Investigation of Sea-to-Air Transfer in Lakes: Testing HAB Particle Aerosolization Tank Methodology

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Background

- Harmful Algal Blooms (HAB's) are an increasing threat, especially in South Florida. In 2018, Florida Governor Scott declared a state of emergency for 7 counties due to HABs, including blue-green cyanobacteria.
- HABs affect water quality through the release of toxins, including microcystin (a hepatotoxin) and β-methylamino-L-alanine (BMAA) that is connected with neurodegenerative diseases. It has been speculated that these toxins may become aerosolized into inhalable particles[1,4]. To better understand these health effects, an improved understanding of the water-air transfer of these toxins is needed.
- Most aerosol generation methods have been tested on seawater. Glass frit bubblers have been used in previous studies and have been shown to more reliably mimic the production of organic-rich aerosol from seawater than atomizers or neubulizers.[5,6] However, recent studies have shown that frits over-estimate the smaller, organic-rich particles.[2,7]
- Plunging-jets mimic breaking waves more accurately and reliably and may be more ideal for generating lake spray aerosol.[2,6,7]

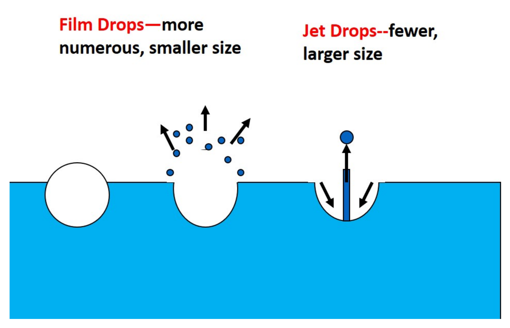

Figure 1. The process of bubbles bursting, aerosolizing particles

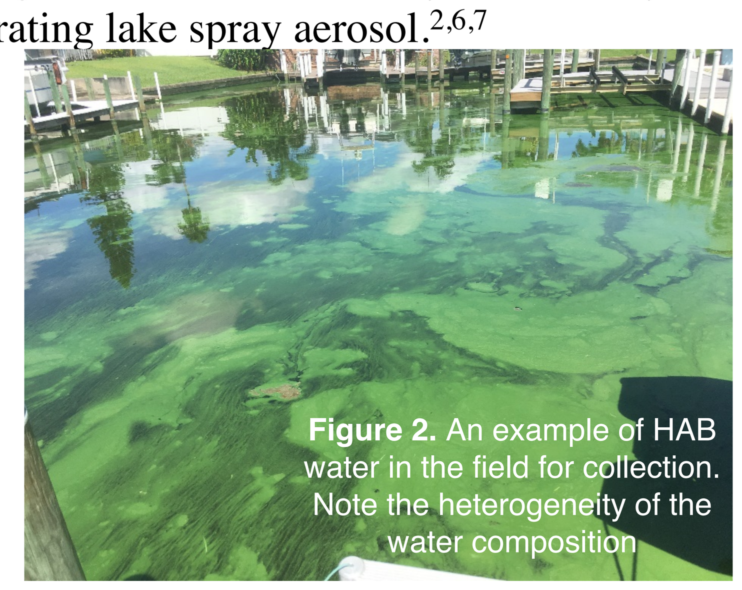

Figure 2. An example of HAB water in the field for collection. Note the heterogeneity of the water composition

Goal: What is the water to air transfer of toxins, and how can we optimize the physical generation of aerosols?

Approach

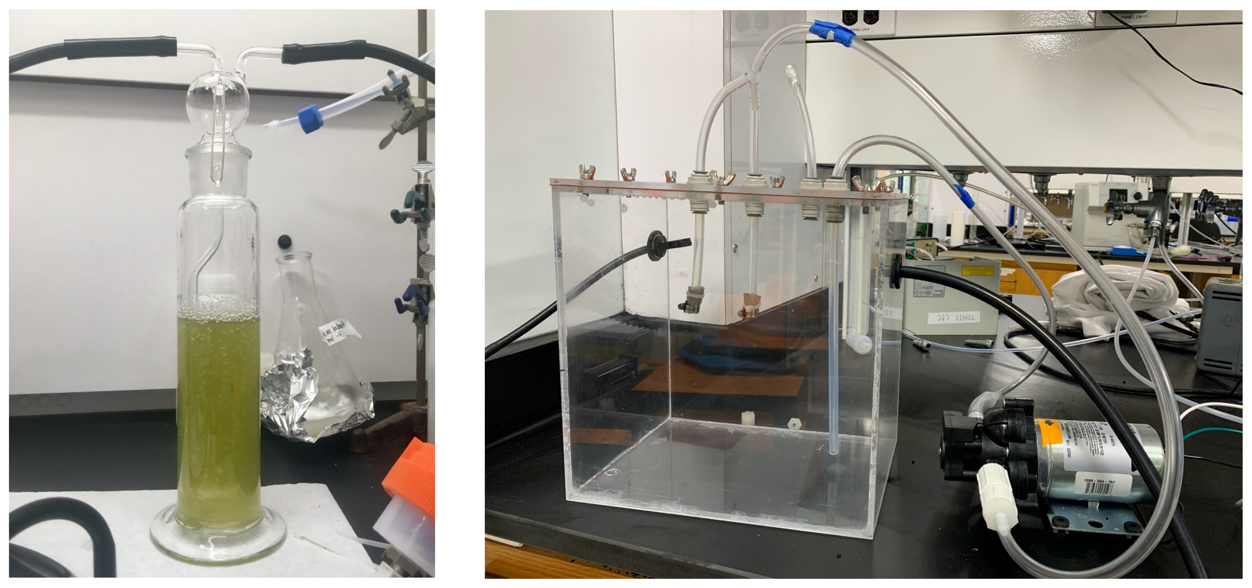

Figure 3. Left: Glass frit bubbler with HAB water. Right: Plunging-jet bubbler, pictured with the water pump and two out of three inlets attached. This design is similar to that of May et al. 2016 used for lake spray aerosol

- In this study, we built and tested methodology for generating lake spray aerosol: 1) glass frit has been a reliable bubble generation method used in previous studies, but it generates a narrow band of bubble size; 2) a plunging-jet bubbler to attempt more realistic condition simulation
- We tested our aerosol generators with filtered seawater for comparison to other systems and previous work and with collected lake water samples containing HABs. Less work has been performed on lake water.
- Aerosol particle concentrations and size distributions were quantified using a scanning mobility particle sizer (SMPS, Classifier model 3082, differential mobility analyzer model 3081, condensation particle counter model 3010)
- Bubble distributions were captured using a benchtop shadowgraph (made by SUSTAIN Lab, designed by C. Guigand)

Glass Frit Experiments

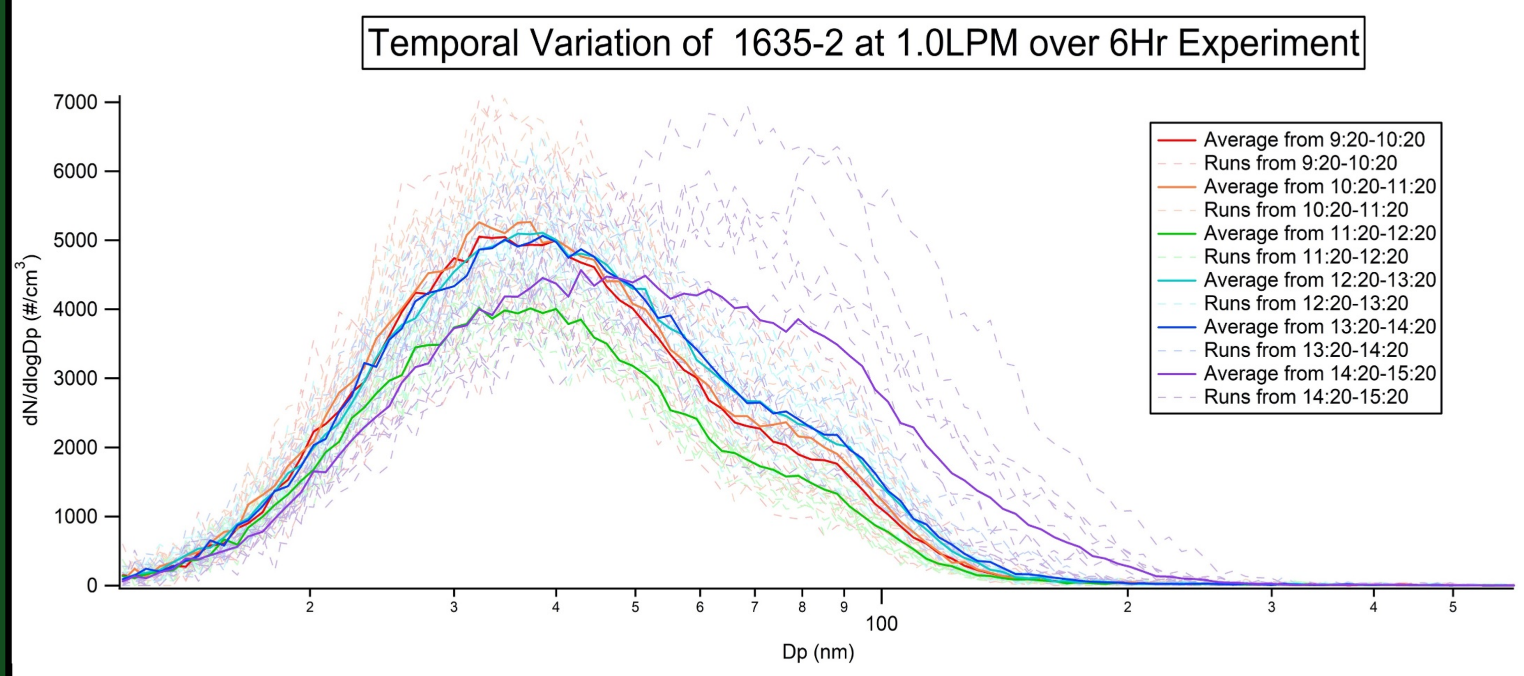

Figure 4. Hourly changes in the aerosol size distribution over the span of a 6-hour experiment. Canal water from a dead-end canal in Cape Coral was used to generate aerosols.

- Collecting aerosolized toxins requires several hours of sampling time to meet the limit of quantification for the toxins. We tested the stability of the aerosol size distribution in our bubbler set up.
- Our aerosol size distribution is similar to other experiments using seawater despite the use of fresh lake water but peaks at a smaller size, likely due to the presence of more organic material.
- The aerosol size distribution is reliable for around 5 hours of sampling with little variance in size distribution
- Some filters show the presence of Microcystin LR, a toxin emitted by Microcystin, confirming the water-to-air transfer of at least some of the toxins.

Bubble Size Distributions from the Plunging Jet

- The bubble size distribution plays a key role in the production of jet and film drops, with subsequent impacts on particle size and composition—two key factors that shape the health impacts of aerosols.[2]
- Bubbles were captured using a shadowgraph and analyzed using MATLAB
- Top layer was trimmed from the image, since bubbles popping at the surface were indistinguishable from one another
- To differentiate the bubbles, the image was switched to black and white and MATLAB identified the bubbles circled in green
- A statistics algorithm was then run to determine eccentricity and area among other characteristics

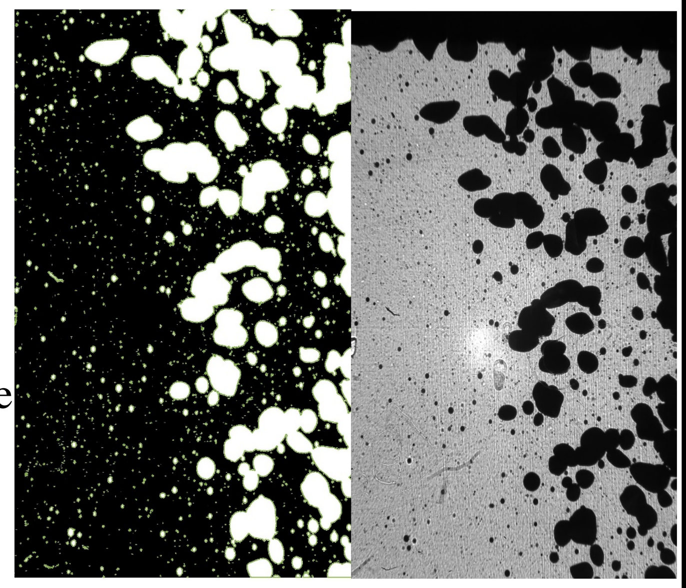

Figure 5. Left: The processed image with recognized bubbles outlines in green. Right: The original image from the experiment using the shadowgraph.

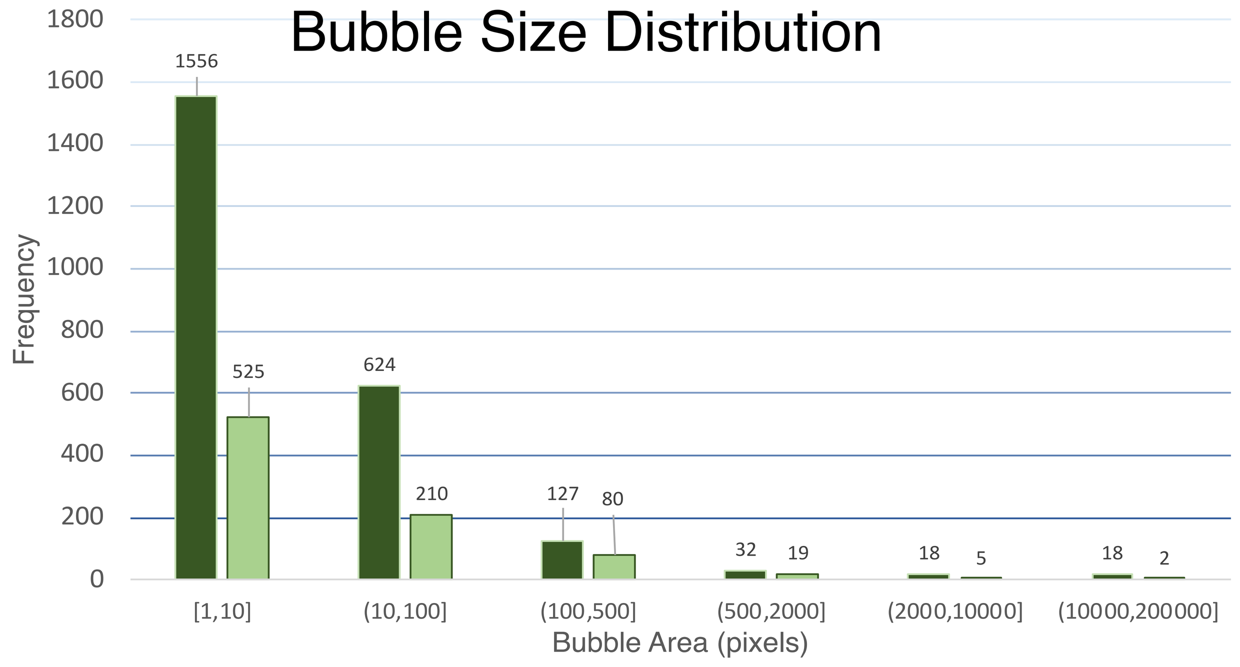

Figure 6. Comparison of bubble size by area and eccentricity for DI water run in the jet bubbler.

Results:

- Smaller bubbles were generated more frequently than larger bubbles, but a full spectrum (50μm– 2mm) was made with the plunging jet bubbler
- Not perfect system due to camera stacking a 3D space into a 2D image, so bubbles became layered and combined
- Many images with lake water were not able to be used due to the thick, poorly mixed nature of the water.

Comparison of Bubbler Types

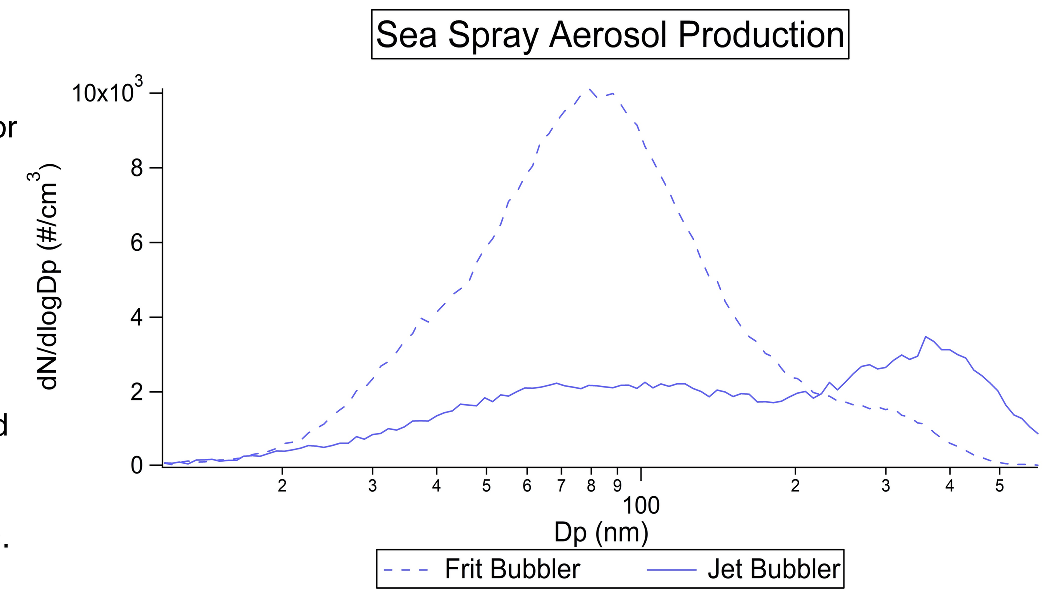

Figure 7. Aerosol size distribution for sea spray aerosol generated from filtered seawater using the plunging jet method (solid line) and the frit bubbler (dashed line).

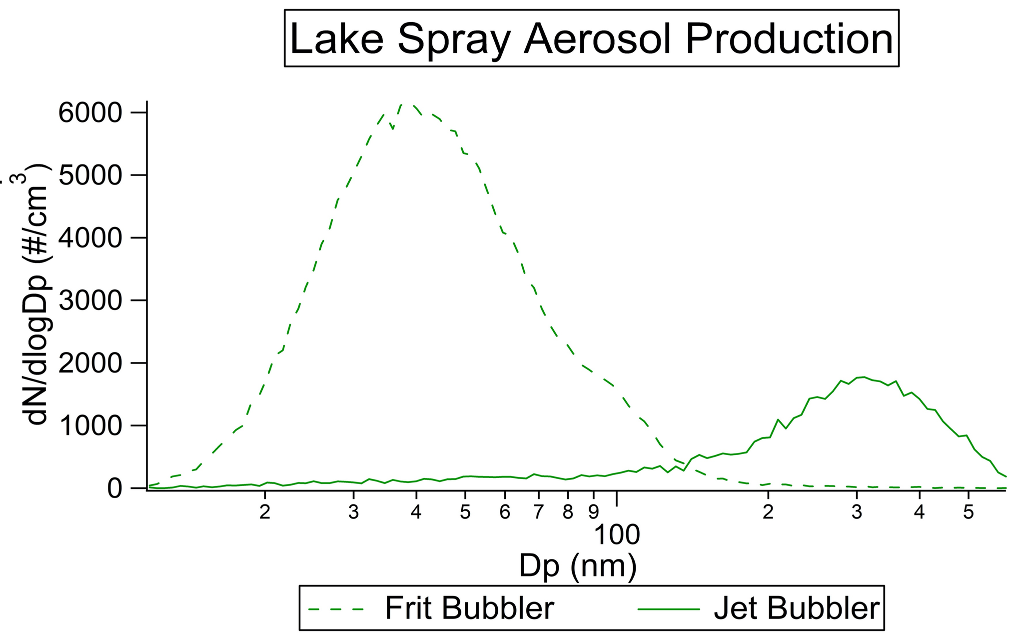

Figure 8. Aerosol size distribution for low HAB water run in the jet bubbler (1650-1, water taken Clewiston Dock on Lake Okeechobee) and the frit bubbler (1635-2).

- The plunging jet bubbler peaks at a large radius while the frit appear to mainly favor the production of smaller, presumably organic-rich, particles.
- Modes peak similar to previous studies[3], with the plunging-jet bubbler having primary and secondary peaks, but plunging-jet peaks higher than previous studies
- The frit bubbler produces more sea spray aerosol and at a smaller radius
- The plunging jet bubbler has a more bimodal size distribution that peaks at a larger size mode.
- The peak of the jet bubbler at the larger radius appears a bit large compared to previous work[2].

	Frit- Seawater	Jet- Seawater	Frit- HAB	Jet- HAB
Mode (nm)	81.9	365.4	38.0	304.2
Geometric Mean (nm)	82.3	136.9	43.0	225.0
Geometric Standard Deviation	1.9	2.5	1.6	2.0
Total Concentration (#/cm^3)	5834	2813	3127	818

Table 1. Aerosol size distribution characteristics for Seawater and Low HAB water, noted in figures 7 and 8.

Conclusions & Future of Project

Conclusions:

- The frit bubbler produces a stable particle size distribution (stable for over 5 hours) that peaks at smaller, ultrafine particle sizes (less than 100 nm), and the jet bubbler produces fewer particles at a larger particle sizer
- Bubbler experiments have confirmed the water-to-air transfer of certain forms of microcystin, a cyanotoxin.

Future Work:

- Refine physics of bubble generation through repeated trials and increased photography of new and previous methods
- Methods to deal with heterogeneous, poorly mixed systems are needed to work with lake water containing HABs

References: [1]Van Dolah, 2000; [2]Prather et al., 2013; [3]May et al., 2016; [4]Cox et al., 2005; [5]Gaston et al., 2011; [6]Fuentes, 2010; [7]Collins et al., 2014

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