Using Flow Fields to Observe the Role of Diel Vertical Migration on Biomixing

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Abstract

This experimental set-up will be used to investigate the diel vertical migration (DVM) of zooplankton, *Daphnia* magna in this experiment, and the effects that DVM has on biomixing. The experiment will produce flow fields that will be used to draw conclusions on zooplankton's role in biomixing. DVM is heavily dependent on light as a driving factor, zooplankton escape from light in the field but swim towards light in the lab. Therefore, this phototactic behavior will be taken advantage of to drive DVM in the experiment through LED lights. The images from a camera tracking the spatiotemporal distribution of zooplankton, will be used to obtain flow fields through particle image velocimetry (PIV) and particle tracking velocimetry (PTV). These flow fields will provide information such as dissipation rates of hydrodynamic tails, allowing the scale of zooplankton mixing to be investigated. Zooplankton are an essential aspect of the aquatic systems and understanding the scale at which DVM influences biomixing provides insight into the role of DVM in processes such as the carbon cycle and biological productivity.

Figure A: *Daphnia* swimming, the two wing like appendages are flagella used to propel the Daphnia through the water, leaving fluid trails in its wake.

Introduction:

Some of the most essential and active members of the ocean and its biological processes, are some of the smallest. Zooplankton are a main primary consumer in aquatic food chains, consuming phytoplankton and moving this energy and biomass up through the food chain as well as down through the water column. Zooplankton are a large contributor to "marine snow," organic matter sinking through the water column to the sea floor, bringing carbon from the surface to the seafloor. Marine snow contributes to the carbon cycle and the ocean's biological pump, sequestering carbon and making it a part of the ocean's carbon sink. The role zooplankton play in the ocean's biological pump makes understanding zooplankton and their movements through the ocean important to further understanding biological processes in the ocean. The movements of zooplankton are quite unique and produce unique outcomes as a result. Zooplankton perform diel vertical migration, rising to the surface during the night to feed and sinking back to deeper waters during the day to avoid predation. These diurnal movements through the water column result in active carbon sequestration as biomass from the surface is actively brought to deeper waters through DVM. Additionally, this mass migration can possibly cause mixing within the water column, bringing much needed nutrients from the deep ocean to the surface, and oxygen from the surface down into deep, low oxygenated water. To understand DVM and the role it plays in large processes, we must understand the driving factors of it and the scale at which is produces biomixing

References:

Houghton, I. A., Koseff, J. R., Monismith, S. G., & Dabiri, J. O. (2018). Vertically migrating swimmers generate aggregation-scale eddies in a stratified column. *Nature*, *556*(7702), 497–500.

Noss, C., & Lorke, A. (2014). Direct observation of biomixing by vertically migrating zooplankton. *Limnology and Oceanography*, *59*(3), 724–732.

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Lab Setting:

- Metal frame holding 2 LED panels and a ` 12x12x40 cm tank
- Inside tank is a 10x40 cylinder to produces cleaner images without harsh borders like corners present
- The tank is in the middle, 1 LED panel and diffuser on both sides of the tank, top and bottom on adjustable bars to make both LEDs the same distance from the water
- LEDs are attached to a relay module connected to an Arduino that is programmed into a "night" and "day" sequence
- In front of the tank is a camera, perpendicular to this camera (to the right or left of the tank depending on space) is a laser
- The laser is attached to a refractor that creates a laser field that dissects the width of the tank, producing a laser sheet directly in front of the camera
- The below images (Figures C and D) shows the set-up of the tank and frame without the inner cylinder, Figure D showing the laser field with seeding particles present
- The Daphnia are housed in two separate colonies and moved into tank for experiment

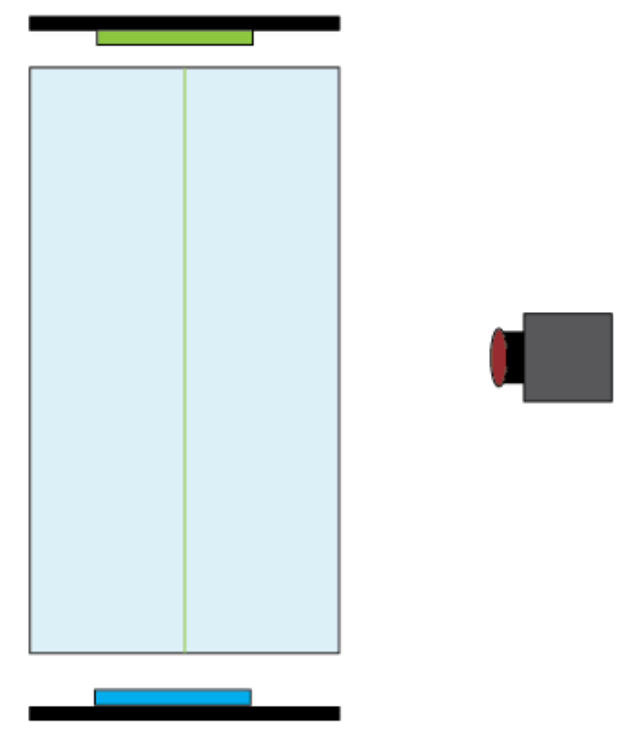

Figure B: Experimental set up of tank including top LED (green box), bottom LED (blue box), laser field (green line), and camera perpendicular to laser field

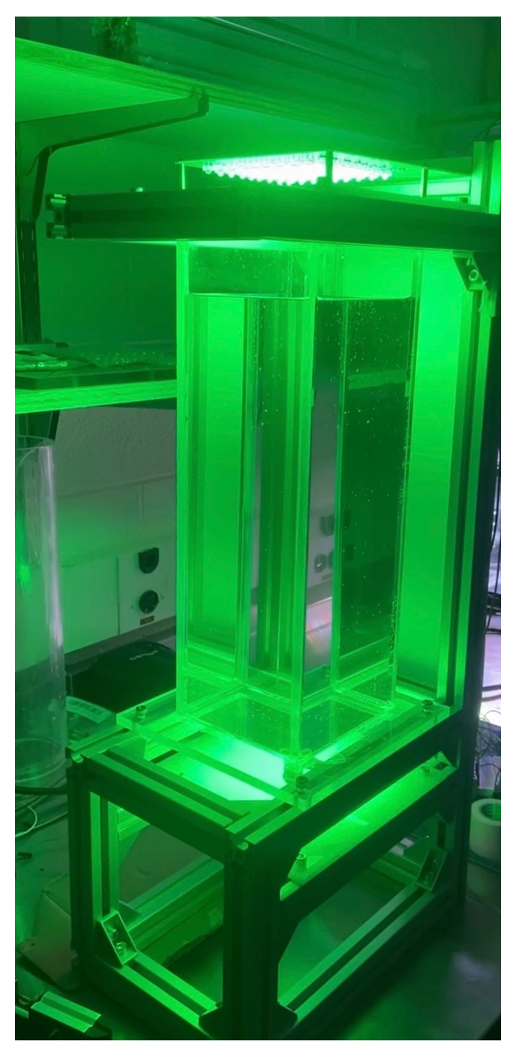

Figure C: Experimental tank and frame with green LEDs, with out laser or seeding particles present

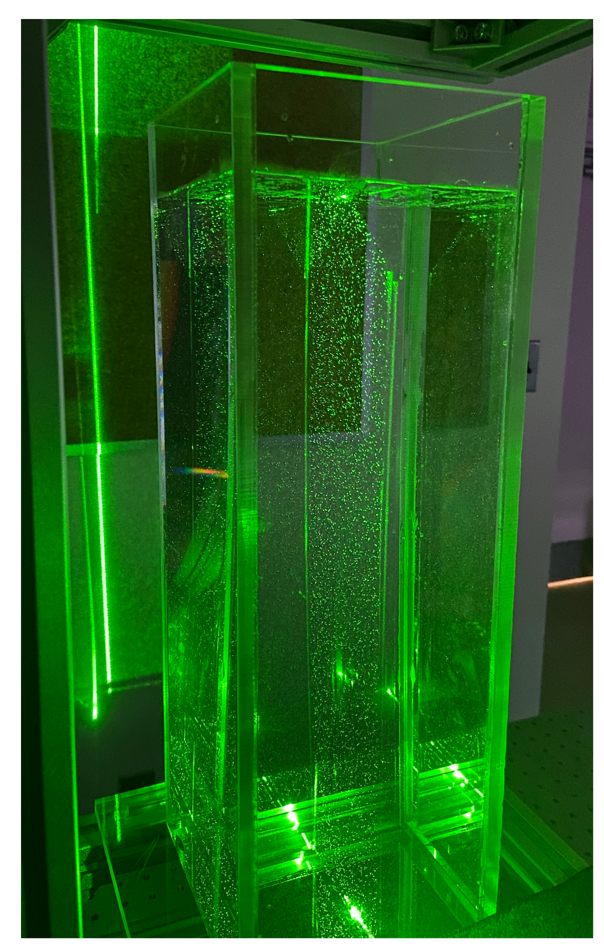

Figure D: Experimental tank without frame or LEDs, but with green laser field and seeding particles present

Methods:

- In order to drive the *Daphnia* motion, the phototactic behavior of the *Daphnia* is used, LEDs from the top and bottom of the tank are shone at different times to force upwards and downwards motion for "day" and "night" periods
- The green laser hits the pink seeding particles and reflects an orange color, this allows for two different colored "dots" to be tracked: green dots as the *Daphnia* reflect the green from the green laser and orange dots as the pink seeding particles reflect orange instead
- A spatial temporal camera to tracks the *Daphnia's* movement and creates a image collection of both the *Daphnia* and the seeding particles
- Since the LEDs would would disrupt the laser field and camera interaction, Arduino coding and relay modules are used to have the LEDs flash off for short periods of time during their "on" cycle
- During the flash off, the LED goes off, the then laser goes on, the camera takes several images, the laser then goes off and the LED then goes back on
- These periods of "off" time are short enough not to disrupt the Daphnia's phototactic reaction
- Processing the image for hue separates the *Daphnia* from the seeding particles, allowing the seeing particles to be used to track the *Daphnia*'s flow field through PIV, and using PTV to track the paths of the *Daphnia* themselves

PIV and PTV:

- PIV, particle image velocimetry, is a grid-based velocity field that measures with interrogation windows and cross correlation
- PTV, particle track velocimetry, is particle based and the vectors are attached to individual particle movement rather than the movement of an interrogation window

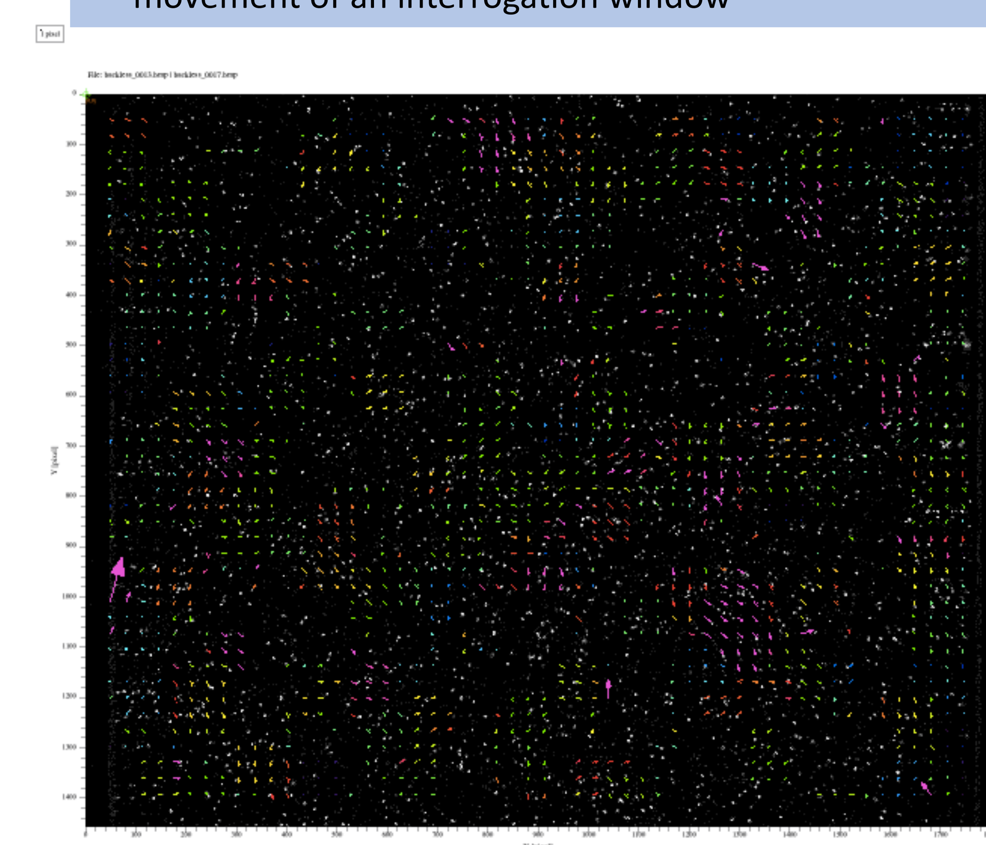

Figure E: A flow field created from seeding particles using PIV, the arrows are velocity vectors

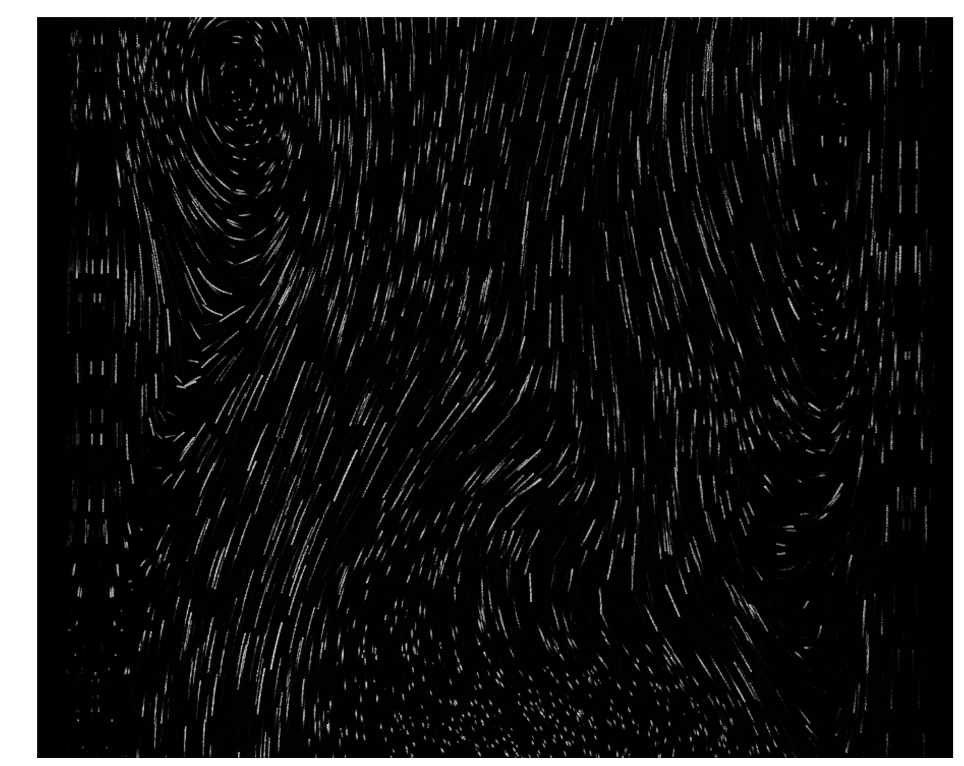

Figure F: A combination of images layered to show particle movement and create a path line of the seeding particles whilst in motion

Conclusion and Next Steps:

This is the experimental set-up for an on-going senior thesis. Two rounds of experiments are being run. The first round is light based with wavelength and light intensity as the independent variables. For green, blue, red and white LEDs, duty ratios of 100%, 75%, 50% and 25% are recorded using the experimental set-up and looked at for *Daphnia* reaction time and swimming speed at each light intensity of color (wavelength) light will be measured through PTV (no seeding particles, just tracking *Daphnia* motions). With reaction time in mind, the off-period of LEDs for the laser and camera to be on will be determined. From here another round of experiments measuring the flow field of the *Daphnia* will be run. The goal of obtaining the flow field of the *Daphnia* is to obtain information on the biomixing caused by the *Daphnia*. Looking at the dissipation rate of the kinetic energy produced by the *Daphnia* can give us information on the scale at which *Daphnia* influence their environment chemically and physically. *Daphnia* exist on such a small scale, their mixing may be independent of larger flow fields, such as wind and currents, but still have an effect on the greater mixing regime in an aquatic system. A continuation of this experiment would be to add stratification and measure the affects of a increasingly stratified system on the DVM and biomixing of *Daphnia*.