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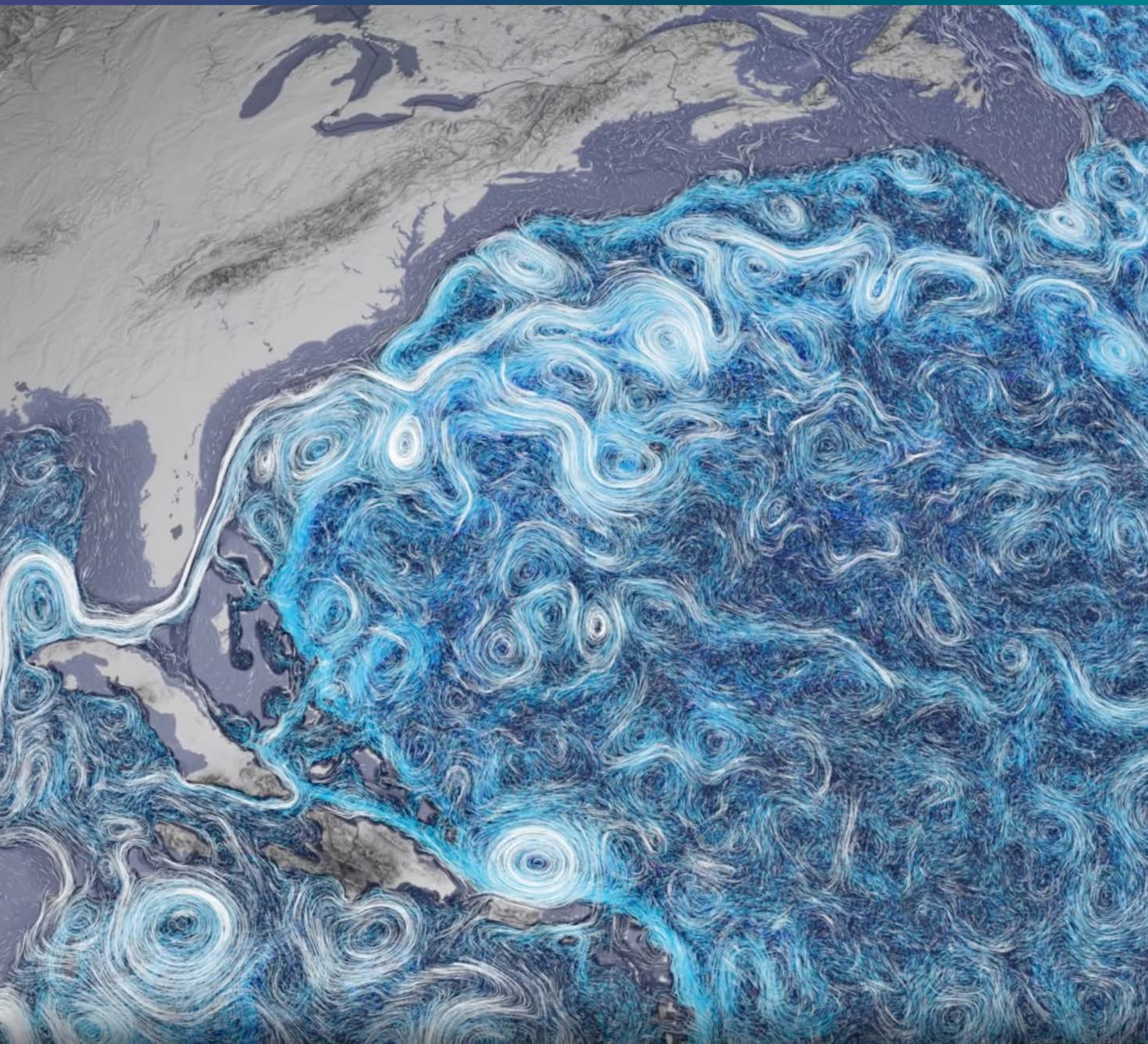
Ocean Fronts



Ocean fronts separate water masses of different physical and biogeochemical properties.

Ocean fronts are hotspots for marine biodiversity and play an important role in the climate system, influencing the exchanges of CO_2 and heat between the ocean and the atmosphere.

Climate change is impacting ocean fronts with far reaching consequences for ecosystems and fisheries.

From ancient Norsemen to modern-day fisher communities, the importance of ocean fronts has long been recognised. Ocean fronts act as hotspots for marine biodiversity, attracting fishes and various other marine animals, making them significant areas for fisheries. Additionally, ocean fronts play an important role in regulating the Earth's climate by influencing the exchange of heat and carbon dioxide (CO_2) between the ocean and the atmosphere.

As the oceans get warmer with climate change, the location, number and intensity of ocean fronts may change. This could have far-reaching implications for the climate system, marine ecosystems and global fisheries.

Here we take a closer look at the importance of ocean fronts and the potential implications of future changes in frontal activity.

What are ocean fronts?

The seemingly continuous ocean hosts many ocean fronts. Just like fronts in the atmosphere, which separate cold air masses from warm air masses, ocean fronts separate water masses with different physical and biogeochemical properties, including salinity, temperature, nutrients and biomass.

Ocean fronts can range in length from tens of metres up to many thousands of kilometres, and can be as wide as hundreds of kilometres. They can persist over a variety of timescales, ranging from days to years. Many ocean fronts emerge and disappear at the same locations during the same season year after year.

While some can be observed from ships, ocean fronts are usually identified using satellite images or oceanographic instruments such as drifting buoys. The buoys are equipped with sensors that can detect variations in the physical properties of water such as temperature, salinity and nutrient content.

Figure 1: Photo taken in the Gulf of Alaska showing a front between blue waters loaded with glacial sediments and clays coming from rivers and the darker Gulf of Alaska waters (2007, Ken Bruland, professor of ocean sciences at University of California-Santa Cruz). Source: https://www.adn.com/science/article/mythbusting-place-where-two-oceans-meet-gulf-alaska/2013/02/05/

Ocean fronts form when water masses with distinct physical properties interact. This can happen through various processes in which ocean currents, jets, meanders, tides, winds, topography and the Earth's rotation all play a role.

For instance, winds can push water masses with different temperatures towards each other, giving rise to a front at their boundary. Strong currents can also carry water from different regions (Figure 1), causing them to meet and form ocean fronts where they intersect.

Ocean fronts can be classified according to their formation:

Western boundary current fronts: these are associated with strong persistent currents along the western boundaries of the world's ocean basins. Famous examples of these currents with many fronts are the Gulf Stream in the Atlantic Ocean, and the East Australian Current made famous in the "Finding Nemo" movie (Figure 2).

Subtropical convergence fronts: trade winds at lower latitudes and westerlies at higher latitudes can cause cold water masses from high latitudes to meet up with warm water masses from the tropics. This creates the perfect environment for marine life, like in the Subtropical Convergence in the South Atlantic Ocean (Figure 2).

Southern Ocean fronts: these are related to the dynamics of the Antarctic Circumpolar Current, the world's strongest current that flows clockwise around Antarctica. The Polar Front, for example, is a natural boundary that separates cold Antarctic waters from warmer sub-Antarctic waters, with not only different waters on each side but also different ecosystems and climates (Figure 2).

Coastal upwelling fronts: when wind blows parallel to the coast it can cause cold water from the deep ocean to rise to the surface, a process known as upwelling. The contrast between the cold water from the depth and the warmer surface water gives rise to fronts, such as those found in the California Current System (Figure 2).

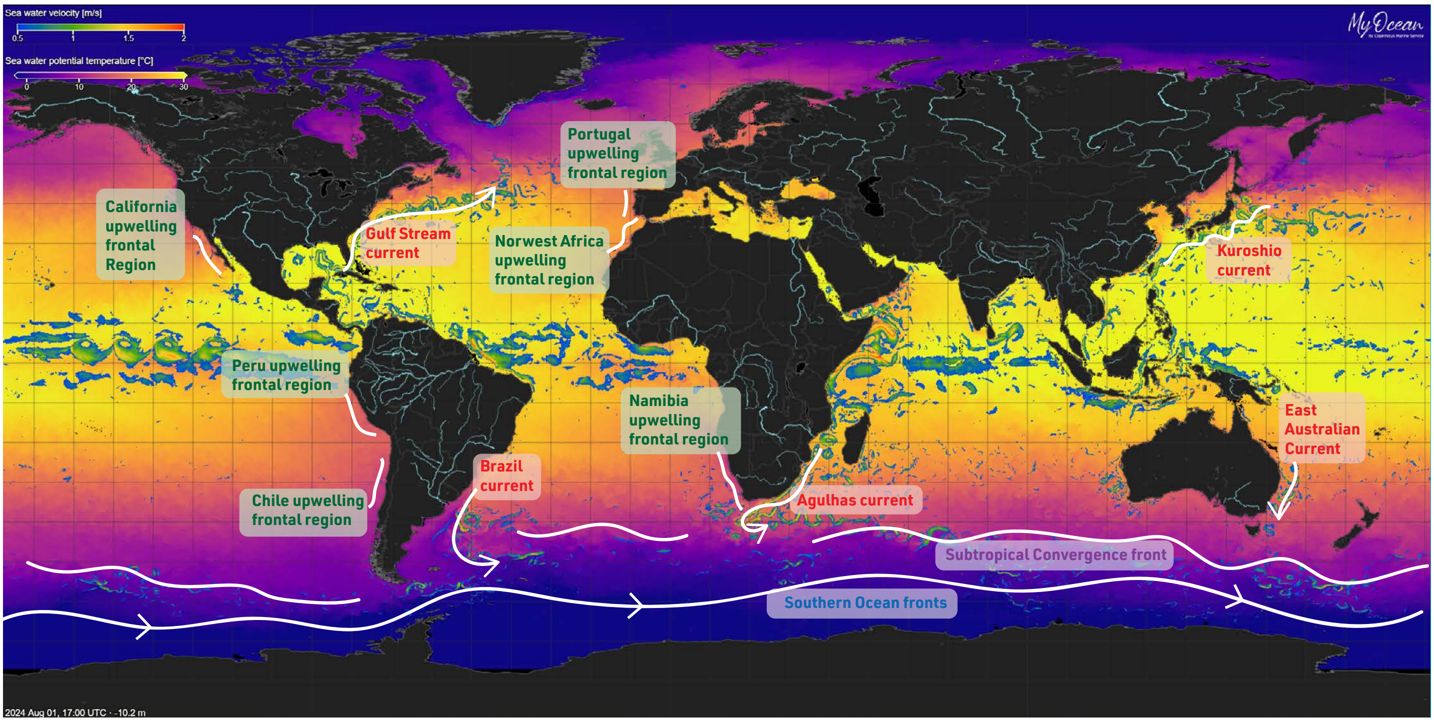


Figure 2: Major global frontal regions and associated ocean currents. Red indicates warm western boundary currents, green are persistent upwelling frontal regions, blue are Southern Ocean fronts and in purple the subtropical convergence front. Sea surface temperature and sea surface velocity map was made available by Copernicus Marine Service through their MyOcean visualisation web portal Source: [https://marine.copernicus.eu/access-data/myocean-viewer].

What are the differences between currents, eddies, jets, meanders & fronts?

Looking out over the still ocean on days with no wind or waves, it is hard to imagine just how turbulent the ocean really is. Oceanographers had no idea until the first satellites revealed that the entire ocean was, in fact, 'boiling' with movement (Figure 3).

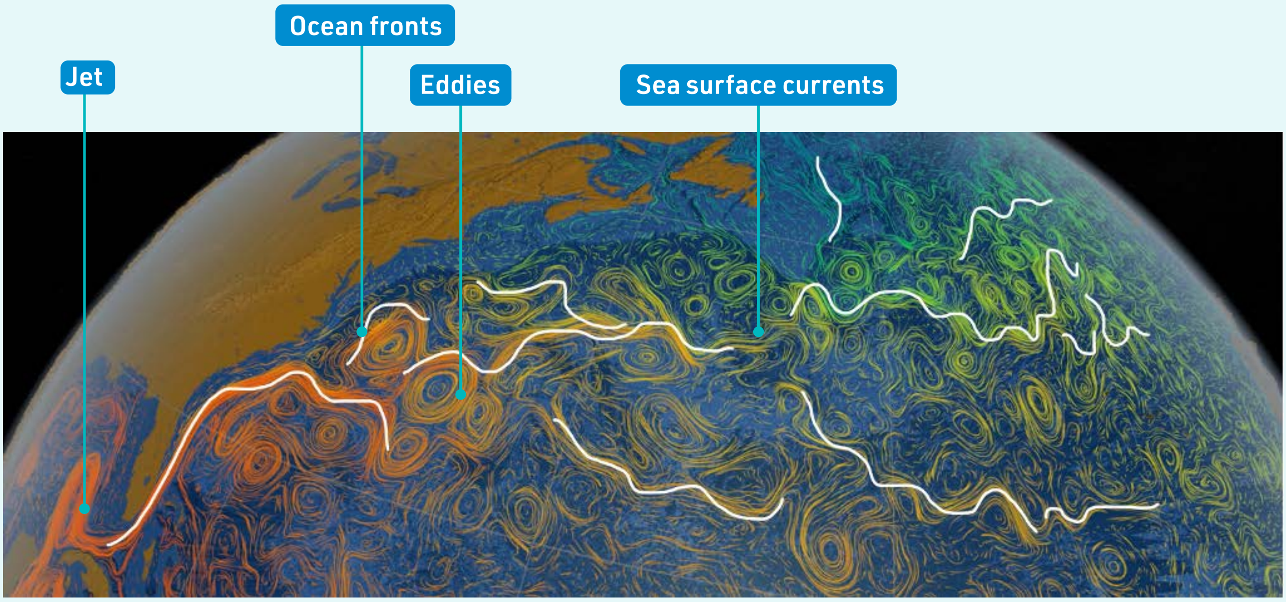


Figure 3: This computer visualisation shows the Gulf Stream's sea surface currents (lines and swirls) and temperatures (in colour where red is warm and green is colder). Ocean currents are the thicker colourful lines, ocean fronts are highlighted in white, the narrow warm current around Florida, USA, the long peninsular in the left of the image is a jet, while the spinning swirls are eddies. Credit: MIT/JPL project entitled Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2).

Currents occur when water is flowing in one direction, as it is being pushed by the wind and tides, or moving due to its own weight. **Eddies** - whirlpools that can be up to hundreds of kilometres wide are found everywhere, spinning at walking pace while they trundle westwards at a crawling pace. Fast flowing narrow currents, known as **jets**, form on the west sides of the oceans, racing away from the equator before swinging back towards the east. Freed from the land, they oscillate wildly through the open ocean, forming **meanders**, like those in a river but hundreds of kilometres wide. The meanders form eddies and the eddies form jets, in a constant dance of walking and spinning.

A product of all this motion is the prevalence of ocean **fronts** - the place of sudden change, separating waters with different properties. Anything added to the ocean in a blob, such as an oil spill, the eddies will tend to stretch into long thin sinuous filaments. But the eddies and meandering jets are a product of dramatic gradients in some vital properties of the ocean - like the temperature, salinity and sea level.

Hotspots for marine life

An important aspect of ocean fronts is their role as biodiversity hotspots. Because fronts are places where water masses converge, fronts are regions where nutrients and small prey organisms from different sources are concentrated togeher. This attracts a variety of marine species seeking food and favourable environmental conditions to grow.

Additionally, many ocean fronts facilitate the upwelling of cold nutrient-rich water from the deep ocean to the surface. This process fuels the growth of microscopic algae called phytoplankton (Figure 4), which form the basis of marine food webs. Phytoplankton attract zooplankton, which feed on them and in turn attract larger animals like fish, squid and whales. These animals then become prey for larger predators such as seals and sharks. Hence, by influencing the distribution of phytoplankton, ocean fronts shape entire marine ecosystems.

Due to the abundance of food and favourable environmental conditions, marine animals often seek out ocean fronts as habitats of choice for reproduction, migration and foraging. Studies have shown that predators such as the southern elephant seals in the Southern Ocean, blue sharks in the Gulf Stream, and loggerhead sea turtles in the southwestern Atlantic can track ocean fronts as part of their foraging strategies.

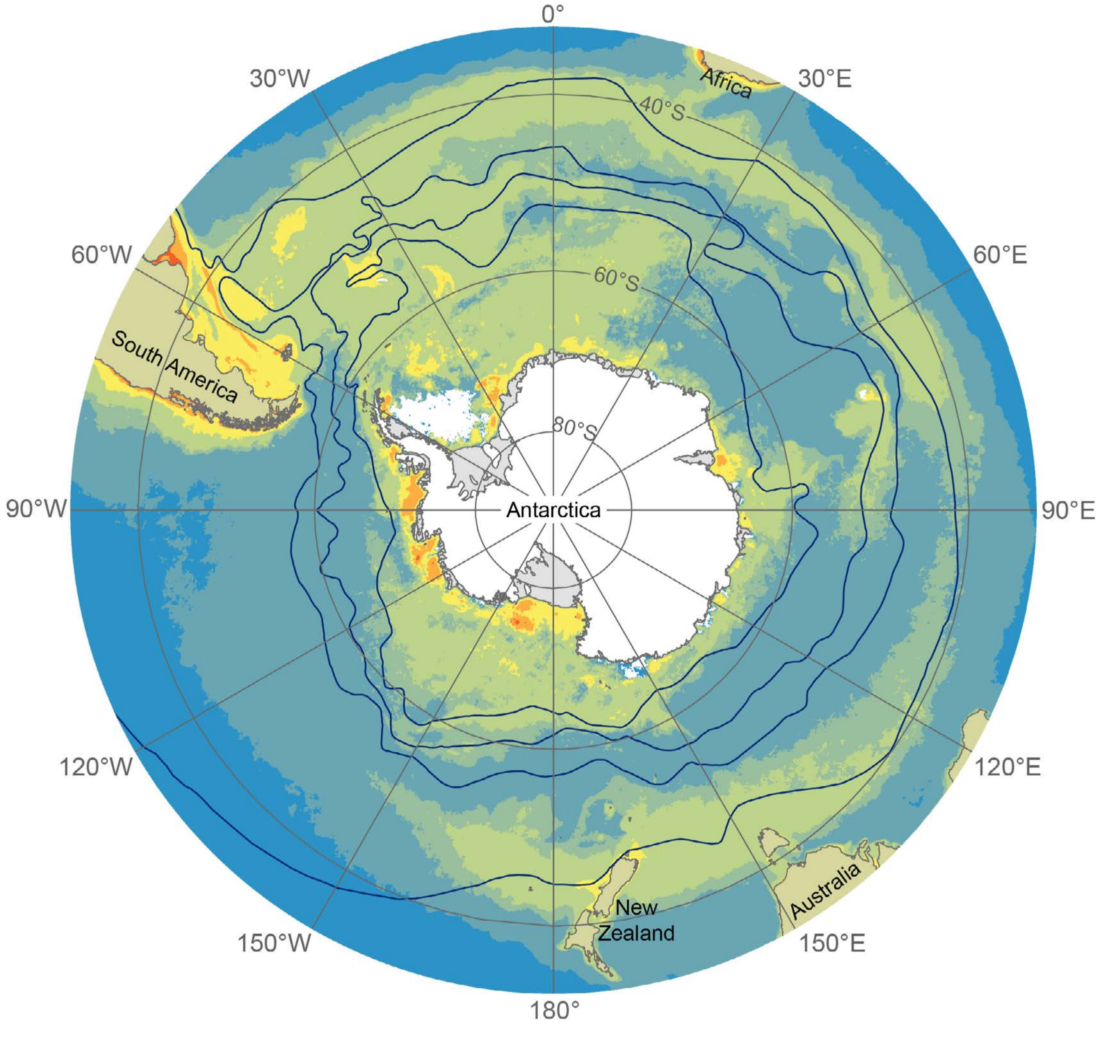


Figure 3: Mean summer chlorophyll concentrations, where greens, yellows and reds are high values (background colours), and positions of fronts (lines) in the Southern Ocean over the 2002-2015 period. Chlorophyll is the green pigment found in phytoplankton, so more chlorophyll means more phytoplankton biomass. Here the phytoplankton is seen to concentrate along many of the Southern Ocean fronts, as indicated by elevated chlorophyll levels (green and yellow hues). Source: Adapted from Deppeler and Davidson[4] (2017) https://doi.org/10.3389/fmars.2017.00040

The influence of ocean fronts on heat and CO_2 exchanges

The ocean exchanges heat and CO_2 with the atmosphere through its surface. In the context of climate change, the ocean acts as a climate "shock absorber", absorbing more than 90% of the excess heat in the climate system and almost 30% of CO_2 emissions from human activities.

The ocean absorbs CO_2 in two main ways:

- **CO_2 dissolving into the surface layer:** CO_2 molecules in the atmosphere come into contact with the surface of the ocean and physically dissolve into the water's surface layer, making the ocean more acidic in the process. This process is influenced by temperature, salinity and the concentration of CO_2 in the atmosphere and in the ocean. Generally, colder water can absorb more CO_2.
- **CO_2 uptake by phytoplankton:** phytoplankton, just like plants on land, use carbon dioxide (CO_2) to convert solar energy into food. When phytoplankton die and sink to the ocean floor, the carbon absorbed in their biomass can be stored for long periods of time, effectively removing carbon from the atmosphere.

By stimulating phytoplankton growth, ocean fronts enhance the uptake of CO_2 and potentially its long-term storage at depth. They also influence the exchange of heat and CO_2 between the ocean and the atmosphere through upwelling and downwelling.

Upwelling at ocean fronts brings cold water, which is high in nutrients and CO_2, from the deep ocean into contact with warmer air at the surface. This results in the transfer of heat and CO_2 from the ocean to the atmosphere.

Downwelling at ocean fronts, where surface waters sink, transports heat and CO_2 from the surface to deeper layers of the ocean. Ocean fronts are also often sites where water is mixed more vigorously, which influences exchanges of heat and CO_2 with the atmosphere.

As a result, changes in ocean fronts will influence the exchanges of heat and CO_2, changing how well the ocean can act as the climate shock absorber. Therefore, it is vital to understand how ocean fronts will change in the future.

Satellite photo of the Garabogazköl Basin, a lagoon off the Caspian Sea in northwestern Turkmenistan taken on April 4th, 2017, by Landsat 8. The multiple white lines are foamy filaments that indicate the edges of small ocean fronts. These frontal filaments are most likely short-lived and related to waves, wind patterns, and other local ocean dynamics. Source: https://earthexplorer.usgs.gov/

Climate change and ocean fronts

By altering ocean temperature, currents, and wind patterns, climate change is likely to affect ocean fronts. Due to the high productivity and abundance of fish near fronts, a change in frontal activity would likely change fish catches and have far-reaching socio-economic impacts.

Evidence suggests that fronts have already changed with the warming of our oceans[1,2]. Recent work by the ARC Centre of Excellence for Climate Extremes has investigated how frontal activity has changed in regions of the oceans that are warming faster than others over the past two decades[1]. It has been shown that regions near the Equator and the subtropics have seen decreasing frontal activity while regions at high latitudes have experienced increasing activity during this period. This was matched by less chlorophyll (indicating less phytoplankton) in waters near the Equator and the subtropics, and more chlorophyll (more phytoplankton) at high latitudes, reshaping ecosystems in these regions.

These equatorial and subtropical regions, where frontal activity was observed to be declining, are important for fisheries, contributing to an annual catch of around 5 million tonnes of fish. Continued ocean warming and a further decrease in fronts in these regions could pose significant challenges to the local population, especially for the more than 3 billion people dependent on fish for their daily protein intake and micronutrients.

How fronts will change in the future in response to climate change remains an active topic of research. Given the implications for the climate, marine ecosystems, global fisheries and potential socio-economic impacts, better projections of how ocean frontal systems will change in coming decades are needed.

Written by

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