Investigating the Effects of Diel Patterns of Attenuation for an Ultrasonic Suspended-Sediment Measurement System

Wayne Carpenter, Senior R&D Engineer, University of Mississippi, National Center for Physical Acoustics, University, MS, wocarpen@olemiss.edu
Bradley Goodwiller, Research Scientist, University of Mississippi, National Center for Physical Acoustics, University, MS, btgoodwi@olemiss.edu
Daniel Wren, Research Civil Engineer, USDA, ARS-NSL, Oxford, MS, daniel.wren@usda.gov
Jason Taylor, Research Ecologist, USDA, ARS-NSL, Oxford, MS, jason.taylor@usda.gov

Introduction

The use of ultrasonic acoustic technology to measure the concentration of clay-sized sediments transported by streams has the potential to greatly increase the temporal and spatial resolution of sediment measurements while reducing the need for personnel to be present at gauging stations during storm events. In order to improve measurement capabilities for fine sediments in stream channels, The National Center for Physical Acoustics (NCPA) at The University of Mississippi has developed a remote, autonomous acoustic attenuation system for deployment in streams. This acoustic attenuation system operates at 20 MHz (megahertz) and was designed to measure fine suspended sediments in ephemeral streams (Figure 1).

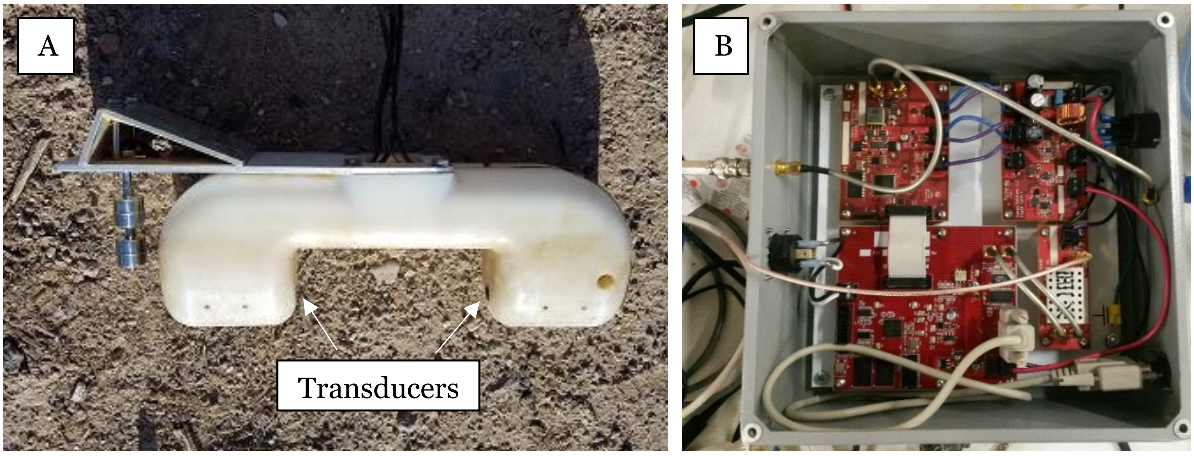

Figure 1. Single Frequency Acoustic Attenuation System (SFAAS) was developed by NCPA to measure fine suspended sediment concentrations using 20 MHz acoustic signals. A) Transducers are held 18 cm apart in a fixed position; B) Electronics box handles signal generation, data collection and pre-processing.

The Single Frequency Acoustic Attenuation System (SFAAS) was tested on the Middle Rio Grande near San Acacia, New Mexico, and in Goodwin Creek in Panola County, Mississippi. The acoustic data from the SFAAS were compared to sediment concentrations from physical samples in both deployments. Diel patterns were found in the acoustic signals from the Middle Rio Grande and appeared to be independent from the measured fine suspended sediment concentrations. These diel patterns were not observed in field deployments in Goodwin Creek, an ephemeral stream in Panola County, Mississippi. This is likely due to thorough mixing of the water column along with the short, steep hydrographs that characterize the Goodwin Creek watershed. A follow-up experiment at The University of Mississippi Biological Field Station was used to investigate the potential causes of the diel patterns in the acoustic data.

Background

It has been shown that algae can affect acoustic signal propagation at 20 MHz (Zips and Faust 1989; Rodriguez-Molares et al 2014; Qin and Shang 2019). While studying harmful algal blooms in saltwater, Kim et al. (2018) saw patterns in their acoustic backscatter (3.5 MHz) data which they attributed to the daily cycle of algae rising and falling in the water column. Similar daily fluctuations in signal strength that could not be attributed to changes in sediment concentration were observed in the Rio Grande study, and it was hypothesized that algal movements could be the cause. To test this hypothesis, the SFAAS was deployed at The University of Mississippi Biological Field Station to investigate the relationship between acoustic signal attenuation, light intensity, dissolved oxygen, and water temperature in an environment without sediment transport.

Procedure

The SFAAS was deployed in a limnocorral in a research pond at The University of Mississippi Biological Field Station in Abbeville, Mississippi, in July 2020 in collaboration with USDA-ARS-NSL (U.S. Department of Agriculture, Agriculture Research Service, National Sedimentation Laboratory). Each 2.5 m diameter limnocorral had a different nitrogen-phosphorus ratio that resulted in a range of algal biomasses, and the tests described here were focused on Treatment #3, 110 N:P (Figure 2). The work presented here is a subset of larger dataset.

Figure 2. Limnocorrals in a pond at The University of Mississippi Biological Field Station

Water temperature, dissolved oxygen, light intensity, and acoustic signal were recorded over several days continuously. Minidot by Precision Measurement Engineering was used to log and measure dissolved oxygen. Water temperature and light intensity were logged and measured with a HOBO Pendant Temperature/Light 64K by Onset Computer Corporation. The data logger used a solar radiation shield for accurate temperature measurement in sunlight. Light intensity was measured at 0.5m, 1m, and 1.5 m depths. The SFAAS was located approximately 15 cm below the surface of the water.

Results

Cyanobacteria was the dominant algal group in the limnocorral as measured by physical samples, and vertical movement was modulated by changes in cell density, gas vesicles inside the cells, and gas bubbles between cells in dense colonies. Treatment #3 had the most algal activity of the limnocorrals. Figure 3 shows a week-long study of the daily rising and falling light intensity and the received acoustic signal relative to a clear water signal. Looking at the daily trends, the acoustic signal and light intensity display strong and consistent negative correlation, with the maximum acoustic attenuation (minimum signal level) occurring on average 5 hours after the light intensity peak.

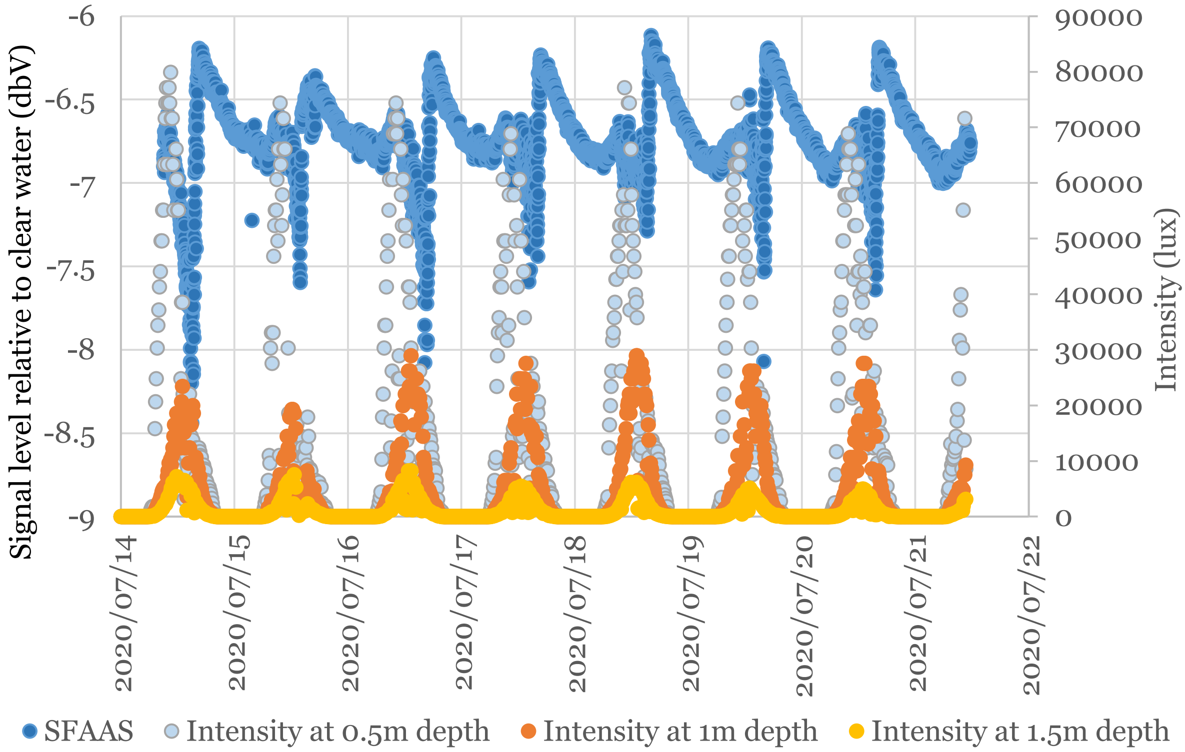

Figure 3. Acoustic data from UMFS suggest a relationship between light intensity and algal movement.

Separate experiments to test the effects of light intensity and water temperature demonstrated that they are not directly responsible for the observed variation in acoustic attenuation. Given the high algal biomass (chl a = 50 µg/L) and dominance of cyanobacteria (60%) in our experimental limnocorral during deployment, it is possible the pattern observed in Figure 3 could be related to the algal community responding to increasing light intensity by rising in the water column each morning before retreating to lower depths when water temperatures peaked. This may occur in dense colonies because increasing light intensity leads to high photosynthetic rates during the day, which can produce oxygen bubbles within colonies that increase buoyancy and cause algal cells to rise in the water column. In contrast, respiration at night consumes the oxygen bubbles, resulting in sinking algal colonies.

Minimum and maximum acoustic signals were matched with light intensity measurements taken during the same period each day over the week. Figure 4 shows what appears to be a threshold phenomenon, where signal was typically approximately -6.3 dBV for light intensities <15,000 lux, and -7 to -8.3 dBV for light intensities >15,000 lux. This again shows that increasing light intensity was related to increased attenuation and absorption of the acoustic signal.

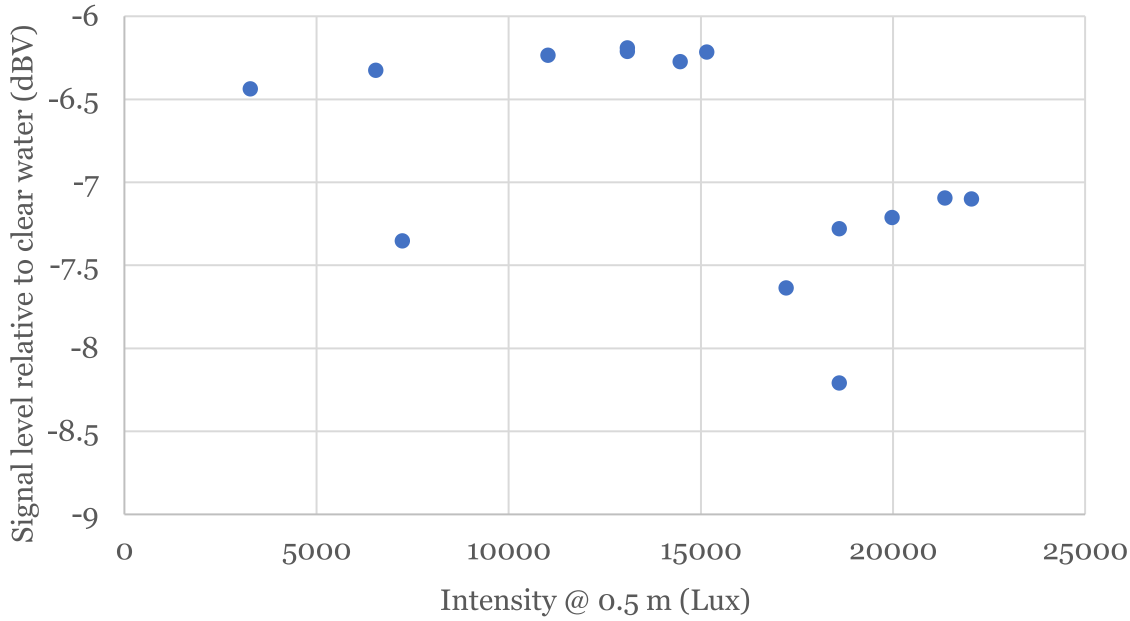

Figure 4. Relationship between the daily maximum and minimum acoustic signal relative to clear water and measured light intensity at 0.5 m for the one-week period shown in figure 3.

Figure 5 shows that acoustic attenuation was positively correlated with diel patterns in dissolved oxygen, although acoustic attenuation measurements were apparently not affected by the long-term decrease in dissolved oxygen concentration. These data indicate the potential to link oxygen concentrations, acoustic attenuation, and some measure of algal activity or biomass. The dissolved oxygen sensor was removed on occasion for cleaning.

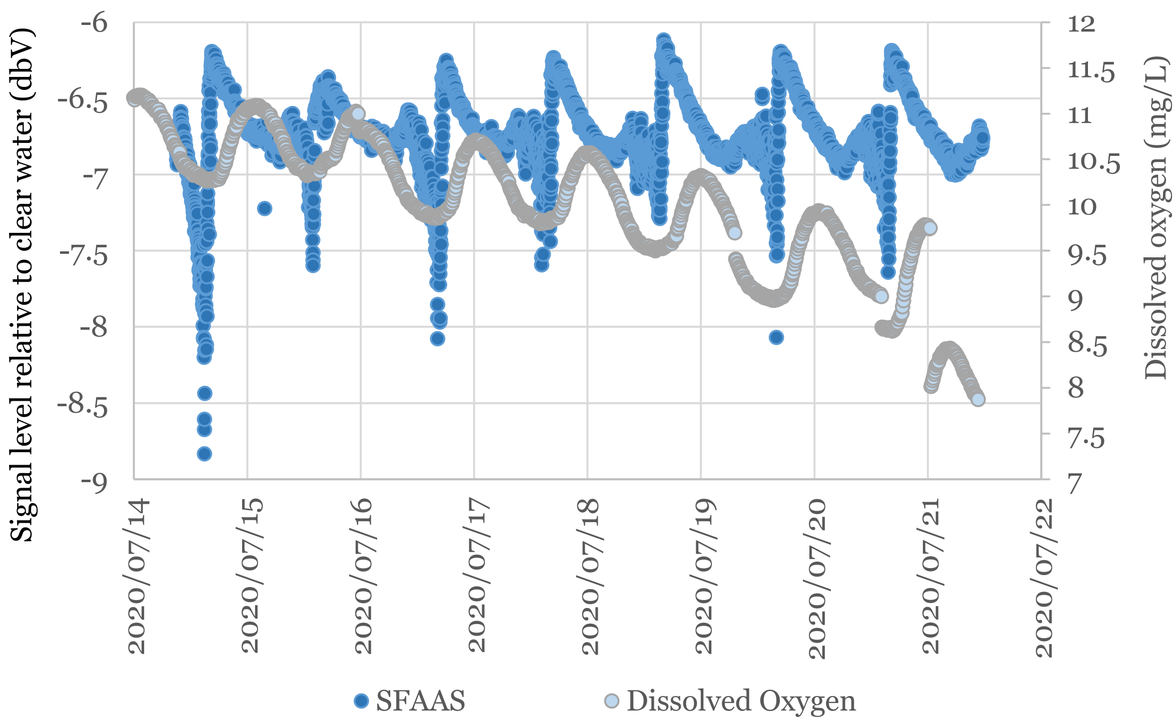

Figure 5. Dissolved oxygen and acoustic attenuation from a limnocorral at The University of Mississippi Biological Field Station.

Conclusion

The results showed daily patterns in acoustic signal attenuation that were correlated with patterns in light intensity, water temperature, and dissolved oxygen. It is possible that algal movements in response to light intensities caused the patterns observed at both the Middle Rio Grande and in limnocorrals. However, no comparison has been made to the experimental limnocorral N:P ratio and the N:P ratio present during the Rio Grande installation. In addition, more data on diel patterns in algal biomass coupled with high frequency acoustic measurements are needed for confirmation of this trend. For some rivers or streams, it may not be possible to use high-frequency acoustic attenuation for measuring fine suspended sediments. While reliable sediment measurements may not be possible in some rivers and streams, our results suggest that it may be possible to use the SFAAS to track algal movements and estimate biomass. The SFAAS was deployed at Goodwin Creek in a location that is only submerged during high-flow events. Even though many of these events last for multiple days, we have not seen any similar diel patterns. In a stream such as Goodwin Creek, where hydrographs are short in response to runoff events, the high temporal resolution of the SFAAS can provide valuable sediment transport data. The low base flow of Goodwin Creek, coupled with rapidly rising flows and short hydrographs that often last for only a few hours, are likely reasons for the successful use of the SFAAS in that environment.

References

Kim, H., Kang, D., and Jung, S.W. 2018. "Development and application of an acoustic system for harmful algal blooms (HABs, Red Tide) detection using an ultrasonic digital sensor," Ocean Science Journal, 53:91-99.

Qin, J. and Shang. S. 2019. "Design and application of ultrasonic measurement systems for akashiwo sanguinea," Traitement du Signal, 36(1):93-101.

Rodriguez-Molares, A., Howard, C., and Zander, A. 2014. "Determination of biomass concentration by measurement of ultrasonic attenuation," Applied Acoustics, 81:26-30.

Zips, A. and Faust, U. 1989. "Determination of biomass by ultrasonic measurements," Applied and Environmental Microbiology, 55(7):1801-1807.