Numerical and Experimental Comparisons of Oceanic Overflow

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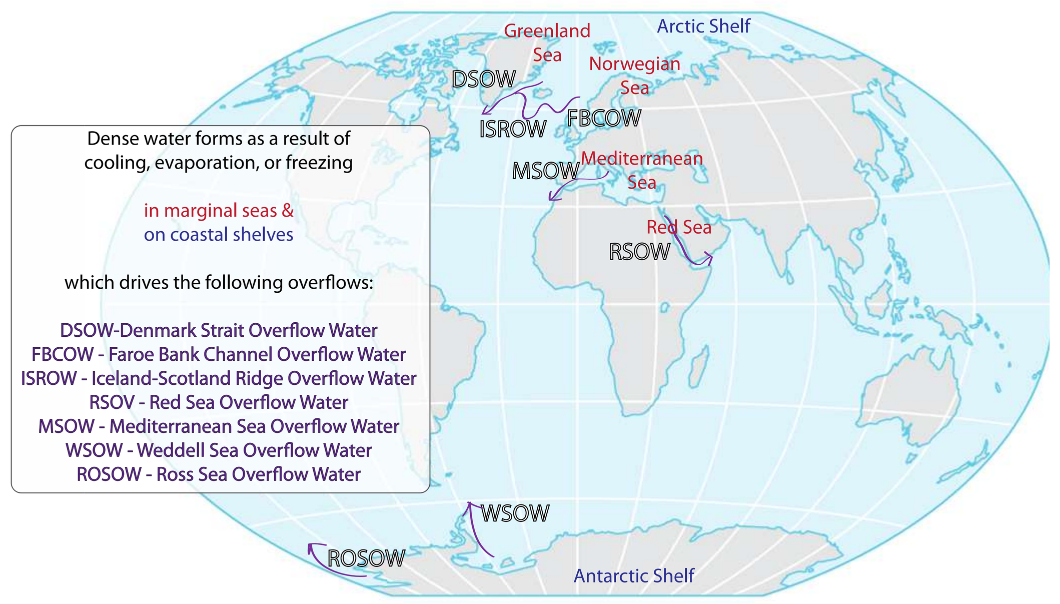
Abstract.

Overflows in the ocean occur when dense water flows down a continental slope into less dense ambient water. These density driven plumes occur naturally in various locations in the global ocean, but it is important to study idealized and small-scale models which allow for stronger confidence and control of parameters.

The work presented here is a direct qualitative and quantitative comparison between physical laboratory experiments and lab-scale numerical simulations.

Physical parameters are varied, including the Coriolis parameter, the inflow density anomaly, and the inflow volumetric flow rate. Laboratory experiments are conducted using a rotating square tank and high resolution camera mounted on the table in the rotating reference frame. Video results are digitized in order to compare directly to numerical simulations. The MIT General Circulation Model (MITgcm), a three dimensional, full physics ocean model, is used for the numerical simulations. These simulations are run under the full range of physical parameters corresponding to the specific laboratory experiments.

Overflow Locations.



Experimental Methods.

Goal: Obtain high-quality video to use as qualitative data to compare to numerical simulations. Our experiment is modular in that we can vary relevant parameters to observe different effects on the dense water plume.

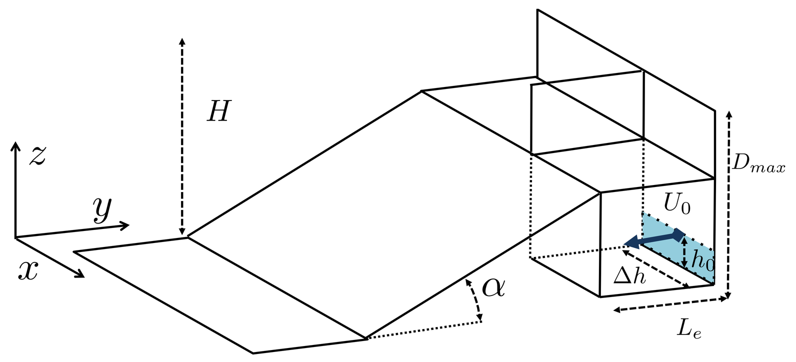


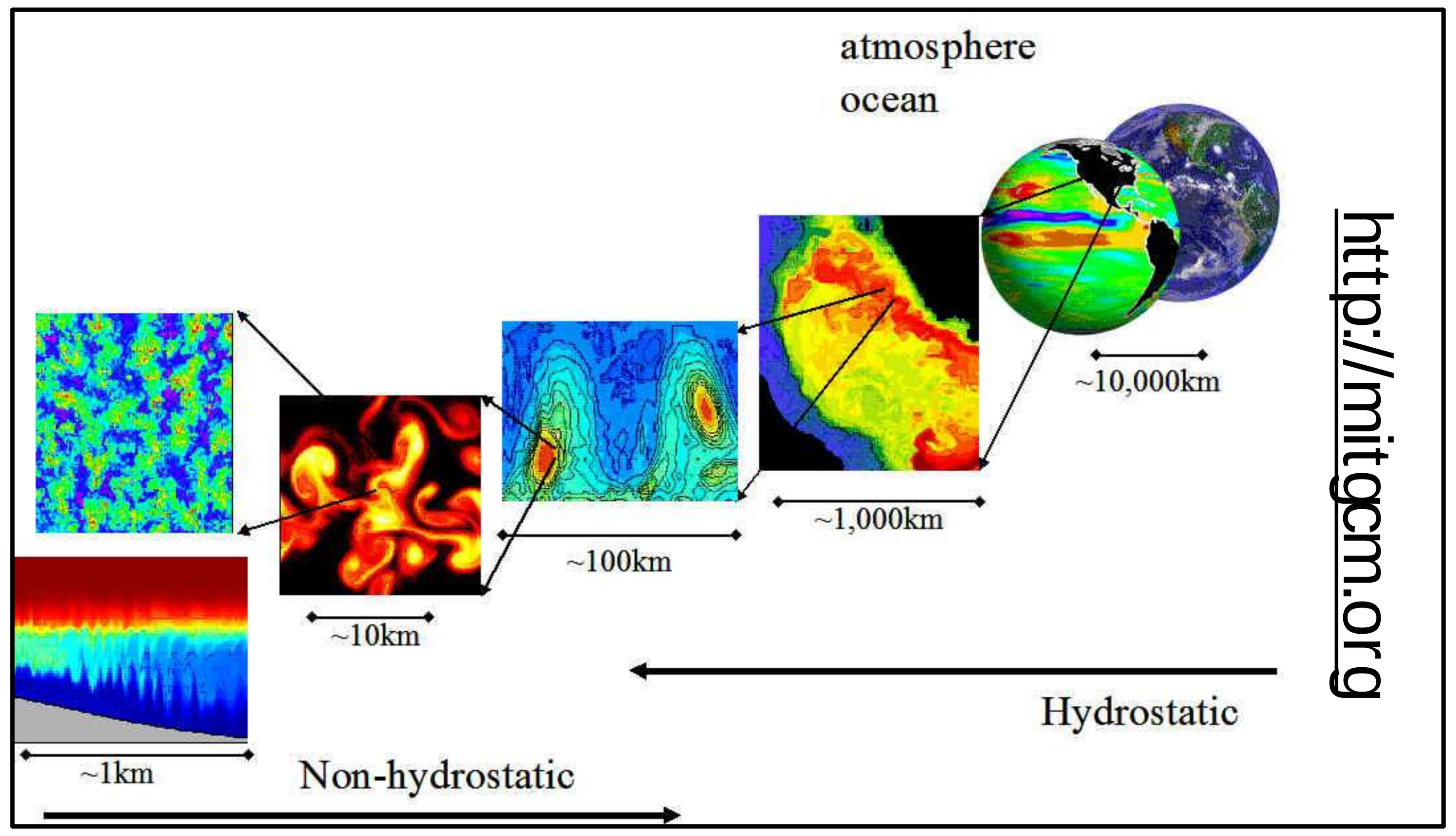
Figure 1: Experimental schematic of overflow slope.

Case	Inflow rate ($\frac{kg}{m^3}$)	Rotation (rpm)	Density ($\frac{cm^3}{s}$)
1	0.50	10	1.024
2	0.50	10	1.035
3	0.50	10	1.043
4	1.10	10	1.024
5	1.10	10	1.035
6	1.10	10	1.043
7	0.50	5	1.024
8	0.50	5	1.035
9	0.50	5	1.043
10	1.10	5	1.024
11	1.10	5	1.035
12	1.10	5	1.043
13	0.50	0	1.024
14	0.50	0	1.035
15	0.50	0	1.043
16	1.10	0	1.024
17	1.10	0	1.035
18	1.10	0	1.043

Figure 2: Specified parameter values for each experiment.

Numerical Methods.

The numerical model used for the simulations of the lab experiments is the general circulation model developed at the Massachusetts Institute of Technology (MITgcm). The MITgcm solves the governing equations using the finite volume method with an Arakawa C-grid discretization scheme for placement of the model's physical control volumes.



Model Formulation.

We seek a solution for steady flow of a dense layer of constant thickness over a sloping bottom. In our specific model, the MITgcm numerically solves the **non-hydrostatic incompressible Boussinesq equations:**

$$\frac{D\vec{\mathbf{v}}_h}{Dt} + f\hat{\mathbf{k}} \times \vec{\mathbf{v}}_h + \frac{1}{\rho_0}\nabla_h p' = \vec{\mathbf{F}}_h$$

$$\epsilon_{nh}\frac{Dw}{Dt} + \frac{g\rho'}{\rho_0} + \frac{1}{\rho_0}\frac{\partial p'}{\partial t} = \epsilon_{nh}\vec{\mathbf{F}}_w$$

$$\nabla_h \cdot \vec{\mathbf{v}}_h + \frac{\partial w}{\partial t} = 0$$

$$\rho' = \rho(\theta, S) - \rho_0$$

$$\frac{D\theta}{Dt} = \mathcal{Q}_\theta$$

$$\frac{DS}{Dt} = \mathcal{Q}_S$$

$\left.\begin{array}{l} \vec{\mathbf{F}}_h \\ \vec{\mathbf{F}}_w \\ \mathcal{Q}_\theta \\ \mathcal{Q}_S \end{array}\right\}$ Forcing and dissipation terms are provided by physics packages in MITgcm.

The variables are the following:

- $\vec{\mathbf{v}}_h$: Horizontal components of the velocity vector
- f : The Coriolis parameter
- ρ_c : Constant reference density of the ambient fluid
- ∇_h : The horizontal gradient operator
- p' : Pressure perturbation
- w : Vertical component of the velocity vector
- g : Acceleration constant due to gravity
- ρ' : Density perturbation
- $\vec{\mathcal{F}}_h$: Horizontal momentum forcing and dissipation
- $\mathcal{F}_w$: Vertical momentum forcing and dissipation
- $\mathcal{Q}_\theta$: Temperature forcing and diffusion terms
- $\mathcal{Q}_S$: Salinity forcing and diffusion terms
- ϵ_{nh} : Non-hydrostatic parameter set equal to one

Results.

A variety of parameter combinations were used in our experiments. The comparison presented is of experiments using two different inflow densities but with a constant rotation rate and inflow rate across both experiments.

Low Density Case	High Density Case	Inflow Rate	Rotation Rate	Slope Angle
ρ'=1024 kg/m³	ρ'=1035 kg/m³	U=1.1 cm³/s	ω=10 rpm	α=10°

Figure 1 and 2: A) Final frame from experiment. B) Plot of plume front every 5 seconds from experiment. C) Final frame from numerical model. D) Plot of plume front every 5 seconds from numerical model

Figure 1: Low Density Case

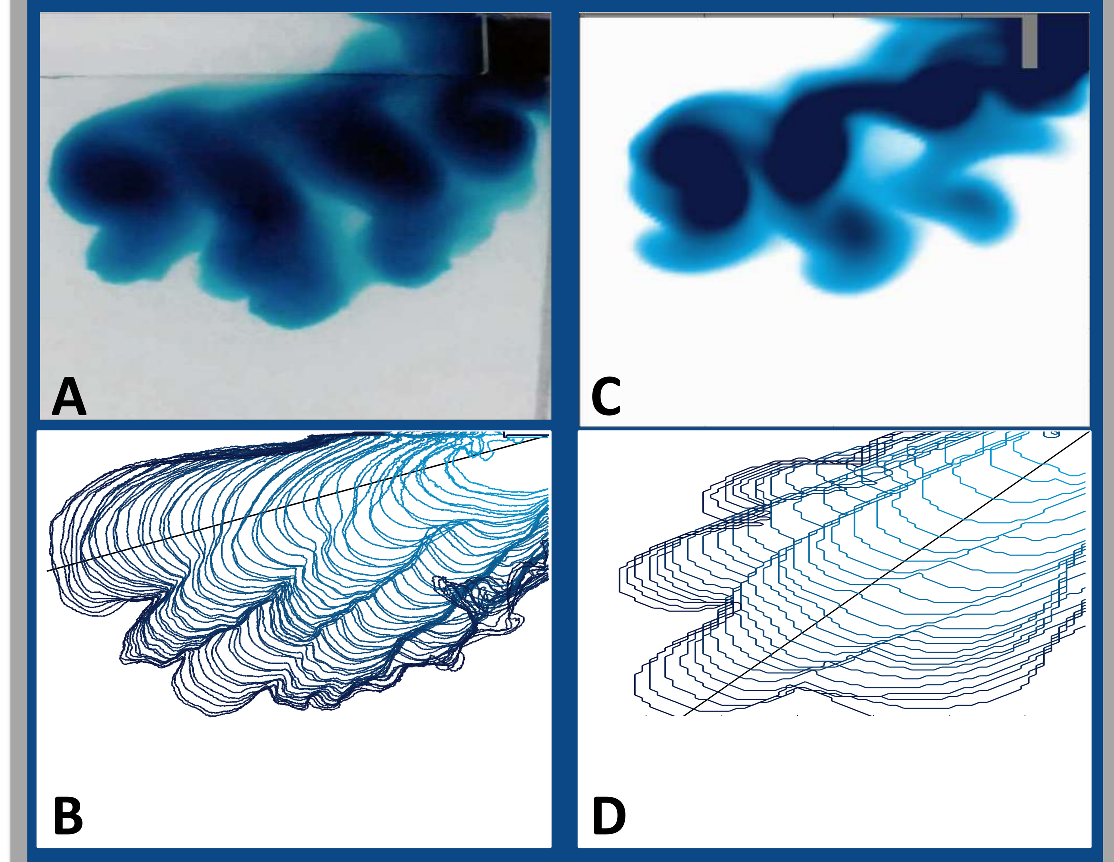
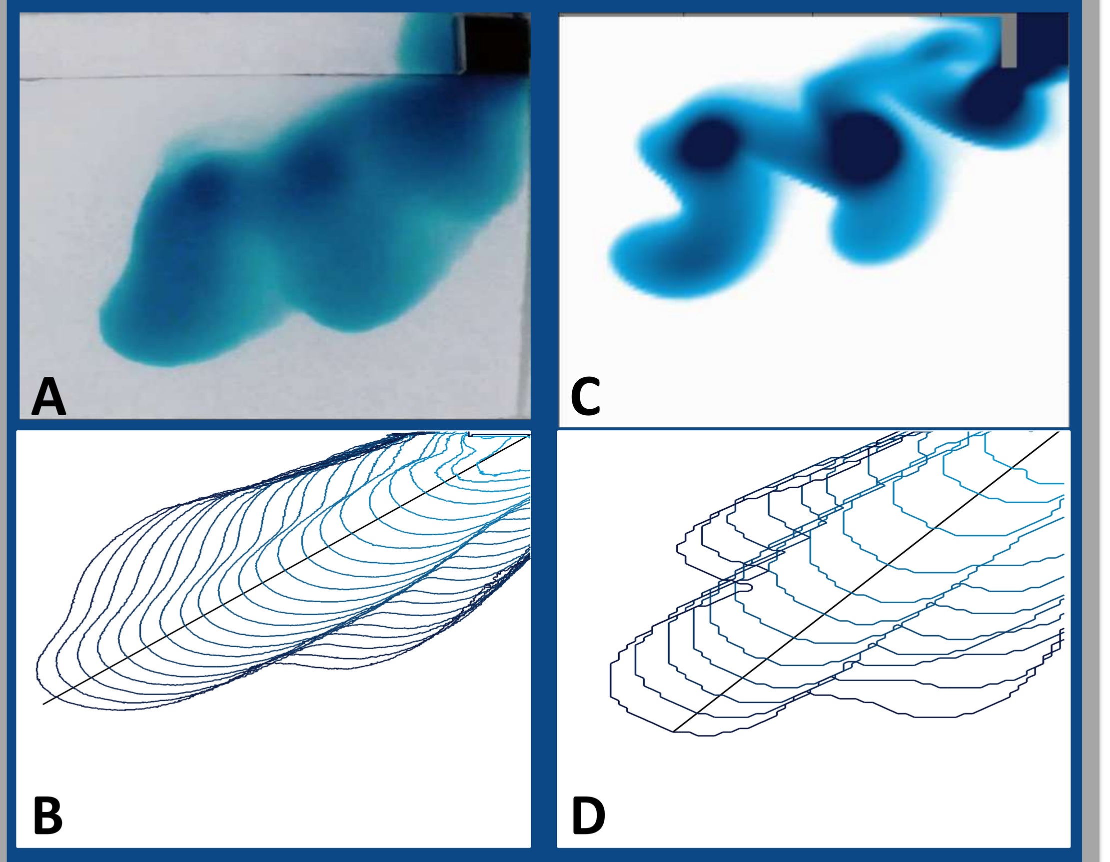


Figure 2: High Density Case



Future Work.

Although we have acquired a great amount of both video and numerical data, we think more research can be done on both the experimental and numerical components of this project. Experimentally, we would like to see more cases done with a varying slope angle; this would add a new parameter to are existing set. We would also like to vary the inflow density even more to better observe the overflow trends. Numerically, we would like to run particularly interesting cases at higher resolutions to resolve the smaller scale features that our current simulations cannot display. More time also needs to be put into fine tuning the numerical parameters to better represent our experimental counterpart. Finally, more quantitative comparisons between recorded video converted into MATLAB data and our numerical simulations would provide us. with further insight. We would like to look at transport, which it the flow rate of the plume down the slope. Additionally, we would like to find the entertainment of the plume to quantitatively measure the mixing.

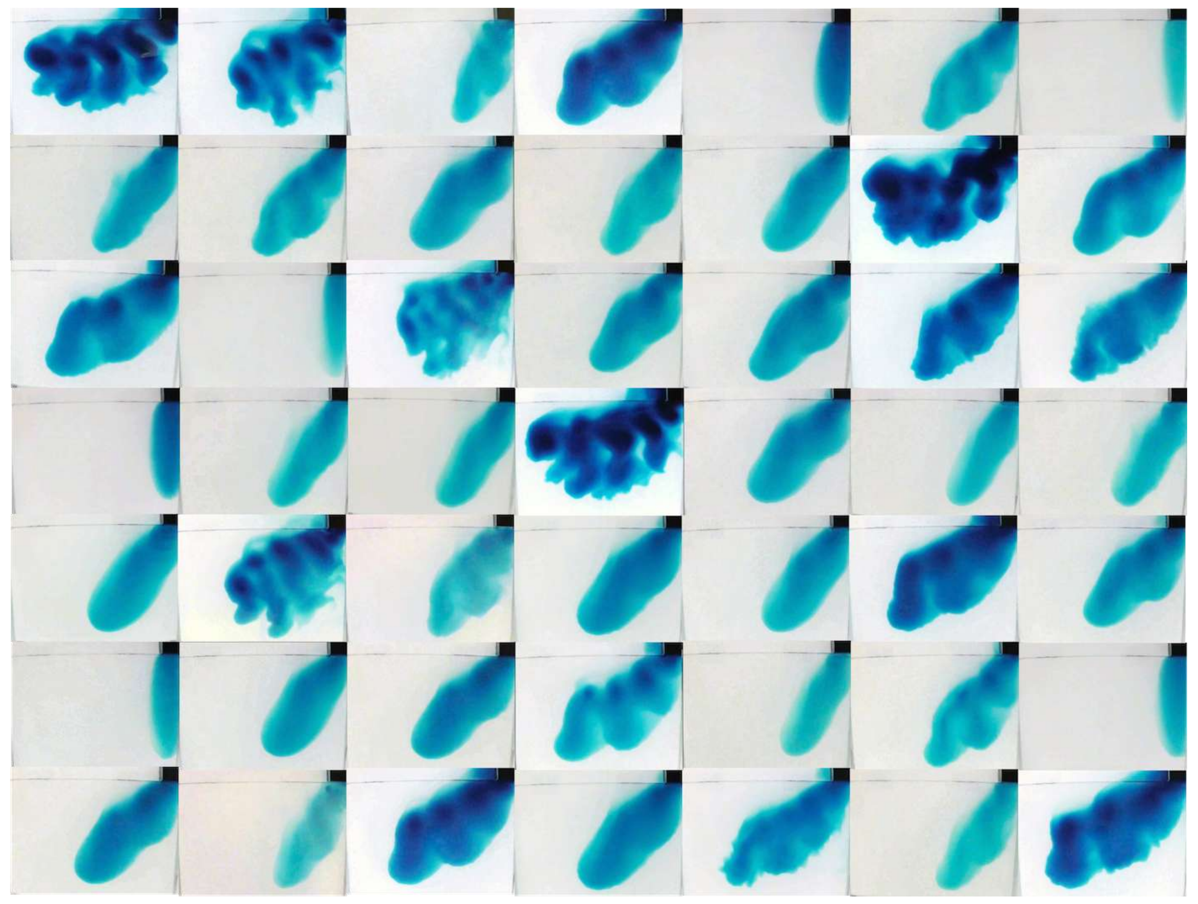


Figure 3: Assortment of experimental overflows to display visual plume diversity.

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