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CONTROLLING GLOBAL WARMING USING TERRAFORMING METHODS A “Prime Mission” For Space?

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ABSTRACT

This paper examines the financial feasibility of using space based satellites to shade the earth to control global warming. By using iterative runs of standard global climate models from NASA figures for the amount of incoming solar radiation that must be blocked are estimated. A financial model based on weight of 2 mil aluminized mylar was made. This model showed that at current launch costs, controlling global warming would require expenditures greater than or equal to (on a yearly basis) the national budgets of the USA, Canada, Germany and France combined. Such costs indicate that this robust method of global warming control is not currently feasible if launched from the surface of the earth. However, it raises a very good question of whether a space based control system would be fiscally reasonable if the materials and construction were done with Mars, asteroid, or lunar material. No data is presented, but the author believes that Mars colony based manufacturing is highly likely to be the lowest cost method of control for our planet, and should be investigated.

KEYWORDS

Climate modeling, global warming, global warming control, global warming cost

INTRODUCTION

Thoughts that led to this paper began several years ago at the Mars Society conference 2002 in Boulder, Colorado. A presentation on “Mars Kites” (Poston 2002) was made, based on modeling work performed in the mid-1970s. Poston’s effort regarding Mars and Venus temperature regulation appears to be based on the prior work of Buckingham on satellite reflectors (Buckingham 1967). Poston presented a concept for bringing Mars and Venus to Earth normal mean temperature over 100 years. A claim was made during this presentation that this was relatively low cost, perhaps a few hundred million to accomplish for either planet.

The first reference found for the idea of using satellites to modify the weather comes from Debra Udell (Udell 1980). Her concept is complete with probes and monitoring. This was further developed by Franklin Chen (Chen 1998) into a complex system making use of the ideas of Udell though much of it may have been redeveloped independently. Some amount of work has been done by others in this general area of space mirror satellites, (Wood 1995-2005; Sylvan 2002; Sistach 2003). The major public references are patents related to the area, starting with Buckingham, though Buckingham apparently

never envisioned his work in the context of control of global warming. (Buckingham 1967; Tagirov 2002) There is also work related to solar energy production (Davis 1977; Keigler 1981; Stern and Cornwall 1991) which makes use of reflector satellites.

In the context of current political climate, the author travels quite a bit to parts of the developing world. As a result of that, the author believes it is utterly unrealistic to believe that the world is going to get together and cut CO₂ and other greenhouse gas production in any significant way. Everyone wants a good life, and they will do what they must to get it. The masses in China are not going to go without in order to avoid burning their coal. Indians are not going to cut their standard of living just because some Greens in Europe want them to. Russia stands to gain from global warming. The Kyoto accords, even if fulfilled, would not slow global warming significantly. This gave an impetus to study how to deal with global warming control methods which could work without cutting greenhouse gases.

When the NASA global climate modeler (Shopsin, Chandler et al. 1999-2005) was made available to the public, this work was started. Prior to this work, others have made predictions based on arithmetic calculations (Sylvan 2002). A layman's review discussion was made in Popular Science magazine (Behar 2005) this year of various proposals for global warming control.

- Cut CO₂ emissions so warming stops/reverses
- Sequester CO₂ gas
- Plant and ocean life fertilization
- Increase albedo (cloud cover)
- Satellite shading

At the beginning, this paper was simply going to be an investigation of how much it would cost to execute a satellite based system. While the Poston model (Poston 2002) believed that a Mars or Venus temperature control system would have a quite reasonable cost, this was not supported with any hard numbers. If he was correct, then since an earth based system would have far less modification to do than either Mars or Venus, there was the possibility that an earth based system would be so trivial as to be an obvious choice. After creating a financial model with real world numbers, the astronomically high cost almost resulted in scratching any publication entirely since the cost was so obviously impossible. However, on reflection, the results brought up the question of how much it would cost to use this method of LEO satellites if the manufacturing were done off planet. This presents the likely scenario that a Mars manufacturing colony is the justification for going to Mars that is needed.

MODELS AND METHODS

Satellite concept

The system schematic in Fig.1, which is not drawn to scale in any sense, illustrates an error that has been made more than once for satellite blocking of sunlight. In the Poston model, it was assumed that the sun is a point source of light due to its distance. However,

this is incorrect due to the large size of the sun. There is an approximate 5 hundredths of a degree negative angle which astronomers are familiar with that causes the shadow of the moon during an eclipse to have an inverted truncated conical center section. This changes the calculations for the Poston model a great deal since that model's error caused results to improve significantly the farther from the planet's surface a satellite was located, whereas in reality such satellites become less and less effective.

Satellite Location in Low Earth Orbit

Because there is a negative angle, the amount of sunlight shading drops the farther an orbiting shade is from the earth. In addition, any space based system shading should account for the possibility of a radical loss of technology here on earth. LEO satellites will eventually decay and burn up in the atmosphere. We don't want to unintentionally create a frozen earth that lasted for 5 million years. That is what would happen if we placed our satellites in an orbit where they would be stable for a very long time and some calamitous war or other event occurred that set back civilization for a thousand years. This last is a flaw in the design of Lowell Wood (Wood 1995-2005; Behar 2005) of Lawrence Livermore Laboratory.

Use of the Global Climate Modeler

The NASA Global Climate Modeler (Shopsin, Chandler et al. 1999-2005) standard model was used as the basis for all experimental runs (see Fig. 2). The GCM allows for introduction of two separate time periods of years when received solar energy in watts/meter² can be modified. The standard model was copied and modified to account for solar decrease.

A set of five separate runs were made for the modeler, as shown in Fig. 3. Each run took about 3 days to complete on a 3.2 GHz Intel computer with 1 GB of RAM. One side effect of these runs is that the computer overheated, causing a fault in the arithmetic unit, and so the computer had to be replaced. Several runs were abandoned before completion when it became clear that the trend line was diving down too fast and so would not be acceptable.

GCM Runs

1. Subtracted 2 watt per m² per year during 5 years, 2015-2020 and maintains at 2020 level afterward. (0.146% decline per year for 5 years.)
2. Subtracted 1 watt per m² per year during 30 years, 2015-2045 and maintains at 2045 level afterward. (0.0732% decline per year for 30 years.)
3. Subtracted 0.5 watt per m² per year during 30 years, 2015-2045 and maintains at 2045 level afterward. (0.0366% decline per year for 30 years.)
4. Cuts solar influx during 5 years by 1 watt per per square meter years 2015-2020. Then starts up again in 2025 to cut by .01 watts per square meter until 2100. (Mixed 0.0732% & 0.000732%)

5. Cuts solar influx during 5 years by 1 watt per per square meter years 2015-2020. Then starts up again in 2025 to cut by .02 watts per square meter until 2100. (Mixed 0.0732% & 0.00146%)
- 6.

Financial Model

For the financial model, the basic assumptions were that one kilogram cost of launch to LEO ranges from current \$44,000 - \$22,000 to a low of \$22 per kilogram. Cost of material has a high of \$5MM per km² and a low of \$500K per km². It should be pointed out, however, that the commonly accepted numbers for USA versus Russian space launch cost per kilogram are not likely terribly accurate. A more realistic total cost analysis I did for a single mission gives real total cost for the USA at around \$175,000 per kilogram using the space shuttle.

This model assumes that cost of the program is spread over 30 years, even though the total number of elapsed years is 70. This was done because there were 30 active launch years in the scenarios modeled using GCM, and because the model becomes more complicated if amortized over 70 – 80 years due to interest cost and varying assumptions for how much borrowing would occur. This was also done to avoid underestimation which tends to be a weakness of space enthusiasts.

For each entry the financial model uses the the numbers in Table 1 which can be calculated. The earth is modeled as a flat disc, which is not entirely accurate, but accurate enough for this order of magnitude financial model. The number of watts per square meter is a value taken from solar radiation readings. The result gives the area required to block one watt over the entire earth. From that can be calculated the values for the model used in run number 5

Yearly program expense at current launch costs

In Fig. 4 using currently accepted nominal values for launch cost, we see a low of between \$4.5 and \$5 trillion per year during years program is active with a high of between \$9 and \$9.5 trillion per year. The low value is based on using Russian launch capability. Again, note that if current actual cost of \$175,000 per kilogram is used, the high numbers are multiplied by a factor of roughly 4X. That would give a real top end cost of roughly \$40 trillion per year. In Fig. 5 we can see the effect on the program of lowering launch cost only. In Fig. 6 we can see a program that could be plausibly supported when the cost of launch is \$220 per kilogram or less, and satellite costs are \$500 K or less per km².

EVALUATION AND CAVEATS

The experimental runs of the NASA GCM indicated that global warming control was completely feasible. It also indicated that it was easy to overshoot one's target temperature by putting up too much shading. A real world system would need very careful modeling and monitoring. Any system design would need to be able to quickly

remove satellites from orbit should that become necessary. While this should be obvious, it is not discussed in most proposals.

The figures developed in this paper are fairly simple estimates. They should not be taken as hard and fast numbers. The author does not believe that they are accurate to better than a factor of 2. That means that if a low number says \$4.5 trillion, the real cost is just as likely to be either \$2.25 trillion per year or \$9 trillion per year. However, a factor of 5 inaccuracy is probably the upper bound, meaning it is unlikely that the cost per year at today's launch costs would be more than \$225 trillion per year. So these figures should be used as a "ballpark" guideline.

In today's dollars, the USA could support a long term program which cost between \$20 and \$40 billion per year because that is within the current range of NASA's budget. The world as a whole could be reasonably believed capable of supporting a program that cost between \$100 billion and \$500 billion per year. Those costs may well be tiny compared to the cost of losing huge amounts of arable coastal land and port cities, or the cost of desertification attributable to a global warming scenario. However, political realities being what they are, it is unrealistic to presume that nations are capable of spending anywhere close to the real cost of a future loss. Consequently, at current and currently foreseeable launch cost, even the \$4.5 trillion per year lowest feasible cost is not very likely to happen.

We also see that it is not until we get launch costs between approximately \$220 per kilogram to \$22 per kilogram (\$100 to \$10 per pound) that cost of such a program comes into view as a reasonable probability. However, those launch costs are, at this point, pure pie-in-the-sky (no pun intended.) There is no believable way for us to get to that launch cost. There are highly questionable proposals, such as the space elevator (Edwards 2005) and "Lightcraft" (Myrabo 2001) which both require lasers that don't exist yet. Perhaps a rail launcher could, but I have not seen numbers I consider believable for one. If such proposals get built and proven, then perhaps we could. But in a context where even \$44,000 per kilogram is in fact a fake number that leaves out ancillary costs, accepting such a proposal as fact is not reasonable.

Questions Raised About Global Warming Control By Satellite

1. While the GCM is probably a pretty good model for the effect of lowering solar radiation on the earth, a satellite based system is not going to block sunlight equally across the earth. The equatorial belt is the obvious best price-performance location for such shades. What is the likely effect on the Earth's weather of unequal blocking of sunlight? This question requires some relatively straightforward changes to the GCM to test. However, those changes can only be made by programmers familiar with the source code.
2. Similarly, for efficiency reasons, the lowest square kilometers of satellites are going to be in rough equatorial orbits. How will that affect earth weather? This is a specific case of the above question.

3. What effect is likely on plant life? Given that this would be happening in the context of significant rises in CO₂ in the atmosphere, and given that most of the blocking would occur at tropical latitudes, which are not the major farming regions of the world, it is unlikely that this would be a problem for agriculture. It is clear that lower levels of sunlight don't cause problems in northern and temperate regions. What is far more significant is the number of hours of sunlight. (Behar 2005)
4. Given that plants fix a great deal of CO₂, it may be worth modeling the effect of using reflector satellites which reflect only in the center of the green portion of the spectrum, to illuminate the night side of the Earth to greatly extend growing cycles daily. It might be possible that such an effort could result in control of CO₂, and hence global warming, with far fewer satellites.

CONCLUSIONS AND A CHALLENGE FOR THE FUTURE

The concept of reducing global warming by satellite control is viable, this is certain. Exactly how many square kilometers of satellites is necessary is subject to debate, but this study using NASA's Global Climate Modeler would tend to indicate that it is on the order of 100,000 km² though this rises the farther they are from the earth, and with the degree of blocking they provide. There is little reason to believe that a satellite based system launched from earth is financially feasible. However, a satellite system built somewhere else besides the earth could possibly be feasible.

It is the author's opinion, based on "back of the envelope" guesses, that it would be much less expensive in a high launch cost environment to build global warming control satellites on Mars, perhaps the moon, and perhaps using asteroid materials. Manufacturing materials in situ, using Mars as a base of operations, could well be the primary mission for space in the 21st century. I would like to propose a challenge to engineer such a manufacturing mission in a similar way to "The Case for Mars". If all the pieces and processes can be nailed down, costs can be compared.

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FIGURES

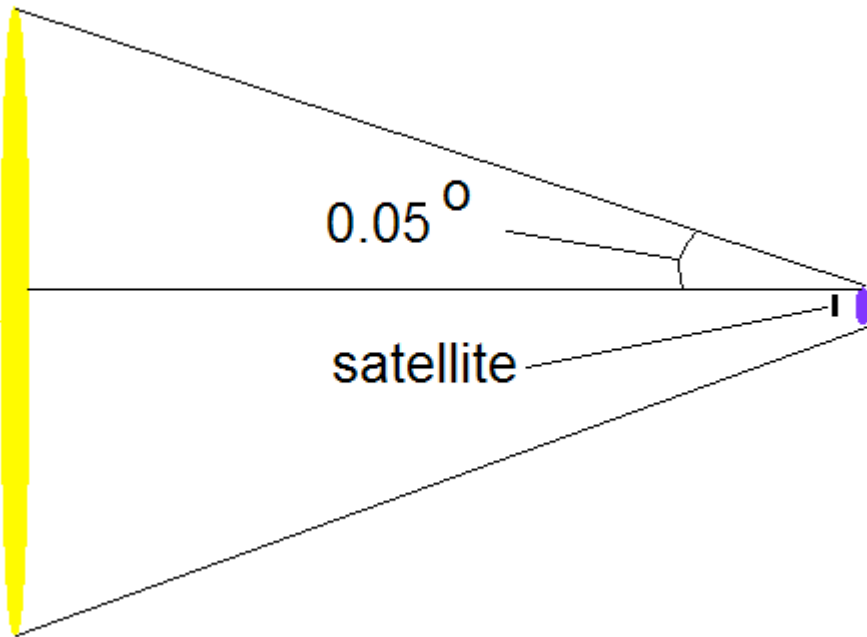


Figure 1 – System schematic

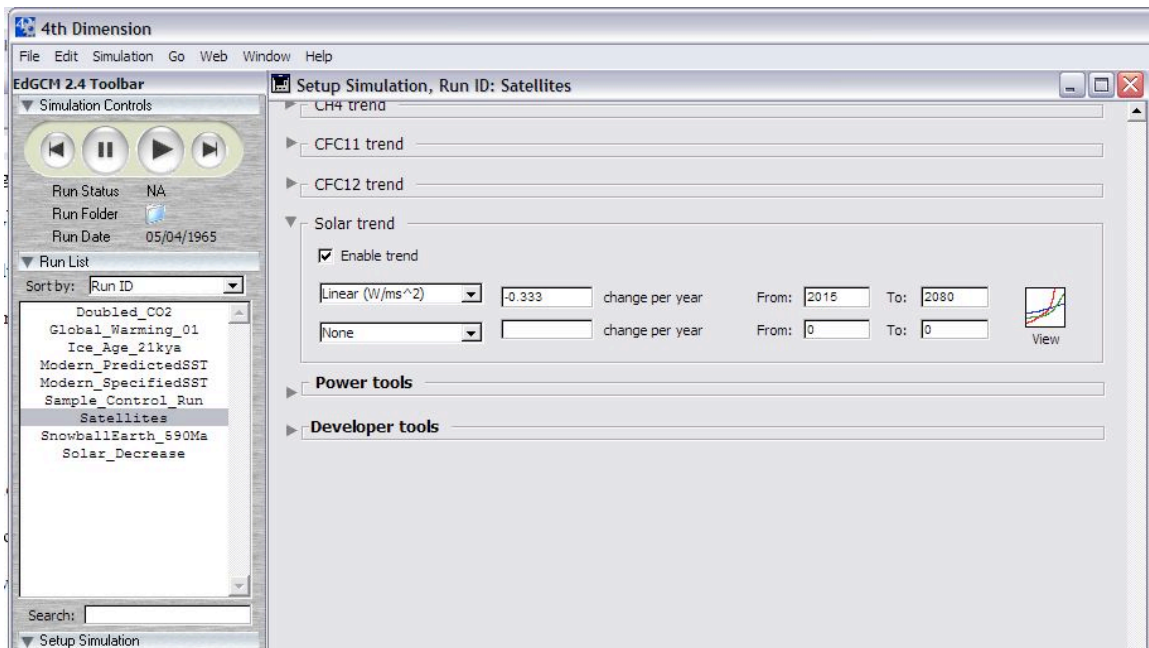


Figure 2 – Global Climate Modeler – Solar Trend Example

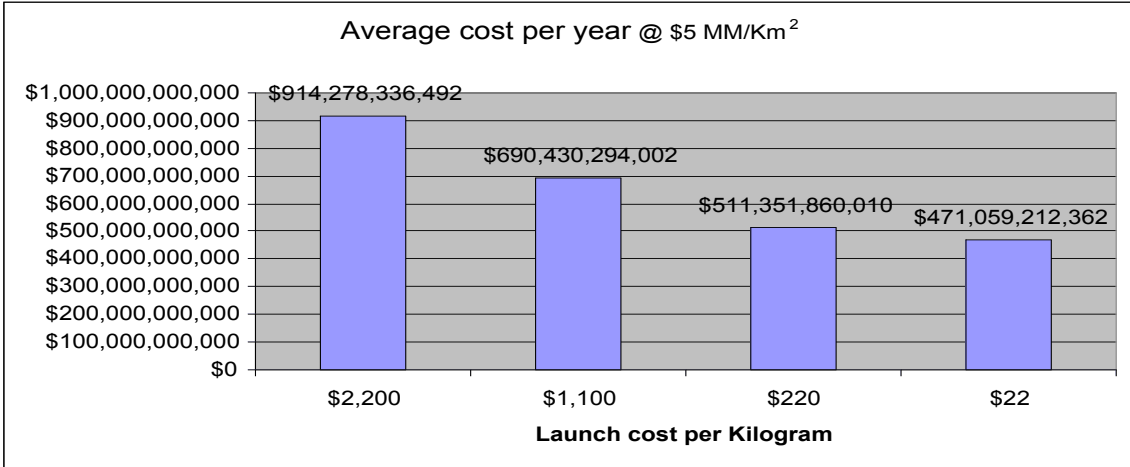


Figure 5 – Varying cost of launch with a \$5 million per km² satellite cost

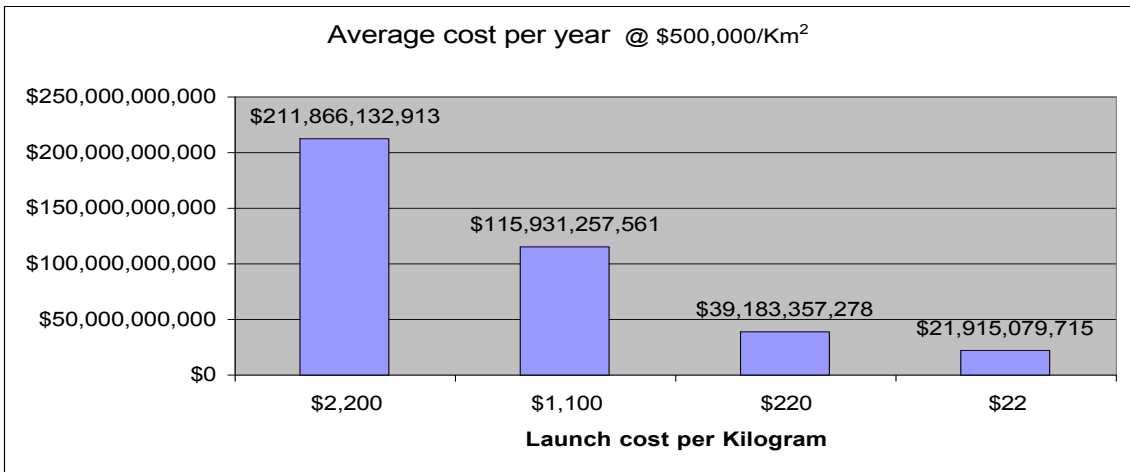


Figure 6 – Varying cost of launch with \$500 K per km² satellite cost

TABLES

| Mean Radius of the earth km | Area of earth circle intercept km² | Watts per meter² insolation | Area to block 1 watt insolation meter² | Total area intercept to block 1 watt per meter² for entire earth. (1 earthwatt) km² |
|------------------------------------|--|---|--|--|
| 6,371.30000 | 127,528,127.31227 | 1,366.62 | 0.00073 | 93316.45 |

Table 1 – Fixed numbers defining basic quantities

| Cost of Aluminized mylar per square km | Mylar cost per earthwatt cut | kg per square km | Launch cost per kilogram | (Launch cost per pound.) | Launch cost per earthwatt cut | Total cost per earthwatt cut | Earthwatts over 70 years, of which 30 are active | Cost of all launches | Average cost per year |
|--|--|------------------|--------------------------|--------------------------|---|---|--|--|---|
| 5,000,000 | \$466,582,251,512 \$467 billion | 2,180.73 | \$44,000 | \$20,000 | \$8,953,921,699,600 \$9 trillion | \$9,420,503,951,112 \$9.5 trillion | 30 | \$282,615,118,533,354 280 trillion | \$4,037,358,836,112 4 trillion |
| 5,000,000 | \$466,582,251,512 | 2,180.73 | \$22,000 | \$10,000 | \$4,476,960,849,800 \$4.5 trillion | \$4,943,543,101,312 \$5 trillion | 30 | \$148,306,293,039,357 \$148 trillion | \$2,118,661,329,112 \$2 trillion |
| 500,000 | \$46,658,225,151 | 2,180.73 | \$44,000 | \$20,000 | \$8,953,921,699,600 | \$9,000,579,924,751 | 30 | \$270,017,397,742,530 | \$3,857,391,396,312 \$4 trillion |
| 500,000 | \$46,658,225,151 | 2,180.73 | \$22,000 | \$10,000 | \$4,476,960,849,800 | \$4,523,619,074,951 | 30 | \$135,708,572,248,533 | \$1,938,693,889,212 \$2 trillion |
| 5,000,000 | \$466,582,251,512 | 2,180.73 | \$2,200 | \$1,000 | \$447,696,084,980 | \$914,278,336,492 | 30 | \$27,428,350,094,760 | \$391,833,572,712 |
| 5,000,000 | \$466,582,251,512 | 2,180.73 | \$1,100 | \$500 | \$223,848,042,490 | \$690,430,294,002 | 30 | \$20,712,908,820,060 | \$295,898,697,412 |
| 5,000,000 | \$466,582,251,512 | 2,180.73 | \$220 | \$100 | \$44,769,608,498 | \$511,351,860,010 | 30 | \$15,340,555,800,300 | \$219,150,797,112 |
| 5,000,000 | \$466,582,251,512 | 2,180.73 | \$22 | \$10 | \$4,476,960,850 | \$471,059,212,362 | 30 | \$14,131,776,370,854 \$15 trillion | \$201,882,519,512 \$200 billion |
| 500,000 | \$46,658,225,151 | 2,180.73 | \$2,200 | \$1,000 | \$447,696,084,980 | \$494,354,310,131 | 30 | \$14,830,629,303,936 | \$211,866,132,912 |

| | | | | | | | | | |
|---------|-------------------------|----------|---------|-------|--------------------------|-------------------|----|---------------------|-------------------|
| 500,000 | \$46,658,225,151 | 2,180.73 | \$1,100 | \$500 | \$223,848,042,490 | \$270,506,267,641 | 30 | \$8,115,188,029,236 | \$115,931,257,500 |
| 500,000 | \$46,658,225,151 | 2,180.73 | \$220 | \$100 | \$44,769,608,498 | \$91,427,833,649 | 30 | \$2,742,835,009,476 | \$39,183,357,200 |
| 500,000 | \$46,658,225,151 | 2,180.73 | \$22 | \$10 | \$4,476,960,850 | \$51,135,186,001 | 30 | \$1,534,055,580,030 | \$21,915,079,700 |
| | | | | | | | | \$1.5 trillion | \$22 billion |

Table 2 Calculations of Alternatives