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A consensus-based, revised and comprehensive catalogue for Mediterranean water masses acronyms

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Abstract

Addressing the need for clear communication in Mediterranean oceanography, this study presents a revised and comprehensive catalogue of water mass acronyms. Although there is no universal set of standard rules for assigning acronyms to water masses, as these can vary among different research groups, regions, or scientific communities, scientists generally aim for clarity and consistency when naming and abbreviating water masses to facilitate communication within the scientific community. The team of experts, guided by the CIESM (the Mediterranean Science Commission) C2 Committee on the Physics and Climate of the Ocean, reviewed existing literature and established new acronyms and naming guidelines. This standardized system, emphasizing clarity and consistency, replaces the current variable practices employed by different research groups.

Keywords: Mediterranean water masses; acronyms; rules; spatial distribution; literature review.

Introduction

The Mediterranean Sea is a dynamic, semi-enclosed basin characterized by diverse water masses, each with unique origin, circulation patterns, and properties. This basin and its water masses significantly influence regional climate, marine ecosystems, and surrounding economies. Recognizing these water masses and understanding their spreading pathways is crucial for regional and global oceanography, as they influence the Atlantic Meridional Overturning Circulation (Johnson, 1997; Rahmstorf 1998; Aldana-Campino & Döös, 2020; Kubin *et al.*, 2023; Schroeder & Chiggiato, 2022; Poulos, 2023).

Historically, Mediterranean water masses have been identified by a range of acronyms, reflecting the basin's complex hydrodynamics and the distinct research traditions of scientific communities working in the region. These terms, while practical, have sometimes introduced ambiguity. This paper seeks to provide clarity by offering a systematized catalogue of Mediterranean water mass acronyms. Through expert collaboration within the CIESM C2 Committee on the Physics and Climate of the Ocean and a thorough literature review, we propose a revised catalogue and refined rules for assigning water mass acronyms, building upon the 2001 CIESM catalogue (CIESM, 2001).

A critical aspect is a clear understanding of the terminology. Following Tomczak (1999) and Emery (2001), one can distinguish between "water masses" (WMs), "water types" (WTs) and "source water types" (SWTs).

WMs represent bodies of water with a shared formation history that occupy a physical extent, and their properties evolve through mixing and dispersal. WMs are thus identified by a segment on the temperature/salinity (θ/S) diagram. On the other hand, a WT is a mathematical concept referring to a particular combination of hydrological/physical properties that does not occupy any physical space but is a single point on the θ/S curve. A SWT is therefore a point on a θ/S diagram representing the properties of a WT in its source area, unaltered by mixing processes. A WM is produced by mixing and dispersion processes applied over one or more SWTs. The reader is referred to Tomczak (1999) and Emery (2001) for further discussion on water mass definitions and aspects, keeping in mind a quote from the latter: "The natural world is a complex organism, and attempts to describe it through a system of definitions and classifications will inevitably leave room for argument". In this study, the update of the nomenclature uses the term "water mass" to describe the Mediterranean waters as they are measured and understood within oceanographic practice, be they SWTs or water masses generated by the mixture of several SWTs.

Expanding on the CIESM table published in 2022 (CIESM, 2022), this catalogue offers a refined and consistent system that supports clear communication and fosters collaboration across the oceanographic community. It goes beyond simply compiling acronyms; it signifies a commitment to enhancing the accuracy and clarity of scientific communication in Mediterranean oceanography. The agreed-upon system offers a shared language for researchers and educators, fostering collaboration across disciplines and regions.

Materials and Methods

This study employed a multi-pronged approach to revise and update the catalogue of acronyms for Mediterranean water masses. Firstly, an extensive literature review analyzed existing knowledge on the characteristics, distribution, and nomenclature of these water masses. This comprehensive review provided a foundation for understanding the current state of knowledge. Secondly, a group of experts in Mediterranean oceanography were consulted. An initial questionnaire (Fig. 1A) gauged their perspectives on the need for revision and gathered suggestions for improvement. Following this, consensus-building meetings (Fig. 1B) facilitated open discussions and ultimately led to the formulation of agreed-upon acronyms.

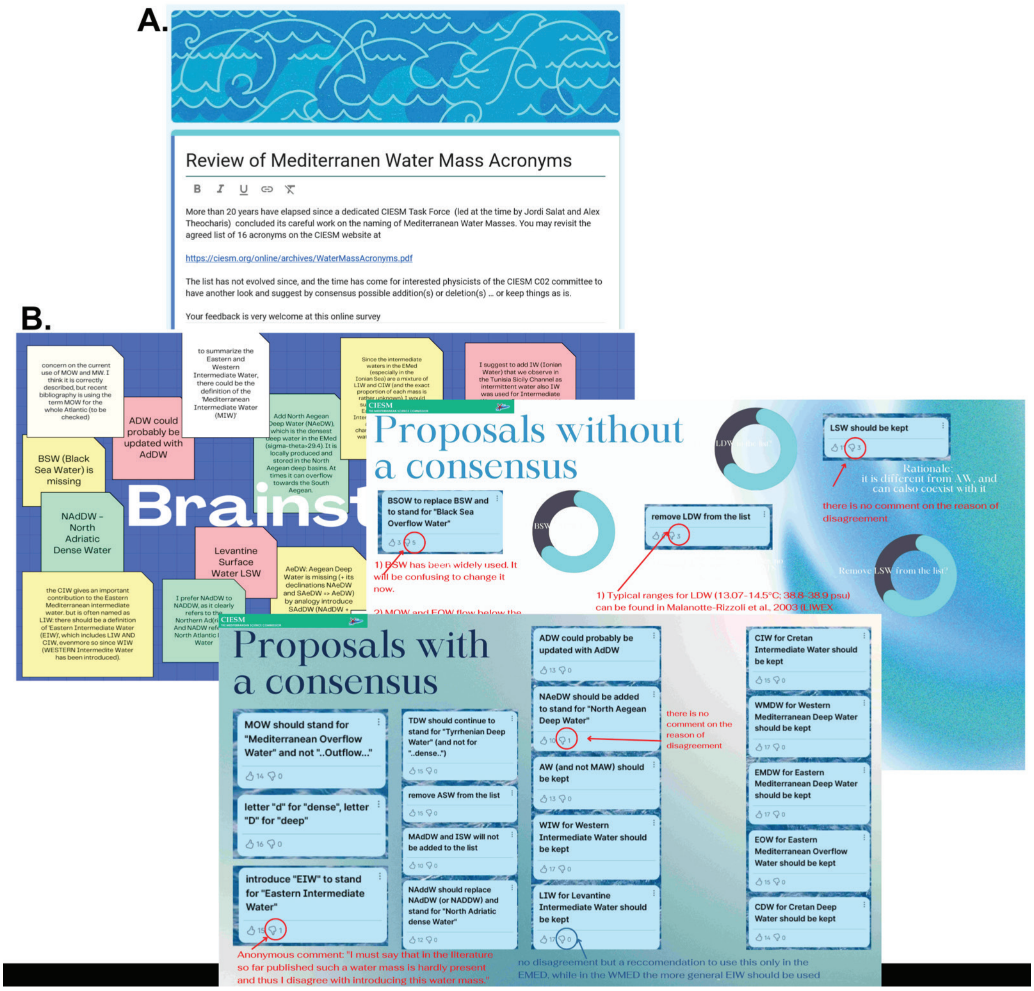

Fig. 1: (A) Screenshot of the header of the online questionnaire which was initially used to identify expert opinions on Mediterranean water mass acronyms (B) Screenshots of the online tool used to brainstorm and lead the discussion about different proposals on acronyms and definitions to find a consensus. Discussion focused specifically on items where no initial consensus was identified, to reach to a final list of fully consensual revisions.

The revision process was guided by a set of rules developed by the expert group, which emphasize clarity, consistency, and adherence to common oceanographic naming conventions. Key principles include (a) using the first (up to three) letters of the acronym to indicate the water mass's formation location, followed by (b) a single letter denoting its vertical level (S=surface, I=intermediate, D=deep, d=dense, O=overflowing at a sill), and (c) the letter W signaling a water mass. Any potential ambiguity is addressed by incorporating lowercase letters for differentiation (e.g., "Ad" for Adriatic, "Ae" for Aegean). Although these principles have been traditionally followed by oceanographers, this paper serves also to formally introduce them.

The rationale behind these revisions centers on ensuring clear and consistent communication within the oceanographic community. This standardized system accommodates the evolving nature of the field, facilitating the incorporation of new water masses and research findings.

As a final remark, and in light of the geographical and temporal variability in the Mediterranean, we have chosen not to include specific temperature, salinity, density or depth ranges for individual water masses, as these values change considerably both in time and along their routes and across subbasins. For instance, Levantine Intermediate Water (LIW) characteristics differ significantly between formation areas and locations such as the Sicily or Otranto Straits. Including such ranges could also render the catalogue less relevant over time, given the rapid trend observed in these properties across the basin (e.g., Kubin *et al.*, 2023; Margirier *et al.*, 2020).

Results: Mediterranean Water Masses Acronyms

This section presents the revised water mass acronyms. Each paragraph includes the acronym, its definition (including spatial and temporal origins, vertical location, and geographical occurrence), relevant references, and, when applicable, an explanation for any revisions made to the previous 2001 CIESM definitions. The descriptions are complemented by Figure 2 mapping the water mass acronyms and their geographical distribution within the Mediterranean. This visual aid clarifies each water mass' origin (location), depth level (surface, intermediate, deep), and general distribution patterns. While simplified, it enhances comprehension; for more details on their distributions and pathways, refer to the papers cited for each water mass in the next paragraphs.

Surface Water Masses

AW - Atlantic Water

Atlantic Water (AW) is the upper Mediterranean layer, with a (near)surface salinity minimum. Since it undergoes progressive salinification during its journey (e.g., Millot & Taupier-Letage, 2005a; (Theocharis *et al.*, 1993; Malanotte-Rizzoli *et al.*, 2014; Ben Ismail *et al.*, 2012; Estournel *et al.*, 2021), it was common to refer to it as MAW (Modified AW), but the use of "modified" has been discarded since CIESM (2001). AW originates from North Atlantic Central Water (NACW) and Surface Atlantic Water (SAW) entering through the Gibraltar Strait (Millot, 2008; Millot & Garcia-Lafuente, 2011), in variable proportions.

Distribution: Mediterranean

Previous acronym: AW, no revision.

LSW - Levantine Surface Water

Levantine Surface Water (LSW) is formed through summer heating and evaporation of AW, with surface salinity maximum (above the AW salinity minimum). It influences the Eastern Mediterranean by: (i) triggering dense water formation of LIW and LDW (see following paragraphs), (ii) activating mixing within anticyclones, and (iii) impacting preconditioning for dense water formation in the southern Adriatic subbasin (Hecht *et al.*, 1988; Theocharis *et al.*, 1999a; Ozer *et al.*, 2017, Kubin *et al.*, 2019; Menna *et al.*, 2021; Kassis & Korres, 2020).

Distribution: Eastern Mediterranean

Previous acronym: LSW, no revision.

BSW - Black Sea Water

Black Sea Water (BSW) originates from the Black Sea and enters the Mediterranean as a (near)surface salinity minimum layer. This brackish water mass is most prominent in the northern Aegean subbasin but can also be found in the western Cretan subbasin (Gertman *et al.*, 2006; Zervakis *et al.*, 2000; Velaoras *et al.*, 2021).

Distribution: Aegean subbasin

Previous acronym: BSW, no revision.

Intermediate Water Masses

LIW - Levantine Intermediate Water

Levantine Intermediate Water (LIW) is formed via dense water convection (Waldman *et al.*, 2018; Pinardi *et al.*, 2019; Kubin *et al.*, 2019) in the Levantine subbasin, exhibits a mid-depth salinity maximum and plays a crucial role in the Eastern Mediterranean's vertical stratification (Theocharis *et al.*, 1993;Malanotte-Rizzoli *et al.*, 2014; Lascaratos *et al.*, 1999; LIWEX Group, 2003; Millot & Taupier-Letage, 2005b; Ozer *et al.*, 2017;Taillandier *et al.*, 2022).

Distribution: Eastern Mediterranean

Previous acronym: LIW, required no revision in the Eastern Basin, but its use is no longer recommended in the Western Basin (see EIW definition).

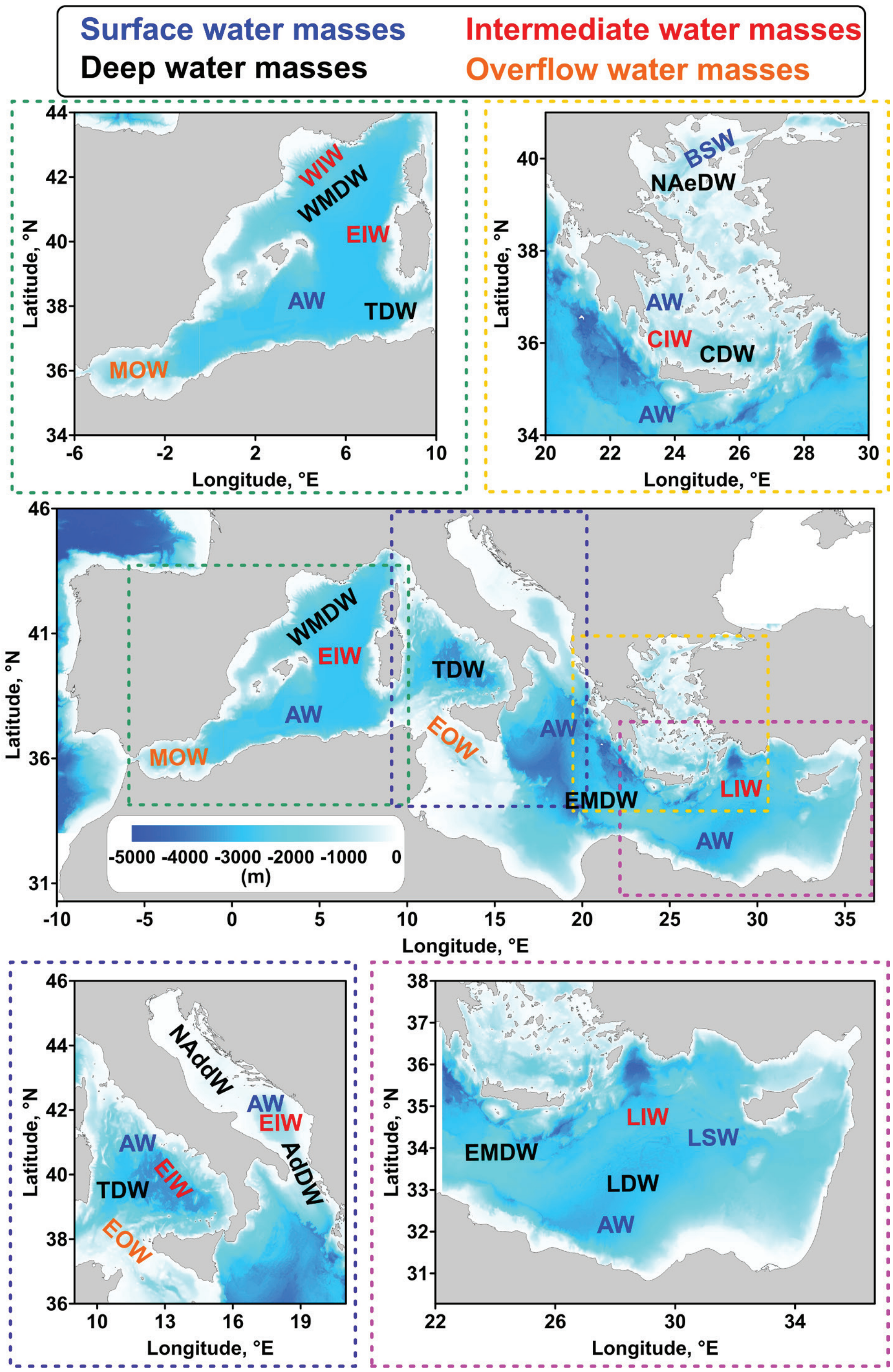

Fig. 2: Visual synthesis of the agreed-upon acronyms and their corresponding water masses. The central panel shows the whole Mediterranean, with the acronyms of water masses that have a basin-wide relevance, while the coloured boxes are shown in more detail in the upper/lower/left/right corners, including also the acronyms of locally found water masses. The level of the water masses is colour coded (legend on top).

CIW - Cretan Intermediate Water

Cretan Intermediate Water (CIW) is formed in the Cretan subbasin through shelf cascading and/or dense water convection. It shares similarities with LIW differs in origin and characteristics. This mid-depth salinity maximum plays a crucial role in the Eastern Mediterranean's vertical stratification (Schlitzer *et al.*, 1991; Theocharis *et al.*, 1999b; Velaoras *et al.*, 2014; Taillandier *et al.*, 2022).

Distribution: Eastern Mediterranean

Previous acronym: CIW, required no revision in the Eastern Basin, but its use is no longer recommended in the Western Basin (see EIW definition).

EIW - Eastern Intermediate Water

Eastern Intermediate Water (EIW) is a general term for intermediate waters formed in the Eastern Mediterranean. Although not a water mass per se, EIW combines LIW and CIW, which west of the Sicily Channel are not distinguishable anymore, due to the unknown volumes and proportions of their mixing. Its properties influence deep water formation in both Mediterranean basins (Robinson *et al.*, 2008; Grignon *et al.*, 2010; Ben Ismail *et al.*, 2014; Borghini *et al.*, 2014; Margirier *et al.*, 2020).

Distribution: Western and Eastern Mediterranean

Previous acronym: not defined. EIW was introduced by Millot (2013) as a generic term for intermediate waters in the Western Mediterranean. Here we propose to extend its use to the Eastern Mediterranean, for situations where distinguishing LIW and CIW is unnecessary or impractical due to complex mixing.

WIW - <u>W</u>estern <u>I</u>ntermediate <u>W</u>ater

Western Intermediate Water (WIW) forms through winter open ocean and shelf convection in the northwestern Mediterranean. Characterized by a temperature minimum and oxygen maximum at intermediate depths, WIW has relatively low salinity due to continental water influence and limited mixing with EIW (Juza *et al.*, 2019; Vargas-Yáñez *et al.*, 2012, 2023).

Distribution: Western Mediterranean

Previous acronym: WIW, no revision.

Deep and dense Water Masses

WMDW - <u>W</u>estern <u>M</u>editerranean <u>D</u>eep <u>W</u>ater

Formed primarily through deep ocean convection in the northwestern Mediterranean, Western Mediterranean Deep Water (WMDW) may occasionally be formed by shelf water cascading events. Extensive research (Rohling & Bryden, 1992; Leaman, 1994; Schroeder *et al.*, 2010; Durrieu De Madron *et al.*, 2013; Coppola *et al.*, 2017; Somot *et al.*, 2018; Testor *et al.*, 2018) documents its formation, distribution, and properties.

Distribution: Western Mediterranean

Previous acronym: WMDW, no revision.

EMDW - <u>E</u>astern <u>M</u>editerranean <u>D</u>eep <u>W</u>ater

Eastern Mediterranean Deep Water (EMDW) originates from the mixing of dense water masses during their sinking in the Adriatic and Aegean subbasins (occasionally Levantine too). While not a distinct water mass itself, the name is retained for historical reasons. Its origin can be inferred through unique thermodynamic properties (Roether & Schlitzer, 1991; Roether *et al.* 2007; Bensi *et al.*, 2013; Ben Ismail *et al.*, 2014; Cardin *et al.*, 2015; Velaoras *et al.*, 2019; Ozer *et al.*, 2020).

Distribution: Eastern Mediterranean

Previous acronym: EMDW, no revision.

CDW - <u>C</u>retan <u>D</u>eep <u>W</u>ater

Cretan Deep Water (CDW) forms in the Cretan subbasin through shelf cascading/convection and/or deep convection. Dense waters from the north Aegean Sea also contribute to it. CDW becomes part of the bulk EMDW upon exiting the Cretan straits (Theocharis *et al.*, 1999a, 1999b; Gertman *et al.*, 2006; Velaoras *et al.*, 2019; Potiris *et al.*, 2024a). Notably, during the Eastern Mediterranean Transient (EMT), this outflow was termed Cretan Sea Overflow Water (CSOW) (Klein *et al.*, 1999).

Distribution: Eastern Mediterranean

Previous acronym: CDW, no revision.

TDW - <u>T</u>yrrhenian <u>D</u>eep <u>W</u>ater

Tyrrhenian Deep Water (TDW) results from the mixing of EIW, EOW, and WMDW (see following definitions), and dominates the deep layers of the Tyrrhenian subbasin (Hopkins, 1988; Rhein *et al.*, 1999; Millot & Taupier-Letage, 2005a; Falco *et al.*, 2016; Schroeder *et al.*, 2016). While hypotheses propose deep convection east of the Strait of Bonifacio contributing to TDW formation (Fuda *et al.*, 2002; Napolitano *et al.*, 2019), evidence is lacking.

Distribution: Tyrrhenian subbasin

Previous acronym: TDW, required no revision.

NAddW - <u>N</u>orth <u>Ad</u>riatic <u>d</u>ense <u>W</u>ater

One of the Mediterranean's densest water masses, North Adriatic Dense Water (NAddW) forms through shelf convection during cold bora winds in the northern Adriatic subbasin. This extremely cold water plays a crucial role in the subbasin's circulation and contributes to the bulk EMDW after mixing with AdDW (see following definitions) (Zore-Armanda, 1963; Artegiani *et al.*, 1997; Vilibić & Supić, 2005; Mihanović *et al.*, 2013; Querin *et al.*, 2016; Vilibić *et al.*, 2023).

Distribution: Adriatic subbasin

Previous acronym: NAdDW or NADDW (North Adriatic Deep Water), to be replaced by NAddW (North Adriatic Dense Water), to reflect the water mass being dense ("d") rather than "deep" ("D") due to shelf occurrence. "NAd" signifies its formation in the North Adriatic.

AdDW - <u>Ad</u>riatic <u>D</u>eep <u>W</u>ater

Formed through deep convection during cold winter outbreaks in the southern Adriatic, Adriatic Deep Water (AdDW) drives the Adriatic-Ionian circulation and contributes to the bulk of EMDW by flowing through the Otranto Strait (Zore-Armanda, 1963; Schlitzer *et al.*, 1991; Vilibić & Orlić, 2001; Gačić *et al.*, 2002; Pirro *et al.*, 2022; Kubin *et al.*, 2023).

Distribution: Adriatic subbasin

Previous acronym: ADW, to be replaced by AdDW, since "Ad" clarifies its Adriatic origin (matching NAddW) to avoid confusion with Atlantic or Aegean water masses (defined below).

NAeDW - North Aegean Deep Water

North Aegean Deep Water (NAeDW) forms through shelf cascading in the northern Aegean subbasin, where it accumulates in deep trenches, contributes to CDW and eventually to the bulk EMDW (Theocharis & Georgopoulos, 1993; Zervakis *et al.*, 2000; Gertman *et al.*, 2006; Velaoras *et al.*, 2017; Potiris *et al.*, 2024b).

Distribution: Aegean subbasin

Previous acronym: not defined. Already used in some papers, here NAeDW is introduced to address the previously missing acronym for deep water present in the North Aegean subbasin. "NAe" signifies its origin (North Aegean) to avoid confusion with Adriatic water masses (e.g. NAdDW).

LDW - Levantine Deep Water

Levantine Deep Water (LDW) forms within the Levantine subbasin's Rhodes Gyre and occasionally through deep convection, contributing to the bulk EMDW (Sur *et al.*, 1992; Kontoyiannis *et al.*, 1999; Roether *et al.*, 2007; Malanotte-Rizzoli *et al.*, 2014; Kubin *et al.*, 2019).

Distribution: Levantine subbasin

Previous acronym: LDW, no revision.

Overflow Waters

EOW - Eastern Mediterranean Overflow Water

Eastern Mediterranean Overflow Water (EOW) represents a mixed overflow of water masses (EIW and upper EMDW) cascading from the Eastern Mediterranean into the Tyrrhenian subbasin through the Sicily Channel (Gasparini *et al.*, 2005; Sparnocchia *et al.*, 1999; Astraldi *et al.*, 2001). EOW serves as a generic term for the multiple water masses involved in this overflow process, rather than a single water mass.

Distribution: Sicily Channel and Tyrrhenian subbasin

Previous acronym: EOW, no revision.

MOW - Mediterranean Overflow Water

Mediterranean Overflow Water (MOW) represents the collective overflow of Mediterranean water masses exiting the Mediterranean through the Strait of Gibraltar. MOW comprises a complex mixture of water masses and serves as a generic (Millot *et al.*, 2006; Garcia-Lafuente *et al.*, 2007; Millot, 2008, 2009; Millot & Garcia-Lafuente, 2011; Millot, 2014; Naranjo *et al.*, 2015).

Distribution: Eastern Atlantic

Previous acronym: MOW, the acronym is maintained with a slightly modified definition ("O" now means "Overflow" instead of "Outflow").

Discussion and Conclusion

Standardizing water mass acronyms in Mediterranean oceanography signifies a crucial step towards improved scientific practices. This unified system fosters collaboration by offering researchers a common language across diverse disciplines. It signifies a willingness among scientists to critically evaluate their own knowledge and practices, acknowledging areas where improvement is needed. Consistent terminology allows for seamless data exchange between institutions and projects, ensuring datasets are comparable and facilitating comprehensive analyses. Furthermore, a standardized catalog serves as a valuable educational resource, simplifying the learning process for students and professionals studying the dynamics of Mediterranean water masses, contributing to the training of the next generation of oceanographers and marine scientists.

This approach not only aligns regional practices with global oceanographic standards but also promotes interoperability with international datasets and initiatives. Standardized acronyms enable robust analyses of long-term trends and changes within the Mediterranean. Consistent labeling of water masses allows scientists to gain deeper insights into climate-driven shifts, environmental variations, and their impact on the region's marine ecosystems. In essence, this revision signifies a commitment to scientific clarity, collaboration, and a deeper understanding of the Mediterranean Sea's complex dynamics.

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