Large-Scale Variability Over Mediterranean Associated with the Indian Summer Monsoon

D. Rizou, H.A. Flocas, P. Athanasiadis, and A. Bartzokas

Abstract The objective of this study is the investigation of the large scale variability of the atmospheric circulation over the Mediterranean region in relation to the Indian summer monsoon. For this purpose composite anomalies of selected fields at various isobaric levels are analyzed for strong versus weak monsoon years. Gridded, monthly mean data, such as geopotential height, horizontal wind components, vertical velocity and relative vorticity at 300 hPa were used, as obtained from the ERA-40 Reanalysis Data Base, with $2.5^{\circ} \times 2.5^{\circ}$ resolution for the boreal summer (June-September) and for a 44-year period (1958–2001). The standardized Dynamic Indian Monsoon Index by Wang and Fan (1999) was employed to determine the strong and weak monsoon years in the 44-year period. It was found that there are significant differences between *strong* and *weak* composites for all fields, especially in the upper troposphere. The results suggest that these differences may be related to the existence of Rossby wave trains as well as to the intensity and the meridional shift of the upper-level jet streams.

1 Introduction

El-Nino Southern Oscillation (ENSO), South Asian and African monsoons, tropical hurricanes and Sahara dust constitute some of the factors of the tropical and subtropical climate variability that influence the Mediterranean region. Rodwell and Hoskins (1996, 2001) studied the impact of the Asian monsoon

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C.G. Helmis and P.T. Nastos (eds.), *Advances in Meteorology, Climatology and Atmospheric Physics*, Springer Atmospheric Sciences,
DOI 10.1007/978-3-642-29172-2_99,

on the Mediterranean and showed that the subsidence over the eastern Sahara/Mediterranean is influenced by the South Asian summer monsoon. More specifically, the strong diabatic heating associated with the rainfall in the South Asian summer monsoon region induces intensified easterlies in the equatorward portion of the North Pacific subtropical anticyclone, the Kelvin-wave response (Gill 1980), and a Rossby-wave response to the west of the monsoon region, which interacting with the southern flank of the mid-latitude westerlies, produces a region of adiabatic descent in the North African and Eastern Mediterranean (EM) regions. Ziv et al. (2004) proposed that the Etesian winds and the persistent subsidence over the region, which appear systematically during the summer, are linked to the Asian monsoon. They found that both of these features of the eastern Mediterranean circulation respond to the varying intensity of the Indian summer monsoon (ISM, also known as the Southwest Asian monsoon) on the inter-diurnal time-scale.

In this frame, the aim of the present study is to investigate the influence of the Indian summer monsoon on the atmospheric circulation over the greater Mediterranean region on a seasonal scale, during strong and weak monsoon years, as a first attempt to further examine the impact of the Indian summer monsoon on the EM climatic regime during summer and related large scale physical processes.

2 Data and Methodology

The dataset used in this work was the monthly mean ERA-40 Reanalysis Data of the European Center for Medium-Range Weather Forecast (ECMWF), on a $2.5^\circ \times 2.5^\circ$ grid and at standard pressure levels from 1,000 to 300 hP. Geopotential height, horizontal wind components data and several dynamic and thermodynamic parameters, covering boreal summers (June-September) from 1958 to 2001, were employed.

The Dynamic Indian Monsoon Index (DIMI) by Wang and Fan (1999) was used to select the extreme ISM years. DIMI is defined as the difference of 850 hPa zonal wind between a southern (5°N-15°N, 40°E-80°E) and a northern region (20°N-30°N, 70°E-90°E). Strong (weak) ISM years are defined as years when DIMI is above +0.65 sigma (below −0.65 sigma). As a result, 12 strong ISM years (1965, 1966, 1968, 1972, 1974, 1979, 1982, 1984, 1985, 1987, 1997, 1999) and 12 weak ISM years (1958, 1959, 1961, 1970, 1973, 1975, 1978, 1980, 1983, 1988, 1994, 1998) were derived.

Seasonal (JJAS) mean anomalies of the above mentioned data were calculated as the seasonal deviations from the climatological seasonal means for the period 1958–2001 separately for strong and weak ISM years. Derived *strong* and *weak* composites of representative fields (geopotential height, zonal and meridional wind components) are presented.

3 Results

The *strong* and *weak* composite anomalies of the zonal-wind component at 300 hPa are shown in Fig. 1. The examination of the *weak* composite (Fig. 1b) reveals a meridional shift of the subtropical jet (STJ) in the Asia region equatorward, as compared with its climatological mean position. On the other hand, the phases of the zonal wind anomaly in the strong ISM years (Fig. 1a) are opposite to those in the weak ISM years. In detail, the STJ is shifted to the north of its mean climatological position extending further to the west over EM. The STJ appears anomalously strengthened (weakened) over EM in the strong (weak) ISM years. The aforementioned STJ shift is also evident in the 300 hPa relative vorticity anomaly composite for the strong ISM years (not shown), where an anomalous positive vorticity is located poleward of the anomalous westerly zonal wind. It is well known that the

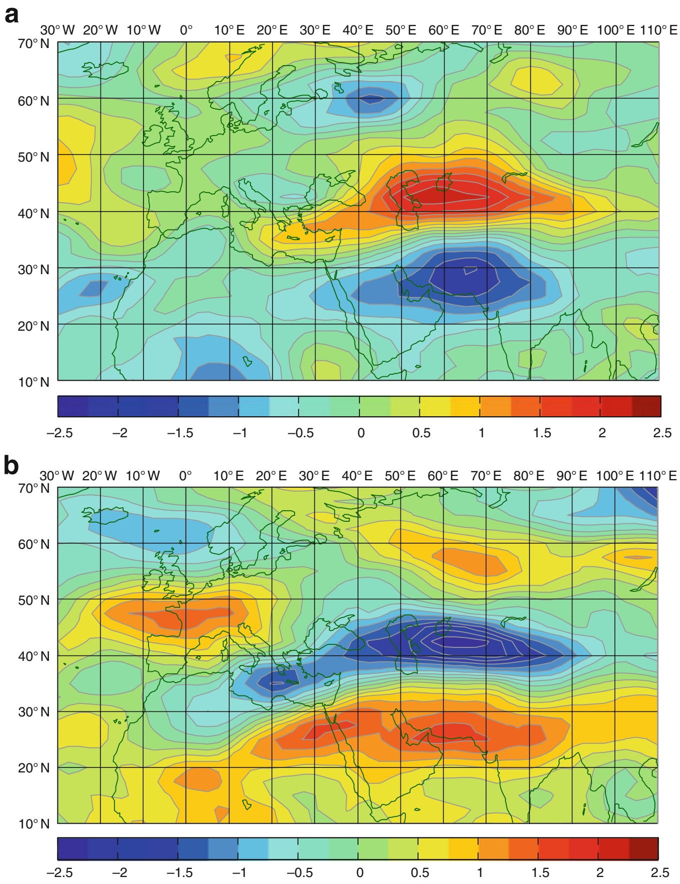

Fig. 1 Seasonal (JJAS) mean anomalies of zonal wind (m s^{-1}) at 300 hPa during (**a**) strong ISM years and (**b**) weak ISM years, from 44-year (1958–2001) climatology

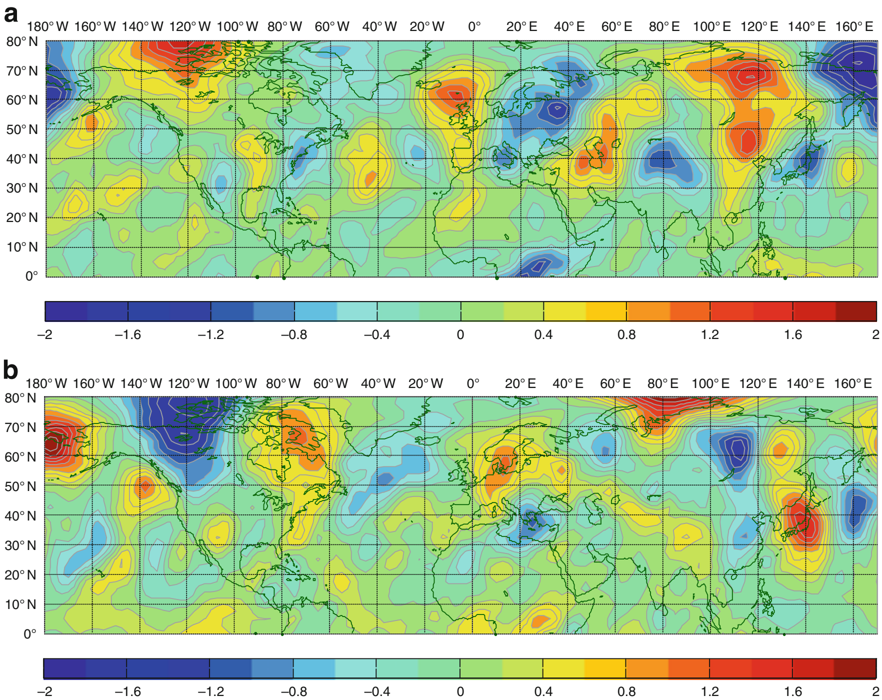

Fig. 2 Seasonal (JJAS) meridional wind component anomalies (m s^{-1}) at 300 hPa during (**a**) strong ISM years and (**b**) weak ISM years, from 44-year (1958–2001) climatology

position of the STJ is prominent for the development of the monsoon circulation cell (Yin 1949). As long as the STJ lies on the southern side of the Tibetan Plateau at about 30°N, it inhibits the development of summer monsoon. As the STJ slides to the north of Himalayas and Tibet at about 40°N and reforms over central Asia during the summer months, the summer monsoon cell finally develops. Additionally, the intensity and position of the STJ over the Mediterranean are key parameters for the climate variability over the region regarding heat wave events and precipitation (Prezerakos and Flocas 2002; Baldi et al. 2006; Gaetani et al. 2011).

The corresponding seasonal anomalies in the 300 hPa meridional wind field are displayed in Fig. 2. It is evident that the meridional wind anomalies in the strong ISM years are of significant magnitude over a large region, extending to the entire midlatitude band, whereas in the weak ISM years the anomalies are much weaker and of opposite sign. Furthermore, for the strong ISM years (Fig. 2a) the meridional wind anomalies depict a well-organized Rossby wave train of alternating southerlies and northerlies, propagating in mid-latitudes over the whole Northern Hemisphere and expanding to subpolar and polar latitudes over central and western Europe, east Asia, the Pacific Ocean and north-western America. The anomalies become more intense over Eurasia continent and the wave train appears as emanating from the equatorial region and propagating on a great cycle, that is on a plane that intersects the center of the Earth.

It is interesting to note that the wave train propagation along the above region coincides with the position of the subtropical jet in the area (see Fig. 1). In fact, Fig. 2a reveals an anomaly pattern that is meridionally confined to the vicinity of the jets with anomalies that are zonally oriented, while the pattern in Fig. 2b appears unorganized with anomalies with no specific orientation. Many studies focus on the importance of the upper-level tropospheric jets as wave-guides for the observed low-frequency waves (e.g. Hoskins and Ambrizzi 1993; Branstator 2002).

According to the linear wave theory applied in these studies, the waveguide action of the jet has the potential to enhance the longitudinal extent of low-frequency disturbances, since they are meridionally confined and their energy propagates further before being dissipated. According to Branstator (2002), disturbances in the vicinity of the mean jets lead to covariability between widely separated areas.

Regarding the lower atmosphere, composites of geopotential height anomalies at 850 hPa are presented for both weak and strong ISM years in Fig. 3. In the geopotential height pattern of anomalies for the strong ISM years (Fig. 3a) an intense and extended positive anomaly is located over the Atlantic Ocean, western and central Europe and north-west Africa, while negative anomalies extend from the ISM region through the Persian Gulf and further along southern Turkey to the Aegean sea. According to this pattern, the Azores subtropical anticyclone and the Asian thermal low appear enhanced during strong ISM years. Greece lies in the middle of the two anomaly fields (enhanced baroclinicity), where anomalous northeasterly wind currents occur. Consequently, the strengthening of these two systems will have an impact on the Etesian winds as well, which result from the combination of the above mentioned systems (Ziv et al. 2004). These results are in agreement with the wind vector anomaly pattern at 850 hPa (see Fig. 3a) for strong ISM years, where an anomalous north current is prevalent over Eastern and central Mediterranean. The anomaly composite related to weak ISM years reveals a similar spatial distribution as in the strong years, though reversed. Accordingly, the wind vector anomalies for the weak ISM years (see Fig. 3b) present an opposite pattern, with anomalous southerlies dominating over EM, corresponding to weakened Etesian winds. On the other hand, the 500 hPa vertical velocity anomaly fields (not shown) depict anomalous subsidence over the EM for the strong ISM years and an anomalous upward motion in the weak ISM years. At the same time, the temperature anomalies at 1,000 hPa over the region, represent a regime characterized by negative (positive) values during strong (weak) ISM years (not shown), resulting from the combined action of two primary factors; the mid-tropospheric subsidence and lower-level cool advection, associated with the Etesians (Ziv et al. 2004).

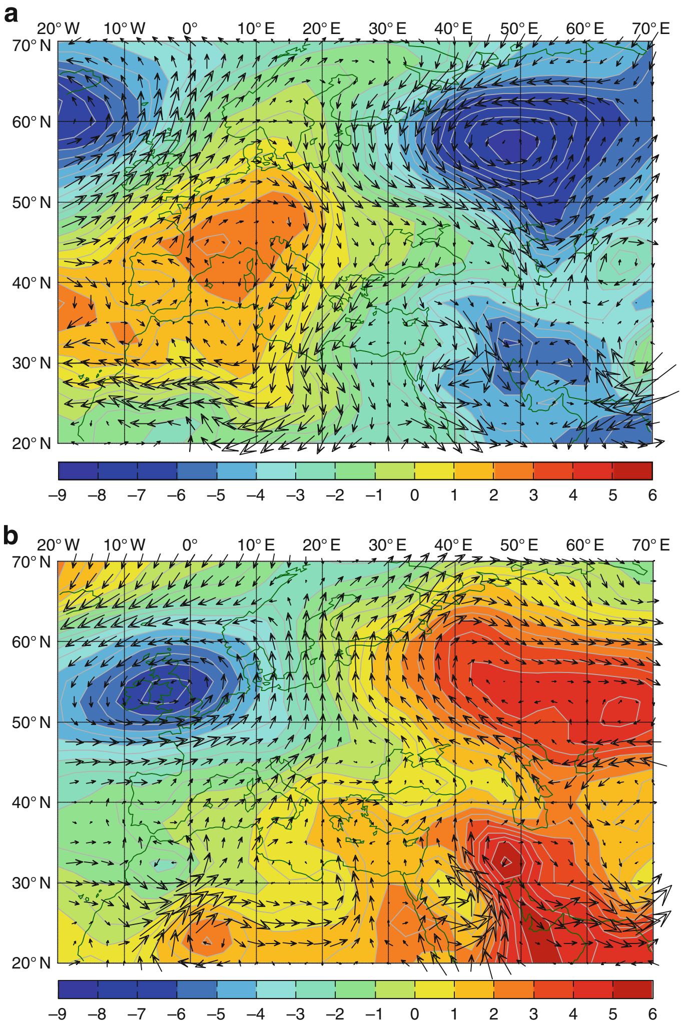

Fig. 3 Seasonal (JJAS) mean anomalies of geopotential height (gpm) and wind vector anomalies at 850 hPa during (**a**) strong ISM years and (**b**) weak ISM years. Anomalies are departures from the 1958–2001 climatology

4 Conclusions

In this study the anomalous characteristics of observed large-scale synoptic fields during extreme ISM years are analyzed and compared, as a first attempt to investigate the impact of the ISM on the EM region. The results indicate that the differences between the anomaly composites in strong and weak ISM years of examined fields are significant implying further analysis of the related dynamics.

In the strong ISM years the STJ over South Asia was found meridionally shifted poleward, compared with its climatological mean position, expanding enhanced over EM. On the contrary, it was found that the weak ISM years favor the equatorward shift of the STJ over South Asia and a weakening of its intensity over EM.

The meridional wind anomaly pattern at 300 hPa during strong ISM years revealed a well-organized Rossby wave train, zonally oriented and confined to the STJ along mid-latitudes. In the weak ISM years, the anomaly composite of 300 hPa meridional wind was completely different, scattered anomalies with no specific orientation. These preliminary results imply that a well-organized Rossby wave train is a response to the intensified Indian monsoon forcing, as Rodwell and Hoskins (1996) described.

Finally, the geopotential height anomaly patterns in the lower atmosphere for the extreme ISM years indicated the intensification of the Azores anticyclone and the Asian thermal low in the strong ISM years and the respective weakening of both systems in the weak ISM years. As a result, enhanced northerlies appear to be dominating over EM in the strong ISM years, as concluded from the 850 hPa meridional wind anomalies, with an impact on the temperature regime of the region.

Acknowledgments This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program “Education and Lifelong Learning” of the National Strategic Reference Framework (NSRF) – Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

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