# Exercise 7

1) Western Boundary Current:
Consider the Atlantic Ocean to be a rectangular basin, centered on 35°N, of longitudinal width $L_x$=5000 km and latitudinal width $L_y$=3000 km. The ocean is subjected to a zonal wind stress of the form

$$\tau_x = -\tau_s \cos\left(\frac{\pi y}{L_y}\right); \ \tau_y(y) = 0,$$

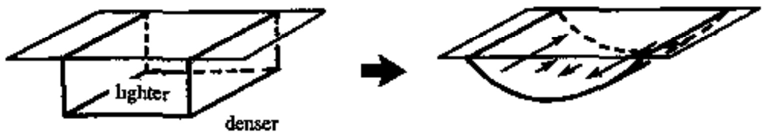
where $\tau_s$=0.1 N m$^{-2}$. Assume a constant value of $\beta = df/dy$ appropriate to 35°N, and that the ocean has uniform density 1000 kg m$^{-3}$.
   a) From the Sverdrup relation, determine the magnitude and spatial distribution of the depth-integrated meridional flow velocity in the interior of the ocean.
   b) Using the depth-integrated continuity equation, and assuming no flow at the eastern boundary of the ocean, determine the magnitude and spatial distribution of the depth-integrated zonal flow in the interior.
   c) If the return flow at the western boundary is confined to a width of 100 km, determine the depth- integrated flow in this boundary current.
   d) If the flow is confined to the top 500 m of the ocean (and is uniform with depth in this layer), determine the northward components of flow velocity in the interior, and in the western boundary current.
   e) Compute and sketch the pattern of Ekman pumping (i.e., $w_{EK}$) implied by the idealized wind pattern, given above.

2) Abyssal Circulation
Consider a basin on a sphere bounded by two meridians $\varphi_1$ and $\varphi_2$ and extending from the equator ($\theta$=0) to the North Pole ($\theta=\pi/2$). A bottom water source of magnitude $S_0$ is located at $\theta$=30N. Calculate and schematically draw the corresponding interior abyssal circulation and the transport of the western boundary circulation as function of latitude. Substitute $S_0$=20Sv, $\varphi_1$=0, $\varphi_2=\pi/4$ and plot the boundary current transport $T_w(\theta)$.

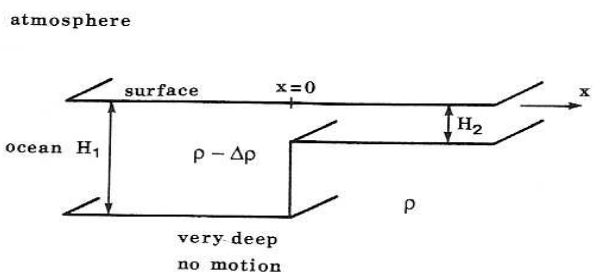
3) In a certain region, at certain time, the atmospheric temperature along the ground decreases northward at the rate of 1°C every 35 km, and there are good reasons to assume that this gradient does not change much with height. If there is no wind at ground level, what are the wind speed and direction at an altitude of 2 km? To answer, take latitude=40°N, mean temperature=290K, and uniform pressure on the ground.

4) Through the Strait of Gibraltar, connecting the Mediterranean Sea to the North Atlantic Ocean, there is an inflow of Atlantic waters near the top and an equal outflow of much more saline Mediterranean waters below. At its narrowest point (Tarifa Narrows), the strait is 11 km wide and 650 m deep. The stratification closely resembles a two-layer configuration with a relative density difference of 0.2% and an interface sloping from 175 m along the Spanish coast (north) to 225 m along the African coast (south). Taking $f = 8.5 \times 10^{-5}\ s^{-1}$, approximating the cross-section to a rectangle, and assuming that the volumetric transport in one layer is equal and opposite to that in the other layer, estimate this volumetric transport.

5) Determine the geostrophically adjusted state of a band of warm water as depicted below. The variables are $\rho_0$ = density of water below, $\rho_0 - \Delta\rho$ = density of warm water, $H$ = initial depth of warm water, $2a$ = initial width of warm-water band, $2b$ = width of warm-water band after adjustment. In particular, determine the value $b$, and investigate the limits when the initial half-width $a$ is much less and much greater than the deformation radius $R$.




6) Geostrophic adjustment
Find the solution for geostrophically adjusted state of the following initial configuration. The layer spread to infinity in the y and x directions.
Hint: You might need to solve separately for each part of x.




7) Consider steady flow of a homogeneous fluid over a ridge, as shown in the following figure. Assume the flow upstream is geostrophically balanced and invariant in the y direction, and that the Coriolis parameter f is constant. Assume further that the undisturbed depth $H_0$ is much greater than the height of the ridge $h$, and that the surface elevation is small compared to $H_0$. Find $v$ (component of the velocity normal to the page) for $-a \le x \le 0$, for $0 \le x \le a$ and for $x \ge a$.