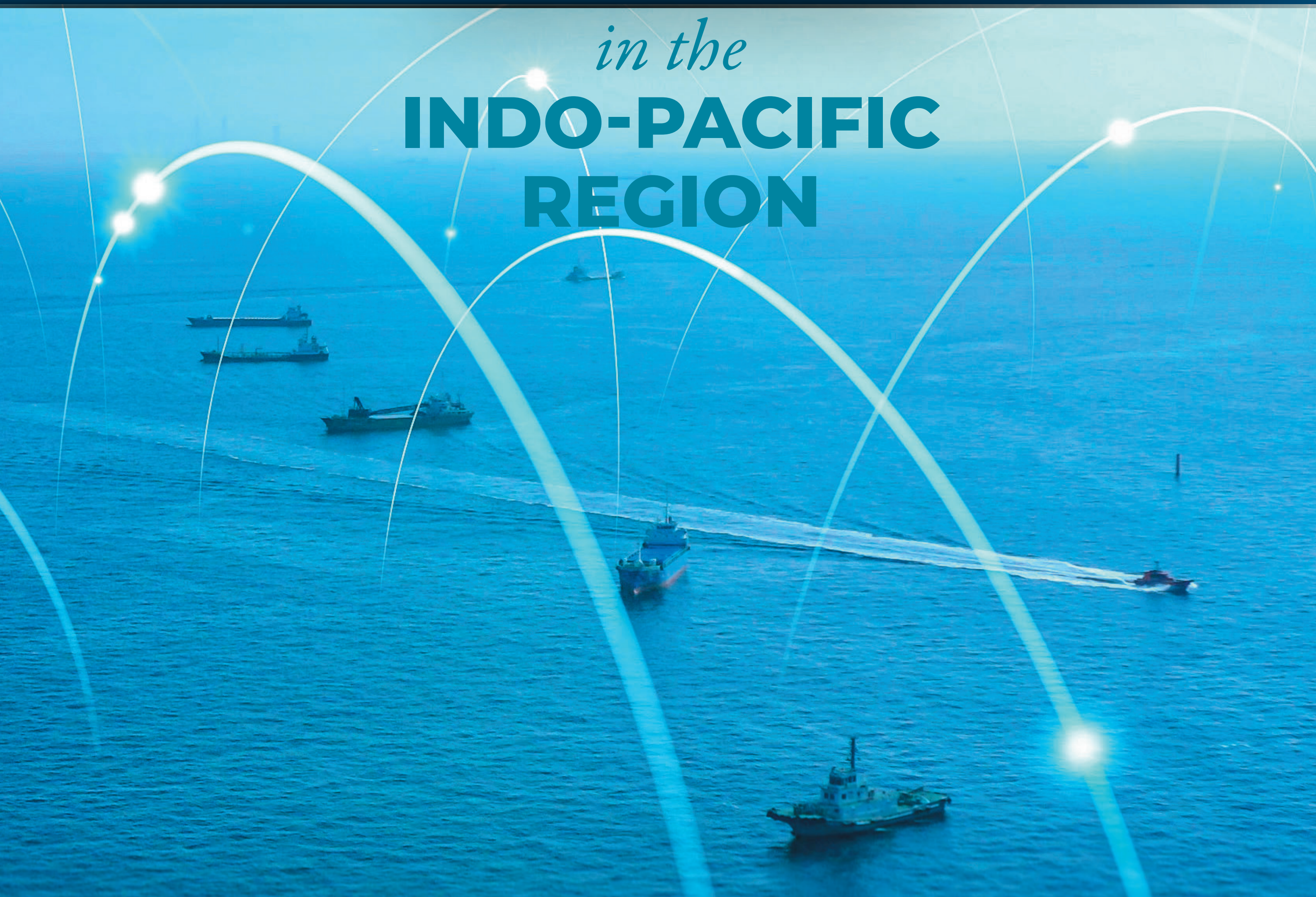
Indian Council of World Affairs

MARITIME DOMAIN AWARENESS

in the

INDO-PACIFIC REGION



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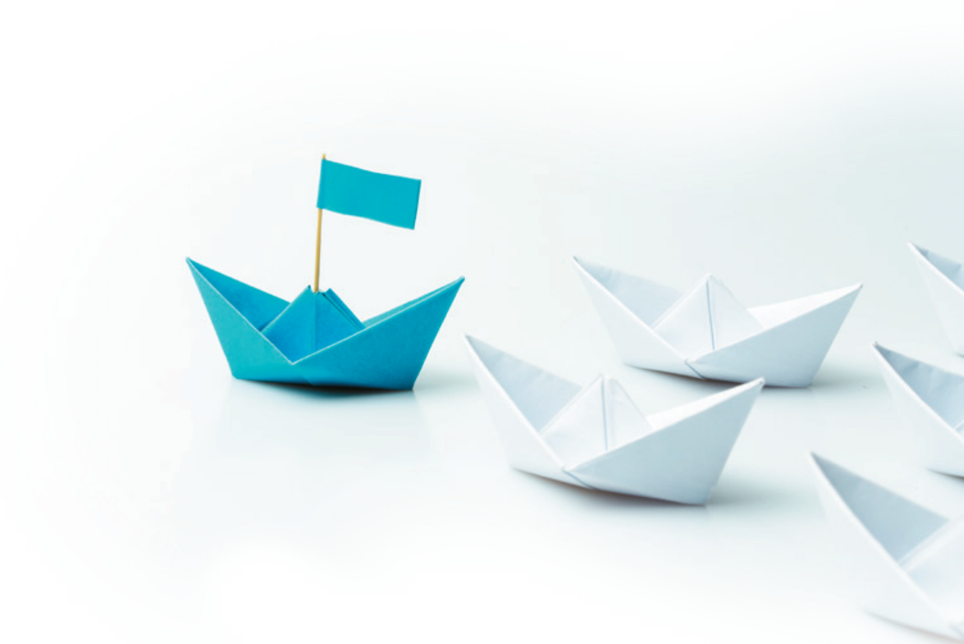

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Foreword

The Indo-Pacific region has come to be an epicentre of the world given the fact that this region contributes to around 60% of global GDP and 65% of the world population is located here. This marks a significant global shift from a trans-Atlantic construct that had dominated the world for at least half a millennium. Owing to this, the Sea Lines of Communication (SLOCs) and the trade routes of the Indo-Pacific region today see the traffic of cargo ships, crude carriers and bulk carriers with over 90,000 ships sailing across the Malacca straits annually.

Despite this centrality for global economy, the Indo-Pacific region is confronted by a number of security challenges such as territorial disputes-both continental and maritime, maritime piracy, dark shipping, IUU fishing, organized crime, human trafficking, arms trafficking, narcotics and ecological concerns. Hence, the imperative need for efficient and effective Maritime Domain Awareness (MDA) (to complement the continental law and order efforts of countries in this region) for maintaining good order and tranquillity at sea, upholding rule of law in sovereign territorial waters, exclusive economic zones and high seas beyond national jurisdiction, and enhancing global peace and security.

This publication provides an in-depth examination of MDA in the Indo-Pacific Region by dwelling into the potential of emerging technologies, regional cooperation, and the integration of space-based assets in enhancing maritime security through surveillance and cooperation. While acknowledging the varying capacities of countries in ensuring effective MDA and the need to enhance these through cooperation, it positively assesses the leading role that some countries are taking in this regard especially the US, Japan and Australia. Each of the papers covered within this publication highlight a distinct yet interconnected aspect of maritime security in the Indo-Pacific Region.

The first paper by Dr. Sripathi Narayanan delves into the evolution of MDA not only historically but also in the understanding of the term itself. It highlights MDA's transition from a narrow focus on security concerns to a more comprehensive understanding that includes ecological, environmental, and economic dimensions. The paper emphasizes how MDA is about tracking vessels, preventing illegal activities, and safeguarding and monitoring global trade routes and making them crime-free and that it is also increasingly being understood to include sustainability of marine resources, and addressing issues about international law and global governance. The paper acknowledges the growing recognition of the maritime domain's significance in ensuring the safety, security, and economic prosperity and its implications for broader regional and global security architecture.

The second paper by Capt. Sarabjeet Singh Parmar goes on to examine regional cooperation in enhancing of MDA in the Indo–Pacific region. This aspect emphasizes the need for center-to-center information exchanges, trust building, and shared capacity building among regional players. It notes the importance of Quad's initiative of Indo-Pacific Maritime Domain Awareness (IPMDA) in taking positive and concrete steps in this area, invites other like-minded countries to join these efforts, and advocates similar initiatives for coordination and action by other groupings such as Indian Ocean Rim Association (IORA), Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC), ASEAN Defence Ministers Meeting-Plus (ADMM-Plus) and the Indo-Pacific Oceans Initiative (IPOI). It positively notes the work of the Information Fusion Centre-IOR based in Gurugram, India. The author highlights that maritime security in the Indo Pacific region cannot be achieved by unilateral policies and action of one country alone but demands a collaborative approach to address concerns in this global common.

The third paper examines the technological advancements that have revolutionized maritime surveillance. Cdr Abhijit Singh tracks the evolution of maritime monitoring from basic radar and AIS systems to more sophisticated technologies, including satellite-based Earth Observation (EO), AI, drones, Radio Frequency (RF) detection, and web-based platforms. He makes the case for integrating considerations related to advancements in technology in national policy frameworks on MDA as also in bilateral and regional frameworks of cooperation and capacity building in this field.

Cdr. (Dr) Arnab Das explores the geopolitical importance of the Indo–Pacific region with particular reference to the Underwater Domain Awareness (UDA) in the fourth paper. He argues for the need of customized or indigenous frameworks, acoustic technologies, and Marine Spatial Planning (MSP) to cater for the peculiar scopes of tropical and equatorial and underwater challenges of the region.

The fifth paper by Dr Vijay Sakhuja underscores how Fourth Industrial Revolution (4IR) solutions- AI, machine learning, big data, robotics, and automation are transforming the maritime domain. This paper demonstrates the impact of these technologies on ship operations, port activities, logistics upgradation, and maritime surveillance and the need to keep abreast of these through cooperation, capacity building and exchange of best practices.

The sixth paper by Mr Keshav Verma, focuses on the influence of satellites as space technologies on the Maritime Domain Awareness of the Indo-Pacific region. It outlines the significance of satellite systems such as Synthetic Aperture Radar (SAR), Automatic Identification Systems (AIS), and meteorological satellites for real-time maritime domain awareness. This chapter describes the significant role of space assets in effective management of and in expanding reach into the maritime domain.

The papers covered here are critical for policymakers, security experts, practitioners, and researchers who seek to address the complex challenges facing the region in the maritime domain. By highlighting the interconnection between emerging technological, regional and inter-regional cooperation and sustainable development practices, this publication intends to serve as a valuable resource for guiding future efforts aimed at strengthening maritime governance and security. The recommendations made here will be useful in guiding the development of policies for a peaceful, secure and sustainable maritime order in the Indo-Pacific region and beyond.

The preparation of this publication has been coordinated by Mr. Keshav Verma, Research Associate, ICWA.

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RECONCEPTUALISING MARITIME DOMAIN AWARENESS IN THE 21ST CENTURY

Dr. Sripathi Narayanan

Maritime Domain Awareness (MDA) is a self-explanatory phrase that stresses the need to closely monitor the maritime space, which covers more than two-thirds of the earth's surface area. As per the International Maritime Organisation (IMO), MDA is defined as an instrument for the *"effective understanding of any activity associated with the maritime environment that could impact upon the security, safety, economy or environment."*[1] However, MDA as a concept today extends beyond the IMO definition to cover a wider canvas, which has far-reaching implications for littoral and non-littoral states and for security in its traditional and non-traditional sense.

Moving Beyond the Security Paradigm

In the aftermath of the 9/11 terrorist attacks, as part of the overall security undertaken by the US, maritime space was identified as a domain that can undermine state security, just as civilian air travel had demonstrated. While the attention paid to the maritime domain then was in the context of the terrorist events that preceded it, the importance of maritime space has a much longer history. Since the earliest days of seafaring, securing the sea line of communication (SLOC) from disruption was given a premium.

It was in this context that Chanakya, or Kautilya, in his *magnum opus, Arthashastra,* delved to a considerable extent on maritime affairs. He had identified the need for a *Nav Parishad* (Board of Admiralty) as one of the six boards of administration. The *Navadhyaksha* (Superintendent of Ships), who comes under the Board of Admiralty, was tasked with examining the accounts related to navigation and maintaining security over different kinds of water bodies, i.e., the coastal waters, open seas and inland water

In the aftermath of the 9/11 terrorist attacks, as part of the overall security undertaken by the US, maritime space was identified as a domain that can undermine state security, just as civilian air travel had demonstrated.

1 Amendments to the International Aeronautical and Maritime Search And Rescue Manual, International Maritime Organisation, May 25, 2012, https://www.mardep.gov.hk/filemanager/en/share/msnote/pdf/msin1242anx1.pdf.

> What has not been duly acknowledged by historians and in historiography is the role of the maritime domain in shaping events over the millennia.

bodies. The responsibilities of the *Nav Parishad* and the *Navadhyaksha* also included safeguarding maritime trade, merchant ships and port towns while also overseeing the collection of customs, taxes and overseeing shipbuilding.[2]

In the *Arthashastra*, Chanakya also explained how to deal with piracy and pirates. He states that pirate ships, or *himsrika*, vessels that are bound for the country to an enemy, as well as those that violate the customs and rules in force in port towns, shall be destroyed. What prompted the *Arthashastra* to talk about the need for a Board of Admiralty was that the Indian subcontinent, independent of the reign of the Mauryan Empire, had extensive trade and commercial ties via the seas that reached the shores of ancient Greece and Roman civilisations. This maritime mercantile engagement was not solely driven by commercial interest but more by a greater undertaking of the waters of the Indian Ocean Region, especially that of the predictable seasonal reversing of the wind and *the monsoon,* which facilitated long-distance voyages.

However, for long, maritime security was limited by the importance attached to it in its scope and implications. What has not been duly acknowledged by historians and in historiography is the role of the maritime domain in shaping events over the millennia. For instance, the Chola naval expedition in 1017 and 1025 AD to the Sri Vijaya Empire in modern-day Sumatra, Indonesia, was in response to the disruption of Southern India's trade with the Song Empire of China by the Southeast Asian Kingdom.

However, a more pertinent development that has had a lasting impact was the fall of Constantinople to the Ottoman forces in 1453. This was one of the catalysts that encouraged Western European

2 Dr Avantika Lal, Naval Warfare in Ancient India, World History Encyclopaedia, August 15, 2018, https://www.worldhistory.org/article/1259/naval-warfare-in-ancient-india/.

In contemporary times, before the coining of maritime domain awareness as a term, the principle of the same was prevalent in the post-Second World War era.

countries to scout out alternative routes to sustain their trade ties with Asia, beginning with India. Consequently, the voyages sponsored by the Royal Courts of Portugal and Spain paved the way for the Age of Discovery, or the Age of Exploration, to accelerate. The subsequent era of the Age of Imperialism that followed has now shaped the contemporary global landscape.

In contemporary times, before the coining of maritime domain awareness as a term, the principle of the same was prevalent in the post-Second World War era. This, however, was limited to monitoring the maritime military capabilities and deployments of naval assets of the US-led and the Soviet Union-led blocs by one another, owing to the Cold War rivalry between the then two superpowers.

Going beyond the rivalry between the two superpowers, another aspect that can be considered a form of MDA was in the waters of the Persian Gulf region during the Iran-Iraq eight-year war. The Tanker War, as the maritime escalation of this conflict came to be referred, was an attempt by Iran and Iraq to undermine one another's ability to use tankers to export their respective crude oil between 1984 and 1988[3], the mainstay of their respective economies. The escalation of the tanker war had undermined the "overall security of shipping to and from neutral Gulf countries."[4] The need for securing the SLOCs of the Persian Gulf saw the deployment of a US-led flotilla in the Persian Gulf after UN resolutions that deplored the "attacks on neutral shipping and civil aircraft."[5] This deployment of the US and its allies, especially France and the UK, though ostensibly meant for SLOCs' protection, can also be seen from what has traditionally

3 Cordesman, A., & Wagner, AXiv. the tanker war and the lessons of naval... Center for Strategic and International Studies. (1990). https://csis-website-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/media/csis/pubs/9005lessonsiraniraqii-chap14.pdf

4 Ibid 3

5 United Nations. United Nations Security Council resolutions 582. UNSCR, (1986). http://unscr.com/en/resolutions/582

> American President George W. Bush in 2002 said that the "heart of the Maritime Domain Awareness program is accurate information, intelligence, surveillance and reconnaissance of all vessels, cargo, and people extending well beyond our (United States') traditional maritime boundaries.

been called "gunboat diplomacy,"[6] a practice that was prevalent during the colonial era. However, the tanker wars, as military tactics, had their roots in colonialism which were further refined during the Atlantic theatre of the Second World War.

After the tanker wars, it was the terrorist attack on the USS Cole, while docked in the Yemeni port of Aden in October 2000, which can be seen as a precursor to 9/11, that also came to shape the perception towards maritime security. The USS Cole incident was meant to incite a response from Washington on lines akin to the post-9/11 military adventurism by the US in Afghanistan. This is so, as the *9/11 Commission Report* quoting the intelligence report observed that *"(probably Osama bin Laden) … wanted the United States to attack, and if it did not, he would launch something bigger."*[7]

It was against this backdrop that the overall US security apparatus at the turn of the new millennium was revisited, including the approach towards maritime security. This revised approach by the US was reflected in the Aviation and Transportation Security Act, enacted in November 2001, which had made specific reference to *"maritime transportation (including port security)."*[8] This American legislation was also accompanied by other international instruments and initiatives. However, the approach to MDA was still seen from the prism of security. This sentiment was echoed when then-American President George W. Bush in 2002 said that the *"heart of the Maritime Domain Awareness program*

6 United Nations. United Nations Security Council resolutions 598. UNSCR. (1987). http://unscr.com/en/resolutions/598

7 "The National Commission on Terrorist Attacks". The 9/11 Commission Report, 2004. https://9-11commission.gov/report/911Report.pdf.

8 Congress. Text - S.1447 - 107th Congress (2001-2002): Aviation and Transportation Security Act, 2001. https://www.congress.gov/bill/107th-congress/senate-bill/1447/text.

is accurate information, intelligence, surveillance and reconnaissance of all vessels, cargo, and people extending well beyond our (United States') traditional maritime boundaries."[9] The continued emphasis on maritime security continued to be the primary focus of MDA and was further reinforced by other developments like the terrorist attacks on Mumbai in November 2008,the challenge imposed by Somalia-based piracy that disrupted commercial shipping in the western Indian Ocean, and similar instances in other parts of the world.

However, the time has come to relook at MDA and move beyond the security prism. This is because developments in the open seas do not only solely impinge on SLOCs and state security but also upon a wider array of issues that include but are not limited to concerns on food and nutrition, ecology and environment, climate change and global warming, energy and natural resources, science and technology, the international rule-based system and the existing global order. Additionally, MDA is multi-dimensional as it stretches from the seabed through the column of water, the surface of the water and the airspace above the surface of the seas and oceans of the world.

The Widening Canvas of MDA

In the contemporary context, the maritime domain covers a multi-dimensional canvas. As has been defined by the International Maritime Organisation (IMO), the maritime domain covers *"all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, vessels and other conveyances."*[10] In addition to this, the maritime space is not only limited to the surface of the water and

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9 Department of Homeland Security. National plan to achieve Maritime Domain Awareness, 2005. https://www.dhs.gov/xlibrary/assets/HSPD_MDAPlan.pdf.

10 "Amendments to the International Aeronautical and Maritime Search And Rescue (IAMSAR) Manual," MSC.1/Circ.1415, 25 May 2012, https://www.mardep.gov.hk/en/msnote/pdf/msin1242anx1.pdf.

the column of water but also covers the seabed, beneath the seabed, the airspace above the waterline and outer space.

Thus, unlike in the past, where concerns about the seas were limited to the security and safety of SLOC, as had been identified in the Arthasastra, contemporary maritime concerns cover a wide range of issues. What makes contemporary development pertinent is its impact on shaping the future course, especially in the light that all issues are interrelated and interdependent upon one another. What makes the maritime space different from the continental space is the fact that this domain transcends both traditional and non-traditional human activities. Apart from fisheries and shipping, one of the oldest professions in the world, and offshore energy to new areas like seabed mining, this has the potential to be the future driver of critical mineral resources that could sustain humanity. Additionally, about a tenth of mankind, or 680 million people, live near the coastline of the world.[11] Of these, about 60 million are engaged in fishing and aquaculture for their livelihoods, which in turn translates as an important source of nutrients for 3.3 billion people.[12] In terms of global commerce, approximately 80 per cent of world trade in value and 90 per cent in terms of volume are transported by the seas, which accounts for about 3 per cent of global greenhouse gas emissions.[13]

Additionally, the oceans of the world are a major carbon sinkhole and as such have come to play a vital role in regulating the global climate. By some accounts, the oceans generate about half of the Earth's oxygen, absorb a quarter of all carbon dioxide emissions and capture 90 per cent of the excess heat generated by these emissions.[14] It is this facet of the open marine hydrosphere that regulates the climatic seasons of the world, beginning with the *monsoons*.

11 "United Nations". The ocean – the world's Greatest Ally Against Climate change, n.d. https://www.un.org/en/climatechange/science/climate-issues/ocean#:~:text=The%20ocean%20generates%2050%20percent,the%20impacts%20of%20climate%20change.

12 "The State of World Fisheries and Aquaculture 2020." www.fao.org, n.d. https://www.fao.org/interactive/state-of-fisheries-aquaculture/2020/en/#:~:text=Across%20the%20world%2C%20the%20fisheries,a%20slight%20increase%20from%202016.

13 Ibid 11

14 Ibid 12

Additional offshore energy will come to play an increasing role in energy security. The seabed has considerable reserves of hydrocarbons in the form of crude oil and natural gas, and the same is already a significant source of conventional sources of energy. By some accounts, about a third of global crude oil and natural gas are extracted from offshore energy fields.[15]On the other hand, since 1991, offshore wind has been growing steadily as a clear source of energy. It has been estimated that the installed wind turbine capacity in 18 countries of the world stands at 57 GW.[16] Additionally, the seabed is also important in transporting hydrocarbons via undersea pipelines and electricity via undersea cables. In terms of communication and data, undersea cables are responsible for the transmission of about 95 per cent of global data and telecommunications.[17]

A Challenging Opportunity

Given the shifting nature of the global economy and technological space, which is now paying premium attention to issues like climate resilience, green transition and sustainability, the maritime domain is also playing its part. In terms of green transition, part of offshore wind, tidal and other forms of electricity generation are also potential sources. Under reckoning are the considerable reserves of other natural resources like metals. Polymetallic nodules and polymetallic sulphides found on the seabed are crucial sources of minerals like copper, cobalt, nickel, zinc, silver, gold and rare earth elements (REE). REE has already led the way in the global green transition. In the coming years, it is expected that the importance of REE will only increase by many folds and will be the primary driver of electricity and energy.

On the flip side, the maritime space does face considerable challenges, which in turn will become new opportunities. For one, unlike offshore hydrocarbon extraction, deep-sea mining as a sector is still in its infancy. To realise the competitive potential of this sector, there is a need for greater investment in research and

15 “World Ocean Review”. Sating Our Energy Hunger ", 2014. https://worldoceanreview.com/en/wor-3/oil-and-gas/sating-our-energy hunger/#:~:text=The%20future%20of%20offshore%20oil,depths%20greater%20than%201500%20metres.

16 “ Ministry of New and Renewable Energy”. Offshore Wind., n.d. https://mnre.gov.in/en/off-shore-wind/.

17 Robin Chataut. “Undersea Cables Are the Unseen Backbone of the Global Internet.” The Conversation, November 8, 2024. https://theconversation.com/undersea-cables-are-the-unseen-backbone-of-the-global-internet-226300.

innovation, and the same is being done. However, a real limitation is that as of 2022, a bit less than a quarter of the seafloor has been mapped in high resolution. One of the main challenges has been the logistical cost of such an exercise and the fact that the average depth of the seafloor is over 3.5 kilometres.[18] The second challenge is the fact that the current scientific and industrial capacity and capability are not advanced enough to fully harness the true potential of the seas.

Resultantly, deep-sea resource extraction, whose sustainability and ecological sensitivity are still a subject of debate, will attract significant investment in terms of money, research and development of new technologies and systems, and, most importantly, policy formulation and the subsequent international legal regime.

International Maritime Order and Security

The global normative order, as it stands today, is already under considerable strain owing to numerous maritime territorial disputes and marine infringements stemming from not all signatories upholding the letter or the spirit of the United Nations Convention on the Law of the Sea (UNCLOS). Given this, the evolving maritime space would have to factor in potential areas of divergence and the resultant impasse in the normative order. This challenge would have to take into consideration concerns of ecology, the environment and the Fourth Industrial Revolution.

With the world increasingly moving towards a greener world, which would also include global carbon zero or net zero emissions, the role of the oceans and seas would gain greater importance. First, it will begin by reducing the carbon footprint in the maritime domain. This would mean issues like ocean garbage or marine litter would have to be addressed in the continental space since 80 per cent of all pollution in seas is a result of land-based human activity.[19]This would also mean that existing traditional human activities like fisheries and shipping would also have to adapt to address environmental concerns. In terms of the shipping

18 Ruby, Caitlin, and Georgianna Zelenak. Seafloor mapping, 2022. https://oceanexplorer.noaa.gov/explainers/mapping.html.

19 " United Nations." SDG actions platform, n.d. https://sdgs.un.org/partnerships.

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sector, the call to arms would be in terms of alternative fuel and energy sources. As such, efforts are being made to move away from carbon-intensive fuels to alternatives like hydrogen, ammonia, methanol or wind-powered shipping.[20] Whereas when it comes to fisheries, the call to arms would not be limited to energy sources of fishing fleets and sustainable fishing practices but also includes illegal, unregulated and unreported (IUU) fishing.

The second challenge would be in terms of the Fourth Industrial Revolution, which covers aspects like automation, robotics, artificial intelligence, machine learning, fully autonomous vehicles and others. This revolution would be driven by rare earth elements and other critical metals, which in turn would increase the dependency on seabed mining. And in the same context, autonomous or unmanned systems would also be critically important. The third aspect would be undersea cable and pipeline, which would find a greater role than what it is at present, especially in the light of ambitious initiatives like One Sun, One World, One Grid, which aims to interconnect existing power grids to carry electricity across regions and continents with a load capacity of 2600 gigawatt by 2050.[21]

It is in this light that Underwater Domain Awareness (UDA), a sub-section of MDA, becomes important. This is so, as the growing role of the sub-surface of the oceans would come to be as important a space as the surface of the oceans. The challenges and impact of the underwater domain also have an ecological and environmental footprint. It has been for this very reason that an

20 Ibid 11

21 “The Times of India”. One Sun, One World, One Grid: India-UK’s Ambitious Global Solar Grid Plan Explained, 2021. https://timesofindia.indiatimes.com/india/one-sun-one-world-one-grid-india-uks-ambitious-global-solar-grid-plan-explained/articleshow/87502775.cms.

international treaty drawing from the UNCLOS called the Biodiversity Beyond National Jurisdiction (BBNJ) Agreement, popularly known as the Treaty of the High Seas, was adopted in 2023. The BBNJ aims at addressing and managing the maritime environment in the high seas that does not fall under the jurisdiction of any one country. The scope of the BBNJ covers what is otherwise a grey area in UNCLOS, making the new Treaty herald a new era in modern maritime domain governance.

MDA in an Evolving Global Order

Apart from the challenges that stem from the interpretation and reinterpretation or the misinterpretation of UNCLOS, as is the case with other aspects of the maritime domain. Some of these have been traditional issues like the security of SLOCs and illegal economic activities like illegal IUU fishing and pollution, which are predominantly limited to oil spills and similar challenges.

Concerns about IUU fishing and the challenges on this count arise from governments not in a position or willing to enforce international norms or through blatant neglect by some governments in enforcing the same. It is in this light that cooperative mechanisms like the White Shipping Agreements and information-sharing mechanisms gain importance as they monitor civilian activities at sea, be it small fishing vessels to larger merchant shipping. White shipping agreements and coastal/maritime surveillance systems like radars and sea buoys, when linked with regional and information fusion centres, are key tools in addressing concerns on the seas. The analysis and dissemination of the information that is gathered through these channels are critical tools in addressing maritime challenges like piracy, armed robbery, contraband smuggling, IUU fishing, dark shipping, irregular human

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migration (IHM) and ecological and environmental challenges.

Given this backdrop, MDA, as it stands now, would not only be limited to monitoring the high seas by individual entities but also have to be incorporated within the broader ambit of a global, rules-based order. In this context, the BBNJ is but a small step while other larger issues would have to be factored in since the maritime domain, as the legal framework, is already a playfield of geopolitical contestation. The tenets of UNCLOS have been a bone of contention, and in some cases, being weaponised by some. The undersea infrastructure, damage to undersea cables and pipelines too is increasingly being considered to be vulnerable to sabotage.

With prospects of the seas becoming a new engine of the global economy and green transition, international laws, rules, regulations and conventions in the maritime domain would be a bone of contention and open to question and disregard. Irrespective of the global order that would come into play, MDA would play a decisive role in drafting a new international regime and in the regulation and enforcement of the same, as it has traditionally done in the documented history of mankind.

REGIONAL COOPERATION AND CAPACITY BUILDING FOR ENHANCING MDA CAPABILITIES IN THE INDO-PACIFIC

Captain Sarabjeet S Parmar (Retd.)

Unpacking MDA

The importance of MDA, especially in today's complex maritime world of ever-increasing sea-borne commerce and non-traditional threats cannot be sufficiently emphasised.[22] Recognising the ubiquitous use and gains from establishing a regional and globally linked MDA network, the Quad launched the Indo-Pacific Partnership for Maritime Domain Awareness (IPMDA) in May 2022. The IPMDA aims to provide an integrated maritime picture of the Pacific Islands, Southeast Asia and the Indian Ocean Region (IOR). Once functional, the IPMDA will enable nations to tackle maritime crimes, track dark shipping and improve the ability to respond to climate and humanitarian events and address IUU fishing, which have been categorised as a non-traditional threat. Therefore, the success of the IPMDA would depend on the aggregate capacity and capability of nations planning to plug into this initiative. The MDA is a complex subject, and there is no internationally recognised definition. Therefore, the first step would be to identify how nations define MDA and seek convergence.

The International Maritime Organisation (IMO) defines MDA as, "*The effective understanding of anything associated with the maritime domain that could impact the security, safety, economy or environment.*"[23] The US adopted the same definition and amended it to read as the impact on "*the security, safety, economy or environment of the US.*"[24] Australia defines MDA as "*the*

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22 Sarabjeet Singh Parmar, "Plotting the Quad's Maritime Domain Awareness Course" in Yogesh Joshi and Nishant Rajeev (eds.), "Quad Cooperation: Maritime Security in the Indo-Pacific," Institute of South Asian Studies South Asia Discussion Papers, Singapore, October 2022.

23 International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual, Volume II, 2016 Edition, p. xxi.

24 National Maritime Domain Awareness Plan for the National Plan for Maritime Security, December 2013, p. (iv), downloadable at https://www.hsdl.org/?abstract&did=747691.

effective understanding of anything associated with the maritime domain that could impact the security, safety, economy or environment of a nation."[25] Per Japan's basic plan for ocean policy, MDA is "*the efficient understanding of situations associated with the oceans while bearing in mind how to handle the effective collection, consolidation and sharing of diverse information about the ocean that contribute to maritime security, ocean environmental protection, marine industry promotion and science and technology development*".[26] The Indian Navy's unclassified strategy document, Ensuring Secure Seas: Indian Maritime Security Strategy (IMSS 2015), states that, "*MDA is an all-encompassing term that involves being cognisant of the position and intentions of all actors, whether own, hostile or neutral, in all dimensions of a dynamic maritime environment, across the areas of interest*".[27]

There are linkages across these definitions, and one underlying commonality is the quantum of information that needs to be analysed and shared for necessary actions to be taken. A high degree of cooperation needs the linking of information or fusion centres across the region, which are manned by liaison personnel from various countries. These personnel work as a team that forms an essential part of the MDA network. To ensure a robust MDA network, these centres would need technology and trained manpower to facilitate quick analysis and real-time sharing of raw and processed information. This requires a host of capacities and capabilities(C&Cs) at the level of individual countries as well as at the subregional levels of the Indo-Pacific.

Identifying Countries and Fields to be Developed

Surveillance is the means that provides inputs to the MDA network. There are many types of assets that provide inputs. This matrix extends from Human Intelligence (HUMINT) to high-end technologies that extend from the sub-surface domain to space. The MDA can be divided into two main areas: sea surface to space and underwater. The first area has many

25 Australian Maritime Doctrine, RAN Doctrine 1 – 2010, Second Edition, Sea Power Centre Australia, p. 199.

26 "The Basic Plan on Ocean Policy," Cabinet Decision, May 15, 2018, Provisional Translation, foot note 14, p. 26, available at https://www8.cao.go.jp/ocean/english/plan/pdf/plan03_e.pdf.

27 Ensuring Secure Seas: Indian Maritime Security Strategy (Naval Strategic Publication 1.2) (IMSS 2015), Integrated Headquarters of the Ministry of Defence (Navy), New Delhi, 2015, p. 165.

convergences that appeal to most nations and greatly aid the addressing of Threats, Risks, and Challenges (TRCs). However, the complexities of the underwater domain due to the nature of the environment and sensitivities impacting sovereignty, security and living and non-living resources necessitate a more cogent and careful approach to this area. Hence, Underwater Domain Awareness (UDA) is dealt with as a separate entity by most countries.

Countries build C&Cs to address TRCs based on their national interests, which can be restricted due to domestic policies, existing national instability, budgetary constraints or non-availability of national expertise to develop them. As the ability to enhance stability, ensure security, and preserve peace in their maritime zones of nations would be a major criterion, Indo-Pacific nations can be clubbed into four main categories:

- Countries that possess the C&Cs to address TRCs and have the bandwidth to help other countries develop C&Cs.
- Continental nations that do not have the C&Cs to address TRCs in their maritime zones.
- Small countries, especially island nations, have large maritime zones but lack the C&Cs to address the TRCs in these zones.
- Countries that have the requisite C&Cs to address TRCs but are restricted due to internal or international pressures.

While the first category would have to support the second and third categories in developing the required C&Cs, the fourth category would need to be drawn into suitable existing cooperative mechanisms. As a part of regional cooperation, the MDA should be approached as a "Maritime Security Multilateral Cooperative Mechanism"; hence, the degree of trust will dictate the extent of interaction and C&C development. While the sharing of information is mainly restricted to white shipping, there are indications that nations are beginning to accept that dark shipping should also be included. The 2022 meeting of Quad leaders in Tokyo introduced the concept of IPMDA as a fundamental requirement for peace, stability and prosperity through appropriate investments over five years. Tracking of Black shipping was mentioned as one of the benefits of

> The 2024 meeting of Quad leaders in the US mentioned that the IPMDA working through various countries, agencies and fusion centres had provided access to dark vessels maritime domain awareness data that helped over 24 nations monitor activities in their Exclusive Economic Zones more effectively. This spread of trust and sharing of information across white and dark spectrums will greatly aid regional cooperation.

the initiative.[28] The 2024 meeting of Quad leaders in the US mentioned that the IPMDA working through various countries, agencies and fusion centres had provided access to dark vessels maritime domain awareness data that helped over 24 nations monitor activities in their Exclusive Economic Zones more effectively.[29] This spread of trust and sharing of information across white and dark spectrums will greatly aid regional cooperation.

Some countries may be hesitant to be seen as part of the IPMDA. For such countries, there are other existing mechanisms that offer an alternate methodology, like the Maritime Security and Capacity and Capability Development pillars of India's Indo-Pacific Oceans Initiative. Further, as a stand-alone method, trilateral or minilateral with acceptable countries can be formed to develop the required C&Cs. Further, regular and sustained engagements at various bilateral/trilateral/multilateral levels, the conduct of real-time and virtual exercises and building the capacity of countries through joint and collaborative efforts in training, co-development and processing of information will help the cause of MDA.[30]

Fusion Centres and Capacity and Capability Building

The Indo-Pacific is a vast maritime area and, hence, there is a need for a well-connected network of fusion centres at the subregional level and

28 The White House Statements and Releases, "FACT SHEET: Quad Leaders' Tokyo Summit 2022," 23 May 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/05/23/fact-sheet-quad-leaders-tokyo-summit-2022/.

29 Ministry of External Affairs/ Government of India, "Fact Sheet: 2024 Quad Leaders' Summit," 21 September 2024, https://www.mea.gov.in/bilateral-documents.htm?dtl/38327/Fact_Sheet_2024_Quad_Leaders_Summit#:~:text=Together%2C%20the%20Quad%20is%20leading,benefit%20from%20critical%20and%20emerging.

30 Parmar, Plotting the Quad's Maritime Domain Awareness Course, Op Cit.

information hubs at the national level to establish a dynamic and potent MDA in the region. Towards this, the Indo-Pacific, based on dynamics and the peculiarities of the maritime security environment, could be divided into subregions as follows:

- Arabian Sea
- Bay of Bengal
- Southern Indian Ocean (Western part)
- Southern Indian Ocean (Eastern part)
- South China Sea
- East China Sea
- Pacific Islands Area
- Balance of the Pacific Ocean

While the fusion centres would cater to national and subregional requirements, the information hubs could be many and established at national levels where the setting up of a fusion centre is limited due to C&Cs restraints. The number of fusion centres could be based on the quantum of maritime traffic and the security environment. However, it would be prudent to keep the number of fusion centres limited to avoid considerable overlaps, especially where information sharing is concerned. The ability of fusion centres to absorb and process information received would remain limited given the quantum received. The quantum of information received would always increase when a subregional security situation deteriorates, a specific example being the Red Sea area when attacks on shipping by the Houthis started.

The fusion centres, with an established flow of raw and processed information between information hubs and fusion centres, would be the nodal points over which the web of an effective MDA network would be overlaid. These fusion centres that cover a specific subregion would have their subregional networks and garner information from national information centres. Presently, there are centres across the Indo-Pacific, out of which only a handful can be considered for the role of subregional fusion centres. In the Indo-Pacific region, the US Coast Guard Maritime Intelligence Fusion Centre Pacific (MIFC PAC), India's Information Fusion Centre — Indian Ocean Region (IFC-IOR), Singapore's Information Fusion Centre

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(IFC)[31] and the Regional Maritime Information Fusion Centre (RMIFC) in Madagascar fall in this bracket. The Pacific Fusion Centre (PFC), located at Port Vila, Vanuatu, relocated from Canberra in December 2021, could be developed into a subregional fusion centre. Therefore, while the Indian IFC-IOR could focus on the Arabian Sea and the Bay of Bengal, the RMIFC at Madagascar could focus on the western part of the IOR, the Singapore IFC could focus on the South and East China Seas, and the PFC could focus on the Pacific Islands area. The eastern part of the IOR would need a fusion centre that could be established in Australia. The MIFC PAC, based in Alameda, California, could focus on the balance of the Pacific Ocean area. However, for a more focused approach and to include the US Navy, an important agency in the MDA network, a suitable hub could be created in Hawaii for better linkage with the region. Or a fusion centre could be created in Hawaii for a more comprehensive MDA network.

Some fusion centres have International Liaison Officers (ILOs) to facilitate the transfer of information and regional cooperation. Fusion centres housing ILOs would need to build suitable infrastructure and provide amenities for the ILOs, which would be a one-time investment followed by a recurring maintenance and support expenditure. This could be done by the host nation independently or under bilateral agreements with the ILO nation. Depending on the requirement, the same arrangement could be followed at information hubs. It is evident that there will be a requirement to develop the C&Cs of fusion centres and information hubs, which are not considered "subregional or national in their mandate, capacity and activities," so that there is synergy in analysis and information sharing.

31 For more details see Deon Canyon and Jim McMullin, "Maritime Domain Awareness and Maritime Fusion Centers", DKI APCSS Security Nexus Perspectives, 21-2020, https://apcss.org/wp-content/uploads/2020/10/N2526-Canyon-Maritime-awareness2.pdf.

Under IPMDA, the Quad intends to carry out the following[32]:

- Deliver cutting-edge capability and information into the region.
- Leverage electro-optical data and advanced analytic software to sharpen the MDA picture.
- Conduct new regional Maritime Initiative for Training in the Indo-Pacific (MAITRI).

This will enable partner nations in the Indo-Pacific region to maximise tools provided through IPMDA and other Quad partner initiatives to monitor and secure their waters, enforce their laws, and deter unlawful behaviour. India will host the first MAITRI workshop in 2025.

The Quad is presently supporting three pilot programmes in the IOR, Southeast Asia and the Pacific Islands with plans to extend the programmes to more partners.[33] However, some nations may not like to engage directly with the Quad. For such nations there are ample areas under regional organisations and initiatives under which the development of Capacities and Capabilities can be undertaken subregion wise. These include the following:

- Indian Ocean Rim Association (IORA) focus area on maritime security and strategy.
- The Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) security cooperation sector.
- The ASEAN Defence Ministers' Meeting Plus (ADMM Plus) platform.

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32 MEA Fact Sheet: 2024 Quad Leaders' Summit, OP Cit.

33 The White House Statements and Releases, "The Quad Leaders' Summit Fact Sheet," 20 May 2023, https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/20/quad-leaders-summit-fact-sheet/.

- The Maritime Security and Capacity Building and Resource Sharing pillars of the Indo-Pacific Oceans Initiative (IPOI).
- Existing minilaterals, and when required, new minilaterals to address specific requirements of nations.

This approach could cover nations that fall under the second to fourth category of nations mentioned earlier, especially the fourth category.

Regional Cooperation

The advantages of regional cooperation in the field of MDA can be founded in the following aspects:

- Showcasing and imbibing of C&Cs.
- Adopting best practices and procedures.
- Enabling and enhancing doctrinal and strategic learning.
- Benchmarking existing C&Cs in an international and regional environment.
- Developing trust, mutual friendship and respect.

Centre-to-Centre cooperation under the MDA network can be considered an important part of maritime security multilateral cooperative mechanisms.

However, the differing C&Cs of fusion centres and information hubs, and the presence of ILOs from nations that do not share cordial relations, will limit the type of information that can be shared, and in turn regional cooperation. However, as the focus is on common non-traditional threats and challenges, the information analysed and shared would be more acceptable. As of now, the information shared is on white shipping (commercial vessels). In time, progress could be made to look at black shipping (illegal vessels).

An effective MDA network is one major part of regional cooperation; the second major part is the action on the ground to address the Threats, Risks and Challenges. There are several success stories that have resulted from the sharing of information and actions on the ground. The Houthi actions in the Red Sea have resulted in a resurgence of piracy off the Horn of Africa in December 2023. Both combined threats have witnessed coordinated actions and assistance to the targeted ships. One such incident saw India, Seychelles, and Sri Lanka address a piracy attack on a Sri Lankan trawler about 955 nautical miles east of Mogadishu. The operation

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started with the piracy attack on 27 January 2024 and subsequent arrest of the pirates on 29 January 2024. The real-time sharing of information between the IFC-IOR and Regional Coordination Operations Centre (RCOC), Seychelles, the active involvement of the Sri Lankan and Seychelles ILO based at the IFC-IOR, and the timely deployment of maritime assets from India and Seychelles resulted in the Seychelles Coast Guard intercepting the pirated trawler and the arrest of the pirates.[34]

Addressing non-traditional threats is becoming more challenging due to the inception of direct state support or indirect support by a state. This has led to a blurring of lines between non-traditional and traditional TRCs. The blurring is impacting regional cooperation and changing the existing contours of regional maritime security. The Red Sea situation is a case in point. The Houthi attacks led to the US initiating “Operation Prosperity Guardian” under the Combined Task Force (CTF) 153 of the Combined Maritime Forces (CMF). The mission of CTF 153, established in April 2022, is to focus on international maritime security and capacity-building efforts in the Red Sea, Bab al-Mandeb and Gulf of Aden.[35] Set up in December 2023 by the US after the first Houthi attacks on 19 November 2023, Operation Prosperity Guardian was to bring together and include the UK, Bahrain, Canada, France, Italy, the Netherlands, Norway, Seychelles and Spain.[36] However, the US-NATO allies — France, Spain and Italy — declined to join the operation and are operating independently. Presently, Italy commands CTF 153 and states

34 Narrative developed with inputs from the Indian Navy.

35 CTF 153, Red Sea Maritime Security, https://combinedmaritimeforces.com/ctf-153-red-sea-maritime-security/.

36 US Release/ Department of Defence, “Statement from Secretary of Defence Lloyd J Austin III on Ensuring Freedom of Navigation in the Red Sea”, December 18, 2023.https://www.defense.gov/News/Releases/Release/Article/3621110/statement-from-secretary-of-defense-lloyd-j-austin-iii-on-ensuring-freedom-of-n/.

that it would deploy a ship to protect its national interests in response to specific requests made by Italian shipowners.[37] This national tasking vis-à-vis a coalition requirement raises questions on the efficacy of CTF 153. The same question could arise if France, Spain or any other nation with divergent tasking were to command CTF 153. India, which became a full member of the CMF in November 2023, also opted for independent patrols with a focus on piracy while it also helped ships attacked by and damaged by the Houthis. The situation is typical of instability on land impacting the maritime domain in the Red Sea case, the instability and resultant conflict stemming from Gaza provided an avenue and reason for the instability in Yemen to impact shipping. Coupled with this is the interplay of international relations that many nations have to balance with Israel, Iran, Saudi Arabia, Yemen and Qatar, to name a few. While these would impact regional cooperation and interoperability with respect to actions on the ground, the same could impose restrictions on information sharing in the fusion centre and information hub web. However, the sharing of selective information would continue as nations would have less to lose from garnering information as compared to participating in physical execution on the ground.

Underwater Domain Awareness

Monitoring underwater domains due to the physical properties like the water body, especially the movement of sound under the surface of the sea, has always been a challenge. "*The importance and challenges of the underwater battlespace continue to grow, as do investments in subsurface capabilities.*"[38]Unmanned underwater vessels (UUVs) have added to the existing inventory of underwater assets that include nuclear-powered and conventional submarines. A submarine's main advantage is stealth. Submarine operations thrive on the degree of difficulty in detecting a submarine. Non-nuclear submarines are quieter than nuclear submarines, and Air Independent Propulsion (AIP) has drastically reduced the requirement to come to the surface or "snort" for access to atmospheric

37 Reuters, "What is US-led Red Sea coalition and which countries are backing it?", December 22, 2023, https://www.reuters.com/world/us-red-sea-taskforce-gets-limited-backing-some-allies-2023-12-20/.

38 The Military Balance 2022, International Institute of Strategic Studies, Routledge, 15 February 2022, p. 7.

A smaller grouping of nations with a high degree of trust and Capacities & Capabilities could work together to establish underwater sensor networks and share information across a limited network.

oxygen. This capability makes the detection of submarines more difficult, making the development of a Underwater Domain Awareness (UDA) picture more difficult than a surface MDA picture. UUVs further complicate the development as they are smaller since they are more difficult to detect, and more importantly, they are expendable as they are less expensive as compared to manned submarines, and, more importantly, lives are not at stake. A combination of manned submarines and UUVs operating in larger numbers could increase the underwater traffic density, especially in areas of interest. For manned submarines, this would be areas of adequate depth and would generally be off choke points, along Sea Lines of Communication (SLOCs), and areas where International Shipping Lanes (ISLs) merge. In the case of UUVs, the depth restrictions would reduce depending on the size of the vessel, and, hence, UUVs could be deployed closer to the coast near identified Vital Areas and Vital Points. This would make detection even more difficult due to coastal surface traffic density, resulting in more ambient noise. A major legal issue that arises from UUV operations is the identification of the nationality of a UUV. In the case of submarines, it could be easier as compared to UUVs. Hence, while submarines are placed in the category of Grey Shipping (military vessels), unidentified UUVs could be looked at as Black Shipping. Developing a UDA picture would need the installation of underwater sensors at strategically identified places, most of which would fall within the maritime zones of countries. Underwater operations have long been a sensitive issue with many countries due to the lack of trust, the perceived impact on national sovereignty, and the cost of setting up and maintaining an underwater network of sensors. Achieving a comfortable degree of UDA will take time and would depend on the establishment of a well-connected MDA network covering the surface and air environments. A smaller grouping of nations with a high degree of trust and C&Cs could work together to establish underwater sensor networks and share information across a limited network.

Conclusion

MDA should be approached as a "Maritime Security Multilateral Cooperative Mechanism." While the IPMDA initiative can be placed as the main driving force due to the Capacities and Capabilities of the Quad countries, the ambit and area are too large for the Quad; hence, there is a need for maximum like-minded nations to work together. IORA, BIMSTEC, ADMM Plus, IPOI and minilaterals provide alternate avenues if direct association with the Quad is not acceptable. As the present format of exchange is comfortable with white shipping information sharing, the focus of cooperation should remain on addressing non-traditional threats and challenges. The ambit can be increased once black shipping information sharing is considered acceptable by most nations. With regional cooperation to address TRCs on the ground, there is a need for nations to work together to shape favourable and positive maritime subregional environments. The Quad and other nations need to work together to develop trust, enhance capacity, encourage more information sharing, and create synergy by:[39]

- Holding regular and sustained engagements at various bilateral/trilateral/multilateral levels.
- Conducting real-time and virtual exercises.
- Building capacity of nations through joint and collaborative efforts in training, co-development, and processing information.
- Encouraging effective and robust sharing of "actionable information" under existing information-sharing

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39 These points were culled from the deliberations from the panel that discussed MDA during the Indo-Pacific Regional Dialogue (IPRD) 2021 organised by the National Maritime Foundation from 27 to 29 October 2021.

agreements and positioning of ILOs at international fusion centres.

- Developing and sharing technical solutions to promote wider information sharing across sectors, agencies, and regions.
- Developing cyber resilience in information-sharing mechanisms.
- Extending engagements to various maritime stakeholders, particularly the shipping industry, coastal communities and academia, to aid the strengthening of cooperation.
- Ensuring best practices to avoid/minimise duplication while maintaining complementarity towards optimising collective efforts.

RECENT TRENDS IN MARITIME DOMAIN AWARENESS

Mr. Abhijit singh

The legendary military theorist Sun Tzu recognised intelligence as a critical factor in battle. “Foreknowledge”, he averred, “could neither be elicited from spirits, nor from the gods, nor by analogy with past events, nor from calculations;” it needed to be gathered by those with a “deep understanding of their adversary and the battlefield.”[40] The idea has resonated through the centuries, particularly in the maritime domain, where strategic decision-making depends on comprehensive situational awareness. In the ancient era, maritime awareness was rudimentary, relying on lookout posts, patrol ships, and signal fires. Civilisations like the Greeks and Romans employed coastal watchtowers and early warning systems to monitor and control activity at sea, safeguarding trade routes and territorial boundaries.[41] These tools underscored the enduring importance of foresight and intelligence in addressing maritime threats, but they were still, by contemporary standards, insufficient to deal with complex challenges.

In the modern era, Maritime Domain Awareness (MDA) has evolved into a sophisticated system featuring cutting-edge technologies and expansive cross-border collaboration.[42] Today, MDA extends far beyond its traditional naval roots, shifting from a sole focus on gaining an informational edge over adversaries to managing non-traditional threats, such as piracy, smuggling, illegal fishing, and environmental degradation[43]Scholars and practitioners increasingly recognise that the contemporary maritime environment is complex, necessitating the need for a shared understanding of operational challenges among diverse stakeholders. New-age MDA has thus evolved into a model of collective synergy, with navies, coastguards, and international organisations pooling resources, intelligence, and efforts to collaboratively tackle shared challenges.

40 Sun Tzu, The Art of War, translated by Samuel B. Griffith (Oxford University Press, 1963)

41 Lionel Casson, Ships and Seamanship in the Ancient World (Johns Hopkins University Press, 1995)

42 On the evolution of MDA see Peter Dombrowski and Andrew C. Winner, The Indian Ocean and US Grand Strategy: Ensuring Access and Promoting Security (Georgetown University Press, 2014)

43 For a critical analysis of MDA as a framework and its expansion beyond naval operations see Christian Bueger, "A Glue That Withstands Heat? The Promise and Perils of Maritime Domain Awareness”, in Maritime Security: Counter-Terrorism Lessons from Maritime Piracy and Narcotics Interdiction, Edward R. Lucas et al (eds) (Amsterdam: IOS Press, 2020), pp 235-245, https://doi.org/10.3233/NHSDP200065

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This paper explores the latest trends in MDA, focusing on its transformation into a data-driven, technology-centric discipline. It highlights advanced tools, such as earth observation (EO) satellites, artificial intelligence (AI), machine learning (ML), and unmanned systems, underscoring the growing significance of real-time surveillance and proactive responses to emerging threats. The modern concept of MDA, as argued in this paper, marks a shift from being a wholly military effort to a collaborative framework involving governments, private stakeholders, and international organisations. As the maritime domain grows increasingly contested and complex, MDA serves as a key enabler of security, resilience, and cooperation at sea.

Evolving Trends

Maritime Domain Awareness (MDA) has undergone a remarkable transformation, propelled by technological advancements and an increasingly complex maritime environment. Developed in the late 20th century to combat localised threats like piracy, smuggling, and illegal fishing, MDA has evolved into a sophisticated framework incorporating state-of-the-art technologies.[44] This evolution mirrors the growing complexity of the maritime domain, where the imperatives of security, economic stability, and environmental protection have become more critical than ever.

The shifts in MDA strategies merit deeper assessment. In its early stages, various generations of sensors provided detailed maritime information over extensive offshore areas. Notable among these were maritime radar, introduced in the 1950s, and the Automatic Identification System (AIS), which

44 Bueger, "A Glue That Withstands Heat? The Promise and Perils of MDA"

Consequently, recent advancements in MDA have emphasised cutting-edge innovations, with satellite-based systems now forming the mainstay of maritime surveillance. These systems provide high-resolution imagery of vast oceanic expanses and leverage tools, such as Optical Radar, Synthetic Aperture Radar (SAR), and Radio Frequency (RF) detection. These tools enable the tracking of "dark ships" operating without AIS, the detection of oil spills, the monitoring of illegal dredging, and the analysis of environmental phenomena in real time.

became operational in the 1990s.[45] While ground-based maritime radars and AIS data effectively identified conventional threats, they often failed to provide comprehensive and seamless coverage of vast oceanic spaces. While effective in detecting conventional threats, these systems were limited in scope and scalability.[46] As global maritime traffic increased and sophisticated threats, such as illegal fishing networks and grey-zone activities emerged, the limitations of these elementary systems became increasingly evident. With threats often concealed through activities like AIS manipulation, illegal cargo transfers in remote waters, and loitering near sensitive infrastructure, the demand for a more robust and advanced surveillance system intensified.

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45 Soldi, Giovanni, et al. “Space-Based Global Maritime Surveillance. Part I: Satellite Technologies.” ArXiv Preprint ArXiv:2011.11304, November 2020. https://arxiv.org/abs/2011.11304

46 Buegar, “A Glue That Withstands Heat? The Promise and Perils of MDA”

> The most profoundly consequential development for MDA in the modern era has been the emergence of EO satellites, singularly transforming how maritime law enforcement agencies monitor vast and remote oceanic regions.

automating anomaly detection, predicting vessel movements, and processing large datasets to identify hidden patterns and emerging threats with unprecedented efficiency.[47]

This transformation has been further catalysed by the emergence of web-based platforms that consolidate data from AIS, satellite imagery, and social media intelligence, delivering actionable insights for efficient responses to maritime threats. Real-time integration of diverse data sources has enhanced situational awareness and fostered collaborative decision-making. Consequently, MDA's scope now extends beyond traditional naval operations to address a wider spectrum of maritime threats, including illegal fishing, environmental degradation, and geopolitical conflicts.[48]

Earth Observation

The most profoundly consequential development for MDA in the modern era has been the emergence of EO satellites, singularly transforming how maritime law enforcement agencies monitor vast and remote oceanic regions.[49] EO satellites provide high-resolution, consistent coverage, enabling near-real-time tracking of vessel movements, environmental changes, and sensitive maritime zones. Their versatility stems from integrating multiple sensing technologies—optical imaging, SAR, and multispectral sensors—delivering a detailed and comprehensive picture of the maritime domain.

47 Baek, WK et al, "Monitoring Maritime Ship Characteristics Using Satellite Remote Sensing Data from Different Sensors", Ocean Science Journal, Vol 59, no 8 (2024),), https://link.springer.com/article/10.1007/s12601-023-00131-0?utm

48 Brewster, David, and Anthony Bergin. "AI Revolutionises Maritime Intelligence." National Security College, July 24, 2024. https://nsc.anu.edu.au/content-centre/article/opinion/ai-revolutionises-maritime-intelligence.

49 For a detailed discussion on the use of EO satellites, see Kurekin et al, "Operational Monitoring of Illegal Fishing in Ghana through Exploitation of Satellite Earth Observation and AIS Data." Remote Sensing, Vol 11, no. 3 (2019), https://doi.org/10.3390/rs11030293

a) *Optical Satellites*

Optical EO satellites capture high-resolution images of the Earth's surface, enabling activities such as tracking vessel movements, detecting oil spills, and monitoring illegal practices like unregulated fishing.[50] Advanced constellations, including Planet Labs' Dove and Maxar's World View series, offer imagery with revisit times of hours or days, making them invaluable for near-real-time surveillance.[51] Similarly, the European Space Agency's Sentinel satellites provide free, high-quality multispectral data with frequent revisit cycles, making them particularly effective for environmental monitoring and activity tracking in sensitive regions.[52]Other key contributors to MDA include Airbus's SPOT and Pleiades constellations,[53]South Korea's Kompsat series,[54]China's Jilin constellation,[55] and India's Resources at satellites.[56] Together, these systems deliver high-resolution optical imagery with diverse revisit rates, supporting global efforts to track vessels, document environmental changes, and detect maritime pollution.

b) *Synthetic Aperture Radar*

Despite its advantages, optical imaging has notable limitations in adverse weather or low-light conditions. These challenges, common in high-traffic or contested maritime zones, reduce the reliability of optical satellites for uninterrupted surveillance. SAR technology addresses these shortcomings by penetrating cloud cover, fog, and even light vegetation while operating effectively in low-

50 Domenico Baretta, "Enhancing Maritime Domain Awareness through Ship Detection in Satellite Imagery", Space4Water, January 4, 2024, https://www.space4water.org/news/enhancing-maritime-domain-awareness-through-ship-detection-satellite-imagery

51 Michael Jeffe, "WorldView Legion Brings More 30 cm-class Satellite Imagery to the Market", Maxar Blog, November 18, 2024, https://blog.maxar.com/leading-the-industry/2024/worldview-legion-brings-more-30-cm-class-satellite-imagery-to-the-market

52 ESA's Sentinel caters to the operational needs of Copernicus, the Earth observation component of the European Union's Space programme, "The Sentinel Missions", ESA website, https://www.esa.int/Applications/Observing_the_Earth/Copernicus /The_Sentinel_missions

53 For EU satellite constellations Pléiades and SPOT see European Space Agency's Earth Online portal https://earth.esa.int/eogateway/missions/pleiades

54 Kompsat-2 Instruments, Earth Online, https://earth.esa.int/eogateway/missions/kompsat-2

55 "Jilin Constellation", EO Portal, https://www.eoportal.org/satellite-missions/jilin-con

56 "ResourseSAT-2," ISRO, https://www.isro.gov.in/RESOURCESAT_2.html

light or night time conditions.[57]In recent years, SAR has been the mainstay of surveillance assets in maritime zones prone to adverse weather, such as the Indian Ocean during monsoon seasons, and contested areas like the South China Sea. These capabilities ensure persistent, all-weather surveillance, enabling maritime agencies to monitor activity in strategic sea spaces, regardless of environmental conditions.

The SAR market has historically been dominated by legacy players like Maxar's MDA and Airbus, whose satellites deliver high-resolution imaging for diverse applications.[58] However, several countries have developed their own SAR programmes tailored to national security and surveillance needs.[59] India's RISAT series and Japan's ALOS-2, for instance, are critical for disaster management and maritime monitoring.[60]

Recently, emerging players like ICEYE, Capella Space, and Synspective have disrupted the SAR landscape with cost-effective, low-Earth-orbit constellations.[61] These newcomers offer high-resolution imagery, rapid revisit rates, and sub-meter accuracy, making SAR data more accessible and versatile. ICEYE's rapid revisit capabilities enable near-continuous monitoring of critical maritime zones, while Capella Space delivers ultra-high-resolution imagery ideal for precision surveillance.[62]

c) *Optical-SAR Fusion*

The true strength of EO satellites lies in the fusion of optical and SAR capabilities, creating a multi-sensor approach to maritime surveillance. This integration offers unparalleled clarity and depth for monitoring activities at sea. SAR can detect vessels that disable their AIS transponders to evade detection,

57 The SAR Satellite Revolution: New Possibilities with 24/7 Earth", ESRI, June 18, 2023, https://www.esri.com/about/newsroom/blog/sar-satellite-revolution/

58 Poling, Gregory B. "From Orbit to Ocean: Fixing Southeast Asia's Remote-Sensing Blind Spots." Naval War College Review, Vol 76, no. 2 (2023): 1-21. Newport, RI: Naval War College, https://digital-commons.usnwc.edu/cgi/viewcontent.cgi? article=8165&context=nwc-review

59 Yoon-Kyun-Lee et al, "Assessment of Maritime Vessel Detection and Tracking Using Integrated SAR Imagery and AIS/V-Pass Data", Ocean Science Journal, Volume 59, no 27, (2024)

60 RISAT-2, EO Portal, https://www.eoportal.org/satellite-missions/risat-2

61 ICEYE, Earth Online, https://earth.esa.int/eogateway/missions/iceye

62 ICEYE, Earth Online

> The true strength of EO satellites lies in the fusion of optical and SAR capabilities, creating a multi-sensor approach to maritime surveillance. This integration offers unparalleled clarity and depth for monitoring activities at sea.

while optical imagery provides visual confirmation of their cargo or activities. This synergy is particularly effective for identifying illegal fishing operations, tracking oil spills, and monitoring unauthorised infrastructure developments in contested waters.[63]

Beyond vessel monitoring, EO satellites have broader applications in environmental management and disaster response. They are crucial for detecting and mapping oil spills, assessing climate change impacts on coastal ecosystems, and supporting emergency responses to maritime disasters. Advanced multispectral and hyper spectral imaging further enhance these capabilities, enabling detailed analysis of water quality, detection of harmful algal blooms, and identification of pollution hotspots.[64]

Together, these technologies make EO satellites indispensable for both maritime security and the sustainable management of oceanic resources. Together, these technologies have redefined how maritime agencies address challenges in the maritime domain, making EO satellites indispensable for both maritime security and the sustainable management of oceanic resources.

VIIRS

Another valuable tool is the Visible Infrared Imaging Radiometer Suite (VIIRS), a satellite-based imaging system that detects low-light and infrared signals. VIIRS excels in identifying small-scale maritime activities, such as detecting "dark vessels"—ships operating without AIS transponders—by tracking their

63 Zhang, Zenghui et al, "Optical and Synthetic Aperture Radar Image Fusion for Ship Detection and Recognition: Current state, challenges, and future prospects", IEEE Geoscience and Remote Sensing Magazine, June 2024, https://ieeexplore.ieee.org/document/10555387

64 "Exploring the exciting potential of hyperspectral imaging for water quality monitoring", Space4Water, January 03, 2023 https://www.space4water.org/news/exploring-exciting-potential-hyperspectral-imaging-water-quality-monitoring

navigation lights even in remote areas.[65] The system is particularly effective in monitoring illegal fishing operations at night, where traditional optical or radar systems may fall short. Additionally, it provides data on sea surface temperatures and chlorophyll concentrations, enabling the detection of environmental changes that could influence fishing patterns or marine ecosystems. Its integration into broader MDA frameworks enhances situational awareness by offering a complementary data stream supporting security and environmental monitoring.[66]

RF Detection

Complementing EO technologies, RF detection systems have emerged as transformative tools for identifying and tracking "dark ships"—vessels operating without visible tracking systems like AIS. RF technologies, such as those developed by Hawk Eye 360, analyse emissions from communication and navigation equipment to locate and monitor these elusive vessels.[67] This capability is crucial for addressing activities like smuggling, illegal fishing, and unauthorised trans-shipment, all of which depend on evading traditional detection methods. By mapping RF signals, Hawk Eye 360 provides a layered and comprehensive view of maritime activity, bridging gaps left by AIS and other conventional tools.[68]

Pacific nations, including Australia, Japan, and many Southeast Asian states, have benefitted significantly from RF detection technologies. Australia, in particular, has been highly successful in integrating RF detection into its broader maritime surveillance framework to combat

> RF detection systems have emerged as transformative tools for identifying and tracking "dark ships"—vessels operating without visible tracking systems like AIS.

65 "Using bright lights to reveal the 'dark' fleet", Glonbal fishing Watch, June 8, 2018, https://globalfishingwatch.org/research /viirs/

66 Elvidge, Christopher D., et al. "Automatic Boat Identification System for VIIRS Low Light Imaging Data," Remote Sensing, Vol 7, no. 3 (2015)

67 "Locating Dark Ships in the Era of Space-based RF Geolocation", Hawkeye 360, https://www.he360.com/resource/locating-dark-ships-in-the-era-of-space-based-rf-geolocation/

68 "Locating Dark Ships", Hawkeye 360

illegal fishing in its Exclusive Economic Zone (EEZ) and monitor unauthorised maritime activities near sensitive military installations.[69] The technology complements Australia's extensive use of satellite imagery and patrols, creating a more comprehensive picture of marine activity. Japan, too, has effectively employed RF detection to identify vessels involved in illegal fishing and ship-to-ship transfers of sanctioned goods that often operate without AIS.[70] Southeast Asian states like the Philippines have similarly used RF tools to detect unregistered vessels and fishing boats in their territorial waters and EEZs.[71]

Drone Technology

Notwithstanding the tremendous advances in EO technology, drone-aided surveillance, among other new-age MDA tools, has garnered the most enthusiasm.[72] This is mainly due to the potential of drones for thermal imaging and AI-driven object detection, which has been driving search and rescue operations, enabling rapid identification of individuals or objects in distress.[73] Not only do payload-capable drones deliver emergency supplies, such as life jackets or communication devices, but they also help with environmental monitoring. Their multi-spectral sensors help detect water pollution, harmful algal blooms, and changes in water quality. The remarkable evolution of drone technology has been aided by innovations in fuel cells and solar-powered systems that have extended drone endurance, enabling longer missions over remote oceanic areas.[74] Modular payload designs add versatility, allowing drones to be

69 "Australian Defence looks to modernise maritime electronic warfare capabilities", Australian Defence Magazine, August 18, 2023, https://www.australiandefence.com.au/defence/sea/defence-looks-to-modernise-maritime-electronic-warfare-capabilities

70 "Japan developing artificial intelligence system to monitor suspicious activity at sea", The Straits Times, August 31, 2018, https://www.straitstimes.com/asia/east-asia/japan-developing-artificial-intelligence-system-to-monitor-suspicious-activity-at-sea?

71 Lily Schlieman, "Illegal, Unreported, and Unregulated Fishing in Southeast Asia: Trends and Actors", Stimson Centre, November 6, 2023, https://www.stimson.org/2023/illegal-unreported-and-unregulated-fishing-in-southeast-asia-trends-and-actors/

72 "High-altitude Triton drones with 373 mph speed to secure Australian sea borders", Interesting Engineering, July 31, 2024, https://interestingengineering.com/military/australia-drone-border-sea-surveillance, https://interestingengineering.com/military/ australia-drone-border-sea-surveillance

73 Burke, Claire, et al, "Requirements and Limitations of Thermal Drones for Effective Search and Rescue in Marine and Coastal Areas." Drones, no. 4 (2019): 78. https://doi.org/10.3390/drones3040078.

74 Rajabi, Mohammad Sadra, et al, "Drone Delivery Systems and Energy Management: A Review and Future Trends" Handbook of Smart Energy Systems, pp. 1–19, April 21, 2023, https://doi.org/10.1007/978-3-030-72322-4_196-1.

> Not surprisingly, new-age drones are revolutionising strategic surveillance. Swarm technologies today make multiple drones operate collaboratively, covering vast maritime zones.

equipped with SAR sensors, pollution detectors, or other tools tailored to specific missions.

Not surprisingly, new-age drones are revolutionising strategic surveillance. Swarm technologies today make multiple drones operate collaboratively, covering vast maritime zones.[75] Integration with AI and ML allows autonomous platforms to efficiently analyse data, identify threats, and make decisions without constant human oversight. Unsurprisingly, drones are increasingly being used to combat illegal fishing, smuggling, and other maritime crimes. They are frequently deployed to monitor strategic infrastructure, such as ports and oil rigs, and assess the environmental impact on marine ecosystems. Despite these advancements, drones face challenges. Harsh maritime weather, such as high winds and heavy rain, can hinder operations. Although endurance and range have improved, drones still fall short of manned systems for extended missions. Additionally, sophisticated communication systems make drones vulnerable to hacking and signal jamming, posing significant cyber security risks.[76]

Web-based Platforms

A key feature of modern MDA is the adoption of web-based platforms, which facilitate seamless collaboration and real-time data sharing among stakeholders. Tools like IORIS, Mercury, and Sea Vision exemplify this technological shift, enabling more integrated and responsive maritime governance. IORIS, developed under the EU's CRIMARIO initiative, serves as a regional maritime security platform, enabling Indian Ocean nations to address threats, such as illegal fishing, trafficking, and environmental challenges through

75 "Drone Swarm Technologies", US Government Accountability Office, Sept 14, 2023, https://www.gao.gov/products/gao-23-106930

76 Wang, Jingbo, et al. "Applications, Evolutions, and Challenges of Drones in Maritime Transport." Journal of Marine Science and Engineering, Vol 11, no. 11 (2023), https://doi.org/10.3390/jmse11112056

IORIS, developed under the EU's CRIMARIO initiative, serves as a regional maritime security platform, enabling Indian Ocean nations to address threats, such as illegal fishing, trafficking, and environmental challenges through information sharing and capacity building.

information sharing and capacity building.[77] Meanwhile, Mercury, the EU NAVFOR's web platform, supports real-time communication and coordination for missions like Operation Atlanta, which focuses on counter-piracy and maritime security in the Gulf of Aden and the Indian Ocean.[78] Its synchronous text-based chat feature ensures constant communication among partner navies, facilitating the timely exchange of critical updates.

Adding to these capabilities is SeaVision, a US-led initiative that offers a user-friendly interface for monitoring vessel movements and maritime activities. Widely adopted by law enforcement agencies to enhance situational awareness, it enables stakeholders to address emerging maritime threats collaboratively.[79] Similarly, India's Information Fusion Centre for the Indian Ocean Region (IFC-IOR) leverages partnerships with several multinational maritime security centres to exchange vital information, creating a unified operational picture.[80] This integrated approach enhances decision-making in areas such as anti-piracy operations and environmental monitoring. The ability of these web-based platforms to harmonise diverse datasets—including ship tracking, weather patterns, and intelligence reports—

77 "IORIS: The Maritime Operational Coordination & Communications Platform for the Indo-Pacific", CREMARIO II, https://www.crimario.eu/ioris-the-maritime-operational-coordination-communications-platform-for-the-indo-pacific/

78 Timo Behr et al, "The Maritime Dimension of CSDP: Geostrategic Maritime Challenges and Their Implications for the European Union." Study. European Parliament, Directorate-General for External Policies, Policy Department, January 29, 2013. https://www.europarl.europa.eu/thinktank/en/document/EXPO-SEDE_ET(2013)433839.

79 "Sea Vision, A Web-based MDA tool", US Department of Transportation, https://info.seavision.volpe.dot.gov/

80 "Maritime Security: Memorandum of Understanding (Mou) Between the Information Fusion Centre - Indian Ocean Region (IFC-IOR) and Regional Coordination Operations Centre (RCOC)," Government of India, Ministry of Defence, Press Release, February 22, 2023, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1901371

> India's Information Fusion Centre for the Indian Ocean Region (IFC-IOR) leverages partnerships with several multinational maritime security centres to exchange vital information, creating a unified operational picture.

positions them as indispensable tools for modern maritime governance.

Commercial Satellite Providers

The growing interest in MDA tools has spurred the involvement of private players. In recent years, commercial satellite providers (CSPs) like Planet Labs, Maxar, and Spire have revolutionised access to advanced EO data, offering satellite-based information at significantly lower costs than traditional government-operated systems.[81] These CSPs have also introduced innovation and scalability to MDA efforts. For example, Planet Labs has a constellation of small satellites that deliver daily updates and enable the frequent monitoring of maritime activities. In March 2024, the company secured a US Navy contract for vessel detection and monitoring across key areas of the Pacific, highlighting its growing role in maritime operations.[82]

Similarly, Spire Global, a space-to-cloud data and analytics company, has made significant contributions to MDA. Operating a fleet of over 110 miniaturised satellites (CubeSats), Spire provides real-time insights by integrating data streams, such as AIS signals and RF detection. These capabilities have empowered law enforcement agencies to combat illegal fishing and trafficking in high-traffic maritime zones.[83]

Beyond security, CSPs support sustainability initiatives by monitoring marine pollution, assessing climate change impacts, and detecting illegal resource extraction. By combining EO imagery, radar, RF signals, and AIS data, CSPs reinforce a multi-sensor approach to maritime surveillance, providing governments and stakeholders with

81 Gopalakrishnan Suryanarayana, "The Role of Commercial Satellites in Maritime Surveillance," Journal of Space Policy 45 (2022)

82 "Planet Awarded Contract for Vessel Detection and Monitoring by Naval Information Warfare Center (NIWC) Pacific", Yahoo.com, https://finance.yahoo.com/news/planet-awarded-contract-vessel-detection-160000315.html

83 "Spire Global Nanosatellite Constellation", October 2024, https://www.eoportal.org/satellite-missions/spire-global#eop-quick-facts-section

actionable intelligence. Emerging players like ICEYE[84] and Capella Space[85] further enhance MDA capabilities with cost-effective, small SAR constellations that deliver high-resolution imagery even in adverse weather or night time conditions, making them indispensable tools for maritime operations.

Quantum Technology

Another emerging but still unproven technology for MDA is quantum computing. Unlike traditional systems, which often struggle with the immense volume of data generated by satellites, AIS, and radar systems, quantum computers could transform maritime surveillance by processing vast datasets with unprecedented speed and efficiency. Leveraging qubits—capable of existing in multiple states simultaneously—quantum computing promises exponential increases in computational power.[86]

This could enable real-time anomaly detection, allowing systems to swiftly identify irregularities in maritime traffic, such as unauthorised vessel movements or suspicious activity near sensitive areas. Quantum algorithms could also enhance predictive analytics by combining historical and real-time data to forecast potential maritime incidents, enabling stakeholders to respond proactively and allocate resources more effectively. Despite its potential, quantum computing remains in the experimental stage and has not yet been integrated into MDA operations. Current research focuses on how it could complement existing systems, with practical applications likely emerging as the technology matures.

> Unlike traditional systems, which often struggle with the immense volume of data generated by satellites, AIS, and radar systems, quantum computers could transform maritime surveillance by processing vast datasets with unprecedented speed and efficiency.

84 "New ICEYE Ocean Vision strengthens maritime security applications," ICEYE, March 7, 2024, https://www.iceye.com/press/press-releases/new-iceye-ocean-vision-strengthens-maritime-security-applications

85 Capella Space, "How SAR Technology Enhances Maritime Security," accessed November 29, 2024, https://www.capellaspace.com.

86 Salvador E. Venegas-Andraca, Marco Lanzagorta and Jeffrey Uhlmann, "Maritime Applications of Quantum Computing", Conference Paper, 2015, https://ieeexplore.ieee.org/document/7404356

Role of AI and Advanced Technologies

Another major development in MDA is the integration of AI and ML to enhance the efficiency and accuracy of maritime surveillance. Geospatial analytics firms, such as Ocean Mind, Skylight, and Orbital Insight, are leveraging these technologies to automate vessel detection and flag suspicious activities.[87] By combining remote sensing data with inputs from AIS and Vessel Monitoring Systems (VMS), these platforms enable faster and more precise responses, empowering law enforcement agencies and fisheries managers to act quickly.

Ocean Mind, originally a collaboration between Satellite Applications Catapult and Pew Charitable Trusts, uses SAR and electro-optical imagery to detect illegal fishing and maritime crimes.[88] Its real-time alerts help stakeholders prioritise and allocate resources effectively. Similarly, Skylight, a division of Vulcan Inc., integrates multiple data streams with AI-driven tools to identify unusual vessel behaviour.[89] While Orbital Insight is not exclusively focused on MDA, its object-detection technology is widely recognised as cutting-edge. In July 2024, it secured a contract from the US National Geospatial-Intelligence Agency to track illicit maritime activity in the Indo-Pacific region.[90]

Crowd Sourcing and Public Engagement in MDA

In parallel to AI, innovative platforms like Global Fishing Watch are exploring crowd sourced solutions to maritime challenges. Initially launched as collaboration between Google, Oceana, and Sky Truth, Global Fishing Watch has revolutionised the fight against illegal fishing by publishing fishing vessel AIS data in real-time.[91] The platform invites public participation, amplifying its surveillance reach and transforming ordinary citizens into active

87 "Protecting marine life with AI," Skylight, https://www.skylight.global/news/protecting-marine-life-with-ai

88 "Project Eyes on the Seas", Pew Institute, March 16, 2016, https://www.pewtrusts.org/en/research-and-analysis/issue-briefs/2015/03/project-eyes-on-the-seas

89 Protecting marine life with AI," Skylight.

90 Orbital Insight wins NGA contract for maritime surveillance in Indo-Pacific region, Space News, July 23, 2024, https://spacenews.com/orbital-insight-wins-nga-contract-for-maritime-surveillance-in-indo-pacific-region/

91 "Oceana, SkyTruth and Google Launch Global Fishing Watch, First Free, Online Tool to Reveal Commercial Fishing Activity Worldwide," Oceana, September 15, 2016, https://usa.oceana.org/press-releases/oceana-skytruth-and-google-launch-global-fishing-watch-first-free-online-tool-reveal/

> Despite their transformative potential, MDA technologies face significant barriers to adoption, particularly in developing regions like South Asia, the Middle East, and Africa. A major obstacle is financial constraints and lack of technical skills.

contributors in monitoring suspicious activity. It also integrates VMS data from partner nations and overlays it with VIIRS satellite imagery, offering a comprehensive view of maritime activities.

Challenges in Implementing MDA Technologies

Despite their transformative potential, MDA technologies face significant barriers to adoption, particularly in developing regions like South Asia, the Middle East, and Africa. A major obstacle is financial constraints. Advanced tools such as space-based systems and sophisticated platforms come with high costs, which many governments with limited budgets find prohibitive. Building the infrastructure and maintaining private systems requires substantial investment and technical expertise, often lacking in these regions, slowing the deployment of MDA technologies.[92]

Concerns over sovereignty and data security further hinder adoption. Many governments are reluctant to use commercial satellite services, fearing that third-party access to sensitive data could compromise national autonomy.[93] For instance, the Quad's Indo-Pacific MDA initiative has been more successful in the Pacific region than the Indian Ocean. IOR littoral states have hesitated to adopt technologies like Hawk Eye 360 due to concerns about foreign access to strategic information. This mistrust extends to broader collaborative efforts, as nations prioritise sovereignty over collective maritime security.[94]

92 Christian Buegar, "The Promises and Perils of Maritime Domain Awareness," Center for International Maritime Security, April 2020, https://www.safeseas.net/wp-content/uploads/2022/11/Bueger-2020-The-promises-and-perils-of-MDA.pdf

93 Deon Canyon et al, "A Network of Maritime Fusion Centers Throughout the Indo-Pacific, A Network of Maritime Fusion Centers Throughout the Indo-Pacific", et al, Daniel K Inouye Centre for Security in the Asia Pacific, February 2021, https://dkiapcss.edu/nexus_articles/a-network-of-maritime-fusion-centers-throughout-the-indo-pacific/

94 Popular MDA Initiatives and Implications for ASEAN, Daniel K Inouye Centre for Security in the Asia Pacific, February 2, 2024, https://dkiapcss.edu/nexus_articles/popular-mda-initiatives-and-implications-for-asean/

> The fragmented governance and diverse political dynamics among Indian Ocean littoral states have limited MDA's effectiveness that requies attention.

Bureaucratic inertia and limited technical expertise exacerbate these challenges. The fragmented governance and diverse political dynamics among Indian Ocean littoral states have limited MDA's effectiveness. Many regional capitals have slow-moving bureaucracies that resist partnerships with private providers, delaying the integration of advanced tools.[95] Even when systems are deployed, the lack of trained personnel and technical know-how leads to underutilised or mismanaged capabilities. Regional rivalries, especially in the Middle East, further complicate cooperation and information sharing. Similarly, weak frameworks in Africa and a preference for indigenous solutions in South Asia contribute to delays in adopting external technologies.

While the IOR is vital as a critical trade corridor and geopolitical hotspot, many regional states are wary about using foreign MDA tools on account of sovereignty concerns and mistrust over third-party data access. It does not help that many Indian Ocean states lack the technological infrastructure and expertise required to integrate advanced systems, leaving them reliant on traditional tools ill-suited for modern challenges. The high costs of space-based technologies further exacerbate the issue, with many IOR nations unable to afford the sophisticated systems that have proven effective in the Pacific.

Fostering Partnerships, Technology Sharing, and Affordable Solutions

Overcoming the challenges in implementing MDA technologies requires a multidimensional strategy that emphasises partnerships, technology sharing, and the development of cost-effective

95 Cordner, Lee. "Maritime Security Risk Treatment: India; Indian Ocean Region Middle, Small and Developing States; Major External Powers." In Maritime Security Risks, Vulnerabilities and Cooperation, 189–224. Springer, 2017. https://link.springer.com/chapter/10.1007/978-3-319-62755-7_7

Organisations, such as the Indian Ocean Rim Association (IORA), are well-positioned to lead MDA efforts by creating frameworks for joint funding and collective action.

solutions. Regional and international collaboration is a crucial starting point. Regional countries can pool resources and foster trust through coordinated investments in shared MDA tools. Organisations, such as the Indian Ocean Rim Association (IORA), are well-positioned to lead MDA efforts by creating frameworks for joint funding and collective action. Similarly, partnerships with developed nations and international organisations can bridge gaps in resources and expertise, as evidenced by the European Union's support for MDA initiatives in Africa, which has significantly bolstered maritime security in the region.

Public–private collaboration also plays a vital role in advancing MDA capabilities. In recent years, Indo-Pacific states have sought to grow their engagement with private entities to develop tailored solutions, ensuring the new technologies address specific security needs while maintaining oversight of strategic operations.[96] Public-private partnerships are especially valuable for capacity building, where private-sector expertise can accelerate the development of infrastructure and training programmes. The efficacy of these arrangements is dependent on transparent agreements that outline clear protocols for data sharing and usage, building confidence in collaborative ventures. It also helps mitigate sovereignty and data security concerns.

A more critical enabler of effective MDA is training. Navies and coastguards are investing in education and technical training programmes to maximise the potential of MDA technologies. These efforts range from hands-on training in the use of satellite imagery to workshops on

96 NPS Initiative Creates Public-Private Partnership for Enhanced Maritime Awareness, Naval Postgraduate School, December 31, 2009, https://nps.edu/-/nps-initiative-creates-public-private-partnership-for-enhanced-maritime-awareness.

> A more critical enabler of effective MDA is training. Navies and coastguards are investing in education and technical training programmes to maximise the potential of MDA technologies. These efforts range from hands-on training in the use of satellite imagery to workshops on integrating AI and data analytics.

integrating AI and data analytics. Beyond individual skill-building, capacity-building efforts also focus on fostering institutional capabilities. This includes establishing dedicated MDA units, creating protocols for data sharing, and developing response strategies to maritime threats.

Navigating the Coming Era of Advanced MDA

The transformation of MDA from a traditional coastal defence measure to a sophisticated global surveillance framework is undeniable. Emerging technologies, powered by AI, are revolutionising terrestrial systems such as AIS and coastal radars, while high-grade satellite imagery and RF detection create a multi-layered surveillance network. This system not only detects AIS spoofing and illegal loitering but also combats smuggling, curbs illegal fishing, and supports environmental monitoring and disaster response. For regions lacking access to advanced satellite infrastructure, terrestrial tools remain indispensable.

Yet, the future of MDA hangs in the balance. Despite breakthroughs in autonomous systems, AI-driven analytics, and integrated platforms, fundamental challenges endure. Financial limitations, technological disparities, and geopolitical fragmentation leave the Indo-Pacific littorals vulnerable to persistent threats like illegal fishing, smuggling, and environmental degradation.

> The transformation of MDA from a traditional coastal defence measure to a sophisticated global surveillance framework is undeniable.

To chart a sustainable path forward, Indo-Pacific nations must prioritise regional partnerships, strengthen public–private collaborations, and invest in scalable, cost-effective solutions. A unified strategy that integrates advanced technologies with strong international cooperation offers the best hope for closing capacity gaps and addressing shared maritime threats. The decisions made today will not only define the efficacy of MDA but also the security and prosperity of the Indo-Pacific. The stakes are monumental, and the cost of inaction far outweighs the price of progress.

UNDERWATER DOMAIN AWARENESS (UDA) FRAMEWORK – A NEW PERSPECTIVE FOR MARITIME DOMAIN AWARENESS (MDA) IN THE TROPICAL WATERS OF THE INDO-PACIFIC STRATEGIC SPACE

Cdr. (Dr.) Arnab Das

The Indo-Pacific Strategic Space has become the *de facto* arena for geopolitical and geostrategic power play in the 21st century. Global powers want to maintain their strategic presence in this region to ensure dominance. Defined by the tropical waters of the Indian Ocean and the Pacific Ocean, the Indo-Pacific strategic space presents unique challenges and opportunities. Recognising these tropical characteristics is essential to attempt any dominance in the region.

Maritime domain awareness (MDA) is defined by the International Maritime Organization (IMO) as the effective understanding of activities associated with the maritime domain that could impact security, safety, economy, or environment.[97] Notably, over 90% of maritime threats and resources lie below the surface of the water. Further, it is critical to understand that the underwater domain requires specialised expertise in acoustics for domain awareness. On surface and sub-surface MDA are distinct, requiring nuanced approaches. Conventional MDA gained momentum following the 9/11 incident in the US and, in the Indian Ocean Region (IOR), post the 26/11 attack. However, MDA initiatives have remained event-driven and security-centric, limiting participation from other stakeholders. The criticism has been that the MDA in the IOR and beyond has remained on the surface. The massive infrastructure built in the aftermath of the 26/11 attack is only able to monitor the surficial threats. The sub-surface threats that are real, in the backdrop of the political volatility and the non-state actors, having significant disruptive capabilities in the IOR need urgent attention.

The Underwater Domain Awareness (UDA) needs to be defined far beyond being treated as a mere underwater dimension of the conventional MDA. The UDA should manage the challenges and opportunities for all four stakeholders, namely strategic security (including internal and external security threats, given the political volatility), blue economy (given the rich biodiversity and mineral resources), sustainability & climate change risk (given the tropical characteristics), and the science & technology providers (given that

97 https://en.wikipedia.org/wiki/Maritime_domain_awareness#:~:text=Maritime%20domain%20awareness%20(MDA)%20is,safety%2C%20economy%2C%20or%20environment.

the underwater domain requires specialised acoustic capabilities and knowhow). A cohesive approach would allow resource pooling and synergised efforts among stakeholders, ensuring safe, secure, and sustainable growth in the tropical waters of the Indo-Pacific strategic space.[98]

The tropical waters suffer 60% degradation in sonar performance, compared to the temperate/polar waters, where these systems were designed and developed. The Cold War era, which saw the design and development of sonar systems for the war efforts of the two superpowers, managed to achieve significant success in terms of mitigating the uncertainties of the underwater medium.[99]However, these efforts were only in the Greenland-Iceland-United Kingdom (GIUK) gap, known for their temperate and polar characteristics. The West, led by the United States (US), continues to push this hardware to the developing world at a very high cost despite knowing their sub-optimal performance in tropical waters. The security bogey created in the region only encourages excessive spending on military hardware to politically satisfy the masses that the leadership is pro-active. Large spending on military hardware at the cost of other socio-economic and socio-cultural demands keeps these nations struggling with budget constraints forever. Good governance is the biggest causality in these circumstances, and thus we need to focus on bringing transparency and technology into the mechanism, with adequate space for traditional knowledge and practices to remain relevant.[100]

Digital transformation has proven to be a powerful tool for good governance. In the Indo-Pacific strategic space, this transformation, through initiatives like Marine Spatial Planning (MSP) under the UDA framework, can effectively manage the region's challenges and opportunities, ensuring safe, secure, and sustainable

98 Defining Underwater Domain Awareness (UDA) in the backdrop of the conventional Maritime Domain Awareness (MDA). Available at https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://en.wikipedia.org/wiki/Underwater_domain_awareness&ved=2ahUKEwiI-cfx7-OFAxWRa2wGHdBVBRQQFnoECDEQAQ&usg=AOvVaw3PpXKUDWgTCFl1s2g1ekiM.

99 Urick, R.J. (1983) Principles of Underwater Sound. 3rd Edition, McGraw-Hill, New York.

100 Arnab Das, "New Perspective for Oceanographic Studies in the Indian Ocean Region",Journal of Defence Studies, Vol. 8, No. 1, January–March 2014, pp. 109–117. Available at https://idsa.in/system/files/8_1_2014_NewPerspectiveforOceanographicStudiesintheIOR.pdf.

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growth. Extra-regional powers often promote fragmentation to ensure their geostrategic dominance in the Indo-Pacific region. However, an Indigenous effort is inescapable, given the over 10,000 years of civilizational legacy this region enjoys.[101] This paper presents a unique UDA framework to ensure nuanced policy and technology intervention alongside acoustic capacity &capability-building to drive the good governance mechanism for the tropical waters of the Indo-Pacific strategic space.

Tropical Challenges & Opportunities

The tropical waters of the Indo-Pacific strategic space present unique socio-political, socio-economical, and socio-cultural characteristics. These characteristics largely get ignored in the mechanism in managing political, economic, and cultural aspects, leading to significant long-term costs.[102]

The tropical waters present rich biodiversity, sustaining dense human population. The diversity in flora and fauna also allows significant cultural diversity among the human settlements. The high population density, along with cultural diversity, results in massive political activities, making governance a tough job. The Indo-Pacific strategic space, particularly the IOR, is characterised by heightened political activities and fragmented polity both domestically and regionally, ensuring extra-regional powers to meddle in governance. Meeting the needs of a growing population—providing food,

101 Arnab Das, "Strategic Security @100 – A New Perspective Based on the Underwater Domain Awareness (UDA) Framework for the Tropical Waters of the Indo-Pacific Strategic Space", UDA Digest Expert Article, Dated 29 Nov 2023. Available at https://digest.foundationforuda.in/2023/11/29/strategic-security-100-a-new-perspective-based-on-the-underwater-domain-awareness-uda-framework-for-the-tropical-waters-of-the-indo-pacific-strategic-space/.

102 Arnab Das, "The Indo-Pacific Strategic Space and the Global Order - A New Perspective on Underwater Domain Awareness", Indo-Pacific Defence Forum, 16 Aug 2023. Available at https://ipdefenseforum.com/2023/08/the-indo-pacific-strategic-space-and-the-global-order/.

meaningful career opportunities, and ensuring governance mechanisms—presents significant challenges. As land-based resources become insufficient, nations increasingly exploit water bodies, often at the cost of sustainability and exacerbating climate change impacts.

The tropical climate allows year-round accessibility. This allows human activities throughout the year, making it possible to have high agricultural productivity, industrial output, connectivity for trade & interactions, low energy consumption for human comfort, and more. Thus, population growth is high, putting significant pressure on resources. However, the lack of good governance makes it economically challenging to ensure growth. The water bodies have hardly been used for connectivity and even the blue economy has hardly been the main contributor to the GDP. The water bodies have become a curse, both in terms of natural disasters and the least contributor to their well-being. As a consequence, the water bodies suffer as a dump for waste, causing serious sustainability concerns.

The IOR boasts over 10,000 years of civilizational legacy, with a rich maritime heritage that enabled the subcontinent's maritime supremacy in the 13th century. However, traditional knowledge and practices are being completely ignored under Western pressure. Extra-regional powers are driving their technology and know-how in these tropical waters, knowing fully well that they are not relevant in the tropical waters. The outcome of such mindless collaboration is sustainability concerns, climate change risk, low productivity, inefficient & ineffective resource management, and more. This dominance of Western culture over the youth—in a demographic heavily represented region—is alarming. The integration of unique traditional knowledge and practices grounded to the local site-specific characteristics with modern technology and know-how is necessary[103].

To explain the above argument, let us connect a few applications:

Sediment Management

The tropical region has a unique sediment transport pattern,

103 Arnab Das, "Bharat @100 – A New Perspective Based on the Underwater Domain Awareness (UDA) Framework", UDA Digest Expert Article, Dated 06 Jan 2024. Available at https://digest.foundationforuda.in/2024/01/06/bharat-100-a-new-perspective-based-on-the-underwater-domain-awareness-uda-framework/.

and unless the site-specific characteristics are factored in, the sediment management can never be successful. Western partners are pushing for dredging as a *de facto* solution for sediment management, at a huge sustainability and climate change risk, only to ensure a massive return on investment (RoI) for them by selling heavy engineering dredging equipment. Western nations, with their demographics, do not have the manpower to invest in local site-specific R&D to customise their know-how to the tropical waters. Poor sediment management affects navigability of inland water transport, coastal erosion, erosion in the river banks, port management, floods, water resource management, and more. Reservoirs, which are used as buffers for urban flooding and water storage, are over 50% silted, reducing their effectiveness and threatening dam safety due to raised water levels.[104]

Acoustic Survey

The acoustics are the only means for the underwater survey, thus the 60% degradation in sonar performance in tropical waters is a serious concern for domain awareness to build a good governance mechanism. Across varied applications, ranging from surveillance for strategic security to resource mapping both living & non-living, navigability for coastal & inland connectivity, environmental & climate change risk assessment, and more, the acoustic survey will remain the critical tool. The continued import of sonar systems from the West at the cost of multiple socio-economic requirements has been a matter of serious concern. The fragmented approach across the stakeholders has also ensured a lack of resources for site-specific indigenous R&D effort to solve the tropical distortions.

Addressing tropical challenges is crucial for fostering good governance in the Indo-Pacific region. Digital transformation is the *de facto* governance tool; however, it is hindered by the tropical limitations causing serious sub-optimal sonar performance. Local site-specific R&D is the only way forward, and we

104 https://udafoundation.in/sediment-management

also need to factor in the indigenous knowledge while mapping the modern tools to solve real-world problems in the tropical waters.

Marine Spatial Planning (MSP)

"Marine Spatial Planning (MSP) is a process that brings together multiple users of the ocean – including energy, industry, government, conservation, and recreation – to make informed and coordinated decisions about how to use marine resources sustainably. MSP generally uses maps to create a more comprehensive picture of a marine area – identifying where and how an ocean area is being used and what natural resources and habitats exist. It is similar to the Geographical Identification System (GIS) based land-use planning, but for marine waters"[105].

The essential implementation of the MSP is nothing but the generation of a spatio-temporal map across varied applications to allow nuanced intervention for enhanced management of the challenges and opportunities. The interventions could be long-term strategic policy-related or tactical operational effectiveness-related. MSP has to provide actionable inputs to effectively plan the interventions. The generation of the spatio-temporal maps is the manifestation of the digital transformation in the underwater domain, both on the surface and sub-surface.[106]The digital transformation will require a three-step effort, namely *to see, to understand, and to share*, as discussed below:

To See focuses on deploying sensors and platforms to collect data. The sensors are largely acoustic, however

MSP has to provide actionable inputs to effectively plan the interventions. The generation of the spatio-temporal maps is the manifestation of the digital transformation in the underwater domain, both on the surface and sub-surface. The digital transformation will require a three-step effort, namely to see, to understand, and to share.

105 https://en.wikipedia.org/wiki/Marine_spatial_planning

106 Arnab Das, "Marine Spatial Planning – A New Perspective Based On The Underwater Domain Awareness (UDA) Framework". Available at https://mrc.foundationforuda.in/marine-spatial-planning-a-new-perspective-based-on-the-underwater-domain-awareness-uda-framework/.

not limited to them. Platforms will include variants like surface or sub-surface, static or dynamic, manned or unmanned, manual or automated, automated or semi-automated, and many more. Each of these sensors and platforms will have to be of the right specification and standard to meet the application requirement.

To Understand involves processing the collected data by the to *see* mechanism. This data analytics will have three broad steps, namely pre-processing, processing, and post-processing. Pre-processing will include noise filtering to enhance the 'Signal-to-Noise Ratio' (SNR), mitigation of the underwater channels distortion, and any sensor or recording-related errors. The underwater channel in the tropical waters will require specialised appreciation of the local site-specific characteristics to ensure effective mitigation. The application-specific processing will be critical for making sense of the recorded data. Post-processing will mean the removal of known errors in the entire pre-processing and processing stage during the presentation on the display. Expertise in the 'Digital Signal Processing' (DSP) will be critical for the entire processing; however, to make them accurate, processing large data sets and computationally efficient Artificial Intelligence (AI) based data analytics skills will be important in ensuring real-time output.

To Share means presenting the actionable inputs in an appropriate display. These displays could be large screens for policymakers and high-level decision-makers among the stakeholders. However, the practitioners will require laptops or computer screens and, most interestingly, the field specialists and the community members like fishermen and aquaculture cultivators will have to be presented with the inputs on small mobile screens. The second aspect is the user-friendly display format, as each user will require specific inputs, unique to their application requirement. Thus, customisation will be critical across all the users to make it meaningful.

The conventional MSP effort, led by the Western powers, has been largely hardware intensive with minimal customisation across the site-specific geographic and user uniqueness. The hardware-intensive effort has made it extremely costly, making it unappealing to the Global South. Moreover, the lack of customisation makes it irrelevant, as the local site-specific characteristics are overlooked during data processing. Modelling& Simulation (M&S) has been the tried and tested means to build an appreciation of the local conditions

> The conventional MSP effort, led by the Western powers, has been largely hardware intensive with minimal customisation across the site-specific geographic and user uniqueness.

using simulation models to capture the nuances of the local parameters. The models will have to be field-validated using real experimental data sampling in select locations. Once the model is field validated, the simulation will be able to provide data for almost all kinds of diverse underwater conditions. AI-based data analytics will be a key component of this M&S effort. In the present computational advancement, such efforts are possible at a very affordable cost, compared to the field deployment across the entire geographical location. The Global South will be able to participate in this MSP initiative only through this M&S approach. This will be the real inclusive way forward.[107]

To explain the M&S-based approach, a unique example of underwater noise monitoring due to shipping is presented in Figure1. The outcome can be used across three distinct users, namely Acoustic Stealth for the strategic security community, Acoustic Habitat Degradation for the conservation of marine mammals,

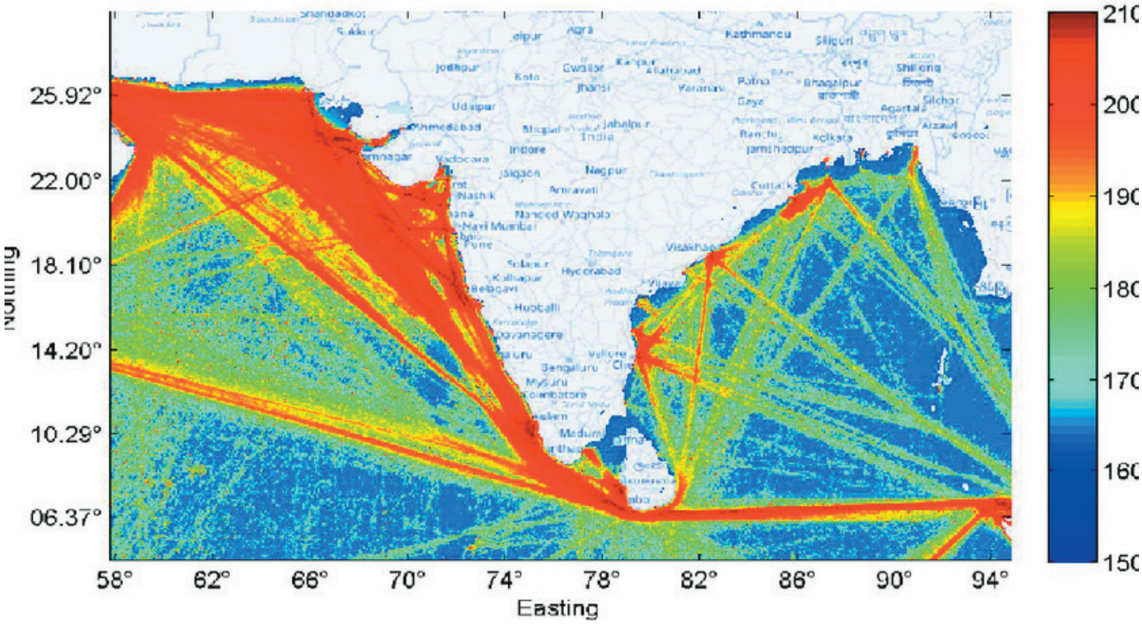


Figure1 MSP for Underwater Radiated Noise (URN) from Shipping

107 https://maritimeresearchcenter.com/marine-spatial-planning/

and the shipbuilders and shipyards for building better& efficient platforms.[108]

In Figure1, the Automatic Identification System (AIS), data along with the classification society inputs on the ship machinery, is used to generate the URN at source. The underwater parameters are extracted from the ETOPO database to generate the propagation loss, and the two are combined to get a spatio-temporal map, as seen in Figure 1. It is the best example of M&S building a real-time map as shown.

Underwater Domain Awareness (UDA) Framework

The UDA framework is the nuanced driver for the MSP implementation, particularly in the tropical waters of the Indo-Pacific strategic space.[109]The schematic description of the UDA framework is presented below in Figure2.

The challenges of the tropical waters are enumerated below:

- Lack of resources for the digital transformation.
- Fragmented approach by the stakeholders and the partners within the region.
- Lack of technical know-how and expertise.
- Sub-optimal performance of the sonars in tropical waters.
- Political reluctance due to fear of upsetting the electorate.
- Huge capacity and capability deficit to drive such a mega initiative.
- Overdependence on the Western power for technology and know-how.

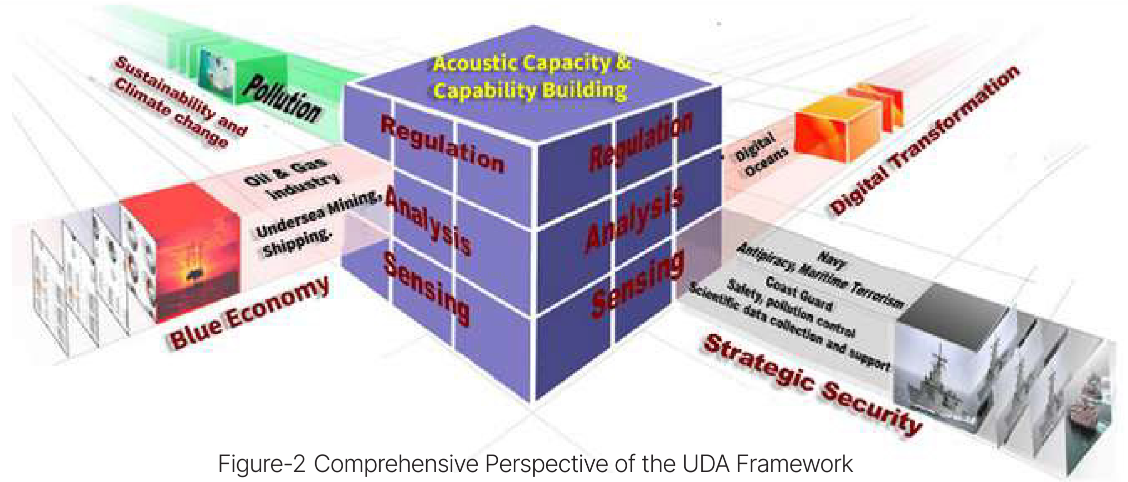


Figure-2 Comprehensive Perspective of the UDA Framework

108 I:\MEPC\82\MEPC 82-INF.31.docx

109 https://udafoundation.in/wp-content/uploads/2024/10/Underwater-Domain-Awareness.pdf

We will discuss each of these points one by one to illustrate the relevance of the UDA framework. The details of the UDA framework are provided in the UDA framework website referred to below.

- The pooling of resources and synergizing of efforts, propagated by the UDA framework, will ensure optimum resource deployment for any new initiative like digital transformation. The expertise and resources from each stakeholder will be pooled to ensure the availability of resources for the bigger cause.
- The structured approach will allow multiple stakeholders and nations within the region to collaborate on specific terms, rather than an open-ended jamboree. Every partner can effectively compute their RoI, to ensure their motivation levels are always maintained.
- The Indigenous effort combined with modern tools will allow real-world problem-solving with the least interference from the West. The clarity of thought will allow specific support from outside, rather than complete surrender.
- The local site-specific R&D will allow effective mitigation of the tropical distortions. The precise estimation of the underwater channel characteristics will make the mitigation far more effective.
- The inclusive approach and participation of the local communities with their Indigenous knowledge and capabilities will allow the political will to propagate these new initiatives effectively. The Indigenous communities getting direct benefits from the developmental process will make it inclusive.
- The focus on comprehensive acoustic capacity & capability building will allow each of the levels of the stakeholders and national entities capable of driving it on their own in their sphere of influence. The long-term approach will be effective in sustaining it.
- The indigenous effort will allow local participation and minimise political interference from the West. Effective utilisation of the resources will make it grounded to the local cause rather than chasing the west for their benefit.

The comprehensive, structured, and inclusive way forward presented by the UDA framework will allow significant collaboration across the stakeholders and also among nations within the region and beyond. The comprehensive aspect facilitates safe, secure, sustainable growth for all in the tropical waters. The entire horizontal construct in Figure2 ensures all the stakeholders are factored in. The structure will allow a nuanced way forward for the stakeholders, practitioners, young professionals, and policymakers to seamlessly interact with each other. The inclusive aspect will translate to the multiple hierarchies of the society, including the native communities, to find relevance in the development process. The cubes within the larger cube will translate to the specific project ideas that the young aspiration students and professionals can identify as their future career opportunities. These youth undertaking projects in these areas will make them far more employable in the new world order.

The seamless policy & technology interventions, along with the acoustic capacity and capability-building, will allow the entire ecosystem to generate the appreciation and capacity to drive this new initiative across multiple levels. The digital transformation will be driven by the UDA framework, bringing a cohesive and seamless road map. Multiple fractions of the policymaking will be able to coordinate to bring about the change along with the technology support to effectively implement the transformation. The acoustic capacity &capability-building will be extremely critical to managing the tropical challenges and opportunities.

The UDA framework needs to be rolled out across five pillars, namely research, knowledge, skilling, innovation, and policy. The research component will include the mapping of indigenous knowledge and traditional practices into the modern tools of science & technology for effective digital transformation. The knowledge has to be propagated through the academic curriculum in the academic institutions and with a substantial body of work generated to document the Indigenous initiatives. The skilling at multiple levels, including the native communities, will be a critical aspect to build capacity across varied strata. The innovation to ensure real-world problem-solving will be an important aspect of the start-up ecosystem. The policy framework will be the main driver to bring all five pillars under one structure.

Acoustic Capacity and Capability-building

The tropical waters are extremely unique, impacting acoustic propagation substantially. The signal at the source is modified in amplitude, spectrum, and phase before being recorded at the receiver location. The

> The UDA framework needs to be rolled out across five pillars, namely research, knowledge, skilling, innovation, and policy.

determining factor is the depth of the sound axis (an axis with minimum sound speed), which ensures that the acoustic signal gets focused around it during propagation in the underwater medium. Snell's law applies, and due to total internal reflection experienced by the acoustic signal, it continues to bend towards the sound axis on either side. The depth of the sound axis near the poles is 50 m, and at the equator, it is 2000 m; thus, acoustic signals near the poles propagate like a focused beam (around the sound axis) even at depths of 200 m, while near the equator (tropical waters), even depths of 2000 m behave like shallow waters. The multiple interactions of the acoustic signal with the surface and bottom boundary in tropical waters cause severe distortions due to the varied boundary conditions. Further, the surface and the bottom boundaries in the tropical waters have unique roughness to cause severe distortions. The typical hypsometric definition of deep versus shallow water based on the extent of the continental shelf (depth of water is largely 200 m) does not apply acoustically. In the Cold War Era, when acoustic research was at its peak, the R&D was largely limited to the GIUK gap, which is a temperate and polar region. The 200 m depth in the GIUK gap was enough for the acoustic signal to face minimal interaction with the surface and the bottom. Thus, the acoustic and hypsometric definitions of shallow water (less than 200 m depth) were the same in the GIUK gap, however in the tropical waters, even at depths of 2000 m, the acoustic propagation suffers significant distortions. Acoustically, the region that ensures multiple interactions of the acoustic signal with the surface and the bottom is called the shallow waters and is otherwise called the deep waters. The other factor is the temperature dependence of the sound speed (the most dominant among the three factors of temperature, salinity, and depth). Every 1-degree Centigrade of temperature changes the speed of sound by 4.6 m/s; thus, with temperature fluctuations in tropical waters, the speed of sound varies substantially, causing serious distortions in acoustic propagation.[110]

The acoustic characteristics and their impact on the source signal are

110 Paul C Etter, "Underwater Acoustic Modelling and Simulation", Fourth Edition, CRC Press, 2013, Taylor and Francis Group.

measured under two parameters. The first is the ambient noise at the receiver location, and the second is the underwater channel characteristics, determining the acoustic propagation from the source to the receiver. The 'Source-Path-Receiver' model is the determining factor in both these cases.[111]

Source The characteristics of the signal at the source, whether for generating noise or the actual desired signal, will determine its modification during propagation. The precise estimation with detailed transformation into a model will be extremely critical for further processing. It is well known that low-frequency noise (below 1 kHz) is largely the shipping noise. The spectral band from 2.5 to 15 kHz is dominated by wind noise, and the biological noise is spread across multiple bands specific to the marine species. All these noise sources get modified while propagating in the underwater medium.

Path The journey from the source to the receiver is critical for the source signal, and the modification it undergoes during this propagation needs to be modelled to estimate the underwater channel distortion. The tropical waters suffer substantial modification, so the underwater channel model is extremely important. Multiple models have been proposed by the researchers that are accurate and also computationally efficient. The Parabolic Equation (PE) model is a wave theory-based model, recognised as the most optimum model for low-frequency shallow water applications.

Receiver Knowledge of the receiver characteristics is equally important, as the models can be limited within the desired specifications. These receivers also act as filters for the out-of-band noise, and the underwater channel model can be precisely modelled to suit these specifications.

The entire acoustic capacity and capability-building for effective UDA can be best driven by the Marine Spatial Planning (MSP) implementation using Modelling and Simulation (M&S) and supported by field experimental validation. This will require three broad categories of expertise as shown below:

High-End Data Scientists The entire M&S will require digital signal processing (DSP) and data analysts (artificial intelligence and machine

111 DSP Varma & Arnab Das, "Acoustic Capacity Building in the Indian Ocean Region". Available at https://www.indiandefencereview.com/spotlights/acoustic-capacity-building-in-the-indian-ocean-region/2/#.

learning included) who will deal with the hardware and software to ensure effective and real-time processing. The entire design and development of the computational infrastructure and M&S framework will be undertaken by them.

Domain Specialists The inputs provided by the data analysts have to be interpreted by the multidisciplinary domain specialists to ensure effective policy interventions at the strategic level and even operational interventions at the tactical level. This is a critical stage to make sense of the data for real-world problem-solving in real time.

Field Deployment Specialists The field deployment of sensors and collection of real-world samples will require specialists to have a deeper appreciation of the site-specific local conditions and comfort level with the waterfronts. The Indigenous communities who have lived next to the waterfront are the best suited for this task. Their indigenous knowledge and traditional practices can be extremely useful for field-experimental validation.

The five pillars of research, knowledge, skilling, innovation, and policy will have to be aligned accordingly to build the acoustic capacity and capability-building.

Conclusion

The Government of India has announced the Security And Growth for All in the Region (SAGAR) vision to manage the challenges and opportunities in the IOR. It also envisages a leadership role for India in the region and dreams of rekindling the rich maritime heritage we had in the past. Geopolitically and geostrategically, it is an ambitious vision to ensure India's claim in the global power play. However, operationalising it on the ground will require far greater effort domestically and also at a regional level. The Indo-Pacific strategic space can be governed, managed and monitored only with a far deeper appreciation of the UDA in the tropical waters of the region. The Indo part of the Indo-Pacific strategic space could be a good start, and the UDA framework could be a good driver for realising the MSP in the IOR. It is well backed by the SAGAR vision. The Government of India has announced multiple mega initiatives to substantiate the SAGAR vision, like the Sagarmala, Gati-Shakti, Inland Water Transport, Jal Jeewan Mission, and more. However, it may be said that none of these can be achieved without a strong UDA realisation. The internal capacity & capability building

> The Indo-Pacific strategic space can be governed, managed and monitored only with a far deeper appreciation of the UDA in the tropical waters of the region.

can further be extended to the region and beyond.

The role out can be undertaken in three steps:

Outreach Multiple webinars, seminars, workshops, and more can be hosted to sensitise the policymakers, stakeholders, practitioners, academia, and more to appreciate the nuances of the UDA framework. This will be a critical step to build consensus and also generate the required momentum. Initial generic sensitisation and then specific interactions based on the identified areas of interest can be addressed.

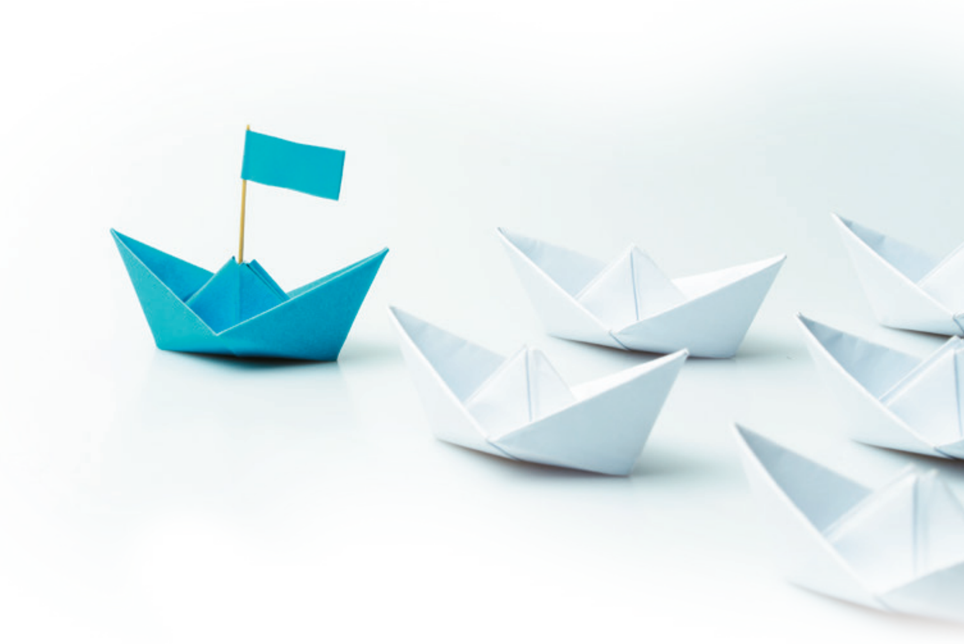
Engage The outreach has to be followed by engagement at multiple levels. The students at multiple levels and the young professionals will have to be offered internships and fellowships across varied disciplines to allow them a deeper understanding of the subject. The stakeholders can sponsor some of these internships and fellowships to build a seamless pipeline for their future absorption. The stakeholders and policymakers can also depute some of their young officers to join the fellowship program and articulate their intervention gaps.

Sustain The last but not least is the sustain stage, where specific long-term projects will be drafted for implementation. These projects could be related to policy drafts, technology implementation, or even on infrastructure building. The pool of human resources developed during the second stage can be deployed at multiple levels to implement these projects. The UDA framework will provide a structured way forward across multiple sectors and applications.

The UDA framework should become an agenda for all the multilateral forums, including the Indian Ocean Rim Association (IORA), the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC), ASEAN and more. Even for bilateral cooperation, the UDA framework can become an important agenda. The digital transformation driven by the UDA framework will become the most critical tool for good governance, particularly in the tropical waters of the Indo-Pacific strategic space.

ENHANCING MARITIME DOMAIN AWARENESS THROUGH EMERGING TECHNOLOGIES

Dr. Vijay Sakhuja



Over 70% of the earth's surface is covered by water, which corresponds to a surface area of 361 million square kilometres, and the average depth of the oceans has been assessed as 3,682 meters (12,080 feet).[112] Also, only 26% of the seabed had been mapped.[113] Therefore, it is fair to assume that there is a lack of knowledge among humans about the oceans and seas, particularly the underwater domain, which is still very limited.

Another less known fact about these large bodies of water is the economic value of the oceans and seas. The United Nations estimates it between $3 trillion to $6 trillion.[114] Furthermore, the ocean economy contributes over $1.5 trillion annually, supporting diverse cultures and economies.[115]

The Federation of Indian Chambers of Commerce and Industry (FICCI) Task Force on Blue Economy report, "Blue Economy Vision 2025: Harnessing Business Potential for India Inc. and International Partners", notes that these large bodies of water provide goods (fish, oil, and gas), services (marine transport, telecommunications, and marine tourism), and livelihoods to people living along the coast and in islands.[116]

The oceans are also a major sink for carbon and heat absorption and take in over 90% of excess heat and 25% of carbon dioxide (CO2) emissions from

> It is fair to assume that there is a lack of knowledge among humans about the oceans and seas, particularly the underwater domain, which is still very limited.

112 "Introduction to the Oceans", http://www.physicalgeography.net/fundamentals/8o.html (accessed 20 August 2024).

113 "Seabed 2030 announces latest progress on World Hydrography Day", Seabed 2030 announces latest progress on World Hydrography Day — Seabed 2030 (accessed 20 August 2024).

114 "Preparatory process of the 2025 United Nations Conference to Support the Implementation of Sustainable Development Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development" https://sdgs.un.org/sites/default/files/2024-06/N2413601%20eng.PDF, (accessed 10 September 2024)

115 "Ocean, Seas and Coasts", https://www.unep.org/topics/ocean-seas-and-coasts#:~:text=The%20ocean%20economy%20contributes%20over,enhance%20planet%20and%20societal%20resilience.&text=Decades%20of%20Mangrove%20forest%20change,Securing%20a%20Sustainable%20Future%20for%E2%80%A6 (accessed 12 September 2024).

116 "Blue Economy Vision 2025: Harnessing Business Potential for India Inc. and International Partners", https://ficci.in/api/study_details/20896(accessed 20 August 2024).

> The knowledge gap precludes greater understanding of the oceans and seas. This gap can be filled by marshalling Industry 4.0 or Fourth Industrial Revolution (4IR) technologies, which have also been referred to as the "frontier technologies", given the fact that they are "innovative, fast-growing, deeply interconnected and interdependent".

the atmosphere annually.[117] In terms of climate mitigation services, this is valued at $1 trillion/decade.[118]

The above are some of the many important and highly promising pointers of this unexplored 'reservoir of wealth'; however, the knowledge gap precludes greater understanding of the oceans and seas. This gap can be filled by marshalling Industry 4.0 or Fourth Industrial Revolution (4IR) technologies, which have also been referred to as the "frontier technologies", given the fact that they are "innovative, fast-growing, deeply interconnected and interdependent". For example, "Artificial Intelligence (AI), machine learning, robotics, additive manufacturing (3D printing), the Internet of Things (IoT), distributed ledger technology (DLT) or Block chain, and quantum computers".[119] Also, fusing these technologies with "biotechnology, nanotechnology and cognitive, social and humanitarian sciences",[120] humankind can understand the marine life and the nature of non-living resources available to these water bodies.

Over the last few years, there has been a widespread proliferation of these technologies, which have enhanced "machines' ability to perceive and accurately interpret the world around us".[121] These technologies can help determine the material and mineral wealth of the oceans and

117 "What are the world's biggest natural carbon sinks?", https://www.weforum.org/agenda/2023/07/carbon-sinks-fight-climate-crisis/ (accessed 11 September 2024).

118 Olga Rukovets, "How Much Carbon Can the Ocean Hold? Lamont Researchers Aim To Find Out",https://news.climate.columbia.edu/2024/06/07/how-much-carbon-can-the-ocean-hold-lamont-researchers-aim-to-find-out/ (accessed 27 August 2024).

119 "Bracing for the New Industrial Revolution Elements of a Strategic Response", https://www.unido.org/sites/default/files/files/2020-06/UNIDO_4IR_Strategy_Discussion_Paper.pdf(accessed 16 September 2024).

120 Ibid.

121 "Using Deep-Learning AI to Protect Marine Mammals", https://aijourn.com/using-deep-learning-ai-to-protect-marine-mammals/(accessed 16 September 2024).

AI lies at the core of the ongoing maritime-techno revolution. Autonomous vessels use AI and data-driven operations to help in improving operational performance of ships, as well as add to the safety of the crew.

seas and also provide real-time data of physical, chemical and biological (plant and organism life) conditions so that the maritime domain can be harnessed sustainably.

The International Maritime Organisation (IMO) under the United Nations defines maritime domain as "all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, and vessels and other conveyances".[122] Furthermore, it elucidates Maritime Domain Awareness (MDA) as the "effective understanding of anything associated with the maritime domain that could impact the security, safety, economy, or environment"[123] concerning these bodies of water.

There is a direct relationship between MDA and 4IR, and in this context, this paper highlights the role of emerging technologies to support security, safety, economy, or the environment at sea as envisaged under the definition of MDA by the IMO.

Ship Operations

AI lies at the core of the ongoing maritime-techno revolution. Autonomous vessels use AI and data-driven operations to help in improving operational performance of ships, as well as add to the safety of the crew.[124] Also, timely preventive-predictive maintenance reduces downtime for ships and platforms. Further, these vessels require less crew, which frees up their living spaces for cargo storage. Such vessels also lessen the crew's exposure to accidents at sea, such as fire, oil leakage, pollution, and

122 "Enhancing maritime domain awareness in West Indian Ocean and Gulf of Aden", https://www.imo.org/en/MediaCentre/Pages/WhatsNew-1203.aspx(accessed 29 August 2024).

123 IMO, "Amendments to the International Aeronautical and Maritime Search And Rescue (IAMSAR) Manual," MSC.1/Circ.1415, 25 May 2012, https://www.mardep.gov.hk/en/msnote/pdf/msin1242anx1.pdf, (accessed 29 August 2024).

124 "How Autonomous ships are revolutionizing the maritime industry?", https://maritime-professionals.com/how-autonomous-ships-are-revolutionizing-the-maritime-industry/ (accessed 31 August 2024).

> 4IR technologies are gaining traction among seaports and are being integrated at a rapid pace. The ports have begun to use 4IR technologies for enhancing operational efficiency, and many ports are aspiring to be Smart Ports.

search and crew rescue operations, which in the majority of cases are caused by human error. In harbours, AI-enabled robots can perform risky jobs like tank inspections and access poorly ventilated spaces as well as hull check-ups.

The IMO has designated autonomous ships as Maritime Autonomous Surface Ships (MASS) into four categories[125] depending on the autonomy levels in ships. Several MASS construction projects are currently under development. However, there is a strong belief among industry experts that smart vessels cannot be fully unmanned for operations. For instance, the Government of Japan regulations "do not allow fully autonomous vessels to operate without people on board" due to "potential cyber threats" since these have not been "thoroughly evaluated and addressed" due to a lack of adequate information for the "overall architecture of autonomous type of ships".[126] The **autonomous ships** market is very favourable, and in 2023, it was worth $5.61 billion and is expected to touch $12.25 billion by 2032 with a CAGR of 9.1%.[127]

According to the IMO, trials for autonomous and remote-controlled ships are ongoing in some sea areas.[128] It is estimated that these types of vessels will be put into operation for short voyages between nearby ports before they can be sailed across the oceans. Furthermore, the onboard and offshore operators will need to build required operational and technical knowledge to conduct their operations, keeping in mind the safety and security of these vessels.

125 "IMO takes first steps to address autonomous ships", http://www.imo.org/en/MediaCentre/PressBriefings/Pages/08-MSC-99-MASS-scoping.aspx (accessed 28 August 2024).

126 "Naval Marine & Ports Technologies Market Research Report", https://www.fortunebusinessinsights.com/naval-marine-and-ports-technologies-industry ((accessed 28 August 2024).

127 Ibid.

128 "Autonomous shipping", https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx (accessed 28 August 2024).

Smart Ports and Supply Chains

4IR technologies are gaining traction among seaports and are being integrated at a rapid pace. The ports have begun to use 4IR technologies for enhancing operational efficiency, and many ports are aspiring to be Smart Ports, which, industry experts believe, "will survive".[129] There are also trends in making these ports sustainable, which means that the ports should use these technologies for operational and financial efficiencies, including environmental consideration by focusing on energy transition. According to "Smart Ports Market Insights", in 2022, the Global Smart Ports Market was estimated to grow from $2.46 billion to $12.98 billion by 2031 at a CAGR of 23.1%.[130]

Smart ports have a complex network for wide-ranging operations involving large numbers of devices, equipment, and machineries, including transports that are connected, thereby facilitating access from multiple locations across different nodes in the port. The exponential growth in devices and data increases the demand for bandwidth for executing varied services with high speed. The Fifth Generation (5G) wireless communications technology enables quick access to data along the supply chain, i.e., ship-port-transport-production zone and vice versa. Smart Ports are integrating block chain technology to ensure that operations are not only transparent but also effective and secure.

As far as container operations at the port are concerned, these boxes are part of the seamless supply chain that runs shore-ship-shore, during which data are exchanged among various stakeholders. Many of these are 'just in time' cargo and are critical for many industries that rely on a near-continuous supply of raw materials as well as the dispatch of finished products.

5G enables quick access to data for "monitoring of extensive port activities and the tracking of goods, containers and vehicles over long distances can be made possible, for example, by a private 5G network that can ensure continuous monitoring

129 "How the Fourth Industrial Revolution is Impacting Ports of the Future", https://www.boldbusiness.com/digital/fourth-industrial-revolution-impacting-ports-future/ (accessed 21 August 2024).

130 "Smart Ports Market Insights", https://www.skyquestt.com/report/smart-ports-market (accessed 21 August 2024).

by cameras, sensors and IoT devices in real time”. [131]

Cloud Computing

Cloud computing involves the use of the internet to deliver hosted services cost effectively.[132]For instance, the United Arab Shipping Co. was able to save the cost of fuel by 3–5% by using a cloud.[133] Cloud computing assists autonomous ships with numerous onboard operations as well as navigation. Samsung Heavy Industries uses cloud services for improving shipping operations.[134]

Digital Twinning

Digital Twin is a virtual replica or digital representation of a physical ship or maritime asset, incorporating real-time data and advanced simulation technologies”[135] It converts the physical shape of the vessel and enables shore-based agencies to instantaneously monitor various parameters of ships machinery or offshore platform structures. It “helps predict breakdowns before the equipment fails, and enables remedial measures through replacements and repair, thereby enhancing operational efficiency”.[136] The use of this technology is gathering momentum in the shipping industry and is being used for “fuel maintenance optimisation, real-time feedback on ship performance, and even predictive vessel upkeep”.[137]

Big Data

Volume, velocity, variety, veracity, and value are the five important characteristics of big data and are referred to as the 5Vs.[138] It is estimated that the maritime industry “generates roughly 100-120 million

131 “Digital Port: Automation, Remote Monitoring & Maintenance in Smart Ports”, https://www.cocus.com/en/port-automation-remote-monitoring/(accessed 23 August 2024).

132 “Cloud computing”, https://searchcloudcomputing.techtarget.com/definition/cloud-computing (accessed 23 March 2020).

133 “Shipping and Maritime Industry Powered by Cloud Computing”, https://seanews.co.uk/shipping-news/shipping-and-maritime-industry-powered-by-cloud-computing/(accessed 23 August 2024).

134 “Amazon cloud will help shipbuilder develop autonomous shipping”, https://www.rivieramm.com/news-content-hub/news-content-hub/amazon-cloud-will-help-shipbuilder-develop-autonomous-shipping-23696 (accessed 23 March 2020).

135 “Digital Twin”, https://sinay.ai/en/maritime-glossary/what-is-a-digital-twin/ (accessed 10 September 2024).

136 “Maritime Digital Trends in 2018”, http://www.ipcs.org/columns_select.php?column_name=Maritime%20Matters (accessed 15 March 2020).

137 “The Rising Role of Digital Twins in Shipping”, https://digitaltwininsider.com/2024/04/30/the-rising-role-of-digital-twins-in-shipping/ (accessed 16 September 2024).

138 “What are the 5 V's of Big Data?”, https://www.teradata.com/glossary/what-are-the-5-v-s-of-big-data (accessed 29 August 2024).

data points every day, from different sources, such as ports and vessel movements".[139]These gigantic data are both structured and unstructured and need to be processed to make them useful for multiple operations at sea. Traditional data management systems are deficient in dealing with the 5Vs for which big data information systems are most useful.

Data Cables and Storages

There is a proliferation of systems and devices, and these generate and share zettabytes (ZB) of data, which in the long run are estimated to be in the order of yotobyte (YB). Nearly 90% of the data is pushed through submarine cables that are capable of transmitting large volumes of data per second. These enable fast and also reliable methods of data transmission, making them the most important infrastructure for global digital connectivity.

Currently, there are 406 active cables that run over 1.2 million kilometres under the sea and come out at about 1,000 landing stations on the shore.[140] The longest submarine cable network in the world is the 2Africa submarine cable, which runs over 45,000 kilometres across Africa, Asia, and Europe (33 countries). Three billion people, representing 36% of the global population, are expected to benefit using submarine cable.[141] The global demand for cable networks is growing, and the submarine cable market is projected to touch $29.7 billion by 2029 from the current $18.2 billion, growing at a CAGR of 10.3%.The telecommunication industry is investing in subsea cabling to different geographies.[142]

Data storage houses the servers and generates enormous amounts of heat as well as aggravators of climate change and therefore necessarily requires cooling systems. They are over 8,000 data centres globally, and the majority of these are located in the US, Europe, and China and many more are planned. For instance, Ireland currently has 82 data centres,

139 "Use of big data in the maritime industry", https://www.patersonsimons.com/wp-content/uploads/2018/06/TMS_SmartPort_InsightBee_Report-to-GUIDE_01.02.18.pdf (accessed 10 April 2020).

140 "Undersea cables are the unseen backbone of the global internet", https://theconversation.com/undersea-cables-are-the-unseen-backbone-of-the-global-internet-226300(accessed 25 August 2024).

141 "Deploying the largest subsea fiber-optic cable system ever", https://www.2africacable.net/(accessed 25 August 2024).

142 "Submarine Cable Systems Market Size, Share & Industry Growth Analysis Report by Application (Communication Cable and Power Cable), Component (Dry Plant Products and Wet Plant Products) Offering, Voltage, Type (Single Core and Multicore), Insulation, End User and Region - Global Forecast to 2029", https://www.marketsandmarkets.com/Market-Reports/submarine-cable-system-market-184625.html (accessed 25 August 2024).

> Robots and autonomous platforms use AI and machine learning (ML) to gather marine data and help understand marine ecology and its habitat.

14 are being built, and 40 more have been approved.

Robots and Autonomous Vehicles

Robots and autonomous platforms use AI and machine learning (ML) to gather marine data and help understand marine ecology and its habitat. Humankind is now using bio mimetic and mimicking nature to develop devices and platforms. These necessitate miniaturised sensors and cameras to watch and assess marine life. Similarly, 4IR is critical for measurements of the physical and chemical properties of the seawater. Factors such as the temperature of the water, level of salinity, oxygen content, acidity levels, and presence of nutrients and microbes are best monitored using these platforms to conduct various underwater operations and observations.

These platforms are most suitable for seabed exploration, and the Nippon Foundation-GEBCO Seabed 2030 Project will use AI Platform for its operations to "deliver intelligence for subsea exploration and monitoring of the ocean with exceptional efficiency and accuracy". [143]

Human Skills

There are now clear trends in the integration of 4IR technologies across the maritime domain. However, human resources, both at sea and ashore, have not been socialised into these technologies and require up-skilling, re-skilling, and retooling to enable them for their effective utilisation. The industry leaders have acknowledged the importance of educating not only the crew and operators but have also imposed upon themselves the task of building knowledge about these technologies by adopting innovative models for operations. In fact, 4IR technologies are creating new types of jobs rather than jettisoning them, which

143 "Seabed 2030 and SeaDeep join forces to advance ocean exploration through AI", https://www.oilfieldtechnology.com/offshore-and-subsea/18092024/seabed-2030-and-seadeep-join-forces-to-advance-ocean-exploration-through-ai/ (accessed 19 September 2024).

> The current 4IR-led techno-naval transformation has forced navies to shift operations from platform-centric to network-centric warfare and now towards autonomous warfare that pivots on complex integration of unmanned-autonomous platforms at sea, in the air, underwater, ashore, and even in outer space.

should be the catalyst for shedding unfounded fears of these technologies.

Naval War Fighting

The current 4IR-led techno-naval transformation has forced navies to shift operations from platform-centric to network-centric warfare and now towards autonomous warfare that pivots on complex integration of unmanned-autonomous platforms at sea, in the air, underwater, ashore, and even in outer space. There is strong evidence of 'desire and quest' among navies to achieve technological proficiency and translate 4IR technology into operational competence so that the enemy could be engaged further out into the sea and on shore, with limited or even 'no-contact' with the platform resulting in a new type of warfare. The navies are also embracing commercially available communication devices, such as smart phones, tablets, and hybrid devices such as micro-UAVs, which fall into the category of wearable technologies. Swarm drones have gained popularity, and their use is growing rapidly to perform numerous tasks and support operations, such as reconnaissance, surveillance, strikes against enemy targets, electronic warfare through jamming, and other such missions. In fact, these can be target combat platforms at sea by conducting kamikaze-type attacks using dive-bombing features, thus offering cheap options for attacking a powerful enemy.

Likewise, underwater drones, including in swarm formations, are capable of operating autonomously and intelligently navigating to avoid obstacles to carry out reconnaissance and combat missions. Besides these, they can be used as decoys against submarines as well as act as scouts for submarines by gathering data, carrying out reconnaissance for submarines, and carrying explosives to detonate near enemy underwater platforms.

> Underwater drones, including in swarm formations, are capable of operating autonomously and intelligently navigating to avoid obstacles to carry out reconnaissance and combat missions.

It is possible to leverage AI for advancing operational training and war-gaming. Innovative and challenging scenarios can be created that can offer unexpected tactics. These can be supplemented with augmented reality and virtual reality to overcome actual battlefield experience.

Issues of Cyber Warfare

The 4IR-enabled battle space at sea will be dotted with an assortment of autonomous and unmanned platforms and diverse devices that would be deployed for varied tasks. While there is a bright future for 4IR technologies, it is equally important to understand that hackers will be on the prowl and intrude on storage infrastructure and devices. This will entail a hardening and recovery plan to regain control over data. Robust cyber warfare capabilities will be needed to retain battle-space superiority. AI is useful for detecting cyber attacks, but attackers will find new ways to manage the AI-ML-Deep Learning-enabled battle space.[144]

Concluding Thoughts

4IR technologies are impacting both maritime (commercial) and naval (war fighting) operations at different levels. AI, ML, and Big data applications are helping improve MDA, including countering illegal and unauthorised activities. Similarly, autonomous platforms and robots can potentially improve the overall sustainable use, help improve efficiency, and strengthen MDA.

The use of autonomous transport and cranes in port operations for loading and discharging of cargo has already begun, and autonomous tugs are being developed for assisting ship movements in harbours. This is being made possible through the rapid data exchange between ships, terminals, shore-based transportation networks, and the end user for an

144 "How Artificial Intelligence Is Changing Cyber Security Landscape and Preventing Cyber Attacks", https://www.entrepreneur.com/article/339509 (accessed 08 August 2024).

> 4IR technologies are impacting both maritime (commercial) and naval (war fighting) operations at different levels. AI, ML, and Big data applications are helping improve MDA, including countering illegal and unauthorised activities. Similarly, autonomous platforms and robots can potentially improve the overall sustainable use, help improve efficiency, and strengthen MDA.

efficient movement of transportation of goods with greater transparency and authenticity.

The use of smart, intelligent, and autonomous systems in ports, ships, rail, and road networks eliminates paperwork and reduces processing times. Smart business models and contracts are engendering huge advantages. The shipbuilding industry is undergoing transformative changes resulting in lower building time supported by robots and AI-enabled machines.

4IR advancements also require a workforce with new skills, which, in current times, is quite low. There is huge market demand for millions of skilled human resources, and India, as the top producer and largest non-US supplier of technology professionals and international students in AI-related fields, is poised to support the growth of 4IR technologies across sectors.

SPACE TECHNOLOGY IN ENHANCING MARITIME DOMAIN AWARENESS IN THE INDO-PACIFIC REGION

Mr. Keshav Verma

The Indo-Pacific region is stated to be a massive expanse region that stretches from the eastern coastline of Africa to the western coast of the American states. There is an oceanic space in between the two. This region is not just a spatial area but one comprising different cultures, economies and geopolitical aspects. The Indo-Pacific comprises more than half of the world's population, meaning it plays an integral role in world trade, power dynamics and global climate trends. Regions, such as the South China Sea and the Strait of Malacca, form maritime choke points for shipping lanes that transport one-third of the world's trade and half of its containerised cargo.

Geopolitically, the Indo-Pacific is of utmost relevance due to its vast untapped natural deposits, including oil, undiscovered resources and tidal energy. Competition between countries to gain dominance over such regions has increased the demand for maritime domain awareness (MDA). Under such circumstances, it has become imperative to attain the security of key ocean resources and maintain regional equilibrium. The MDA involves gaining insights and monitoring oceanic activities for the improvement of security, maintaining control over marine life, taking appropriate measures to protect marine resources and maintaining the law above the surface of the sea.

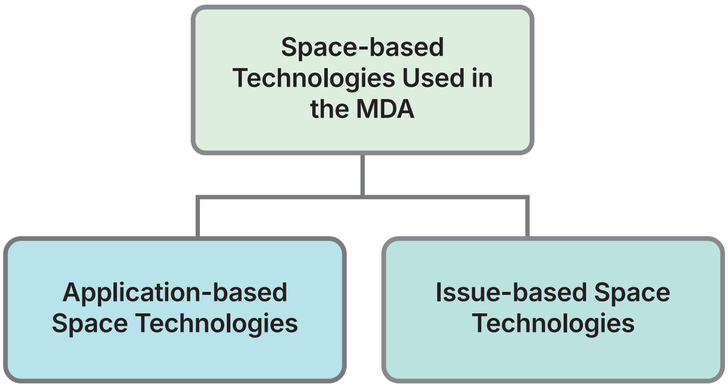
In this context, space technologies appear to be a game changer when augmenting MDA capabilities. The addition of satellite systems into the maritime domain enables an unprecedented level of surveillance, communication and data collection. With satellites, it is now possible for a nation to get images and data of large areas of the ocean with a level of precision that most conventional techniques would not be able to deliver. Maritime threats can easily be monitored through satellite-based technologies that help track ships and identify suspicious activities. Synthetic Aperture Radar (SAR) satellites, for instance, can spot boats even in bad weather or at night, allegedly allowing for greater coverage of vital trade routes. This capability allows the countries affected by illicit activities, such as smuggling and Illegal, Unreported and Unregulated (IUU) fishing, to respond quickly, improving the region's security.

In addition, satellite communication systems enable better coordination among nations working on maritime security. Effective communication is crucial to joint operations and information sharing in multistate regions. Through space technologies, nations can facilitate a more integrated effort, focusing on communication regarding maritime navigation, environmental impact and other security threats likely to be experienced.

Besides, the inclusion of space-based assets also facilitates environmental monitoring and disaster response, which is essential in an area that frequently suffers natural catastrophes, such as typhoons and tsunamis. The use of satellites can include early warning systems that assist in alleviating the effects of such events on maritime activities and coastal populations. In this context, technologies pertaining to outer space contribute to security and foster adaptation and mitigation in the context of climate change.

As technology continues to develop, there are possibilities for extensions such as artificial intelligence (AI) and machine learning, which can improve the ability to analyse satellite data. These technologies are capable of speeding up action by analysing and supporting decision making by sifting through extensive datasets to spot trends, forecast maritime activities and so on, thus enhancing MDA systems.

Space-based Technologies Used in the Maritime Domain



Application-based Space Technologies:

Satellite-based Automatic Identification System

Satellite-based Automatic Identification System (S-AIS) is transforming the MDA in the Indo-Pacific by enabling advanced vessel tracking capabilities, particularly in remote and expansive oceanic regions. Unlike traditional AIS, which depends on terrestrial stations, S-AIS leverages satellites to capture AIS signals from ships, ensuring global coverage even in

> Space technologies appear to be a game changer when augmenting MDA capabilities. The addition of satellite systems into the maritime domain enables an unprecedented level of surveillance, communication and data collection. With satellites, it is now possible for a nation to get images and data of large areas of the ocean with a level of precision that most conventional techniques would not be able to deliver.

areas far beyond the reach of shore-based infrastructure. This capability is particularly critical in the Indo-Pacific, where vast stretches of open sea pose significant monitoring challenges.

This technology has also strengthened regional collaboration through initiatives like the **Sea Vision** platform[145] and India's **Information Fusion Centre — Indian Ocean Region (IFC-IOR)** in Gurugram[146], which rely on S-AIS to provide a comprehensive maritime overview. The increasing accessibility of S-AIS, driven by advances in satellite technology and cost reduction, makes it a cornerstone of efforts to ensure maritime security, sustainability and governance. Emerging tools like the crowd-sourced **Sea Watch app**, which aims to combat illegal, unregulated and unreported IUU fishing through increased transparency, highlight the growing potential of innovative platforms in augmenting MDA.[147] Together with fusion centres and international partnerships, S-AIS and related technologies represent a pivotal step toward comprehensive maritime oversight in the Indo-Pacific.

Satellite Communication for Maritime Connectivity

Today, satellite communication is a cornerstone of maritime connectivity in the Indo-Pacific, as it is critical for navigation, safety,

145 Brewster, David. "New Satellite-Based Technologies a Game Changer for Indo-Pacific Maritime Security." The Strategist, August 2, 2023. https://www.aspistrategist.org.au/new-satellite-based-technologies-a-game-changer-for-indo-pacific-maritime-security/.

146 Press Information Bureau. Maritime security: Memorandum of understanding (MOU) between the Information Fusion Centre - Indian Ocean Region (IFC-IOR) and Regional Coordination Operations Centre (RCOC), 2023. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1901371.

147 SeaWatch Labs. About Seawatch App, 2014. https://seawatch.io/#:~:text=SeaWatch%20is%20a%20crowdsourced%20mobile,activity%20they%20encounter%20at%20sea.

security and economic activities in this strategically vital and resource-rich region. Navigation systems like the US' GPS and India's Navic enable precise positioning and route planning for vessels operating across the Indian and Pacific oceans. Emergency systems, including the *Global Maritime Distress and Safety System* (GMDSS), enhance maritime safety by enabling rapid response to incidents, such as cyclones and ship accidents, which are common in these waters. **GMDSS** was established by the **International Maritime Organization (IMO)** under the **SOLAS (Safety of Life at Sea) Convention.**[148]

High-throughput satellites (HTS) provide real-time connectivity for shipping and fishing fleets[149] in the Indo-Pacific. Inmarsat's Fleet Xpress is widely used by merchant vessels and fishing boats in the region,[150] enabling broadband communication and crew welfare services. Meanwhile, SpaceX's Starlink[151] Maritime is expanding its coverage to serve luxury cruise lines and research vessels in remote Indo-Pacific waters.

Space Technologies for Oceanographic Monitoring

Satellites with advanced sensors monitor key parameters, such as Sea Surface Temperature (SST), ocean colour, chlorophyll concentration, sea-level height, ocean currents and salinity. Thermal infrared sensors, like those on NASA's Aqua and Terra satellites, track SST, while altimetry satellites, such as Jason-3[152] and Sentinel-6[153] observe sea-level changes and circulation patterns. Instruments like the *Ocean and Land Colour Instrument* (OLCI) on Sentinel-3 provide data on phytoplankton concentrations essential for marine ecosystem assessments.[154]SAR satellites,

148 Danphone. What is GMDSS? global maritime distress and safety system, n.d. https://www.danphone.com/about/gmdss/.

149 P., Antriksh. "High Throughput Satellite Market Size, Share, Growth & Industry Analysis." Kings Research, 2024. https://www.kingsresearch.com/high-throughput-satellite-market-1127#:~:text=In%20aviation%2C%20HTS%20supports%20in%2Dflight%20connectivity%2C%20allowing,crucial%20for%20navigation%2C%20safety%2C%20and%20crew%20welfare.

150 "Fleet Xpress: Inmarsat Maritime." Inmarsat, n.d. https://www.inmarsat.com/en/solutions-services/maritime/services/fleet-xpress.html.

151 "Starlink Business: Maritime." Starlink, n.d. https://www.starlink.com/business/maritime.

152 "NASA". Jason 3, September 29, 2021. https://sealevel.jpl.nasa.gov/missions/jason-3/summary/.

153 "Sentinal Online." Sentinal 6, n.d. https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-6/overview.

154 EUMETSET. "Ocean Colour Fluorescence Product." EUMETSAT, n.d. https://www.eumetsat.int/S3-OLCI-FLUO#:~:text=Published%20on&text=Within%20the%20framework%20of%20New,a%20slope%20and%20an%20offset.

Satellite-based Automatic Identification System (S-AIS) is transforming the MDA in the Indo-Pacific by enabling advanced vessel tracking capabilities, particularly in remote and expansive oceanic regions. Unlike traditional AIS, which depends on terrestrial stations, S-AIS leverages satellites to capture AIS signals from ships, ensuring global coverage even in areas far beyond the reach of shore-based infrastructure.

including Sentinel-1, detect oil spills, monitor ice movements and assess surface roughness.[155] In contrast, satellites like SMOS and Aquarius measure salinity to improve understanding of ocean-atmosphere interactions.

Space technologies address critical challenges in the Indo-Pacific, where vast maritime areas and strategic sea lanes require constant monitoring. They support disaster management by enabling early detection of cyclones, tsunamis and storm surges while assessing post-disaster impacts. Earth satellites enhance fisheries management by identifying potential fishing zones using SST and chlorophyll data and monitoring IUU fishing activities. Marine pollution, including oil spills and plastic debris, is detected and tracked using SAR and optical imaging satellites, which help assess coastal erosion and sediment transport. Space-based altimetry and remote sensing technologies are essential for studying regional phenomena, such as the Indian Ocean Dipole and the Indo-Pacific Warm Pool, which influence global weather patterns and climate. Satellite systems are pivotal for the MDA in the Indo-Pacific, where piracy, smuggling and illegal fishing threaten regional stability. India's RISAT series of satellites, equipped with SAR, monitor unauthorised activities in the ocean.[156]Similarly, Australia employs satellite data to monitor illegal fishing in its Exclusive Economic Zone (EEZ), a challenge exacerbated by the region's vastness.

155 Sari, Dian Puspita, Mukhtasor, and Muhammad Zikra. "IOP Conference Series: Earth and Environmental Science." In Mapping Oil Spill Using Sentinel-1: Study Case of Karawang Oil Spill. IOP Publishing, 2020.

156 D.S., Madhumathi. "SARS UP: The Indian Radar Imaging Satellites Story Has Only Begun." The Hindu, January 6, 2020. https://www.thehindu.com/sci-tech/science/india-boosts-radar-satellite-count-with-two-launches-in-2019/article30463501.ece.

Satellite-based Weather Forecasting and Monitoring

Satellite-based weather forecasting and monitoring are indispensable tools for enhancing the **MDA** in the Indo-Pacific region. With its vast expanse, dynamic climatic conditions and high vulnerability to extreme weather events, such as typhoons, cyclones and monsoons, the area demands robust weather monitoring systems to ensure safety, security and sustainability.

Weather satellites, both polar-orbiting and geostationary, play complementary roles in this effort. **Geostationary satellites,** such as India's **INSAT-3D INSAT-3DR**[157] and the *US***GOES-16**, provide continuous imagery and atmospheric measurements of specific regions[158]. Positioned approximately 22,000 miles above the equator, these satellites maintain a fixed view of the Earth, enabling real-time monitoring of meteorological phenomena. They deliver high-frequency updates, with the ability to take images every 15 minutes or even every minute during severe weather events. This capability is crucial in detecting and tracking cyclones, monsoon depressions, and storm surges, allowing maritime nations to issue timely warnings, minimise damage to life and property, and secure shipping routes.

On the other hand, polar-orbiting satellites travel in a north-south orbit, offering global coverage twice daily. These satellites provide high-resolution atmospheric profiles of temperature, moisture and wind patterns, vital for long-term climate modelling and seasonal forecasting. Their global perspective complements the regional focus of geostationary satellites, ensuring that no critical weather developments are overlooked, even in remote maritime areas. India's **INSAT program,** one of Asia-Pacific's most significant communication and meteorological satellite networks, delivers critical weather data to the **India Meteorological Department (IMD)** and regional partners. The **Philippines**, a country frequently hit by typhoons, relies heavily on satellite-derived storm path projections and precipitation data for disaster preparedness. Similarly, Australia's **Bureau of Meteorology** uses satellite

157 INSAT-3DR (Indian National satellite-3d Repeat). EoPortal. (2016). https://www.eoportal.org/satellite-missions/insat-3dr#mission-status.

158 NASA. (2016). Geostationary Operational Environmental satellite-16. https://eospso.nasa.gov/missions/geostationary-operational-environmental-satellite-16#:~:text=GOES%2D16%20has%20provided%20continuous,climatic%2C%20solar%20and%20space%20data.

data to track cyclones in the Indian and Pacific Oceans, ensuring safety for its ports and coastal areas.

Issue-based Space Technologies

Defence and Security

Ensuring maritime security and enhancing MDA in the Indo-Pacific region is paramount, given the challenges posed by IUU fishing, piracy, smuggling and geopolitical tensions. Traditional methods of maritime monitoring, such as manned patrols and expensive surveillance equipment, are often resource-intensive, limited in scope and insufficient to address the complexities of modern maritime threats. Space technologies, however, have revolutionised maritime security by offering unparalleled capabilities for monitoring, communication and coordination, making them an essential tool for the MDA.

Equipped with advanced imaging technologies, such as SAR and optical sensors, satellites deliver real-time, high-resolution imagery of vast oceanic areas. Unlike traditional methods, satellite-based surveillance operates day and night and in all weather conditions, ensuring reliable data collection even in the most challenging circumstances. India's **Radar Imaging Satellite (RISAT)** series employs advanced SAR technology to monitor maritime activities in the ocean.[159] These satellites provide critical capabilities for detecting and tracking vessels, monitoring EEZs, and identifying illegal activities. Similarly, Japan's **Advanced Land Observing Satellite-2 (ALOS-2)**[160] delivers high-resolution SAR imagery for environmental and maritime surveillance, with applications extending to defence operations by monitoring disputed maritime zones and ensuring navigational safety in busy sea lanes.

Furthermore, by capturing AIS signals from vessels, including those operating in remote or open ocean regions, satellites enable authorities to track ships, identify suspicious behaviour, and ensure compliance with international maritime laws. This is particularly crucial in combating IUU fishing, a persistent issue in the Indo-Pacific. By integrating satellite imagery

159 Ibid 12.

160 "EoPortal". Alos-2 (advanced land observing satellite-2) / daichi-2. (2024). https://www.eoportal.org/satellite-missions/alos-2#alos-2-advanced-land-observing-satellite-2-sar-mission—daichi-2.

Satellite systems are pivotal for the MDA in the Indo-Pacific, where piracy, smuggling and illegal fishing threaten regional stability. India's RISAT series of satellites, equipped with SAR, monitor unauthorised activities in the ocean. Similarly, Australia employs satellite data to monitor illegal fishing in its Exclusive Economic Zone (EEZ), a challenge exacerbated by the region's vastness.

with AIS data, governments can pinpoint unauthorised fishing activities and enforce regulations effectively.

Despite their advantages, the integration of space technologies in maritime security is not without challenges. High costs associated with satellite development and launch, data processing complexities, and vulnerabilities to cyber attacks are significant concerns. However, public-private partnerships, advancements in satellite miniaturisation and regional cooperation are mitigating these challenges, making space technologies more accessible and efficient.

Search and Rescue (SAR)

Integrating space technology into search and rescue operations has revolutionised the efficiency and effectiveness of saving lives and mitigating maritime risks. One of the most prominent examples is the Cospas-Sarsat International Satellite System,[161] which provides global distress alert and location information for maritime, aviation and land-based users. This system, supported by satellite constellations, ground stations and user terminals, is instrumental in the rapid detection and response to emergencies at sea.

India's INSAT and GSAT satellites, equipped with COSPAS-SARSAT transponders, monitor distress signals across the Indo-Pacific region. Japan's Himawari[162] and ALOS-2 satellites provide meteorological data and radar imaging for rescue missions, while Australia's NovaSAR-1 detects small vessels in emergencies. Indonesia's

161 Cospas-Sarsat System Overview. SARSAT. (n.d.). https://www.sarsat.noaa.gov/cospas-sarsat-system-overview/.

162 Geostationary meteorological satellite "himawari" (GMS). JAXA. (n.d.). https://global.jaxa.jp/projects/sat/gms/index.html.

LAPAN-A3/IPB monitors[163] its vast archipelagic waters, and South Korea's KOMPSAT[164] series supports SAR in regional seas. New Zealand, Malaysia and Singapore contribute via COSPAS-SARSAT systems, emphasising collaboration to enhance maritime security and disaster response in this strategically vital region.

Space Collaborations in the Indo-Pacific Region

In understanding the importance of space technology in MDA, Indo-Pacific countries have come together to forge alliances that will create resilient and cooperative frameworks. In May 2022, at the Quad Summit, India, Japan, the United States and Australia launched the Initiative for Indo-Pacific Partnership for Maritime Domain Awareness.[165] At this initiative, satellite technology is used to keep track of activities occurring, especially within the Indo-Pacific Ocean. It also calls for enhanced sustainable development through robust naval watching.

Given the technological depth, Japan has also begun to make deep permeation into the use of space technology in her security and MDA policies. Japan's national security action plan emphasises the need for greater cooperation between the Japan Aerospace Exploration Agency (JAXA) and the Self-Defence Forces of Japan.[166] Additionally, collaboration with India and the US in the last few years has enhanced Japan's ability in satellite surveillance and marine security.

Japan's interest in space infrastructure development in Southeast Asia, especially through the Asia-Pacific Regional Space Agency Forum (APRSAF), underscores its commitment to cooperating at a regional level. This forum also enables cooperation for space exploration and the advancement of satellite technologies to solve common ocean and environmental problems.[167]

163 LAPAN-A3/IPB. eoPortal. (n.d.). https://www.eoportal.org/satellite-missions/lapan-a3#spacecraft.

164 Kompsat-3A (Korea Multi-Purpose satellite-3a) / arirang-3a. eoPortal. (n.d.-a). https://www.eoportal.org/satellite-missions/kompsat-3a#mission-status.

165 Prime minister's participation in the Quad Leaders' Summit. (2022). https://www.mea.gov.in/press-releases.htm?dtl/35354/Prime_Ministers_participation_in_the_Quad_Leaders_Summit.

166 Bingen, K. A., & Young, M. (2024). From Earth to Uchū: The Evolution of Japan's Space Security Policy and a Blueprint for Strengthening the U.S.-Japan Space Security Partnership. https://aerospace.csis.org/wp-content/uploads/2024/08/240823_Bingen_Earth_Uchu-min.pdf.

167 "About Aprsaf." Asia-Pacific Regional Space Agency Forum, n.d. https://www.aprsaf.org/about/.

India, which is an emerging space power, has also made great strides in space-based MDA. ISRO has constructed satellites for earth observation, satellite communication, navigation and disaster management. India has emphasised the need for greater security and collaboration in space technology through its IPOI (Indo-Pacific Ocean Initiative). The synergy between India's IPOI and Japan's *Free and Open Indo-Pacific (FOIP)* reflects a shared vision for a stable and prosperous maritime environment.

The Quad leader's Summit among India, Australia, Japan and the US has been instrumental in promoting the MDA. The 2023 Summit between the Quad nations stressed the need to fuse space technologies towards better securing the region.[168] This partnership also entails assisting other states with public goods, such as providing coastal surveillance radars and disaster relief assistance, as in the case of the Philippines. In addition, the adoption of the Indo-Pacific cooperation policy by Bangladesh in April 2023 is another significant step in these efforts. In expressing its Indo-Pacific Outlook and emphasising the peaceful exploitation of space and ocean resources, Bangladesh positioned itself closer to India and its allies. This partnership leverages satellite data for navigation and earth observation and digital technologies to build the resilience of coastal populations to disasters and foster sustainable development.

Beyond defence, space partnerships can also be said to be contributing to sustainable development and environmental protection in the Indo-Pacific. Satellite-based systems are also used to monitor the seas and the effects of climate change and to manage fishery resources. Further, India has partnered with ASEAN in setting up a satellite tracking and data reception ground station, both for civilian and strategic purposes, in Ho Chi Minh City, Vietnam.[169] Additionally, India also collaborates with ASEAN under the India-ASEAN Cooperation in Space Technology and Applications to work on disaster relief, environmental monitoring and marine monitoring systems.[170] In addition, ISRO offers training programs

168 White House. (2023, May 20). Quad Leaders' Joint Statement. https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/20/quad-leaders-joint-statement/.

169 Miglani, Sanjeev, and Greg Torode. "India to Build Satellite Tracking Station in Vietnam That Offers Eye on China." Reuters, 2016. https://www.reuters.com/article/us-india-vietnam-satellite/india-to-build-satellite-tracking-station-in-vietnam-that-offers-eye-on-china-idUSKCN0V30B3/.

170 Government of India. ASEAN India S&T Cooperation, n.d. https://www.aistic.gov.in/ASEAN/aboutUs.

> India's INSAT and GSAT satellites, equipped with COSPAS-SARSAT transponders, monitor distress signals across the Indo-Pacific region. Japan's Himawari and ALOS-2 satellites provide meteorological data and radar imaging for rescue missions, while Australia's NovaSAR-1 detects small vessels in emergencies.

for scientists from ASEAN and develops space science and satellite communication capabilities.

Moreover, India has helped Vietnam develop space-based systems for the surveillance of the South China Sea. The NavIC system of India is being expanded to the member countries of ASEAN and is aimed at providing navigational services in the Indo-Pacific. In these manners, India provides satellite information for the suppression of unauthorised actions and the prevention of threats to maritime traffic while striving to impart indigenous capabilities of space technologies to the ASEAN countries. Such endeavours foster India to enhance its relationship with ASEAN while promoting regional stability and technological development.

The ability of satellites to give data regarding the weather, the rising of the seas or the erosion of coasts in real time is of immense service to the disaster-affected areas in the Indo-Pacific. Space technologies allow for a timely response to disasters, thus reducing the loss of lives and property. The *Humanitarian Assistance and Disaster Relief (HADR)* activities in the context of the Japan-US-Australia-India Partnership are self-evident about how created space solutions can meet such critical needs.[171]

Further, India's South Asia Satellite (GSAT-9) is undeniably an excellent illustration of the development of a space asset by a state for the welfare of its regional nations. This geostationary satellite was launched in 2017 and is intended for the provision of communication and meteorology services to all the South Asian countries, including Sri Lanka, Nepal, Bhutan, the Maldives and Bangladesh. With the assistance of the satellite, these countries will be further equipped in the areas of weather

171 The White House. The Wilmington Declaration joint statement from the leaders of Australia, India, Japan, and the United States, September 21, 2024. https://www.whitehouse.gov/briefing-room/statements-releases/2024/09/21/the-wilmington-declaration-joint-statement-from-the-leaders-of-australia-india-japan-and-the-united-states/.

prediction services, navigational services and disaster management services, which are important for maritime safety and security.[172] For instance, Bangladesh uses this data set from GSAT-9 to better oversee its large shorelines and fishing regions.

Small island developing states (SIDS), like Fiji, Vanuatu, Samoa and the Solomon Islands in the Indo-Pacific, are faced with the difficulties to effectively administer their vast maritime zones. Always more resources and adequate maritime infrastructures are required to be able to cope with the challenges of surveillance and maritime aggression. Space collaborations have been crucial in bridging these divides. For instance, Quad nations have engaged with Pacific island nations to offer satellite monitoring services.[173] For instance, Earth resources satellites are able to provide images with high spatial resolution that enable these nations to manage illegal fishing and enforce their Exclusive Economic Zones (EEZ) boundaries.

Abstracting the knowledge gained from other collaborative space programs, the MDA improves, and regional cohesion is enhanced through technological transfer. Under ISRO, Indian scientists are imparting knowledge to their counterparts from neighbouring countries in their training programs, which will help them develop indigenous satellites. For example, Bhutan Sat (also known as INS-2B), sponsored by ISRO and built in collaboration with Bhutan, is used to monitor the environment and prevent disasters, all of which benefit the marine and river ecosystems in Bhutan.[174]

Further, the US initiated activities on Space Situational Awareness (SSA) to support regional activities in monitoring space debris and protecting satellites that are important for the MDA. For example, countries such as India and Australia have been active participants in these programs, which made the integration of satellite assets across the Indo-Pacific quite smooth.[175]

172 Air Marshal B.K. Pandey. GSAT-9: South Asia Communication Satellite, 2017. https://www.sps-aviation.com/story/?id=2059.

173 Allies, partners tap into technology to monitor maritime domain, 2023. https://ipdefenseforum.com/2023/11/allies-partners-tap-into-technology-to-monitor-maritime-domain/.

174 Haidar, Suhasini. “Launch of India-Bhutan Sat Marks New Era in Ties: Bhutan King.” The Hindu, November 26, 2022. https://www.thehindu.com/news/national/launch-of-india-bhutan-sat-marks-new-era-in-ties-bhutan-king/article66188509.ece.

175 Space situational awareness, 2024. https://swfound.org/media/207890/fs24-01_space-situational-awareness.pdf.

The MDA augmentation in the Indo-Pacific region is possible through a more coherent strategy for regional and cross-regional partnerships. The existing collaborations, like the Indo-Pacific Partnership for Maritime Situational Awareness and the Information Fusion Centre – Indian Ocean Region based in India, have shown the effectiveness that can be derived from pooled assets and intelligence.

Future Prospects and Recommendations

Currently, the Indo-Pacific region has become the epicentre of significant political and economic activities around the globe, where the MDA is central to safeguarding peace, security and sustainable development. While there will always be challenges in such a vast and complex region, new strategies to address the challenges will have to be framed likewise. The expected benefits can only be realised through the development of advanced technologies, enhanced multilateral cooperation and the implementation of new policy initiatives on the MDA in the Indo-Pacific.

The MDA augmentation in the Indo-Pacific region is possible through a more coherent strategy for regional and cross-regional partnerships. The existing collaborations, like the Indo-Pacific Partnership for Maritime Situational Awareness and the Information Fusion Centre – Indian Ocean Region based in India, have shown the effectiveness that can be derived from pooled assets and intelligence. However, the initiatives need to be broadened to encompass the involvement of more stakeholders, such as small and medium island and developing countries in the region. To do this, more capacity-building projects should be promoted. Japan, the US and Australia are already advanced countries that are able to assist other developing countries with technologies so that the countries can actively participate in regional security.

The growth in technology corresponds with new ways of enhancing MDA capabilities. Focusing resources on new technologies, such as artificial intelligence (AI), machine learning (ML) and big data analytics, has the potential to change the way that maritime data is collected and exploited. These can process and sift through millions of sensor and satellite bits of information to find patterns, pre-empt threats and make decisions quickly.

Space-based solutions using low-cost miniaturised satellites will also be more feasible for smaller countries with the growth of nano-satellite technology. International initiatives like CubeSat constellations, developed by several countries, will help ensure a more efficient and cheaper way to keep an eye on the important parts of the ocean.

Technology should not only be used for observing but should also be employed to tackle various environmental challenges. The advanced sensor satellites will be capable of assessing marine ecosystems, evaluating levels of maritime pollution and measuring the effects caused by climate change on the coastal regions. For example, thermal and hyperspectral imaging can assist in the detection of marine pollution, such as oil spills and other contaminants, targeting quick intervention.

Moreover, countries within the Indo-Pacific region ought to be in favour of putting standardised protocols aimed at enhancing data and maritime surveillance technologies dissemination. Accordingly, issues of collaboration and the protection of privacy and sovereignty would be addressed. On the other hand, using space for a naval purpose should have more international agreements governing them. Such treaties should be able to address issues relating to the need for the demilitarisation of space and the cyber threats directed towards satellite systems. The UN Committee on the Peaceful Uses of Outer Space (COPUOS) may be in a position to assist in developing international conventions on MDA's peaceful exploitation of space technology through the enactment of binding treaties.

Public-private partnerships (PPPs) are critical in addressing the resource gap and encouraging innovation in the MDA. There should be collaboration between the government and the private sector, which will provide for the development of satellites, data collection and solving communication problems, which is cost-effective and practical. For instance, commercial players, such as SpaceX and Inmarsat, have already been helping

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in enhancing maritime interaction and monitoring in the Indo-Pacific. To encourage private sector participation, governments should offer incentives, such as tax benefits, funding for research and development, and access to state-owned data. Regulatory frameworks should also be streamlined to facilitate the launch and operation of privately developed satellite systems.

Furthermore, countries need to develop a comprehensive approach to maritime domain awareness by establishing strong satellite networks, ground facilities, and cyber-security infrastructure to prepare for and withstand any kind of slow threats, such as physical and cyber-attacks. Joint R&D projects of regional countries can help deliver advanced solutions in space technologies in areas, such as AI-based image and data processing systems and nano-satellite constellations, benefiting the stakeholders. Also, enhancing human resources through education, training, scholarships and exchange programs will be vital for the further development of technology. Coordination of national strategies with regional and global goals will increase efficiency in the use of resources while avoiding duplication of efforts and ensuring unity of actions aimed at the development of space technologies for the interests of MDA. Taken together, the initiatives will help ensure a more stable and wealthier Indo-Pacific region.

Conclusion

The maritime space of the Indo-Pacific is crucial in terms of global security, international trade and environmental sustainability. As threats emerge, the region is in a position to tap into its combined potential and new cutting-edge technologies to create a more secure future. Collaboration among nations through satellite-based systems depicts the strength of

> Countries need to develop a comprehensive approach to maritime domain awareness by establishing strong satellite networks, ground facilities, and cyber-security infrastructure to prepare for and withstand any kind of slow threats, such as physical and cyber-attacks.

unity in tackling complex maritime challenges. Still, the greater potential is in promoting innovation and inclusion. When the larger and resource-poor countries are given the necessary tools and platforms for knowledge sharing and capacity building, then the region can succeed in turning around the Indo-Pacific into a zone of prosperity. The vision of interconnected nations with the sharing of technology and personnel based on trust and with a common objective sets a robust basis for a peaceful and progressive Indo-Pacific. The future is bright, but it is anchored in collective resolve, strategic vision and commitment to the cause of sustainable development.

Investing in space technology today ensures the Indo-Pacific's stability and resilience for tomorrow.

BIO-PROFILES

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Dr. Sripathi Narayanan is a Research Fellow with the Indian Council for World Affairs (ICWA). He was awarded his doctorate from the University of Madras. His research interest includes the political and security situation in South Asia especially in Maldives, Myanmar and Sri Lanka along with understanding the nuances of maritime security. With a Masters and M.Phil in Defense and Strategic Studies, Sripathi is also a keen observer of the evolution in military affairs, security and geopolitics.

Prior to joining ICWA, Sripathi had been a consultant with the Policy Planning and Research Division of the Ministry of External Affairs, Government of India. He has also worked with prominent think-tanks in Delhi and was with O.P. Jindal University's Jindal School of International Affairs as Assistant Professor. He has written extensively in areas of his interest in a number of platforms including book chapters, journals, web-portals and print media.

Capt. Sarabjeet Singh Parmar (Retd.)

Captain Sarabjeet S Parmar was commissioned into the Indian Navy on 01 July 1987 and retired on 30 June 2023.He has commanded two ships and a frontline anti-submarine warfare and anti-shipping helicopter squadron. He was member of the XI Indian Antarctic Summer Expedition in 1991, attended the Management Defence Course Conducted by the British Government at Colombo in 2005, and represented the Indian Navy in the first international HOSTAC (helicopter operations from ships other than aircraft carriers) conference held at Norfolk, USA in 2008. He has been a Research Fellow at the Manohar Parrikar Institute for Defence Studies and Analyses and worked in the Indian Navy's strategic apex level offices where, as Director Strategy was part of the core teamthat published the Indian Navy's unclassified maritime security strategy document titled *Ensuring Secure Seas: Indian Maritime Security Strategy* in 2015, carried out regional maritime assessments and completed the doctrine development plan. He was the Executive Director and Senior Fellow at the National Maritime Foundation prior retirement. He has written and spoken extensively on maritime security and strategy issues at various national and international conferences and his main areas of research include national and maritime strategy and security related aspects in the Indo-Pacific, piracy, HADR, and international maritime law with a focus on lawfare.He is presently a Distinguished Fellow at the Centre of Military History and Conflict Studies at the United Service Institution of India, New Delhi, and a Distinguished Fellow at Council of Strategic and Defence Research, New Delhi.His writings can be accessed at: https://www.researchgate.net/profile/Captain-Sarabjeet-Parmar https://independent.academia.edu/sarabjeetparmar

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Editor of two books on maritime security - Indian Ocean Challenges: A Quest for Cooperative Solutions (2013) and Geopolitics of the Indo-Pacific (2014), and the Role of Unmanned and Autonomous Vehicles in Future Maritime Operations. His articles and commentaries have been published in the Asian Bureau for Asian Research (NBR), the Lowy Interpreter, War on the Rocks, the ASPI Strategist, and the CSIS Pacific Forum.

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Arnab was commissioned as an electrical officer in 1994. He was deputed to IIT Delhi in 2001 for his Masters in Underwater Electronics and subsequentlywas appointed as the Project Officer at IIT Delhi to manage the Underwater R&D for Navy. He delivered multiple technology transfers including for the strategic submarine project related to underwater systems and algorithms. He also completed his PhD from IIT Delhi in 2007 in underwater signal processing.

He was invited to Tokyo University in 2014 as a visiting researcher to participate in design and development ofpassive acoustic monitoring systems for fresh water dolphins. He was also at the Acoustic Research Laboratory of the Tropical Marine Science Institute at the National University of Singapore in 2015 for a year, post his retirement from the Navy to understand underwater technology development from a global perspective.

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About ICWA

The Indian Council of World Affairs (ICWA) was established in 1943 by a group of eminent intellectuals led by Sir Tej Bahadur Sapru and Dr. H.N. Kunzru. Its principal objective was to create an Indian perspective on international relations and act as a repository of knowledge and thinking on foreign policy issues. The Council today conducts policy research through an in-house faculty as well as through external experts. It regularly organizes an array of intellectual activities including conferences, seminars, roundtable discussions, lectures and brings out a range of publications. It has a well-stocked library, an active website, and publishes the journal India Quarterly. ICWA has over 50 MoUs with international think tanks and research institutions to promote better understanding on international issues and develop areas of mutual cooperation. The Council also has partnerships with leading research institutions, think tanks and universities in India.


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