Stommel Gyre

A Conceptual Introduction to Western Intensification in Wind-Driven Gyres

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Conceptual Framework

In 1947, Harald Sverdrup developed a model that linked the meridional wind stress distribution to ocean circulation, laying the foundation for our understanding of subtropical gyres. However, his model only captured the eastern limb of the circulation and could not close the gyre.

In 1948, Henry Stommel introduced a linear friction term into the vorticity equation, enabling the closure of the gyre and explaining the phenomenon of *western intensification*. This concept accounts for the formation of strong western boundary currents such as the Gulf Stream, Kuroshio, Brazil, and Agulhas Currents.

The governing equation in Stommels model for the streamfunction ψ is:

$$\beta \frac{\partial \psi}{\partial x} + R\nabla^2 \psi = \frac{\partial \tau_x}{\partial y},$$

where β is the meridional gradient of the Coriolis parameter, R is a linear friction coefficient, and τ_x is the zonal wind stress.

This formulation balances wind forcing, planetary vorticity, and friction, producing an asymmetric gyre with intensified flow along the western boundary.

Code and Animation

- **Code available at:** https://bit.ly/OOM_wind_driven_circulation_stommel_model
- **Animation available at:** https://www.youtube.com/watch?v=V9XJoS9ajHI

Description

This Python simulation implements the Stommel model to solve the streamfunction ψ under the influence of a sinusoidal zonal wind stress and linear bottom friction. A finite-difference approach is used to solve the vorticity equation with upwind treatment of the β-term.

The animation shows how the gyre structure develops as wind stress is gradually applied. The resulting streamfunction reveals western intensification, with velocities derived from the gradient of ψ. The model captures key features of subtropical gyre circulation and highlights the importance of friction in establishing boundary currents.

Reference

Stommel, H. (1948). The westward intensification of wind-driven ocean currents. *Transactions of the American Geophysical Union*, **29**(2), 202-206. https://doi.org/10.1029/TR029i002p00202