Mitigation of Ultraviolet Solar Radiation Involving Calcite (MUSIC)

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OVERVIEW: The authors examined the efficacy of calcite aerosols to block solar radiation to serve in stratospheric aerosol injection.

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SUMMARY

This investigation explores the use of calcite ($CaCO_3$) powder, the most common and radiation-resistant form of calcium carbonate, as an environmentally friendly mechanism for solar radiation management by measuring its ability to deflect ultraviolet radiation from the sun. The experiment took place on a high-altitude balloon (HAB) payload. Three sets of laminated calcite sheets with varying concentrations – two with calcite and one as a control – were tested using two different types of sensors contained in a payload box. We hypothesized that the sheet with the highest calcite distribution would block the most radiation. The results indicated that both sheets with calcite were effective in blocking UV radiation, setting the foundation for future investigations in the field of stratospheric aerosol injection (SAI) using calcite and other environmentally friendly substances.

INTRODUCTION

Solar geoengineering, also known as solar radiation management (SRM), involves deflecting solar radiation from the atmosphere to help prevent global warming. A method of using stratospheric aerosols has been previously attempted by injecting sulfuric acid, but this can damage the ozone layer and cause heating in the lower stratosphere (Keith et al.). Limited research has been conducted on other aerosols. However, since SRM could prove highly effective, different methods must be tested.

Calcite is a form of CaCO3 with a distinct hexagonal crystal structure (Tropf). It is radiation-resistant, undergoing no structural changes under irradiation, proving it suitable for this application (Zhevtun et al.). It can be used in the atmosphere at a low cost and with minimal technical risk, and is commercially available, likely generating less warming compared to other tested alternatives, such as sulfates and solids like titania and alumina. A hybrid approach utilizing alkali metal salts in conjunction with CaCO3 could be much safer than sulfate aerosol (Keith et al.). Therefore, it is not only more environmentally friendly but also has potential for future upgrades to increase effectiveness. Many engineering and research firms already possess the technology to employ calcite SRM, such as solid aerosol dispersers and high-altitude aircraft, indicating that this technique has the feasibility of being implemented within the next five years.

Calcite SRM could be a revolutionary technique in mitigating the effects of climate change, thus reducing industrial economic losses. A recent study has compared the economic impacts of global temperature increases of 2.8°C and 4.5°C from pre-industrial temperatures over the next 75 years. A 4.5 °C increase in global temperature could cost the US $520 billion per year. If efforts are made to limit the rise in temperatures to only 2.8 °C, the United States could reduce economic losses by $224 billion (Cho). This will benefit not only the US but also the rest of the world.

The experiment took place on a high-altitude scientific balloon flight to test the hypothesis that with increasing densities of calcite powder, the amount of ultraviolet radiation reaching the sensors would decrease. This investigation provides a deeper examination of a highly plausible method of solar geoengineering, offering insight into how to mitigate climate change on Earth.

RESULTS

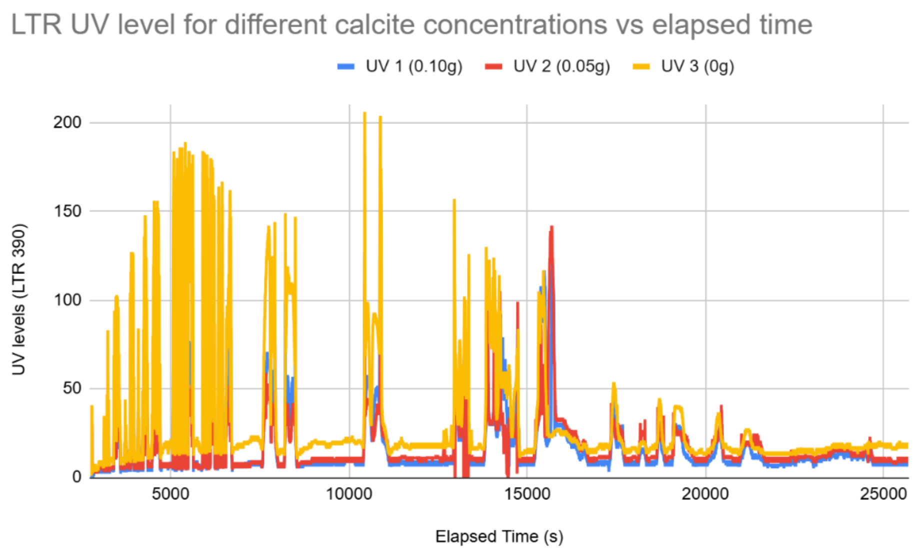

Figure 1. UV for different calcite concentrations vs elapsed time. *Line graph showing change in UV radiation measured by LTR390 sensors over flight duration for different calcite concentrations (n=1). Calcite was placed under either of the three conditions and launched at stratospheric levels.*

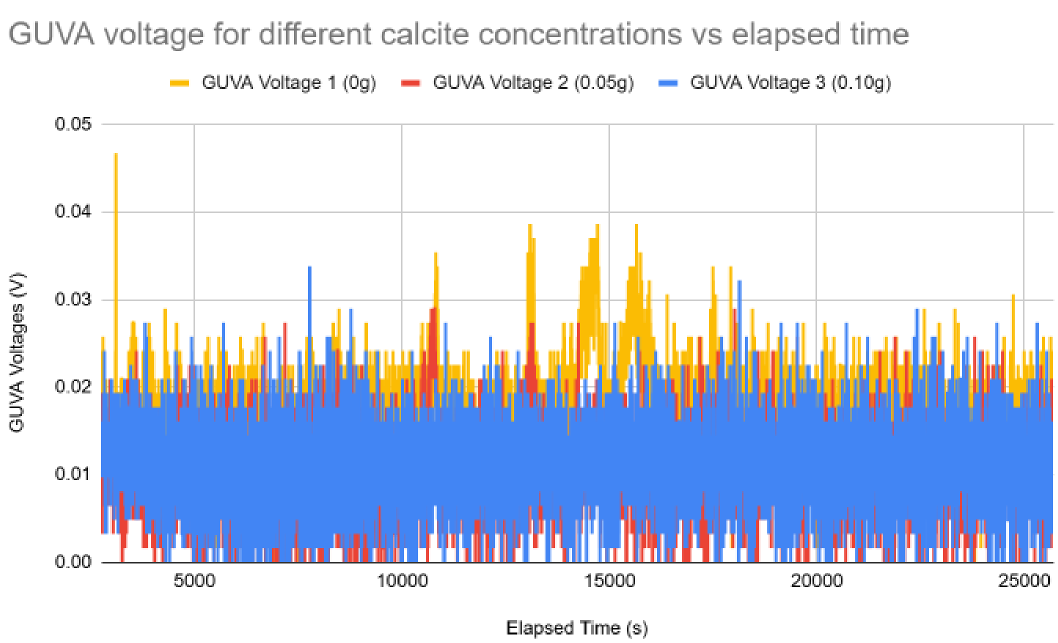

Figure 2. GUVA voltage for different calcite concentrations vs elapsed time. *Line graph showing change in UV radiation measured by GUVA-S12SD sensors over flight duration for*

different calcite concentrations (n=1). Calcite was placed under either of the three conditions and launched at stratospheric levels.

To evaluate the effectiveness of the three calcite samples in blocking ultraviolet radiation, we conducted a one-way ANOVA test. This was done in R for visualization and data processing. ANOVA is appropriate here because it determines whether there are statistically significant differences between the means of three or more independent groups. In this case, we desired to assess whether the UV-blocking performance varied meaningfully across the three calcite samples.

Using the anova_result object in R, the resulting p-value was below the 0.05 threshold, indicating a highly significant difference between at least one pair of the three groups. To further analyze which groups specifically varied from each other, we utilized Tukey's Post Hoc Test using object tukey_result. The confidence test displays the 95% confidence levels in the means of the three different groups (Figure 3).

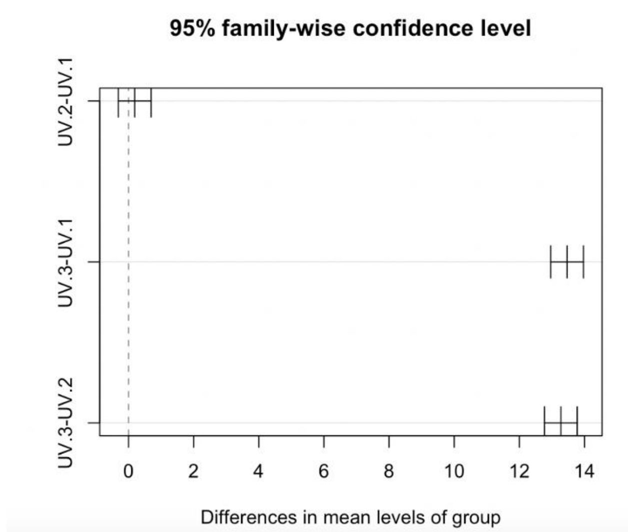

Figure 3. ***Calcite Samples on Blocking UV Radiation: 95% Confidence Interval Test.*** *Confidence interval plot graph showing results of ANOVA test (n=1). The three UV groups were compared using the anova_result object in R. One-way ANOVA, $p < 0.05$.*

DISCUSSION

This study investigated how the concentration of calcium carbonate affected the amount of solar radiation or UV rays detected by the sensors.

Based on the ANOVA test, the comparison between UV 1 (0.1g) and UV 2 (0.05g) yielded a mean difference of just 0.19 with a p-value of 0.647, indicating no statistically significant difference between these two groups. However, UV 3 (0g) differed from both UV 1 and UV 2, with mean differences of approximately 13.4 and 13.3, and p-values less than 0.000001. The results confirm that the 0.10g and 0.5g concentrations were both effective at blocking UV radiation, significantly more so than the control of 0g.

The confidence interval graph (Figure 3) shows that the UV2 - UV1 bar crosses the zero line, indicating that their difference in mean is not significant. However, the UV3 - UV1 and UV3 - UV2 bars are far from the zero line and do not cross. This implies that UV 1 (0.1g) and UV 2 (0.05g) block around the same amount of ultraviolet radiation.

Therefore, our hypothesis was partially proven. Calcite does deflect UV radiation; however, increasing densities did not necessarily block more. More than 0.05g need not be used when attempting to optimize the quantity of calcite in future experimentation. It may be better to test lower concentrations to determine the optimal balance, minimizing the amount of the substance while still reaching the same threshold for blocking UV rays.

While spreading the calcite on each of the laminate sheets, an uneven distribution may have occurred throughout the sheet due to an improper spreading technique. After spreading, we observed that not all the calcite powder could be spread onto each sheet, as some calcite was lost on the spreading tool. These may have led to the true concentration on each sheet being slightly more or less than intended. This could have inconsistently increased the amount of UV light passing through each laminate sheet, but it was likely negligible.

Moreover, there is a possibility that the epoxy between the electrical connections of the payload was not secure. This is because the two-part epoxy utilized did not have an adequate mixing nozzle, resulting in several epoxy attempts involving epoxy that did not cure properly. While the epoxy mixed in the final attempt was deemed to cure appropriately, there could still have been some untested, uncured epoxy that interfered with the electrical components of the payload, thus resulting in an unpredictable statistical error.

The procured research indicates possibilities for calcium carbonate in future stratospheric aerosol injection (SAI) endeavors. While calcium carbonate is not biodegradable, it is a naturally occurring inorganic compound that is environmentally sustainable and safe for humans. Further research is needed to determine the effects of calcium carbonate on the atmosphere and its surrounding environment. Aerosols, such as sulfuric acid/sulfur dioxide, have already been shown to impact the atmosphere negatively, and it must be determined whether calcium carbonate could have similar effects.

Our experiment was limited to utilizing an even distribution of calcite powder, as opposed to an aerosol, which would be implemented for SAI. An aerosol could not be accurately tested within the HAB, as the suspension of particles within the air would not last without the appropriate atmospheric conditions. However, aerosol conditions can be simulated with the aid of a recursive pump system that mimics a continuous suspended aerosol state. Such a setup could provide more accurate data on the exact efficacy of calcite aerosols in the atmosphere.

Mining large amounts of calcium carbonate from chalk or limestone deposits for SAI use may result in a significant carbon footprint. However, the environmental benefits from the decrease in temperature may compensate for this. As a result, further studies are needed to determine the optimal aerosol concentration within the atmosphere, aiming to minimize environmental damage and achieve the desired global temperature reduction.

If calcite SAI is not researched to be a viable application to reduce global temperatures, other aerosols, such as black carbon, aluminum, and barium titanate, may also be researched using the same guidelines. Each aerosol could be tested in a computer simulation based on chemical and physical properties. The simulation could estimate the optimal particle coverage across the globe as well as its overall efficiency based on its properties. It is vital to prioritize environmental sustainability above all other considerations when selecting potential aerosols.

Additionally, there is a significant amount of social controversy surrounding SAI. Many individuals believe that solar geoengineering is a risky option and should be considered only as a last resort in the event of a global environmental disaster. However, preliminary research must be conducted to ensure that a last-minute solution will be available at all. Specifically, small-scale testing, such as the HAB payload testing done in this study, and preliminary aerosol distribution system designs will be necessary to form the foundation of such a solution.

MATERIALS AND METHODS

Payload Construction

An experimental payload box, primarily made of polycarbonate with dimensions of 4”x4”x8”, was provided by the NASA TechRise committee. Lab-Grade Calcium Carbonate powder was obtained from Flinn Scientific

Three GUVA-S12SD sensors and three LTR390 sensors were obtained from Adafruit to measure UV transmission. The Payload Interface Board was provided by the NASA TechRise committee. The Metro M4 Express microcontroller and the MicroSD Breakout Board+ were obtained from Adafruit. Additional materials included a Kingston 32Gb High Endurance UHS-I microSDHC Card and small UV lights provided by NASA TechRise. Sensors were tested individually for functionality after being wired to a plastic breadboard and a Metro M4 microcontroller. CircuitPython code was uploaded to the Mu Editor software to determine the amount of UV light each sensor was receiving. A UV LED was placed in front of each sensor, and if the UV readings of each sensor increased as the distance of the UV LED decreased, the sensor would be deemed viable. Once all sensors were deemed viable, each sensor was wired together with the Metro M4, the flight PCB, and an Adafruit MicroSD Breakout board, which would collect data from each sensor on a 32GB MicroSD card. The wires were connected via a solderable breadboard. Once wired and soldered, 2-part epoxy resin was spread onto each wire connection to prevent wiring disconnects during flight.

Matte and clear laminate sheets were tested for UV transmission, and Uinkit Matte Thermal Laminating Sheets were selected, as they transmitted the most significant amount of UV light to the selected sensors. To uniformly distribute the calcite placed in front of the sensors, 0.10 g and 0.05 g calcite samples, mixed with water in the form of a paste, were spread on separate 1.25” x 3.25” laminate sheet pieces, along with a control laminate sheet without calcite. After drying, each set of sheets was heat laminated for mounting onto the payload. Three sensor mounting plates were designed in Inventor and 3D printed with PETG filament (Figure 4). PETG filament was used to manufacture a series of mounting plates on the payload. This material was chosen due to its lightweight yet durable composition that can withstand a high-altitude balloon flight.

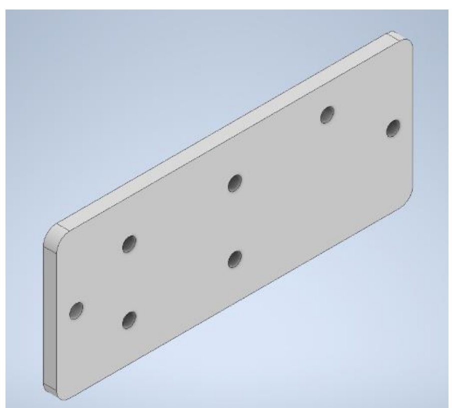

Figure 4. Calcite mount model. *AutoCAD Inventor model screenshot of calcite mount.*

After soldering and epoxying the electrical components, final payload testing took place before the full epoxying of all components into the box. Testing was conducted both with and without the Metro M4 microcontroller connected to the computer to ensure the payload ran as expected and to verify there were no wiring issues, particularly with the power buses.

Calcite sheets were placed along one side of the payload box and affixed with epoxy. The wired sensors were bolted onto the mounting plates. The mounting plates were bolted behind the calcite sheet with brass standoffs. The Metro M4 microcontroller and payload interface board were mounted using standoffs, and the breakout board was secured with zip ties through the holes in the box to maintain stability and prevent damage throughout flight.

Figure 5. Payload front view. *View of calcite sheets inside finished payload.*

Figure 6. Payload ¾ view. *¾ view of finished payload.*

2.3 Experimental Methods

The scientific balloon was launched at a stratospheric height of 24,000 meters. The payload and all sensors were powered on while on the ground before flight, and stayed on as the balloon ascended, floated at maximum altitude, and descended. All operations ceased after the landing of the balloon. The sensors collected data on the quantity of UV radiation penetrating the calcite sheets, with one GUVA-S12SD and one LTR390 behind each pouch for redundancy. The

LTR390 sensors directly collected data on UV levels. The GUVA-S12SD sensors collected UV data in the form of voltage output, with a higher voltage corresponding to higher UV input.

ACKNOWLEDGMENTS

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