Reviewer 2 does Geoengineering Podcast Program Outline
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Outline: Solar Geoengineering Modeling and Applications for Mitigating Global Warming: Assessing Key Parameters and the Urban Heat Island Influence

I. **My Background:** PhD Physics from Northeastern Univ. I have worked in industry for 35 year is the area of physics of failure and wrote the only book on thermodynamic degradation science.
In 2019 I semi-retired and decided to learn climatology. I wanted to understand the issues. Often people in other disciplines can make contributions in related areas. My first interest was in the UHI controversy – was urbanization causing any significant global warming. This got me into solar geoengineering albedo modeling and UHI amplification effects.

II. My view of Solar Geoengineering (SG) and objective of this paper
I think of SG as the engineering fundamental equations that help us detail what has to be done for SRM. So my interests is in physics based modeling. I am not an expert in SRM implementation – so it is not my area of expertise.

My main goal in this paper was to provide the geoengineering equations for SRM. Provide better estimates and in this paper compared to the literature, the results show marked improvements in SRM area requirements which we can discuss why my numbers are much lower than compared to literature values

III. Overview of Paper findings

1) Goal: Provide SG area modification requirements for a reversal of the global warming (GW) of about a 1C rise (1950-2019)

$$\Delta P_{\mathrm{Rev}} = -\Delta P_T (1+f)\, A_F \qquad \Delta P_T = \frac{2.38 W/m^2}{(1+f)} = 1.47 Wm^{-2}$$

$$\Delta P_T = -\frac{S_o}{4}\frac{A_T}{A_E} X_C \mathrm{H}_T \left[(\alpha_T' - \alpha_T)\right]$$

Although the equations can apply to any period of time, in this paper I focused on estimates to reverse the global warming that occurred from 1950 to 2019 which is about a 1oC rise. So the first goal is to provide area requirements for a 1oC reversal. Because of my background in UHI, In the equations, I also provided for a land heat amplification term which is applicable to UHI areas as well as natural hot spot regions.

2) Improvements from literature:
   a. **Dessert Modification** : In 2004 Gaskill et al. proposed that one could apply reflective polyethylene-aluminum surface treatment to desert areas to increase their reflectivity by 44%. Deserts he thought would be good areas since they are not very utilized, are relatively flat, have high irradiance (high sunlight percentage per day). Of course they would be hard to maintain.
   Gaskill et al. proposed to increase the mean desert albedo from 0.36 to 0.8, and estimated a significant reverse forcing of $-2.75\ Wm^{-2}$. This would require an area of 2% of the earth. Deserts cover about 33% of the earth. With this 2% treatment he estimated a reverse forcing of 2.75Wm-2. This is close the estimated forcing caused by man. IPCC AR6 WG I Report (2021), the effective radiative forcing is only 2.72 Wm-2 (Page 91 of the Technical Summary) for the much longer 1750-2019 period. Estimate for 1950-2019 is 2.38Wm-2. So Gaskell was in the ball park in 2004.
      i. In this paper the comparative results only needed 1.5Wm-2 which reduced the area requirements to about 1%

Space Mirrors-Shading In the area of space mirrors, there have been a number of estimates for mirror sizes ranging from the size of 2xIndia to the size of Texas. I provided comparisons to a 2015 paper by Sanchez and McInnes. Their goal was a reversal of 5.8Wm-2 which would equate to a reversal of about 1.08C. My goal was a reversal of 1^{o}C and for this goal. I only required a reversal of 1.5Wm-2. So my goal in energy units was a saving of over 3 from their requirement. This alone leads to an shading saving of a factor of 3 in area.

Sanchez Shaded L1 (optimal distance from the Earth 2.44x10^{6} km)

	Sanchez 2015	**My paper**	**Wikepedia 2001 Lowel Wood**	**Savings**
Goal	5.8Wm-2	**1.47Wm-2**	**NA**	**4**
Temperature Goal	_-1.08C	-0.95C		
Disc Area	6.4E6 km2 2.6E6 km2 (3.3E6 km2 India, that is 0.65% of earth shade would be 3-4.5% on earth – very large estimate)	1.33E5 km2 (~1/2 size of England)	(1.6e6km2) 1% sunlight (1/2 size of India)	~48 (12)
Disc Radius	1434km radius Disc	205 km	714 km	~7
Earth Radius	6000-8000 km	1000km		~7

IV) My numbers in general are about a factor of 3 better in area with the exception of space mirrors which appear to be much larger improvement compared to the literature results.

V) Why are my numbers better than the literature – what are the differences?
Go through how the numbers work out and the albedo advantage in SG

- First one has to establish a goal. In this paper I used 1C rise from 1950 to 2019
- We can convert this to energy per unit area units using the Stephan Boltzmann Equation you get 5Wm-2
- What does this mean. It is like having a 5watt lightbulb on every square meter of the earth which increase global warming by 1C
- So it appears often Solar geo-engineers stop here and they use this as their goal but this goal is too high WHY?
- What makes up the 5Wm-2?
- About half is due to feedback which is dominated by water vapor
- How does that work – when you heat the air, air expands so you can fit more water vapor into the air before it reaches saturation causing mainly rain
- So warm air hold more water vapor
- Well if we cool the air – cooler air hold less so if water vapor.
- So if feedback is a doubling effect we only need to do half as much work/time/area and assume that feedback will reverse - so now we go from about 5Wm-2 to 2.5Wm-2
- Now notice this 2.5Wm-2 is a key goal for the carbon removal people but not for the solar geoengineering …Why
- In SG we can reduce the 2.5Wm-2 to about 1.5Wm-2 by taking advantage of the fact that when we cool a hot spot we also reduce its re-radiation effect. This is 62% reduction.
- This is our final reversal goal to reduce a 1C global warming increase that occurred from 1950 to about 2020
- Note the solar geoengineering albedo advantage. The Solar engineer only has to do 1.5Wm-2 of work/time/area compared to the carbon removal engineer who requires a larger reversal of 2.5Wm-2. That's a 1Wm-2 out of 2.5Wm-2 advantage or 40% less work per time per area. I called this in one of my papers, the albedo advantage in GW mitigation.
- Thus is about a factor of 3 reduction from 5wm-2 to 1.5Wm-2

VI) SG still has sizable area modification issues both in space and the earth – we are trying to solve a 3-D volume problem with a 2-D surface solution and this ends up with large modification requirement of areas. On the Desert treatment we found that we needed about 1% for earth brightening

VII) How can we improve feasibility?
My preprint on ResearchGate: **Solar Geoengineering to Stop Annual Global Warming**

a. Goal is a reversal of 0.02°C per year

My Results

	Annual SG	**SG**	**Feasibility factor**
Goal	-0.02°C/Year	-1°C	50
Energy Units	0.03Wm-2/year	1.47Wm-2	50
Space Disc Area	640 km2 (207 factor lower)	1.33E5 km2	207
Space Disc Radius	14.3km (Factor of 14.4 lower)	205 km	14.3
Desert Area	1E5 km2	5.44E6 Km2	50
Desert Radius	150 km	1316 km	9

1) <u>Use of the SG Equation to estimate the Urbanization Warming effect</u>

a. Why do we care about SG of urbanization

- 55% of the world's population live in cities, 75% of our energy is consumed in cities and 80% of CO2 originates from cities.
- Additionally, humid cities have exasperated heat waves issue causing health issues
- SG of urbanization we would anticipate would have minimal governance issues say compare with sun diming with reflective particles.

b. Recent literature findings on urbanization warming:

i. Zhang et al. (2021) "The magnitude of the urbanization effect on global land averaged annual mean surface air temperature change over 1951–2018 in this study is 0.038°C decade^{-1} and the corresponding urbanization contribution is 12.7%, which is larger than the results reported by the IPCC Fifth Assessment Report (of 10% in Hartmann et al., 2013)."

c. Findings in this paper using the SG equations also are able to estimate this urbanization effect and support these results finding a GW effect between 7%-13%.

d. Urbanization only occupies about 0.25% of the earth. How is this possible?

e. UHI have what is called a footprint which is the increase area larger than the city itself where heat extends beyond the city limits. The average footprint is about 3x the city area. This means that UHIs amplifying heat. This amplification is reason that the small area can increase the UHI global warming problem and contribute about 13% to the global warming.

f. What about black Roads and roofs. This paper also finds that 1 acre of asphalt road or roof tops on average creates 2.5GWh of heat per year. This is about 7.5 times more energy than a solar power plant produces per acre per year. It also equates to the energy of burning 75000 gallons of gasoline per acre per year.

2) Major Advantages of SG versus Carbon Removal

- 38% less reversal of Wm-2 Work/area/time due to the albedo-GHG factor
- Something we can all do – go outside and paint our driveway and roof white, buy a white car
- Less legislation – less problems with governance – no issue with the oil industry –
- Earth brightening should be welcomed in hot cities
- No arguments from CO2 Nay Sayers

- Maybe more immediate results due to water vapor sharing GHG re-radiation

3) Negative Solar Geoengineering is currently the norm: Urbanization for most areas has disregarded and chosen to paint the earth black with the use of black asphalt of roads and roofs and even cars. The average land albedo is about 25% reflectivity. Most roads are about 5-12% reflective and UHI are below 15% reflective. Unfortunately much has to change in order to implement earth brightening. The world seems to understand carbon removal, and have not idea that solar heating of a black road or even turning on your oven is also contributing to global warming. How can we do earth brightening when most of the world is paining the earth black?

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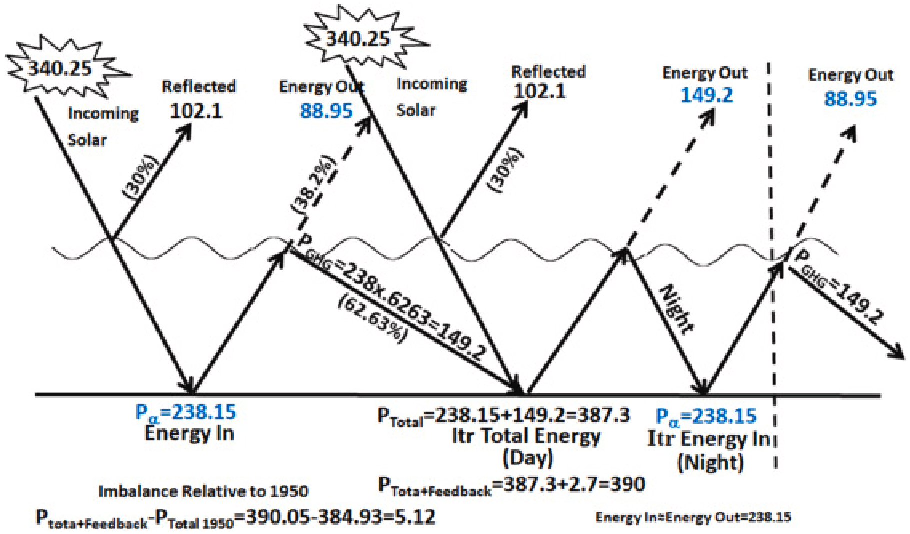

Year	T_S (K)	T_α (K)	$\tilde{f}_{2019}$ / $\tilde{f}_{1950}$	α'_{2019} / α_{1950}	P_α Energy In W/m^2	$P_{GHG'}$ / P_{GHG}	P_{Total} W/m^2
2019	287.48	254.57	0.6263*	30.0065	238.153	149.155	387.308
1950	287.04	254.51	0.6180	30.08	237.903	147.024	384.927
Δ2019–1950	0.44	0.067	0.0083*	(0.244%)	0.25*	2.13	2.38
Δ2019–1950 A_F = 2.15	0.95	0.144	–	–	0.54	4.58	5.12
Total with Feedback	287.99	254.65	–	–	–	–	390.05

$$P_{GHG'\_2019} = P_{GHG\_1950} + \Delta P_{GHG'} = 147.024\ W/m^2 + 2.13\ W/m^2 = 149.15\ W/m^2$$

With the small change in albedo, relative to 1950 the increase to $P_{\alpha'}$ is then,

$$P_{\alpha'} = P_\alpha + \Delta P_{\alpha'} = 237.9W/m^2 + 0.25W/m^2 = 238.15\ W/m^2$$