Spring 5-23-2022

Microplastics in Our Oceans May Inhibit Aerosols From Cooling the Atmosphere

Michael Rafla
University of San Diego

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A Thesis

Presented to

The Faculty and the Honors Program

Of the University of San Diego

By

Michael Rafla

Chemistry/Environmental and Ocean Sciences

2022

Abstract

Sea spray aerosol (SSA) are liquid gaseous particles emitted directly from the ocean, making their way into the atmosphere. It is hypothesized that SSA enters the atmosphere from mechanical processes such as wind and ocean waves. Winds and waves promote bubble formation and these bubbles which make their way onto the ocean surface. After these wave-created bubbles rise to the ocean surface, the bubble ruptures and water evaporates which causes gaseous drops to be released into the air: this is the main source of SSA. SSA matter is known to affect Earth's climate, by scattering light energy and solar radiation from the surrounding environment. They can also affect global temperature levels because they aid in cloud formation. With Earth's waters covering about three-fourths of the planet's surface area, SSA is crucial for managing Earth's radiation budget. Their important environmental role may be blunted due to an ominous problem: ocean pollution. Microplastics in our oceans affect how and if aerosols form. This study goes into detail of how microplastics affect SSA formation and its implications. This experiment utilizes ocean movement laboratory simulations to measure SSA generation in the presence of various microplastics. The data suggests that larger microplastics have a greater, more significant effect on reducing aerosol production than finer, powdery plastics.

Introduction

Global warming is a worldwide issue that has been prominent for several decades and it is yet to be completely understood or solved. In order to bring light to the threat level that this issue poses, it is important to take a look at some metrics: Within the next 2 decades, global temperatures are likely to rise 1.5 degrees celsius or about 2.7 degrees fahrenheit. There is a global warming trend with records being broken each year. In fact, the last 7 years have been the warmest to ever be recorded. More than 1 million species are at risk of extinction by climate change. Ice sheets in Greenland and the Antarctic have decreased on average about 400 billion tons of ice per year (earthday.org, 2021). It is a well known fact that global warming has the potential to stop life, as we know it, on Earth. Common methods that have been implemented to combat global warming include driving electric vehicles, minimizing our emission of greenhouse gasses, shifting from the use of fossil fuels to renewable energy, and decreasing our food waste and landfill. Although these are all valid methods to disrupt global warming, it is not nearly enough. Global temperatures are nevertheless rising at an alarming rate. This research paper will attempt to tackle this worldwide issue through an atmospheric chemical lens via the production of aerosol particles.

Atmospheric chemistry is influenced by sea spray aerosol (SSA). SSA particles are largely produced through bubble-mediated film and jet droplet generation, as well as through the direct ripping of droplets off wave tops at high wind speeds (Schulz et al., 2014). Wind is also a contributing factor to note as a driving force of wave formation and thus a driving force of aerosol formation. Other production methods include the spilling of droplets from breaking waves, splash droplets from precipitation, and secondary droplets thought to be generated by their parent main film drops' collision on the water's surface. In this regard, it is worth noting that the composition of SSA particles might vary from one place to the next. They are enriched by organic material that is picked up by the bubbles rising in the water column and from the micro-layer at the sea surface during their formation from bubbles. The composition of SSA is quite complex, varying from one location to the next: for example, proteins, enzymes, bacteria, viruses, fatty acids, and sugars are all components which have been derived from the sea surface microlayer (SSML) and which have been discovered in SSA (Schiffer et al., 2018). Although the numerical concentrations of sea spray aerosols are not as high as those of anthropogenic aerosols such ammonium sulphates, their contribution is important since our oceans cover about 75% of the Earth, whereas anthropogenic aerosols are created locally (Schulz et al., 2014). Without our oceans, the planet would be too hot and unsuitable for sustainable life.

Now that the composition of SSA particles have been somewhat established, we can now understand how SSA cools our planet. These aerosol particles contribute to atmospheric cooling by scattering incoming solar radiation. Through a phenomenon known as the Albedo Effect, SSA particles are able to reflect away incoming heat from the sun into the atmosphere. In order for the Earth to be in radiative balance, or to have no net change in global temperature levels, incoming solar radiation - outgoing solar radiation must equal 0. Radiative balance for the Earth should be the metric we should strive for to inhibit global warming. Additionally, these aerosol particles can serve as nuclei for cloud formation. Through the Albedo Effect, SSA has the ability to offset the radiative forces of greenhouse gasses (Horowitz et al., 2020). The other ways that SSA can counteract the effects of greenhouse gasses is through the direct interaction of SSA’s halogens and greenhouse gasses. As SSA is generated and its particles are released into the atmosphere, halogens, including Chlorine, Bromine, and Iodine are released as well. Reductions in ozone, a greenhouse gas which traps heat in the atmosphere, result primarily from its direct reaction with halogens to form species such as BrO and Clo (Horowitz et al., 2020). SSA increased Cl and Br concentrations by 20 to 40% which in turn directly interacts with ozone causing a decrease in the ozone concentration by 3 to 6% (Horowitz et al., 2020). SSA can also reflect heat through the formation of clouds. Clouds form from building block particles known as cloud condensation nuclei (CCN). CCNs are essentially particles upon which water vapor condenses and subsequently forms cloud droplets. Thus, it is important to enhance SSA generation as much as possible when it comes to cooling our planet. However, though the ocean comprises 75% of the Earth's surface area, not all of that 75% is viable to produce SSA due to the pollution of microplastics floating on the surface. This research study will go into detail of how microplastics can get in the way of SSA production by quantifying their effects. For this experiment, it is hypothesized that larger microplastics will be more effective at blocking SSA generation.

Methods

In order to test the hypothesis in question, it is necessary to replicate real-life ocean conditions as much as possible. In the laboratory, a 500 mL round-bottom flask was used as the reaction chamber. 350 mL of distilled water was first added to the flask. According to the instructions of the Instant Ocean powder, it was calculated that 8.94 grams of instant ocean powder would be required for the 350 mL of distilled water. A medium-sized stir bar was added and set to a higher setting of rotation (levels 7-10). The air supply, which flowed through a glass frit, was also turned on with a flow rate of 0.6 L/min to ensure proper bubble formation. Then aerosol measurements would be taken using the Scanning Mobility Particle Sizer (SMPS). After 5 trials (160 seconds) of the seawater mixture was taken, 1.3 E^{-4} grams of surfactant (palmitic acid) was added to the reaction mixture. Another 5 trials would be run after the surfactant was added. At this point in the procedure, either 0.92 grams of polyethylene (tiny powdery plastic), 30 large 1 cm x 1 cm P4 plastic pieces, or 40 small 0.5 cm x 0.5 cm P4 plastic pieces (larger plastic bag pieces) would be added. Then 5 trials would be run with the SPMS.

After all data was collected through the SPMS, the native file would be converted into a text file (.txt file) which would then be opened using Microsoft Excel. From there, each trial would be analyzed for outliers. Data would then be manipulated to make graphs with error bars, showing how the addition of each substance affected aerosol concentrations.

Figure 1. Experimental Setup

Results

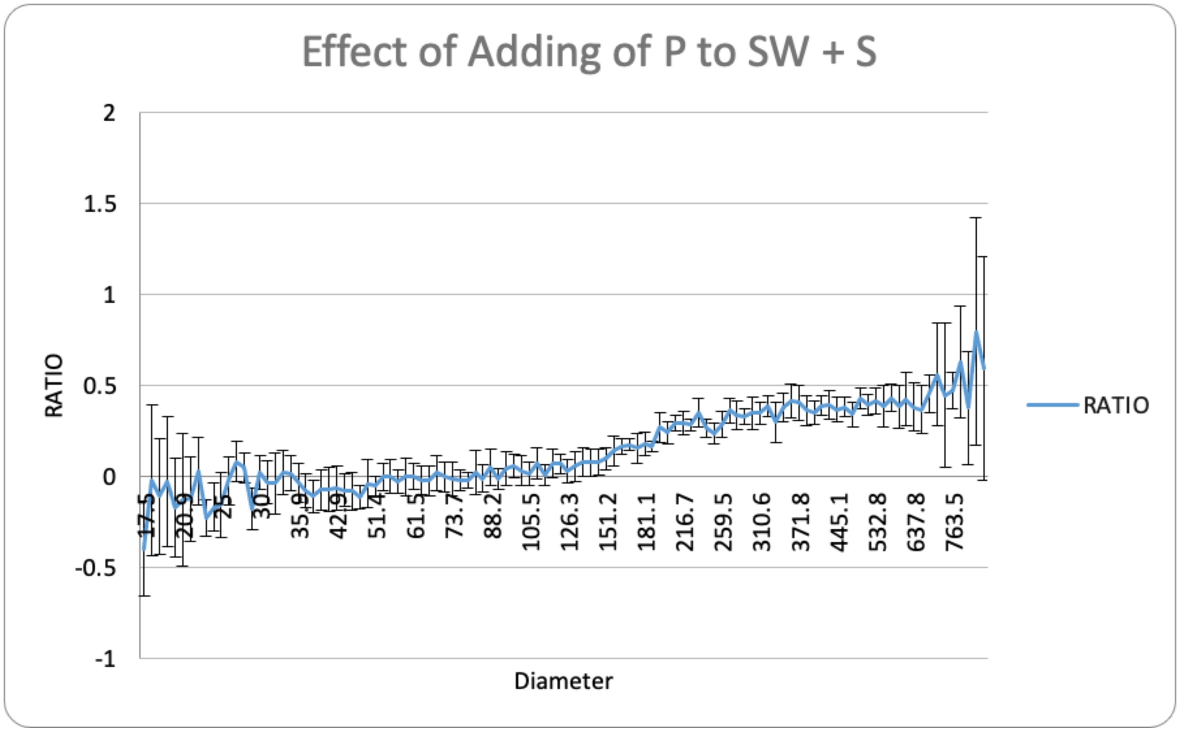

Figure 2. The effect of adding polyethylene to the seawater and surfactant mixture on aerosol generation on 10/06/21. Ratio refers to (concentration of aerosols after solute added) / (concentration of aerosols before solute added). If the ratio is > 1, SSA concentration increased. If ratio < 1 SSA concentration decreased.

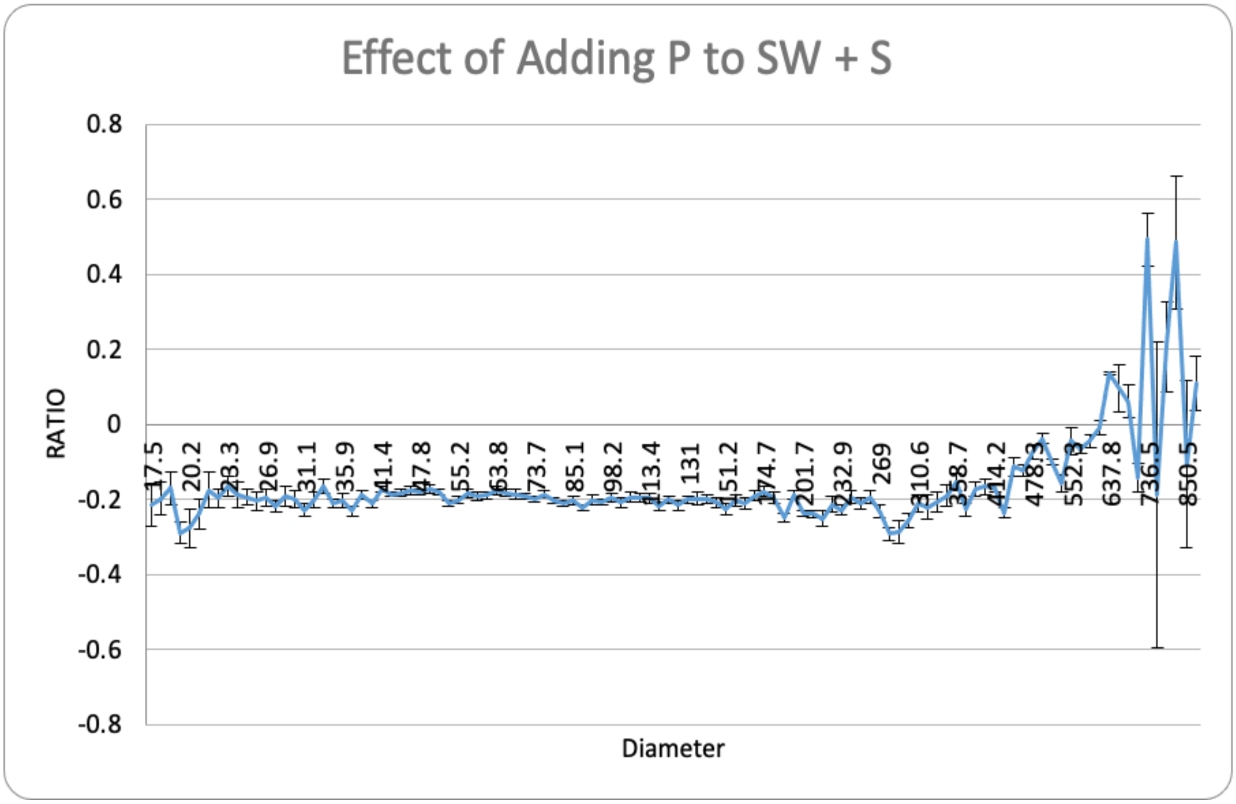

Figure 3. The effect of adding polyethylene to the seawater and surfactant mixture on aerosol generation on 10/27/21. Ratio refers to (concentration of aerosols after solute added) / (concentration of aerosols before solute added). If the ratio is > 1, SSA concentration increased. If ratio < 1 SSA concentration decreased.

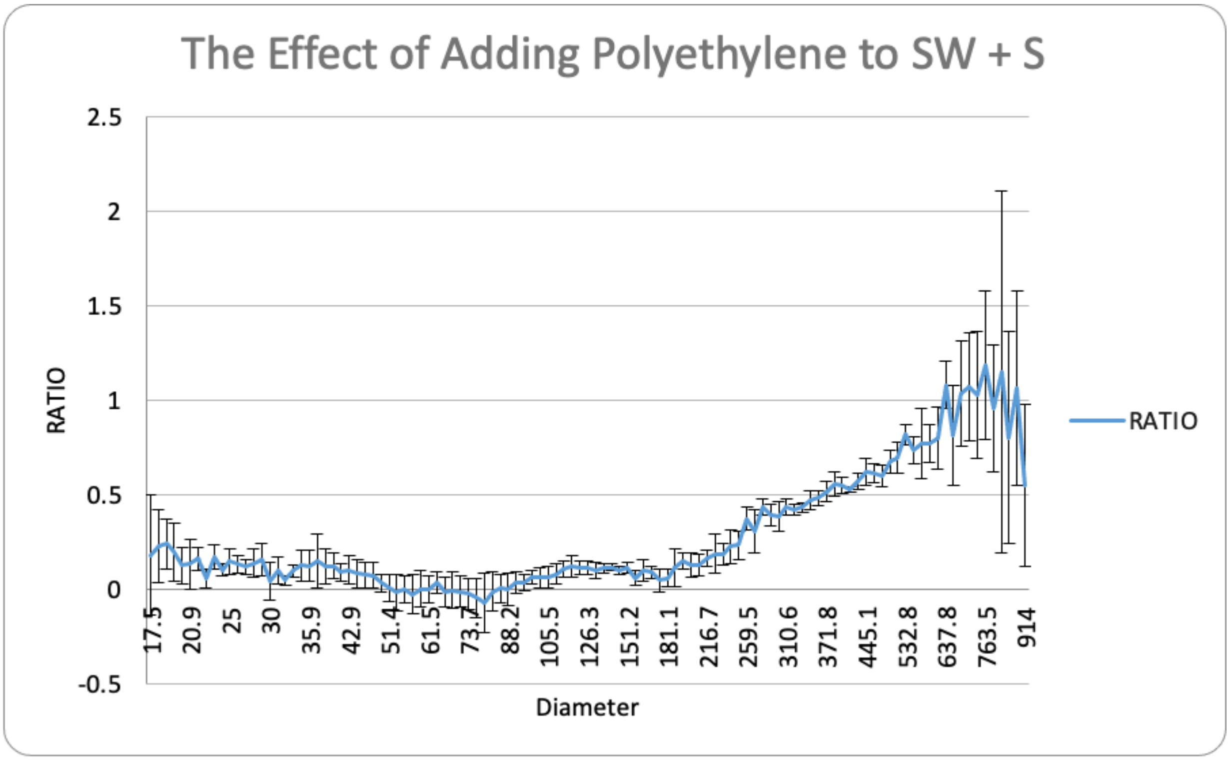

Figure 4. The effect of adding polyethylene to the seawater and surfactant mixture on aerosol generation on 11/03/21. Ratio refers to (concentration of aerosols after solute added) / (concentration of aerosols before solute added). If the ratio is > 1, SSA concentration increased. If ratio < 1 SSA concentration decreased.

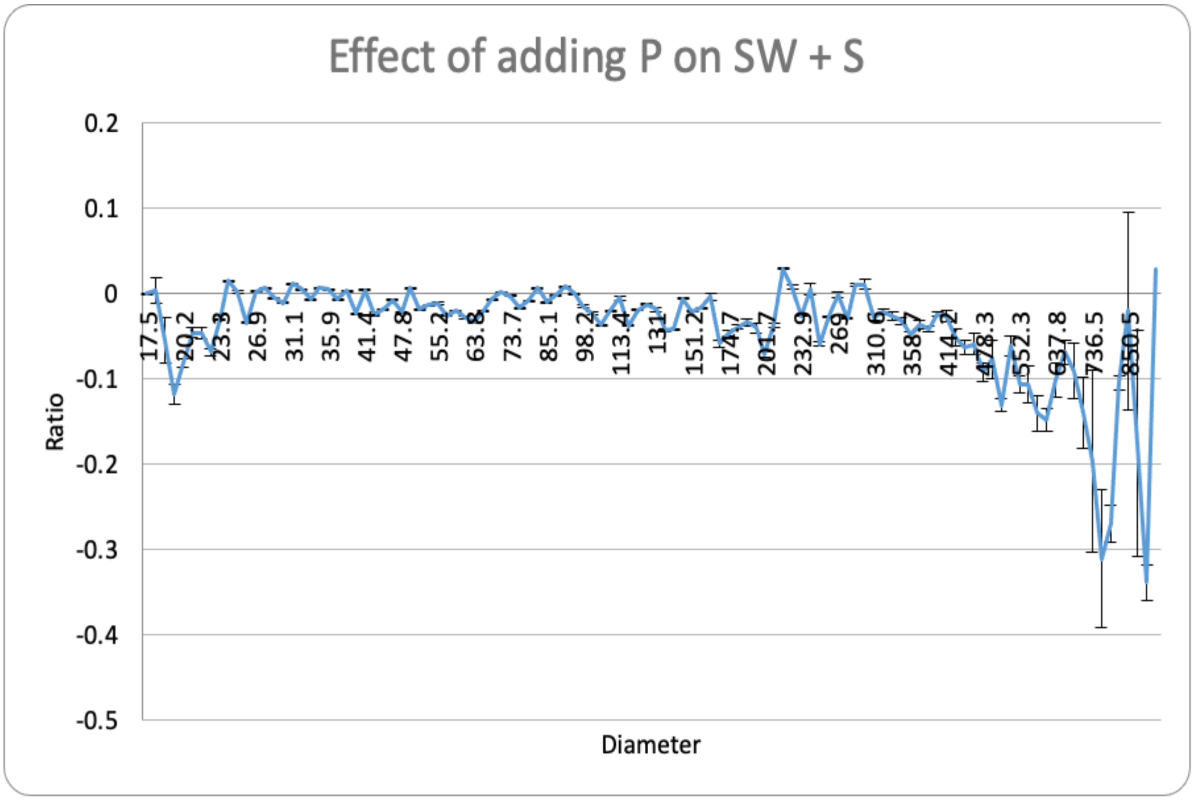

Figure 5. The effect of adding polyethylene to the seawater and surfactant mixture on aerosol generation on 11/17/21. Ratio refers to (concentration of aerosols after solute added) / (concentration of aerosols before solute added). If the ratio is > 1, SSA concentration increased. If ratio < 1 SSA concentration decreased.

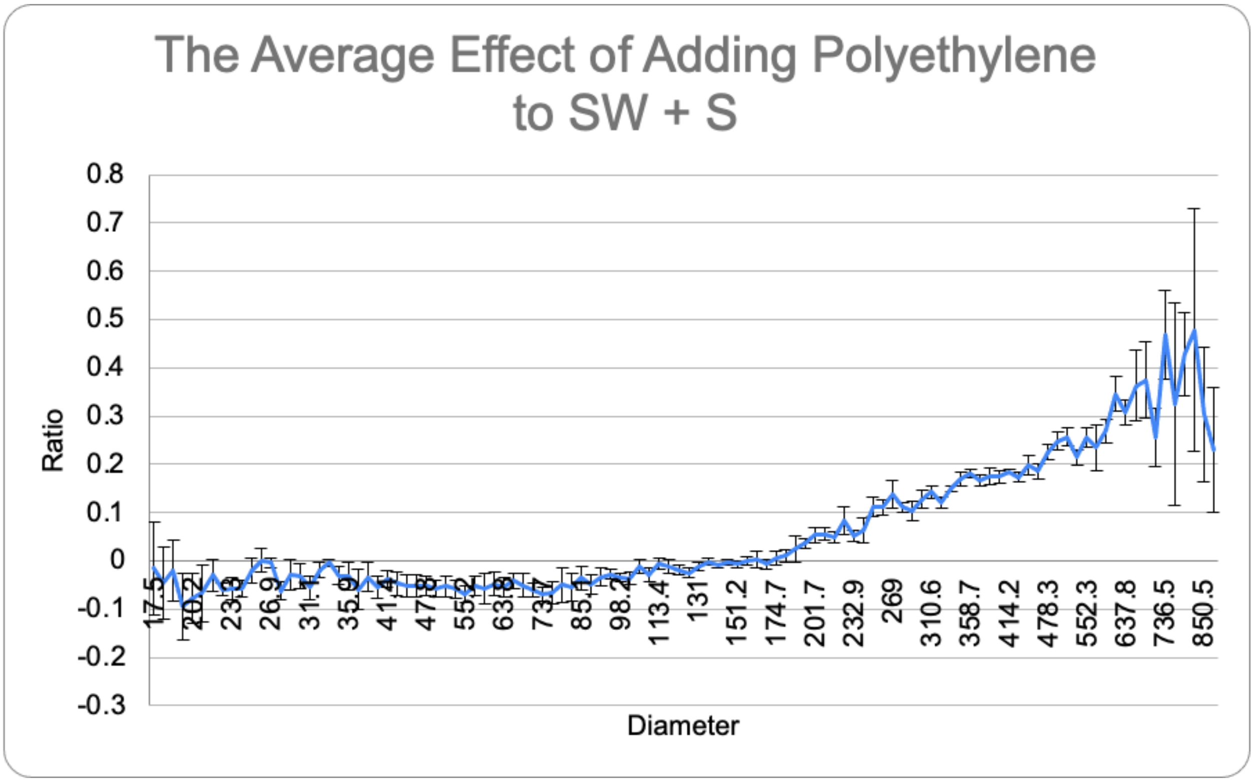

Figure 6. The average effect of adding polyethylene to the seawater and surfactant mixture on aerosol generation from all experimental runs. Ratio refers to (concentration of aerosols after solute added) / (concentration of aerosols before solute added). If the ratio is > 1, SSA concentration increased. If ratio < 1 SSA concentration decreased.

Smaller plastics resulted in more aerosol generation while the larger ones inhibited it. The addition of polyethylene to the seawater and surfactant mixture showed negligible effects for the small to medium sized aerosol particles with diameters ranging from 17.5 nm to approximately 150 nm. Once that threshold is surpassed (diameter > 150 nm), there is an increase in the ratio or the concentration of aerosol generation after the addition of polyethylene (Fig. 2 - 4 & Fig. 6). One of the experimental runs did not follow this pattern, however. It showed an opposite effect for those larger diameter particles, causing them to decrease in concentration (Fig. 5). Looking at the aggregate polyethylene data, the trend holds: with smaller and medium sized aerosols being largely unaffected while the larger aerosol particles increase in concentration (Fig. 6).

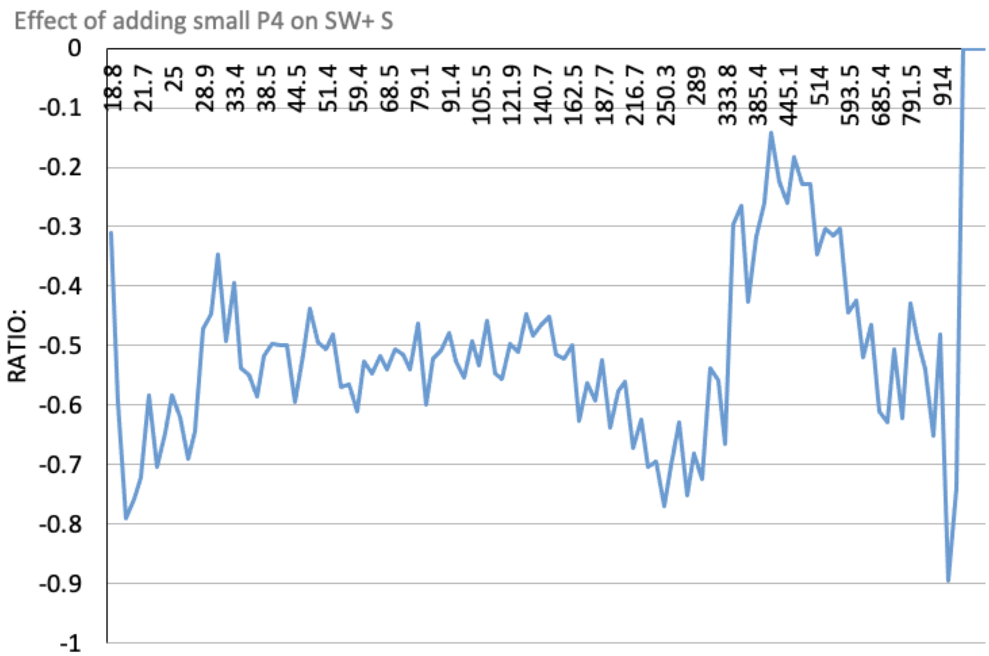

Figure 7. The effect of adding small 0.5 cm x 0.5 cm P4 plastic pieces to the seawater and surfactant mixture on aerosol generation on 10/13/21. Ratio refers to (concentration of aerosols after solute added) / (concentration of aerosols before solute added). If the ratio is > 1, SSA concentration increased. If ratio < 1 SSA concentration decreased.

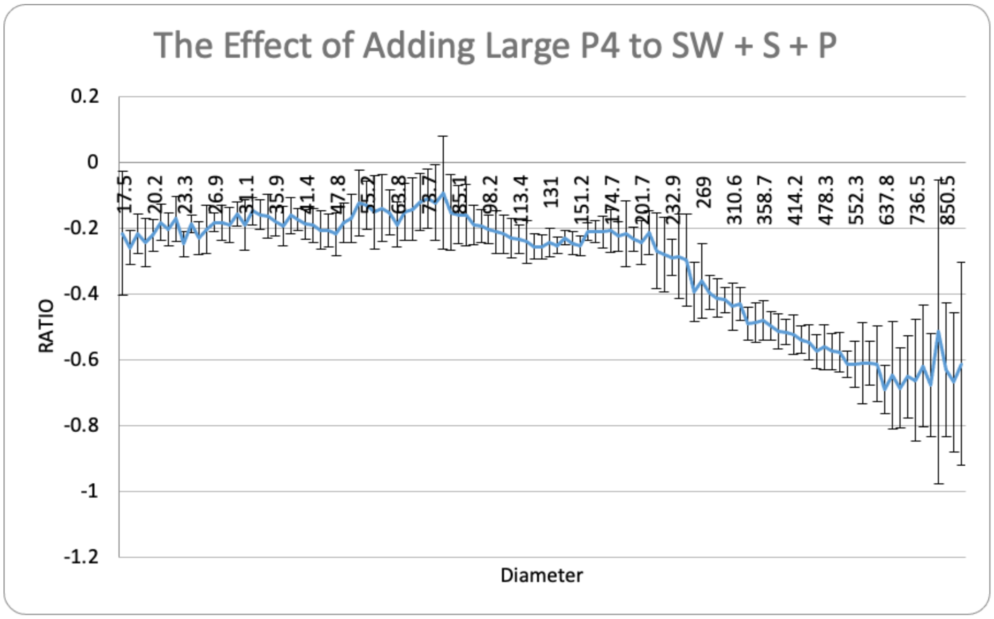

Figure 8. The effect of adding large 1 cm x 1 cm P4 plastic pieces to the seawater and surfactant mixture on aerosol generation on 11/03/21. Ratio refers to (concentration of aerosols after solute added) / (concentration of aerosols before solute added). If the ratio is > 1, SSA concentration increased. If ratio < 1 SSA concentration decreased.

Moving onto the larger P4 plastic pieces obtained from an everyday plastic bag, aerosol generation was inhibited. When the smaller 0.5 cm x 0.5 cm P4 plastic pieces were added to the seawater and surfactant mixture, there is no recognizable pattern with previous results. However, all aerosol diameters were negatively affected, meaning that they decreased in concentration (Fig. 7). It is important to note that order effects (i.e. what is added and when) may explain this unrecognizable, unpredictable trend seen in Figure 7. However, when the large 1 cm x 1 cm P4 plastic pieces were added to the seawater, surfactant, and polyethylene mixture, the smaller diameter aerosol particle concentrations are largely unaffected or have slightly decreased, while the larger diameter particle concentrations are substantially decreased (Fig. 8). This data suggests that adding large P4 plastic pieces seems to have an inverse effect for when the polyethylene was added (Fig. 8 & Fig. 6).

Discussion

The experimental results from this study show that the larger P4 plastics led to decreased aerosol generation while the smaller polyethylene plastic led to increased SSA generation. Thus, our hypothesis was supported. This implies that those small powdery plastics like polyethylene may be beneficial for SSA generation and in turn will lead to an increased cooling effect of our atmosphere. Conversely, larger plastics decrease SSA generation and therefore less cooling pressure, causing global temperatures to increase. This does not mean, however, that we should in fact be polluting our oceans with small powdery plastics. We already have enough of a problem to deal with as it is. Pollution of our oceans is not an issue that is dwindling in our current day and age. In fact, ocean microplastic concentrations are predicted to quadruple by the year 2050 ("Ocean plastic pollution," 2022). Knowing this information, it is extremely worrisome that an increase in concentration of microplastics, especially the larger plastics, can lead to even more harmful global warming effects that we have been experiencing today. It is important to develop mathematical models to predict how sustainable life on Earth will be for species at the risk of extinction due to warming habitats. Setting a "deadline" of extinction may help society be more likely to take action and contribute to animal conservation efforts. One place to start is to have government-funded vessels roaming the oceans with large nets which would at least collect those larger plastics. For existing cargo ships completing their ocean routes, the government could provide them with these subsidized nets at port.

If we have shown an effect of microplastics, it is important to ask ourselves the following question: what does that mean for the real ocean? How much microplastic is on the ocean planet compared to what has been conducted in the simulated lab environments. According to Tanhua et al., the average microplastic concentration in our oceans is approximately 50 m^{-3} (2020). However, the polyethylene concentration that my research team and I used in the experiments is .00263 g/mL. These two values are difficult to compare with one another because one is a number density and the other is a mass density. Future research efforts should take foundational steps in most accurately replicating ocean conditions in terms of microplastic concentration, surfactant composition, bacteria, etc. floating on the surface. It may be worthwhile to capture real ocean water to limit confounds.

The results from my research team's experiments still does not explain how plastic can enhance SSA generation. So we must ask ourselves: If a bubble is about to pop, is there a way that plastic floating particles can result in more aerosols being released to the atmosphere? One possible explanation for this research question is the following. Polyethylene plastic on surfactant film makes film thicker which may cause bubbles to pop sooner. This leads to the idea that the SSA particles being released are probably bigger because the film did not have time to thin out. This would subsequently lead to increased concentrations of aerosols > 100 nm (minimum size to form CCN and clouds). In order to test this hypothesis regarding bubble popping dynamics, we would need to obtain a high speed camera. This proposed study would use the camera to capture this whole process in action if we are able to see chunks of plastics on the surface of bubbles that are about to pop. Learning about SSA and how humans can change their ways of life to better our environmental longevity is an important area of research that should continue to be researched until the problem at hand is under control.

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