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Link Foundation Fellowship Report

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Prepared for: Dr. Javad Hashemi
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1 - Introduction. The confluence of the river and ocean is a crucial and critical coastal region. The river inputs can vary from sediments and nutrients to wastewater and fertilizers. Notably, water quality, coastal management, and overall ecosystem health are directly impacted by these constituents. Strategies to maintain coastal health, mitigate anthropogenic impacts, and predict the fate of riverine biogeochemical outputs require reliable knowledge of the physical processes that mix the outflow and ambient waters. These local dynamics are highly influenced by tides, river discharge, winds, currents, and turbulent mechanisms. Mixing and turbulence of river plumes occur across engineering to geostrophic scales, ranging from the frontal propagation $[O(\text{km})]$ to turbulent motion $[O(<1\text{cm})]$. These features cannot be resolved by remote sensing or entirely sampled by moorings and boat surveys. Consequently, they demand creative data sampling plans and complex data processing to fully characterize this evolving and migrating environment. My main objective is to investigate the role of mixing processes at the horizontal boundary between the fresh buoyant discharge and ocean waters, which we call front.

Results. During this project, we developed and successfully executed a unique survey that has provided a cutting-edge dataset. The method we developed is centered on an autonomous underwater vehicle (T-REMUS), which allows continuous and highly resolved data collection, depicting the different scales and evolving dynamics of the plume. This is particularly pertinent to an observational effort in the Merrimack River plume, spanning approximately 8 hours, while tracking the plume front. This strategy performed over thirty-two frontal crossings, which can be organized into perpendicular sections of the frontal zone. These crossings were captured as quasi-synoptic snapshots from the moment of liftoff until the plume's arrest. The assembly of the instrument's datasets and drone footage enables the conversion of reference frames regarding the crossing angle and frontal curvature, the correction of velocities with respect to front propagation, and other pertinent procedures that permit the comparison of these crossings.

By comparing and describing these crossings, we can analyze the evolution of the plume front, encompassing density, particulate matter, turbulence, and cross-front and along-front velocity structures over time. Complemented by drone imagery, drifter pathways, and additional CTD profiles, we evaluate the buoyant plume's shape, depth variation, density changes, propagation, and other evolving characteristics. The results showcase distinct phases corresponding to changing dynamics, offering a comprehensive picture of the evolution of the frontal zone. Over time, the distinction between phases gradually diminishes, indicating a saltier mixed plume. The progression starts, shortly after high tide peak, with a sharp density gradient at the front is observed, with higher salinity variance extending approximately 80 m into the plume. Dissipation rate and backscatter intensity peak at the front, influenced by downwelling, which also pushes the T-REMUS downward. Then the transition phase maintains the density gradient but with a broader frontal region and higher salinity gradients extending over 100 m into the plume. The plume becomes deeper and more unstable, reaching depths of over 6 m with billow-like formations. Lastly, in the geostrophic phase, the plume shallows, cross-front propagation and density gradients decrease, and downwelling weakens. Foam begins to lag behind the front, and other foam lines form, potentially due to lateral transport and a swirling effect as the plume starts to rotate, influenced by geostrophic steering.

Another analysis of interest is the evolution of turbulent dynamics in the frontal zone. The rotating cell at the frontal head generates intense turbulence, five to seven orders of magnitude higher than ambient levels. This unique feature may be crucial in driving the plume's dissipation and propagation, and it has not yet been fully described in the literature.
Significance and impact. The significance of our findings resonates deeply within both practical and academic domains. In practical terms, this study wields substantial influence on coastal management strategies and augments the precision of numerical models used to forecast the trajectory of riverine biogeochemical outputs and their dynamic behavior. In the academic sphere, our work distinguishes itself by providing an unprecedented level of detail regarding the front, covering most of its duration, typically encompassing a full tidal cycle. Moreover, by bridging the gap between engineering and geophysical-scale processes and employing innovative instrumentation, our project speaks to the future of coastal sampling technologies. This opportunity has inspired a vision where I can continue to contribute to oceanographic research, strengthening its societal impact.

Where might this lead? The method elaborated in this project holds great potential for other applications and extensions. It can readily be adapted and employed as a sampling blueprint for different propagating oceanic features, such as distinct water masses and eddies. Additionally, the detailed portrayal of the front presented in our research, promises to enhance the outputs of coastal models. These models often struggle to depict sharp gradients accurately. Consequently, our work may enable the development of parametrizations of the front's dynamics and foster a deeper comprehension of these dynamics, facilitating their integration into model equations. This could ultimately aid more precise and comprehensive coastal modeling.

2. A list of all archival journal papers or scholarly reports, either published or expected to be submitted/published, that have acknowledged or will acknowledge Link Foundation support.

1- Title: River Plume’s Front Sampling: A High-Resolution continuous Method Combining an AUV, a Drone, and Surface Drifters
   Authors: Agata Piffer Braga, Daniel G. MacDonald, Nikiforos Delatolas
   In preparation for submission to Limnology and Oceanography Methods

2- Title: The Evolution of a River Plume Front: Insights from Highly Resolved AUV Data of Frontal Crossings During a Tidal Pulse
   Authors: Agata Piffer Braga, Daniel G. MacDonald, Kimberly Huguenard and Preston Spicer
   In preparation for submission to Frontiers in Marine Science

3- Title: Evolution of Turbulent Structure in an Advancing River Plume Front
   Authors: Agata Piffer Braga, Daniel G. MacDonald, Louis Goodman
   In preparation for submission to Journal of Geophysical Research

4- Title: Observing System Simulation Experiment of Plumes Samplings
   Authors: Ratna Prakarsha Kandukuri, Daniel G. MacDonald, Agata Piffer Braga
   In preparation for submission to Frontiers in Marine Science
4. How did the Fellowship make a difference?

The Link fellowship supported one year of my research efforts and allowed me to pursue skills, including critical thinking, problem-solving, data analysis, communication, project management, and technical expertise. It provided me with the means to focus on my career, deepen my understanding of the field, and fostered my curiosity for other potential research areas. The impact of these experiences is clearly visible in the structure of my PhD thesis, which I reformulated and successfully defended to my committee during this year. The Link fellowship not only improved my personal fulfillment and career opportunities but also contributed to advancements in the field, making a lasting impact on society and the scientific community.