

# Laboration 1: Geostrophic adjustment

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## 1 Aim

The purpose of this lab is to understand what controls the evolution of a disturbance initially at rest on a rotating plane, more commonly known as geostrophic adjustment. To study this phenomena, you will use a simplified ocean model based on the linear shallow water equations.

$$\frac{\partial u}{\partial t} - f_0 v = -g \frac{\partial h}{\partial x} \quad (1)$$

$$\frac{\partial v}{\partial t} + f_0 u = -g \frac{\partial h}{\partial y} \quad (2)$$

$$\frac{\partial h}{\partial t} + D_0 \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) = 0 \quad (3)$$

## 2 Exercises and model setup

The model we are going to use is based on the equations above. Either you can use the model you programmed during the Numerical Methods course, or you can use the model given on Athena. For each laboration and exercise you need to program new parts in the model to study different physical processes, waves and circulation in the ocean and atmosphere. Before starting with the exercises, the following should be programmed in the code:

### 2.1 Model physics and numerics

#### 2.1.1 Coriolis

Start by programming the Coriolis force in the model. Since we are going to study a disturbance on a rotating plane we need the Coriolis force in our model.

- Remember that Coriolis needs to be implemented on all time steps (Euler forward and leapfrog)

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- Remember that we are using a C-grid, thus  $v$  and  $u$  are not on the same points.
- Remember that periodic boundaries will affect the computation of Coriolis.

### 2.1.2 Parameters

Use parameters that are similar to the world ocean when running the experiments.

**But remember to make sure that you are resolving the Rossby radius, and that the domain is large enough to get a good relaxation. If your results differ to much from the analytical solution you maybe need to re-think the settings.**

$$L_x \sim 6 \cdot 10^6 \text{ m}$$

$$L_y \sim 4.5 \cdot 10^6 \text{ m}$$

$$D_0 \sim 4000 \text{ m}$$

$$g = 9.81 \text{ m s}^{-2}$$

$$f_0 = 10^{-4} \text{ s}^{-1}$$

- Set fixed  $N_X$  and  $N_Y$
- Let  $\Delta x, \Delta y$  be determined by  $L_X, L_Y$  and  $N_X, N_Y$
- Let  $\Delta t$  be determined by a Courant number, phase speed, and  $\max(\Delta x, \Delta y)$ .
- Let  $N_T$  be determined by  $T_{\max}$ , which is the simulation period

### 2.1.3 Main loop

Construct the main time loop so that the model **does not** store the fields every time step!

## 2.2 Geostrophic adjustment for a step-function

In this exercise you are supposed to study the geostrophic adjustment for an initial disturbance consisting of a discontinuity in  $h$  that is symmetric in  $y$ .

### 2.2.1 Model setup

- Implement a disturbance in  $h$ , which is described by a step function in East - West. A good practice is to program the initial condition as a CASE or LOGICAL to be able to turn it on or off for other exercises.
- The code already describes a Gaussian disturbance of the sea surface height as an initial condition, **do not** take this away, instead make this as one of the options for the initial condition!
- Use periodic boundaries in north and south.
- Use open boundaries in east and west. Make sure that the sponge (S in the code) is large enough.

## 2.3 Exercise 1a

- Derive the final steady state of sea surface height and the velocities starting from the linearized shallow water equations. (The derivation does not have to be included in the report, only the final solution!)
- Run the model until the system only varies very little in time (steady state).
- Verify your model results with the results you obtained analytically.
- Tweak the parameters. Which parameters are most important?
- Discuss the results from tweaking parameters.

## 2.4 Exercise 1b

In this exercise, you are studying the different energetics of the system. The system can be considered to be in steady state when the energy of the system changes very little with time.

- Write down the analytical expression for the total kinetic and potential energies.
- Program the kinetic energy and the available potential energy in your Shallow Water Model.
- Run the model with two different depths; one shallow  $D_0 \sim 500\text{m}$  and one deep  $D_0 \sim 10000\text{m}$ .
- Run the model with two different  $f$ .
- Study how the energies of the system (kinetic, potential, and total) vary in time for the two cases with different depth and with different Coriolis parameters. (*Tip: Try plotting  $E_{tot}/E_K$  and  $E_{tot}/E_P$  to more clearly see the differences in the systems*)
- Give a physical explanation of the results.
- How do the results change? Try to explain the changes and compare with theory.

Good luck!