Ocean Gyres & Western Boundary Currents

Computer Lab Exercise

In this lab we will study one of the classic problems in physical oceanography: the wind-driven double-gyre circulation.

Consider a simple situation in which winds blowing over a hypothetical ocean are purely zonal and vary in strength with latitude according to:

$$\tau = \tau_{\max}(\sin^2(\pi y/L) + 0.1\sin(2\pi y/L)), \tag{1}$$

as shown in fig. 1. There are two aspects of the current resulting from this wind stress:

(i) the Ekman transport at right angles to the direction of the wind, and

(ii) the geostrophic flow, at right angles to the horizontal pressure gradients which result from the shifting of water by the Ekman transport.

Draw arrows on fig. 1 to represent the Ekman transport, the pressure gradient that develops and the resulting geostrophic flow.

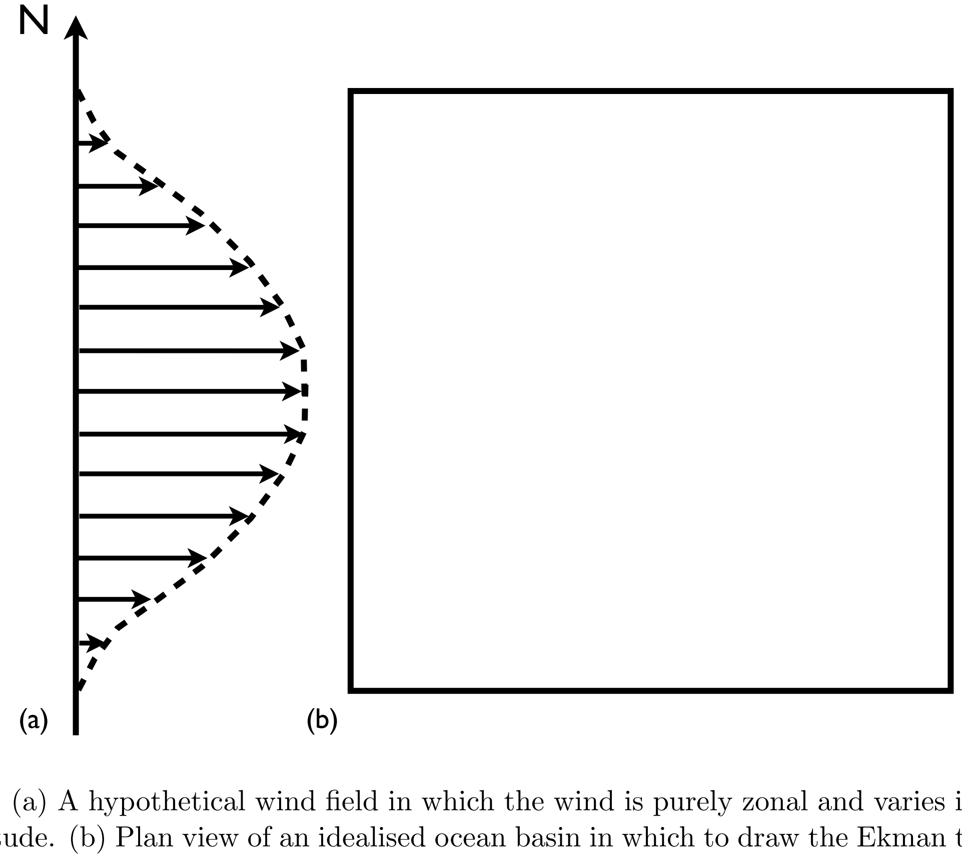

Figure 1: (a) A hypothetical wind field in which the wind is purely zonal and varies in strength with latitude. (b) Plan view of an idealised ocean basin in which to draw the Ekman transports, pressure gradients and geostrophic currents that result from the wind field in (a).

This relationship was first demonstrated by H. Sverdrup in 1947, and it shows that the volume of water transported by the wind depends not on the absolute value of the wind stress but on its curl. This can be written mathematically as

$$\Psi(x, y) = \frac{1}{\beta} \int_x^L \frac{\partial \tau}{\partial y} dx, \tag{2}$$

where Ψ is the streamfunction and β is the (assumed constant) gradient in the Coriolis parameter. There are several assumptions which underlie this equation, we will investigate these using an idealised numerical model.

The model will be set to use a 256×256 sized domain with 15 km resolution, giving a square domain size of $L = 3840$ km. There are just two ocean layers in the vertical, and timesteps are 20 minutes. The circulation is driven by the prescribed, zonal wind stress forcing from eqn. 1. (Note that the second term is a small correction to generate a slight asymmetry between the two gyres.) The wind input is balanced by a combination of bottom and sidewall frictional losses.

After this lab, you should be able to

- Describe a conceptual picture of the combination of Ekman dynamics and geostrophy which gives rise to the Sverdrup theory.
- Include a qualitative description of the phenomena you observed in the model.
- Explain why & where Sverdrup theory failed in some cases and worked in others; and extrapolate to the real ocean.

How to run the model

The model is written in FORTRAN, which means you'll be using it as a virtual black box, but you should feel free to look through the code to see what it looks like!

- Download the code as a zip file – double click to extract the directory containing the code.
- Most model parameters are controlled by the `input.params` file. You should familiarise yourself with the parameters in this file.
- The model must be compiled before execution – type `make q-gcm` on the command line.
- The code can then be run by typing `./q-gcm`.
- The model writes all data to the `outdata` directory – if `outdata` doesn't exist the model will crash. Data from previous runs which has not been copied out will be overwritten.
- The matlab script `read_output.m` reads the pressure data and makes a movie of the upper layer streamfunction. The movie data is also saved in a `.mat` file for later viewing.

Tasks for this lab

- Complete fig. 1.
- Run the model to equilibrium (about ten years) with default parameters and look at the output.
- Write a matlab script to calculate Ψ (using eqn. 2).
- Make qualitative comparisons of the model output with your results from fig. 1 and eqn. 2.
- Alter the model until you begin to approach Sverdrup's prediction. There are at least two ways to do this: (i) by ramping up the Laplacian viscosity, `ah2oc`, from 100 m^2/s to a large value (no larger than 1000 m^2/s); or (ii) by scaling down the wind stress field using the parameter `taumax`. You may complete this part in small groups (no more than 4 people) if you wish.