Strong winds

Observed trends, future projections

Philippe DROBINSKI
UMR LMD, France

Pinhas ALPERT
Tel-Aviv University, Israel

Leone CAVICCHIA
CMCC, Italy

Emmanouil FLAOUNAS
National Observatory of Athens, Greece

Assaf HOCHMAN
Tel-Aviv University, Israel

Vassilki KOTRONI
National Observatory of Athens, Greece

Introduction

The Mediterranean Sea is an almost enclosed basin surrounded by mountain chains with a complex coastal orography and numerous islands, many of which mountainous. The complexity of the physiographic characteristics deeply influences the atmospheric circulation at local scale, giving rise to strong regional wind regimes (see fig. 1) (HMSO, 1962). In the Alboran Sea (the westernmost Mediterranean), the levanter blows from the east and in winter it can be strong and long lasting (up to 10 days). In the western Mediterranean, the north-north-west cold dry mistral and its companion wind the tramontane blow in the Gulf of Lion, occasionally up to the African coasts. The northeasterly strong cold bora affects the entire Adriatic Sea and bora-type winds also occur in the northern Aegean Sea. In this region, storm surges are produced by a regional wind, the westerly southwesterly libeccio, mainly during winter, and the warm and wet southeasterly sirocco is produced mainly in the fall. In the Levantine basin, the prevailing winds are the etesians, strong dry north winds like those that prevail in the Black Sea. The wind speeds associated with these regional wind regimes often reach surface values > 15 m s^{-1} (with gusts of over 20-25 m s^{-1}). The Mediterranean basin is also one of the main regions of cyclogenesis in the world and the strongest windstorms are often associated with a cyclone (Lionello et al. 2016).

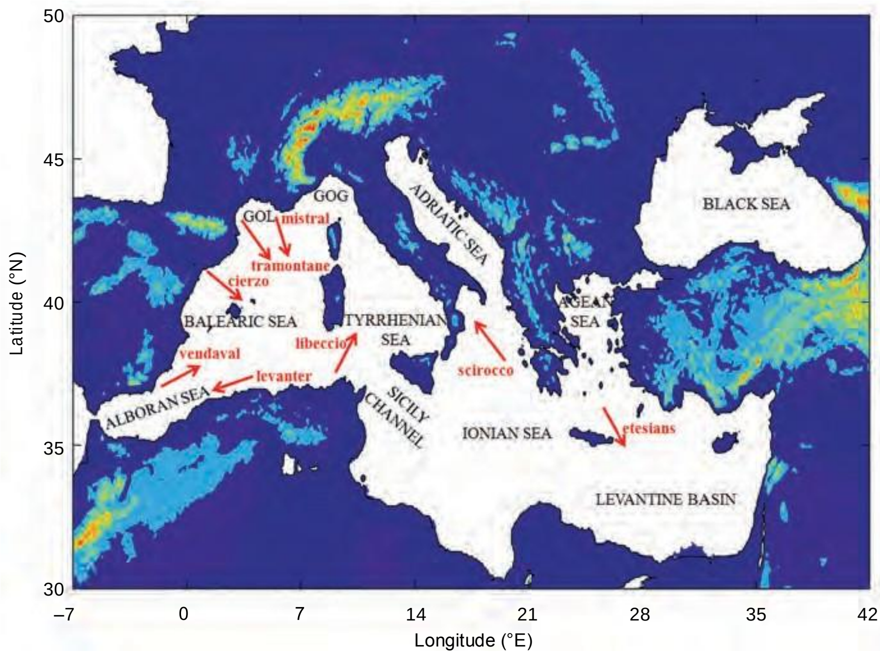

Figure 1
The Mediterranean Basin and its main winds.The names of the main sub-basins are in uppercase letters, and the name of the winds are in red lowercase letters. GOL stands for Gulf of Lion and GOG for the Gulf of Genoa.

The strongest windstorms and most intense cyclones often produce high impact weather such as storm surges, landslides and flooding. They can also contribute to the rapid spread of forest fires (Hernandez et al. 2015) and create hazardous conditions for sailing, maritime shipping and aviation. They also control the Mediterranean Sea circulation. Indeed, winds like the mistral often produce sea surface cooling, and coastal upwellings, and are the main factor involved in ocean convection and deep water formation (Millot and Taupier-Letage, 2005). The succession of strong wind events partly explains the upper ocean circulation and deep water formation in winter. Finally, these strong and sustained regional winds could be a key to energy production and play an important role in the energy transition as one possible solution for the mitigation of greenhouse gas emissions in the context of global change. How these strong wind systems will evolve in a warming climate is therefore a major question, as any changes in their frequency and characteristics are expected to play a key role in future changes in the Mediterranean regional climate.

Observed spatial and temporal variability of strong winds

Large-scale climate variability is crucial to European atmospheric circulation, especially the North Atlantic Oscillation, which is the first mode of wind variability in Europe, explaining more than a third of winter variability. It contributes to intense Mediterranean cyclogenesis (Raible, 2007) and therefore largely influences wind extremes over the Mediterranean. In spite of their generally limited size and duration, Mediterranean cyclones are known to cause serious damage in the highly populated coastal areas surrounding the basin, due to the combination of strong winds and heavy rainfall. The majority of intense Mediterranean storms present a dynamical structure equivalent to the one of mid-latitude extra-tropical cyclones (Flaounas et al., 2015). Under certain specific conditions, a few storms may develop into tropical-like cyclones (also known as medicanes), and the associated wind can reach the hurricane strength of 33 m s^{-1} (Cavicchia et al. 2014a). Medicane events occur once or twice a year, mainly in fall and winter in the western Mediterranean close to the Balearic Islands, and in the Ionian Sea (Cavicchia et al. 2014a). Almost all extreme winds in the region are connected with cyclones (Nissen et al., 2010). The spatial pattern of cyclones over the Mediterranean is characterized by several maxima (Alpert et al. 1990; Lionello et al. 2016). Figure 2 shows the locations where cyclones form and cyclone track density in the ERA-Interim reanalysis. The most intense cyclogenesis areas are located in the Gulf of Genoa, south of the Atlas Mountains, close to Cyprus, and in the North Aegean and Black Sea.

Observations of surface wind speed in recent decades reveal an overall negative annual trend over the continents in the Northern Hemisphere, referred to as wind stilling (McVicar et al. 2012). The prevailing hypotheses explaining these trends are changes in surface roughness, changes in aerosol loads or changes in the atmospheric circulation (Jacobson and Kaufman, 2006; Bichet et al. 2012; McVicar et al. 2012). However, wind stilling in the Mediterranean region is minor compared to inter-annual variability, even though negative trends have been found for both etesian wind outbreaks and speed in the eastern Mediterranean (e.g. Poupkou et al., 2011). Nevertheless, at larger scale, and especially for the strongest winds, no consensus concerning the magnitude of the trend or even the sign has been reached as the uncertainties in the different datasets are still too large.

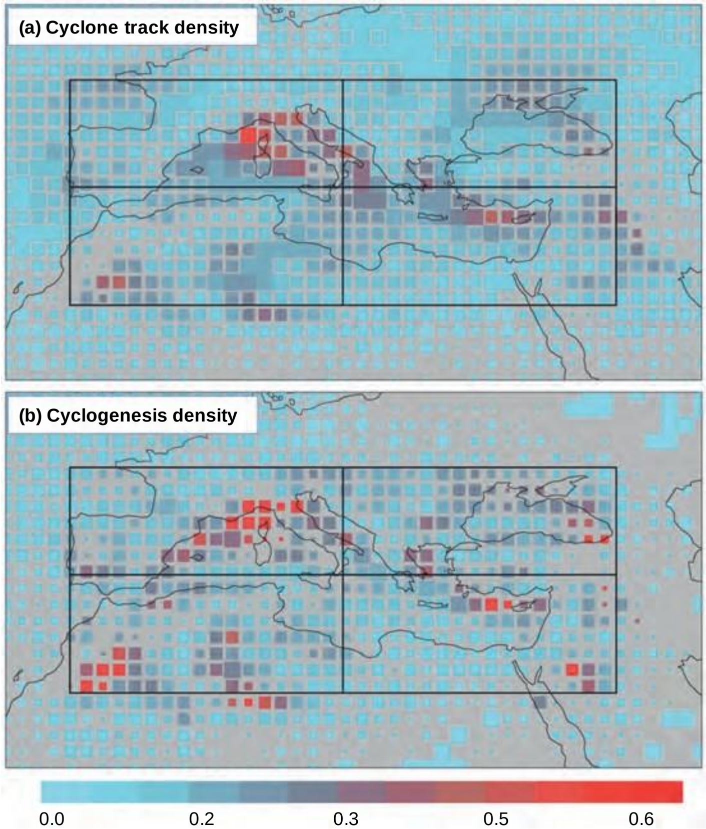

Figure 2
Cyclone track density (a) and cyclogenesis density (b). Colors indicate the probability that a cyclone crosses/forms in each 1.5° x 1.5° cell of the domain in the 6-hourly ERA-Interim reanalyses.
Adapted from Lionello et al. 2016.

Accurately simulating past wind speed variability and trends at scales smaller than 100 km is a prerequisite for future projections of local wind climatology, which relies on downscaling global climate models. Several studies have demonstrated the added-value of downscaling techniques to simulate the strong winds and the cyclonic activity in the Mediterranean region (e.g. Obermann et al. 2016; Vrac et al. 2012).

Projected changes in wind speed in the context of global change

In the context of expected changes in the 21st century, wind speeds over the Mediterranean region are not expected to be significantly affected by increased greenhouse gas conditions (Rockel and Woth, 2007). The projections of high overland wind speeds in the Mediterranean region, analyzed from eight regional climate models, generally predict wind stilling, in agreement with the findings of Beniston et al. (2007) who suggest a negative change in high wind speed over and south of the Alps or latitude 45°N, locally reaching -10% between the 1961-1990 period and the 2071-2100 period. However the uncertainty remains large as pointed out by Vrac et al. (2012) and Rockel and Woth (2007), who found that the decreasing signal is only captured by all regional climate models during winter months and is only statistically significant in November (see fig. 3). Najac et al. (2009) projected fewer high wind days in southern France whereas Anagnostopoulou et al. (2013) forecast a strengthening of etesian winds associated with the strengthening of the anticyclonic action center, and the deepening of the Asian thermal low over the eastern Mediterranean.

Concerning cyclone-associated winds in the Mediterranean, two factors need to be considered in the context of global change, first, the frequency of cyclones, and second, the intensity of cyclones measured in terms of wind speed. Under climate change conditions, the total number of Mediterranean cyclones is projected to decrease. By analyzing a large number of CMIP5 models, Zappa et al. (2015) found a decrease in the frequency of extra-tropical cyclones throughout the Mediterranean basin as high as 25%, with all models agreeing on the sign of the change. Figure 4 shows the changes in the winter cyclone track density in the most pessimistic emission scenario in comparison with historical simulations. Although fig. 4 shows an overall clear decreasing

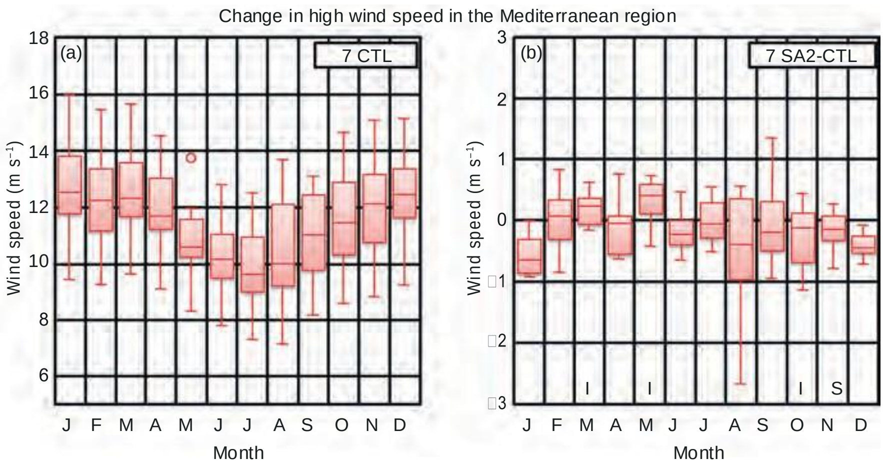

Figure 3

Distribution of 99th percentile of daily mean wind speeds from 8 regional climate models, averaged over the land area of the Mediterranean region. Absolute values for present-day control simulations (CTL) and differences between future scenarios and control runs (SRES/A2-CTL). Open circles denote outliers (i.e. the distance from the lower 25% or the upper 75% quartile is more than 1.5 times the interquartile distance). "S" means at least 6 out of 8 models show statistically significant changes. "I" means at least 6 out of 8 models show changes that are not statistically significant.

Adapted from Rockel and Woth, 2007.

signal for the Mediterranean, in certain areas such as the Levant and near Morocco, cyclones may occur more frequently in the future (Nissen et al. 2014). Concerning cyclone intensity, interestingly there is a signal of opposite sign. Both Cavicchia et al. (2014b) and Romero and Emmanuel (2013) show that the frequency of medicanes will decrease by the end of the 21st century. However both studies agree that more violent storms are to be expected.

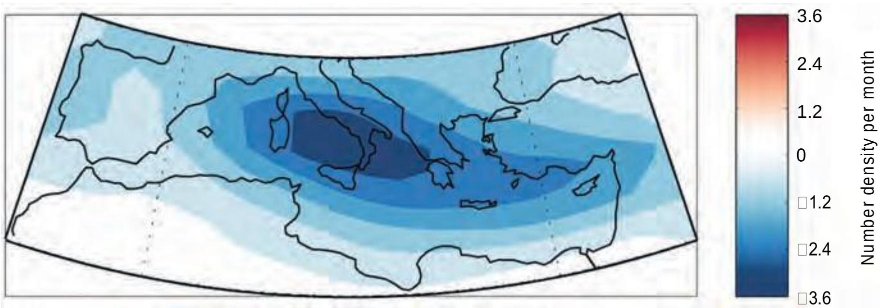

Figure 4
Winter multi-model mean change in the cyclone track density under the most pessimistic emission scenario (2082-2099) compared with historical simulations (1976-2005). Units are the number of cyclones per month per unit area (5° spherical cap).
Adapted from Zappa et al. 2015.

Consequences

Changes in wind speed in the Mediterranean region will have serious consequences in different fields. A decrease in wind speed can weaken the thermohaline circulation due to both a reduction in wind stress and heat flux (e.g. Somot et al., 2006). Changes in wind patterns can have significant implications for the potential of wind as an energy resource (e.g. Koletsis et al. 2016) and more generally can affect local populations and the economy. Indeed, windstorms and cyclones are the weather events with the biggest impacts in the Mediterranean region, due to the combination of heavy rainfall and strong winds. Because of their small spatial extent, climate models are not yet able to capture all the aspects of future cyclone activity. Despite the expected decrease in cyclone frequency, most studies suggest that high impact weather systems and related wind storms will remain a significant risk in the Mediterranean region.

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