On Implementing an Albedo Solution with UHI Global Warming and Cooling Estimates

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Abstract

Solar geoengineering is vital in global warming as results can reverse trends and reduce the probability of a tipping point from occurring. As well, the pace and depth of implementing the GHG solution is tenuous. It is of interest in this paper to focus on the implementation of a surface solar geoengineering solution to global warming. It is reasonable to anticipate that an albedo solution is practical. However, research in this area seems stagnant and implementing even urban heat island (UHI) cool roofs on a unified worldwide global level has not gone forward. In particular, in this paper we provide some basic modeling and insights into "Earthly components" that one could focus on to increase opportunity for reducing climate change. Modeling illustrates that by solar geoengineering selecting hotspots, the effective area could be roughly 13 times smaller than a nominal non-hotspot areas in influencing global warming.

1.0 Introduction

When we talk about climate change solutions, in the race against time, it is advantageous to look at the practical aspects of implementing an albedo solution. In view of the slow progress that is being reported in terms of greenhouse gas reduction, and the continual increase in the Earth's average yearly temperature, it is important to revisit the alternate albedo solution. Unlike geoengineering solutions, GHGs mitigation is highly difficult to result in reversing climate change, especially with reports on large deforestation occurring [1]. Furthermore, it takes about 30 years to reduce 50% of any increase; and reducing GHG emissions then amounts to slowing the current warming trend. Lastly, a solar absorption solution now appears to be the only way to stop the potential tipping point, which has likely not occurred to date [2].

In this paper, implementation is discussed on geoengineering an albedo surface solution based on results from a companion paper [3]. There have been a number of geoengineering solutions proposed [4-6]. These may be considered either atmospheric of surface based solutions. In this study, we focusing on target surface regions. We treat absorption and re-radiation as part of one process. That is prior to greenhouse gas reemission, short wavelength absorption first occurs. This initial absorption followed by radiation is partially reradiated back to Earth by GHGs. In this application, we view this as part of the albedo effect in our assessment.

Furthermore, not all absorptions areas on the Earth are equal. In this work we will look at the following types of target areas having:

- high solar irradiance
- large heat capacities
- low albedo
- ability to amplify nature's albedo

To clarify the last factor, we infer that cooling down certain areas, may prompt natural compounding albedo changes to occur such as increases in snow fall and ice formations.

In terms of short wavelength absorption, these factors are likely the most important. The leading factor is the albedo itself, it is possible to mitigate, since it's a surface effect. Each factor amplifies solar radiation absorption compared to a nominal land area. Although the task is highly challenging, it is easier to do geoengineering of surface reflectivity compared with building cities. Furthermore, results here provide help in the area of UHIs and similar components of the Earth. Therefore, one key strategy is to study Solar Amplified Areas (SAA) relative to Nominal Land Albedo (NLA) areas (30% albedo) and determine if it is possible to make a significant impact on global warming. The goal is to change a SAA to one with a target albedo surface (TAS).

2.0 Data and Methods

In our initial paper on geoengineering the albedo solution to global warming [3], we identified key parameters and simple expressions for geoengineering the required percentage of area $\%\Delta\alpha$ needed to provide an adequate solution.

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The simplified expressions (also see Appendix A and B) and estimates for a 1.5% area are

$$\Delta P_{\text{Rev\_}S} = -\lambda_{\%\Delta\alpha\Delta T}\ \ \%\Delta\alpha\ (1+f)\ A_R = \Delta P_T\ (1+f)\ A_R = -4.8W/m^2 \tag{1}$$

and $\beta^4 \Delta P_{\text{Rev S}} = \Delta P_{\text{Rev OLWR}} = -2.97\text{W/m}^2$ [3] so that

$$\Delta T_{\text{Rev}} = -\frac{2.97\text{W/m}^2}{\lambda_o} = -0.89°K \tag{2}$$

Here we define

ΔP_{Rev} is the reverse power per unit area change
$\lambda_{\%\Delta\alpha\Delta T}$ = albedo-plank parameter, 1Watt/m^2/%ΔAlbedo [3] (also see Appendix C)
%Δα is the percent change in the global albedo, we are using 1.5%
f= the re-radiation parameter about 0.63 [3] (also see Appendix A)
A_R is an estimate of the anticipated GW amplification reduction, about 2
$\Delta P_T = \lambda_{\%\Delta\alpha\Delta T}\ \ \%\Delta\alpha$ is the reverse forcing change from the target area, with values listed it is 1.5W/m^2
λ_o is the Planck parameter about 3.3 W/m^2/°K
$\Delta P_{\text{Rev OLWR}}$=-2.97W/m^2 is the change in the outgoing longwave radiation

If we take the increase warming trend at the end of 2019 as 0.95°K, then this is about a 93% correction. In solar geoengineering, anticipating an allowance for the climate system to equilibrate [7] may be unnecessary, since the lagged transient climate response is anticipated to be similar. That is, a positive or negative albedo change is likely not to have a strong hysteresis effect.

Note that the 1+f factor accounts for one process of initial absorption change ΔP_T followed by subsequent partial re-radiation by GHGs. This is described in detail in our companion paper [3]. These values help to provide a rough goal that we use in this paper to exemplify this solution.

2.1 Albedo Modeling

We can write the short wavelength solar absorption as

$$P = \frac{Q}{A} = \frac{S_N}{4}\sum_i \frac{A_i'}{A}(1-\alpha_i) + \frac{S_N}{4}\text{H}_{T-N}\frac{A_T'}{A}(1-\alpha_T) + \frac{S_N}{4}\frac{A_C}{A}(1-\alpha_C) \tag{3}$$

Here A_i is the i^{th} effective area having an albedo α_i, S_N=1361W/m^2 and A is the surface area of the Earth and A_C is effective area cloud coverage. We consider a change to a hotspot target effective area A_T with albedo α_T. In addition, because we select a particularly problematic solar absorbing target area compared to a nominal area (N), it has sensible hotspot heat storage potential $H_{T\text{-}N}$, due to related heat capacity a function of the heat capacity, mass, temperature storage, and solar irradiance. Essentially this has the effect of amplifying the area size. The hotspot de-amplification potential is described and enumerated in Appendix C.

Here the effective surface areas are given by

$$Effective\ SurfaceArea = Surface\ Area\ x\ \%Solar\ Irradiance. \tag{4}$$

We note that the Earth Albedo change is just a function of the target area variation, that is

$$\left(d\alpha_T\right)_\alpha = \sum\left(d(Albedo_T)x\%Solar\ Irradiance\ x\ SurfaceArea\right)_i, \tag{5}$$

where the subscript α indicates all other Earth albedo components are held constant. Note that in looking at changes, only the target irradiance will be part of the change and this will be factored into H.

The overall equation prior to changing the albedo is subject to the constraints

$$P = 240W/m^2 \ \ and\ \ A = \sum_i A_i' + A_T' + A_C = A_E' + A_C \ \ but\ \ A_E' = (1-\%A_C)xA_E = 0.33A_E \tag{6}$$

This indicates that because of cloud coverage area A_C, about 67% actual area of the Earth is blocked from the sun. This is likely conservative as clouds do let some sunlight through. However, that leaves 33% of the Earth available for solar radiation absorption.

We now alter the albedo of a SSA target area so that

$$P' = \frac{Q'}{A} = \frac{S_N}{4}\sum_i \frac{0.33A_i}{A}(1-\alpha_i) + \frac{S_N}{4}\frac{0.33A_T}{A}\mathrm{H}_{T-N}(1-\alpha_T') + \frac{S_N}{4}\frac{A_C}{A}(1-\alpha_C) \tag{7}$$

Using the example goal P_T=1.5W/m^2 in Eq. 1, the change in heat absorbed is just a function of the target area as suggested by Eq. 5, where

$$\Delta P_T = P - P' = \frac{S_N}{4}\frac{0.33A_T\mathrm{H}_{T-N}}{A}\left[(1-\alpha_T)-(1-\alpha_T')\right] = 1.5W/m^2 \tag{8}$$

However, the same results can be obtained by changing the albedo of a nominal area, so in this case H_{T-N} =1, the equivalent change for the NLA area is

$$\Delta P_{T-N} = \frac{S_N}{4}\frac{0.33A_N}{A}\left\{(1-\alpha_N)-(1-\alpha_N')\right\} = 1.5W/m^2 \tag{9}$$

3 Results and Discussion

Comparing the target to the nominal changes, we have

$$\frac{\Delta P_T}{\Delta P_{T-N}} \approx \frac{A_T\mathrm{H}_{T-N}\left[(1-\alpha_T)-(1-\alpha_T')\right]}{A_N\left[(1-\alpha_N)-(1-\alpha_N')\right]} = 1 \tag{10}$$

As an example, assume $\mathrm{H}_{T-N} \approx 9$ (see Appendix B) and α_N=0.3 [8], α_T=0.12 [11], α_N'=α_T'=.9 we obtain

$$\frac{A_N}{A_T} = \frac{\mathrm{H}_{T-N}\left[(1-\alpha_T)-(1-\alpha_T')\right]}{\left[(1-\alpha_N)-(1-\alpha_N')\right]} = \frac{9\left[(1-.12)-(1-.9)\right]}{\left[(1-.3)-(1-.9)\right]} = \frac{9(0.78)}{0.6} = 12 \tag{11}$$

This indicates that the nominal area would have to be 12 times larger than the target area for the equivalent results.

In assessing our goal, we have from Eq. 8

$$\Delta P_T = \frac{S_N}{4}\frac{0.33A_T\mathrm{H}_{T-N}}{A_E}\left[(1-\alpha_T)-(1-\alpha_T')\right] = 1.5W/m^2 \tag{12}$$

For $\mathrm{H}_{T\text{-}N}$=1

$$\Delta P_T = 340\frac{A_T}{A}\left[0.78\right]x0.33 = 1.5W/m^2 \tag{13}$$

then

$$\frac{A_T}{A} = 0.01714 = 1.714\%\, of\ Earth \tag{14}$$

For $\mathrm{H}_{T\text{-}N}$=10

$$\frac{A_T}{A} = 0.1714\%\, of\ Earth \tag{15}$$

Recall that the goal for a 1.5W/m^2 corresponded to a 1.5% albedo change (see Sec. 2.0). Then we can check this with the following expression, (letting $H_{T\text{-}N}$=1), the albedo percent change is given by

$$\Delta\alpha\% = 0.33\frac{A_T}{A}\frac{\left[(1-\alpha_T)-(1-\alpha_T')\right]}{\alpha} = 0.33(1.714\%)\frac{\left[(1-.12)-(1-.9_T)\right]}{29.4118} = 1.49\% \tag{16}$$

Where a=29.4118 is listed in AR5 [8].

3.1 Results Compared to Urban Heat Island Area

We can compare these results to the total global urbanized area. Estimates of urbanization vary, extrapolated values to 2019 from Schneider [9] is about 0.188% [2] while studies from GRUMP [10] is 0.953% [2] of the Earth's area. Therefore, compared to these 2019 estimates for urban heat island and surrounding areas, the required area changes for different $H_{T\text{-}N}$ values are summarized in Table 1.

Table 1 Comparing solar geoengineering results to UHI areas

$H_{T\text{-}N}$	A_T/A (%)	Schneider Factor (A_T/A) /0.188%	GRUMP Factor (A_T/A)/ 0.953	GW% 1/Schneider Factor	GW% 1/GRUMP Factor
1	1.714	9	1.8	11	56
3.1	0.55	2.65	0.53	38	>100
8.4	0.2	1.1	0.21	91	>100
9	0.19	1	0.2	100	>100

It is of course still a highly challenging task to alter this much area. Yet considering that mankind is capable of building complex cities compared to geoengineering an albedo change, it should be far less complex.

3.1 Advantages of UHI

The results in Table 1 are somewhat troublesome as it suggests that UHIs are highly problematic. The fact the UHIs and their coverage could contribute significantly to global warming has been a controversial topic [5].

UHI have their own hotspot amplification factors [5] that vary between 3.1 and 8.4 which are listed in Table 1 as estimates for $H_{T\text{-}N}$. Furthermore, the albedo is about 0.12 [11]. Results are highly dependent $H_{T\text{-}N}$. We note that column 5 and 6 are rough estimates of global warming due to UHI and their surrounding coverage. Although a number of the estimates used appear not to be well defined numbers for UHIs, the albedo and two $H_{T\text{-}N}$ values cited here have been studied in Feinberg [5]. The unexpected results related to the last two columns is interesting to note, while not the main goal of this paper, the values have been supported by other authors cited in Feinberg's paper [5].

Generally, UHIs meet a lot of the requirements having high heat capacity with large hotspot areas and massive sensible heat storage. The key featured result is we have a comparative estimate relative to UHIs as well as area estimates. It is not easy to evaluate $H_{T\text{-}N}$. However, roof surfaces allow for more stable albedo maintenance over time compared to other areas like mountain regions.

3.2 Some Hotspot Target Areas

Hotspot areas are likely targets for albedo change. Desserts would be highly difficult to maintain any albedo change. However, mountains and UHI cool roofs in cities might be good targets areas. Some interesting known hotspots include

- Flaming Mountains, China
- Bangkok, Thailand (planet's hottest city)
- Death Valley California
- Titat Zvi, Israel
- Badlands of Australia

- Urban Heat Islands

We note that mountain areas in cool regions should not be excluded as such changes may prompt natural compounding albedo effects to occur from increases of snow fall and ice formations. Albedo changes could be done in summer months, and then in winter months compounding effects can be assessed.

As a summary, Equations 1 and 12 can be combined to provide the resulting solar geoengineering estimate for reverse forcing obtained in this study where

$$\Delta P_{\mathrm{Rev}\_S} = -\lambda_{\%\Delta\alpha\Delta T}\ \ \%\Delta\alpha\ (1+f)\ A_R = \left\{ \frac{S_N}{4} \frac{0.33 A_T \mathrm{H}_{T-N}}{A} \left[(1-\alpha_T) - (1-\alpha_T') \right] \right\} (1+f)\ A_R \tag{17}$$

4 Conclusions

The alternate solution to global warming is viewed as vital in mitigating global warming. Today, technology has numerous advances that include drone technology, artificial intelligence, and advances in materials that may be helpful. Mankind has addressed many technological challenges successfully. It is not illogical to consider a global albedo solution while time permits prior to a potential tipping point.

Furthermore, as we described, an albedo solution has many advantages over greenhouse gases improvements. Primarily, it can reverse global warming trends, where greenhouse gas improvements have little reverse impact unless negative CO_2 emissions can be successfully implemented.

In this paper we have provided a number of important estimates that include:

- Changing the albedo has 160% benefit due to GHG reemission
- A reasonable target albedo goal forcing reduction overall of 4.8W/m^2 ($\Delta P_{\mathrm{Rev\_LWR}}$=-2.97W/m^2)
- Selecting proper target areas can reduce the required area to 0.18 to 9 times the size occupied by global urbanized area
- Likely target areas may include problematic hotspots including UHI with urbanized areas and mountains
- Selecting proper hotspot areas can reduce the required target are by a factor of roughly 13
- An unexpected result indicated that UHIs could be responsible for 11% to most of global warming. Results were highly dependent on $H_{T\text{-}N}$. These results should be considered unrefined estimates.
- It is important to task agencies worldwide, such as NASA, to work on solar geoengineering, which at this late time is likely more important than space exploration and many other projects that countries are concerned about.

Appendix A Reemission Percent

This is detailed in Feinberg [3]. However, we provide a simplistic view for 1950 by assuming no forcing at that time. Looking at typical energy budget diagrams, blackbody portion of the budget is about 240W/m^2 where the total increases to obtain the 1950 temperature is about 385W/m^2. This implies the reemission must be

$$240\mathrm{W/m^2} \ / \ 385\mathrm{W/m^2} = 62\%$$

Appendix B Estimating the Potential for Hotspot Sensible Heat Storage $H_{T\text{-}N}$

A candidate hotspot sensible heat storage potential $H_{T\text{-}N}$ was described in Section 2. Here we provide a rough overview to clarifying and enumerate this factor. It is likely more rigorous solutions can be developed. Such solutions are outside the scope of this paper.

We consider a ratio for a target (T) area relative to a nominal (N) area defined in Sec. 2. Consider a target area with sensible heat storage q due to a mass *m*, having specific heat capacity *Cp* experiencing a heat day-night ΔT change, then the suggested potential for sensible hotspot heat storage $H_{T\text{-}N}$ has the form

$$H_{T-N} = \frac{q_T}{q_N} x \frac{I_T}{I_N} = \frac{m_T C_{PT} \Delta T_T}{m_N C_{PN} \Delta T_N} x \frac{I_T}{I_N} \tag{B-1}$$

where we also including irradiance (I) ratio.

As a numeric example, first consider a 90% irradiance target area (compared to the equator) with a nominal mid-latitudes (45°) roughly 70%, compared to say the Arctic and Antarctic Circles at 40% [12]. Then the irradiance ratio is

$$\frac{I\%_T}{I\%_N} = \frac{90\%_T}{70\%_N} = 1.3 \qquad \text{(B-2)}$$

For the sensible heat numeric portion, consider a rocky area as the target (such as Flaming mountain). This can be compared with a nominal vegetative land area. As a rule of thumb, most rocks have a density of 2.65 g/cm^3, about 50% difference compared to a nominal soil area of 1.33 g/cm^3 [13]. The heat capacity of rocks compared with vegetated land is 2000 to 830J/Kg/^{o}K [14]. Then ΔT is estimated from tables for a day-night cycle [15]. The estimate of

$$\frac{q_T}{q_N} = \frac{m_T C_{PT}\Delta T_T}{m_N C_{PN}\Delta T_N} = \frac{\rho_T C_{PT}\Delta T_T}{\rho_N C_{PN}\Delta T_N} = \left(\frac{2.65}{1.33}\right)_{\rho} \left(\frac{2000}{830}\right)_{C_P} \left(\frac{23(\Delta 10C)}{14.84(6.9)}\right) = 2x2.4x1.66 = 6.72 \qquad \text{(B-3)}$$

Then including irradiance

$$H_{T-N} \approx 9 \qquad \text{(B-4)}$$

Appendix C Planck-Albedo Feedback Parameter

This parameter comes about from the following assessment [2,3]

$$\lambda_{\%\Delta\alpha} = \frac{\Delta E_o}{\frac{\alpha_1-\alpha_2}{\alpha_1}100} = \frac{E_o\left(\alpha_1-\alpha_2\right)}{\frac{\alpha_1-\alpha_2}{\alpha_1}100} = E_o\alpha_1/100 = 1W/m^2/\%\Delta albedo \qquad \text{(C-1)}$$

where Eo=340 W/m^2 and we see the closer that α_1 is to 29.4118%, the nearer a value of 1.000W/m^2/Δ%albedo is obtained. We note the value 29.4118% (100/340) is listed in AR5 [8]. This value relates for a 1^{o}K change [2,3] so that

$$\lambda_{\%\Delta\alpha\Delta T} = 1W/m^2/\%\Delta albedo/°K \qquad \text{(C-2)}$$

Therefore, one can estimate the feedback parameter

$$\lambda_{\alpha} = \lambda_{\%\Delta\alpha}\ x\ \%\Delta\alpha \qquad \text{(C-3)}$$

and the temperature change given by Eq. 2.

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