The Indian Ocean and its Role in the Global Climate System

Edited by Caroline C. Ummenhofer and Raleigh R. Hood









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Preface

The Indian Ocean is unique and different and represents one of the great frontiers in climate science and oceanography. The Indian Ocean and its surrounding countries stand out globally as the region with the highest risk of natural hazards, with coastal communities vulnerable to weather and climate extremes. The vagaries of the Asian monsoon directly affect more than a billion people and a third of the global population lives in the vicinity of the Indian Ocean. The Indian Ocean is also particularly susceptible to human-induced climate change, with robust warming trends and pronounced changes in heat and freshwater observed in recent decades. Paired with a sparse and relatively short instrumental record, the Indian Ocean thus represents challenges to predict and forecast environmental conditions and their effects on climate and weather in the surrounding countries.

The Indian Ocean is unusual among tropical ocean basins due to its lack of steady easterlies and relatively deep thermocline, seasonal reversal of monsoon winds and concurrent ocean currents, and lack of northward heat export due to the Asian continent to the north. These characteristics shape the very dynamic intraseasonal and seasonal variability, air-sea interactions, and biological responses of the Indian Ocean. However, the advent of new technologies, an expanded observation system, and rapid advances in environmental predictions and forecasting capabilities in recent decades open new and exciting opportunities for improved environmental and climate risk management in a region particularly vulnerable to changing conditions.

Given the unique characteristics of the Indian Ocean and that it has traditionally been understudied, understanding of the Indian Ocean as a wholistic system is still limited. This book provides a rare interdisciplinary synthesis of recent advances in knowledge and understanding of the physical climate system in the Indian Ocean, interlinked with interactions with its biogeochemistry and ecology, and impacts on human and natural systems in surrounding countries. Recent trends and future projections of the Indian Ocean, including warming and extreme events—both in the physical and biogeochemical realm—such as marine heatwaves, climate and weather extremes, ocean acidification, and deoxygenation are detailed. The textbook identifies recent new understanding and technologies to provide stakeholders with relevant knowledge for more informed decision-making and highlights knowledge gaps to encourage students, practitioners, and researchers to help overcome these.

With a total of 20 peer-reviewed chapters, more than 175 figures, 3000 references, 100 educational resources and links directing readers to more in-depth information, and 100 glossary entries of key concepts, the book delivers a comprehensive overview of our current understanding of the Indian Ocean from an interdisciplinary perspective. Contributions by more than 90 authors from around the world with expertise across a wide range of fields (e.g., atmospheric and climate science, biogeochemistry, ecology, environmental science, fisheries, geology, history, meteorology, microbial ecology, numerical modeling, all fields of oceanography, paleoclimate, remote sensing, statistics, and weather forecasting) underpin the content of this textbook. Furthermore, all chapters were peer-reviewed by at least two experts in the field: constructive and valuable feedback from \sim 40 reviewers ensured that the material in the individual chapters and the book as a whole provided a comprehensive, interconnected, and up-to-date review of Indian Ocean science. The time and efforts of all members of the Indian Ocean research community that helped in completing this book are greatly appreciated.

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Glossary

- Aerosols Fine solid particles or liquid droplets in the atmosphere. Aerosol particles have diameters typically less than $1 \,\mu m \, (10^{-6} m)$.
- Agulhas Current Strongest western boundary current in the Southern Hemisphere that is fed by the waters flowing east and west of Madagascar to flow poleward along the eastern bank of the African continent.
- **Agulhas leakage** Relatively small component of the Agulhas Current that leaks westward into the Atlantic Ocean through eddies that are generated southwest of the Cape of Good Hope, South Africa. The warm and salty eddies derived from the Indian Ocean play a significant role in the upper branch of the global meridional overturning circulation.
- Agulhas Return Current Part of the poleward flowing Agulhas Current that retroflects south of the Agulhas Bank to flow eastward within the northern boundary of the Antarctic Circumpolar Current.
- Air-sea gas exchange Transfer (flux) of gases across the ocean/atmosphere interface. The flux is bidirectional and can lead to a release of gas from the surface ocean to the overlying atmosphere (=emission) or to an uptake of gas from the atmosphere into the surface ocean. The flux is mainly driven by the gas partial pressure difference between the surface ocean and the overlying atmosphere and the wind speed.
- Amount effect Phenomenon observed in many tropical settings in which the ratio of ¹⁸O/¹⁶O in rainwater is inversely proportional to the rainfall amount.
- Atlantic Meridional Overturning Circulation (AMOC) Zonally integrated meridional transport of surface and deep currents in the Atlantic. The AMOC transports up to $35 \text{ Sv} (1 \text{ Sv} = 10^6 \text{ m}^3 \text{ s}^{-1})$ and consists primarily of a northward-flowing, warm, and saline upper limb, and a southward-flowing, cold, and fresh lower limb.
- Anoxia Conditions in which the environment is completely devoid of oxygen (i.e., anaerobic or anoxic conditions).
- Antarctic Oscillation Also known as the Southern Annular Mode. Leading mode of large-scale atmospheric variability in the Southern Hemisphere, characterized by an anomalous pressure center over Antarctica and a zonally symmetric pressure anomaly of opposite sign at mid-latitudes. The positive (negative) phases of the mode are associated with poleward (equatorward) displacement of the midlatitude westerly winds.
- Anthropogenic carbon dioxide CO_2 generated by human activities, such as fossil fuel combustion, that enters the natural carbon cycle (usually through the atmosphere).
- **Biogeochemistry** Studies the cycling of crucial elements in natural systems. Thus biogeochemical refers to the processes that involve biological, geological, and chemical transformations of key elements such as carbon and nitrogen.
- Biological pump Transfer of carbon from the ocean surface to the deep ocean by sinking particles.
- **Bjerknes feedback** Positive feedback loop named after Jacob Bjerknes describing ocean-atmosphere interactions over the tropical Pacific that govern the development of El Niño-Southern Oscillation (ENSO) events. It involves reinforcing variations between surface winds, sea surface temperatures, and thermocline depth.
- **Boreal summer intraseasonal oscillation** Intraseasonal oscillation characterized by both eastward and northward propagating components most frequently observed in the Asian boreal summer monsoon systems.
- **Carbon biomass** Mass of organic carbon molecules/compounds in living biological organisms in each area or ecosystem at a given time.
- **Carbonate pump** Physicochemical processes that transport carbon as dissolved inorganic carbon (DIC) to the ocean's interior from the surface. The carbonate pump is the "hard tissue" component of the biological pump. It is propelled by calcium carbonate shell-forming surface-inhabiting marine organisms, like coccolithophores. Upon death or by their cast-off shells, the DIC formed is an important part of the oceanic carbon cycle.

- **Carbon isotopes** Isotopes are atoms of the same element but with different masses and may be stable or radioactive; two carbon isotopes (12 C and 13 C) are stable and one (14 C) is radioactive. Carbon isotopes may be selectively enriched or depleted relative to the others owing to differences in mass by processes related to climate and/or metabolism. Carbon isotopes are also used to measure primary production (13 C or 14 C uptake rate). δ^{13} C ratio is a common paleo proxy.
- **Central Pacific El Niño-Southern Oscillation (ENSO)** Type of ENSO event characterized by maximum surface anomalies in the central equatorial Pacific, distinct from canonical ENSO in terms of its spatial and temporal characteristics, as well as its teleconnection patterns. Also referred to as "ENSO Modoki", where "Modoki" is a Japanese word for "similar but different."
- **Chlorophyll-a** Green pigment absorbing most energy from wavelengths of violet-blue and orange-red light and used in oxygenic photosynthesis to generate chemical energy by photosynthetic plants.
- **Cloud radiative feedbacks** Effect of cloud fields on warming or cooling the atmosphere by altering vertical profiles of solar and/or infrared heating, and the changes in weather induced by these heating anomalies
- **Cold pool** Short-lived (up to one day) locally cooler zone of air (O(10-100 km)) in the atmospheric boundary layer formed by the sinking of negatively buoyant air (as a downdraft) that has been cooled by evaporation of cloud and rainwater (O(1 K)).
- **Convective quasi-equilibrium** Theoretical framework for the tropical atmosphere that assumes the atmospheric lapse rate is maintained close to a moist adiabat due to the occurrence of frequent, intense moist convection.
- **Coral bleaching** Whitening of coral resulting from the loss of a coral's symbiotic microalgae or the degradation of the algae's photosynthetic pigment during exposure to elevated temperatures.
- Cyclogenesis Broad term encompassing different processes leading to the formation of some sort of cyclone of any size.
- **Dark Ages Cold Period** Period spanning ~450–750 CE that was characterized by anomalously cool conditions across many parts of the Northern Hemisphere and may also have been associated with reduced rainfall across parts of Asia.
- **Denitrification** Microbial-driven stepwise reduction of nitrate (NO_3^-) to dinitrogen (N_2) gas. During this metabolic pathway (which occurs under low oxygen (suboxic) conditions), N₂O is produced as an obligate intermediate. However, when O₂ concentrations drop further and are on the verge of anoxia or sulfidic conditions (i.e., anoxia with the presence of hydrogen sulfide), N₂O is consumed by reduction to N₂.
- **Deposition** (wet/dry) Transfer of particles from the atmosphere to the surface ocean. Wet deposition is synonymous with the wash-out of atmospheric particles by rain.
- **Diabatic heating** Warming of air parcels through the addition of radiative heating or latent heat release associated with water phase change.
- **Diapycnal** Occurring across a surface of constant density in the ocean. When the density surface is horizontal, diapycnal exchange can be interpreted as vertical exchange.
- **Diazotrophs** Microbes (bacteria and archaea) that fix atmospheric nitrogen (N_2) gas into a more usable form, such as ammonia, and are able to grow without external sources of fixed nitrogen.
- **Diurnal warm layer** Thin (O(1-10 m)) stably stratified layer of the upper ocean that warms as much as 1-3 K per day through absorption of solar radiation and cools by a similar amount through infrared surface cooling and downward mixing at night.
- **Dust storm** A meteorological phenomenon common in arid and semi-arid regions, arising when a strong wind blows loose sand and dirt from a dry surface and moves fine sediment particles from one place and deposits them in another.
- **Eccentricity** Measure of the amount by which the Earth's orbit about the sun deviates from a circle, with periods of 405, 124, and 95 thousand years. The 124 and 95 thousand-year eccentricity bands are referred to as the ~100,000-year band.
- El Niño The warm phase of the El Niño-Southern Oscillation (ENSO), characterized by anomalous surface warming and weaker trade winds in the eastern equatorial Pacific Ocean.
- El Niño-Southern Oscillation (ENSO) Strong year-to-year climate variability originating in the equatorial Pacific Ocean through coupled ocean-atmosphere interactions. ENSO manifests itself in anomalous surface warming (El Niño) or cooling (La Niña) in the central to eastern equatorial Pacific that typically peaks in boreal winter.

- **Endemism** Ecological state of a biological species being native and restricted to a particular geographic region as a result of isolation or in response to environmental conditions.
- **Endosymbiotic dinoflagellates of corals** Photoautotrophic unicellular algae of the family Symbiodiniaceae (colloquially called zooxanthellae) residing within host coral cells, where the products of their photosynthetic processing provide most of the coral host's metabolic energy requirements.
- **Eutrophic environments** Surface ocean with high nutrient concentrations leading to high biological productivity (high photosynthesis). Eutrophic conditions are usually found in coastal areas due to nutrient input by rivers or groundwater.
- **Euphotic zone** Surface layer of the ocean that receives sunlight, allowing phytoplankton to perform photosynthesis (biological production), typically defined as extending down to the light level where there is only 1% of the flux compared to the surface.
- Free troposphere Portion of the atmosphere above the marine atmospheric boundary layer and below the tropopause.
- **Hadley circulation** Thermally driven meridional circulation in the atmosphere consisting of poleward flow in the upper troposphere, subsiding air over high-pressure regions of the subtropics, a return surface flow as part of the trade winds, and rising air in the Intertropical Convergence Zone.
- Halocline A sharp change in oceanic salinity at a particular depth.
- **Holocene Climate Optimum** Interval generally dated to 9500–5500 years ago and representing the first half of the Holocene (the climate period since the termination of the last ice age, 11,600 years ago); characterized by anomalous warmth in the high northern latitudes, likely owing to orbitally driven changes in summer sunlight.
- Hypersaline Water characterized by high salt concentration.
- **Hypoxia** Phenomenon that occurs in aquatic environments when dissolved oxygen in seawater is reduced in concentration to a point where it becomes detrimental to aquatic organisms living in the system. An aquatic system completely devoid of dissolved oxygen is termed anoxic but a system with low concentration (in the range between 1% and 30% saturation) is called hypoxic or dysoxic. Most fish cannot live below 30% saturation and hypoxia and the shoaling of hypoxic waters often leads to the mortality of smaller pelagic fish.
- **Indian Ocean Dipole (IOD)** Coupled ocean-atmosphere phenomenon in the tropical Indian Ocean peaking in boreal fall. Its positive phase is characterized by anomalous tropical southeastern Indian Ocean surface cooling and anomalous warming in the western tropical Indian Ocean.
- **Indonesian Throughflow (ITF)** Exchange of water from the Pacific Ocean into the Indian Ocean driven by the large-scale pressure gradient between the two ocean basins that weaves its way through the multitude of islands within the Indonesian archipelago.
- **Indo-Pacific Warm Pool** Broad region of sea surface temperatures warmer than about 28°C that spans the tropical Indian and western Pacific Oceans.
- **Interdecadal Pacific Oscillation (IPO)** Decadal mode of climate variability occurring in the Pacific with a period of 15–30 years. Its positive phase features a meridionally broad El Niño-like surface temperature anomaly pattern with cooling at higher latitudes in the North and South Pacific; similar to the Pacific Decadal Oscillation, which exhibits a more prominent Northern Hemisphere signal than the IPO.
- **Intertropical Convergence Zone (ITCZ)** Basin-scale near-equatorial belt of low pressure where the northeast trade winds meet the southeast trade winds. As these winds converge, uplifted moist air forms a band of heavy precipitation that migrates latitudinally with the seasons.
- Intraseasonal variability (ISV) Temporal oscillations with a dominant timescale falling within 20–100 days and peaking near 30–60 days.
- **Intraseasonal oscillation (ISO)** All-season slowly eastward moving ($\sim 5 \text{ m s}^{-1}$), large-scale (O(104km)) tropical cloud complex with a period ranging from 20 to 100 days.
- Kelvin wave Large-scale gravity wave in the atmosphere and ocean in balance with the Coriolis force, which exists either along a topographic boundary or an equatorial waveguide; Kelvin waves propagate eastward along the equator, but can also propagate along coastlines in the ocean and along mountain ranges in the atmosphere.
- Lacustrine Relating to lakes. Lacustrine sediments are composed of mineral and biological materials often linked to climate.

- La Niña The cold phase of the El Niño-Southern Oscillation (ENSO), characterized by anomalous surface cooling and stronger trade winds in the eastern equatorial Pacific Ocean.
- Leeuwin Current Poleward flowing eastern boundary current off the coast of Western Australia that transports relatively warm and fresh waters southward. This current is fed by the Indonesian Throughflow (ITF) and zonal flows from the subtropical southern Indian Ocean.
- Little Ice Age Period of global cooling spanning ~1450–1850 CE that was likely triggered by reduced solar irradiance and several large volcanic eruptions.
- **Madden-Julian Oscillation** (**MJO**) Boreal winter manifestation of the intraseasonal oscillation (ISO), characterized by predominantly eastward propagation across the Indo-Pacific Warm Pool. A traveling large-scale pattern of tropical deep convection that is flanked to the east and west by suppressed tropical rainfall. It is usually first observed near the east coast of Africa and travels eastward at 4 to 8 m s^{-1} .
- **Maritime continent** Region of large (Sumatra, Java, Papua New Guinea) and small islands and Indonesian Seas that act as a leaky boundary between the tropical Indian Ocean and the western Pacific Ocean and trigger frequent diurnal thunderstorm activity.
- Mascarene High Semi-permanent subtropical anticyclone located over the southern Indian Ocean.
- **Medieval Climate Anomaly** Period of anomalous climate spanning ~850–1250 CE characterized by enhanced warmth in the North Atlantic region.
- **Mesoscale** In oceanography, mesoscale refers to processes that occur at scales of eddies, typically from 10 to 100km or larger. Timescales are generally on the order of about one month.
- **Mesoscale eddies** Energetic, swirling, time-dependent water circulations occurring almost everywhere in the ocean with space scales of 50–500km and timescales of 10–100 days.
- **Methanogenesis** Final step of microbial organic matter decomposition (respiration), which takes place under strictly anaerobic (anoxic) conditions and results in the release of CH_4 . This process represents the major natural production pathway of CH_4 .
- **Microbial loop** Trophic pathway in the marine microbial food web where dissolved organic carbon is returned to higher trophic levels via its incorporation into bacterial biomass, and then coupled with the classic food chain formed by phytoplankton-zooplankton-nekton.
- **Mode of variability** Natural, recurrent climate phenomenon with an underlying space-time structure that displays a preferred spatial pattern and temporal variation in components of the climate system (e.g., ocean, atmosphere, cryosphere).
- **Moist static energy** Energy of an air parcel due to its internal and gravitational potential energy and latent heat content. This can be calculated as h = cpT + gz + Lq, where h is moist static energy, c_p is the specific heat capacity of dry air at constant pressure, T is temperature, g is gravitational acceleration, z is height, L is the latent heat of vaporization of water, and q is specific humidity.
- **Moisture mode** Type of tropical weather disturbance whose existence, scale, and propagation characteristics depend critically and predominantly on the evolution of water vapor within and above the marine atmospheric boundary layer.
- **Monsoon** Seasonally reversing winds coupled with the seasonal cycle of precipitation. Over South Asia, these winds are typically from the southwest during the months of May–September and from the northeast from October through early May.
- **Monsoon depression** Low pressure, westward propagating system observed in a monsoon trough. Over India, these have traditionally been categorized by the India Meteorological Department as monsoon lows, monsoon depressions, deep depressions, and cyclonic storms based on their wind speed and sea level pressure anomaly strengths.
- **Monsoon Intraseasonal Oscillation** Dominant mode of tropical intraseasonal variability observed over Asia in boreal summer. See also boreal summer intraseasonal oscillation.
- Nitrification Microbially-driven stepwise oxidation of ammonia (NH_4^+) to nitrate (NO_3^-). This is a chemoautotrophic (carbon fixation using energy derived from chemical reactions) metabolic pathway that occurs under oxic to suboxic conditions that produce N_2O as a by-product. This reaction is mediated by nitrifying bacteria and archaea. Due to its widespread occurrence, it is an important process for N_2O production in the global ocean.
- *Noctiluca scintillans* Mixotrophic dinoflagellate that meets its energy requirements through ingestion of external prey and via photosynthesis by green endosymbionts *Protoeuglena noctilucae* within its central cytoplasm.

- **Obliquity** The tilt of the spin axis with respect to the plane of the ecliptic that varies between a minimum of 22.05 degree and a maximum of 24.45 degree. Changes in the obliquity with a period of about 41,000 years affect the seasonality of incoming solar radiation equally in both hemispheres with a greater signal at high latitudes.
- **Oligotrophic environments** Surface ocean with depleted nutrient concentrations leading to low biological productivity (low photosynthesis). Oligotrophic conditions are usually found in the central gyres of the major ocean basins.
- Orography Portion of topography dealing with mountains. In coastal areas, mountains can steer or channel the winds.
- **Oxygen isotope** (δ^{18} **O**) Isotopes are atoms of the same element but with different masses that may be stable or radioactive; all oxygen isotopes (¹⁶O, ¹⁷O, and ¹⁸O) are stable. Oxygen isotopes are selectively enriched or depleted by processes related to climate and/or metabolism.
- **Oxygen Minimum Zone (OMZ)** Zone in which oxygen saturation in seawater in the ocean is at its lowest. This zone typically exists at depths of about 200 to 1500 m, depending on local circumstances. OMZs are found worldwide, especially in areas where the interplay of physical and biological processes concurrently lower oxygen concentrations and restricts the water from mixing with surrounding waters.
- **Pacific Decadal Oscillation (PDO)** Sea surface temperature pattern that varies on decadal timescales, characterized by pronounced sea surface temperature anomalies in the North Pacific and sea surface temperature anomalies of opposite signs in the tropical Pacific, and is closely related to the strength of the wintertime Aleutian low-pressure system; similar to the Interdecadal Pacific oscillation (IPO).
- **Phenological** Biological processes that undergo periodic cycles in nature generally related to seasonal and longer term variability.
- **Precession** Axial and apsidal precession are the wobble of Earth's axis and rotation of Earth's elliptical orbit over time with periods of about 19 and 23 kyr, respectively, which affect the seasonal cycle of incoming solar radiation and its hemispheric distribution.
- **Primary production** Synthesis of organic molecules by fixing atmospheric or aqueous carbon dioxide using light as the energy source (photosynthesis) or by oxidizing or reducing inorganic chemical compounds as the energy source (chemosynthesis).
- Rectifier effect Imprint of variability of one timescale onto another, usually longer, timescale.
- **Rossby wave** Planetary waves in the atmosphere and ocean that arise from the meridional variation of the effective Coriolis force due to the Earth's rotation, typically propagating westward with phase speeds that decrease with increasing latitude.
- Scleractinian corals Reef-building stony or hard corals in the phylum Cnidaria that build calcium carbonate skeletons.
- Sea-breeze Mesoscale circulation observed in coastal regions featuring an onshore near-surface wind and return flow aloft. This is driven by the daytime warming of land relative to the ocean and the resultant pressure gradients. Monsoons have historically been described as large-scale versions of the sea breeze, but recent advances in dynamics suggest this is not the case.
- Shared Socioeconomic Pathways (SSP) Global emissions pathways under different socioeconomic scenarios for use in Coupled Model Intercomparison Project Phase 6 (CMIP6), and widely used in the Intergovernmental Panel on Climate Change Sixth Assessment Report for future projections.
- **Solubility pump** Uptake and transfer of CO₂ from the atmosphere to the ocean driven by the CO₂ solubility and sinking of water masses to the deep ocean.
- **South Australia Current system** Coupled system of surface and deeper currents in the region south of Australia that permit exchange with the southeast Indian Ocean. The complex circulation includes shelf break currents flowing predominantly eastward and the counterflowing Flinders Current beneath that can rise up to the sea surface further offshore.
- **Southern Annular Mode** Leading mode of large-scale atmospheric variability in the Southern Hemisphere, characterized by an anomalous pressure center over Antarctica and a zonally symmetric pressure anomaly of opposite sign at mid-latitudes. The positive (negative) phases of the mode are associated with poleward (equatorward) displacement of the midlatitude westerly winds. Also known as the Antarctic oscillation.
- **Speleothem** Deposits formed in caves through the precipitation of minerals (typically calcium carbonate) from drip water. Speleothems are a commonly used proxy for past climates, particularly in (sub)tropical regions.

- **Spring predictability barrier** Refers to the fact that El Niño-Southern Oscillation (ENSO) forecast skill is significantly reduced during boreal spring, and any time a forecast is made for the other side of spring, because of the tendency for the ENSO phase to shift as El Niño and La Niña episodes decay after their usual winter peak.
- **Submesoscale** Submesoscale processes are those small-scale processes that occur at space scales of less than 10km and have timescales from hours to days.
- **Subsidence** Large-scale (O(10^2-10^4 km)) descent of atmospheric column mass coupled to rising motion elsewhere and sustained by column infrared cooling (O(1 hPa/day or 10^{-1} m s⁻¹)).
- Subtropical Geographic and climatic zone located between 30 to 40 latitudes in the Northern and Southern Hemispheres.
- **Tasman leakage** Large-scale current system that links the East Australian Current western boundary current of the South Pacific to a broad westward flow south of Tasmania into the southern Indian Ocean subtropical gyre.
- **Teleconnection** Changes in atmospheric or oceanic circulation over widely separated, geographically fixed spatial locations; often a consequence of large-scale wave motions, whereby energy is transferred from source regions along preferred atmospheric/oceanic paths.
- **Thermocline** Zone of maximum vertical temperature gradient, separating warm and cold layers of water. The 20°C isotherm is often used as an indicator of thermocline depth in tropical oceans.
- Trace gases Gaseous constituents of the Earth's atmosphere with atmospheric mixing ratios (mole fractions) less than 1%.
- **Troposphere** Lowest layer of the Earth's atmosphere, with a depth of ~ 10 km near the poles to nearly 20 km in the deep tropics, where most clouds and weather occur.
- **Walker circulation** The time-mean, thermally driven zonally oriented overturning circulation in the tropics with rising branches situated over the maritime continent and Indo-Pacific Warm Pool, and sinking branches found over eastern tropical Africa and the eastern Pacific Ocean.
- **Wyrtki jets** Wind-driven eastward jets in the surface layer of the Indian Ocean that occur twice per year (April–May and October–November) along the equator during the transition between the Northeast and Southwest Monsoons.

Acronyms

AMOC	Atlantic Meridional Overturning Circulation		
BCE	Before Common Era		
BP	Before Present		
CE	Common Era		
CLIVAR	Climate and Ocean: Variability, Predictability, and Change		
CMIP	Coupled Model Intercomparison Project		
DIC	dissolved inorganic carbon		
DJF	December-January-February		
DMI	Dipole Mode index		
DMS	dimethyl sulfide		
DOC	dissolved organic carbon		
ECMWF	European Centre for Medium Range Forecasting		
EEZ	exclusive economic zone		
EKE	eddy kinetic energy		
ENSO	El Niño-Southern Oscillation		
EOF	empirical orthogonal function		
FAO	Food and Agriculture Organization (of the United Nations)		
GCM	general circulation model		
GDP	gross domestic product		
ICOADS	International Comprehensive Ocean-Atmosphere Data Set		
IIOE	International Indian Ocean Expedition		
IMOS	Integrated Marine Observing System		
IndOOS	Indian Ocean Observing System		
IOD	Indian Ocean Dipole		
IPCC	Intergovernmental Panel on Climate Change		
IPO	Interdecadal Pacific Oscillation		
ISO	intraseasonal oscillation		
ISV	intraseasonal variability		
ITCZ	Intertropical Convergence Zone		
ITF	Indonesian Throughflow		
JGOFS	Joint Global Ocean Flux Study		
JJA	June-July-August		
JMA	Japan Meteorological Agency		
MAM	March-April-May		
MHW	marine heatwave		
MJO	Madden-Julian Oscillation		
NAO	North Atlantic Oscillation		
NPP	net primary productivity		
OHC	ocean heat content		
OMZ	oxygen minimum zone		
PDO	Pacific Decadal Oscillation		
POC	particulate organic carbon		
RAMA	Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction		