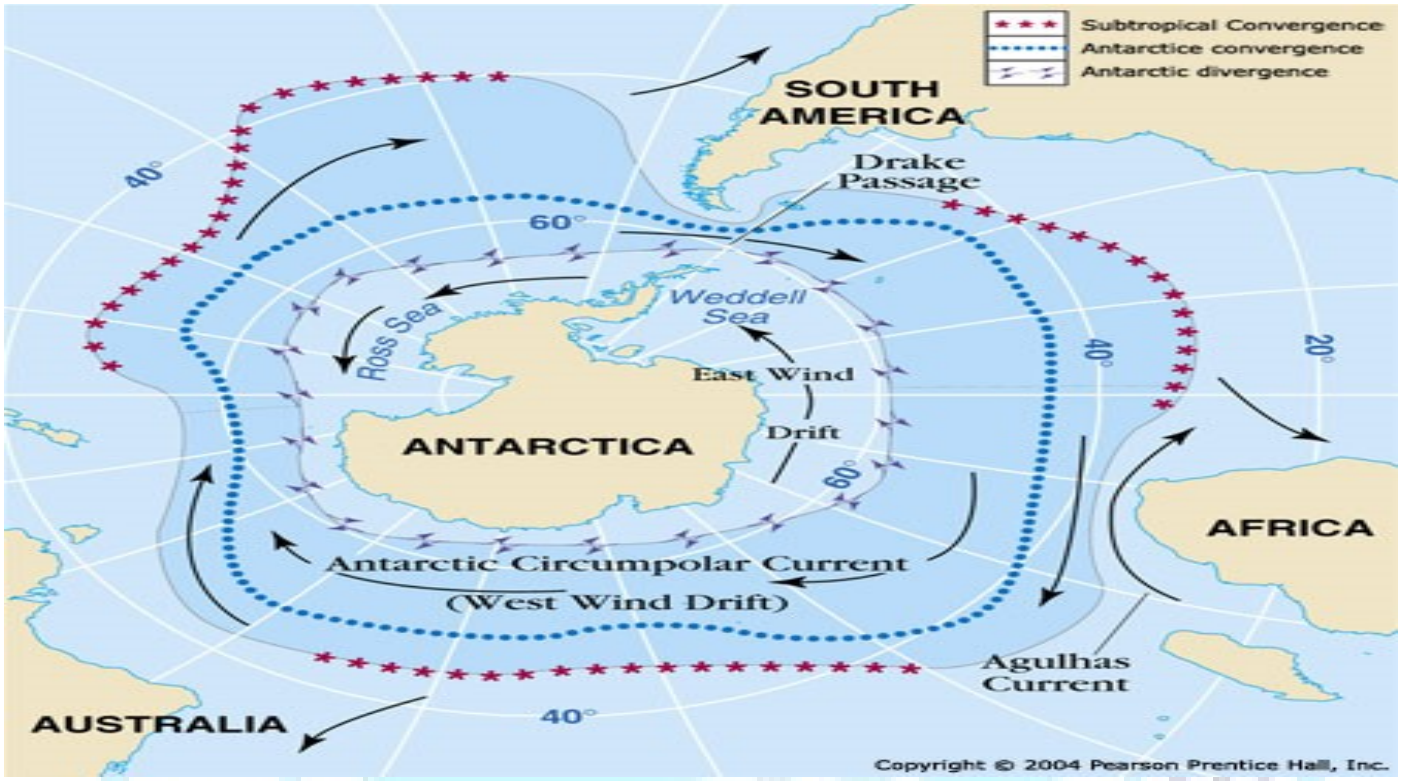
5. Southern Ocean Carbon Anomaly – Geography

A key 2024-2025 study has explained Southern Ocean Carbon "anomaly" as a temporary effect due to increased surface freshening and stratification.



Southern Ocean Carbon Anomaly - Meaning and Significance

The Southern Ocean Carbon Anomaly refers to the unexpected strengthening of carbon dioxide (CO_2) absorption by the Southern Ocean in the early 21st century, despite climate model projections that it would weaken as a carbon sink. Climate models predicted declining CO_2 uptake (or even net CO_2 release). Actual observations showed the Southern Ocean absorbing more CO_2 than expected since the early 2000s. This mismatch between model projections and real-world observations is termed the *carbon anomaly*.

Key Physical Characteristics of the Southern Ocean

Geographical and Climatic Features

Southern Ocean surrounds Antarctica, extending northward up to 60° South latitude. It is the only ocean that fully encircles the globe, uninterrupted by continental landmasses. Connects the southern reaches of -

1. Atlantic Ocean
2. Pacific Ocean
3. Indian Ocean

It is the coldest ocean on Earth, with extensive seasonal sea ice cover.

Global Importance

Covers 25–30% of the global ocean area. Accounts for ~40% of total oceanic uptake of anthropogenic CO_2. Plays a central role in -

1. Global carbon cycle
2. Heat redistribution
3. Climate regulation

Why the Southern Ocean Is a Major Carbon Sink?

Vertical Stratification Mechanism

The ocean exhibits strong vertical layering (stratification) -

1. Cold, fresh surface waters (low density)
2. Warm, salty, carbon-rich deep waters (high density)

The surface layer acts like a "lid", limiting gas exchange between deep waters and the atmosphere.

Carbon Trapping Function

CO_2 absorbed at the surface is -

1. Transported downward via ocean circulation
2. Stored for centuries in deep waters

This makes the Southern Ocean a long-term carbon sink rather than a short-term buffer.

What Earlier Climate Models Predicted?

For nearly two decades, climate models projected a weakening of the Southern Ocean carbon sink due to climate change.

Model-Based Expectations

Strengthening of westerly winds due to -

1. Greenhouse gas forcing
2. Stratospheric ozone depletion

Poleward shift of wind belts

Enhanced upwelling of deep, carbon-rich waters

Expected Outcome

1. Carbon-rich deep waters would reach the surface.
2. CO_2 would be released back into the atmosphere.
3. The Southern Ocean would lose its buffering capacity.

The Observed Reality - The Carbon Anomaly

Despite these expectations - Observations since the early 2000s showed -

1. Increased CO_2 uptake
2. Continued strengthening of the carbon sink

This contradicted the prevailing climate model consensus.

This unexpected behavior is the Southern Ocean Carbon Anomaly.

New Scientific Evidence Explaining the Anomaly

Landmark Study - Published in Nature Climate Change. Title - *"Southern Ocean freshening stalls deep ocean CO_2 release in a changing climate"*

What the New Research Found

1. Climate Models Were Partially Correct

1. Stronger winds around Antarctica did occur.
2. Deep, carbon-rich waters were pushed - ~40 metres closer to the surface since the 1990s.
3. Under normal conditions, this should have led to CO_2 outgassing.

2. The Key Missing Factor - Freshwater "Lid"

The surface ocean became less salty (fresher) due to -

1. Increased precipitation
2. Melting Antarctic glaciers and ice shelves
3. Sea-ice melt and redistribution

Freshwater is lighter than salty water, so it stays on top.

Resulting Effect

1. Stronger surface stratification
2. Formation of a protective freshwater lid
3. Carbon-rich waters remain trapped 100–200 metres below the surface
4. CO_2 is prevented from escaping into the atmosphere

3. Why CO_2 Uptake Increased

1. Surface waters continued to absorb atmospheric CO_2.
2. Trapped deep waters could not release stored CO_2.
3. Net result - higher-than-expected carbon absorption

This explains the observed anomaly.

Why the Anomaly Is Temporary

Signs of Change Since Mid-2010s

1. Freshwater lid is thinning in some regions
2. Surface waters are becoming saltier again
3. Wind-driven mixing is intensifying

Potential Future Scenario

1. Stronger winds may break through the stratification
2. Sudden release of - Long-stored deep-ocean CO_2
3. Southern Ocean could rapidly shift from - Carbon sink → Carbon source

Why This Matters for Climate Change

Scientific Implications

Highlights limitations of current climate models.

Demonstrates the importance of -

1. Salinity
2. Freshwater fluxes
3. Ice–ocean interactions

Shows that short-term climate stability may mask long-term risks.

Policy and Global Climate Implications

1. Reliance on oceanic carbon sinks is risky
2. Natural sinks are not permanent safeguards
3. Strengthens the case for -
    1. Rapid emissions reduction
    2. Improved polar monitoring
    3. Better ocean–climate modelling

Source - https -//www.thehindu.com/sci-tech/science/southern-ocean-carbon-anomaly-reveals-what-models-can-still-miss/article70422336.ece