Ecole Polytechnique **Printemps 2018**

Modal de Géophysique

Gravity current

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1.1 Introduction

Gravity currents play an important role in a vast array of geophysical and engineering applications and have been the subject of extensive theoretical, numerical, and experimental investigations over the past few decades. A Gravity current is buoyancy driven flow arising from the sudden release of a fixed volume of heavy fluid into a larger body of less dense ambient fluid. The driving density contrasts for these flows may be due to temperature, salinity, or the presence of suspended material (Moodie 2002; Shin et al. 2004; Simpson 1999). They are common in nature: snow avalanches, submarine rock slides, dust storms, explosive volcano eruption, lava flows, mud flows (see Huppert (2006)). The purpose of the experiments is to get insights on the variation of the flow as a function of the parameters involved in the fluid dynamics. This experimental study focuses on two types of gravity currents. The first experiment is a model for classic forms of gravity currents (avalanches, lava flows, mud flows or dust storms). The second experiment models the strait of Gibraltar. Here the work is to understand the characteristics of a gravity current flowing over a seamount.

1.1.1 Materials

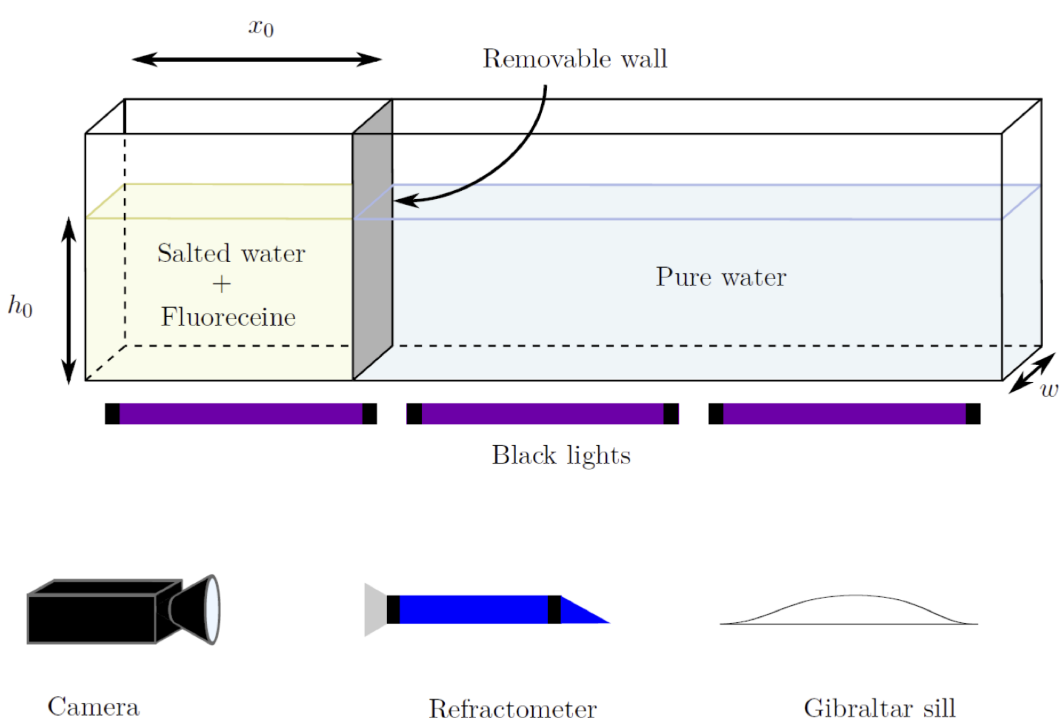

Figure 1.1: Given material to do the experiment

The tank is 282 centimeters long and w is 16.4 centimeters long.

To prepare the salted water, you will use a precise graduated cylinder and you will check the concentration using the refractometer. At the end of the experiment, you will empty the tank into the sink and clean the bottom tank with the sponge to remove the residual salt and fluorescein. At last, you will use a computer to process the data.

1.1.2 Methods

Measuring salt concentration

You will measure salt concentration with a refractometer. The refractometer measures the index of salted water, hopefully it is directly graduated in salt concentration. To use it, you just have to drop off some salted water on the blue prism. The mobile piece of the refractometer has to be closed to spread the water drop. You just have to read the water salinity and water density on the refractometer. The link between the salinity (t in %) and the density is $d = 1.0 + 0.007t$ and the concentration is related to the salinity with a linear function : c (g/L) $= 11.5t$ (%).

Measuring gravity currents

Quantitative analysis of the experiments is based on image processing of the signal recorded by the camera. It requires only two things : to put the time on the photographs and to know the distance traveled by the gravity flow.

1.2 Gravity Currents

1.2.1 The experiment

First of all, you need to see what is a gravity current. The experimental apparatus consists of a large water tank that is initially divided into two parts by a removable wall. Fill the largest part of the tank (on the left) with tap water and fill the other part (on the right) with salted water ($10\,\mathrm{g\,L^{-1}} = 0.8\%$). You will prepare around 7.5 liters of salted water so place the removable wall so that $h_0 = 15$ cm and $x_0 = 30$ cm. To make the experiment visible, you will have to add some fluorescein, a fluorescent chemical product, into the salted water (1 volumes of pipette for 2 liters). To enhance contrast, you have to turn off the light and to turn on the black lights. Remove quickly but carefully the wall, a gravity current takes place.

What are your first observations? What could be interesting to measure ?

1.2.2 Dimensional analysis

After observing the phenomenon, it is of primary importance to perform the dimensional analysis. It allows to have quickly some trends on the system.

Vashy-Buckingham Theorem :
The number of dimensionless terms that can be formed, p, is equal to the nullity of the dimensional matrix. If a physical equation has n variables and if k is the rank of the dimensional matrix, one can build $p = n - k$ dimensionless numbers.

For simplicity, k is the rank of the matrix of the exponents of the dimensions (dimensional matrix).

	ρ	$\Delta\rho$	g	L	H	ν	U
$[M]$							
$[T]$							
$[L]$							

Thus here one can build up 7-3=4 dimensionless numbers. Among them, you can have approximate values for usual dimensionless numbers which are characteristic of the flow :

Froude number   Reynolds number

What can you tell about viscous effects versus inertial effects ? What does the value of the Froude number show ?

1.2.3 Measurements

What is the speed of the flow ? Repeat the experiment but now focusing on the time evolution of the flow. With the camera you can record the flow front positions in time.

Recording the data

1. First turn on the computer and the camera, make sure the camera is linked to the computer (USB 2).
2. Create your own directory (one per experiment).
3. Open StreamPix6 SingleCamera.
4. Click on the Load button in the Camera category.
5. Choose the grabber Lumenera (USB3.0/USB2.0). The preview starts.
6. In External Modules, active the Time Overlay and place it at the position 3 in FrontandPosition..
7. Re-adjust if necessary the ROI in such a way that the whole tank appears in the camera field.
8. Turn off the light and turn on the black lights.
9. Correct the Adjustments is such a way that the image is clear and that there is a good contrast between the left and right part of the tank (change the Gain, Contrast and Brightness). Set the Exposure to the maximum value.
10. Save the sequence with New Sequence on Disk in your folder.
11. Start the acquisition and a few seconds later, quickly remove the wall. At the end of the experiment, stop the acquisition.
12. Export the Full Sequence to movie clip .avi. Save.
13. Note in your notebook the characteristics of the experiment (height, salinity, volume) and its name.

Using the data :

1. Open th .avi file in the ImageJ software.
2. A window opens, validate the use of Virtual Stack and the Conversion to Grayscale and press OK.
3. Obtain an orthogonal view of the front flow: Image-Stacks-Orthogonal view. Move the horizontal yellow line on the front of the current of gravity.
4. In the XZ picture you obtain the profile of the greyscale depending of the position (horizontal) and the time (vertical) (here without unity). Save this picture and open it.
5. Crop the image by selecting only the slope and Image-Crop.
6. Make the picture the most binary possible by: Image-adjust-threshold (and move the cursor to have a good red/grey difference and validate. Then, Process-Binary-Make binary. Fill up the white and dark area if necessary to get a clear black and white slope. Save the picture
7. Select the whole picture and Analyze-Plot profile. You obtain the Gray value (the time) as a function of the distance in pixels. Save it as a .txt file.
8. Open the file in python and plot the position of the front as a function of time. You will have to rescale your data: use the time between two pictures for the time axis and use the distance between the wall and the end of the experiment for the other axis.

Plotting the data in linear-log diagram allows to determine an exponential relationship if the data points collapse on a straight line.

$$y = ke^x \quad \text{with} \ \ Y = \log(y) \quad \rightarrow \ \ Y = \log(k) + \log(e) \cdot x \tag{1.1}$$

Plotting the data in log-log diagram allows to show a power law relationship if the data points collapse on a straight line..

$$y = A \cdot x^k \quad \text{with} \ \ Y = \log(y) \ \ \text{and} \ X = log(x) \quad \rightarrow \ \ Y = \log(A) + k \cdot X \tag{1.2}$$

1.3 The Box model

With the dimensional analysis only, we cannot get a scaling law for the speed of the spreading of the liquid. We propose here to build a simple model of forces equilibrium, see Ungarish 2009. We model the high density liquid as a box which lays out, and gets thinner, see Fig. 1.2.

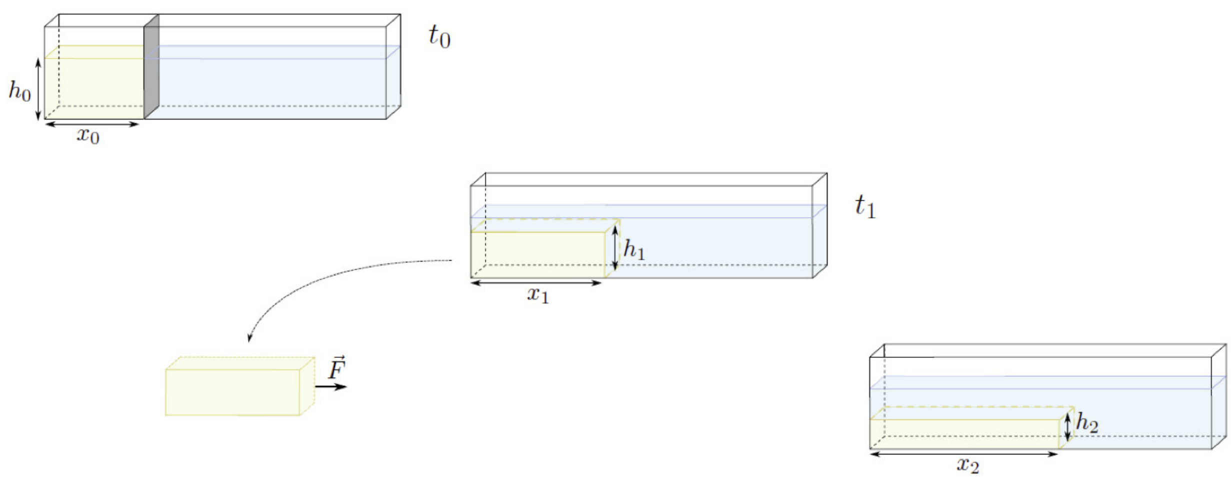

Figure 1.2: The box model kinematics

Here, we want to find the spreading velocity $\dot{x}$ of the salted liquid. We will simply use elementary hydrodynamics to find the scaling law.

First, through volume conservation of the spreading box, give a simple relationship between $x(t)$ and $h(t)$.

Now, can you remind the expression of the Froude number with $h(t)$ and $\frac{dx(t)}{dt}$.

At last, give the differential equation governing the evolution of $x(t)$.

Now, so far as you have a differential equation you can try to solve it. What is the power law of x in t ? (i. e.: what is α if you write $x \propto t^\alpha$?)

At the light of your first experiments and this power law, can you give the range of validity of the Box model ?

1.4 Assessing the model

In order to assess the model, we will vary the different parameters: the density difference, the height of salted water and the initial volume of salted water.

1.4.1 Varying salt concentration

Redo the experiment varying the salt concentration ($5\ \mathrm{g\,l^{-1}}$, $20\ \mathrm{g\,l^{-1}}$, $50\ \mathrm{g\,l^{-1}}$, $100\ \mathrm{g\,l^{-1}}$) at a fixed height (15 cm) and fixed volume (7.5 l). Process the data as before.

How the maximum speed is varying ? Do these results assess the Box model ?

1.4.2 Varying height of salted water

Redo the experiment varying the height (5 cm, 15 cm, 30 cm) at a fixed volume (7.5 l) and fixed salt concentration ($10\ \mathrm{g\,l^{-1}}$). Process the data as before.

How the maximum speed is varying ? Do these results assess the Box model ?

1.4.3 Varying the volume of salted water

Redo the experiment varying the initial volume (3.75 l, 7.5 l and 15 l) with fixed height (15 cm) and fixed salt concentration ($10\ \mathrm{g\,l^{-1}}$). Process the data as before.

How the maximum speed is varying ? Do these results assess the Box model ?

Conclusion : The best way to conclude such a study is to plot all the points on the same curve: the master curve. You may rescale all the curves with the scaling factor.

Can you comment this plot ?

1.5 The strait of Gibraltar

The strait of Gibraltar is modeled with a little bump placed on the bottom of the tank. The water of the Mediterranean sea is denser (Salinity of $38\ \mathrm{g\,l^{-1}}$) than this of the Atlantic Ocean ($S = 35\ \mathrm{g\,l^{-1}}$). Thus, it exists a strong gravity current which have some particularities.

1.5.1 Experiment

Place the little bump on the bottom of the tank as represented on the fig. 1.3. Place the gate over the little bump and fill the compartments with Atlantic and Mediterranean waters. Mediterranean water (Salted water) is denser and colored with fluorescein. For the first experiment, use a $10\ \mathrm{g\,l^{-1}}$ concentration.

What do you observe ? Describe the flow behavior.

1.5.2 Is there a control parameter ?

Can you do a quick dimensional analysis ?

The interesting parameters are: the difference of density between the two fluids and the height of water above the bump.

Redo the experiment varying the height of water (7 cm, 10 cm, 15 cm) at a fixed salinity ($10\ \mathrm{g\,l^{-1}}$).

Redo the experiment varying the salinity ($5\ \mathrm{g\,l^{-1}}$, $20\ \mathrm{g\,l^{-1}}$, $50\ \mathrm{g\,l^{-1}}$) at a fixed height of water (10 cm).

What is the relevant parameter, the total height of water or the height of water above the bump ?

1.5.3 Conclusion

Can you trace all the results as a function of the Froude number above the bump ? What is your conclusion ?

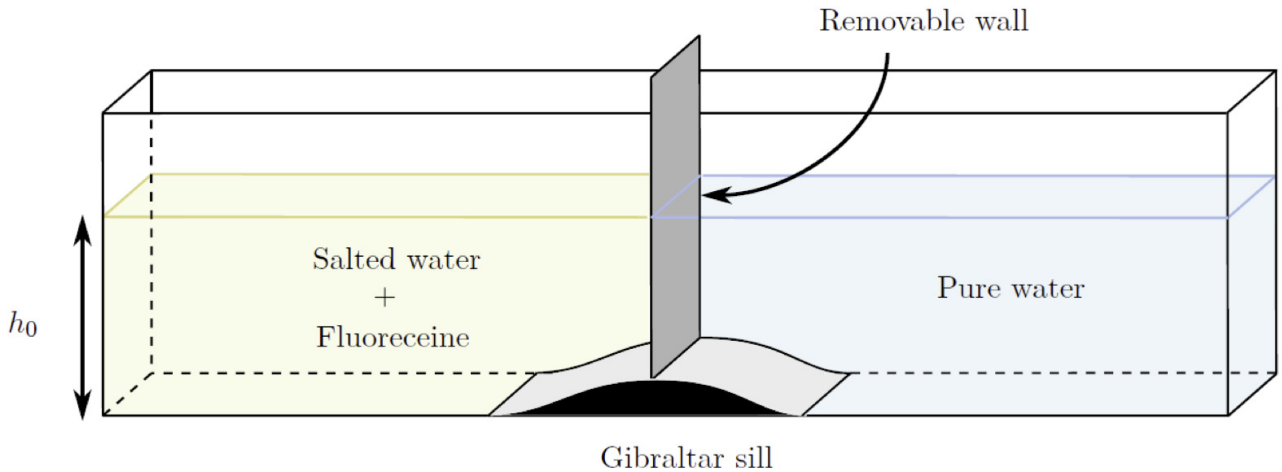

Figure 1.3: Gibraltar experiment

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