Climatic Change and Environmental Disasters in the Mediterranean Area

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The Mediterranean region is particularly vulnerable to a wide range of climatic risks due to its unique geographical and climatic characteristics. Rising temperatures, changing precipitation patterns, and increased frequency of extreme weather events are some of the key challenges faced by this region. The Mediterranean climate, characterized by hot, dry summers and mild, wet winters, is already experiencing the impacts of climate change, posing significant risks to the environment, ecosystems and human communities in the area.

When discussing climate change's impact on environmental disasters, it's important to consider that it only interacts with a part of the risk involved, known as the hazard. The other part, related to socioeconomic factors, is independent of it and encompasses vulnerability and exposure. The term "hazard" refers to conditions or situations that can cause harm or damage to people, property, the environment or society as a whole. Hydrometeorological hazards can result directly from extreme weather or climate events (e.g., tornadoes) or contribute to the process as driving factors (e.g., snow avalanches). "Vulnerability" refers to the susceptibility of individuals, communities or systems to harm or damage caused by natural hazards. It encompasses social, economic and environmental factors that influence the ability to cope with and recover from disasters. "Exposure" refers to the presence and proximity of people, assets or activities in hazard-prone areas. Risk and potential impacts are determined by the combination of vulnerability, exposure and hazard, which must be considered when discussing observed and future trends in hydrometeorological risks in the Mediterranean.

Heavy Rainfalls, Floods and Landslides

Floods are the most frequent and costly natural disasters in the Mediterranean, causing significant economic damage (more than 85 billion euros' worth of damage since 1900), affecting human life and health, drinking water supplies and hydroelectric energy production, increasing solid contribution in rivers and discharging pollutants directly into the sea. Both the climatic and geomorphological characteristics of the Mediterranean region favour the generation of flash floods as a result of heavy rains, but also floods due to extended rainfalls or snowmelt. Heavy rainfalls and floods are affected by climate change.

Mean daily precipitation intensity and the 95th percentile of daily precipitation are expected to increase, while precipitation frequency and wet spell length may decrease. The intensity of precipitation and hydrological extremes is already higher in the northern Mediterranean compared to the south, and this difference is expected to increase with global warming (MedECC, 2020)

Although long-term flood-rich periods can often be explained by natural climate variability, in recent decades, floods have shown mixed trends in the Mediterranean region. Negative trends have been found in annual flow extremes in the northern and eastern Mediterranean Basin. Flood trend attribution is uncertain, but key drivers of this negative trend can often be identified. Causes may include changes in rainfall-runoff processes at the catchment scale, such as water table changes due to overexploitation or recharge of aquifers, land use changes like defor-

estation, urbanization, wildfires and agricultural use changes, and structural flood protection measures like flood-control reservoirs, dikes or levees. The opposite trend has been found for the total annual number of floods (mainly flash floods) for southern Italy, northeastern Spain and the south of France, following the FLOODHYMEX database (Llasat et al., 2013), which includes 385 flood events with catastrophic damages. This increase can be due to changes in precipitation patterns, such as convective precipitation, but also to other non-climatic factors that affect flood hazard, vulnerability and exposure. This is the case for coastal areas, where population and urban settlements are rapidly increasing in flood-prone areas. On some occasions, it is possible to identify common catastrophic events that have affected two or more Mediterranean Countries, constituting a major challenge for collaboration between the different civil protection bodies and promoting the creation of an international civil protection body. This was the case of the superstorm in November 2001 that caused hundreds of deaths in Tunisia and great damage in Spain.

Flood hazard projections vary, but generally, flood events exceeding current protections are expected to increase globally under different warming levels. River flood magnitudes are anticipated to increase significantly in most of Mediterranean Europe under 2°C warming, except for Bulgaria and southern Spain. A general increase is projected in the 100-year daily peak flow and in the average frequency of peak flow events for the majority of the northern Mediterranean river network. Some studies suggest an increase in floods corresponding to a 10-year return level in southern French basins, but with varying magnitudes depending on the specific basins. However, other studies indicate a decrease in high flows in the Mediterranean Region at 1.5°C and 2°C scenarios, primarily due to reduced precipitation. These differences can be attributed to variations in climate models, scenarios, downscaling approaches and the use of large-scale hydrological models not calibrated for small river basins in the Mediterranean region (MedECC, 2020). Projections indicate that countries in the northern Mediterranean, such as Italy, France, Spain and Portugal, may face a significant increase in flood impact. However, southern Mediterranean countries could experience a decrease in flood impacts. Floods not only cause economic damage but also have a significant impact on human lives. Among the 385 flood events in the FLOODHYMEX database from 1981 to 2010, 333 people lost their lives. About 55% of the victims were swept away while crossing torrential streams, indicating the potential for reducing casualties through improved risk awareness (Llasat et al., 2013). The FFEM-DB, a multinational database covering the Euro-Mediterranean region from 1980 to 2020, includes 2,875 flood-related fatalities. During this period, if we only consider flood events with over 10 fatalities, Turkey experienced 28 events, resulting in 706 deaths; the southeastern part of France witnessed eight events with 192 deaths; Italy had seven events with 123 deaths; Greece had two events with 37 deaths; Israel had one event with 14 fatalities; and the northeastern part of Spain and Balearic Islands had two events resulting in 25 deaths (Papaginiaki et al., 2022).

Heavy rainfall events can produce landslides and debris flows, and for this reason these will be affected by climate change. Italy has one the biggest landslide risks of all the Mediterranean countries. As an example, the Cavalese-Stava mudflow in July 1985 caused 329 fatalities, and the landslide in May 1998 in southern Italy caused 148 fatalities.

Extratropical Cyclones and Medicanes

The Mediterranean is one of the main cyclogenetic areas of the world, the most important areas being the northwestern Mediterranean, North Africa and the north shore of the Levantine Basin. These cyclones contribute to high-impact weather events, including strong winds and heavy precipitation. The region experiences both extratropical cyclones and hybrid depressions known as “medicanes” or tropical-like cyclones. These are mesoscale maritime extratropical cyclones that exhibit some characteristics similar to tropical cyclones. They are relatively rare but can be highly destructive and pose significant risks to coastal areas in the Mediterranean region (intense precipitation, flash floods, landslides). They can also produce high waves and pose hazards to maritime activities. In the recent past, there has been an absence of strong trends in cyclone numbers affecting the Mediterranean region, however when trends are detected these are mostly negative. Similarly, the number of explosive Mediterranean cyclones has likely decreased.

The statistical record of medicanes has limited reliability and sample size, given their maritime characteristics, small size and infrequent occurrence, and consequently temporal trends cannot be calculated.
Climate change may influence the characteristics and frequency of medicanes in the future. As the Mediterranean region experiences warming temperatures, changes in sea surface temperature patterns, atmospheric moisture content, and atmospheric stability, which could affect the formation and behaviour of medicanes. However, the specific effects of climate change on these cyclones are still uncertain and require further study.

Wind Storms

Observation-based studies of winds over the Mediterranean are rare, and depend on the availability of homogenized and long time series. In most regions, wind trends were found to be non-monotonic in recent decades and concrete conclusions are difficult to establish. Despite the uncertainties in future projections, there is general agreement on limited wind speed reduction over most of the Mediterranean, with the exception of the Aegean Sea and northeastern land areas. Regional projections over the Adriatic reveal strong sensitivity in the climate change signal of the local Bora and Sirocco winds. In particular, the frequency of winter Bora events is forecast to increase while the frequency of Sirocco events is expected to decrease. Overall, the mean wind speed during Bora and Sirocco events is expected to be reduced, with the exception of Bora in the northern Adriatic. RCM projections of Mistrals and Tramontanes show small changes in the former and a significant decrease in the frequencies of the latter. The Etesian winds over the Aegean Sea is one of the few exceptions since increases in the wind speed are expected for the future. Future changes in the wind strength over the sea will likely remain low, even at the end of the 21st century in pessimistic scenarios.

Storm Surges and Wave Heights

Maritime storms play an important role both on the coast and offshore. In the Mediterranean, the effect of the tide is not relevant. However, local winds and the variations they can experience due to climate change, have a significant effect on the waves. The wave climate in the region is milder than in the Atlantic, with smaller mean wave heights and shorter periods, and presents an important spatial variability due to the complex orography and coastline surrounding the basin. Annual maxima along the coastlines are largest (above five metres) on the northwestern coast of Africa, but high values well above four metres occur in several parts (MedeCC, 2020).
Regarding future changes in waves, they will be determined by changes in the wind field over the Mediterranean Sea. Published studies point towards a generalized reduction of the mean significant wave height field over a large fraction of the Mediterranean Sea, especially in winter. Similarly, wave extremes are expected to decrease in number and intensity, although there is no consensus whether very large extreme events, associated with very strong winds, would also decrease. The loss of coastal ecosystems, however, such as mangroves and coral reefs, intensifies the vulnerability of coastal areas to storm surges and erosion, further exacerbating the impacts of climate change in the region. (MedECC, 2020).
Although tsunamis are not as frequent in the Mediterranean region as in other parts of the world, their effects are not negligible. The most recent disaster occurred in 1956 in the Aegean Sea, with runup heights reaching 25 metres. However, since they are geohazards, climate change will not have an impact on them. However, the meteotsunamis that occur in some parts of the Mediterranean, causing serious damage to boats anchored in ports, can be affected. Current studies still show great uncertainty, so it cannot be concluded how they will be affected by climate change.

Extreme Temperatures

Although extreme temperatures were not among the main causes of disasters in the Mediterranean, climate change of anthropogenic origin has led them to be among the main risks for the population. Extreme temperatures have risen significantly over the past century, particularly in the last few decades. Basin-wide, annual mean temperatures are now 1.5°C above late-19th-century levels. Heat waves have become more frequent and severe, and the number of warm nights has increased over most Mediterranean loca-

tions including Iberia, North Africa, Italy, Malta, Greece, Anatolia and the Levant. Prolonged heat waves not only have direct impacts on human health, leading to heat-related illnesses and fatalities, but they also affect agriculture, energy demand and infrastructure. Heatwaves exacerbate the risk of wildfires, which have become a significant threat to Mediterranean forests, leading to biodiversity loss and economic damage.

One of the major climatic risks in the Mediterranean region is the threat of droughts and water scarcity. As temperatures rise and rainfall patterns become more erratic, water resources are being severely strained

Projections indicate that the Mediterranean Basin will continue to warm at a faster rate than the global average, with temperatures exceeding the global mean by 20% annually and 50% during summer. The intensity of extreme temperatures is expected to increase more rapidly than the intensity of moderate temperatures, leading to more frequent and severe heat waves. By the end of the 21st century, summer daily maximum temperatures may increase by up to 7°C compared to the recent past, and the number of tropical nights may increase by over 60%.

Droughts

One of the major climatic risks in the Mediterranean region is the threat of droughts and water scarcity. As temperatures rise and rainfall patterns become more erratic, water resources are being severely strained. This poses a significant challenge for agriculture, as irrigation-dependent crops face water shortages and reduced productivity. Moreover, water scarcity also affects domestic water supply, industry and tourism, putting additional pressure on already stressed ecosystems and economies, sometimes forcing migration and favouring the outbreak of conflicts (Tramblay et al., 2020).

Drought frequency and intensity have increased in the Mediterranean since 1950 due to anthropogenic climate change, corresponding with an increase in the dry spill length. For instance, summer low flows have reduced by between 15% and 25% for the Jordan River Basin. This increased drought frequency and severity is translated into soil moisture and hydrological droughts, but with increasing complexity due to non-linear vegetation responses and the influence of human activities in the face of approaching hydrological drought (Tramblay et al., 2020).

Climate simulations project increased duration and intensity of droughts in the region by the end of the 21st century. For the worst emission scenario, droughts are projected to happen five to 10 times more frequently, especially in North Africa. Low flow frequency is expected to decrease in Euro-Mediterranean areas (France, Spain, Italy, Balkans and Greece) from 12% with +1.5°C warming up to 35% with 3°C warming. Future projections show an increase of the low flow period during summer and an increased frequency of no-flow events in France, Spain, Portugal, Morocco and Tunisia. Water availability may decrease by 2-15% for 2°C warming in the Mediterranean region. Water demand is already high and will likely increase in the future, particularly in North Africa.

Wildfires

The Mediterranean is a high fire-risk region, where fires are the cause of severe agricultural, economic and environmental losses and even human casualties. For instance, the fire seasons in 2017 and 2018 were severe in many regions of southern Europe, with large wildfires associated with unusually intense droughts and heat waves. Forest fires can be exacerbated by drought conditions. Although some forest fires can be provoked or be the result of recklessness, they mostly depend on the state of the vegetation and the climatic and meteorological situation. Consequently, fire regimes will be affected by climate change, if they have not been already.

However, the quantitative evidence available indicates that fires are decreasing in recent decades across a large part of the European Mediterranean region (Turco et al., 2013). The increased efforts in fire suppression have probably played an important role in driving the general downward trends described for most of the Mediterranean area. In recent decades fire management strategies have improved thanks to

new technologies and experience, while climate drivers have led to an opposite trend. Although the measures that are currently applied are being very effective in reducing the burned area, climate projections suggest that under conditions of a 2°C temperature increase, in most Mediterranean regions wildfires would increase by more than 40%.

Conclusions

Hydrometeorological hazards in the Mediterranean, that can be affected by climatic change, represent a threat, and can have significant negative consequences if not properly managed. Their assessment and understanding is crucial for implementing effective prevention, mitigation and response measures to reduce associated impacts. By identifying and addressing vulnerabilities and reducing exposure to those hazards through measures such as land-use planning, early warning systems and infrastructure development, societies can enhance their resilience and reduce their adverse consequences. Additionally, mitigating climate change through reducing greenhouse gas emissions is essential to limit the extent of these risks and protect the delicate balance of the Mediterranean ecosystem for future generations. The uncertainties are still manifold, stemming from the modelling chain used to assess the impact of climate change on these hazards, non-linear processes and the complex interaction with socioeconomic factors.

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