Research Experience

My Ph.D. research is to study the impact of aquatic vegetation on hydrodynamics, sediment transport, and interfacial gas exchange in rivers and coastal areas. I employ experimental and numerical techniques to study these phenomena to develop process-based models. For the experiments, I primarily employ velocimetry techniques such as Particle Image Velocimetry (PIV) and Acoustic Doppler Velocimetry (ADV) to characterize flow turbulence in flumes with vegetation. I perform Large Eddy Simulations (LES) to characterize the flow where experimental measurements are challenging (e.g., near the bed, within the vegetation canopy).

Hydrodynamics of vegetated channels has been a subject of study for the last three decades, with increasing interest due to its ecological impacts. ADV and PIV are the common methods employed to study these flows. However, to take velocity measurements using ADV or PIV, a portion of the vegetation patch is usually removed for instrument access or a clear field of view. It is usually assumed that the flow measurement in such gaps is representative of flow within the vegetation canopy. However, no comprehensive study had been performed to access the measurement error introduced by this practice. I used a combination of PIV measurements within gaps of varying size, and numerical simulations (LES) of identical flows to quantify the measurement error introduced due to this technique. Further, I developed a framework to obtain representative measurements of turbulence from the data collected within canopy gaps. This will allow researchers in my research area to accurately quantify canopy flows and develop better process-based models. The research has been published in Physics Of Fluids (Ranjan et al. 2022).

Suspended sediment accounts for over 80% of the sediment transported in natural waterways. Sediment suspension in the water column leads to density stratification which results in the modulation of turbulence. However, aquatic vegetation is known to enhance turbulence and mixing in the water column. Effects of density stratification and turbulence modulation due to suspended sediments in vegetated canopies has not been studied. I used high-resolution LES to simulate suspended sediment transport in vegetated channels and found that the effects of stratification are primarily limited to the near-bed region, thus affecting sediment resuspension and bedload transport. I also derived a Rouse-type formulation for suspended sediment concentration (SSC) profile in emergent rigid vegetation (Ranjan & Tinoco, 2023).

Gas release from coastal marshes is an important component of the carbon cycle. I performed experiments on a wave flume to characterize the effect of vegetation-generated turbulence on the gas transfer rates in vegetated coastal waterways. I used wave gauges to characterize free surface waves and used optical dissolved oxygen (DO) sensors to measure the reaeration rate of the water. I used ADV and PIV techniques to characterize the flow and currently, I'm working on developing a process-based model for gas transfer rate in vegetated channels under waves.

Besides my doctoral research, I have also performed experiments in a wind tunnel to measure the initiation of motion of commonly found plastic objects in landfills. I used load cells to measure the wind load on common plastic objects and determine the initiation of motion. This information was used to develop a framework for plastic transport from landfills (Yadav et al.,2020), and for risk assessment of the environmental release of plastics (Yadav et al., 2022). I have also collaborated with fish biologists to study the turbulence response of Sea-Lamprey which is an invasive fish species affecting the Great Lakes ecosystem. I performed novel flume-based experiments at the Hammond Bay Biological Station (HBBS) to determine if Sea-Lamprey are attracted or repelled by turbulence-generating structures. We found that a single turbulence statistic is not sufficient to explain the response of Sea-Lamprey and can be better explained by considering joint statistics of turbulence. These results will be used by conservationists to increase the trapping efficiency of Lamprey traps.

I have always been enthusiastic about sharing science with the community and showcasing the contemporary scientific work being done in my research field. In 2021, I teamed up with fellow researchers in aerosol chemistry and designed a Schlieren imaging setup to access the effectiveness of masks in reducing the spread of droplets. We showcased this setup at the Engineering Open House (EOH) and won the first prize across the engineering campus. A YouTube link to the award-winning video is here.

References

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