



Aircraft for Dispersal of Calcite Plumes for Heat Mitigation

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Abstract

Aircraft are evaluated as an alternative to towers for distribution of calcite particle plumes. Airplanes and airships are compared. The proposed plumes will block solar radiation and offset warming from global climate change regionally. Using aircraft is much more cost-effective than towers because the capital costs are much lower. One airport needs to be constructed for a small fleet of aircraft versus many tall towers and many sets of redundant equipment. The operational costs are higher. Even though labor costs are lower for airplane operation, the energy costs are higher than for towers. It is less efficient to transport calcite into the air with airplanes than with permanent towers. Airships are more efficient at transporting payload and therefore use approximately the same energy as permanent towers. Using aircraft has other advantages, such as getting the material higher into the air so that it has less effect on the health of people in the region. Also, there is less impact on ecology and scenic values when towers are removed from the conservation area.

Keywords: Aerosol reflectivity, Arid and humid climates, Climate engineering, Particulate dispersal, Solar geoengineering, Solar radiation management, Urban heat mitigation.

1. Introduction

The purpose of this paper is to show that calcite particles can be cost-effectively dispersed into the air using aircraft such as airplanes and airships, which are also called dirigibles. Hoback (2026) found that calcite plumes could be made above Las Vegas, Nevada. Those plumes would reduce solar radiation, reduce temperatures, and decrease air-conditioning use. The option proposed by Hoback used towers that were 400 to 500 m tall to disperse the material as high as possible. A ring of 76 towers would have been placed around Las Vegas. A conveyor would connect them to quarries. Each tower requires a processing facility.

Calcite is the most common mineral form of limestone. It is widely available, including in the Las Vegas area.

One disadvantage of the competing proposal for towers was that either they would have to be placed in the conservation area that rings the city, or they would have to be placed in the city. In either case, they would likely make the area less scenic. Another disadvantage of distribution using towers was that particles would settle on the city, and that may impact human health. However, when placed higher by aircraft, the health impact is reduced.

Hoback (2026) evaluated using calcite milled to a range from 3 to 5 microns and a range from 10 to 12 microns, which are referred to as nominal sizes of 4 and 11 microns, respectively. It was shown that for dispersal from towers, using 4 microns was more cost-efficient. For dispersal with aircraft, the mass is the controlling variable in determining many factors such as the number of aircraft, number of crews, and fuel use. Hoback (2026) shows that using particles in the size of 10 to 12 microns requires three times the mass because of nonlinear changes in optical effects. The size of 4 microns will be more strongly preferred in the option for using aircraft dispersal. Therefore, only the particle size of 4 microns is considered here.

For consistency with previous work, data from 2021 will be used (Hoback, 2026). The air-conditioning season in Las Vegas is April through November. Some days in November do not require cooling, or at a very low amount, so it is not included. Cooling was required 193 days in 2021, and 185 days required cooling of at least one degree C. With global climate change, in the future it may be effective to operate a mitigation system through November. It will be assumed that the system operates 185 days per year, but that is based on finding suitable wind conditions. The system would normally operate 10 hours a day from sunrise until late afternoon.

The scope of this paper does not include a full examination of health and ecological advantages and disadvantages. However, some implications for health will be mentioned. An example is that using calcite in the range of 3 to 5 microns has greater potential for health consequences compared to using it in the range of 10 to 12 microns. Future papers are needed to explore these ideas.

2. Dispersion

The radiative transfer has been modeled previously (Hoback, 2024; Hoback, 2025). Solar radiation interacts with calcite aerosol. Much light is backscattered which reflects it away from the surface. When there is less shortwave radiation reaching the ground, temperatures increase less quickly. Longwave radiation from the ground

doesn't interact with calcite as much, so it free escapes which cools the surface. Peak daily temperatures are modeled to be reduced by 5 to 6 C when half the solar radiation is blocked. At any point in time, a constant amount of calcite aerosol needs to be placed into the air.

An optical depth of 0.69 produces a reduction in solar radiation by half. There is insignificant difference in results when releasing the material from the heights of towers or aircraft (Hoback, 2025). It is necessary to blanket the target area, which is in this case the metro area of Las Vegas. Las Vegas is roughly circular with a diameter of 40 km.

Advection with wind will bring hot desert air into the city. To cool the air, the target area needs to extend upwind of the city. This is difficult with towers because they may be restricted by a nature area. The towers are less effective when they are close to the city because the plumes that they create do not have as much time to cool the air.

It is advantageous to have the calcite plumes dispersed to the air as far upwind as possible. Air-conditioning use under plumes is improved by two factors. First, solar heat gain (SHG) is the effect of sunlight on buildings and coming through windows. Under a water cloud or a calcite plume, SHG is immediately reduced. Second, the air temperatures determine the cooling degree days (CDD). Air temperatures change slowly whenever conditions change (Smedman et al., 1997). Advection is heat carried in the air as it blows from hot areas to cold areas. To cool the air requires that it travel a long distance. In 10 to 20 km, the air will be significantly cooled.

The particles need to be spread evenly so that the effects are even. In practice, the effects will not be completely even because the turbulent movement of air will cause local areas of higher concentration. However, the concentration is considered to be roughly even when the plumes from different sources widen such that they overlap. For towers, the spacing of 2 km is governed by horizontal dispersion. Hoback (2026) showed that when towers are spaced 2 km laterally apart, in 10 km the plumes are expected to overlap to produce a plume of constant thickness. Likewise, aircraft need to be spaced closely horizontally so that their plumes overlap. Turner (2020) shows that for instantaneous sources, dispersal is the same in both directions.

Aircraft cause significant air turbulence, so they will cause rapid dispersal of calcite. When aircraft are 20 km upwind and cause turbulence, the plumes should be uniform if they are placed by aircraft that are 6 km apart (Turner, 2020). Aircraft cargo capacities may not be large enough to hold enough material to cover a swath of 6 km, so they may fly more closely. Practically, based on the wind speed, this determines the time interval between parallel flights.

The material will spread laterally, so it will thin out as it progresses downwind. However, the thinning will not be significant in the center of the target area. The 40 km width of the plume will not allow much thinning to occur in the middle. Areas along the lateral edges of the city will have lesser protection from heat.

The aerosol should not be placed too far upwind because such a placement allow for more spreading. Therefore, a distance upwind of 10 km is suitable for this.

Aerosols that are the size of 3 to 5 microns are not governed by gravity settling. They are controlled by air movements. Particles that are of the size of 4 microns take, on average, more than a day to settle (Tegen and Lacis, 1996). It is not expected that the particles will persistently settle on the ground in Las Vegas when released from an altitude of 2 km or more. If atmospheric conditions cause the aerosol to reach the ground level in high concentrations, then the flight altitude can be adjusted.

3. Wind and Altitude

Wind speed is a primary factor in determining the optimum system. When wind is faster, more material needs to be placed into the air to replace what has been blown away. When it is windier, greater aircraft cargo capacities are needed. This could be met by having more aircraft or larger ones. Higher material requirements also increase the amount of limestone that needs to be quarried, transported, and milled. That increases labor costs and energy use.

Hoback (2026) used a maximum operating wind speed of 20 kph at the tower height. This may be adjusted since there may be less need for the system when winds are high. The urban heat island (UHI) effect tends to break down when the wind speed is higher. For most Australian cities studied, the UHI decreased with ground-level wind speed, and it had a much-reduced effect at 6.5 kph (Al-Obaidi et al., 2021). If a system is run in higher winds, the cooling requirements are lower. A maximum operating wind speed of 20 kph will be used here, but further analysis could change that.

Wind is generally slowest nearer the ground, as shown in Figure 1 (NOAA, 2023). This suggests that to have the most efficient system, aircraft should fly as low as possible. Aircraft are recommended to have a vertical clearance of 300 m above the highest obstacle, but 150 m clearance is permitted (FAA, 2012).

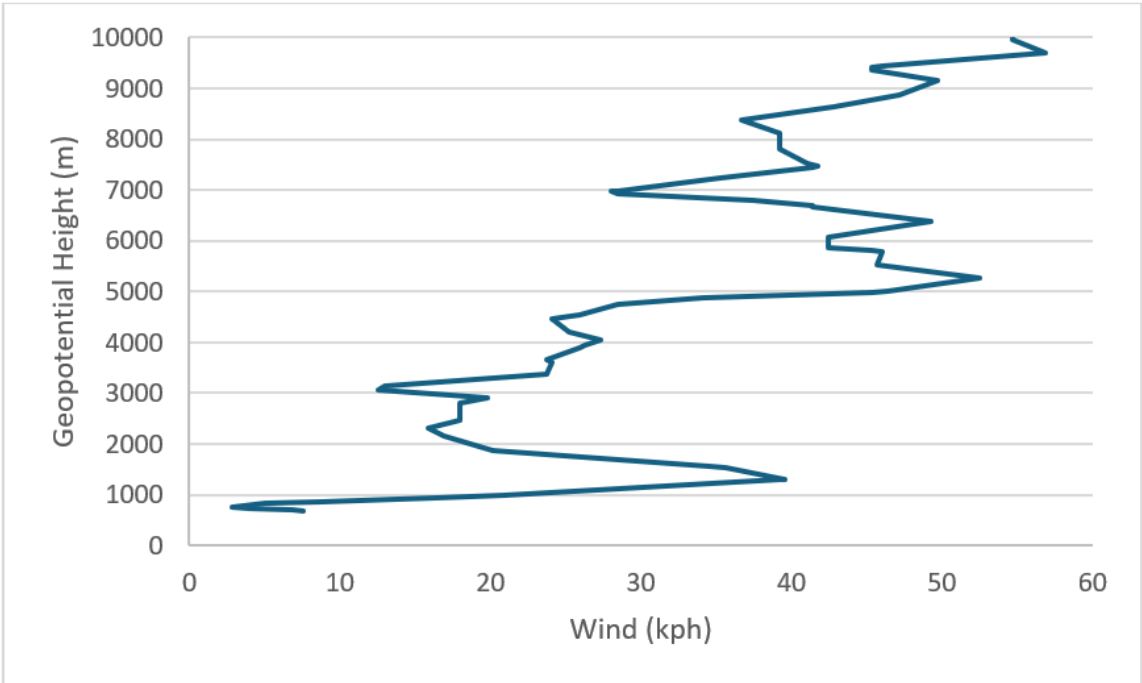


Figure 1. Radio balloon sounding of wind for Las Vegas, April 1, 2021, 12 UTC.

Noise would be too high if airplanes regularly flew 150 meters above the ground. Noise is a health issue, causing neurological and gastrointestinal problems when above 60–65 dB because it causes stress (Smith, 2017). Loud noise also causes mental errors (Veitch and Arkkelin, 1995).

Noise from airplanes is standardized by measurement at 450 m, and the measured values vary slightly for each variant. For example, the Boeing 777 variants produce takeoff sound levels between 85.2 and 94.3 at 450 m (FAA, 2012). The airplanes will be cruising at slow speeds to distribute calcite, so they will likely be quieter than during takeoff. Data is not available for sound at slow cruising speeds, so takeoff sound levels will be used.

The goal should be that the sound is unnoticeable. The level of background noise in cities varies around 45 dB. The variants of the Boeing 777 would have to maintain 1800 m above ground to be that quiet. Therefore, the goal should be to fly above 1800 m. However, the planes will be flying upwind of Las Vegas, so the population impact is lower. Also, noisy aircraft might be tolerable occasionally in exchange for reduced temperatures.

In Las Vegas, large areas of the desert are uninhabited. A few small towns are scattered through southern Nevada. In most directions away from Las Vegas, planes could fly lower and not disturb people. The goal will be to stay above 1.8 km, but that might be compromised if favorable wind conditions exist down to 1 km. If airplanes need to fly over the city, they will stay above 1.8 km. The same altitude will be used for airships because they may have noisy propulsion systems too.

Figure 1 shows that between 1 km and 6 km, the best wind speed is found at 3063 m altitude for that sounding, which is 2370 m above ground. The wind speed at that height is 12.6 kph.

Radio balloon data was found for April 1 through October 31, 2021 (NOAA, 2023). Radio balloons are launched every 12 hours. At those times, the best wind speed was found between 1 km and 6 km above the ground. Figure 2 shows that on most days, it is possible to find slow winds. The speeds were below 20 kph for 77.1% of the readings. The median wind speed between 1 and 6 km is 9.4 kph.

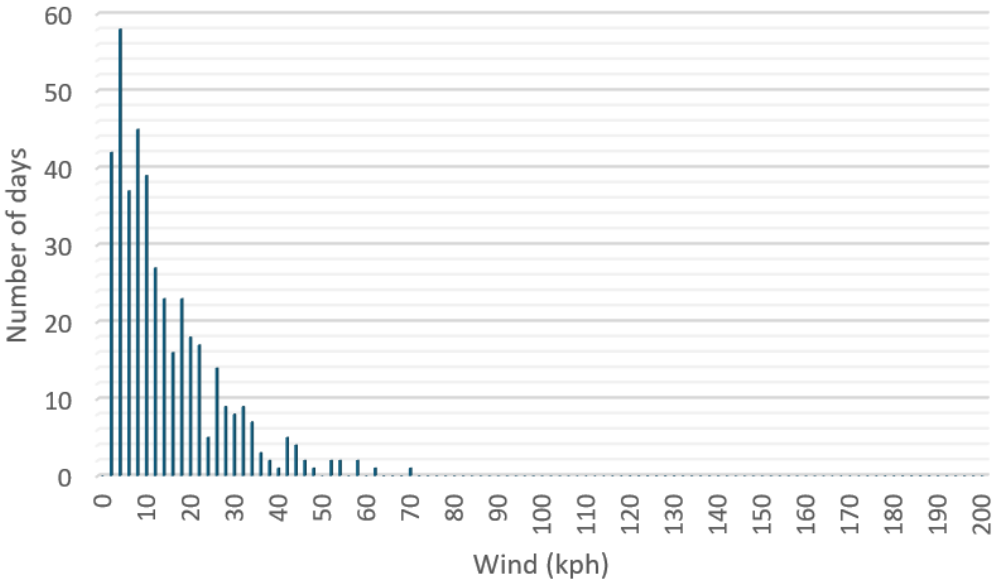


Figure 2. Best wind speed for 2021 in Las Vegas.

The heights above ground that correspond to the best speeds in Figure 2 are shown in Figure 3. It is common to find the best speed near the ground. The average height was 2.5 km above ground. Jet fuel use will be based on assuming the average climbing height is 3 km.

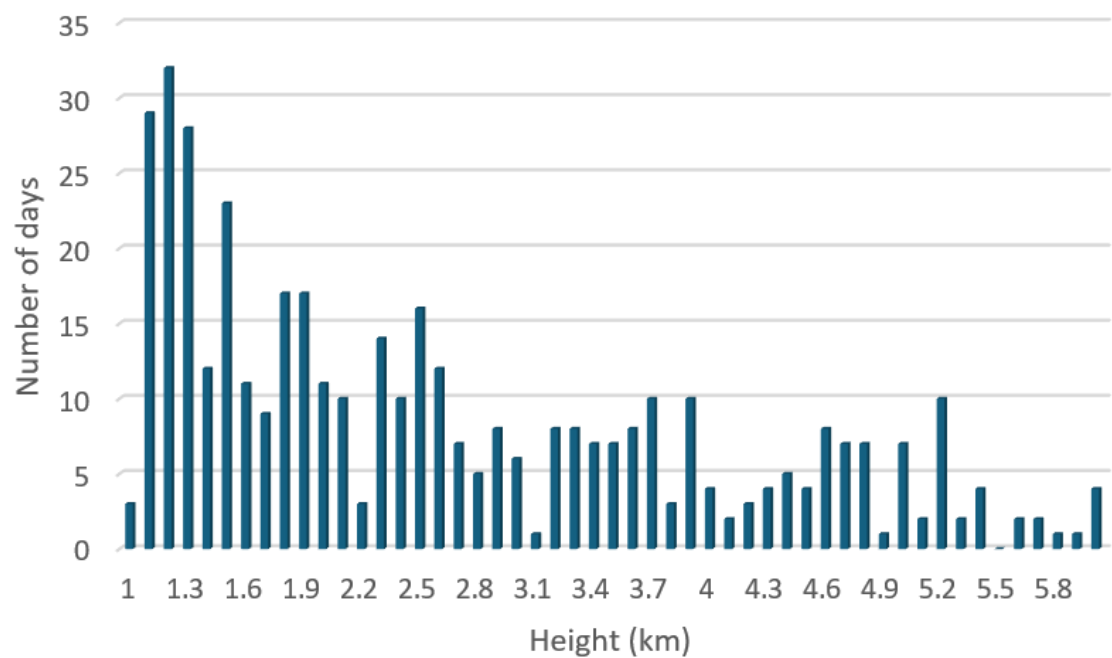


Figure 3. Best height above ground for 2021 in Las Vegas.

Flying above 4,267 m (14,000 ft) requires cabin pressurization or oxygen. When flying above 3,810 m (12,500 ft) for more than 30 minutes, it is also required. The planes will be above 3,810 m for only a short time, and the wind is usually best below 4,267 m. It is possible that the planes can be unpressurized and stay below 4,267 m or simply provide oxygen for the times when flying above that. That would simplify the design of planes if new custom aircraft were made.

For this analysis, a maximum operational wind speed of 20 kph was used. When the wind is faster, the system could still run, but it would do so at a reduced effectiveness. Equipment that is conservatively designed may be able to operate at faster speeds for a short time. For example, a system may be able to handle high wind speeds if slow speeds occur before and after that time. If high wind is expected, the aircraft could place calcite into the air further upwind during slow winds. Alternatively, higher concentrations of calcite could be placed above the city during slow winds so that it cools more, and that may keep temperatures down when high winds limit system efficiency. Additionally, it may be found that developing a system that can handle higher wind speeds is economical.

4. Flexibility of Aircraft

Implementing heat mitigation with aircraft provides for more flexibility. An example of this is adjusting to the angle of the sun.

The solar heating in the morning is very significant for the bottom layers of the air, which are near the ground. Figure 4 shows the idealized air temperatures versus height on a typical day in Las Vegas. Actual air temperatures versus height are only measured twice a day, so the intermediate values are extrapolated based on experience worldwide.

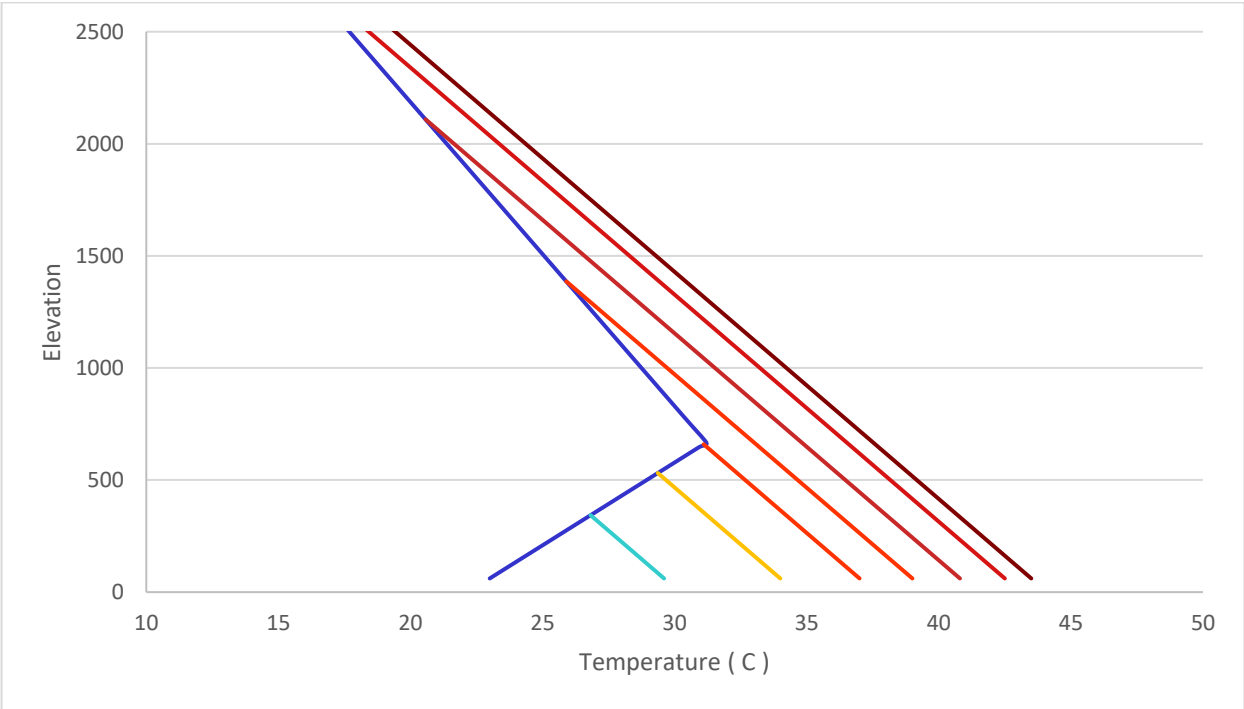


Figure 4. Idealized Temperature versus Height for Las Vegas, NV. The blue color is the sunrise temperature profile. Shades of increasing red show increasing increments of heating required for the ground-level temperature changes.

Figure 4 shows a typical temperature inversion at sunrise whereby the temperatures increase with altitude to the point of inversion. The inversion develops because air cools at night from ground radiation. The slope at the top of the curve is the adiabatic lapse rate that drives vertical convection.

As the ground is heated from solar radiation, the air temperatures increase at the ground level. This is shown for increments of heating in Figure 4. Notice that during the morning, it takes less heat to warm the air than later in the day. The same amount of heating later has a lesser impact on temperatures. This emphasizes that controlling temperatures at sunrise is important.

In addition to temperatures, the amount of solar radiation that a person feels on their skin or that a building feels on its envelope is also important for comfort. Solar heat gain (SHG) is highest in the middle of the day, so for that concern, the morning is less important. Distribution of calcite via towers should meet this part of the need.

Towers will be discussed for comparison. When towers are used in the distribution of calcite, the towers have to remain in a fixed position. The position of the tower has many factors controlling it. Hoback (2026) recommended that they be placed 10 km outside of the target area so that the material can disperse laterally.

Figure 5 shows that if the towers are close to the target area, then the morning sun will reach part of the city. If towers are 500 m tall and located 10 km outside of a targeted area, sunlight would reach the city unfiltered for only about 20 minutes. This time depends upon the latitude and season of the target area.

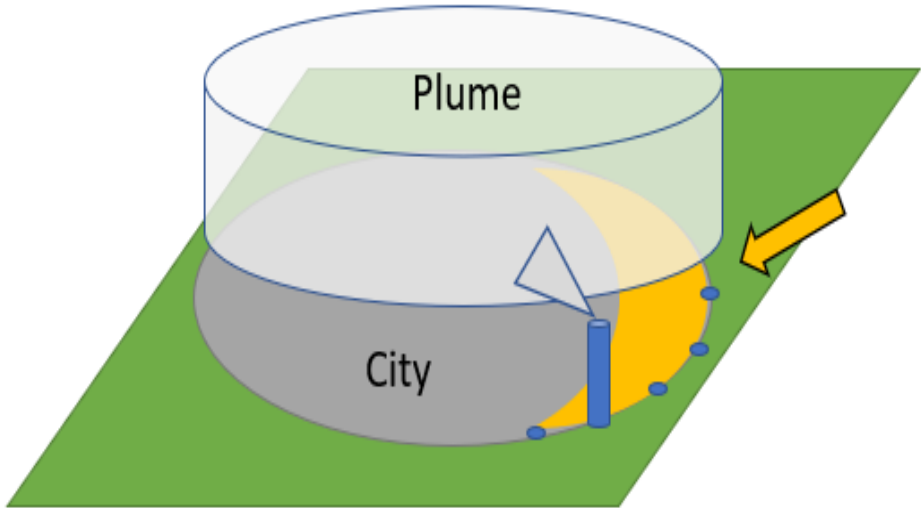


Figure 5. Sample Dispersion of Calcite from Towers. Towers are in fixed locations, so they do not adjust to the angle of the sun. The arrow represents sunlight in the early morning. One sample tower is shown, and the wind is assumed from the East.

One option for Las Vegas was to put the towers right at the urban growth boundary. This would mean that varying swaths of the city would be unprotected for many hours as the angle of the sun increased to the zenith. In many cities, compromises would have to be made about the locations of the towers versus the benefit, and this issue complicates those decisions.

Figure 6 shows that aircraft are flexible because they can adjust throughout the day to the angle of the sun. Even though aircraft may fly as high as 6 km, they directly protect the target area.

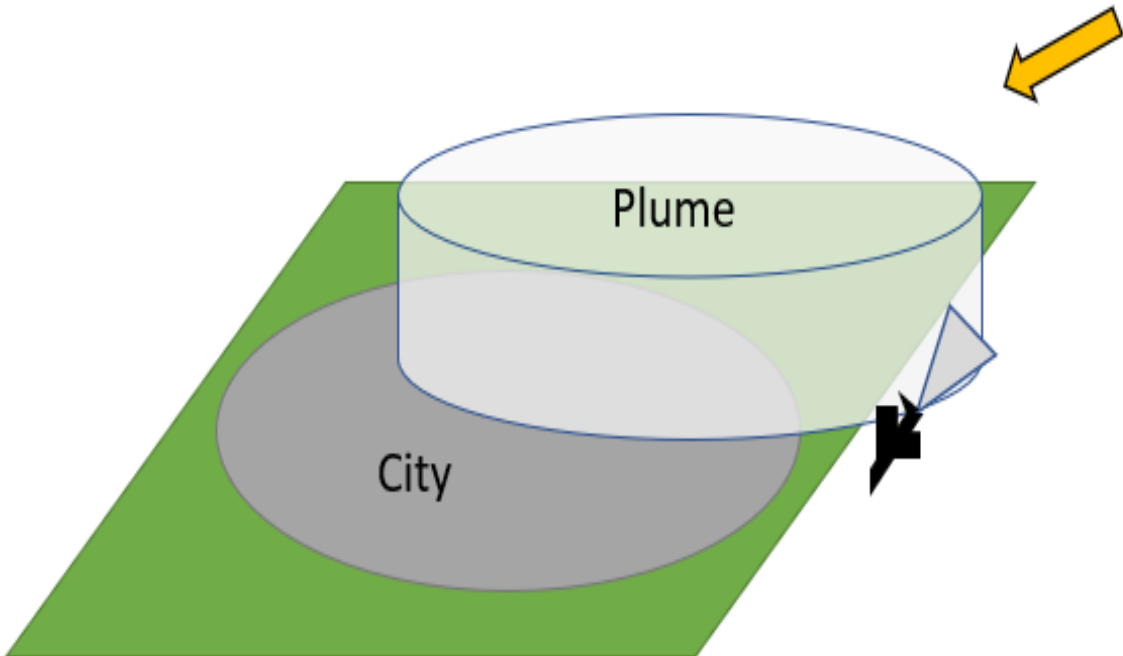


Figure 6. Sample Dispersion of Calcite from Aircraft. Aircraft can adjust to the angle of the sun. The wind is assumed from the East.

Air traffic patterns may restrict the locations for placing calcite. Commercial aircraft take off in the direction towards the wind. That is the side of a city where aircraft would spread the calcite. Commercial aircraft are usually above 3 km in relative altitude when they are 20 km outside a city. If the aircraft were releasing calcite at a relative altitude of 2 km, they could operate within 20 km of the city, but if they were higher in altitude, they may have to be further from the city.

5. Exposure

Calcite particles may be distributed from towers or from aircraft. Towers are intended to be 472 m tall. Dispersal from aircraft varies in height. On average, aircraft would fly about 3 km above the ground and 20 km upwind. The worst-case scenario for air quality is when the aircraft are lowest to the ground.

Modeling of exposure from large particles is a function of their falling rate, but the particles used should spread as aerosol. Therefore, dispersion models are appropriate.

Simple and advanced dispersion models are available. A simple model such as from Turner provides average conditions (Turner, 2020). Simple models do not account for the full range of atmospheric conditions. The results will be compared to the Air Quality Index (AQI), by US standards. Those standards for this material measure the values averaged over a 24-hour period. Therefore, a simple model is sufficient to find average conditions, and the Turner method will be used.

The stability class determines the turbulence of the air. Solar insolation or heating on hot days makes the air more turbulent, but the mitigation effort will reduce the insolation which will make the air more stable. For this reason, the stability class was chosen as “slightly unstable.” Wind also affects the stability class, but the system is designed for a maximum operational wind speed of 20 kph, so the range of stability is less than with any possible wind.

Assuming the wind speed averages 1 kph for several hours, the exposure was found using atmospheric dispersion methods of Turner. Figure 7 shows the peak concentrations are 6.9 and 2.5 mg/m³ for 11 and 4-micron particles when released from towers, respectively, and 0.3 when release from aircraft that are 1800 m high. Usually, wind speed has a large effect on pollutant concentration because wind dilutes the pollutants. However, the production of plume of calcite has to keep proportionate to the wind speed. The total mass in the air above the city needs to remain constant. Therefore, these results are not sensitive to wind speed.

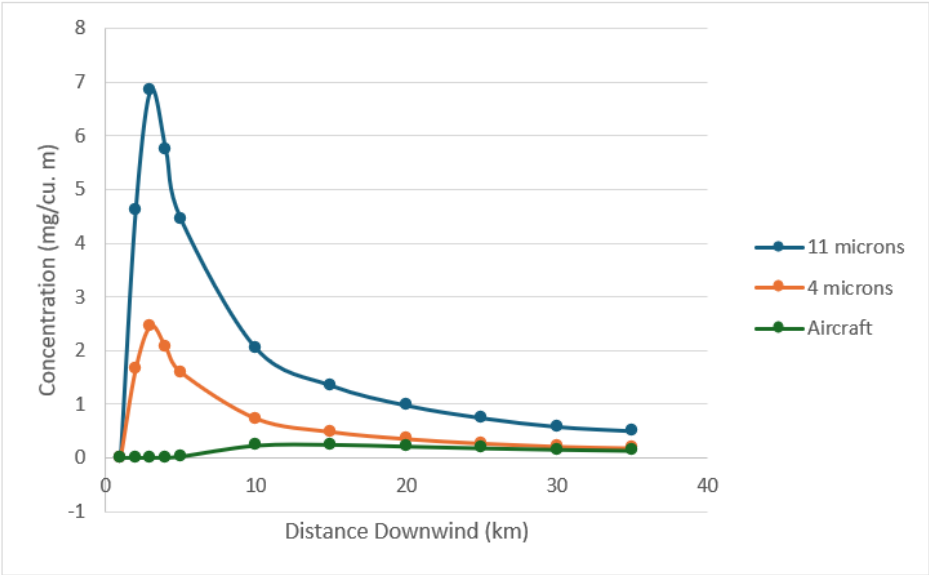


Figure 7. Results of dispersion models in various scenarios.

The AQI in US standards, lumps all air pollutants together into two groupings based on size (EPA, 2013). Particles of less than 2.5 microns are PM2.5 and less than 10 microns are PM10. Calcite particles would be in the PM10 range. Based on that, the instantaneous value of PM10 would be about double what is considered the normal range in the worst-case scenario. Normal is moderate air quality with an index value of 100 or lower, and that corresponds to 0.154 mg/m³ of PM10. Yet, PM10 is averaged over a 24-hour period in the AQI, so the standard would be met on that basis.

Also, it is worth giving some perspective on this. All particles do not equally affect health. Air pollutants below PM2.5 are generally considered to be combustion products (soot). Pollutants below PM10 are generally considered to be crystalline silicates (sand). Those assumptions are generally true since they are the largest sources of pollutants in those ranges. Soot and sand have strong health consequences, but there is much less concern breathing the same amounts of calcite. Miners report no symptoms from high levels of expose (Mulya and Kurniawati, 2019). It is informative to look at the US OSHA limits for calcite even though occupational standards do not apply here. OSHA limits calcite to 10 mg/m³ (OSHA, 2023). That is 33 times higher than expected in Las Vegas.

The health consequences of breathing particles need to be weighed against the improvement in health from avoiding heat stroke. As climate change worsens, many areas may not be habitable without heat mitigation.

6. Savings

Hoback (2026) proposed a distribution of calcite from towers such that 50% of the solar radiation was reflected to the sky. It is the goal of this work to attempt the same level of heat mitigation with aircraft.

Aircraft can produce the same cooling as towers when they distribute the same amount of material in the air as with towers. Changing the altitude of placement has little effect on temperatures

Hoback (2026) showed that \$1.4 B per year would be saved in air-conditioning in Las Vegas when 50% of the solar radiation is blocked. Additionally, \$140 M per year would be saved in the treatment of people suffering severe organ damage from heat stroke. If the aerosol remains high in the air over the city, then there are expected to be minimal health consequences from it. When aircraft produce plumes with the same effectiveness, the savings would be the same.

In the options for towers, the towers were close to the city, so the calcite could not evenly spread over a short distance. Therefore, in that analysis, the whole city was not protected. However, with aircraft dispersal upwind, the plume will be evenly spread. That suggests that more could be saved through using aircraft. Dispersal with aircraft has some uncertainty from the effect of changing wind directions. It was assumed that these factors equaled and that the same savings would be achieved.

7. Aircraft

It will be necessary to acquire several large aircraft to disperse the calcite. Limestone has a high density, so the cargo requirements are controlled by mass and not volume. Airplanes and airships will be considered. Examples of airships are blimps and Zeppelins.

7.1. Airplanes

Large airplanes such as MD 11, DC 10 and Boeing 777 match the expectations. There may not be enough larger airplanes such as Boeing 747s available in used condition to economically acquire the necessary fleet.

The calculations are based on using a Boeing 777. Similar results would be found from using similar airplanes. Several variants are produced for many airplanes. All airplanes would have to undergo modification to distribute particles. Removing seating from a passenger craft would increase the cargo capacity above the listed values. The specifications used are 103,000 kg payload, 171,200 L fuel capacity, range 11,121 km, cruising speed of 892 km/h, and it was assumed that it used 10% of the fuel tank to climb to 10 km above ground.

Depending on the wind speed, airplanes may distribute their cargo in one pass along a city, or they may need to reverse and pass a few times. Based on dispersion analysis, airplanes can be spaced as far as 6 km, but 2 to 3 km may be more typical based on cargo capacities. Airplanes traveling at 266 kph, which bank at 30 degrees, will complete a 180-degree turn in a diameter of 2.1 km. The proposed speed of 266 kph is about one-third of the cruising speed of the recommended airplane models. Therefore, it should be slow enough that they can distribute particles. At that speed, an airplane can travel the width of Las Vegas in 9 minutes.

If the maximum service wind speed is 20 kph, then 19 Boeing 777s have the cargo capacity to meet the demand. However, based on assumptions of air speed and dispersal rates, 21 airplanes would need to be operational. Two additional airplanes would be purchased so that some airplanes could be under maintenance.

The expected route takes 99 minutes. The cargo would be loaded with unit load devices which slide quickly into place. The assumptions are that it takes 30 minutes to load the cargo area with calcite, 30 minutes to taxi, take off and approach the area of dispersal, 9 minutes to disperse the material, and 30 minutes to return to the airport and land. If the filling time can be reduced, then this cycle may take 85 minutes. When the wind is slower, the planes may need to double back, and that increases the dispersal time to 18 minutes. However, that is balanced by other efficiencies when the wind is slower.

Up to five airplanes would be expected to be refilled at once with material. Therefore, five bays and crews need to be provided. During peak operation, an airplane would have to take off or land about every 3 minutes. The demands that this operation would place on most current airports are excessive, so a new landing strip is necessary.

7.2. Airships

Airships or dirigibles are very efficient at carrying heavy loads. To carry the same payload as a Boeing 777, an airship would be larger than any airship ever constructed. For that reason, the results of this section are speculative.

Blimps are limited in size because they have no internal structure to carry stress, so a rigid-structure Zeppelin would need to be used. A Zeppelin has inner gas bags full of helium or hydrogen. Lockheed Martin's LMH1 is too small for this load in its default arrangement, but the series is expandable to up to a payload of 500 metric tons, and that would exceed the requirements.

Airships can be constructed for roughly the same cost as aircraft with the same payload. One disadvantage of airships is that they usually fly slowly, but the speeds can be increased into the same range as the airplanes that will be used. The airplanes are assumed to fly slowly when distributing the calcite.

A significant challenge is that airships' buoyancy would change when dropping payload. The flight altitude of an airship is determined by its balance between uplift and ballast. As ballast is dropped, the uplift exceeds the ballast, and the airship rises in the air. This is not desirable since there is an optimum altitude for the distribution of the dust. Also, the airship needs to be able to land.

Airships can pump the lifting gas into pressurized containers. This reduces the volume of the craft's gas bags and therefore reduces lift. Practically, the maximum that the buoyant forces can change is 30%. Therefore, the dropped payload shouldn't exceed 30% of the total mass of the airship.

The 1917 Zeppelins were known to fly as high as 6400 m. However, it is unknown whether that was with a full payload. Zeppelins delivering calcite may be limited to lower altitudes. Therefore, they may have to distribute the calcite at altitudes with less favorable winds.

It is assumed that the Zeppelins have the same payload capacity as the airplanes, and that they fly at 90 kph. The airships would take 142 minutes per cycle to load, takeoff, approach the target area, distribute the material, and then return and land. Therefore, it will be estimated that 67% more aircraft and more crew will be required. The needs for a landing strip will be different for airships, but the total size of the facility will be about the same.

8. Costs

Calcite needs to be quarried, transported to the airport, milled to 4 microns, and loaded into aircraft. Then the aircraft need to carry the calcite to where it is needed and then disperse it. Approximate costs are found to judge whether the concept is feasible. All costs are for 2021. Detailed engineering is necessary to find precise costs.

8.1. Capital Costs

Quarrying and milling will be roughly the same as from Hoback (2026) with one exception. Rather than having a mill at each of the 76 towers, there is one larger mill site at the airport.

Limestone is widely available, but testing would be performed to locate the most suitable deposits near Las Vegas. The lightest colored limestone, such as chalk, is the best for reflecting sunlight. It is planned to have the limestone source within 10 km of the new airport, but it could be on the same site if conditions allow it. The quarry and airport should be within 30 minutes of flying time from Las Vegas which is 445 km, but it is likely that a suitable site can be found within 100 km. Limestone quarrying will be handled as an operational expense through an outside contractor.

The quarry and landing strip should be close together to limit the transportation costs of material. The material and suitable places to land are common, so it is likely that they can be close. Material can be moved from the quarry to the processing area by conveyors or rail. Until a specific site is chosen, the transportation costs are unknown. Assuming that quarry and airstrip are within 3 km, then for a new rail connection, \$10 M is estimated.

The amount of limestone is increased by 8% above previous estimates. The previous work did not consider the mode of reflection of solar radiation between the ground and calcite plume. That reduces its effectiveness by 8%. Therefore, calcite required for 50% solar filtering above Las Vegas has a weight of 1,669,000 kg. This is the mass required at any point in time. The wind speed determines the replacement rate.

The cost of property acquisition is very low. The new airport will likely be in the middle of the desert on government-owned land. Land values should be relatively inexpensive in the desert away from Las Vegas. Land purchased from the US Bureau of Land Management in desert areas may cost \$2,000 per hectare, but that is subject to negotiation. An area of 5,000 hectares should provide for growth. A cost of \$10 M is assumed.

The milling requires two stages. The first stage requires 82 ball mills to break down feedstock to 0.5 mm. Mill design calculations are shown in the supplementary materials. The second stage requires 123 rod mills to reduce the size to 3 to 5 microns. Six-hundred cyclones are used at various stages to sort the material. Material that is too large is redirected back to the mill. Material that is too small is waste. The total costs of mill machines are \$31.8 M. Additional equipment at the mill includes conveyors and equipment to load aircraft. This is estimated at \$14.0 M. The mill building is estimated at \$7.3 M.

Silos will store processed calcite at the mill and the aircraft loading areas. The cost of large silos is \$5.2 M each. Two will provide supply for four days.

Electrical power will have to be brought to the site to run milling equipment. Transmission line costs roughly \$0.67 M per km. Until a site is chosen, the actual cost won't be known. It is budgeted that \$10 M should provide up to 15 km of new transmission line.

A single 3300 m runway is sufficient for intervals between takeoffs and landings every 3 minutes. The runway length is determined so that large, heavy craft can take off in high temperatures. Two runways would allow for takeoff and landing during crosswinds. Two hangars are provided. Also, on the site is an office building, employee parking, taxiways, a control tower, and navigation equipment. The total cost of the airport is estimated as \$122.4 M. This is very low compared to the cost of other airports because it has no terminal, which is the most expensive part of any commercial airport.

The largest capital expense is aircraft. Commercial airlines need to keep aircraft visually appealing for their company reputations, so they often purchase new aircraft and then retire them later. It is unnecessary to use new aircraft here. Boeing 777's in used condition are available for a price of \$30 M (Huber, 2022). Many planes are available for lower prices, but until they are acquired, there is much uncertainty about their cost. Modifications are roughly estimated as \$9 M per aircraft. Each aircraft will have to have a storage bin and a process for dispersing the material.

In addition, two spotter aircraft are specified. Radio balloons are the best means of getting atmospheric data at altitudes. However, weather balloons are typically released only twice a day. Two spotter planes could be used to monitor atmospheric conditions. Alternatively, a rigorous radio balloon program could be developed. Regardless, spotter craft can also be used for monitoring the effectiveness of calcite dispersal. Mid-sized prop planes cost about \$5 M each. The total cost of all aircraft plus modification is \$712 M.

An expected engineering fee of 6% is included. The total capital cost for the option with airplanes is \$970,9 M. This is much lower than the \$5.4 B cost of the alternative with towers. Table 1 shows the totals. Further details are in the supplementary materials.

Table 1. Capital costs for airplane option.	
Item	Cost
Property	\$10,000,000
Mill Machines	\$31,800,000
Conveyor	\$14,000,000
Mill Building	\$7,300,000
Silos	\$10,400,000
Electrical	\$10,000,000
Airport Development	\$122,400,000
Aircraft	\$712,000,000
Engineering	\$53,000,000
Total	\$970,900,000

The option for airships would require the manufacturing of new aircraft. Therefore, they would cost more than used airplanes. It is assumed that airships of this size will cost \$70 M each. More airships are required since they are slower. Less expense would be required for modification because they would be built custom. The other capital costs are the same since a new landing strip is still required. The highest costs of either option are the aircraft. The total capital cost for the option with airships is \$2.1 B. This is about three times the price compared to airplanes.

8.2. Operational Costs

The operational costs are minerals, parts, labor, and energy. Each item will be broken down by those categories. Electricity in Las Vegas in 2021 was \$0.14 per kWh unless time rate of use is considered, and then there are higher and lower times of the day (NV Energy, 2021). The totals are shown in Table 2.

Table 2. Operational costs for airplane option.	
Item	Cost
Limestone	\$20,900,000
Parts	\$72,200,000
Energy	\$222,000,000
Labor	\$71,500,000
Total	\$386,600,000

Bulk limestone purchases are considered an operational cost. Normally included in the cost of limestone is breaking down minerals into pieces 5 cm in size. Per year, the expected cost of purchasing limestone is \$20.9 M. Milling the particles has an energy cost of \$24.7.

Maintenance of machines is assumed to be 10% per year times the capital cost of those items. Milling machines require replenishment of worn milling balls and rods. The total cost of parts is assumed to be \$72.0 M per year. Of that, aircraft parts are 94% of the total.

Some energy allowances are included in the other costs. For example, the limestone cost is the normal cost as delivered, so quarrying, crushing, and transportation energy is included. Miscellaneous energy for other equipment is assumed to be \$0.5 M.

Jet fuel is the biggest part of the energy cost. It is expected that aircraft will climb to only 3 km on average, so they will use about 3% of their fuel tank for that climb. The airplanes will only fly about 200 km for each flight. The rate of fuel use is found by dividing their fuel capacity of 171,200 L by the range of 11,121 km. Air friction nonlinearly increases with flight speed, so it is much more economical to fly more slowly. This benefit is neglected. The aircraft should only use 8215 L or 5% of its fuel per flight, so the planes will not need to fill during the day. Per year, 147.4 M L of fuel will be used. Using \$6 per gallon, which is at the high end of prices (Welsh, 2022), the total fuel cost is \$194.8 M per year.

Labor consists of 408 employees. A crew of three pilots per airplane is planned. The Boeing 777 and similar craft often have two pilots. However, one pilot will have responsibility for dispersion of the calcite and keeping the aircraft cargo load balanced. One pilot could legally fly the plane, but the flying will be complicated, so two pilots are recommended. There will be 16 active crews. Pilots are limited in the number of hours that they can fly per day, per quarter, per two consecutive quarters, and per year (National Archives, 2023). Considering that flying will occur about 185 days per year, and it will occur between April and October, two crews are necessary per plane. The crew teams rotate on and off shift. The pilots would have little remaining allowed time that they could work for commercial carriers in the winter. Therefore, this is considered their full employment. Pilot salary depends on many factors. It is assumed to be \$150,000 per year plus 30% for benefits. Total pilot compensation is \$16.4 M per year.

The mills will be run continuously. Operating continuously means that fewer mills are required, but the total labor cost is about the same. Four shifts of 50 mill operators give 200 employees. An operator can handle up to 8 mills simultaneously if they are highly automated. It is assumed that they are automated, but it is planned that the operators can handle 4 mills. Other employees are 10 mill maintenance staff, 17 airplane mechanics, 32 ground crew, 3 engineers, 3 meteorologists, 3 spotter pilots, 3 shifts of control tower workers of 5 people per shift, 12 technical staff including flight planners, technologists and medics, 9 administrative personnel, and a crew of 10 for general maintenance and security. The total labor cost is \$71.5 M per year.

The total operational cost for the airplane option is expected to be \$386.6 M per year. This is more than the expected operational cost of the tower alternative. A significant difference is the increased energy cost due to jet fuel.

The operational net savings are the electric savings and health savings minus the operation cost. The savings is \$1.1 B per year with this plan. Since the capital cost is less than \$1 B, the capital expense is paid off in less than one year. Further details are in the supplementary materials.

The option for airships will use more labor, but less energy. Airships usually use about 20% of the energy as airplanes for the same payload, but this improves dramatically with short trips, slower air speeds, and with larger airships (Douardo, 2023). Since this airship will be record-breaking in size and travel relatively slow for short trips, it is expected it could use as little as 2% of the fuel of airplanes. However, 67% more crew are required for airships since they are slower. Many of the other operational costs are the same. The total expected operational cost for the airship option is \$179.3 M per year. This decreases the cost, and so it increases the operational savings per year. Even though there is a higher capital cost, the higher savings means the payback time is similar. The payback time is less than two years.

8.3. Energy

The analysis of energy focuses on the operational energy. The embodied energy from the capital expenses are insignificant in the long term compared to operational expenses.

Currently, Nevada uses carbon-intensive power generation to handle the peak loads from air-conditioning. Therefore, any decrease in air-conditioning use reduces production of greenhouse gases.

Some of the energy used in the operation of this project is direct energy expense, and some of the energy is hidden in materials such as energy to quarry limestone. Limestone quarrying uses 20.6 GWh per year (Hammond and Jones, 2008). The total electric use on site is expected to be 245.4 GWh per year. Milling is more than 98% of electric power use. Jet fuel is 147.4 ML per year for the airplane option, but airships would use 2% of that. Jet fuel produces 3.16 metric tons of carbon dioxide per metric ton of fuel.

The project will produce 311,300 metric tons of carbon dioxide per year for the airplane option. Considering that air-conditioning in Nevada is met through marginal power supplies which are carbon intensive, 4.4 M metric tons less is released for air-conditioning if this project is implemented. The net savings is 4.1 M metric tons.

In the future, if Nevada completely utilizes green power, then the economics for this project may change. Regardless of the fuel type for power generation, this project reduces health care expenses from heat stroke. Health savings alone are not enough to cover the continued operational costs of a system. However, there still will be costs for green power that can be saved. For example, a lower capacity of green power is needed when the peak loading from air-conditioning is reduced.

Jet fuel could be replaced with green alternatives. In that case, the motivation for the project is no longer based on reducing greenhouse gases but is still likely economic.

9. Conclusions

Distribution of calcite by aircraft is an economically feasible way to reduce air-conditioning in Las Vegas. In comparison to distribution by towers, despite needing to build a landing strip, the capital cost is much lower. The tower option required much property, 76 tall towers, and equipment at 76 sites. The labor cost is lower for aircraft because, rather than staffing 76 towers that could turn on with short notice, only one site is necessary for milling calcite. Several airplanes will need to be flown instead, but despite that, the total labor requirement is less. The energy cost is higher for the airplane option because of jet fuel for lifting calcite, but airships match the energy use of towers.

Overall, the option for aircraft has an exceptional payback time. The savings in electricity greatly outweigh the costs to run the system. The capital costs are less than one billion dollars, and they can be paid off with yearly net savings in air-conditioning expenses that exceed one billion dollars per year.

Using aircraft is much better for the scenic value of Las Vegas. Towers and conveyors encircling the city obstruct views of the desert. Airplanes are unnoticeable when more than a few km away. Airships may add to the scenic value.

Airships and airplanes are price competitive as far as payback time. In the long term, the higher savings from airships give them an advantage. However, the required airships are very large, so it is speculative whether they can be made that large.

It was economical to use calcite in the range of 3 to 5 microns. The number and capacity of aircraft is directly a function of the mass of calcite. Tripling the mass required for a size of 10 to 12 microns would triple the number of airplanes and fuel used.

The results show that the solution is cost-effective. However, optimization of all quantities may result in even more efficiency. The purpose was to show that dispersal using aircraft was possible, not to find the optimum scenario.

The contribution of this work shows that several improvements are obtained compared to the option with towers. The costs are lower with aircraft or zeppelins. Aircraft operate at higher altitudes so the potential air quality issues are reduced. Aircraft are more flexible than towers because they can quickly adjust to changing conditions.

It is necessary to have follow-up work about the health impacts of having fine particles in the air. The advantage of pairing fine particles with aircraft is that the particles are released high in the air, so they take a very long time to settle. The particles will disperse over a wide area of the desert. There is a tradeoff in health because people will benefit from lower rates of heat stroke.

Abbreviations:

The following abbreviations are used in this manuscript:

CDD Cooling Degree Days
AQI Air Quality Index
SHG Solar Heat Gain
UHI Urban heat island

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