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Research
Report

The tropical oceanic gyres in the southern hemisphere

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Summary

The tropical oceanic gyres in the southern hemisphere are expansive systems of circulating ocean currents that play a vital role in Earth's climate and marine ecosystems. Driven by prevailing wind patterns and the Coriolis effect, these gyres rotate counterclockwise and are key to the distribution of heat, nutrients, and marine debris across the southern oceans. Notable gyres in this hemisphere include the South Atlantic Gyre, the South Pacific Gyre, and the Indian Ocean Gyre, each with distinct characteristics and significant impacts on global oceanic circulation and biological productivity. The South Atlantic Gyre is defined by the interaction between the westward-flowing South Equatorial Current, the Brazil Current, the Antarctic Circumpolar Current, and the Benguela Current, forming a complex circulation pattern that influences regional climate and marine life. Similarly, the South Pacific Gyre, covering approximately 10% of the global ocean surface, plays a crucial role in the distribution of heat and marine organisms across vast ocean areas. The Indian Ocean Gyre is unique for its dual system: the northern part influenced by monsoon winds, and the southern part following a traditional counterclockwise circulation pattern. These gyres are dynamic and not fixed, adjusting their positions based on seasonal wind patterns and the Earth's rotation. Environmental concerns associated with these gyres include the significant accumulation of marine debris, particularly plastic waste. These gyres act as focal points for the convergence of ocean currents, leading to the formation of garbage patches that pose severe threats to marine ecosystems and contribute to broader environmental issues such as greenhouse gas emissions. Notably, a large portion of this debris originates from land-based sources and is transported via major rivers, highlighting the global nature of this environmental challenge. Research and monitoring efforts have been crucial in enhancing our understanding of the Southern Hemisphere gyres. Advanced observational technologies and collaborative international programs have provided critical data on gyre dynamics, nutrient cycling, and the impacts of climate change. These studies underscore the interconnected nature of oceanic systems and the importance of continued scientific investigation to address the complex environmental issues associated with these essential oceanic features.

Characteristics of Oceanic Gyres

Oceanic gyres are large systems of circular ocean currents that play a crucial role in the Earth's climate system. These gyres are driven primarily by wind patterns and the Earth's rotation, resulting in a continuous flow of water that spans vast areas of the ocean. One of the most notable characteristics of oceanic gyres is their ability to drive the "ocean conveyor belt," a global circulation system that regulates nutrient flow, salinity, and temperature across the oceans[1].

Gyres are dynamic systems, not fixed to any specific location. They shift to align with prevailing wind patterns, which are influenced by the rotation of the Earth[1].
The Coriolis effect, along with planetary vorticity, horizontal friction, and vertical friction, contributes to the circulatory patterns created by wind stress curl[1].
This intricate interaction results in the formation of the major ocean gyres, including the Indian Ocean Gyre, North Atlantic Gyre, South Atlantic Gyre, North Pacific Gyre, and South Pacific Gyre[1]. Subtropical gyres, often referred to as "ocean deserts" due to their oligotrophic characteristics, cover approximately 60% of the ocean's surface. These gyres are known for their low productivity per unit surface area, as the downwelling of water takes nutrients deeper into the ocean, removing them from surface waters[2].
Despite this, their extensive coverage means that they still contribute significantly to the overall ocean production[2]. In subtropical gyres, nutrients are absorbed back into the water when organic particles fall through the ocean's layers[3]. The thickness of the homogenous layer within these gyres influences nutrient recycling; a thicker layer enhances phytoplankton growth by retaining nutrients for longer periods[3]. Conversely, if nutrients drop quickly below this layer, they become cut off from the surface waters[4]. The formation of oceanic gyres is a complex process influenced by several factors, including the Earth's rotation, surface winds generated by solar heating, and the shape of continental landmasses[5]. The interaction of these elements leads to the creation of vast rotating systems that are essential for distributing heat and maintaining the balance of marine ecosystems.

The Southern Hemisphere Gyres

The Southern Hemisphere gyres are large systems of circulating ocean currents driven by wind patterns and the Coriolis effect. These gyres are characterized by their counterclockwise rotation due to the Earth's rotation and are integral to the distribution of heat, nutrients, and marine debris across the southern oceans.

South Atlantic Gyre

The South Atlantic Gyre is located in the southern Atlantic Ocean, bordered to the north by the Intertropical Convergence Zone and to the south by the Antarctic Circumpolar Current (ACC). The gyre's northern boundary is formed by the westward-flowing South Equatorial Current, which brings water towards South America. This water then flows southward along the Brazil Current, forming the western boundary of the gyre. The southern boundary is created by the eastward-flowing ACC, which eventually carries the water towards the west coast of Africa. There, the water is brought northward by the Benguela Current, completing the gyre's circulation pattern[2][6]. The Benguela Current also experiences the

Benguela Niño event, analogous to the Pacific Ocean's El Niño, which impacts the primary productivity in the region's upwelling zones[2].

South Pacific Gyre

The South Pacific Gyre is one of the largest ecosystems on Earth, covering around 10% of the global ocean surface area. It is bounded to the north by the Equator, to the west by Australia, to the south by the Antarctic Circumpolar Current, and to the east by South America. The northern boundary is formed by the westward-flowing South Equatorial Current, which turns southward as it reaches the East Australian Current. The water then flows eastward with the ACC and moves north along the western coast of South America via the Humboldt Current, completing the gyre's circulation[2][7]. This gyre also encompasses Point Nemo, the oceanic point farthest from any landmass, making it a challenging area for scientific sampling[2].

Indian Ocean Gyre

The Indian Ocean Gyre is a complex system of currents extending from the eastern coast of Africa to the western coast of Australia. The gyre consists of two distinct systems: the northern and southern Indian Ocean Gyres. The northern part, known as the Indian monsoon current, is unique because it changes direction seasonally. During the summer, the current flows clockwise due to the southwestern monsoon winds, and during the winter, it flows counterclockwise driven by winds from the Tibetan plateau[8]. The southern part follows a more traditional gyre pattern, circulating water in a counterclockwise direction[8].

Interactions Between Southern Hemisphere Gyres

The Southern Hemisphere is home to several significant oceanic gyres, each playing a crucial role in the global ocean circulation system. These gyres exhibit distinctive interactions influenced by a combination of factors including wind patterns, Earth's rotation, and the presence of continental boundaries.

Mechanisms of Formation and Movement

Gyres in the Southern Hemisphere are primarily formed by the interplay of wind patterns and the Coriolis effect. The rotation of the Earth causes moving water to be deflected to the left, creating a counterclockwise motion in the Southern Hemisphere[7][9].
Additionally, the westerlies, which prevail between 30° and 60° latitude, drive surface water towards the east. When these currents encounter the continents, they are

deflected towards the equator, contributing to the formation of large-scale circular patterns[10].

Types and Characteristics

There are three main types of gyres found in the Southern Hemisphere: subtropical, tropical, and subpolar.

Subtropical Gyres

Subtropical gyres, which are the most prominent, form beneath regions of high atmospheric pressure. These vast and relatively stable ocean areas have a weaker eastern boundary current and a more powerful western boundary current [8]. Due to Ekman pumping, these gyres often drive downwelling, resulting in lower biological productivity compared to their cyclonic counterparts[2].

Tropical Gyres

Tropical gyres are typically driven by wind patterns near the Equator. Unlike subtropical and subpolar gyres, the Coriolis effect has minimal influence at the Equator, leading to an east-west flow rather than a circular one. A notable example is the Indian Ocean Gyre, which consists of two distinct gyres in the northern and southern regions[8].

Subpolar Gyres

Subpolar gyres form under low atmospheric pressure areas in the polar regions. These gyres are driven by wind, which pushes surface currents away from coastal areas. This displacement is compensated by upwelling of cold, nutrient-rich waters, making subpolar gyres regions of high biological productivity [8]. Examples in the Northern Hemisphere include gyres bounded by islands such as Iceland and Greenland, but similar dynamics apply to their Southern Hemisphere counterparts.

Impact of Climate Change

Recent studies indicate that the core positions of subtropical gyres, currently around 30° latitude in both hemispheres, are shifting towards higher latitudes. This movement is supported by satellite observational data and climate model predictions, suggesting that anthropogenic global warming is driving these changes [2].
Such shifts have significant implications for oceanic and atmospheric conditions, affecting wind, temperature, and precipitation patterns globally[11].

Environmental Concerns

Gyres also serve as focal points for environmental issues, particularly plastic pollution. The rotational nature of gyres tends to accumulate debris, creating large patches of floating plastic that pose a threat to marine ecosystems[9].
This accumulation underscores the importance of understanding and mitigating human impacts on these crucial oceanic systems. Interactions among the Southern Hemisphere gyres and their response to environmental changes continue to be a critical area of research, highlighting the interconnected nature of oceanic and atmospheric systems on a global scale.

Environmental Issues

The tropical oceanic gyres in the southern hemisphere are significant accumulators of marine debris, primarily plastic, due to the convergence of ocean currents. A substantial portion of this debris originates from land-based sources and is transported via rivers. Notably, ten rivers globally are responsible for flushing approximately 90 percent of the plastic that reaches the world's oceans: the Yangtze, Indus, Yellow River, Hai River, Nile, Ganges, Pearl River, Amur River, Niger, and the Mekong[2][12].
Garbage patches within these gyres contain plastic and debris of various sizes, from microplastics and small-scale plastic pellets to larger objects such as fishing nets and consumer goods lost from floods and shipping mishaps[2]. These patches are not compact; while most debris is near the surface, it can also be found up to more than 30 metres (100 feet) deep[2].
Plastic debris poses severe threats to marine life and the broader ecosystem. The pollutants can release toxic chemicals and contribute to greenhouse gas emissions, complicating efforts to combat climate change[2][12].
The mobility of marine debris, driven by winds and ocean currents, often leads to its accumulation in areas with weaker currents, such as the centre of oceanic gyres[12].
This phenomenon is evident in the Great Pacific Garbage Patch, where the confluence of currents creates a vortex of plastic waste. Asia, particularly China, leads in ocean plastic pollution, contributing an estimated 2.4 million metric tons annually, about 30 percent of the global total[2][12].

The impact of this pollution extends to various locations, with strong currents distributing debris to shorelines worldwide, thereby harming local environments and marine organisms[12].

Efforts to address these environmental issues include increasing public awareness and scientific research on the effects of plastic pollution. For instance, artist Maria Cristina Finucci founded the "Garbage Patch State" at UNESCO in 2013 to highlight the problem[13].

Such initiatives aim to galvanize global action to mitigate the detrimental effects of plastic waste on oceanic ecosystems.[2]

Nutrient Dynamics and Biological Activity

Primary production in the ocean is heavily dependent on the presence of nutrients and the availability of sunlight. Key nutrients include nitrogen, nitrate, phosphate, and silicate, which are critical in the biogeochemical processes of the ocean. A commonly accepted method for relating different nutrient availabilities to each other in order to describe chemical processes is the Redfield, Ketchum, and Richards (RKR) equation, which outlines the ratios of these nutrients involved in photosynthesis and respiration. With the correct ratios of nutrients and sufficient sunlight, photosynthesis produces plankton and oxygen, with nitrogen often being the most limiting nutrient to production[2].

The marine distributions of dissolved nutrients are produced by complex interactions between biological fluxes and physical transport and mixing processes, with the Southern Ocean playing a key role on a global scale. The upwelling of deep waters and ventilation of the low-latitude thermocline in the Southern Ocean significantly influence the physical and biogeochemical properties of ocean water masses. These processes affect the distribution of macro- and micronutrients by modifying the nutrient-rich waters upwelled to the surface, which are then subducted into the ocean interior as mode and intermediate waters[14].

The nutrient-poor upper ocean waters of the subtropical gyre play globally important roles in ocean carbon uptake, largely mediated by biological processes. However, the exact processes supplying nutrients required to support net biological production in these ecosystems remain unclear. Research highlights the critical role of physical processes, particularly eddies, in regulating nutrient supply and the downward flux of sinking organic matter. The depth over which organic particles are remineralized sets constraints on the productivity of overlying waters, presenting a field-testable hypothesis[4].

Seasonal cycles in atmosphere and ocean circulation strongly influence the biological productivity of near-surface waters. For example, the subtropical regions experience dramatically low productivity due to wind stress curl driving large-scale downwelling, while highly productive coastal boundaries benefit from wind-driven upwelling. This circulation and atmosphere-ocean interaction have significant impacts on biological productivity. High concentrations of phytoplankton, indicated by chlorophyll a distribution, lead to increased solar radiation absorption and influence air-sea interactions[15].

Cold water currents, which contain large amounts of nutrients, are critical to marine life. Regions where cold water mixes with warm, nutrient-poor water often exhibit high levels of biomass and biodiversity. This mixing is crucial for the base of the food chain, supporting significant commercial species such as tuna, swordfish, and squid, and providing essential information for managing fisheries and protecting endangered species[11]

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Research and Monitoring

Since the reviews of Schott and McCreary (2001) and Schott et al. (2009), the spatial coverage of observations and length of time series in the study of oceanic gyres have significantly increased. This enhancement allows the observation of many previously unresolved processes [15].

The sustained efforts of researchers and funding agencies, notably through initiatives such as the International Indian Ocean Expeditions (I and II), CLIVAR, and GOOS, have been fundamental in advancing our understanding of the Indian Ocean's influence on climate variability. These contributions have improved our capability to forecast climate variability and extreme events [15].

The present study leverages a combination of datasets to analyze gyre-scale circulation comprehensively. High-precision altimetric sea surface height (SSH) data, continuously collected since late 1992, provide essential space-time context [16]. The WOCE hydrographic survey, conducted in the South Pacific between 1991 and 1996, included many transects and middepth velocity measurements from autonomous floats. Significant transects were repeated in 1996 and 2001, enriching the dataset with temporal comparisons [16].

The Argo profiling float project, which began deploying floats over most of the South Pacific in 2004, complements SSH data by measuring dynamic height variability on large spatial scales and providing direct velocity measurements at 1000-m depth, thereby continuing the WOCE time series [16].
This combination of data sources has been indispensable in making recent advances in the study of oceanic gyres [16]. The analysis and graphing for these studies were completed using software tools such as Matlab R2015a and Ferret, a product of NOAA’s Pacific Marine Environmental Laboratory [17][16]. Data from several sources, including HadISST, AVISO, and CCMP winds, were used to ensure comprehensive coverage and accuracy in the findings [17].

The efforts of national and international programmes have been crucial in facilitating this research, and the continued support from agencies and collaborative initiatives is essential for future advancements in the field [15][17].

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