Wind-Driven Circulation

A Conceptual Introduction to Subtropical Gyres

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Conceptual Framework

Subtropical gyres are large-scale ocean circulation systems driven by the wind and shaped by the Coriolis effect. They are central to the distribution of heat, salinity, and biogeochemical properties across ocean basins.

In 1947, Harald Sverdrup formulated a theoretical framework relating the wind stress curl to the meridional transport of water in the ocean. His balance, known as the Sverdrup balance, is a linear vorticity equation that links the large-scale ocean response to the overlying wind forcing:

$$\beta v = \frac{\partial \tau_x}{\partial y},$$

where v is the meridional velocity, τ_x is the zonal wind stress, and β is the meridional gradient of the Coriolis parameter.

By integrating this relationship, we can obtain a streamfunction ψ that describes the flow, assuming boundary conditions consistent with a subtropical gyre.

This model captures the eastern portion of the gyre well but lacks western boundary intensification, a limitation that was later resolved by Stommel (1948) using lateral friction.

Code and Animation

- **Code available at:** https://bit.ly/OOM_wind_driven_circulation
- **Animation available at:** https://www.youtube.com/watch?v=KuWUtOGvLsk

Description

This Python simulation gradually applies an idealized zonal wind stress τ_x and calculates the resulting streamfunction ψ under Sverdrup balance assumptions. The wind stress follows a sinusoidal profile, and the streamfunction is computed by successive integrations in the meridional direction.

The animation shows how the ocean interior responds to the imposed wind forcing, generating a subtropical gyre structure. Although simplified, the model reveals the fundamental role of wind curl in generating basin-scale circulation.

This exercise provides an intuitive entry point into wind-driven ocean dynamics and serves as a foundation for more complete models including western boundary currents and frictional effects.