Final Report: INBUCOC – Interacting Buoyant Coastal Currents

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Considerable work is needed to improve our understanding of how coastal waters transport pollution, Harmful Algal Blooms (HABs), and sediments away from the populated coastline. The INBUCOC project used a combination of analytical calculations and laboratory experiments to investigate the effects of multiple river plumes on the formation and dispersal of coastal waters. A hypothetical, simplified scenario would have two rivers, a North River and a South River, with the North River outlet to the north of the South River outlet, flowing southwards along the coast. Relevant examples of this scenario are: 1) the Gulf of Maine into which two of the major rivers that flow are the Penobscot and the Kennebec Rivers; and 2) the Adriatic Sea where the Po River and several smaller rivers drain the Apennine Mountains in eastern Italy. The boundaries and relative location of these plumes are of fundamental importance when there is the possibility of one of the river waters being polluted or carrying harmful algae. One of the main questions the INBUCOC project focused on is: will this pollution or harmful algae affect the populated coastline? Other key questions are: What happens to the North River when it encounters the outlet of the South River? How will the two water masses align relative to each other in the vertical and horizontal? Will, for example, the South River water hug the coast and the North River water either flow offshore of, or underneath, the waters of the South River? Can different vertical and horizontal alignment scenarios influence mixing caused by winds and tides? These are significant questions when there is a possibility of the North River waters being polluted or carrying harmful algae. Will this pollution or harmful algae affect the populated coastline south of the South River? Or, will the South River act as a barrier to such threats to reach the coast? Or, will it merely "dilute" such threats? The principal objectives of this study were: 1) quantify the possible horizontal and vertical alignment scenarios as a function of dynamically relevant non-dimensional numbers using an analytical model; 2) compare the analytical results to laboratory experiments.

Laboratory results and analytical calculations illustrated that the frontal position, the depth profile, and the horizontal and vertical alignments of two buoyant fluids having different densities can be characterized by an important length scale called the Rossby radius of deformation (i.e. approximately the current frontal width). In particular, the relevant dynamical non dimensional numbers for this problem are the ratio of the baroclinic Rossby radii of deformation and the Burger number (i.e. approximately the ratio between the current frontal width and the current total width). The laboratory rotating experiments confirmed the analytical prediction of the location of the two fronts (Fig. 1a,b). After reaching equilibrium, the two buoyant currents align mainly horizontally when the extent of the fronts between fluids 1 and 3 and fluids 2 and 3 are large compared to the extent of the front between fluid 1 and 2. Alternatively, if the extent of the fronts between the three fluids is similar, the buoyant currents align mainly vertically. Furthermore, the Burger number of the lightest fluid (fluid 1) controls the distance of the inner front from the coast, while the Burger number of the intermediate fluid (fluid 2) controls the offshore extent of the outer front.

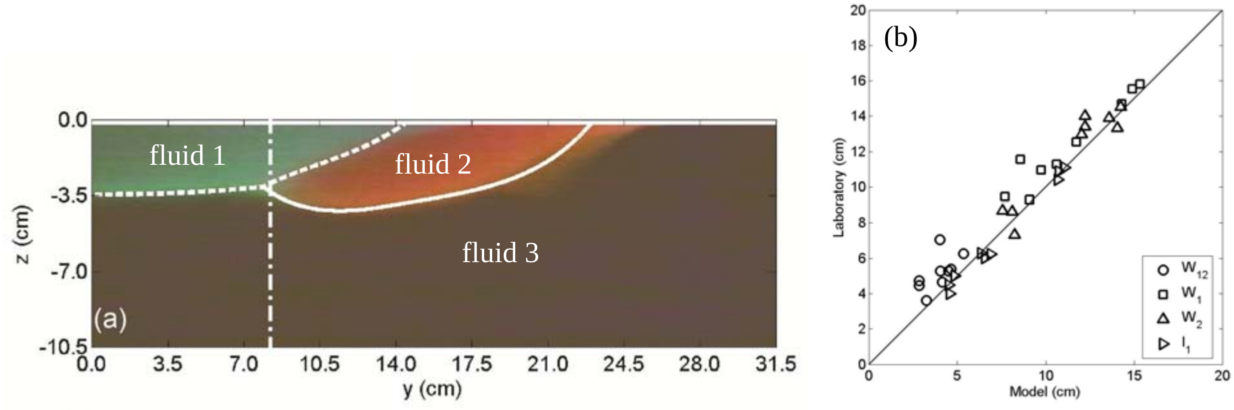

Figure 1. (a) Side view if the two buoyant currents after reaching equilibrium, the dashed and solid lines indicates the model prediction of the two buoyant currents' depth. (b) Comparison of the model prediction of the variables relevant variables with the values measured in the laboratory from images like that presented in (a).

The present study, albeit very idealized, brings some insights on how the water masses of two individual buoyant coastal currents align relative to each other vertically and horizontally. For example, in the scenario in which fluid 2 is polluted or contains harmful algae, one could be concerned with the likelihood of fluid 2 reaching the coastline. The results of the present study suggest the following. For small values of the Burger number of the lightest fluid (fluid 1) the water mass of fluid 2 should flow far away from the coastline, which may ensure that the pollution or harmful algae remain offshore. For values of Burger numbers of order of unity and when the extent of the fronts between fluids 1 and 3 and fluids 2 and 3 are large compared to the extent of the front between fluid 1 and 2, the alignment of the two buoyant currents should be mainly horizontal, hence vertical mixing generated by winds or tides should occur primarily between the polluted waters (fluid 2) and the open ocean (fluid 3). Only a small part of the current close to the coastline (fluid 1) should mix with the polluted current (fluid 2) and the mixed polluted waters should remain offshore. The pollutants or harmful algae should be expected to arrive closer to the coastline for large values of the Burger number of the lightest fluid (fluid 1), when the interfacial front between fluid 1 and 2 is close to the coastline, and for values of Burger numbers of order of unity and when the extent of the fronts between the three fluids is similar. In the latter case, the alignment of the two buoyant currents should be mainly vertical. Hence, mixing generated by winds or tides should occur primarily between the polluted waters (fluid 2) and the fluid close to the coastline (fluid 1) increasing the likelihood of the polluted waters reaching the coastline. The above interpretation of the INBUCOC project results of a very idealized model and laboratory experiments is highly speculative and should be interpreted with care. However, it highlights how idealized studies such as the INBUCOC project may bring insight in interpreting more complex models and oceanic observations. Our model and laboratory experiments do not take into account two important forcings present in the ocean: winds and tides.