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IL NUOVO CIMENTO Vol. 29 C, N. 1 Gennaio-Febbraio 2006
DOI 10.1393/ncc/i2005-10225-y

Mediterranean climate and some tropical teleconnections(*)

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(ricevuto l'1 Settembre 2005)

Summary. — Some strong natural fluctuations of climate in the Eastern Mediterranean (EM) region are shown to be connected to the major tropical systems, *e.g.*, El Niño Southern Oscillation, South Asian Monsoon and hurricanes. Modelling of the severe floods suggests a relation to tropical hurricanes. For a specific event, high-resolution modelling of the severe flood on December 3-5, 2001 in Israel suggests a relation to hurricane Olga. In order to understand the factors governing the Eastern Mediterranean climate variability in the summer season, the relationship between extreme summer temperatures and the South Asian Monsoon was examined. Other tropical factors, like the Red Sea Trough system and the Saharan dust, also contribute to the Mediterranean climate variability.

PACS 92.60.Ry – Climatology.
PACS 92.70.Gt – Climate dynamics.
PACS 92.60.Bh – General circulation.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

The Mediterranean climate is affected by several tropical and subtropical systems. These factors range from the El Niño Southern Oscillation (ENSO) and tropical hurricanes to the South Asian Monsoon and to Saharan dust. This can partly explain some of the 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 is elaborated in sect. **1**, tropical cyclones are discussed in sect. **2**, sect. **3** is dedicated to the South Asian monsoon, and finally Red Sea Trough intrusions into the Eastern Mediterranean and the Saharan dust are discussed in the

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(*) Paper presented at the Workshop on "Historical Reconstruction of Climate Variability and Change in Mediterranean Regions", Bologna, October 5-6, 2004.

two last sections 4 and 5. A special focus is given to the Central and the Eastern Mediterranean.

2. – El Niño and rainfall in Israel and Italy

The El Niño-Southern Oscillation (ENSO) is the largest oscillation of the Earth's climate system after the annual cycle, lasting for 12-18 months each time it occurs. During El Niño episodes lower than normal pressure is observed over the eastern tropical Pacific and higher than normal pressure is prevalent over Indonesia and northern Australia. This pattern of pressure is associated with weaker than normal near-surface equatorial easterly winds. These features characterize the warm phase of ENSO when 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. Anomalies in tropic al Pacific SST and pressure, peaking in December (during the Mediterranean winter rainy season), lead to shifts in global circulations patterns, which may result in changes in circulation patterns in midlatitudes, even in the Mediterranean. Yakir *et al.* [1] and Price *et al.* [2] showed significant connections between ENSO events and winter rainfall in Israel, both indicate increased rainfall occurring in El Niño winters. Price *et al.* [2] 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 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 ($r \simeq 0.67$) with the seasonal NINO4 temperatures (fig. 1). 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 $\simeq 1$ degree in its mean position can have a major impact on the storm tracks, and hence on the rainfall amounts.

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 have been only available since the end of the 1960s. However, since individual rain gauge measurements in the watershed are highly correlated ($r \simeq 0.9$) 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 [3] 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. Alpert *et al.* [4] 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

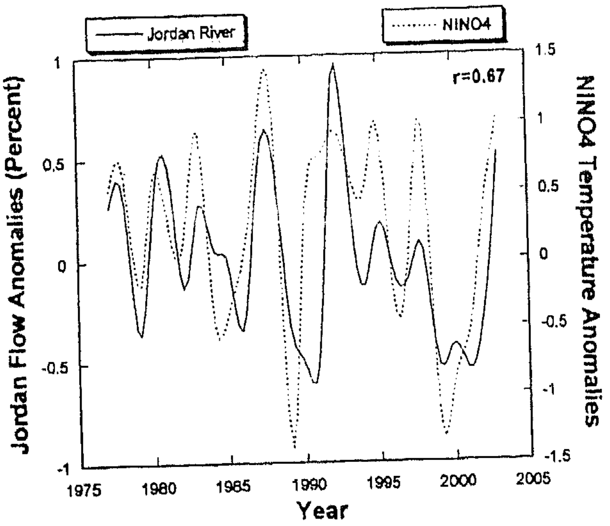

Fig. 1. – The winter streamflow in the Jordan River and the winter NINO4 SSTs in the tropical Pacific. Adapted from [2].

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/d, percentage wise by a factor of 4 between 1951 and 1995. It is interesting to note that the torrential rainfall peaks in El-Niño years.

3. – Tropical Cyclones and rainfall in Israel

Reale *et al.* [5] showed that several cases of severe floods over the western Mediterranean could be traced back to hurricanes. Also, Hoskins and Berrisford [6] 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 [7]. Over the period from December 3-5, 2001, heavy rains fell 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 on December 3-5 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 region. Local topography and geography of the EM region also played a role of an additional triggering factor in the process [7]. 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 NE of Olga. The ascending moist air from Olga was later transported to Europe and finally to the Mediterranean region by the 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 December 3-5 2001 was additionally stimulated by the interaction of the polar and subtropical jets over the region.

4. – South Asian Monsoon and climate in the Eastern Mediterranean

The South Asia Monsoon is the key factor influencing the climate of the eastern and central Mediterranean [8,9]. It causes high variability in SLP over Arabia and the Middle East with high pressures in winter and low pressures in summer.

4'1. *Summer*. – The climatic regime and the dynamic factors governing the EM in the summer season were analyzed. Two main dynamic factors, competing with each other, were found to affect the EM: Upper- to mid-level subsidence and lower-level cool Etesian winds, which counteract each other. The persistent subsidence, causing the rain absence over the EM during summer, was found to be linked to the South Asian Monsoon via a closed circulation clearly seen in the isentropic cross-section [9]. It was found that strengthening (weakening) of the South Asian Monsoon enhances (weakens) both competing dynamic factors over the EM, resulting in the annual minimum of inter-diurnal temperature variations [10]. A long-term trend of the average seasonal temperatures over the EM indicates a warming trend of 0.013 K/y (for the period 1948-2002). This warming was combined with an increase in the extremity of the temperature regime, manifested by an increase in the frequency of both "hot" and "cool" days and by an increase in the seasonal maximum temperatures, 0.020 K/y, which is three times larger than the increase in the respective minimum temperatures. Both trends are demonstrated by the temperature distribution for the two 30-year sub-periods (fig. 2) [10]. It is worth noting also that the warm spells have become longer with time. Similar trends were shown also for the entire Mediterranean basin [11].

4'2. *Winter*. – It has been also recently shown [12] that winter rainfall in Israel in extreme seasons (since 1880) is in a significant negative correlation with the rainfall index for the preceding summer South Asian Monsoon.

5. – Red Sea Trough's trends and EM climate

The Red Sea Trough (RST) synoptic system develops over the EM region in the boreal cool season (October to April), when the Subtropical High retreats southwestward out of the EM. The RST, which is characterized by the easterly winds in its north-eastern part, mostly brings dry weather into the EM countries, with large diurnal temperature variations. The semi-objective classification of the EM daily synoptic systems [13] allowed analyzing the climatic trend in the numbers of RST days (RST's frequencies of occurrence). Since the mid-1960s to the early 2000s the annual numbers of the RST days rose from about 40 to about 100 (fig. 3). This means a general drying of the EM climate. For instance, the drought of the late 1950s-early 1960s over the EM corresponds to a

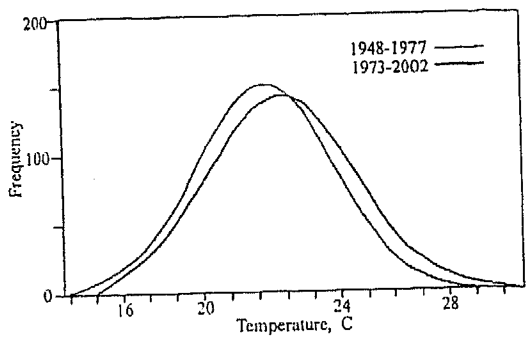

Fig. 2. – Distribution of 850 hPa daily temperatures at the 32.5N, 35E grid point for two 30-year periods: grey line: 1948-1977, black line: 1972-2002. The peak of each curve represents the mode temperature for the respective period. Adapted from [10].

local rise in RST frequencies. Alternatively, two recent remarkably rainy EM winters 1991/92 and 2002/03, correspond to local drops in the RST frequencies.

Averaged seasonal distributions of the RST frequencies during two 28-year adjacent non-over lapping periods have been analyzed on a daily basis following [14]. Comparison of these two periods shows that the rise in the October RST frequencies (fig. 3) was accompanied by the reductions in the Persian Trough (PT) frequencies in the first decade of this month and those of the Subtropical High (SH) in its second and third decades.

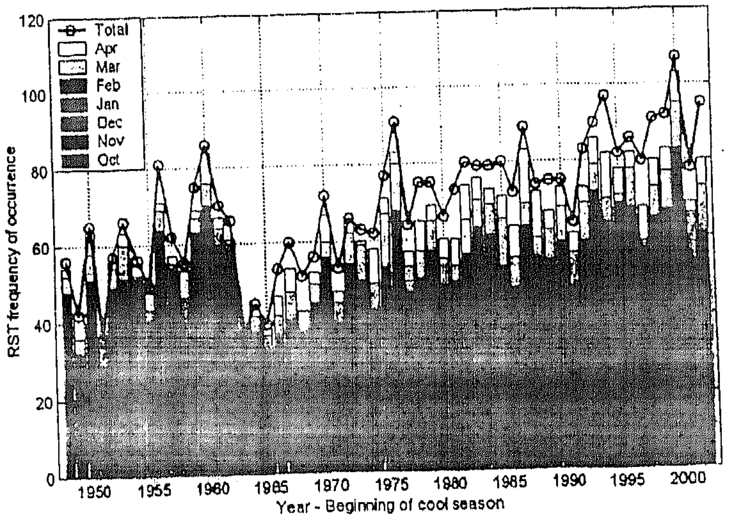

Fig. 3. – The Red Sea Trough frequencies as totals per hydrological year (August to July) and cumulative monthly contributions (October to April).

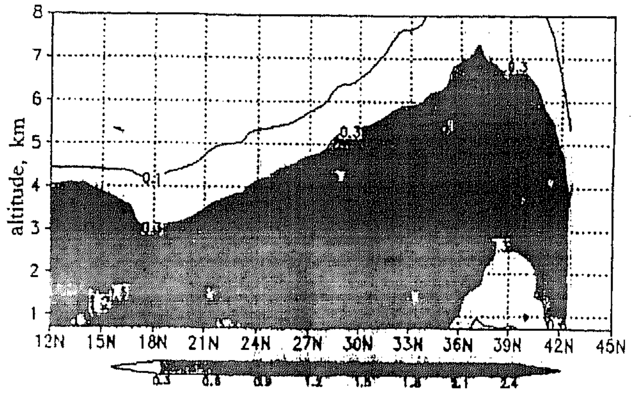

Fig. 4. – Latitudinal cross-section of averaged dust concentrations (10^{-7} kg/m^3) for the month of April, zonal averaged within the longitudinal zone 30°E-40°E. Adapted from [16].

Both PT and SH are the warm season's systems with westerly winds that bring the moisture of the Mediterranean Sea into the EM countries. At the same time, the increase in the October frequency of RST was accompanied by the decrease in the frequency of the Cyprus Lows bringing the rainfall in the region. Consequently, the October increase in RST frequencies explains the general drying EM climate in the early autumn, in spite of the fact of increasing October rainfall over South Israel.

6. – African dust and Mediterranean climate

The role of atmospheric aerosols on the climate system is found to be most significant [15]. 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 [16]. 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. 4).

Supporting evidence for this characteristic feature of the Mediterranean dust transport was obtained from the analysis of lidar dust profiles over Rome (Italy), collected in the 3-year period 2001-2003 during the high dust activity season from March to June [17]. Based on the data set of dust-affected lidar profiles (206), fig. 5 presents histograms of the main parameters of these dust layers. In particular, the bottom boundary (BB) was found to range from 0.5 km to 5 km, with the mean value $BB = 1.6 \pm 0.8$ km; the top boundary (TB) ranges from 2.4 to 8 km, with mean value $TB = 5.1 \pm 1.1$ km, and the thickness (TH) of dust layers ranges from 0.4 km to 7.5 km, with mean value $TH = 3.6 \pm 1.5$ km. Hence, on average, dust over Rome is distant from the surface and penetrates high into the troposphere. Moreover, as shown in fig. 5, 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 [18], based on lidar data collected in the year 2001.

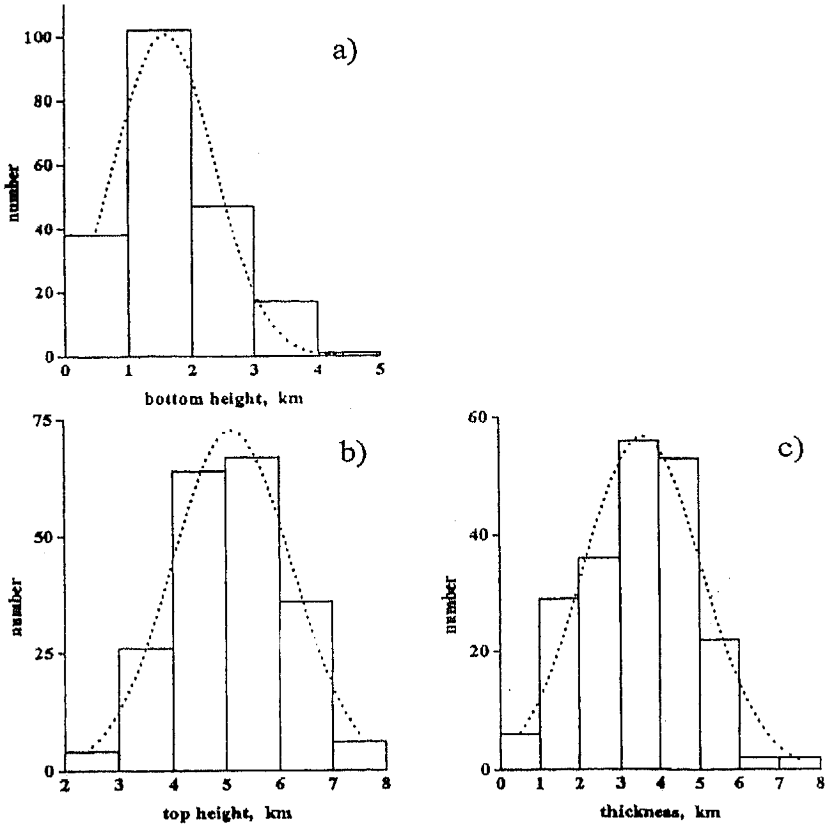

Fig. 5. – Statistical distributions of lidar-derived parameters of the dust layer over Rome from March to June based on the data set of dust-affected lidar profiles (206) between 2001 and 2003: bottom (a) and top (b) heights (km), and thickness, km (c). Fitting curves of the Gaussian distribution are shown by dotted lines. After Kishcha *et al.* [17].

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 [17]. Saharan dust is generally transported over the Mediterranean by southerly winds generated by cyclones [19-22]. In particular, Alpert and Ziv [19] found that spring and early summer are the most favorable 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.* [21], Moulin *et al.* [22], dust outbreaks to the western and central parts of the Mediterranean are linked with two depression centers: Saharan lows and a high over Libya. The high over Libya prevents Saharan lows from following an eastward

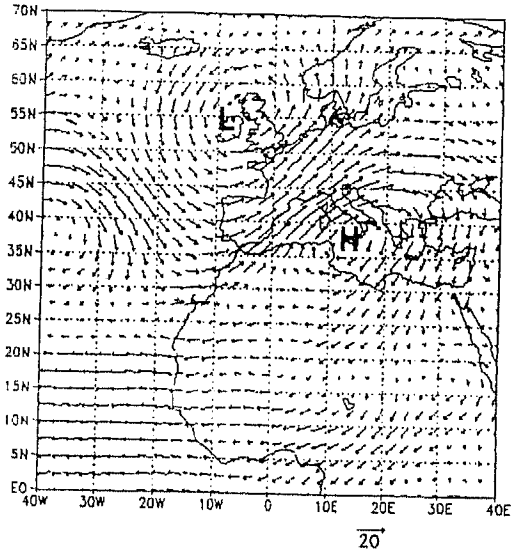

Fig. 6. – Average wind flow of the dusty period 5-9 July 1988 at 700 hPa. Adapted from [23].

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 daily basis for the month of July from 1979 to 1992 [23]. 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 above Italy between 5 and 9 July 1988 is shown in fig. 5. 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 center 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.

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This study was supported by the Israeli Science Foundation (ISF, grant no. 828/02) and also by the GLOWA-Jordan River BMBF-MOS project.

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