre is located over Sicily. Between the Irish low and the Sicilian high, a strong southwesterly flow transports dust from Mauritania across the western Mediterranean to central Europe.

2.8. Conclusions and Outlook

The aforementioned evidence of tropical teleconnections to the Mediterranean climate suggests further analysis in order to test these relationships by using appropriate modelling and statistical methodologies. The factor separation method (Stein and Alpert, 1993; Alpert et al., 1995) may be useful for distinguishing among contributions of several factors and also of their synergetic effects in producing weather patterns over the Mediterranean. Thus, the modelling approach with a well-defined methodology is necessary for a

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clear and simple mechanistic understanding of the different teleconnections discussed here.

2.8.1. Future Research on ENSO Impact on Mediterranean Climate

- Investigate the role of mid-latitude ocean in responding to the atmospheric forcing which have a tropical origin (Lau and Nath, 2001) and its effect on the Mediterranean climate.
- Improve resolution and accuracy of observational studies with the use of a denser, homogeneous set of instrumental records.
- Implement new statistical techniques capable of address local phenomena. These are needed to address ENSO and other tropical influences in the Mediterranean climate. As an example, the new Scale-Dependent Correlation (SDC) technique (Rodó, 2001, Rodó et al., 2002, Rodríguez-Arias and Rodó, 2003) may be useful.
- Analyse and devise modelling experiments which can cope with a complex response to ENSO, also through the alteration of internal modes of variability at mid-latitudes (e.g., NAO, EATL-WRUS, etc.).
- Improve the nesting of regional climate models, increase their horizontal resolution and refine model simulations for a more realistic representation of the Mediterranean climate.
- Explore the different scenarios of the future ENSO frequency and intensity changes, in response to climate change (e.g. Timmermann et al., 1999). Assess their relation to the Mediterranean climate variability and extremes.

2.8.2 Future Research on South Asian Monsoon Variability and the Mediterranean Climate

- To study teleconnections of the South Asian Monsoon with the eastern Mediterranean for different time scales, i.e. interannual, seasonal and decadal time scales. Attempt to evaluate the range of influence of the Asian Monsoon over the entire Mediterranean basin.
- To study long-term trends of various variables, as Saaroni et al. (2003) performed for summer temperature, in relation to long-term trends in the South Asian Monsoon features along the entire year.
- To study the detailed structure of summer circulations over the eastern Mediterranean region prior to and during extreme episodes in which the EM undergoes heat waves or exceptional rain events.

- To incorporate data about the South Asian Monsoon into the seasonal prediction scheme for the Israel winter rainfall.
- To validate the suggested linkages between the Indian Ocean processes and the eastern Mediterranean climate.
- To develop a climatologic basis for continental polar outbreaks events over the Mediterranean. This includes both synoptic and statistical detailed analyses.
- To assess the statistical relationship between the variations in the EM rainfall amount, distribution and intensity, on the one hand, and the long-range variations of the characteristics of the air mass transport associated with the Indian Ocean Dipole, on the other hand.

2.8.3. Future Research on African Monsoon Impacts on the Climate of the Mediterranean

- To study teleconnections between the summer climate in the Mediterranean and the African Monsoon by using numerical simulations. The major tools could be the NCEP–NCAR and ECMWF reanalyses, historical time series of atmospheric parameters in southern Europe (Luterbacher et al., this book), Regional numerical models, scenarios for future climate produced by global climate models, like the ones from the Canadian Centre for Climate Modelling and Analysis (CCCma), and also gridded precipitation data provided by the Global Precipitation Climatology Project.
- To perform numerical simulations with the Regional Model on different time-space scales for the domain including Europe, the Mediterranean Basin and the northern part of the African continent north to the Gulf of Guinea. The effects of SST variability in the Gulf of Guinea on the climate variability in the Mediterranean should be assessed by using an approach similar to that presented by Vizy and Cook (2001, 2002). In turn, the influence of the Mediterranean SST on climate variability in the North African region should be studied.
- To perform time-slice experiments for the future climate evolution by using the regional model, according to different available scenarios. Since the phenomena are embedded in the large scale circulation and in particular in the Hadley cell circulation, therefore a mathematical model of the evolution of the Hadley cell should be elaborated.
- To study the linkage between the Mediterranean climate, CLIVAR VACS (Variability of the African Climate System) and AMMA (African Monsoon Multidisciplinary Activities).

2.8.4. Future Research on Tropical Intrusions into the Mediterranean Basin

- To define general mechanisms of tropical intrusions of the Red Sea trough and the tropical plume into the EM.
- To find out the role of the Red Sea trough and the tropical plume in the general atmospheric circulation over the Mediterranean. In particular, to find out their role in the transport of moisture and angular momentum.
- To study physical reasons and mechanisms of the recent increase in tropical intrusions into the Mediterranean.

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