Ocean Currents: Geostrophic Flow and Wind-Driven Circulation

Physical Oceanography Templates

November 24, 2025

1 Introduction

Ocean currents are driven by wind stress, density differences, and Earth's rotation. This template explores geostrophic balance, Ekman spiral dynamics, Sverdrup transport, and western boundary current intensification.

2 Mathematical Framework

2.1 Geostrophic Balance

Large-scale ocean flow balances Coriolis force and pressure gradient:

$$f\mathbf{k} \times \mathbf{u}_g = -\frac{1}{\rho_0}\nabla p \tag{1}$$

where $f = 2\Omega \sin\phi$ is the Coriolis parameter.

Component form:

$$u_g = -\frac{1}{\rho_0 f}\frac{\partial p}{\partial y} \tag{2}$$

$$v_g = \frac{1}{\rho_0 f}\frac{\partial p}{\partial x} \tag{3}$$

2.2 Ekman Transport

Wind stress drives Ekman transport perpendicular to wind direction:

$$\mathbf{M}_E = \frac{\boldsymbol{\tau} \times \mathbf{k}}{\rho_0 f} \tag{4}$$

The Ekman spiral describes velocity decay with depth:

$$u(z) = V_0 e^{z/D_E} \cos\left(\frac{\pi}{4} + \frac{z}{D_E}\right) \tag{5}$$

$$v(z) = V_0 e^{z/D_E} \sin\left(\frac{\pi}{4} + \frac{z}{D_E}\right) \tag{6}$$

where $D_E = \sqrt{2A_v/f}$ is the Ekman depth.

2.3 Sverdrup Balance

Wind stress curl drives meridional transport:

$$\beta V = \frac{1}{\rho_0} \nabla \times \boldsymbol{\tau} \tag{7}$$

where $\beta = \partial f / \partial y$ is the planetary vorticity gradient.

2.4 Western Boundary Current

Munk's model includes lateral friction:

$$\beta v = A_H \nabla^4 \psi + \frac{1}{\rho_0 H} \left(\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} \right) \tag{8}$$

3 Environment Setup

4 Geostrophic Flow Computation

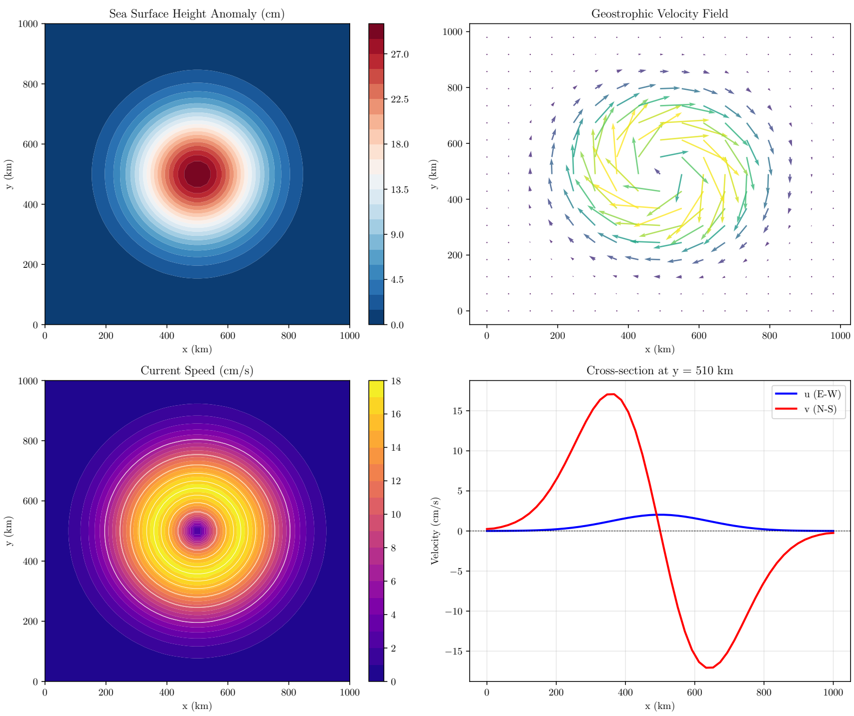

Figure 1: Geostrophic flow around a mesoscale eddy

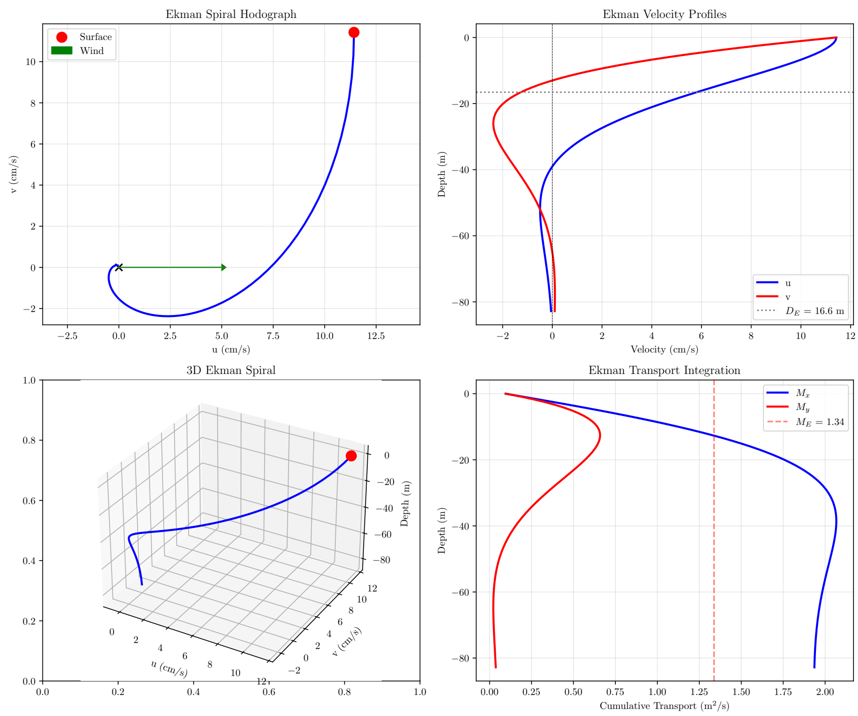

Figure 2: Ekman spiral and transport in the surface boundary layer

5 Ekman Spiral

6 Sverdrup Transport

7 Western Boundary Current

8 Results Summary

8.1 Geostrophic Flow Statistics

Table 1: Geostrophic flow around mesoscale eddy

Parameter	Value
Maximum SSH anomaly	29.8 cm
Maximum current speed	17.2 cm/s
Coriolis parameter	7.29e-05 s^{-1}
Eddy radius	200 km

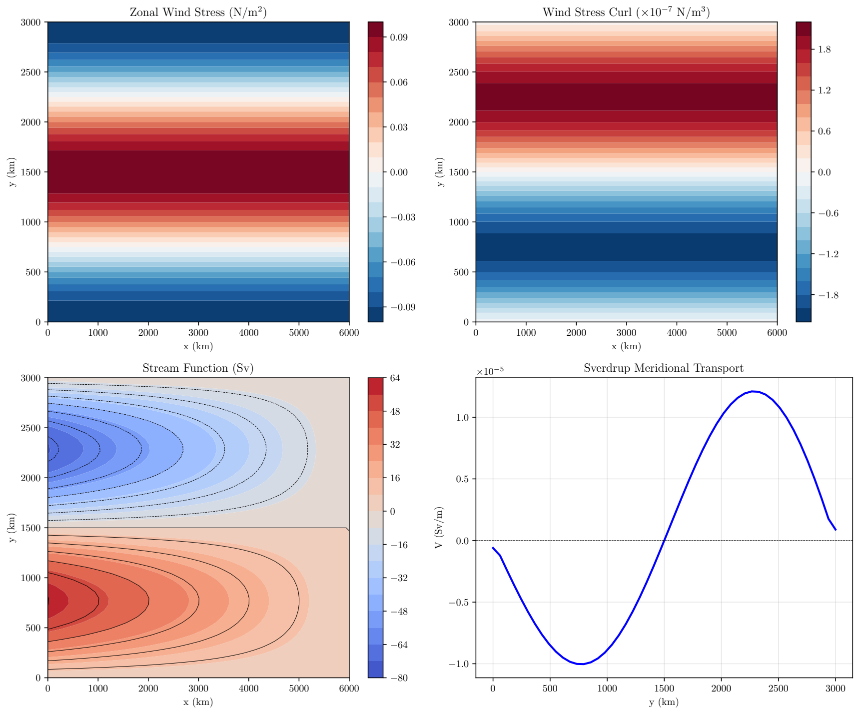

Figure 3: Sverdrup wind-driven circulation

8.2 Ekman Layer Parameters

Table 2: Ekman spiral characteristics

Parameter	Value
Ekman depth	16.6 m
Surface velocity	16.2 cm/s
Wind stress	0.10 N/m^2
Ekman transport	1.34 m^2/s
Surface deflection	45°

8.3 Gyre Circulation

8.4 Physical Summary

- Ekman depth: 16.6 m
- Munk boundary layer: 79 km
- Maximum gyre transport: 72.6 Sv

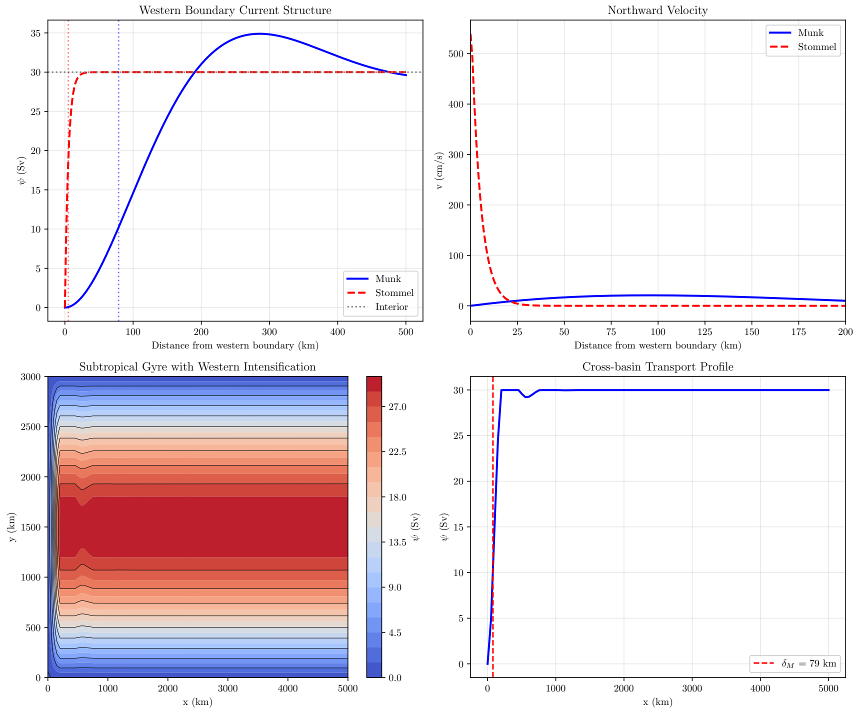

Figure 4: Western boundary current dynamics

Table 3: Wind-driven gyre parameters

Parameter	Value
Maximum transport	72.6 Sv
Munk layer width	79 km
Stommel layer width	5 km
Max WBC velocity	20.8 cm/s
Basin width	5000 km

- WBC velocity: 20.8 cm/s

9 Conclusion

This template demonstrates the fundamental dynamics of ocean circulation. Geostrophic balance governs large-scale flow, with velocities determined by pressure gradients and Earth's rotation. The Ekman spiral shows how wind stress drives surface currents deflected from the wind direction. Sverdrup theory relates interior transport to wind stress curl, while western boundary current intensification results from the need to close the gyre circulation and conserve vorticity.