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12.003 Atmosphere, Ocean and Climate Dynamics
Fall 2008

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Problem set 8: Ocean Circulation

Due date: November 21th, 2008

1. The figure in the next page shows a section across the Gulf Stream at 38°N (in a plane normal to the flow), showing the distribution of temperature as a function of depth and of horizontal distance across the flow (you do not need to use the dynamic height information). Assume for the purposes of this question (for all parts) that the flow is geostrophic.

- (a) Using hydrostatic balance, and assuming that atmospheric pressure is uniform and that horizontal pressure gradients vanish deep in the ocean, estimate the differences in surface elevation across the Gulf Stream (i.e., between 60° W and 72°W). Neglect the effect of salinity on density, and assume that the dependence of density ρ on temperature T is adequately described by the equation:

$$\rho = \rho_{ref} [1 - \alpha_T(T - T_{ref})].$$

- (b) The near-surface geostrophic flow \mathbf{u} is related to surface elevation η by

$$\mathbf{u} = \frac{g}{f} \hat{\mathbf{z}} \times \nabla \eta$$

where g is gravity and f the Coriolis parameter. Explain how this equation is consistent with the geostrophic relationship between Coriolis force and pressure gradient.

- (c) Assuming (for simplicity) that the flow is uniform to a depth $D = 500$ m, and that the flow is zero below this depth, show that the net water transport (volume flux) along the Gulf Stream at this latitude is

$$\frac{gD}{f} \delta\eta$$

where $\delta\eta$ is the elevation difference you estimated in part (a). Evaluate this transport.

2. Click on "Ocean Observations" on the class website and look for the "Wind Stress/Curl" observations. Figure 10.11 in this webpage shows the pattern and magnitude of Ekman pumping acting on the ocean. Estimate how long it would take a particle of fluid to move a vertical distance of 1 km, if it had a speed w_{Ek} . Choose by eye a representative mean value for the pumping velocity.

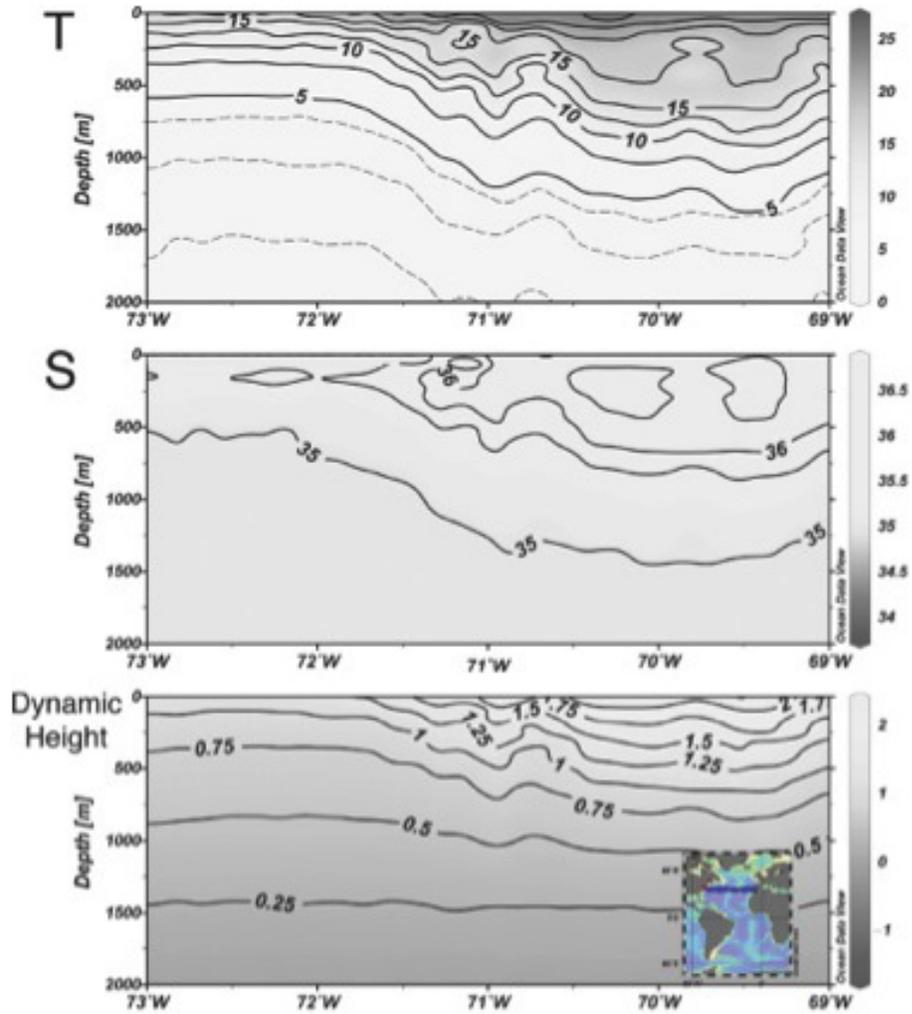


Figure 9.21: Top: Temperature section (in °C) over the top 2 km of the water column crossing the Gulf Stream along 38° N, between 69° W and 73° W (as marked on the inset). Middle: Salinity (in psu) across the same section. Bottom: Dynamic height, D (in m computed from Eq. 9-16) relative to 2 km. Produced using Ocean Data View.

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3. Use the results of Ekman theory to show that when one adds the meridional volume transport in the Ekman layer of thickness δ :

$$\mathbf{M}_{Ek} = \int_{-\delta}^0 \mathbf{u}_{Ek} dz = -\frac{1}{\rho_{ref}} \frac{\hat{\mathbf{z}} \times \tau_{wind}}{f}$$

to the meridional volume transport in the geostrophic interior obtained from Eq. 10-12 in the textbook:

$$\mathbf{M}_g = \int_{-H}^{-\delta} \mathbf{u}_g dz$$

one obtains the Sverdrup transport:

$$\mathbf{M}_{Ek} + \mathbf{M}_g = \text{Sverdrup transport.}$$

Look now at Figure 10.21 in the textbook. What is the sign of the meridional component of the Ekman, geostrophic, and Sverdrup transports in the Pacific between 30°N and 40°N.

4. At 26° N in the North Atlantic, the average wind stress across the interior of the basin from the eastern boundary to the Bahamas is: $(\tau_x, \tau_y) = (-.034, -.01)$ N/m². The average vertical component of the wind stress curl across this latitude is estimated to be -7.26×10^{-8} N/m³. The values have come from a climatology for the period 1991-1997 developed by the National Centers for Environmental Prediction. Using these values
- First estimate the values of the total (zonally integrated) meridional Ekman and Sverdrup transports at this latitude.
 - The Florida Current flows through the Florida Strait to the west of the Bahamas. What transport would one expect to observe if the Sverdrup balance was perfect for the interior?
 - Compare your answer with the direct estimates shown in the figure in the next page.

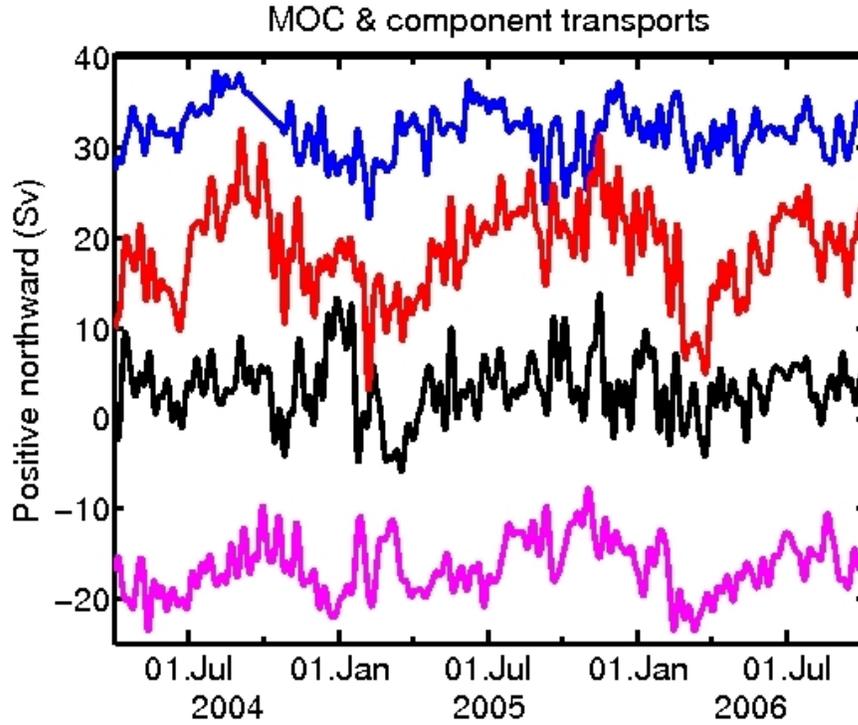


Figure 1: Transport timeseries obtained from the first 2.5 years of observations at 26° N as part of the RAPID program. The different curves show the total transport (red line) and its constituents, i.e. the transport through the Florida Straits (blue line), the Ekman transport (black line), and the geostrophic transport (pink line). The transport units are Sverdrups (Sv, $1\text{Sv} = 10^6\text{m}^3\text{s}^{-1}$). The mean and standard deviations for the different transports are 18.8 5.0Sv (MOC), 31.9 2.9Sv (Florida Straits), 3.3 3.5Sv (Ekman), and -16.3 3.0Sv (transport from mooring densities). Brief descriptions of how the transports are calculated are given below.