Particle Motion in Turbulent Flow and Wetland Gas Transfer

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2019 Transfer-to-Excellence Research Experiences for Undergraduates Program (TTE REU Program)

Abstract

Oceanic turbulence directly influences the transport of marine particles such as debris or organisms, which impact the ecosystem. This research aims to understand the physics of particle motion in turbulent fluids in a laboratory environment. We perform experiments to explore the relationship between fluid flows and particle dynamics. Specifically, we record the kinematic response of fluorescent green polyethylene microspheres with diameters between 125-150 μm. We did this by using custom-designed cameras, and tracking their motions to examine fluid flows in a simulated wetland. The primary goal is to process images to determine the velocity of these microparticles passively following the fluid motions. We characterize the fluid turbulence using the resolved motions of these passive particles. This characterization is used to understand mixing, which leads to a better idea of what happens to particles as they travel and how they interact amongst each other. This allows us to better comprehend the locomotion, feeding, colonizing, and escape mechanisms of marine organisms.

Introduction

- Increasing environmental concerns compel experts in environmental engineering to consider problems such as the effect of turbulence on the dispersion of a contaminant and the transfer of a substance between an interface[1].

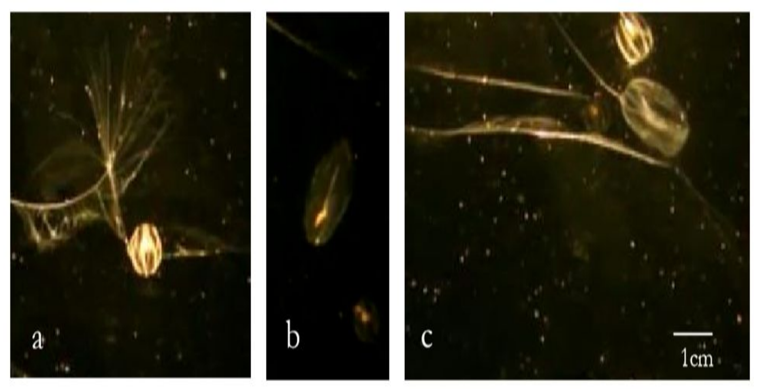


Figure 1. (a) *Pleurobrachia bachei* (b) *Hormiphora californiensis* (c) the two organisms side-by-side. All images captured at the Monterey Aquarium in March 2014.

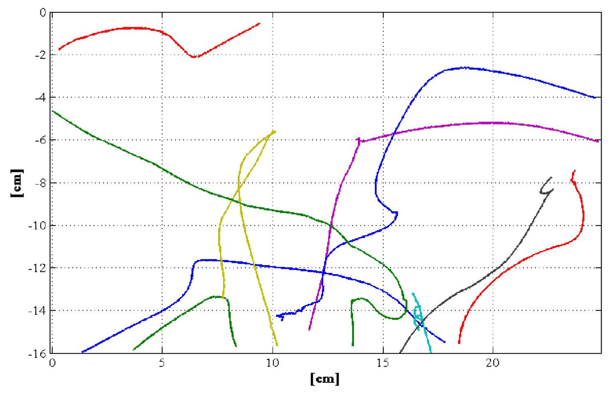


Figure 2. Data collected at the Monterey Bay Aquarium, showing center-of-mass trajectories of *Pleurobrachia bachei* in low-shear flow. Each color is a different animal, and flow is right-to-left.

- In environmental engineering applications, the rate of transport of a molecular species across an air-water interface is dependent on fluid flow near the interface[2].

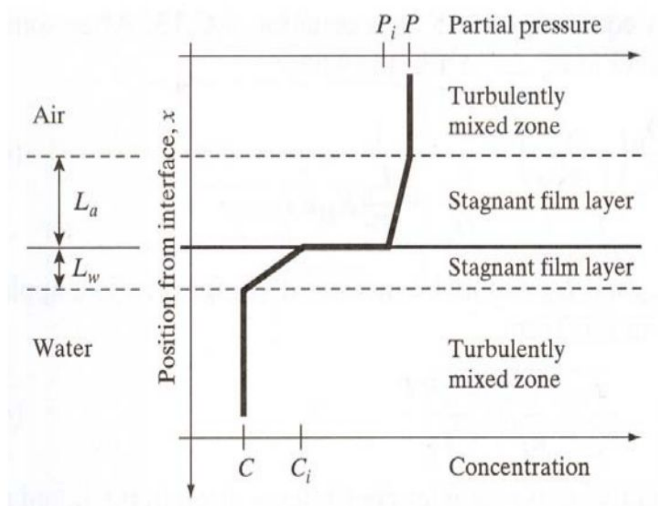


Figure 3. Schematic of two-film model for estimating mass transport across an air-water interface. Adapted from "Environmental engineering science," by Nazaroff, 2001.

Methods

Laboratory Work

- Experiments are conducted using a simulated wetland for particle tracking in turbulent flow and surveying the fluid motions.

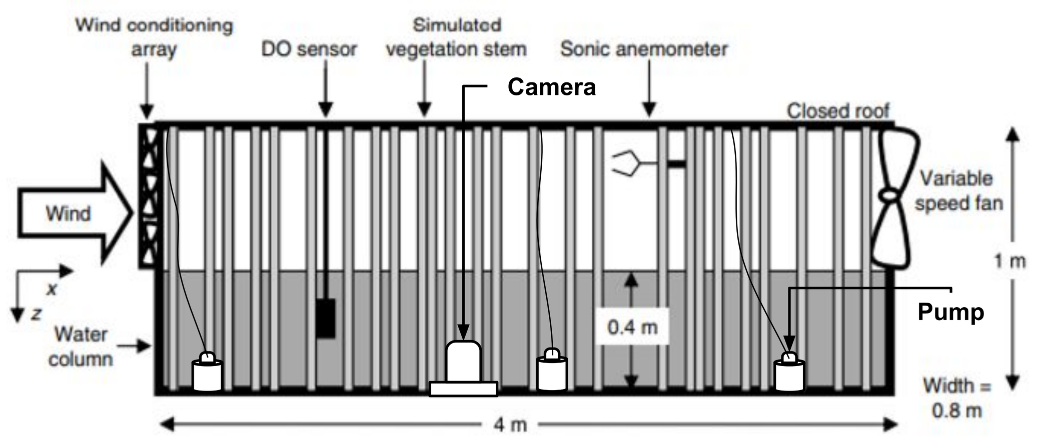
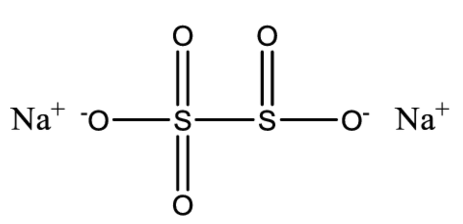
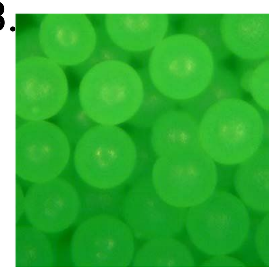
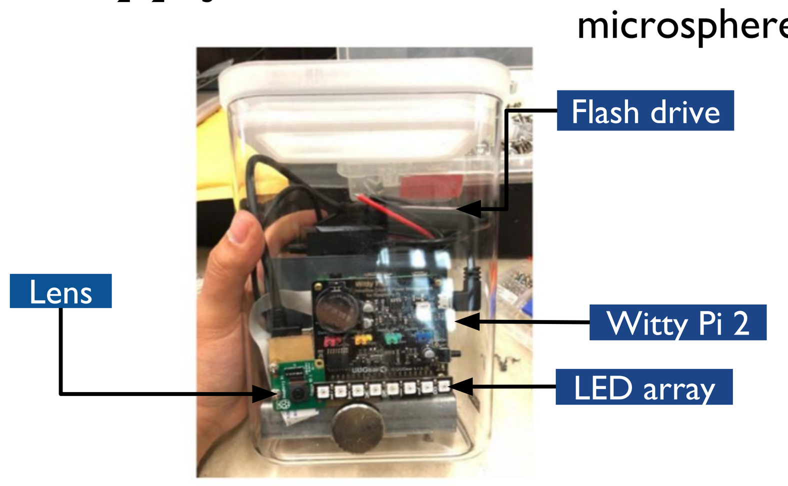


Figure 4. Schematic of the model wetland in the laboratory. Adapted from "Air-water gas exchange in wetlands," by Poindexter, 2013.



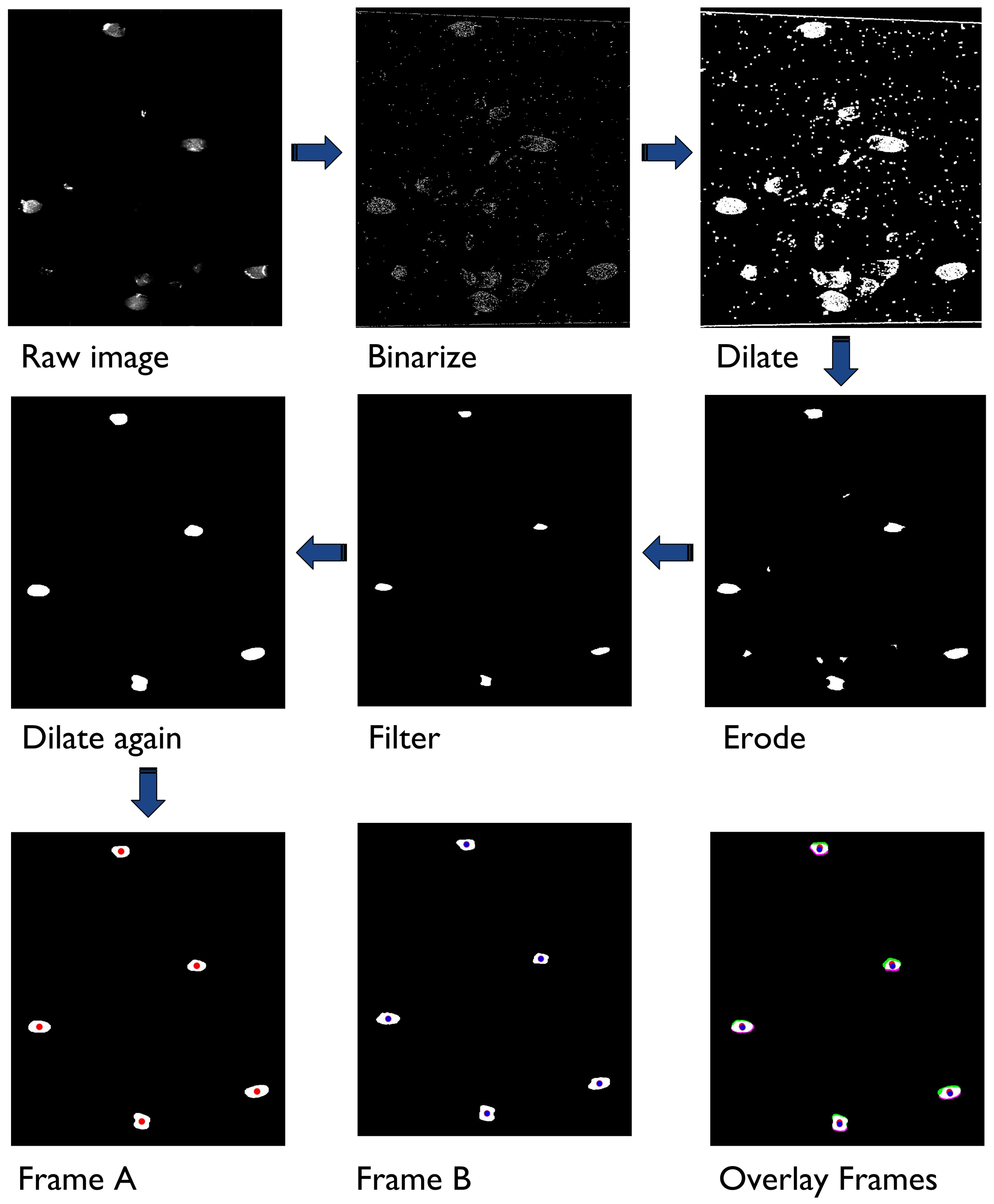


- Sodium metabisulfite ($Na_2S_2O_5$)
- Fluorescent green polyethylene microspheres

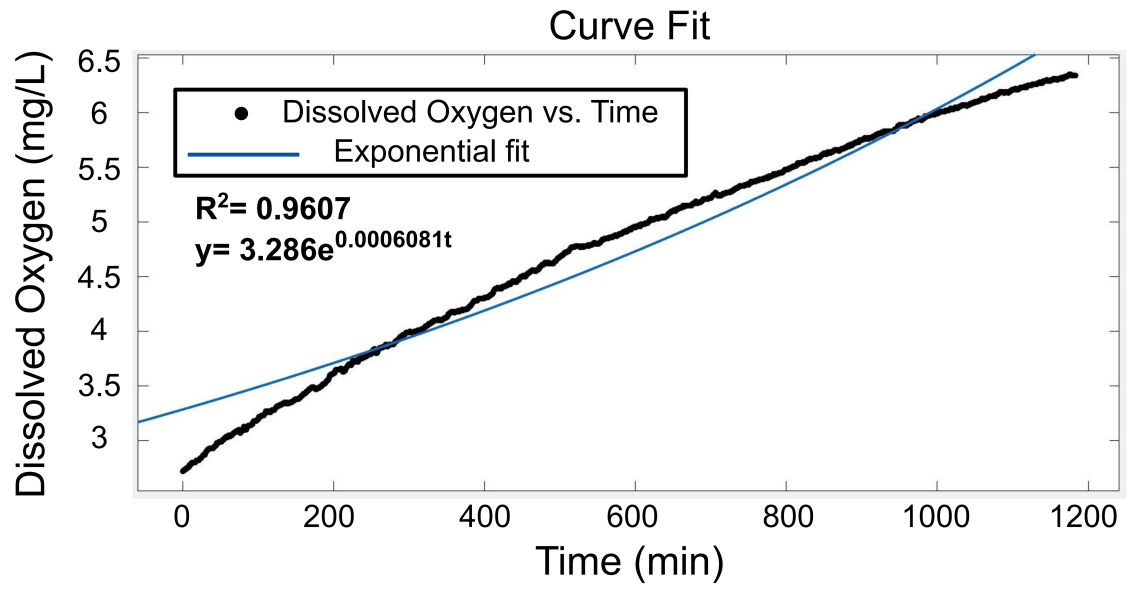


Raspberry Pi Camera

Image Processing

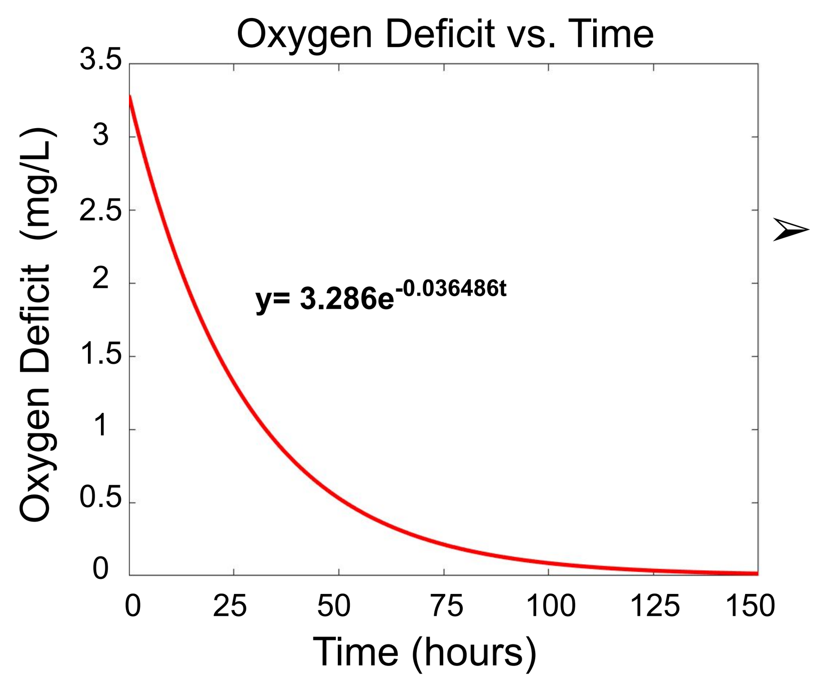


Results



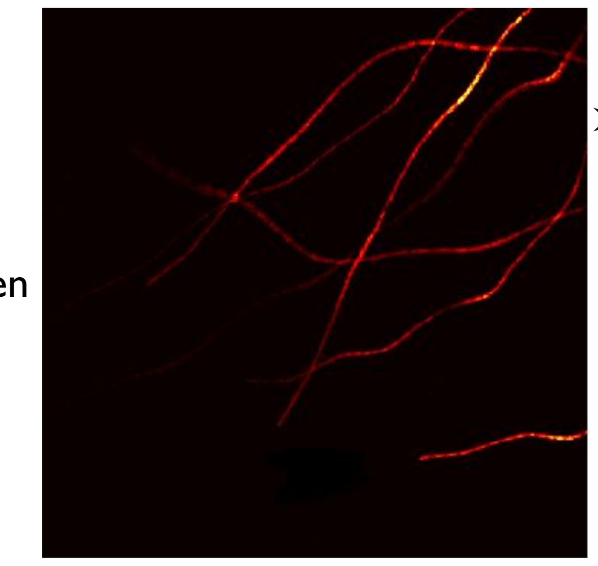
- Exponential curve matches with oxygen equilibration rate

Figure 5. Curve fit of data collected during deoxygenation process.



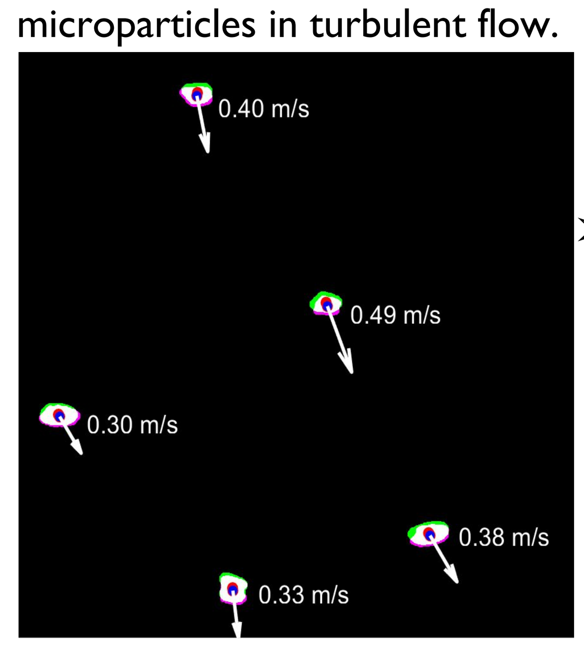
- Gas transfer velocity across air-water interface was determined to be 0.94 cm/hr

Figure 6. Plot of oxygen concentration difference from equilibrium.



- Particle motion is correlated to equilibration rate in the model wetland

Figure 7. Data collected in the laboratory, showing center-of-mass trajectories of microparticles in turbulent flow.



- The velocity of these particles range from 0.3-0.5 m/s

Figure 8. Vector and scalar representation of the motion of particles.

Conclusions

The oxygen deficit decreases exponentially in our simulated wetland, which agrees with the theory being tested in the laboratory. Being able to describe the equilibration rate of oxygen with an exponential model allowed us to measure the near surface stirring in the water, which drives the exchange of fluids across the air-water interface. This is significant because net fluxes of gas exchange in wetlands are sensitive to the availability of oxygen[3]. The calculated velocities of these particles moving in groups imply the water was well mixed, which agrees with the equilibration rate and gas transfer velocity.

Future Work

Further data will be collected and analyzed to characterize the turbulence and inform the wetland management community of the respiration rate of our simulated wetland. Additionally, the impact of how the stirring of particles influences ecosystems will be informed. This will ultimately bring about environmental engineering applications for climate and ecological impact.

Acknowledgement

I would like to thank my mentor Dr. Ankur D. Bordoloi for all the guidance and support he provided throughout my project, particularly image processing. I would also like to thank my Principal Investigator, Professor Evan A. Variano, for selecting me to work in his laboratory and for all the knowledge, wisdom, and advice he shared with me applicable not only in the laboratory and classroom, but life in general. Moreover, I would like to thank Kimberly Huynh for all the assistance on running the experiment and the TTE REU program for my entire research opportunity. Last but not least, I would like to thank the National Science Foundation for funding my research.

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Support Information

This work was funded by National Science Foundation Award # 1757690

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