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THE AMOC COLLAPSE AND ATLANTIC COLD BLOB: CHALLENGES FOR INTERNATIONAL CLIMATE LAW AND GLOBAL OCEAN GOVERNANCE IN A CHANGING CLIMATE

O COLAPSO DA AMOC E A MANCHA FRIA DO ATLÂNTICO: DESAFIOS PARA O DIREITO INTERNACIONAL DO CLIMA E A GOVERNAÇÃO GLOBAL DOS OCEANOS NUM CLIMA EM MUDANÇA

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ABSTRACT

Objective: This article examines the challenges that the potential collapse of the Atlantic Meridional Overturning Circulation (AMOC) and the development of the North Atlantic cold blob pose to international climate law and global ocean governance. It assesses the adequacy of existing international legal instruments in preventing, mitigating and addressing systemic ocean-related climate risks, with particular emphasis on the United Nations Convention on the Law of the Sea (UNCLOS), the Paris Agreement and the Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement).

Methodology: The study adopts a qualitative, deductive and interdisciplinary approach, based on a bibliographic and documentary review of international treaties, scientific literature, reports and relevant regulatory frameworks. It combines scientific

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knowledge concerning AMOC dynamics, freshwater influx, ocean circulation and climate tipping points with a legal analysis of international environmental protection, climate governance and the law of the sea. Particular attention is paid to States' obligations of prevention, due diligence, international cooperation and environmental protection, as well as to the institutional and normative fragmentation affecting global ocean governance.

Results: The findings indicate that the potential weakening or collapse of the AMOC constitutes a systemic climate risk with potentially far-reaching consequences for weather patterns, marine biodiversity, food security, economic stability, human mobility and international security. The analysis identifies significant limitations in the capacity of existing international legal frameworks to address interconnected ocean and climate risks in an integrated and preventive manner. Although UNCLOS establishes important obligations to protect and preserve the marine environment, and the BBNJ Agreement provides additional mechanisms for marine biodiversity conservation, environmental impact assessment, capacity-building and the transfer of marine technology, their effectiveness depends on coherent implementation and institutional cooperation. The study also highlights the importance of applying precautionary approaches, strengthening scientific monitoring and addressing inequalities in global ocean governance.

Conclusions: The article concludes that the potential AMOC crisis requires a transition from fragmented and predominantly reactive approaches towards integrated, preventive and adaptive ocean governance. Strengthening international cooperation, implementing existing legal obligations, improving early-warning and monitoring systems, and coordinating climate and marine environmental policies are essential to reducing systemic risks. The effective integration of UNCLOS, the Paris Agreement and the BBNJ Agreement, supported by scientific evidence and equitable international cooperation, can contribute to greater ocean resilience and legal certainty. Ultimately, safeguarding the stability of ocean circulation systems is a critical component of international climate action, environmental protection and global security.

Keywords: Atlantic Meridional Overturning Circulation (AMOC); North Atlantic Cold Blob; International Climate Law; United Nations Convention on the Law of the Sea (UNCLOS); Global Ocean Governance; Climate Security.

RESUMO

Objetivo: O presente artigo analisa os desafios que o potencial colapso da Circulação de Revolvimento Meridional do Atlântico (Atlantic Meridional Overturning Circulation — AMOC) e a formação da mancha fria do Atlântico Norte colocam ao Direito Internacional do Clima e à governação global dos oceanos. Avalia-se a adequação dos instrumentos jurídicos internacionais existentes para prevenir, mitigar e enfrentar os riscos climáticos sistémicos associados aos oceanos, com particular incidência na Convenção das Nações Unidas sobre o Direito do Mar (CNUDM), no Acordo de Paris e no Acordo relativo à Conservação e à Utilização Sustentável da Diversidade Biológica Marinha das Áreas Além da Jurisdição Nacional (Acordo BBNJ).

Metodologia: A investigação adota uma abordagem qualitativa, dedutiva e interdisciplinar, assente numa revisão bibliográfica e documental de tratados internacionais, literatura científica, relatórios especializados e quadros regulamentares relevantes. Articula o conhecimento científico sobre a dinâmica da

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AMOC, a entrada de água doce nos oceanos, a circulação oceânica e os pontos de inflexão climática com a análise jurídica dos regimes internacionais de proteção ambiental, de governação climática e do Direito do Mar. A análise incide, em particular, nas obrigações dos Estados em matéria de prevenção, diligência devida, cooperação internacional e proteção do ambiente, bem como na fragmentação normativa e institucional que caracteriza a governação global dos oceanos.

Resultados: Os resultados demonstram que o potencial enfraquecimento ou colapso da AMOC constitui um risco climático sistémico, suscetível de produzir consequências significativas nos padrões meteorológicos, na biodiversidade marinha, na segurança alimentar, na estabilidade económica, na mobilidade humana e na segurança internacional. A análise identifica limitações importantes na capacidade dos atuais quadros jurídicos internacionais para responder, de forma integrada e preventiva, à interligação entre os riscos oceânicos e climáticos. Embora a CNUDM estabeleça obrigações fundamentais de proteção e preservação do meio marinho e o Acordo BBNJ introduza mecanismos adicionais de conservação da biodiversidade marinha, avaliação de impacto ambiental, capacitação e transferência de tecnologia marinha, a sua eficácia depende de uma aplicação coerente e de uma cooperação institucional efetiva. O estudo evidencia igualmente a importância da adoção de abordagens de precaução, do reforço da monitorização científica e da redução das desigualdades que persistem na governação global dos oceanos.

Conclusões: O artigo conclui que a potencial crise da AMOC exige a transição de abordagens fragmentadas e predominantemente reativas para um modelo de governação dos oceanos integrado, preventivo e adaptativo. O reforço da cooperação internacional, a aplicação efetiva das obrigações jurídicas existentes, a melhoria dos sistemas de monitorização e de alerta precoce e a articulação entre as políticas climáticas e as políticas de proteção do meio marinho são essenciais para reduzir os riscos sistémicos. A aplicação coordenada da CNUDM, do Acordo de Paris e do Acordo BBNJ, sustentada pela evidência científica e por uma cooperação internacional equitativa, poderá contribuir para reforçar a resiliência dos oceanos e a segurança jurídica. Em última análise, a salvaguarda da estabilidade dos sistemas de circulação oceânica constitui uma dimensão fundamental da ação climática internacional, da proteção ambiental e da segurança global.

Palavras-chave: Circulação de Revolvimento Meridional do Atlântico (AMOC); Mancha Fria do Atlântico Norte; Direito Internacional do Clima; Convenção das Nações Unidas sobre o Direito do Mar (CNUDM); Governação Global dos Oceanos; Segurança Climática.

1 INTRODUCTION

The Atlantic Meridional Overturning Circulation (AMOC) is one of the most significant components of the global climate system, playing an essential role in the redistribution of heat between the hemispheres and in regulating the planet's climatic conditions. Its stability is crucial to the thermal balance of the North Atlantic and,

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consequently, to weather patterns that directly influence Europe, North America, and tropical regions.

In recent years, the scientific community has increasingly warned of a potential progressive weakening of the AMOC, a phenomenon associated with the accelerated melting of Greenland ice and the consequent influx of large volumes of freshwater into the North Atlantic. This process has been linked to the formation of the so-called “cold blob” in the Atlantic, a thermal anomaly that may indicate profound changes in the dynamics of ocean circulation.

One of the most frequently cited authors on this issue is Stefan Rahmstorf, who associates the weakening of the AMOC with the thermal anomaly known as the Atlantic cold blob, or warming hole, south of Greenland. In their 2015 study, the authors argue that the persistent region of cooling in the North Atlantic may constitute evidence of a slowdown in the Atlantic Meridional Overturning Circulation, potentially linked to increased freshwater input from Greenland ice melt (Rahmstorf et al., 2015).

The potential destabilization of the AMOC is not merely an environmental or climatic concern, but also a structural challenge for international security. Its possible impacts include changes in precipitation regimes, reduced agricultural productivity, loss of marine biodiversity, intensification of extreme weather events, and large-scale population displacement. It thus constitutes a genuine issue of global climate security.

In this context, Public International Law is called upon to respond to a systemic and transboundary phenomenon whose complexity exceeds the traditional instruments of State regulation. The existing normative fragmentation between the climate regime, the Law of the Sea, and global environmental governance mechanisms reveals significant limitations in the prevention and management of risks associated with climate tipping points, such as the potential collapse of the AMOC.

Of particular relevance in this regard are the United Nations Convention on the Law of the Sea of 10 December 1982 (UNCLOS), the Paris Agreement adopted on 12 December 2015 and the Agreement under UNCLOS on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement), adopted on 19 June 2023 and entered into force on 17 January 2026. These instruments provide complementary legal frameworks for addressing climate change, marine environmental protection and the conservation of marine biodiversity beyond national jurisdiction. Their practical effectiveness in addressing large-scale climatic instability, including risks associated with the potential weakening

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or collapse of the AMOC, must nevertheless be assessed in light of the specific obligations, due-diligence standards, preventive duties and institutional mechanisms established by each instrument.

This article aims to analyze the challenges posed to Public International Law by the potential collapse of the AMOC and the formation of the Atlantic “cold blob”, assessing the adequacy of the existing international legal framework in addressing systemic ocean-related climate risks.

As a specific objective, the study seeks to identify normative and institutional limitations within the current international legal regime and, on the basis of this analysis, to present proposals and recommendations for strengthening the global maritime regulatory framework. In particular, it aims to contribute to reflection on the need for integrated ocean governance, grounded in the principles of precaution, international cooperation, and common but differentiated responsibilities.

Methodologically, the research is based on a deductive and qualitative approach, grounded in literature and documentary review of international treaties, specialized scientific literature, and relevant normative instruments. This approach makes it possible to articulate scientific knowledge on AMOC dynamics with a public international law analysis of environmental and climate protection regimes.

Thus, the article offers an interdisciplinary reflection between climate science and Public International Law, highlighting the urgency of rethinking global ocean governance mechanisms in the face of systemic risks that may undermine the stability of the Earth’s climate system and international security as a whole.

2 AMOC AND THE ATLANTIC “COLD BLOB”: SCIENTIFIC FOUNDATIONS

The Earth’s climate depends on the continuous movement of the oceans to distribute heat across the globe. (Rodrigues, et al., 2026). In this process, the Atlantic Meridional Overturning Circulation (AMOC) functions as a key mechanism. It transports large volumes of warm surface water from the equatorial regions towards the higher northern latitudes (Pelegrí, 2025, p. 2). This continuous heat flow directly affects the climate of these northern areas, shaping average temperatures and precipitation patterns. Understanding how this system operates is essential for assessing environmental risks and for justifying effective action to protect the planet.

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This oceanic movement is governed by physical principles through a system known as thermohaline circulation. This circulation is driven not only by winds, but by subtle differences in the density of seawater, which vary according to temperature and salinity (Rahmstorf, 2024, p. 19). When warm water reaches the vicinity of Greenland, it releases heat into the atmosphere and cools. This cooling process, combined with its high salinity, makes the water denser, causing it to sink to the deep ocean and begin its return flow southwards along the ocean floor.

Observations of sea surface conditions have nevertheless recorded a regional anomaly that runs counter to the global warming trend. While global average temperatures continue to rise due to pollution (McMonigal et al., 2025, p. 2479), it has been demonstrated that a large area of the North Atlantic has cooled or stopped warming in recent decades. This region is referred to by researchers as the “cold blob” and is understood as a potential early physical indicator that Atlantic currents may be undergoing structural changes in their functioning (Rahmstorf, 2024, p. 21).

The cause of this localized temperature decline has been examined in order to determine whether it results from local climatic factors or from changes in oceanic circulation. Analysis of observational data shows that heat loss from the ocean surface to the atmosphere in this region has not increased; rather, it has progressively decreased (Rahmstorf, 2024, p. 26; Caesar et al., 2018; Chen & Tung, 2018). This finding rules out the possibility that local atmospheric cooling is responsible for the ocean’s temperature drop. Instead, the surface waters are registering lower temperatures because the ocean current arriving from the south is transporting less heat into the region.

The primary cause of this slowdown in heat transport is linked to recent changes in the Arctic freshwater cycle. The sustained rise in global temperatures is accelerating the melting of the Greenland ice sheet, releasing substantial volumes of freshwater, both in liquid form and as ice, into the surrounding seas (Haubner et al., 2026, p. 58). This additional freshwater input reduces the salinity of surface waters in the region. With lower salinity, the water becomes less dense and no longer reaches the threshold required to sink, thereby weakening the “engine” that drives the main circulation system.

This reduction in the water’s ability to sink generates a chain reaction. As the overall strength of the circulation weakens, a smaller volume of warm waters from the south reaches the North Atlantic (Rahmstorf, 2024, p. 19). Since these southern waters

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also transport salinity into the region, the North Atlantic becomes progressively fresher, which in turn further weakens deep-water formation and slows the circulation once again. This cycle is known in the scientific literature as salt-advection feedback and lies at the heart of the current instability of the ocean system (Weijer et al., 2024).

When assessing these scenarios from a risk-prevention perspective, Wood et al. (2025, p. 445) explain that the study of this cycle introduces the concept of "tipping points". A tipping point is a critical threshold at which a sustained external forcing eventually triggers an abrupt or potentially irreversible response in the system's overall state. If the freshwater input exceeds this safety threshold, the AMOC may lose its capacity to recover to its previous state and could undergo a long-term or permanent shutdown, thereby altering the global climate over the long term.

In an effort to anticipate these critical limits, scientists rely on projections generated by computer models based on climate data. The most recent results estimate that the Atlantic circulation may weaken by an average of around five units of flow (sverdrups)[1] over the course of this century, across a range of emissions scenarios (Pelegrí, 2025, p. 8). This indicates a declining trend but does not predict an immediate collapse. Nevertheless, scientists exercise caution, as there is evidence that computer models tend to represent the system as more stable than it may actually be under extreme perturbations (Van Westen et al., 2024; Bhattacharya et al., 2025; Rodrigues et al. 2025b).

In addition to the freshwater originating directly from Greenland, other sources of change further increase the fragility of the Atlantic Ocean system. At the bottom of the Arctic Ocean, a large volume of freshwater is stored in an area known as the Beaufort Gyre[2], which has accumulated increasing reserves over the past two decades. A potential structural release of this freshwater into the Atlantic (Wood et al., 2025, p. 456) would significantly amplify salinity loss in ocean currents and could accelerate changes in circulation, bringing the system closer to irreversible thresholds.

The weakening of this circulation is identified not only through the cooling of the cold blob, but also through physical changes in the pathways of certain ocean currents. Following the principles of Earth's rotation as applied to fluid dynamics, the Gulf Stream is observed to shift laterally, moving closer to the eastern coast of the United States as

[1] Sverdrup (abbreviated as Sv) is a unit of measurement used in oceanography to quantify the volumetric flow rate of ocean currents.
[2] The Beaufort Gyre is a clockwise-rotating ocean current and wind-driven system located in the Arctic Ocean.

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deep ocean flow weakens (Rahmstorf, 2024, p. 27). This westward displacement of the current has been confirmed through deep-sea observational buoys and serves as further empirical evidence that the AMOC is losing strength (Smeed et al., 2018).

As there are no direct records of deep ocean currents from many centuries ago, researchers apply statistical methods to contemporary data in order to estimate when the circulation may be approaching a tipping point. Principles of dynamical systems theory show that, as a natural system nears a critical transition (Wood et al., 2025, p. 449), the speed at which it recovers from small perturbations decreases significantly. Studies that search for such early warning signals conclude that the North Atlantic is losing its resilience in the face of ordinary disturbances (Boers, 2021).

It is important to note that, although variations in salinity are the primary driving factor, the future evolution of the cold blob region will also be influenced by surface wind patterns. There are indications that changes in ocean circulation driven directly by future wind regimes will have the capacity to alter heat distribution, reinforcing temperature declines near the coast of Greenland (McMonigal et al., 2025, p. 2480). This variable highlights the difficulty of producing precise long-term forecasts, as the slow dynamics of ocean circulation interact with intermittent regional wind events.

Assessments of Earth's ancient climate history provide robust empirical context confirming that rapid changes in ocean circulation are not merely a mathematical hypothesis, but a plausible physical reality. The examination of ice cores and ancient deep-sea sediment layers (Pelegrí, 2025, pp. 4–6) shows that, during the last glacial period alone, there were up to twenty-five abrupt climate shifts occurring over very short timescales, oscillating between a slow, cold ocean state and faster circulation regimes. These historical records demonstrate that the Atlantic circulation is highly sensitive and can alter the planet's thermal balance rapidly when salinity and temperature conditions change.

The consequences of a potential complete shutdown of this circulation would generate climatic impacts affecting human life in many regions of the world. The interruption of heat transport in the Atlantic would lead to persistent cooling in Northern regions and Western Europe, while also driving significant shifts in tropical rainfall patterns (Rahmstorf, 2024, p. 28). This would severely affect the regularity of water availability in regions dependent on rainfall across parts of Africa and Asia. At the same time, changes in ocean density would contribute to higher rates of sea-level rise in

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several areas, with direct impacts on the eastern coast of the American continent (Caesar et al., 2018).

From the perspective of environmental governance and current public policy, the scale of these climate risks justifies the need for clear and responsible preventive measures. Although science cannot predict the exact day or year when an irreversible shift may occur, the scientific understanding of system dynamics indicates that society must reduce carbon emissions that disrupt the planet's hydrological cycle (Pelegrí, 2025, p. 14). The current and measurable presence of the cold blob is evidence that changes in the "engine" regulating the global climate are already underway and require serious attention.

3 THE AMOC CRISIS AS GLOBAL CHALLENGE FOR INTERNATIONAL SECURITY

As mentioned in the preceding section, the stability of the global climate depends on the continuous functioning of the Atlantic Meridional Overturning Circulation (AMOC). This network of ocean currents transports large amounts of heat towards the northern regions of the planet, and its collapse would profoundly alter the living conditions of several countries. For a long time, climate reports relied on computer models to assess this possibility and generally concluded that a complete shutdown would be unlikely within this century. However, newer methods based on observational data suggest a different projection, indicating that a collapse of this ocean circulation could occur in the mid-21st century, more likely between 2037 and 2109 (Ditlevsen & Ditlevsen, 2023, p. 1).

The primary physical factor driving this slowdown in ocean circulation lies in the Arctic hydrological cycle. The observed increase in local temperatures is causing a more rapid melting of both terrestrial and sea ice (Madan et al., 2024, p. 1291). This loss of ice results in large volumes of freshwater, which is less dense, flowing southward. It initially enters the Labrador Sea and the Nordic Seas and subsequently continues along the eastern coastline of North America (Straneo & Heimbach, 2013).

The empirical basis for anticipating this loss of circulation lies in the detection of early warning signals derived from direct observations of sea surface temperature. The physics of complex systems shows that, as the ocean approaches a structural transition, it loses resilience, a process that can be measured through increased

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variance and autocorrelation in temperature records (Ditlevsen & Ditlevsen, 2023, p. 2). This diagnosis suggests that the Atlantic system is gradually losing its ability to recover from small disturbances and is moving, with increasing clarity, towards a tipping point.

The direct impact of this continuous freshwater input challenges the older view that a collapse would occur solely because surface waters become isolated in regions where deep-water formation takes place. By entering the region just above the North Atlantic Current, this additional freshwater alters ocean pressure conditions, significantly reducing the density gradient within the current itself and thereby weakening its strength. This overall decline in flow velocity reduces the arrival of dense water required in deeper regions, gradually slowing the entire circulation system (Madan et al., 2024, p. 1291).

To understand the scale of such a shutdown, it is necessary to examine how ocean stability behaves at a broader level. Paleoclimate studies and climate simulations show that ocean circulation can settle into at least four distinct states. These include the modern state observed today, a strong state in which ocean transport extends fully into the Arctic, a weak state in which deep water formation occurs only at mid-latitudes, and, finally, an inactive state in which deep ocean circulation comes to a complete halt (Willeit & Ganopolski, 2024, p. 1417).

This change in temperature and salinity in the North Atlantic is not confined to that region; rather, it triggers fast teleconnections that alter ocean dynamics even in the Southern Hemisphere. Freshwater input from ice melt modifies the entire water column, generating long subsurface waves known as Kelvin waves[3], which propagate rapidly southward along the western boundary of the American continent. This process leads to a measurable increase in heat and salt retention in the South Atlantic over the course of only a few decades (Pontes & Menviel, 2024, p. 1).

The physical interaction between the influx of freshwater into the ocean and global pollution defines the boundaries at which changes in these currents become irreversible. Analyses confirm that the continuous increase in atmospheric carbon dioxide alters the system's response. In this scenario, a collapse triggered by present-day warming could become a persistent state lasting for many centuries if pollution

[3] Kelvin waves are large-scale oscillatory disturbances that travel through the ocean or the atmosphere, guided either by the equatorial waveguide or by coastal boundaries. Because they are capable of transporting heat rapidly while retaining their structure, they play a crucial role in the planetary climate system and act as the earliest signals of the El Niño phenomenon.

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exceeds a certain threshold (Willeit & Ganopolski, 2024, p. 1422). This structural shift indicates that the natural recovery of the circulation may become physically impossible if governments delay the implementation of corrective measures.

As these subsurface waves cross the Equator and reach the African coastline, their energy changes its propagation pattern. Sea surface observations indicate that, at this eastern boundary, the wave is reflected back into the open ocean in the form of Rossby[4], waves, triggering a readjustment in which the volume of water transported by the Brazil Current and the Antarctic Circumpolar Current increases significantly (Pontes & Menviel, 2024, p. 3). This physical reorganization reshapes the entire ocean ecosystem, confirming that disruptions in northern circulation redistribute water and energy unevenly across the South Atlantic.

Alongside these oceanic changes, the progressive slowdown of the current forces the atmosphere to readjust, thereby altering wind patterns across the globe. As the ocean transports less heat from the Equator towards the poles, atmospheric temperature gradients are significantly reduced, leading to a relative increase in heat in the lower atmosphere of the Southern Hemisphere. This compensatory process alters surface pressure patterns, forcing the westerly winds to shift further towards the South Pole, thereby modifying the entire circulation around Antarctica (Sultana & Liu, 2024, p. 1).

From a long-term perspective, adaptation planning must assess the physical mechanisms that could, in the future, restore the functioning of this circulation. A prolonged shutdown leads to a continuous heat imbalance that disrupts ocean–atmosphere exchanges, generating persistent wind patterns that act like a pump, drawing deep water upwards. As a result, these environmental forces gradually erode the freshwater “cap” that forms at the surface (Nobre et al., 2023, p. 1). Breaking down this lighter surface layer would require many centuries to re-establish conditions that allow water to sink again, ultimately producing an oceanic ecosystem with permanently altered conditions compared to those observed today (Stommel, 1961).

In summary, the AMOC crisis should not be understood as an isolated alteration of ocean circulation, but rather as a profound reorganization of the Earth’s climate system, with cascading effects that extend across the Atlantic and into the atmosphere

[4] Rossby waves: large-scale planetary wave disturbances generated in both the atmosphere and the ocean as a result of Earth’s rotation and the variation of the Coriolis force with latitude. These waves are essential for the planet’s climatic balance, as they transport heat between different regions and help determine the evolution and pathways of major global weather systems.

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and other ocean basins. The convergence of observational evidence, dynamical models, and indicators of declining resilience points to a system that is increasingly sensitive to external perturbations, in which small variations may trigger disproportionate and potentially long-lasting changes.

In this context, the possibility of abrupt transitions and more stable alternative states reinforces the critical role of the AMOC as a key element in global climate regulation. Its evolution thus ceases to be merely a matter of natural ocean variability and becomes an issue of international security, requiring continuous monitoring and mitigation strategies that take into account not only global warming, but also the physical stability of the mechanisms that underpin the climate system.

4. PUBLIC INTERNATIONAL LAW IN THE FACE OF GLOBAL OCEAN RISKS

Ocean instability, as evidenced by large-scale threats such as the potential collapse of the Atlantic Meridional Overturning Circulation (AMOC), compels Public International Law to develop global and preventive responses. The ocean acts as the planet's primary temperature regulator and absorbs approximately thirty per cent of global carbon dioxide emissions, triggering a chemical reaction that reduces carbonate ions in seawater and lowers its natural alkalinity, a process known as ocean acidification (Fillol Mazo, 2023), thereby directly threatening the foundation of marine food chains.

Despite this structural issue, international climate law, structured around the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, has remained largely focused on the atmosphere. The mere establishment of global temperature limits does not automatically ensure control of ocean acidification, since such targets could theoretically be achieved by reducing other greenhouse gases without proportionally reducing carbon dioxide, which is the direct driver of changes in seawater pH (Doney et al., 2009).

Given the limitations of climate law in addressing the physical health of ocean currents and the chemistry of seawater, UNCLOS provides a broader legal framework that is being progressively developed through evolving judicial interpretation. Although the text of UNCLOS does not explicitly address climate change, given the historical context in which it was negotiated, its provisions on the protection of the marine environment impose obligations on States to safeguard both national and international

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waters (Zeng & Wang, 2024; Rodrigues et al., 2025; Rodrigues et al, 2025a; Rodrigues et al., 2024).

UNCLOS provides a particularly important legal framework for addressing the marine dimensions of climate change. Article 192 establishes the general obligation of States to protect and preserve the marine environment, while Article 194(1) requires States to take, individually or jointly as appropriate, all measures consistent with UNCLOS that are necessary to prevent, reduce and control pollution of the marine environment from any source. Article 194(2) further requires States to ensure that activities under their jurisdiction or control do not cause damage by pollution to other States or to areas beyond national jurisdiction. These provisions are particularly relevant to climate-related risks because they establish obligations of conduct that require States to exercise due diligence in regulating activities capable of contributing to marine pollution and environmental harm.

The legal relevance of these provisions has been reinforced by the International Tribunal for the Law of the Sea (ITLOS) in its 2024 Advisory Opinion on climate change and international law. The Tribunal recognised that anthropogenic greenhouse gas emissions into the atmosphere may constitute pollution of the marine environment within the meaning of UNCLOS and confirmed that States are therefore required to take all necessary measures to prevent, reduce and control such pollution. The obligation is one of due diligence and requires States to adopt appropriate legislative, administrative and regulatory measures, taking into account the level of risk, the available scientific knowledge and the need to prevent significant harm to the marine environment. (Cabrera Mirassou, 2025, p. 109).

The application of these obligations to the AMOC, however, requires an important distinction. UNCLOS does not establish a specific legal obligation to prevent an “AMOC collapse” as such, nor does it provide a legally predetermined emissions threshold beyond which an internationally wrongful act automatically arises. Rather, the relevance of UNCLOS lies in its broader preventive obligations concerning marine pollution and the protection and preservation of the marine environment. The potential weakening of the AMOC may therefore strengthen the scientific and factual basis for requiring States to exercise a high level of due diligence, particularly where scientific evidence indicates that activities under their jurisdiction or control contribute materially to risks of serious or irreversible harm to the marine environment.

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Accordingly, the legal significance of the AMOC risk should not be framed as establishing an automatic rule of international responsibility whenever a State fails to achieve a particular climate target. The more legally sustainable approach is to examine whether a State has complied with the applicable obligations of prevention, due diligence, cooperation and environmental assessment under the relevant international instruments, taking into account the available scientific evidence, the foreseeability and seriousness of the risk, and the measures reasonably available to that State.

Compliance with these preventive obligations requires a profound and practical transformation of economic activities related to the ocean, representing an essential step in reducing the pressures that could trigger the collapse of key systems such as the AMOC. In order to align ocean, use with environmental stabilization, it is imperative to halt the expansion of offshore oil and gas extraction, alongside a gradual reduction in existing production driven by declining demand for fossil fuels (Hoegh-Guldberg et al., 2023, p. 85).

The progressive end of this dependency must be accompanied by increased investment in offshore renewable energy and the decarbonization of maritime transport. These changes are necessary to prevent irreversible damage to marine ecosystems.

In addition to transforming the energy and extraction sectors, States have recognized the pressing need to establish specific rules for areas beyond national jurisdiction, which cover approximately half of the planet and whose lack of regulation increases vulnerability to climate-related risks (Chen, 2025). After nearly twenty years of complex negotiations, marked by differing views between the freedom of the seas and the common heritage of humankind, States adopted the Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (United Nations, 2023; Bodansky, 2024, p. 299).

In practice, this new international treaty operates as four interconnected agreements in one, establishing frameworks for marine genetic resources, area-based management tools, environmental impact assessments, and capacity-building and technology transfer.

One of the most significant innovations of this new legal instrument is the explicit requirement to integrate the climate variable into the governance of international waters, thereby providing the necessary legal support to implement measures that

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enhance the resilience of ocean dynamics (Karim & Cheung, 2024, p. 2). Unlike earlier regulatory frameworks, the agreement directly acknowledges the need to address marine biodiversity loss driven by climate impacts, including ocean warming, deoxygenation, and ongoing acidification.

This inclusion establishes an obligation to maintain and restore ecosystem health, safeguarding the carbon cycles that underpin the ocean's role in regulating the global climate and contribute to preventing disruptions in ocean circulation systems.

To ensure that this protection is effective in the face of risk scenarios, the treaty establishes enforcement-oriented mechanisms and compliance frameworks for its States Parties. On the one hand, it empowers the Conference of the Parties to develop area-based management tools, including marine protected areas in the high seas, with the aim of creating ecological networks that safeguard regions most vulnerable to severe climate impacts (Bodansky, 2024, p. 311).

On the other hand, the requirement to conduct environmental impact assessments standardizes *ex ante* controls before the approval of new activities, requiring governmental decision-making to evaluate cumulative impacts and to explicitly take into account the consequences of climate change and alterations in seawater chemistry (Karim & Cheung, 2024, p. 2).

The articulation between these different legal instruments leads to the understanding that the effectiveness of the international legal regime does not depend solely on the adoption of new treaties, but above all on the institutional capacity of States to implement them in an integrated manner. Overcoming the fragmentation of international law requires a systemic approach, in which the climate regime and UNCLOS are interpreted and applied as complementary components of a single normative framework designed to respond to the physical and chemical changes occurring in the ocean.

Despite the quality of these new rules, their effectiveness in preventing systemic collapses depends on overcoming the deep structural inequalities that divide States. Analyses of research networks and ocean governance policies reveal a clear asymmetry, in which researchers and institutions from wealthy countries dominate the development of global governance tools, often marginalizing calls for social justice and environmental equity from coastal nations in the Global South (Matovu et al., 2024, p. 97; Rodrigues et al. 2022).

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Building sustainable ocean futures and reducing major circulation crises therefore requires the democratization of science, the establishment of viable funding mechanisms, and the assurance that rules governing the global commons incorporate the capacities and concerns of all regions.

5 THE ROLE OF THE LAW OF THE SEA IN MITIGATING RISKS ASSOCIATED WITH THE AMOC

The global climate system depends on stable oceans, which constitute an immense physical space requiring specific legal frameworks for its governance in both economic and legal terms. The United Nations Convention on the Law of the Sea (UNCLOS) provides the primary foundation for these rules, defining maritime zones under national jurisdiction as well as areas beyond national jurisdiction, such as the High Seas. This area covers approximately 64% of the world's ocean surface and concentrates significant commercial and scientific activities (Almeida & Reitmeier, 2024, p. 13), making it a sector where the absence of more updated legal instruments may increase environmental risks linked to industrial exploitation.

This legal organization is essential to establish rules governing the use of marine biodiversity and mineral resources, regulate maritime transport, and prevent further degradation of marine ecosystems.

As traditional climate laws have clear limitations in protecting the physical and chemical properties of seawater, international adjudicatory bodies have increasingly provided more direct interpretations of States' obligations. The International Tribunal for the Law of the Sea has recently held that anthropogenic greenhouse gas emissions into the atmosphere constitute a form of marine pollution. This finding obliges States to exercise due diligence and to take all necessary measures to prevent, reduce, and control such pollution (Cabrera Mirassou, 2025, p. 109).

This jurisprudential development is particularly significant as it demonstrates the capacity of international law to adapt to new environmental realities without relying exclusively on the creation of new treaties. Through a dynamic and systemic interpretation of existing norms, international courts are able to reshape the scope of States' obligations, incorporating ecological phenomena that were not fully anticipated at the time the original legal instruments were drafted.

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In this way, a more demanding interpretation of the principles of prevention and due diligence is consolidated, reinforcing the idea that States cannot remain passive in the face of environmental risks of high severity and cumulative nature. Ultimately, this jurisprudential evolution expands the scope of international responsibility, making the legal response to complex and unprecedented ecological threats more effective.

Despite these advances in legal interpretation, the management of rapid changes in ocean circulation systems raises practical difficulties regarding the extent of governmental discretion. Scientific uncertainty about precise warming thresholds means there is no guarantee that the system will return to its previous state once certain tipping points are exceeded. This weakens the arguments often used by States to justify inaction with regard to climate targets (Ritz, 2025, p. 234).

For this reason, governments should base their preventive action on evidence of irreversible harm, recognizing that the absence of absolute certainty about future outcomes does not justify non-compliance with environmental obligations.

To implement these preventive obligations in practice, it is necessary to establish standardized procedures for the prior assessment of the impacts of human activities on seawater. Law of the Sea provisions stipulate that States have a duty to conduct thorough assessments of any planned activity—whether public or private—that may cause significant pollution or substantial harm to the marine environment due to the accumulation of carbon (ITLOS, 2024, p. 4).

In the specific case of the risk of a collapse of the Atlantic Meridional Overturning Circulation (AMOC), governmental strategies must move away from a reactive logic based solely on the emergence of immediate national security crises. Adopting an international “riskification” approach provides a more suitable framework for addressing ocean-related problems that unfold over decades or even centuries (Alli et al., 2025, p. 5).This approach prioritizes continuous, global, and long-term governance rather than relying exclusively on emergency responses or exceptional measures.

Changes in Atlantic circulation require a highly structured governance framework, as their effects on the functioning of national economies and societies are direct and unavoidable. Physical changes in ocean temperature translate into measurable risks for food security, energy demand, and global transport costs (Lenton et al., 2025, p. 84). These factors are essential for public budget planning and adaptation strategies.

To address this instability in an organized manner, ocean risk governance must be multi-sectoral, linking institutions at global, regional, and national levels. The

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objective is to integrate these large-scale threats into the current climate and development agenda (Lenton et al., 2025, p. 87).

In conclusion, the growing body of evidence on the impacts associated with changes in Atlantic circulation shows that the stability of ocean systems can no longer be regarded as purely environmental issues but must be understood as a central challenge of global governance. The transformation of complex physical processes into concrete socio-economic risks requires coordinated institutional responses capable of integrating climate, economic, and maritime policies within a coherent framework of preventive action.

In this regard, it is essential to strengthen multi-level cooperation mechanisms that connect international, regional, and national scales, ensuring more effective management of climate uncertainty and its meaningful incorporation into sustainable development agendas and public planning strategies.

6 GLOBAL CLIMATE GOVERNANCE AND THE PROTECTION OF OCEAN SYSTEMS: TOWARDS A NEW FRAMEWORK FOR MARITIME GREEN INNOVATION REGULATION

As discussed in the preceding section, global ocean governance is an area of global governance in which various groups, States, organizations, and other actors work together to manage the maritime domain. In recent decades, the planet has experienced changes linked to climate change, plastic pollution, and increasing ocean acidification, which require us to rethink the existing rules.

The transition to the planet's new environmental conditions requires international law to adapt in order to address contemporary environmental challenges, highlighting the fragmented nature of current ocean governance. The principal legal instrument regulating the seas is the United Nations Convention on the Law of the Sea (UNCLOS). Under this framework, UNCLOS establishes the general obligation for States to protect and preserve the marine environment (United Nations, 1982, Art. 192).

However, in the context of the climate crisis, biodiversity loss, and ecosystem disruption, it is necessary to assess whether UNCLOS is capable of adequately addressing all these challenges simultaneously. This raises the need to promote an integrated approach capable of overcoming the existing fragmentation between national, international, and environmental legal regimes.

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The transition from the Holocene to the Anthropocene requires international law to adapt to the Earth's new reality, as the application of older rules designed for a stable climate is no longer sufficient to address today's environmental challenges (Chen & Liu, 2023, p. 13). This emerging context highlights the fragmented nature of current ocean governance frameworks, while also creating space to reconsider the role of law and to incorporate more integrated approaches to understanding complex systems in the management of global commons.

The primary legal framework governing the seas is the United Nations Convention on the Law of the Sea (UNCLOS), often described as the constitution of the oceans. However, in the context of the climate crisis, marine biodiversity loss, and declining fisheries, it is necessary to assess whether UNCLOS is truly capable of addressing these pressures simultaneously and of promoting a unified approach capable of overcoming the fragmentation between national, international, and environmental legal regimes (Havercroft & Kloker, 2024, p. 14).

Overcoming this institutional divide is essential to achieving a practical balance between the expansion of the so-called blue economy, which often depends on increased resource extraction, and the sustainability requirements of global agendas, which call for stricter limits on exploitation.

An important legal development aimed at reducing this regulatory gap is the recent adoption of the Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (United Nations, 2023, Art. 31). The creation of this treaty over nearly twenty years revealed sharply diverging positions among State representatives, divided between the defense of the principle of the freedom of the seas by technologically advanced countries of the Global North and the demand that marine resources be recognized as the common heritage of humankind by developing countries (Carro Pitarch, 2023, p. 242).

The final text establishes a pragmatic compromise that incorporates both principles as guiding norms for the conservation and management of marine life in the high seas and the Area, which together represent approximately 64% of the world's oceans.

The 2023 BBNJ Agreement introduces structured step-by-step procedures for regulating activities, establishing that environmental impact assessments must carefully evaluate the effects of planned actions. To this end, they are required to draw on the best available scientific knowledge and, where appropriate, the traditional

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knowledge of Indigenous Peoples and local communities (United Nations, 2023, Art. 31(1)(b)–(c)).

For these mechanisms to function effectively in the long term, ocean governance must evolve towards models that strengthen the relationship between people and marine environments, moving away from exclusionary conservation approaches and preventing forms of “ocean grabbing”, which often marginalize local actors in the Global South (Ferse, 2023, p. 3).

The design of comprehensive environmental rules requires the use of governance principles that are capable of transforming reality by integrating ecological, social, and legal dimensions in a balanced manner. The use of systems-based approaches that link society and ecology helps to better understand the complex interactions between people and the environment, encouraging proactive responses to unexpected changes in ecosystem resilience and in the functioning of marine environments (Lombard et al., 2023, p. 1590), for example, it is necessary to:

1. Ecosystem-based management. In other words, rather than regulating only individual species or sectors (e.g. fisheries), policy shifts towards managing the entire marine ecosystem. This means that fisheries regulation is not limited to catch quotas, but also takes into account spawning areas, water temperature, and/or oxygen levels. This approach is already applied in the management of some protected areas in the North Atlantic and within the European Union. As an example, in the Azores (Portugal), in 2023 the Regional Government committed to reviewing its marine protected areas in order to protect 30% of the Azores’ ocean space (Blue Azores, n.d.), as illustrated in Figure 1 below:

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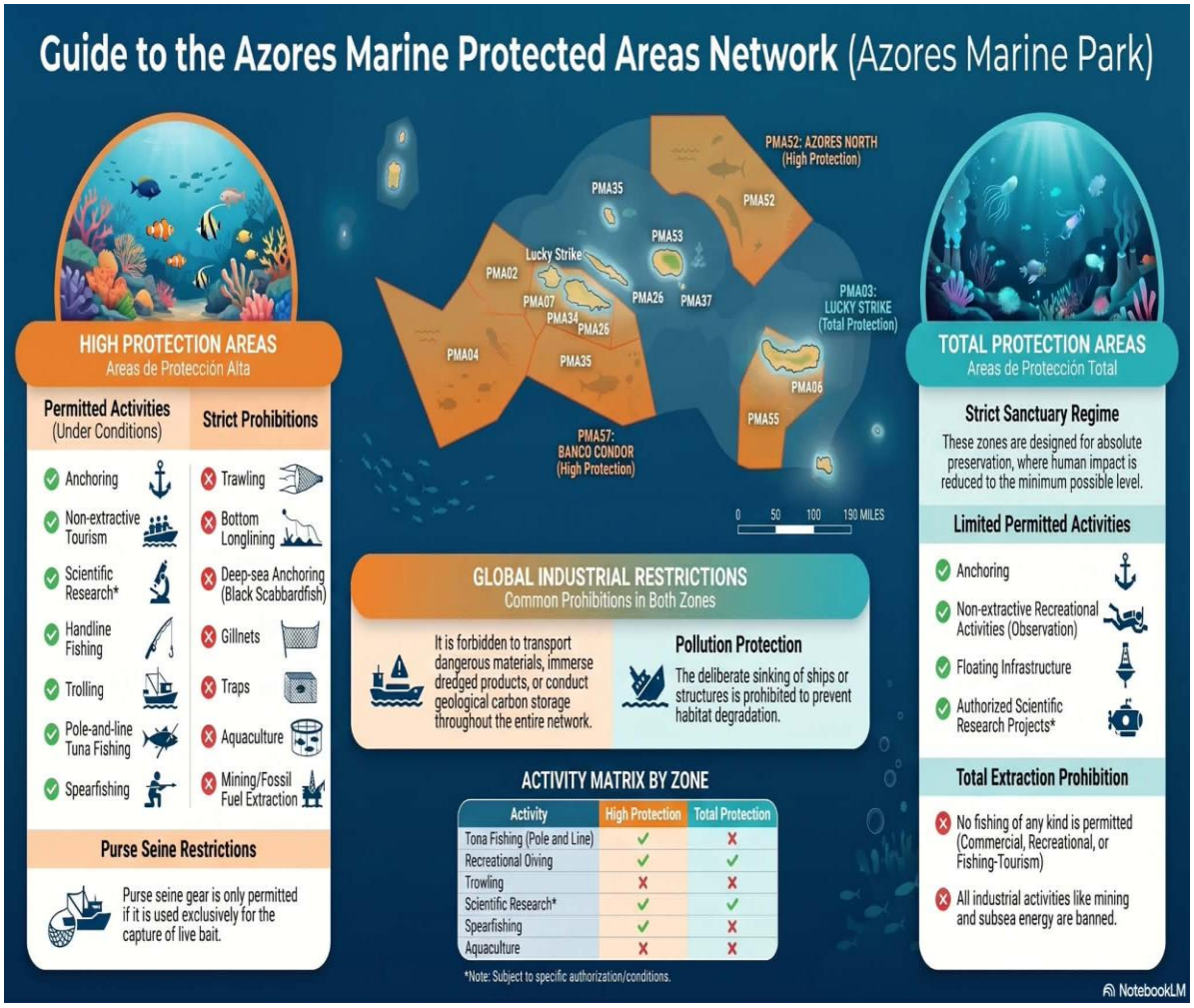


Figure 1. Azores Marine Protected Areas Network (Azores Marine Park). Credit: Created by the author using NotebookLM and adapted from the Azores Marine Protected Areas Network (n/d) infographic published by OTS Azores

2) The establishment of marine protected areas (MPAs) based on scientific and adaptive management principles. In other words, this involves designating zones in the ocean where certain human activities are restricted or prohibited, while maintaining a flexible and adaptive framework capable of being adjusted in response to changing environmental conditions. For example, these areas may be redefined according to species migration patterns, rising sea temperatures, or habitat degradation, thereby ensuring the protection of essential ecological corridors that sustain marine biodiversity.

3) Marine spatial planning (MSP). This refers to the integrated organization of ocean use, treating the sea as a shared space in which different activities must be coordinated and made compatible, such as fisheries, maritime transport, offshore energy exploitation, and environmental conservation. The objective is to avoid

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overlapping uses and conflicts, while reducing cumulative impacts on marine ecosystems, through a rational spatial distribution of human activities at sea.

4. Cumulative and climate-integrated environmental impact assessments. This entails moving beyond the isolated assessment of individual projects and instead evaluating the combined effects of multiple activities over time, including factors such as ocean warming, acidification, and biodiversity loss. In this way, decisions regarding the approval of maritime exploitation or infrastructure projects would take into account the overall impact on the ocean system, rather than focusing solely on immediate local effects.

5. The adoption of adaptive management models. In other words, public policies are not fixed but are continuously reviewed and adjusted based on new scientific data and observed changes in the marine environment. For example, fishing quotas may be adjusted annually according to the evolution of fish stocks, or navigation rules may be modified in response to changes in ocean currents or shifts in ecosystem behavior.

6. Integration between climate policies and ocean policies. This consists of articulating climate and ocean legal regimes in a coherent manner, ensuring that decisions in one domain take into account impacts on the other. For example, the regulation of shipping emissions should be aligned with global climate objectives, while simultaneously promoting the decarbonization of the sector and the protection of ocean chemistry.

7. The implementation of participatory and multi-actor governance mechanisms. This involves engaging a range of stakeholders in decision-making processes, including States, coastal communities, the scientific community, fishers, and non-governmental organizations. This approach enables the integration of local and scientific knowledge, making decisions more legitimate, effective, and better adapted to specific socio-ecological realities.

8. Strengthening continuous monitoring through advanced technologies. This involves the use of tools such as satellites, ocean sensors, and artificial intelligence systems to track changes in the oceans in real time. This enables the rapid identification of phenomena such as marine heatwaves, oxygen depletion, or ecosystem collapse, thereby facilitating more preventive and effective responses.

The implementation of these governance measures and principles makes it possible to identify hidden tensions in marine spatial planning and to create open platforms for addressing power asymmetries that have hindered the development of long-term

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sustainability initiatives. The consolidation of such measures requires international institutions to overcome sectoral fragmentation by adopting rules that ensure mandatory coordination among all relevant actors.

This normative integration is essential to ensure that marine biodiversity protection policies are effectively aligned with strategies aimed at reducing industrial pollution.

In the specific field of reducing industrial pollution, the International Maritime Organization has established direct rules to mitigate the climate impact caused by maritime transport. Mandatory energy-efficiency requirements, such as the *Energy Efficiency Existing Ship Index* (EEXI) and the *Carbon Intensity Indicator* (CII), oblige ships to measure, report, and adjust their fuel consumption, imposing compulsory action plans on vessels that receive the lowest ratings (Bourgeon, 2024, p. 7). This technical framework aligns with the revised strategy for reducing greenhouse gases, which sets control points aimed at cutting the total annual pollution from international maritime transport by at least 20 per cent, striving for 30 per cent, by 2030, compared with 2008 levels (MEPC, 2023, p. 6).

To achieve these net-zero targets by mid-century, the energy transition encourages the commercial use of alternative marine fuels such as ammonia, hydrogen, biofuels, and liquefied natural gas. However, the practical use and combustion of these energy sources pose specific environmental risks that are not fully covered by current international law, since ammonia carries a high risk of acidifying water and is toxic to marine life, while the production and use of hydrogen involve technical hazards such as leakage, oxygen depletion, and explosion in the event of safety failures (Wang et al., 2023, pp. 5–6). The present fragmentation of civil-liability conventions concerning damage, together with gaps in the safety rules governing bunkering infrastructure, creates significant legal obstacles to establishing a regulatory framework capable of effectively preventing secondary pollution damage.

The development of a new set of green-innovation rules for the oceans therefore requires joint governance solutions that integrate marine-life protection plans in areas beyond national jurisdiction with the management codes applicable to emerging energy technologies. Complexity-based governance theories show that international law operates in practice as a self-organizing system shaped by the communication and action of both governmental and non-governmental actors, making it necessary to adopt a multi-centered and easily adaptable legal focus (Chen & Liu, 2023, p. 13). The practical organization of this model demands continuous teamwork, in which fields

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such as the natural sciences, the social sciences, and the humanities speak a shared technical language to support the creation and oversight of global rules that function effectively (Havercroft & Kloker, 2024, p. 14).

Thus, the effectiveness of green-innovation rules at sea depends on the ability to integrate different fields of knowledge and to articulate a flexible, multi-level system of governance capable of responding to the complexity of oceanic and technological systems.

7 PROPOSALS FOR STRENGTHENING THE GLOBAL MARITIME REGULATORY FRAMEWORK

Creating laws for areas of the ocean that lie beyond national jurisdiction is one of the greatest challenges for maintaining planetary climate stability and keeping global temperatures in balance. (Martins, et al., 2024). The potential collapse of the Atlantic Meridional Overturning Circulation (AMOC) represents a critical vulnerability in the system, requiring coordinated, preventive, and multinational responses. The general framework established by the United Nations Convention on the Law of the Sea did not originally provide the practical or technical tools needed to safeguard marine life in areas beyond national jurisdiction. These waters cover approximately 64 per cent of the world's oceans, and the historical absence of regulatory mechanisms increased the risks posed by industrial exploitation (Intergovernmental Panel on Climate Change, 2021). To address this gap, States adopted the BBNJ Agreement in 2023, aimed at ensuring the protection and sustainable use of marine biodiversity in the high seas. The Agreement formally entered into force on 17 January 2026, after the United Nations reached the required threshold of 60 ratifications on 19 September 2025, with Morocco becoming the 60th State to ratify and Sierra Leone the 61st. At present, the Agreement has been ratified by more than 80 States.

To address scientific uncertainty and the severe economic and social impacts that would result from a shutdown of ocean currents, governance approaches must move away from sector-by-sector management and adopt more integrated perspectives. Specialists argue that building a resilient environmental system requires the application of transformative governance principles that bring together ecological, social, and legal dimensions. Approaches that link society and ecology provide clearer insight into the connections between human environments and the ocean, thereby

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facilitating the development of strategies to adapt to unforeseen changes in the ecosystem (Lombard et al., 2023, p. 1591). Putting these principles into practice supports the creation of joint policies that transcend national boundaries and move beyond an exclusive focus on traditional economic growth. By equipping institutions with tools to assess the health of marine ecosystems, the international community gains the legal basis needed to identify shortcomings in marine spatial planning and to reduce well-known power imbalances between States. This holistic perspective is indispensable for anticipating and mitigating the cascading impacts triggered by crises in Atlantic circulation.

The integration of these new governance methods demonstrates that the effectiveness and reach of international law depend on its capacity to foster flexible and adaptive institutions. Only through such continuous adaptation will it be possible to prevent the degradation and eventual depletion of common natural resources, thereby ensuring their long-term preservation.

The practical operation and overall success of the new treaty depend directly on the creation of mechanisms capable of linking real-world evidence with the development of infrastructure across all regions of the globe. To provide robust technical support in the face of multi-causal crises, the Agreement establishes a Scientific and Technical Body with the clear mandate of offering practical advice to the Conference of the Parties. The effective functioning of this body requires internal rules that ensure balanced participation by all members, thereby preventing the risk of international rules being shaped solely on the basis of research produced by a limited group of States (Gaebel et al., 2024, p. 3). To guarantee that the body's recommendations are implemented fairly and equitably, the treaty also creates a mechanism for capacity-building and the transfer of marine technology. These new provisions go far beyond the requirements of earlier conventions, as they establish clear obligations: the technology supplied to developing countries must be reliable, affordable, modern, and easy to operate (Harden-Davies et al., 2024, p. 2). This complementarity between sound scientific advice and the strengthening of local infrastructure constitutes the only practical and legally viable means of enabling States to keep pace with profound changes in ocean temperatures and to assess environmental impacts with due care.

One of the most important spatial-protection tools that contemporary international law offers to strengthen ocean resilience is the establishment of marine protected

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areas on the high seas. The design, implementation, and monitoring of such protected areas have been strongly influenced by the experience of other international regimes responsible for managing large common resources. In the case of the Antarctic system, the work of the relevant commission demonstrated that the requirement of unanimous approval (consensus) frequently led to prolonged deadlocks. This, in turn, forced major concessions, such as the adoption of short expiry periods for the protected areas in the Ross Sea (Nocito & Brooks, 2023, p. 3). This negotiating practice clearly exposed the weakness of decision-making systems that grant a single State the power to veto and block general environmental-protection measures.

As a legal response to these past difficulties, the rules of the new regime on marine biodiversity exceptionally allow, on a precautionary basis, proposals for ocean protection to be adopted by a qualified majority. Such voting is permitted only once it has been demonstrated that all efforts to reach unanimous agreement have failed. This shift in decision-making procedures enhances the agility of ocean governance, an essential feature if the overarching objective is to establish a connected network of protected areas capable of mitigating the severe challenges posed by instability in deep-ocean circulation.

8 CONCLUSIONS

The potential collapse of the Atlantic Meridional Overturning Circulation (AMOC) is a physical disruption that has ceased to be merely an oceanographic concern and has become a practical challenge for public international law and for national security. Managing this risk requires global legal frameworks to move away from reactive approaches and adopt preventive ones, thereby providing greater legal certainty.

The instability of the Atlantic Meridional Overturning Circulation (AMOC) demonstrates the need to examine the international legal consequences of climate inaction through the applicable obligations of prevention, due diligence, cooperation and environmental protection. A failure by a State to comply with an applicable international obligation may, depending on the circumstances, engage its international responsibility where the requirements for an internationally wrongful act are satisfied. However, failure to achieve a particular emission-reduction target should not, in itself, be characterized automatically as an internationally wrongful act. The assessment must instead identify the relevant primary obligation, determine the conduct required

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of the State under that obligation, and establish whether the State failed to exercise the requisite degree of due diligence in light of the foreseeable risk, the available scientific knowledge and the measures reasonably within its capacity. In this context, the increasing scientific evidence concerning the relationship between anthropogenic greenhouse gas emissions, ocean warming and changes in Atlantic circulation strengthens the factual basis for assessing State conduct under existing international environmental and climate obligations.

To address the scale of this scenario, it is essential to overcome the lack of coordination and fragmentation that characterize the current system of ocean governance. The BBNJ Agreement, which entered into force on 17 January 2026, provides important institutional and regulatory mechanisms, including area-based management tools, environmental impact assessments, capacity-building and the transfer of marine technology. These mechanisms can contribute to a more integrated approach to the protection and sustainable use of marine biodiversity in areas beyond national jurisdiction and may support broader efforts to enhance the resilience of ocean ecosystems in the context of climate change. Their effectiveness, however, will depend on implementation by States Parties, institutional cooperation and the integration of the BBNJ framework with UNCLOS and other relevant climate and environmental regimes.

The physical changes driven by AMOC instability, particularly the asymmetric rise in sea level, also require a clear response from the United Nations Convention on the Law of the Sea (UNCLOS) in relation to the landward retreat of coastal zones. To preserve legal stability, the international community is increasingly moving away from the idea that maritime boundaries should shift continuously in accordance with advancing waters. It becomes necessary to permanently fix the already-registered geographical coordinates, preventing States from losing parts of their maritime territory and control over their resources solely because of physical alterations to their coastlines. This measure helps to avert new disputes and ensures that territorial limits remain stable and predictable.

In sum, the severe disruptions affecting Atlantic circulation compel international law to develop structured and adaptable regulatory frameworks. States must ensure continuous public funding to maintain rapid-alert infrastructures and to enforce their decarbonization targets rigorously. The physical and thermal stability of the ocean has

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become an essential condition for the preservation of peace, livelihoods, and legal certainty worldwide.

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