

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

Katrin SCHROEDER¹, Sana BEN ISMAIL², Manuel BENSI³, Anthony BOSSE⁴, Jacopo CHIGGIATO¹, Giuseppe CIVITARESE⁵, Francesco M. FALCIERI¹, Giannetta FUSCO⁶, Miroslav GAČIĆ³, Isaac GERTMAN⁶, Elisabeth KUBIN³, Paola MALANOTTE-RIZZOLI^{1,7}, Riccardo MARTELLUCCI³, Milena MENNA³, Tal OZER⁶, Isabelle TAUPIER-LETAGE⁴, Manuel VARGAS YÁÑEZ⁸, Dimitris VELAORAS⁹ and Ivica VILIBIĆ^{10,11}

¹ CNR ISMAR, Venezia, 30122, Italy

² INSTM, Carthage, 2025, Tunisia

³ OGS, Trieste, 34100, Italy

⁴ Aix Marseille Univ, Université de Toulon, CNRS, IRD, MIO, Marseille, 13000, France

⁵ University of Naples Parthenope, Naples, 80132, Italy

⁶ Israel Oceanographic and Limnological Research, Haifa, 3478403, Israel

⁷ Massachusetts Institute of Technology, Cambridge, MA 02139, USA

⁸ IEO-CSIC, Malaga, 29640, Spain

⁹ HCMR, Anavyssos, 19013, Greece

¹⁰ Ruder Bošković Institute, Zagreb, 10000, Croatia

¹¹ Institute for Adriatic Crops and Karst Reclamation, Split, 21000, Croatia

Corresponding author: Katrin SCHROEDER; katrin.schroeder@cnr.it

Contributing Editor: Elina TRAGOU

Received: 30 August 2024; Accepted: 15 November 2024; Published online: 02 December 2024

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; Tailandier *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).

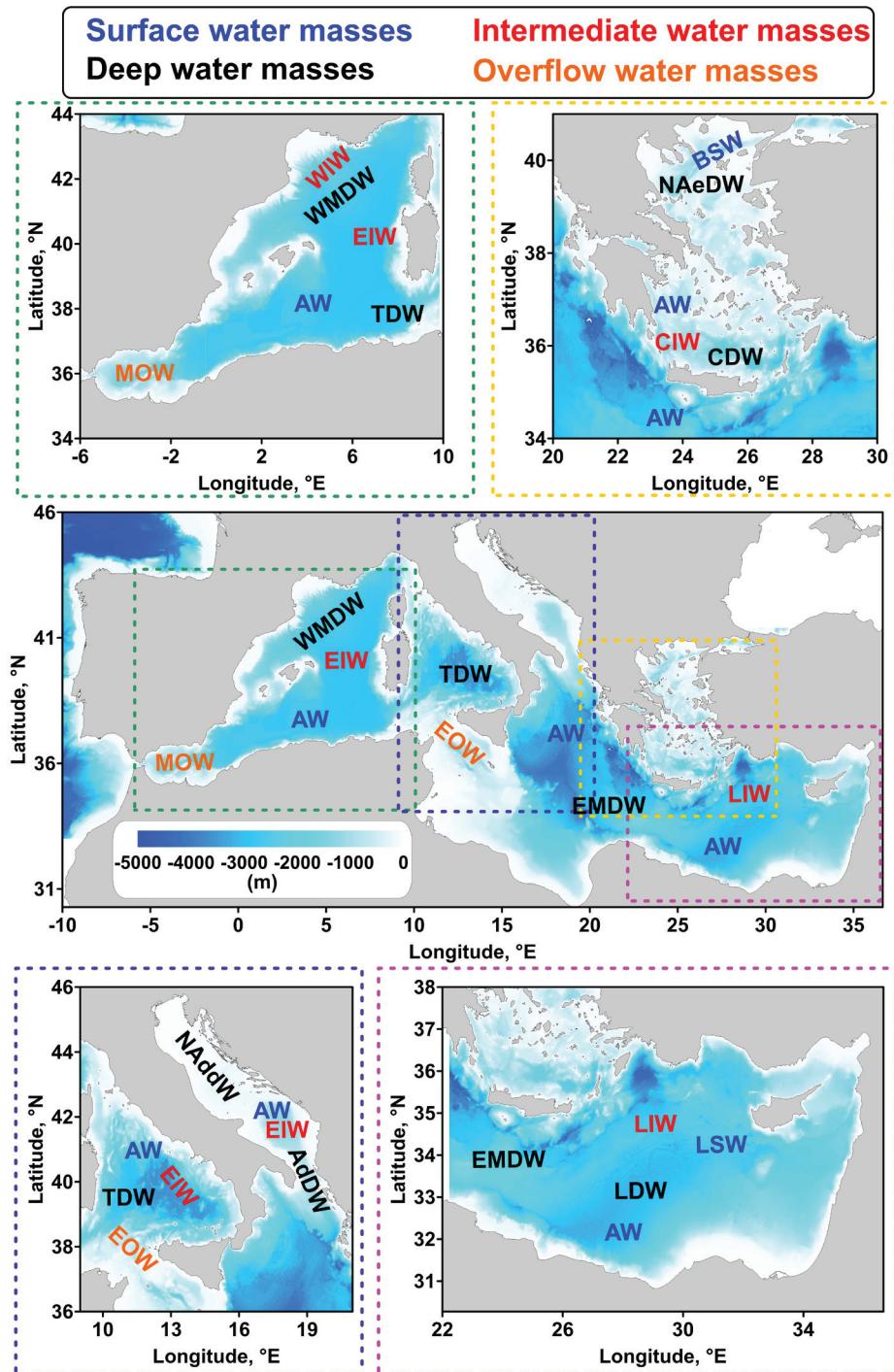


Fig. 2: Visual synthesis of the agreed-upon acronyms and their corresponding water masses. The central panel shows the whole Mediterranean, with the acronyms of water masses that have a basin-wide relevance, while the coloured boxes are shown in more detail in the upper/lower/left/right corners, including 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 but 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; Theocaris *et al.*, 1999b; Velaoras *et al.*, 2014; Taillardier *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 - Western Intermediate Water

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 - Western Mediterranean Deep Water

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 - Eastern Mediterranean Deep Water

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 - Cretan Deep Water

Cretan Deep Water (CDW) forms in the Cretan subba-

sin 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 - Tyrrhenian Deep Water

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 - North Adriatic dense Water

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 - Adriatic Deep Water

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.

Acknowledgements

We would like to express our gratitude to the former CIESM General Director Frederic Briand and Research Officers Laura Giuliano (now General Director) and Paula Moschella for their invaluable contributions to this study. Their expertise, guidance, and support were instrumental in the development of this comprehensive catalogue of Mediterranean water masses acronyms. Finally, we acknowledge the broader community of Mediterranean oceanographers whose research and dedication have advanced our understanding of the region’s complex water masses.

References

- Aldana-Campino, A., Döös, K., 2020. Mediterranean overflow water in the North Atlantic and its multidecadal variability. *Tellus A: Dynamic Meteorology and Oceanography*, 72, 1565027.
- Artegiani, A., Bregant, D., Paschini, E., Pinardi, N., Raicich, F. *et al.*, 1997. The Adriatic Sea general circulation. Part I: Air-sea interactions and water mass structure. *Journal of Physical Oceanography*, 27 (7), 1492-1514.
- Astraldi, M., Gasparini, G.P., Gervasio, L., Salusti, E., 2001. Dense water dynamics along the Strait of Sicily (Mediterranean Sea). *Journal of Physical Oceanography*, 31, 3457-3475.

Ben Ismail, S., Sammari, C., Gasparini, G.P., Brahim, M., Béranger, K. *et al.*, 2012. Water masses exchanged through the Sicily Channel: evidence for the presence of new water masses on Tunisian side of the Channel. *Deep-Sea Research I*, 63, 65-81.

Ben Ismail, S., Schroeder, K., Sammari, C., Gasparini, G.P., Aleya, L., 2014. Interannual variability of water masses in the Sicily Channel. *Journal of Marine System*, 135, 14-28.

Bensi, M., Rubino, A., Cardin, V., Hainbucher, D., Mancero-Mosquera, I., 2013. Structure and variability of the abyssal water masses in the Ionian Sea in the period 2003-2010. *Journal of Geophysical Research: Oceans*, 118, 931-943.

Borghini, M., Bryden, H., Schroeder, K., Sparnocchia, S., Venrano, A., 2014. The Mediterranean is becoming saltier. *Ocean Science*, 10, 693-700.

Cardin, V., Civitarese, G., Hainbucher, D., Bensi, M., Rubino, A., 2015. Thermohaline properties in the Eastern Mediterranean in the last three decades: is the basin returning to the pre-EMT situation? *Ocean Science*, 11, 53-66.

CIESM, 2001. Report of the second Round Table on Mediterranean Water Mass Acronyms, in: Acts of the 36th CIESM Congress, available at: www.ciesm.org/catalog/WaterMassAcronyms.pdf.

CIESM, 2022. Report of the 2022 Round Table on Mediterranean Water Masses Acronyms, available at: https://ciesm.org/MWM_Acronyms/MedWaterMassAcronyms.pdf.

Coppola, L., Prieur, L., Taupier-Letage, I., Estournel, C., Testor, P. *et al.*, 2017. Observation of oxygen ventilation into deep waters through targeted deployment of multiple Argo-O2 floats in the north-western Mediterranean Sea in 2013. *Journal of Geophysical Research*, 122 (8), 6325-6341.

Durrieu de Madron, X., Houpert, L., Puig, P., Sanchez-Vidal, A., Testor, P. *et al.*, 2013. Interaction of dense shelf water cascading and open-sea convection in the northwestern Mediterranean during winter 2012. *Geophysical Research Letters*, 40, 1379-1385.

Emery, W.J., 2001. Water types and water masses. *Encyclopedia of Ocean Sciences*, 6, 3179-3187.

Estournel, C., Marsaleix, P., Ulses, C., 2021. A new assessment of the circulation of Atlantic and Intermediate Waters in the Eastern Mediterranean. *Progress in Oceanography*, 198, 102673.

Falco, P., Trani, M., Zambianchi, E., 2016. Water mass structure and deep mixing processes in the Tyrrhenian Sea: Results from the VECTOR project. *Deep Sea Research Part I: Oceanographic Research Papers*, 113, 7-21.

Fuda, J.L., Etiöpe, L.G., Millot, C., Favali, M., Calcara, M. *et al.*, 2002. Warming, salting and origin of the Tyrrhenian Deep Water. *Geophysical Research Letters*, 29 (19), 1898.

Gaćić, M., Civitarese, G., Miserocchi, S., Cardin, V., Crise, A. *et al.*, 2002. The open-ocean convection in the Southern Adriatic: a controlling mechanism of the spring phytoplankton bloom. *Continental Shelf Research*, 22 (17), 1897-1908.

Garcia-Lafuente, J.G., Román, A.S., del Río, G.D., Sannino, G., Garrido, J.C.S., 2007. Recent observations of seasonal variability of the Mediterranean outflow in the Strait of Gibraltar. *Journal of Geophysical Research: Oceans*, 112 (C10).

Gasparini, G.P., Ortona, A., Budillon, G., Astraldi, M., Sansone, E., 2005. The effect of the Eastern Mediterranean Transient on the hydrographic characteristics in the Strait of Sicily and in the Tyrrhenian Sea. *Deep Sea Research Part I: Oceanographic Research Papers*, 52 (6), 915-935.

Gertman, I., Pinardi, N., Popov, Y., Hecht, A., 2006. Aegean Sea water masses during the early stages of the Eastern Mediterranean climatic transient (1988-90). *Journal of Physical Oceanography*, 36 (9), 1841-1859.

Grignon, L., Smed, D.A., Bryden, H.L., Schroeder, K., 2010. Importance of the variability of hydrographic preconditioning for deep convection in the Gulf of Lion, NW Mediterranean. *Ocean Science*, 6 (2), 573-586.

Hecht, A., Pinardi, N., Robinson, A.R., 1988. Currents, water masses, eddies and jets in the Mediterranean Levantine Basin. *Journal of Physical Oceanography*, 18 (9), 1320-1353.

Hopkins, T.S., 1988. Recent observations on the intermediate and deep water circulation in the southern Tyrrhenian Sea. *Oceanologica Acta, Special issue*, 9, pp. 41-50.

Johnson, R.G., 1997. Climate Control Requires a Dam at the Strait of Gibraltar. *EOS, Transactions American Geophysical Union*, 78 (27), 277-284.

Juza, M., Escudier, R., Vargas-Yáñez, M., Mourre, B., Heslop, E. *et al.*, 2019. Characterization of changes in Western Intermediate Water properties enabled by an innovative geometry-based detection approach. *Journal of Marine Systems*, 191, 1-12.

Kassis, D., Korres, G., 2020. Hydrography of the Eastern Mediterranean basin derived from argo floats profile data. *Deep Sea Research Part II: Topical Studies in Oceanography*, 171, 104712.

Klein, B., Roether, W., Manca, B.B., Bregant, D., Beitzel, V. *et al.*, 1999. The large deep water transient in the Eastern Mediterranean. *Deep Sea Research Part I: Oceanographic Research Papers*, 46 (3), 371-414.

Kontoyiannis, H., Theocharis, A., Nittis, K., 1999. Structures and Characteristics of Newly Formed Water Masses in the NW Levantine During 1986, 1992, 1995. In The Eastern Mediterranean as a Laboratory Basin for the Assessment of Contrasting Ecosystems (pp. 281-322). *NATO Science Series*.

Kubin, E., Poulain, P.M., Mauri, E., Menna, M., Notarstefano, G., 2019. Levantine intermediate and Levantine deep water formation: An Argo float study from 2001 to 2017. *Water*, 11 (9), 1781.

Kubin, E., Menna, M., Mauri, E., Notarstefano, G., Mieruch, S. *et al.*, 2023. Heat content and temperature trends in the Mediterranean Sea as derived from Argo float data. *Frontiers in Marine Science*, 10, 1271638.

Lascaratos, A., Roether, W., Nittis, K., Klein, B., 1999. Recent changes in deep Water formation and spreading in the eastern Mediterranean Sea: A review. *Progress in Oceanography*, 44, 5-36.

Leaman, K.D., 1994. "Chapter 12: The Formation of Western Mediterranean Deep Water." In: Paul E. La Viollette (Ed.), *Coastal and Estuarine Studies*.

LIWEX Group, 2003. The Levantine Intermediate Water Experiment (LIWEX) Group: Levantine basin - A laboratory for multiple water mass formation processes. *Journal of Geophysical Research*, 108 (C9), 8101.

Malanotte-Rizzoli, P., Artale, V., Borzelli-Eusebi, G.L., Brenner, S., Crise, A. *et al.*, 2014. Physical forcing and physical/biochemical variability of the Mediterranean Sea: a review

of unresolved issues and directions for future research. *Ocean Science*, 10 (2), 281-322.

Margirier, F., Testor, P., Heslop, E., Mallil, K., Bosse, A. *et al.*, 2020. Abrupt warming and salinification of intermediate waters interplays with decline of deep convection in the Northwestern Mediterranean Sea. *Scientific Reports*, 10 (1), 20923.

Menna, M., Gerin, R., Notarstefano, G., Mauri, E., Bussani, A. *et al.*, 2021. On the Circulation and Thermohaline Properties of the Eastern Mediterranean Sea. *Frontiers in Marine Science*, 8, 671469,

Mihanović, H., Vilibić, I., Carniel, S., Tudor, M., Russo, A. *et al.*, 2013. Exceptional dense water formation on the Adriatic shelf in the winter of 2012. *Ocean Science*, 9 (3), 561-572.

Millot, C., 2008. Short-term variability of the Mediterranean in- and out-flows. *Geophysical Research Letters*, 35 (15).

Millot, C., 2009. Another description of the Mediterranean Sea outflow. *Progress in Oceanography*, 82 (2), 101-124.

Millot, C., 2013. Levantine Intermediate Water characteristics: an astounding general misunderstanding! *Scientia Marina*, 77 (2), 217-232.

Millot, C., 2014. Heterogeneities of in- and out-flows in the Mediterranean Sea. *Progress in Oceanography*, 120, 254-278.

Millot, C., Garcia-Lafuente, J., 2011. About the seasonal and fortnightly variabilities of the Mediterranean outflow. *Ocean Science*, 7 (3), 421-428.

Millot, C., Taupier-Letage, I., 2005a. Circulation in the Mediterranean Sea. In *The Handbook of Environmental Chemistry*, Volume 5 Part K, Alain Saliot volume Ed., Springer Verlag, Berlin Heidelberg, 29-66.

Millot, C., Taupier-Letage, I., 2005b. Additional evidence of LIW entrainment across the Algerian Basin by mesoscale eddies and not by a permanent westward-flowing vein. *Progress in Oceanography*, 66, 231-250.

Millot, C., Candela, J., Fuda, J.-L., Tber, Y., 2006. Large warming and salinification of the Mediterranean outflow due to changes in its composition. *Deep Sea Research Part I*, 53 (4), 656-666.

Napolitano, E., Iacono, R., Ciuffardi, T., Reseghetti, F., Pouliquen, P.M. *et al.*, 2019. The Tyrrhenian Intermediate Water (TIW): characterization and formation mechanisms. *Progress in Oceanography*, 170, 53-68.

Naranjo, C., Sammartino, S., García-Lafuente, J., Bellanco, M.J., Taupier-Letage, I., 2015. Mediterranean waters along and across the Strait of Gibraltar, characterization and zonal modification. *Deep Sea Research Part I: Oceanographic Research Papers*, 105, 41-52.

Ozer, T., Gertman, I., Kress, N., Silverman, J., Herut, B., 2017. Interannual thermohaline (1979-2014) and nutrient (2002-2014) dynamics in the Levantine surface and intermediate water masses, SE Mediterranean Sea. *Global and Planetary Change*, 151, 60-67.

Ozer, T., Gertman, I., Gildor, H., Goldman, R., Herut, B., 2020. Evidence for recent thermohaline variability and processes in the deep water of the Southeastern Levantine Basin, Mediterranean Sea. *Deep Sea Research Part II: Topical Studies in Oceanography*, 171, 104651.

Pinardi, N., Cessi, P., Borile, F., Wolfe, C.L.P., 2019. The Mediterranean Sea Overturning Circulation. *Journal of Physical Oceanography*, 49, 1699-1721.

Pirro, A., Mauri, E., Gerin, R., Martellucci, R., Zuppelli, P. *et al.*, 2022. New insights on the formation and breaking mechanism of convective cyclonic cones in the South Adriatic Pit during winter 2018. *Journal of Physical Oceanography*, 52 (9), 2049-2068.

Potiris, M., Mamoutsos, I.G., Tragou, E., Zervakis, V., Kassis, D. *et al.*, 2024a. Dense Water Formation Variability in the Aegean Sea from 1947 to 2023. *Oceans*, 5, 611-636.

Potiris, M., Mamoutsos, I.G., Tragou, E., Zervakis, V., Kassis, D. *et al.*, 2024b. Dense Water Formation in the North-Central Aegean Sea during Winter 2021–2022. *Journal of Marine Science and Engineering*, 12, 221.

Poulos, S.E., 2023. Water Masses of the Mediterranean Sea and Black Sea: An Overview. *Water*, 15 (18), 3194.

Querin, S., Bensi, M., Cardin, V., Solidoro, C., Bacer, S. *et al.*, 2016. Saw-tooth modulation of the deep-water thermohaline properties in the southern Adriatic Sea. *Journal of Geophysical Research: Oceans*, 121, 4585-4600.

Rahmstorf, S., 1998. Influence of Mediterranean outflow on Climate. *EOS*, 79, 24, 281-282.

Rhein, M., Send, U., Klein, B., Krahmann, G., 1999. Inter-basin deep water exchange in the western Mediterranean. *Journal of Geophysical Research: Oceans*, 104 (C10), 23495-23508.

Robinson, R. A., Leslie, G. W., Theocharis, A., Lascaratos, A., 2008. Mediterranean Sea circulation. In: *Encyclopedia of Ocean Sciences*: Second Edition, pp. 710–725.

Roether, W., Schlitzer, R., 1991. Eastern Mediterranean deep water renewal on the basis of chlorofluoromethane and tritium data. *Dynamics of Atmospheres and Oceans*, 15, 3-5, 333-354.

Roether, W., Klein, B., Manca, B.B., Theocharis, A., Kioroglou, S., 2007. Transient Eastern Mediterranean deep waters in response to the massive dense-water output of the Aegean Sea in the 1990s. *Progress in Oceanography*, 74, 540-571.

Rohling E.J., Bryden, H.L., 1992. Man-induced salinity and temperature increases in western Mediterranean deep water. *Journal of Geophysical Research*, 97 (C7), 11191-11198.

Schlitzer, R., Roether, W., Oster, H., Junghaus, H.-G., Hausmann, M. *et al.*, 1991. Chlorofluoromethane and oxygen in the Eastern Mediterranean. *Deep-Sea Research*, 38, 1531-1551.

Schroeder K., Chiggiato J. (Eds), 2022. *Oceanography of the Mediterranean Sea. An Introductory Guide*. Elsevier.

Schroeder, K., Chiggiato, J., Bryden, H.L., Borghini, M., Ben Ismail, S., 2016. Abrupt climate shift in the Western Mediterranean Sea. *Scientific Reports*, 6 (23009), 1-7.

Schroeder, K., Josey, S.A., Herrmann M., Grignon L., Gasparini G.P. *et al.*, 2010. Abrupt warming and salting of the Western Mediterranean Deep Water after 2005: Atmospheric forcings and lateral advection. *Journal of Geophysical Research*, 115, C08029.

Somot, S., Houpert, L., Sevault, F., Testor, P., Bosse, A. *et al.*, 2018. Characterizing, modelling and understanding the climate variability of the deep water formation in the North-Western Mediterranean Sea. *Climate Dynamics*, 51 (3), 1179-1210.

Sparnocchia, S., Gasparini, G.P., Astraldi, M., Borghini, M., Pistek, P., 1999. Dynamics and mixing of the Eastern Mediterranean outflow in the Tyrrhenian basin. *Journal of Ma-*

rine Systems, 20 (1-4), 301-317.

Sur, H. L., Özsoy, E., Unluata, U., 1992. Simultaneous deep and intermediate depth convection in the Northern Levantine Sea, winter 1992. *Oceanologica Acta*, 16 (1), 33-43.

Taillardier, V., D'Ortenzio, F., Prieur, L., Conan, P., Coppola, L. *et al.*, 2022. Sources of the Levantine intermediate water in winter 2019. *Journal of Geophysical Research: Oceans*, 127, e2021JC017506.

Testor, P., Bosse, A., Houpert, L., Margirier, F., Mortier, L. *et al.*, 2018. Multiscale Observations of Deep Convection in the Northwestern Mediterranean Sea During Winter 2012-2013 Using Multiple Platforms. *Journal of Geophysical Research: Oceans*, 123 (3), 1745-1776.

Theocharis, A., Georgopoulos, D., 1993. Dense water formation over the Samothraki and Limnos Plateaux in the north Aegean Sea (Eastern Mediterranean Sea). *Continental Shelf Research*, 13 (8).

Theocharis, A., Georgopoulos, D., Lascaratos, A., Nittis, K., 1993. Water masses and circulation in the central region of the eastern Mediterranean: eastern Ionian, South Aegean, and northwest Levantine, 1986-1987. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 40 (6), 1121-1142.

Theocharis, A., Balopoulos, E., Kioroglou, S., Kontoyiannis, H., Iona, A., 1999a. A synthesis of the circulation and hydrography of the South Aegean Sea and the Straits of the Cretan Arc (March 1994 - January 1995). *Progress in Oceanography*, 44 (4), 469-509.

Theocharis, A., Nittis, K., Kontoyiannis, H., Papageorgiou, E., Balopoulos, S., 1999b. Climatic changes in the Aegean Sea influence the Eastern Mediterranean thermohaline circulation (1986-1997). *Geophysical Research Letters*, 26 (11), 1617-1620.

Tomczak, M., 1999. Some historical, theoretical and applied aspects of quantitative water mass analysis, *Journal of Marine Research*, 57, 275-303.

Vargas-Yáñez, M., Moya, F., Serra, M., Juza, M., Jordà, G. *et al.*, 2023. Observations in the Spanish Mediterranean Waters: A Review and Update of Results of 30-Year Monitoring. *Journal of Marine Science and Engineering*, 11, 1284.

Vargas-Yanez, M., Zunino, P., Schroeder, K., Lopez-Jurado, J.L., Plaza, F. *et al.*, 2012. Extreme Western Intermediate Water formation in winter 2010. *Journal of Marine Systems*, 105-108, 52-59.

Velaoras, D., Zervakis, V., Theocharis, A., 2021. The Physical Characteristics and Dynamics of the Aegean Water Masses, in: The Aegean Sea Environment: The Natural System. Springer Nature Switzerland.

Velaoras, D., Krokos, G., Nittis, K., Theocharis, A., 2014. Dense intermediate water outflow from the Cretan Sea: A salinity driven, recurrent phenomenon, connected to thermohaline circulation changes. *Journal of Geophysical Research: Oceans*, 119.

Velaoras, D., Papadopoulos, V. P., Kontoyiannis, H., Papageorgiou, D.K., Pavlidou, A. *et al.*, 2017. The response of the Aegean Sea (eastern Mediterranean) to the extreme 2016-2017 winter. *Geophysical Research Letters*, 44, 9416-9423.

Velaoras, D., Papadopoulos, V. P., Kontoyiannis, H., Cardin, V., Civitarese, G., 2019. Water masses and hydrography during April and June 2016 in the Cretan Sea and Cretan passage (eastern Mediterranean Sea). *Deep-Sea Research Part II: Topical Studies in Oceanography*, 164, 25-40.

Vilibić, I., Orlić, M., 2001. Least-squares tracer analysis of water masses in the South Adriatic (1967-1990). *Deep-Sea Research I*, 48 (10), 2297-2330.

Vilibić, I., Supić, N., 2005. Dense water generation on a shelf: the case of the Adriatic Sea. *Ocean Dynamics*, 55, 403-415.

Vilibić, I., Pranić, P., Denamiel, C., 2023. North Adriatic Dense Water: lessons learned since the pioneering work of Mira Zore-Armanda 60 years ago. *Acta Adriatica*, 64, 53-78.

Waldman, R., Brüggemann, N., Bosse, A., Spall, M., Somot, S. *et al.*, 2018. Overturning the Mediterranean thermohaline circulation. *Geophysical Research Letters*, 45, 8407-8415.

Zervakis, V., Georgopoulos, D., Drakopoulos, P.G., 2000. The role of the North Aegean in triggering the recent eastern Mediterranean climatic changes. *Journal of Geophysical Research*, 105 (C11), 26103-26116.

Zore-Armanda, M., 1963. Les masses d'eau de la mer Adriatique. *Acta Adriatica*, 10, 5-88.