

Research Note

E-Learning Module – 2

Tropical Waters and Unique Characteristics: Physical Characteristics of the Indian Ocean

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Introduction

The Indian Ocean has traditionally functioned as a crucial hub for marine commerce, enabling the linkage between the East and West via ancient trade routes such as the Silk Road and Spice Route. It continues to serve as a crucial international trade pathway, connecting Europe, the Middle East, Africa, and Asia. The Indian Ocean, which constitutes 20% of Earth's surface, is unique in its status as the third-largest body of water. Unlike other oceans, it is land-locked to the north and does not expand into the cold temperatures of the northern hemisphere. Located north of southern Asia, bordered by the Arabian Peninsula and Africa to the west, the Malay Peninsula, Sunda Islands, Australia to the east, and Antarctica to the south, this region is important in global marine affairs¹. The entrance to the Indian Ocean is characterised by limited entry and departure ports, commonly called chokepoints. The Indian Peninsula acts as a partition, separating the northern Indian Ocean into two distinct basins: the Arabian Sea and the Bay of Bengal. Extending India's coastline to almost 7,600 km strategically places the country in a prominent position within the Indian Ocean.²

Covering more than 30% of the world's ocean area, the Indian Ocean is surrounded by 36 coastal and 11 inland nations, supporting nearly 30% of the global population. This geographic setup results in structural and circulation imbalances within the ocean.³

Famous for its warm waters, the Indian Ocean significantly influences regional climate, playing a crucial role in the Earth's climate system. Monsoon winds, fuelled by temperature variations between land and water, bring essential rains to the surrounding areas, affecting agriculture and shaping ecosystems. Beyond its climate impact, the ocean is rich in biodiversity, housing diverse marine life, such as colourful coral reefs and varied fish species. Each country along

¹ S.Z. Qasim, Some Unique Characteristics Of The Indian Ocean. Retrieved From: <https://qspace.gu.edu.qa/bitstream/handle/10576/9788/Some%20unique%20characteristics%20of%20the%20Indian%20Ocean.pdf;sequence=8>

² Bouchard, C., & Crumplin, W. (2010). Neglected no longer: the Indian Ocean at the forefront of world geopolitics and global geostrategy. *Journal of the Indian Ocean Region*, 6(1), 26-51.

³ S.Z. Qasim, Some Unique Characteristics Of The Indian Ocean. Retrieved From: <https://qspace.gu.edu.qa/bitstream/handle/10576/9788/Some%20unique%20characteristics%20of%20the%20Indian%20Ocean.pdf;sequence=8>

its shores has distinct political, population, economic, and environmental characteristics, contributing to their unique geographical profiles.⁴

Originally called "Ratnakara" in Sanskrit, meaning "creator of gems" due to its rich trading history, the Indian Ocean holds various intriguing facts. To comprehend its distinct features, this discussion will focus on its climate, depth, islands, and currents. The Indian Ocean basin is marked by a shallow northern region connecting to the Arabian Sea and the Bay of Bengal, while the southern basin extends towards Antarctica. Given its vast expanse, a comprehensive understanding of the physical characteristics such as size, shape, topography, temperature, and marine life is essential⁵. Developing strategies, technology, and policies for sediment management requires detailed comprehension of these unique Indian Ocean features, as explored in this research note covering both physical traits and socio-economic potential.

Climate

The tropical Indian Ocean is most of the Earth's most giant warm pool. How it interacts with the atmosphere greatly affects climate on both a regional and a global scale. The strong seasonal cycle is closely connected to different types of climate change that happen within a season, between seasons, and over more extended periods. In the equatorial Indian Ocean, the ocean currents change direction four times yearly to match the changes in the Indian Ocean monsoons.⁶

The Indian Ocean differs from the Atlantic and Pacific Oceans because Asia is in the north, making it harder for ocean currents to carry heat northward. The Himalayas and the Tibetan Plateau help make the monsoon system the strongest in the world. Asia has the largest monsoon on Earth. This causes immense changes in ocean currents throughout the year, such as the Somali Current and the Southwest/Northeast Monsoon Current south of India/Sri Lanka. Because there isn't a northward polar relationship like in the Atlantic and Pacific, the monsoon cycle is closely linked to the weather and the oceans. The Indian Monsoon Current greatly affects the current system in the Indian Ocean. In the North Indian Ocean, ocean currents and weather trends change because of monsoon winds that come and go. During the Indian summer monsoon, winds from the southwest push surface currents eastward. During the winter monsoon, winds from the northeast push surface currents westward. Changes in the surface temperature affect how the air and sea interact, affecting regional and world climate systems.⁷

The Indian Ocean is important because it is unlike other tropical seas because it doesn't have consistent equatorial easterlies. This is because the rising branch of the IO Walker circulation is anchored over the maritime continent. This stops climatological equatorial upwelling in the eastern ocean, which doesn't happen in other tropical seas. The Northern Hemisphere has upwelling off northwest Africa, the Arabian Peninsula, and India's east and west coasts. The

⁴ Bouchard, C., & Crumplin, W. (2010). Neglected no longer: the Indian Ocean at the forefront of world geopolitics and global geostrategy. *Journal of the Indian Ocean Region*, 6(1), 26-51.

⁵ Indian Ocean: Climate, Islands, Depth, Location, Currents. Retrieved From: <https://earthclipse.com/science/geography/indian-ocean.html>

⁶ Krishna, K. M., Song, G., Jack, D., & Manjunatha, B. R. (2014). Tropical Indian Ocean surface and subsurface temperature fluctuations in a climate change scenario. *J. Geol Geosci*, 3, 152.

⁷ Masumoto, Y., Hase, H., Kuroda, Y., Matsuura, H., & Takeuchi, K. (2005). Intraseasonal variability in the upper layer currents observed in the eastern equatorial Indian Ocean. *Geophysical Research Letters*, 32(2).

Southern Hemisphere has it along the northern edge of the southeast trades. A unique shallow cross-equatorial cell helps with northern upwelling, which isn't found in other seas. This cell also moves most of the heat across the equator.⁸ The northern IO border is landlocked, which causes wind and sea surface circulation patterns to change with the seasons. This is a unique feature of the IO.⁹

The Indian Ocean gets 6,000 km³ of river overflow, 88,000 km³ of rain, and 103,000 km³ of water evaporates daily. But there are some places, like the Bay of Bengal, where the water balance is positive. On the other hand, more water evaporates than falls in the Arabian Sea, especially near the coast. The most water evaporates in this area, and less water evaporates as you move southeast. On the other hand, there is a small amount of extra rain along the southwest coast of India. Large layers of water with very little oxygen can be seen in the Arabian Sea and the Bay of Bengal because of this mismatch. Different upwelling areas are caused by seasonal changes in circulation, mainly during the monsoon season. These areas differ from other extensive upwelling areas not tied to a specific season.¹⁰

The changes are caused by the Indian Ocean Dipole (IOD), a monsoon wind system with two types that affect the atmosphere over the ocean: easterlies and westerlies. There are three groups in it: neutral, positive, and negative. When the IOD is positive, the west is warm, and the east is cold. When the IOD is negative, the west is normal, and the east is cold. IOD works between the western and eastern parts of the Indian Ocean and is very important for determining how the weather will change from season to season and year in these areas.¹¹

The El Niño Southern Oscillation (ENSO) affects the atmosphere and oceans in the North Indian Ocean, along with the yearly monsoon cycle. Sea surface temperatures (SSTs) that aren't average in the central Pacific Ocean are what ENSO is all about. This causes changes in weather patterns around the world. Even though it mostly happens in the Pacific Ocean, it also occurs in the Indian Ocean. Many cyclones occur over the Bay of Bengal (BoB) during the rainy season.^{12 13} Cyclones can hit the shores of the Arabian Sea and the Bay of Bengal when the monsoon winds change. The rain has a significant effect on currents. From March to May, cyclones form because the Indian summer monsoon moves northward, and the sea surface temperatures are high. From October to December, there is a second peak caused by more rain.¹⁴ There are big effects on the temperature caused by the big difference between the salty

⁸ Schott, F. A., Xie, S. P., & McCreary Jr, J. P. (2009). Indian Ocean circulation and climate variability. *Reviews of Geophysics*, 47(1).

⁹ Wafar, M., Venkataraman, K., Ingole, B., Ajmal Khan, S., & LokaBharathi, P. (2011). State of knowledge of coastal and marine biodiversity of Indian Ocean countries. *PLoS one*, 6(1), e14613.

¹⁰ S.Z. Qasim, Some Unique Characteristics Of The Indian Ocean. Retrieved From: <https://qspace.gu.edu.qa/bitstream/handle/10576/9788/Some%20unique%20characteristics%20of%20the%20Indian%20Ocean.pdf;sequence=8>

¹¹ Indian Ocean: Climate, Islands, Depth, Location, Currents. Retrieved From: <https://earthclipse.com/science/geography/indian-ocean.html>

¹² Indian Ocean. Retrieved From: <https://web.archive.org/web/20010802084832/http://oceanographer.navy.mil/indian.html>

¹³ The World Factbook Indian Ocean. Retrieved From: <https://www.cia.gov/the-world-factbook/oceans/indian-ocean/>

¹⁴ Felton, C. S. (2014). *A study on atmospheric and oceanic processes in the north Indian Ocean* (Doctoral dissertation, University of South Carolina).

Arabian Sea, which evaporates a lot, and the relatively fresh Bay of Bengal, which has a lot of river runoff.¹⁵

Seabed Topography

The Carlsberg Ridge, the Central Indian Ridge, the Southwest Indian Ridge, and the Southeast Indian Ridge are some significant midocean ridges that shape the seabed in the Indian Ocean¹⁶. One thing that makes it stand out is the rough, inverted Y-shaped Mid-Indian Ridge, which is busy seismically and has many fracture zones that run north to northeast. There are a lot of attractive aseismic hills and plateaus, and some of them are even called "microcontinents."¹⁷ The Chagos-Laccadive Plateau and the earthquake Ninety-Degree East Ridge, which is 4800 km long, are two examples. They are both unique features in the Indian Ocean. The northern part of the Seychelles-Mascarene Ridge comprises granitic rocks with the same amount of crust and seismic velocities as continents. Many of these aseismic features line up north-northeast, parallel to the fault zones of the midoceanic ridge. This makes the Indian Ocean lean north-northeast.¹⁸

With an average depth of 3,890 metres (12,762 feet), the Indian Ocean is in the middle of the Pacific and Atlantic Oceans.¹⁹ In the middle of the mountain ranges are several deep valleys with sediment cones and abyssal plains more than 1.5 to 2.5 km thick. Most of the sands in the Indian Ocean build up near the continents and are mostly broken up continental rocks²⁰. The Indus and Ganges cones are two of the most important deposits. There are also smaller amounts in the valleys next to the west and east continents²¹. The sediment is more than 12 km deep in some parts of the Ganges cone. Along the Mid-Indian Ridge, the most widespread sediment type in the Indian Ocean comprises calcareous sediments. Terrigenous clay, siliceous clay and oozes, brown and red clay, and small areas of terrigenous sands include the rest of the sediment

¹⁵ Focus: The Tropical Indian Ocean. Retrived From:

https://iprc.soest.hawaii.edu/news/PDFs/06_09_IOworkshop.pdf

¹⁶ Chatterjee, S., Goswami, A., & Scotese, C. R. (2013). The longest voyage: Tectonic, magmatic, and paleoclimatic evolution of the Indian plate during its northward flight from Gondwana to Asia. *Gondwana Research*, 23(1), 238-267.

¹⁷ Heezen, B. C., Bunce, E. T., Hersey, J. B., & Tharp, M. (1964, January). Chain and Romanche fracture zones. In *Deep Sea Research and Oceanographic Abstracts* (Vol. 11, No. 1, pp. 11-33). Elsevier.

¹⁸ Weatherall, P., Marks, K. M., Jakobsson, M., Schmitt, T., Tani, S., Arndt, J. E., ... & Wigley, R. (2015). A new digital bathymetric model of the world's oceans. *Earth and space Science*, 2(8), 331-345.

¹⁹ Indian Ocean: Climate, Islands, Depth, Location, Currents. Retrieved From: <https://earthclipse.com/science/geography/indian-ocean.html>

²⁰ Ewing, M., Eittrich, S., Truchan, M., & Ewing, J. I. (1969, June). Sediment distribution in the Indian Ocean. In *Deep Sea Research and Oceanographic Abstracts* (Vol. 16, No. 3, pp. 231-248). Elsevier.

²¹ S.Z. Qasim, Some Unique Characteristics Of The Indian Ocean. Retrieved From: <https://qspace.gu.edu.qa/bitstream/handle/10576/9788/Some%20unique%20characteristics%20of%20the%20Indian%20Ocean.pdf;sequence=8>

in the Indian Ocean. Together, they make up more than 70% of all the sediment in the ocean.²²

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The Indian Ocean has a lot of different types of seafloor features, such as seamounts, troughs, and ridges.²⁴ Seamounts are mountains that rise at least 1,000 m (3,300 ft) from the ocean floor and are formed by volcanoes. They are not the same as the plate-boundary volcanic system of mid-ocean ridges because they are usually round or cone-shaped. Hot spot plumes melt through the moving tectonic plate, sending lava to the active volcanoes at the end of the chain. This creates these seamounts. Underwater active and dormant volcanoes can be found in the Indian Ocean. These volcanoes affect the diversity and spread of sediment. A complex sedimentary environment comprises places like the Ganges-Brahmaputra delta, the Red Sea, and the Arabian Sea. How these landforms interact with sound waves by reflecting, refracting, and scattering them can make it hard to tell the difference between seabed echoes, signals, and real things.²⁵

Despite the different types of terrain, the Indian Ocean has a zone of illumination that is 40 to 140 metres deep and lets sunshine in. Some call this layer the euphotic zone or the compensation depth because it's where 1% of the surface is lit up. As you move from the coast to the open ocean, the depth of this zone rises. Some places, like the northern Arabian Sea, the west coast of India, and the coast of Africa, have euphotic zones that are 40 to 60 m deep. Low clarity of about 60 metres is seen in the northern Bay of Bengal and along the east coast of India. This is because a lot of murky water from rivers flows into the Bay. On the other hand, the southern part of the Indian Ocean is very clear, and the euphotic zone goes from 80m to 140m.²⁶

Biodiversity

30% of the world's coral reefs are in the Indian Ocean. This ocean has 40,000 km² of mangroves, nine significant marine ecosystems, and important estuaries. Over the last two hundred years, expeditions and attempts by institutions have helped us learn a lot more about marine and coastal life in the IO. The Ocean Biogeographic Information System says that there are currently 34,989 species in the world, but different countries have different levels of information. The IO makes a big difference in the productivity of living marine resources. Each year, capture fisheries produce about 8 million tonnes of fish and culture fisheries have 23 million tonnes of fish, about 10% of world and 90% of global production, respectively. Most

²² S.Z. Qasim, Some Unique Characteristics Of The Indian Ocean. Retrieved From: <https://qspace.qu.edu.qa/bitstream/handle/10576/9788/Some%20unique%20characteristics%20of%20the%20Indian%20Ocean.pdf;sequence=8>

²³ Ewing, M., Eittreim, S., Truchan, M., & Ewing, J. I. (1969, June). Sediment distribution in the Indian Ocean. In *Deep Sea Research and Oceanographic Abstracts* (Vol. 16, No. 3, pp. 231-248). Elsevier.

²⁴ Polina Lemenkova. Insights on the Indian Ocean tectonics and geophysics supported by GMT. *Riscuri si Catastrofe*, 2020, 27 (2), pp.67-83. ff10.24193/RCJ2020_12ff. fffhal-03033533f

²⁵ Echo Sounder and Speed Log. Retrieved From: <http://thenauticalsite.in/NauticalNotes/EchoSpdLog/MyEchoSpdLog-Lesson01-EchoS.htm>

²⁶ S.Z. Qasim, Some Unique Characteristics Of The Indian Ocean. Retrieved From: <https://qspace.qu.edu.qa/bitstream/handle/10576/9788/Some%20unique%20characteristics%20of%20the%20Indian%20Ocean.pdf;sequence=8>

IO countries are tropical, making them great places for coastal and marine life diversity. 30% of the world's coral reefs are in this area.²⁷

The fisheries in the Indian Ocean are the third most important in the world. In 2020, they made up 15.5% of the world's catch, or 12,220,000 mt. Tuna, small oceanic fish, and prawns are some of the most important species in this area. The Food and Agriculture Organisation says that there are two areas in the Indian Ocean where fishing is allowed. The most critical area is the Eastern Indian Ocean, ranked fifth in the world and will contribute 8.4%, or 6,590,000 mt, to the world's catch in 2020. Shad, skipjack tuna, mackerel, prawns and sardines are some of the most common fish in this area. The Western Indian Ocean is the sixth-largest producing area in the world, with over 7.1% of the worldwide catch, or 5,630,000 mt, in 2020. Skipjack and yellowfin tuna, mackerel, sardines, prawns and cephalopods are the primary fish caught in this area. ²⁸

The Food and Agriculture Organisation says that in 2006–2007, the western Indian Ocean had one of the most significant percentages of ocean fisheries resources used for fishing. Compared to the other two seas, different parts of the Indian Ocean have the lowest oxygen levels. There are strong oxygen minimum layers on both sides of the equator, on the eastern side of the ocean. In the Indian Ocean, these layers can be found in the Arabian Sea and the Bay of Bengal in the north.²⁹

In the Indian Ocean, mangroves cover about 80,980 km². The Sundarbans, on the coast of South Asia, are the world's most extensive mangrove ecosystem, covering 4,795 km².³⁰ These mangroves are essential for keeping the land along the coast stable and for marine species because they are great places to breed and raise their young. Islands in the Indian Ocean have a variety of palm and conifer types as plants. The upwellings cause the nutrients in the surface seas to build up, especially in the northern Arabian Sea and along the coast of South Africa. Because of this event, there is a lot of phytoplankton, which supports large populations of marine animals useful for trade.³¹

Many kinds of marine life live in the nearby seas of the Indian Ocean (IOR), such as whales, dolphins, and fish. These sea creatures use sound to talk to each other, find their way, and hunt. Biological noise can mess up echoes from possible targets or cause sonar signals to pick up fake targets. The underwater world around the IOR is very different, which can lead to complex sound clutter with many sound waves reflecting off each other. This clutter could block out echoes from possible targets, making it hard to distinguish between clutter and real things.

²⁷ Wafar, M., Venkataraman, K., Ingole, B., Ajmal Khan, S., & LokaBharathi, P. (2011). State of knowledge of coastal and marine biodiversity of Indian Ocean countries. *PLoS one*, 6(1), e14613.

²⁸ The World Factbook Indian Ocean. Retrieved From: <https://www.cia.gov/the-world-factbook/oceans/indian-ocean/>

²⁹ S.Z. Qasim, Some Unique Characteristics Of The Indian Ocean. Retrieved From: <https://qspace.gu.edu.qa/bitstream/handle/10576/9788/Some%20unique%20characteristics%20of%20the%20Indian%20Ocean.pdf;sequence=8>

³⁰ Thiemann, T. (2023). Microplastic in the Marine Environment of the Indian Ocean. *Journal of Environmental Protection*, 14(4), 297-359.

³¹ Indian Ocean. Retrieved From: <https://www.britannica.com/place/Indian-Ocean/Trade-and-transportation>

Interference, signal slowing, and higher transmission losses complicate the distribution model, and changes must be made to get valuable data³².

Also, regarding underwater resources, the Indian Ocean is second only to the Pacific. It has a lot of polymetallic sulphides, cobalt-rich crusts, and other essential minerals.³³

Temperature

Compared to other seas in the world, the Indian Ocean is the warmest. Its equatorial temperatures are warmer than those of its neighbours, the other significant seas, and the Indian subcontinent. It is located between Africa, Asia, Australia, and the Indian subcontinent. Near the equator, temperatures are cooler, while near southern Africa and Australia, temps are higher. In the winter, the top water can be warmer than 28 °C in the eastern part of the ocean, close to the Equator. Temperatures in the northern Arabian Sea are about 22 to 23 °C, while temperatures in the Bay of Bengal are about 25 °C.³⁴

The Asian monsoon system is getting stronger because the tropical temperatures in the Indian Ocean are rising. Higher sea surface temperatures near the equator cause more water to evaporate, releasing heat stored in the water into the air. This process feeds the monsoon winds, which bring a lot of rain to the Indian subcontinent. Waters can move from the western Pacific Ocean to the eastern Indian Ocean through passageways that run through the Indonesian Archipelago. Even though the sea stays warm all year, the top temperatures change because of the monsoon season and water flow from large rivers in the area.³⁵

The Indian Ocean Dipole (IOD)³⁶ dramatically affects the Indian Ocean. The weather in close areas can be affected by changes in the Indian Ocean's temperature, especially during events like the Indian Ocean Dipole. These changes in the Indian Ocean's temperature can also impact world climate events, such as El Niño and La Niña in the Pacific Ocean³⁷. As the figure showing changes in sea surface temperature (SST) for different months shows, the Indian Ocean's unique temperature features significantly impact the weather in the region, the monsoons, and even the variability of the world climate.

³² Patra, R., Prabhuraman, S., & Das, A. (2022, February). AI & ML based Implementation of the Underwater Channel Model in the Tropical Littoral Waters of the Indian Ocean Region (IOR). In *OCEANS 2022-Chennai* (pp. 1-8). IEEE.

³³ Venkatshamy, K. (2016). The Indian Ocean Region in India's strategic futures: looking out to 2030. In *Power, Politics and Maritime Governance in the Indian Ocean* (pp. 17-41). Routledge.

³⁴ Indian Ocean. Retrieved From: <https://www.britannica.com/place/Indian-Ocean/Trade-winds-zone>

³⁵ De Deckker, P. (2016). The Indo-Pacific Warm Pool: critical to world oceanography and world climate. *Geoscience Letters*, 3(1), 1-12.

³⁶ Felton, C. S. (2014). *A study on atmospheric and oceanic processes in the north Indian Ocean* (Doctoral dissertation, University of South Carolina).

³⁷ Krishna, K. M., Song, G., Jack, D., & Manjunatha, B. R. (2014). Tropical Indian Ocean surface and subsurface temperature fluctuations in a climate change scenario. *J. Geol Geosci*, 3, 152.

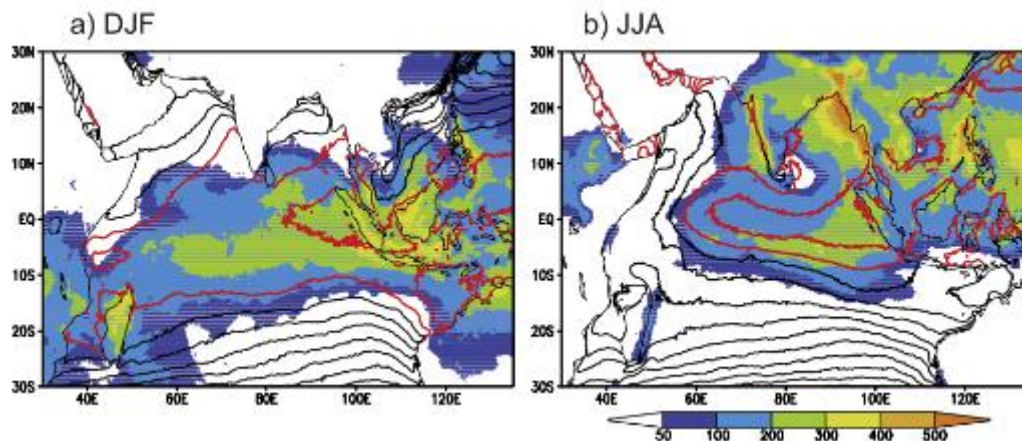


Figure 1: Sea Surface Temperature Variation during a) December, January, and February and b) June, July, and August.³⁸

The Indo-Pacific Warm Pool (IPWP) is a unique world event. It covers a large area and has a surface temperature that stays above 28 °C all the time, which is why it's called the "heat engine" of the planet. The IPWP keeps the surface seas warm all year and covers an area about 200 metres deep in most places. It covers the equator and areas close to it. Even though it's hot and active at the top, dissolved oxygen drops quickly, affecting living things. In the eastern Pacific Ocean, close to the equator, on the other hand, oxygen levels stay high below the surface. Planktonic creatures and other species have very different life cycles because surface waters don't change temperature with the seasons. This is because they don't have to move to warmer waters in the winter or learn to live in waters with vast temperature differences.³⁹ The monsoons directly affect the IPWP, which wind blows in different directions in the summer and winter.

Changes in temperature cause changes in the density of the ocean. Warmer water is less dense than colder water. The speed of sound in the ocean is changed by this difference in density caused by temperature. When the sea surface temperature is high, like in the equatorial and tropical parts of the Indian Ocean, sound moves faster below the water. These temperature changes make acoustic layers called sound channels. Sound waves are bent and confined in these channels, which lets them travel long distances. Also, differences in temperature between the water at the surface and the water lower down can cause thermoclines to form, which act as sound wave barriers or conduits.

Salinity

Because of the Indian Ocean's geography and climate, the Arabian Sea, especially the Red Sea and the Gulf, has very salty water. These water groups create a deep, salty layer in the Arabian

³⁸ Schott, F. A., Xie, S. P., & McCreary Jr, J. P. (2009). Indian Ocean circulation and climate variability. *Reviews of Geophysics*, 47(1).

³⁹ De Deckker, P. (2016). The Indo-Pacific Warm Pool: critical to world oceanography and world climate. *Geoscience Letters*, 3(1), 1-12.

Sea that significantly affects the flow at middle depths. This layer makes it harder for water to move from the southern Indian Ocean to the northern Indian Ocean.⁴⁰

In the Indian Ocean, the surface water saltness varies significantly from place to place, but it usually falls between 32 and 37 parts per thousand. The Arabian Sea has a thick, salty layer that goes out about 120 metres. This is because of solid evaporation at subtropical temperatures with mild yearly changes. Because rivers drain a lot of rainwater into the Bay of Bengal, the salinity of the surface layer is often below 32 parts per thousand.⁴¹

The Indian Ocean has significant seasonal and different monsoonal events that cause big changes in the saltiness of the water's surface. It is called the "dilution" basin because it is near the Great Ocean Conveyor Belt and gets a lot of tropical rain. When tropical storms hit, they lower the saltiness of the water in the basin, making it less salty.⁴² The yearly monsoon cycle is what makes the Indian Ocean richer. During the monsoon, river flow and land runoff add the most to the coastal surface layers. Upwelling brings nutrient-rich, low-oxygen water from deeper layers to the top, which enriches the layers below. The water masses in the north and south of the Indian Ocean have different amounts of liquid oxygen and nutrients. The water in the south has more nutrients than dissolved oxygen, while the water in the north has less nutrients than dissolved oxygen. Large amounts of inorganic phosphate (phosphorous) and nitrate (nitrogen) are in the northern Arabian Sea near the shores of Somalia, Bangladesh, Myanmar, and Indonesia. The amount of silicates in the Indian Ocean is higher than in the Atlantic or Pacific Oceans.⁴³

Because it is less thick, warm water with low salt levels tends to glide over the rest of the ocean for a long way without mixing right away. Because of this, density usually differs between the warm water that has been diluted and the water mass below it.⁴⁴

Way Ahead

The Indian Ocean exhibits diverse characteristics, attracting exploration and commercial activities.

- It is essential to comprehensively assess anthropogenic activities in the IO through a collaborative and multi-faceted approach.
- Enhanced scientific research and monitoring programs are crucial, utilising advanced technologies like remote sensing, oceanographic surveys, and underwater sensors to collect data on sea surface temperatures, ocean currents, and chemical composition.

⁴⁰ S.Z. Qasim, Some Unique Characteristics Of The Indian Ocean. Retrieved From: <https://qspace.gu.edu.qa/bitstream/handle/10576/9788/Some%20unique%20characteristics%20of%20the%20Indian%20Ocean.pdf;sequence=8>

⁴¹ Indian Ocean. Retrieved From: <https://www.britannica.com/place/Indian-Ocean/Trade-and-transportation>

⁴² De Deckker, P. (2016). The Indo-Pacific Warm Pool: critical to world oceanography and world climate. *Geoscience Letters*, 3(1), 1-12.

⁴³ S.Z. Qasim, Some Unique Characteristics Of The Indian Ocean. Retrieved From: <https://qspace.gu.edu.qa/bitstream/handle/10576/9788/Some%20unique%20characteristics%20of%20the%20Indian%20Ocean.pdf;sequence=8>

⁴⁴ De Deckker, P. (2016). The Indo-Pacific Warm Pool: critical to world oceanography and world climate. *Geoscience Letters*, 3(1), 1-12.

- Integrating these datasets will offer a comprehensive understanding of the ocean's physical characteristics and interaction with human activities.
- Research should also focus on how these physical characteristics impact deployed sensors. Encouraging sustainable practices, including responsible fisheries management and pollution control measures, is vital.
- A proactive and collaborative approach, incorporating scientific research, technological innovation, and international cooperation, will contribute to a more sustainable future for the Indian Ocean and its ecosystems.