

# Mitigation of Ultraviolet Solar Radiation Involving Calcite (MUSIC)

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**KEYWORDS:** Geoengineering, Aerosols, Calcite

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

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## **SUMMARY**

1 This investigation explores the use of calcite ( $\text{CaCO}_3$ ) powder, the most common and radiation-  
2 resistant form of calcium carbonate, as an environmentally friendly mechanism for solar radiation  
3 management by measuring its ability to deflect ultraviolet radiation from the sun. The experiment  
4 took place on a high-altitude balloon (HAB) payload. Three sets of laminated calcite sheets with  
5 varying concentrations – two with calcite and one as a control – were tested using two different  
6 types of sensors contained in a payload box. We hypothesized that the sheet with the highest  
7 calcite distribution would block the most radiation. The results indicated that both sheets with  
8 calcite were effective in blocking UV radiation, setting the foundation for future investigations in  
9 the field of stratospheric aerosol injection (SAI) using calcite and other environmentally friendly  
10 substances.

11

12 **INTRODUCTION**

13 Solar geoengineering, also known as solar radiation management (SRM), involves  
14 deflecting solar radiation from the atmosphere to help prevent global warming. A method of using  
15 stratospheric aerosols has been previously attempted by injecting sulfuric acid, but this can  
16 damage the ozone layer and cause heating in the lower stratosphere (1,2). Limited research has  
17 been conducted on other aerosols. However, since SRM could prove highly effective, different  
18 methods must be tested.

19 Calcite is a form of  $\text{CaCO}_3$  with a distinct hexagonal crystal structure (3). It is radiation-  
20 resistant, undergoing no structural changes under irradiation, proving it suitable for this application  
21 (4). It can be used in the atmosphere at a low cost and with minimal technical risk, and is  
22 commercially available, likely generating less warming compared to other tested alternatives,  
23 such as sulfates and solids like titania and alumina. A hybrid approach utilizing alkali metal salts  
24 in conjunction with  $\text{CaCO}_3$  could be much safer than sulfate aerosol (1). Therefore, it is not only  
25 more environmentally friendly but also has potential for future upgrades to increase effectiveness.  
26 Many engineering and research firms already possess the technology to employ calcite SRM,  
27 such as solid aerosol dispersers and high-altitude aircraft, indicating that this technique has the  
28 feasibility of being implemented within the next five years.

29 Calcite SRM could be a revolutionary technique in mitigating the effects of climate change,  
30 thus reducing industrial economic losses. A recent study has compared the economic impacts of  
31 global temperature increases of  $2.8^\circ\text{C}$  and  $4.5^\circ\text{C}$  from pre-industrial temperatures over the next  
32 75 years. A  $4.5^\circ\text{C}$  increase in global temperature could cost the US \$520 billion per year. If efforts  
33 are made to limit the rise in temperatures to only  $2.8^\circ\text{C}$ , the United States could reduce economic  
34 losses by \$224 billion (5). This will benefit not only the US but also the rest of the world.

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

39

40 **RESULTS**

41 This experiment was performed to investigate the effect of calcite aerosols on reducing  
42 UV radiation via solar radiation management (SRM). Other aerosols such as sulfur dioxide have  
43 harmful effects on the environment. However, calcium carbonate has shown promise as an  
44 agent to block out harmful solar radiation (1). Specifically, this experiment analyzed calcite, the  
45 most radiation-resistant form of calcium carbonate, as a prime agent of UV mitigation.

46 To investigate the effects of calcite on the mitigation of solar radiation three sets of  
47 laminated calcite sheets with varying concentrations - 0.00g, 0.05g, and 0.10g - were tested using  
48 two different types of sensors - LTR-390 and GUVA-S12SD - contained in a payload box.

49 The levels of UV radiation detected by the sensors varied across the three calcite densities  
50 (Figure 1, Figure 2). To evaluate the effectiveness of the three calcite samples in blocking  
51 ultraviolet radiation, we conducted a one-way ANOVA test. This was done in R for visualization  
52 and data processing. ANOVA is appropriate here because it determines whether there are  
53 statistically significant differences between the means of three or more independent groups. In  
54 this case, we desired to assess whether the UV-blocking performance varied meaningfully across  
55 the three calcite samples over the time of the flight.

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

61

62 **DISCUSSION**

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

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

71 The confidence interval graph shows that the UV2 - UV1 bar crosses the zero line,  
72 indicating that their difference in mean is not significant (Figure 3). However, the UV3 - UV1 and

73 UV3 - UV2 bars are far from the zero line and do not cross. This implies that UV 1 (0.1g) and UV  
74 2 (0.05g) block around the same amount of ultraviolet radiation.

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

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

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

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

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

105 Mining large amounts of calcium carbonate from chalk or limestone deposits for SAI use  
106 may result in a significant carbon footprint. However, the environmental benefits from the

107 decrease in temperature may compensate for this. As a result, further studies are needed to  
108 determine the optimal aerosol concentration within the atmosphere, aiming to minimize  
109 environmental damage and achieve the desired global temperature reduction.

110 If calcite SAI is not researched to be a viable application to reduce global temperatures,  
111 other aerosols, such as black carbon, aluminum, and barium titanate, may also be researched  
112 using the same guidelines. Each aerosol could be tested in a computer simulation based on  
113 chemical and physical properties (6). The simulation could estimate the optimal particle coverage  
114 across the globe as well as its overall efficiency based on its properties. It is vital to prioritize  
115 environmental sustainability above all other considerations when selecting potential aerosols.

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

122

## 123 **MATERIALS AND METHODS**

### 124 *Payload Construction*

125 An experimental payload box, primarily made of polycarbonate with dimensions of  
126 4"x4"x8", was provided by the NASA TechRise committee. Lab-Grade Calcium Carbonate powder  
127 was obtained from Flinn Scientific

128 Three GUVA-S12SD sensors and three LTR390 sensors were obtained from Adafruit to  
129 measure UV transmission. The Payload Interface Board was provided by the NASA TechRise  
130 committee. The Metro M4 Express microcontroller and the MicroSD Breakout Board+ were  
131 obtained from Adafruit. Additional materials include a Kingston 32Gb High Endurance UHS-I  
132 microSDHC Card and small UV lights provided by NASA TechRise. Sensors were tested  
133 individually for functionality after being wired to a plastic breadboard and a Metro M4  
134 microcontroller. CircuitPython code was uploaded to the Mu Editor software to determine the  
135 amount of UV light each sensor was receiving. A UV LED was placed in front of each sensor, and  
136 if the UV readings of each sensor increased as the distance of the UV LED decreased, the sensor  
137 would be deemed viable. Once all sensors were deemed viable, each sensor was wired together  
138 with the Metro M4, the flight PCB, and an Adafruit MicroSD Breakout board, which would collect  
139 data from each sensor on a 32GB MicroSD card. The wires were connected via a solderable

140 breadboard. Once wired and soldered, 2-part epoxy resin was spread onto each wire connection  
141 to prevent wiring disconnects during flight.

142 Matte and clear laminate sheets were tested for UV transmission, and Uinkit Matte  
143 Thermal Laminating Sheets were selected, as they transmitted the most significant amount of UV  
144 light to the selected sensors. To uniformly distribute the calcite placed in front of the sensors, 0.10  
145 g and 0.05 g calcite samples, mixed with water in the form of a paste, were spread on separate  
146 1.25" x 3.25" laminate sheet pieces, along with a control laminate sheet without calcite. After  
147 drying, each set of sheets was heat laminated for mounting onto the payload. Three sensor  
148 mounting plates were designed in Inventor and 3D printed with PETG filament. This material was  
149 chosen due to its lightweight yet durable composition that can withstand a high-altitude balloon  
150 flight.

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

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

160

### 161 *Experimental Methods*

162 The scientific balloon was launched at a stratospheric height of 24,000 meters. The  
163 payload and all sensors were powered on while on the ground before flight, and stayed on as the  
164 balloon ascended, floated at maximum altitude, and descended. All operations ceased after the  
165 landing of the balloon. The sensors collected data on the quantity of UV radiation penetrating the  
166 calcite sheets, with one GUVA-S12SD and one LTR390 behind each pouch for redundancy. The  
167 LTR390 sensors directly collected data on UV levels. The GUVA-S12SD sensors collected UV  
168 data in the form of voltage output, with a higher voltage corresponding to higher UV input.

169

### 170 **ACKNOWLEDGMENTS**

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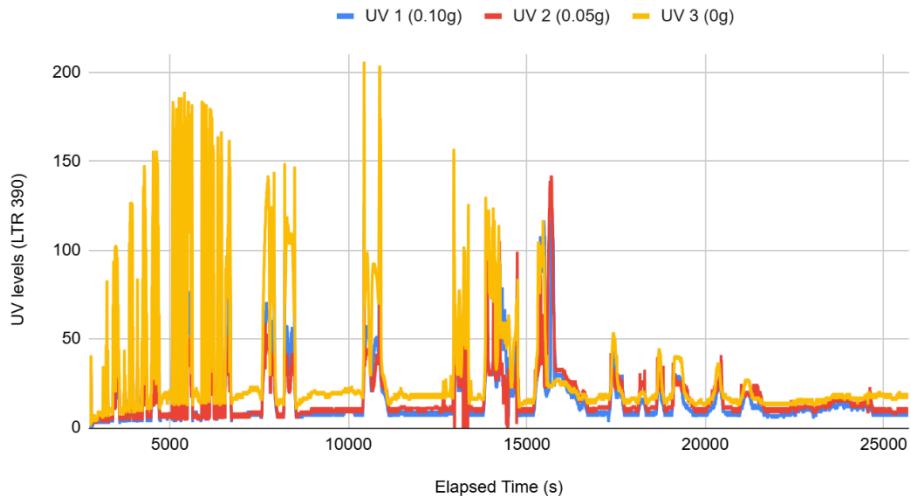
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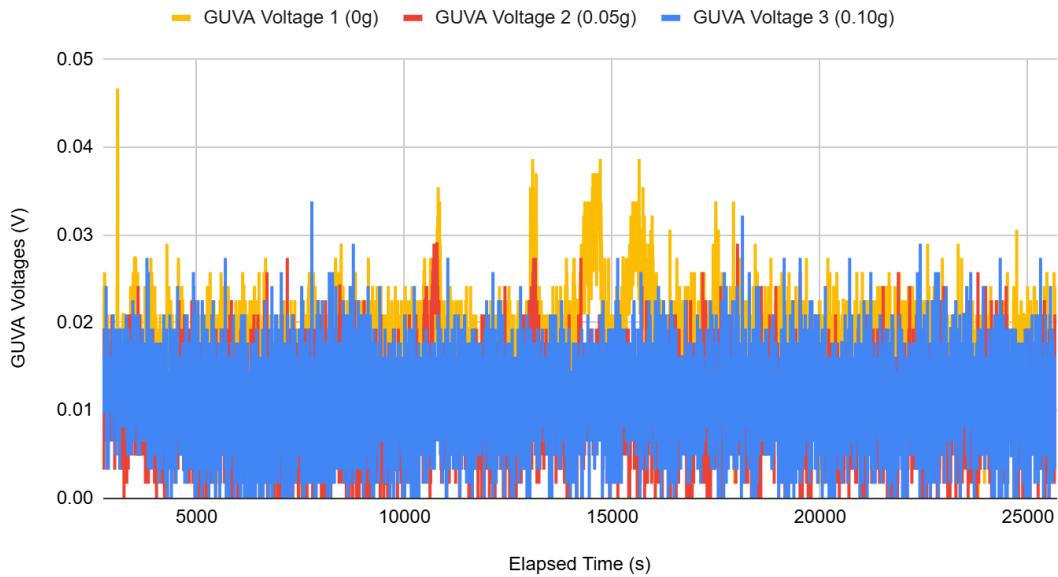
233 **FIGURES AND CAPTIONS**



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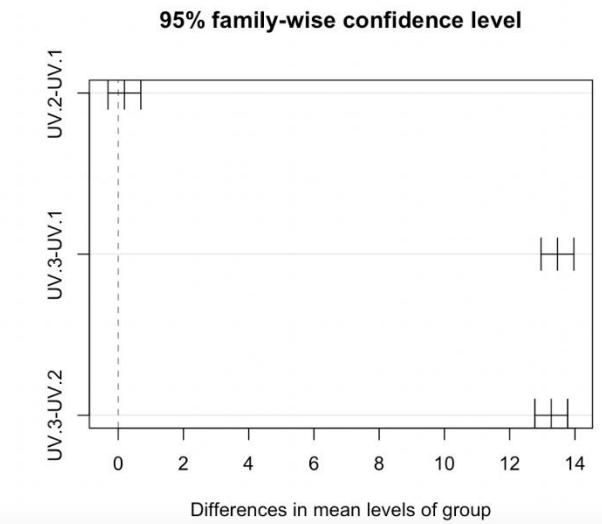
235 **Figure 1: Higher calcite densities indicate lower ultraviolet radiation penetration to the**  
236 **LTR-390 sensors (N=1).** UV radiation levels measured by LTR-390 sensors over flight duration  
237 for different calcite concentrations. Sheets containing 0.00g, 0.05g, and 0.10g were launched to  
238 a stratospheric level.

239



240

241 **Figure 2: Higher calcite densities indicate lower ultraviolet radiation penetration to the**  
242 **GUVA-S12SD sensors (N=1).** Voltage corresponding to UV radiation measured by GUVA-  
243 S12SD sensors over flight duration for different calcite concentrations. Sheets containing 0g,  
244 0.05g, and 0.10g were launched to a stratospheric level.



247 **Figure 3: Calcite displayed to have significance in blocking ultraviolet radiation from the**  
 248 **sun (N=1).** Confidence interval plot graph showing results of ANOVA test between three calcite  
 249 concentrations. The three UV groups were compared using the anova\_result object in R. One-  
 250 way ANOVA test,  $p < 0.05$ .  $p < 0.000001$  between UV 3 (0g) and UV 2 (0.05g) as well as UV 3  
 251 and UV 1 (0.10g) indicates statistically significant difference. No significant difference between  
 252 groups UV 2 and UV 3,  $p = 0.647$ .