Atmospheric Research xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Invited review article

Reviews and perspectives of high impact atmospheric processes in the Mediterranean

Silas Michaelides[a,b,*], Theodore Karacostas[c], Jose Luis Sánchez[d], Adrianos Retalis[e], Ioannis Pytharoulis[c], Víctor Homar[f], Romualdo Romero[f], Prodromos Zanis[c], Christos Giannakopoulos[e], Johannes Bühl[g], Albert Ansmann[g], Andrés Merino[d], Pablo Melcón[d], Konstantinos Lagouvardos[e], Vassiliki Kotroni[e], Adriana Bruggeman[a], Juan Ignacio López-Moreno[h], Claude Berthet[i], Eleni Katragkou[c], Filippos Tymvios[a,j], Diofantos G. Hadjimitsis[b], Rodanthi-Elisavet Mamouri[a,b], Argyro Nisantzi[b]

[a] Energy, Environment and Water Research Center (EEWRC), The Cyprus Institute, Nicosia, Cyprus
[b] Department of Civil Engineering and Geomatics, Cyprus University of Technology Limassol, Cyprus
[c] Department of Meteorology and Climatology, Aristotle University of Thessaloniki, Thessaloniki, Greece
[d] Atmospheric Physics Group, IMA, University of León, León, Spain
[e] Institute of Environmental Research and Sustainable Development, National Observatory of Athens, Greece
[f] Grup de Meteorologia, Departament de Física, Universitat de les Illes Balears, Spain
[g] TROPOS - Leibniz-Institut für Troposphärenforschung e.V., Leipzig, Germany
[h] Instituto Pirenaico de Ecología - CSIC, Zaragoza, Spain
[i] Anelfa, 52 rue Alfred Duméril, Toulouse, France
[j] Cyprus Department of Meteorology, Nicosia, Cyprus

ARTICLE INFO

Keywords:
Mediterranean
Atmospheric processes
Medicanes
Explosive cyclones
Climate change
Drought
Flood
Atmospheric chemistry
Dust and pollution
Extreme weather phenomena
Weather modification

ABSTRACT

The Mediterranean region is a unique area characterized by a large spectrum of atmospheric phenomena, some of which have a high impact on many aspects of human activities, safety and wellbeing. The area is long considered as a hot spot of such atmospheric phenomena deserving multidisciplinary scientific attention. The scientific research that has been carried out on these high impact atmospheric processes that occur in the Mediterranean area is indeed widespread and the available international literature is very extensive. The paper touches initially the temperature and precipitation regimes, followed by a discussion of floods and droughts. The exciting cyclogenetic patterns of explosive cyclones and medicanes are presented in separate sections. The lightning activity and the presence of dust and other pollutants are also presented herein. The atmospheric chemistry of the region which is increasingly becoming of utmost importance for the area under study is distinctly discussed. Attempts to modify the weather (the precipitation, in particular) are outlined too. The effects of climatic change on various atmospheric processes are considered throughout this paper, in addition to a dedicated section on temperature and precipitation.

1. Introduction

Any attempt to delineate and comprehend the complex atmospheric processes that are observed in the Mediterranean region, unavoidably ought to start with a portrayal of the multifaceted and intensively interacting characteristics of this geographical area. In many respects, it is these characteristics and their interplay that make this area a unique ground of atmospheric-related phenomena. Hence, this review paper starts with this introductory section in which a brief overview is given of the characteristics of the Mediterranean region which set the scene for the study of high impact atmospheric phenomena and hydro-meteorological hazards experienced in the region.

The Mediterranean Sea is virtually embraced by three continental bodies, namely Europe to the north, Asia to the east and Africa to the south. It is a water body which is almost isolated from the other oceanic bodies of the Earth since the only connection to a much larger oceanic water mass, namely the Atlantic Ocean, is through the Strait of Gibraltar through which a mass exchange in terms of replenishing the

* Corresponding author at: The Cyprus Institute, Nicosia, Cyprus & Cyprus University of Technology, Limassol, Cyprus.
E-mail addresses: s.michaelides@cyi.ac.cy, silas.michaelides@cut.ac.cy (S. Michaelides).

https://doi.org/10.1016/j.atmosres.2017.11.022
Received 20 July 2017; Received in revised form 9 November 2017; Accepted 14 November 2017

Mediterranean Sea is accomplished.

The area surrounding the Mediterranean Sea is characterized by a mixture of land cover (i.e., the physical material that covers the surface): in brief, extensive desert areas exist to the south and east with narrow vegetated areas around the coast; in contrast, vegetated areas are present to the north. On the one hand, the contribution of atmospheric processes to this land cover formation is of course decisive (c.f., temperature, precipitation and wind regimes). On the other hand, the feedback of the land cover and its interactions with the atmospheric processes must always be borne in mind.

The morphological characteristics of this area have a large influence on the complexity and richness of atmospheric phenomena (see Lionello et al., 2012). Indeed, this influence is considered to have such an extent at which this morphology may be held accountable for the onset and sustainability of some high impact atmospheric phenomena. The Mediterranean Sea is surrounded by complex mountain ranges; in many cases, they extend to high altitudes, essentially modifying the underlying dynamic characteristics of the atmospheric flow at various scales, thus playing a critical role in the regional and local climatology.

Energy and moisture fluxes between the water surface of the Mediterranean Sea and the overlying atmosphere constitute important driving factors for atmospheric processes, not only of relevance to the region but also well beyond it (see Rowell, 2003).

The geographical position of the Mediterranean places the region under the influence of a large spectrum of large-scale atmospheric patterns of the general circulation. Indeed, from the north, the region is prone to influences from circulations associated with the mid-latitudes (see Trigo et al., 2006). The northern part of the region is more frequently affected by the polar front and its latitudinal movement during the year with diverse seasonal variations in both the frequency and intensity of related atmospheric phenomena. The variability of the atmospheric phenomena especially over the north part of the Mediterranean region is linked to the North Atlantic Oscillation[1] (NAO) (e.g., Xoplaki et al., 2003, 2004; Krichak and Alpert, 2005a). Researchers have also investigated the influence of a multitude of other northern hemisphere teleconnection indices on the weather in the Mediterranean, such SCAND, EA and EAWR: the Scandinavian index, the East Atlantic and the East-Atlantic/West-Russian indices, respectively (see e.g., Krichak and Alpert, 2005b; Trigo et al., 2008; Nissen et al., 2010).

From the south, the Mediterranean basin is subjected to strong influences from circulations of tropical and subtropical origin (Alpert et al., 2006). Most notable is the influence of the descending limb of the Hadley cell which during most of the year maintains dry weather conditions with occasional wet spells. The area is even affected by quite distant patterns of the southern hemisphere, such as the that of the El Niño Southern Oscillation (ENSO) which has been held accountable for influencing the variability of weather in the Mediterranean with focus on precipitation (see Price et al., 1998; Mariotti et al., 2002; Alpert et al., 2006). In addition, the Asian monsoon circulation has a westward protruding extension during summer, thus largely influencing the prevailing lower level circulation of the eastern Mediterranean (EM) and the associated weather (see Raicich et al., 2003; Tyrlis et al., 2013).

The area is alternately exposed to air masses of different origin. Tropical continental air, often quite rich in particulate matter originating from the extensive dry deserts of north Africa, is quite frequently affecting large parts of the region (see Michaelides et al., 1999a). Intrusions of continental air of polar or sub-polar origin from the north and northeast are also noted, particularly during the cold periods of the year. In the same periods, polar air masses of maritime origin may sometimes affect the area, though quite modified when they reach the Mediterranean. The proximity of the Atlantic Ocean enriches the variety and interaction of the air masses affecting the area, with frequent intrusions of maritime air masses from the west and southwest.

It has long been realized that the Mediterranean area is affected by two tropospheric jet-streams. The first is the subtropical jet-stream which is a westerly stream forming on the poleward side of the Hadley cell, the existence of which is largely ascribed to conservation of angular momentum (see Reiter, 1963). The other jet-stream is commonly known as the polar front jet-stream accompanying mid-latitude baroclinic disturbances and whose existence is attributed to the large horizontal temperature gradients in the lower troposphere. Both jet-streams are subjected to seasonal north-south displacements, following the seasonal displacement of the meridional large-scale circulations. The synergistic interaction between the polar the subtropical jet-streams is considered as a possible mechanism triggering explosive cyclogenesis in the region (see Conte et al., 1997).

The complex topography and coastline of the Mediterranean region interact with the global atmospheric circulation, inducing regional patterns of high temporal and spatial variability When interacting with the global atmospheric circulation, the characteristic morphology of the Mediterranean region induces regional features such as areas of preferred cyclogenesis and cyclonic rejuvenation (c.f., cyclonic developments bearing the geographic names of the Gulf of Genoa and the island of Cyprus). Storm tracks are also largely determined by the Mediterranean area morphology and thermal characteristics of the underlying surface. The above have important consequences for regional storminess and precipitation regimes (Luterbacher and Xoplaki, 2003).

The Mediterranean region is a unique area characterized as a climate change hotspot, a region whose climate is especially responsive to global change (Giorgi, 2006). Additionally, as already mentioned above, the location of the Mediterranean in a transitional band between the subtropical and the midlatitude zones renders the climatic modeling of this region a very challenging task (Planton et al., 2012).

This review paper aims at presenting in a comprehensive manner the phenomena that are significant in terms of impacting the weather and related hydro-meteorological hazards in the Mediterranean but it focuses primarily on the topics that are pertinent to the issues discussed in separate papers in this Special Issue. In the selection of topics to be reviewed here, the spatiotemporal extent of the respective processes is also taken into consideration, focusing on those which are identified at the synoptic scale. The processes considered here are widely affecting the area of the Mediterranean basin receiving much public and research interest. Localized phenomena or those which are not conducive to much attention from the public or the scientific community are not exclusively reviewed. For example, tornadoes and waterspouts are not considered as a separate topic in this review paper, despite their considerable societal and economic impact, because they generally receive very little attention from the public, meteorologists, researchers and emergency managers (see Antonescu et al., 2017).

This introduction is followed by eleven sections, as follows. The temperature and precipitation regimes over the region are discussed in Sections 2 and 3, respectively. Floods and droughts are specifically discussed in Sections 4 and 5, respectively. Sections 6 and 7 focus on explosive cyclones and medicanes, respectively. Section 8 focuses on lightning activity and Section 9 on dust and air pollution in the area. Section 10 discusses aspects of atmospheric Chemistry. Projects on weather modification that have been undertaken in countries in the Mediterranean are outlined in Section 11. Finally, Section 12 reviews aspects of climate change with particular emphasis on temperature and precipitation.

The literature surveyed in this review paper is by no means exhaustive. The objective of this paper is to review a reasonable amount of existing literature on the respective topics, especially the most recently available and subsequently proceed by scrutinizing the perspectives on these topics.

[1] All symbols and abbreviations are tabulated in the Appendix A.