A Review of the Mediterranean Climate (1902–2021): From Analytical Climatology to the Isotopic Signatures of Precipitation in the Iberian Peninsula

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Abstract

The interaction between sea and climate in the scientific literature about the Mediterranean has changed during the twentieth century. In fact, a perceptual shift is observed if we delve into the different climatic classifications of the Mediterranean defined by climatologists and geographers. This study reviews the most important indices derived from the history of Mediterranean climatology, offering four maps that help visualize the evolution of conceptions of the Mediterranean climate. It also proposes a new index based on tritium isotope concentration. The paper argues that there is a paradigm shift from a "static" towards a "three-dimensional and dynamic" perspective of the Mediterranean Sea. The State Meteorological Agency (AEMET), the Agroclimatic Information System for Irrigation (SIAR), the Portuguese Institute for Marine and Atmospheric Research (IPMA) and the Network of Automatic Meteorological Stations in Catalonia (XEMA) provide meteorological data (temperature, rainfall, evapotranspiration, and atmospheric pressure) which we have used as inputs for four different indices. We have retrieved REVIP records for the period 2000–2021 to study the spatial distribution of long-term precipitation. Finally, we have correlated the REVIP dataset with the North Atlantic Oscillation Index (NAOi) and the Western Mediterranean Oscillation Index (WeMOi). Our methodology consists of two steps: (1) collecting data from various previously cited sources and applying a SWOT matrix to analyze each Mediterranean climate index; (2) showing how the isotopic signature of precipitation could function as a valuable tool for understanding the entire hydrological cycle, encompassing the Mediterranean Sea as a water body. The REVIP dataset could be serve as a valuable tool for tracking the origin, evolution and historical aspects hydrological cycle, as well as for developing new Mediterranean climate indices from a three-dimensional perspective, i.e., incorporating the Mediterranean Sea in the climate system. However, further research is required to determine whether the isotopic signature is influenced by atmospheric processes, such as those associated with torrential rainfall, or if it is the influenced by local or regional characteristics of the Mediterranean Sea.

Keywords

Mediterranean climate · REVIP · Hydrological cycle · History of climatology · Isotopic signature

1 Introduction

The DEEPMED project (ERC-CoG DEEPMED-10100233) is a novel approach to oceanic history that incorporates analyses of deep and bottom layers of the Mediterranean Sea to gauge the causes and effects of the historical incorporation of depth into the human sphere of action, including in particular scientific knowledge.

This study aims to review the different perspectives through which the Mediterranean climate has been studied between 1902 and 2021, introducing the isotopic signature as a novel approach to understand this climate from a volumetric standpoint. To achieve this objective, we used the Spanish Network of Isotopes in Precipitation (REVIP) as a valuable tool for tracking the Mediterranean climate from a maritime perspective.

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Z. Zhang et al. (eds.), *Dynamic Evolution of Atmospheric, Ecological, and Hydrological Systems in Circum-Mediterranean Regions*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-031-86777-4_27

Table 1 Details of meteorological datasets from 2000 to 2021, sourced from the Spanish National Meteorological Agency (AEMET), the Agroclimatic Information System of Irrigation of Spain (SIAR), the Portuguese Institute for Marine and Atmospheric Research (IPMA) and the Network of Automatic Meteorological Stations in Catalonia (XEMA)

AEMET	Station	Latitude	Longitude	SIAR	Station	Latitude	Longitude
1111X	Santander	43 29 28 N	3 48 02 W	C02	Boimorto	43 00 27 N	8 07 37 W
1387	A Coruña	43 21 57 N	8 25 17 W	N106	Arazuri	42 48 05 N	1 43 13 W
5796	Morón	37 09 52 N	5 36 41 W	HU22	Santa Cilia	42 33 38 N	0 42 52 W
2422	Valladolid	41 38 27 N	4 45 16 W	C01	A Capela	43 26 07 N	8 04 20 W
2661	León	42 35 18 N	5 39 04 W	NA107	Lumbier	42 39 02 N	1 17 42 W
2462	Navacerrada	40 47 35 N	4 00 38 W	BU02	Valdelucio	42 43 05 N	4 05 32 W
4121	Ciudad Real	38 59 21 N	3 55 13 W	LE02	M. Mayor	42 30 32 N	5 26 31 W
3469A	Cáceres	39 28 17 N	6 20 20 W	CC12	Gargantilla	40 14 54 N	5 55 12 W
GI01	Gibraltar	36 08 16 N	5 20 43 W	Z02	Belchite	41 18 23 N	0 45 16 W
3195	Madrid	40 24 43 N	3 40 41 W	BA06	Olivenza	38 41 08 N	7 06 02 W
9434	Zaragoza	41 39 38 N	1 00 15 W	CC104	Alcántara	39 43 07 N	6 53 02 W
6325O	Almería	36 50 47 N	2 21 25 W	H02	Lepe	37 15 00 N	7 12 00 W
367	Girona	41 54 42 N	2 45 48 E	CR09	Daimiel	39 04 20 N	3 36 51 W
7178I	Murcia	38 00 07 N	1 10 15 W	SE18	P. Cazalla	37 13 23 N	5 18 38 W
9981A	Tortosa	40 49 13 N	0 29 36 E	**XEMA**	**Station**	**Latitude**	**Longitude**
8416Y	Valencia	39 28 50 N	0 21 59 W	CAT01	Certascan	42 42 37 N	1 18 08 E
IPMA	**Station**	**Latitude**	**Longitude**	CAT02	Portbou	42 25 36 N	3 09 34 E
535	Lisboa	38 42 59 N	9 08 56 W				
554	Faro	37 00 58 N	07 56 06 W				

2 Methods and Materials

We employ two chronological frameworks to offer a comprehensive view of the evolving perceptions of the Mediterranean climate. This approach allows us to draw on various historical indicators using contemporary databases.

First, we conduct a diachronic investigation based on bibliographical references to gain insights into the evolving definitions of the Mediterranean climate from 1902 to 2021. Second, we visually represent this evolution through the creation of four maps derived from updated meteorological databases, with a specific focus on the Iberian Peninsula (see Table 1).

3 Results

Based on our review of the literature spanning from 1902 to 2021, we identify three existing indices and propose a novel one. We utilize meteorological data from the period 2000–2021 and the REVIP dataset to create four maps of the Iberian Peninsula, each corresponding to one of these indices (Fig. 1a–d), along with a SWOT analysis (Table 2).

Figure 1a corresponds with De Martonne index based on the average annual temperature (T) and rainfall (P). The critical value of 10 is established and values between 10 and 20 indicate a Mediterranean climate.

Figure 1b is the Mediterranean index calculated by summing the average potential evapotranspiration (ET) and the average precipitation (P) during the summer (July, August, and September). The critical threshold of 2.5, and if this value is exceeded, it indicates a Mediterranean climate.

Figure 1c is an index based on the subtraction between two Pearson's correlation coefficients (r): the North Atlantic Oscillation index (NAOi), such as the difference between the standardized values of surface air pressure values in Iceland (Reykjavik) and the south-western part of the Iberian Peninsula (Gibraltar); and the Western Mediterranean Oscillation index (WeMOi), such as the difference between San Fernando (Spain) and Padua (Italy), along with precipitation for October, November, December, January, February and March. The critical threshold of 0 is established, and values exceeding this threshold classify the climate as Mediterranean.

Figure 1d introduces a novel index proposed in this paper, which is based on tritium activity concentration in

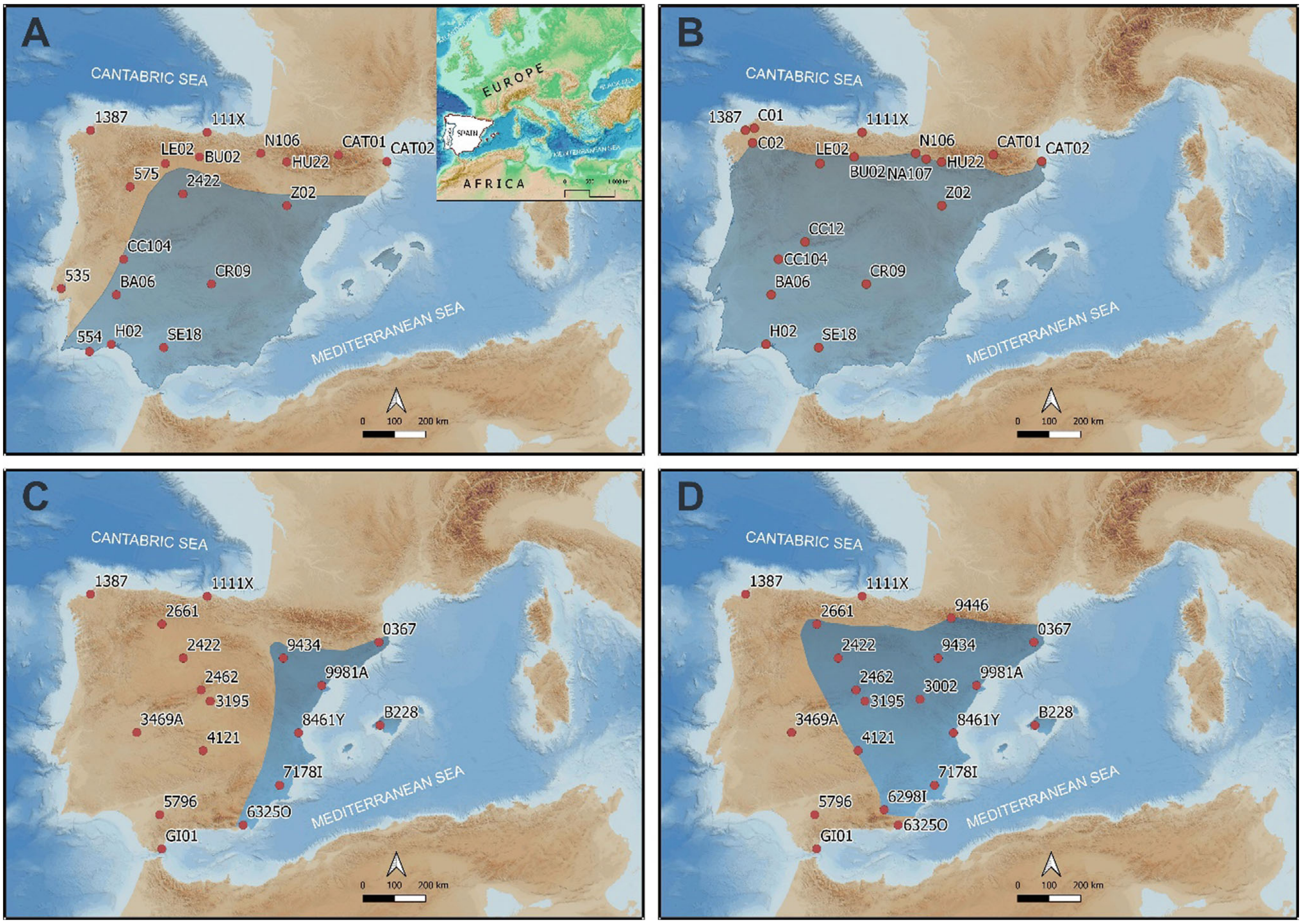

Fig. 1 The extend of Mediterranean climate's influence (in blue color) according to previous climatic indices and meteorological data (2000–2021)

Table 2 Summary and SWOT analysis of historical climatic indices examined from a three-dimensional perspective of the Mediterranean climate

	A	B	C	D
Index	$P/(T + 10)$	$\Sigma ET(j, a, s)/\Sigma P(j, a, s)$	$r(WeMOi/P)/r(NAOi/P)$	Tritium value ≤ 3.5
Reference	Martonne (1926)	Rivas-Martínez (1983)	Martín-Vide and López-Bustins (2006)	This paper
Perspective	Geographical	Bioclimatic	Synoptic climatology	Isotope hydrology
Strengths	Good aridity indicator	Good ecological indicator	Tracks origin of the rainfall	Tracks origin of the rainfall
Weaknesses	Doesn't track sea/atmosphere interaction	Doesn't track sea/atmosphere interaction	Doesn't track water	Doesn't track seawater
Opportunities	Identifies temperate climate	Identifies climax community	Identifies Mediterranean climate	Identifies Mediterranean climate
Threats	Little relevance	Little relevance	Little relationship with seawater	Little dataset and short chronology

precipitation collected by REVIP. This system has been continuously operated since 2000, overseen by the Centre for Studies and Experiments in Public Works (CEDEX). This index is determined by calculating the first quartile of the distribution of tritium values for a specific meteorological station, with the critical threshold of 3.5. Exceeding this threshold indicates a Mediterranean climate.

4 Discussion

4.1 A Review of the Mediterranean Climate from Meteorological Indices

Our historical analysis reveals a significant shift in the characterization of the Mediterranean climate, transitioning from a continental perspective to a more comprehensive maritime-temporal and volumetric approach.

Figure 1a shows the initial stage when the Mediterranean climate emerged as a scientific concept, primarily within the context of regional geography. Several authors have advocated for the contextualization of the Mediterranean climate within the evolving framework of French regional geography (Claval 1988; Ruel 1991; Deprest 2002). It was during this period that Paul Vidal de la Blache introduced the concept of the Mediterranean climate, concurrently associating it with the presence of a dry summer (Vidal de la Blache 1886). Emmanuelle De Martonne, who was Vidal de la Blache's son-in-law, can be credited as the first to devise an aridity index, which served to define the geographical extent corresponding to the Mediterranean climate (Martonne 1942).

Figure 1b aligns with the introduction of the bioclimatic viewpoint initiated by Emberger (1930), who introduced his own index incorporating evaporation indicators to define the Mediterranean bioclimate (Davis 2018). In Spain, Salvador Rivas-Martínez made pioneering contributions to further refine the Mediterranean bioclimate. He introduced a Mediterranean index to measure summer plant evapotranspiration (Rivas-Martínez 1983).

Figure 1c represents a notable shift that occurred after World War II, driven by advances in aviation and synoptic climatology. This transformation brought the interaction between the sea and the atmosphere to the forefront of climatological analysis. The sea ceased to be merely a geographical boundary between continents and became an integral component in understanding climate patterns. This shift led to a change in the primary defining characteristic of the Mediterranean climate. It shifted from being associated with the arid season to the rainy season, with atmospheric pressure taking precedence over temperature.

Figure 1d enriches a valuable dimension to the field by integrating insight from isotope hydrology into synoptic climatology. For decades, the Global Network of Isotopes in Precipitation (GNIP) has served as a vital source of data for the application of isotope tracers in hydrology and climatic studies. Spain contributes to the GNIP database through the REVIP program (CEDEX), as detailed in Jiménez-Hernández et al. (2022). The isotopic signature plays a crucial role in quantifying and distinguishing water masses with diverse origins, serving as practical benchmarks for assessing hydroclimatic processes.

4.2 To What Extent Do These Climate Indices Serve a Three-Dimensional Perspective of the Mediterranean Climate?

According to Gil Olcina (2007), the Mediterranean climate has specific characteristics that distinguish it from temperate climates with a dry season. The defining characteristic of the Mediterranean climate is the presence of an inland sea. Consequently, Fig. 1a, b are of limited value in identifying the Mediterranean climate, as they are based on the aridity characteristic of temperate climates. Figure 1c, d can serve as valuable indicators since they are related to the sea. However, Fig. 1c only encompass atmospheric indicators and does not provide insight into the origin of the water. In contrast, Fig. 1d, by relying on tritium as a hydrological cycle tracer, allow us, for example, to approximate the source of the precipitated water.

Martín-Vide and López-Bustins (2006) conducted a study on the influence of the Mediterranean Sea in the western Mediterranean region. This research revealed a significant increase in winter precipitation when WeMOi values are negative. Therefore, any analysis of precipitation variability in Spain should considerer the Mediterranean component leading to a potentially different climatic regionalization of the Mediterranean climate (as depicted in Fig. 1c). Furthermore, these authors described the region by torrential rainfall, marked by a high concentration of precipitation over a few days, closely associated with the influence of the Mediterranean Sea.

Despite a more limited dataset compared to other indicators, the REVIP dataset can prove to be a valuable ally in studying the influence of the Mediterranean Sea. The similarities between maps Fig. 1c, d would indicate that tritium can be used as a reliable tracer for rainfall.

However, these similarities would not be related to water mass processes, but rather to atmospheric phenomena. Variations in tritium activity are attributed to the recycling of water vapour in the Iberian Peninsula and the prevalence of convective precipitation in the eastern regions (Castaño and Rodríguez-Arévalo 2019).

As a result, tritium can be an excellent tool for identifying torrential rainfall, a distinctive characteristic of the

Mediterranean climate. Nonetheless, it remains imperative to continue the search for isotopic tracers that enable us to identify the entire hydrological cycle from its origin.

5 Conclusions

- Each Mediterranean climatic index corresponds to a specific perspective, technology, and historical context.
- Viewed through a volumetric maritime perspective, utilizing networks like isotopes in precipitation, such as REVIP, provides valuable insights into comprehending the Mediterranean climate.
- An index based on the REVIP dataset has been developed to redefine a new regionalization of the Mediterranean Sea's influence.
- Elevated tritium levels are linked with torrential rainfall, a prominent characteristic of Mediterranean climate precipitation.
- Further research is essential to extend the REVIP dataset, allowing for a comprehensive investigation of the entire hydrological cycle from the Mediterranean Sea to the continent.

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