Eos

Ocean Deserts Could Help Capture CO_2 and Mitigate Global Warming

Various nutrient sources in the upper waters of oceanic subtropical gyres, which are the Earth's largest oligotrophic ecosystems, play a crucial role in governing the sequestration of atmospheric CO_2.

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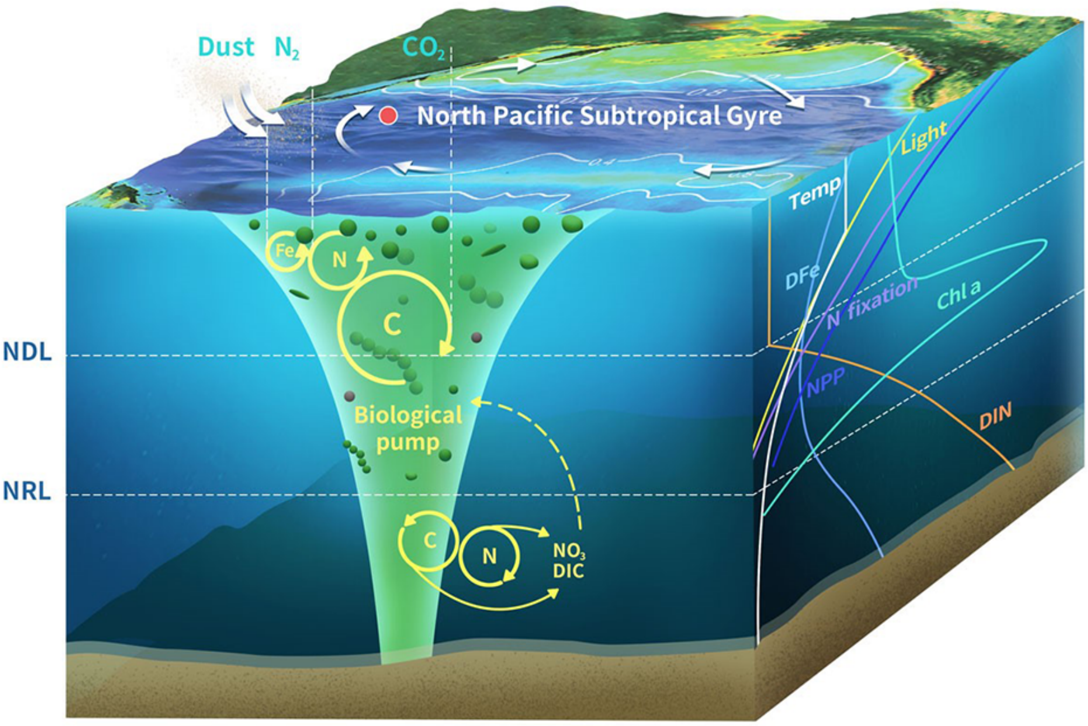


Illustration of vertical nutrient and organic carbon profiles within the oligotrophic North Pacific Subtropical Ocean, elucidating the interplay of various nutrient sources including diazotroph-derived nitrogen that govern the intricate process of carbon sequestration in this expansive oceanic domain. Credit: Hong Zhou

Editors' Vox is a blog from AGU's Publications Department.

Subtropical gyres are basin-wide currents that form vast ocean deserts covering between 26 and 29 percent of the world's surface ocean and impact the supply and movement of nutrients. While there have been some major advances over the past few decades, our understanding of these gyres is still limited.

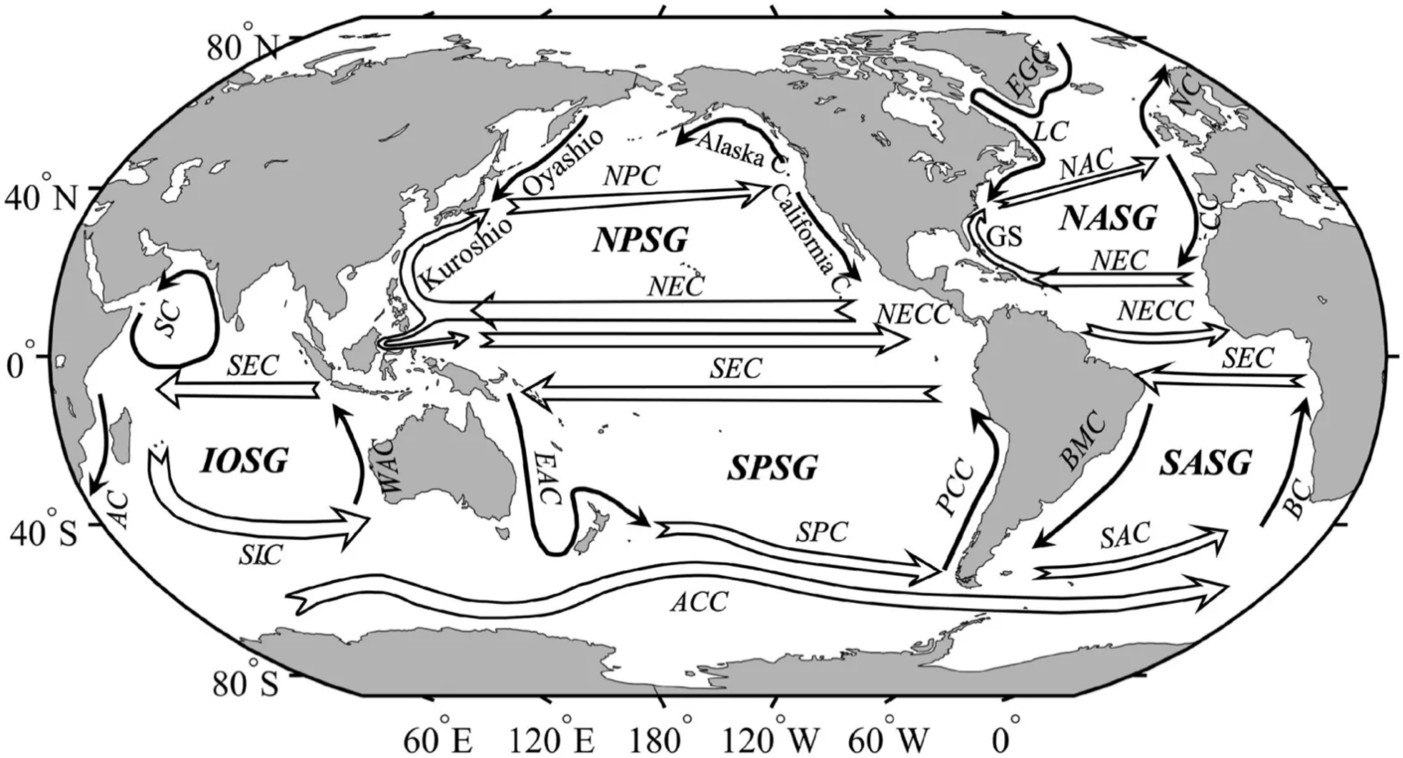
A **recent study** in ***Reviews of Geophysics*** presents a comprehensive data analysis of subtropical gyres in the north Pacific. We asked the authors to give an overview of subtropical gyres, describe how scientists study them, and outline what questions remain.

In simple terms for a non-specialist, what are subtropical gyres and where do they occur?

Remote from continents, subtropical gyres are basin-wide ocean currents that circulate in a clockwise direction in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. They occur globally in subtropical regions and are present in the North and South Pacific Oceans, the North and South Atlantic Oceans, and the Indian Ocean.

Subtropical gyres are formed by winds blowing westward near the equator and eastward at middle latitudes. The Earth's rotation causes seawater to move to the right (in the sense of wind direction) in the Northern Hemisphere and to the left in the Southern Hemisphere, creating an anticyclonic circular motion in the upper several hundred meters of subtropical regions.

These water movements include the North/South Equatorial Current, a swift and narrow poleward western boundary current, an eastward mid-latitude current, and a weaker and much broader equatorward eastern boundary current.



Long-term average patterns of the major global surface ocean currents and identification of the five subtropical gyres (in bold). Credit: Dai and Luo et al. [2023], Figure 1

What are euphotic zones and why are they important to understand and model?

Euphotic zones are the upper layers of the ocean, ranging from tens to over a hundred meters thick, where sunlight penetrates for phytoplankton, the microbial primary producers, to carry out photosynthesis and grow. During photosynthesis, CO_2, water, and nutrients are converted into organic matter, thereby providing food to almost the entire marine ecosystem. When these organisms die, some of them sink to the deep oceans, where they are remineralized back into CO_2 and inorganic nutrients.

Because of the ocean's stratification, which is when less dense (warmer and/or less salty) waters stay above denser (colder and/or saltier) waters, deep waters take hundreds to thousands of years to return to the surface. This allows CO_2 to be stored over long periods in the deep oceans, reduces atmospheric CO_2 concentrations, and partially alleviates global warming. However, the slow water exchange also prevents remineralized nutrients from reaching euphotic zones in many regions, reducing biological productivity. In summary, the euphotic zones are crucial because most marine organisms inhabit these regions, where most energy and organic materials needed for sustaining marine ecosystems are harvested and synthesized.

In many regions, the euphotic zones can be characterized into two vertical layers. The upper euphotic zones are sufficient in light but lack nutrients while the lower euphotic zones are nutrient-rich yet limited in light. In our paper, we highlight why it's necessary to explore the euphotic zones, particularly those in subtropical gyres, using this two-layer framework in order to better predict their changes under future warming climate.

What physical and ecological roles do subtropical gyres play in the ocean system?

Subtropical gyres are a critical component of the ocean's circulation system that redistributes water, salt, heat, carbon, oxygen, and nutrients around Earth.

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Subtropical gyres store a considerable amount of heat and carbon and therefore play an essential role in the functioning of Earth's system, including its climate.

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Subtropical gyres are also the largest continuous ecosystems on Earth. Their currents and water convergence limits nutrients that reach euphotic zones, limiting the growth of organisms. Therefore, subtropical gyres are sometimes referred to as “ocean deserts”.

However, certain microorganisms are well adapted to live in these nutrient-poor regions; for instance, tiny bacterial cells called *Prochlorococcus* are small enough that they can acquire sufficient nutrients to grow. Furthermore, a particular group of microbes termed diazotrophs can fix abundant nitrogen gas into a form that allows them to get enough nitrogen.

It is widely acknowledged that subtropical gyres serve as the primary regions for marine nitrogen fixation due to their ideal conditions for these diazotrophs: they are warm, sunlight is abundant in surface waters, and forms of other nitrogen nutrients are extremely low making them good competitors in these systems. Subtropical gyres cover about 30% of the global ocean and contribute a significant portion of total primary production.

Some studies suggest the oligotrophic subtropical gyres are expanding at an accelerating rate in response to anthropogenically induced climate change. Stressors associated with climate change, such as warming, deoxygenation, and ocean acidification, can have profound impacts on the ecosystems in subtropical gyres.

How do scientists observe and gather data from subtropical gyres?

Scientists deploy a number of tools including ships from which instruments are used to measure physical properties such as temperature, salinity, and currents. Seawater samples are collected to study nutrient concentrations and examine the types of organisms present. The activities of these organisms and how they impact chemical properties of seawater are also explored.

There are challenges to conducting large-scale surveys in the remote and vast subtropical gyres using research vessels including the technological and financial resources that support such work. One strategy to improve our understanding of subtropical gyres with limited resources is to establish time-series stations that are visited regularly to explore how a specific region of the ocean is varying over time.

Increasingly, oceanographers are using robotic technologies such as floats, gliders, saildrones, and wavegliders that do not require research vessels and people working at sea to collect observations about the subtropical gyres.

Photo of a saildrone, an autonomous sailing drone used to collect high quality oceanic and atmospheric observations. Credit: NOAA

Additionally, sediment traps can be deployed several hundred meters below the sea surface for periods of days, months or a year, to collect sinking organic particles and evaluate carbon sequestration.

Satellites also remotely sense temperature, currents, phytoplankton biomass, and other properties to provide valuable data with a frequency of every few days.

How have past time-series studies advanced our understanding of subtropical gyres?

Time-series studies conducted since 1988 in subtropical gyres near Hawaii in the Pacific and Bermuda in the Atlantic have advanced our understanding. These time-series stations have been regularly surveyed roughly every month. The studies have revealed higher primary production in the regions than previously thought, challenging the notion of these gyres as ocean deserts.

One striking observation from these time series is the unexpected temporal variations in biogeochemical characteristics at timescales from hours to decades. Throughout the spring to fall period, the time-series stations near Hawaii and Bermuda experience a regular drawdown of CO_2 due to the activity of phytoplankton engaging in photosynthesis, even in the absence of nitrogen nutrients.

Subsequent studies have further demonstrated that this CO_2 drawdown and the ensuing sequestration within these gyres are partly sustained by N_2 fixation. At decadal time scales, an increase in marine biomass and production near the two stations contradicts suggestions of declining global marine production, warranting further investigation.

What are some of the unresolved questions where additional research, data, or modeling are needed for understanding subtropical gyres?

One important question is whether subtropical gyres are real ocean deserts and if their productivity is as low as what we have traditionally thought. Time-series measurements near Hawaii suggest a moderate level of productivity, while large spatial variations in productivity seem to exist. Satellites can monitor large areas of subtropical gyres, but current algorithms using satellites still cannot produce consistent and reliable estimates of productivity.

Another outstanding question is what are the key mechanisms controlling organic carbon export out of euphotic zones into deeper waters in subtropical gyres?

Addressing these questions could help project the potential capability for carbon sequestration in subtropical gyres and explore if there are viable ways to enhance ocean carbon sequestration to mitigate global warming.

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It is difficult to answer these questions for subtropical gyres due to their low nutrient levels and remote locations. More sensitive instruments and measurement methods need to be developed to detect low nutrient and biomass levels. We also suggest strategies of establishing collaborative observational networks including research vessels, time-series stations, autonomous platforms, and satellites to allow for significant advances in acquiring data in subtropical gyres. These data can be better used by being integrated to biogeochemical models or processed with new algorithms such as machine learning and artificial intelligence.

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