On Implementing an Albedo Solution to Global Warming

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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 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 hotspot areas, the effective area could be roughly 13 times smaller than a nominal non-hotspot areas in influencing global warming.

1 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 the large amount of deforestation occurring [1]. Furthermore, it takes about 30 years to reduce 50% of any increase; and reducing GHG emissions then can only slow global warming from occurring. 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 engineering calculations.

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 reflectivity surfaces compared with building cities. 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. 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

$$\Delta P_{\mathrm{Rev}\_S} = -\lambda_{\%\Delta\alpha\Delta T}\ \ \%\Delta\alpha\ (1+f)\ A/T = \Delta P_T\ (1+f)\ A/T = -3.83 W/m^2 \tag{1}$$

and $\beta^4 \Delta P_{\mathrm{Rev\ S}} = \Delta P_{\mathrm{Rev\ LWR}} = -2.37 \mathrm{W/m^2}$ [3] so that

$$\Delta T_{\mathrm{Rev}} = -2.37 \mathrm{W/m^2}\ \ 1/\lambda_o\ \ = -0.72°K \tag{2}$$

where,

ΔP_{Rev} is the reverse power per unit area
$\lambda_{\%\Delta\alpha\Delta T}$ = 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 is an estimate of the anticipated GW amplification reduction, about 2
T is a climate transient value about 1.25 [7]
$\Delta P_T = \lambda_{\%\Delta\alpha\Delta T}\ \ \%\Delta\alpha$ is the reverse forcing 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

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

$$P = \frac{Q}{A} = \frac{S_N}{4}\sum_i \frac{A_i}{A}(1-\alpha_i) + \frac{S_N}{4}\mathrm{H}_{T-N}\frac{A_T}{A}(1-\alpha_T) \tag{3}$$

Here A_i is the i^{th} area having an albedo α_i, $S_N = 1361 W/m^2$ and A is the surface area of the Earth. We consider a change to a hotspot target 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 hotspot amplification potential $\mathrm{H}_{T\text{-}N}$, a function of the heat capacity, mass, temperature storage, and solar irradiance, This hotspot amplification potential is described and enumerated in Appendix C. The overall equation for the unaltered area is subject to the constraints

$$P = 240 W/m^2 \ \ and\ \ A = \sum_i A_i + \mathrm{H}_{T-N} A_T \tag{4}$$

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

$$P' = \frac{Q'}{A} = \frac{S_N}{4}\sum_i \frac{A_i}{A}(1-\alpha_i) + \frac{S_N}{4}\frac{A_T}{A}\mathrm{H}_{T-N}(1-\alpha'_T) \tag{5}$$

Using the example goal, we note that P_T=1.5W/m^2 in Eq. 1 due to altering a target area 1.5%, the heat absorbed is then

$$\Delta P_T = P - P' = \frac{S_N}{4}\frac{A_T \mathrm{H}_{T-N}}{A}\left[(1-\alpha_T)-(1-\alpha'_T)\right] = 1.5 W/m^2 \tag{6}$$

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

$$\Delta P_{T-N} = \frac{S_N}{4} A_N \left\{(1-\alpha_N)-(1-\alpha'_N)\right\} = 1.5 W/m^2 \tag{7}$$

3 Results and Discussion

Comparing the target to the nominal changes, we have

$$\frac{\Delta P_T}{\Delta P_N} \approx \frac{A_T \mathrm{H}_{T-N}\left[(1-\alpha_T)-(1-\alpha_T')\right]}{A_N\left[(1-\alpha_N)-(1-\alpha_N')\right]} = 1 \quad (8)$$

As an example, assume $\mathrm{H}_{T-N} \approx 10$ and α_N=0.3 [8], α_T=0.1, α_N'=α_T'=.9 we obtain

$$\frac{A_N}{A_T} = \frac{\mathrm{H}_{T-N}\left[(1-\alpha_T)-(1-\alpha_T')\right]}{\left[(1-\alpha_N)-(1-\alpha_N')\right]} = \frac{10\left[(1-.1)-(1-.9)\right]}{\left[(1-.3)-(1-.9)\right]} = \frac{10(0.8)}{0.6} = 13.3 \quad (9)$$

This indicates that the nominal area would have to be 13.3 times larger than the target area for the equivalent results. In assessing our goal, we have for this example from Eq. 6

$$\Delta P_T = 340\frac{A_T 10}{A}\left[0.8\right] = 1.5W/m^2 \quad (10)$$

Then

$$\frac{A_T}{A} = 0.00055 = 0.055\% \quad (11)$$

In this model, we would need to change a relatively small portion of the Earth. We can compare this to the total 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]. Therefore, compared to these 2019 estimates for urban heat island and surrounding areas, the required area change is

- 3.4-17.3 times smaller

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

3.1 Advantages of UHI

UHIs meet a lot of the requirements. Estimates for amplification factors have suggested by Feinberg [5] and they vary between 3.1 and 8.4. Furthermore, the albedo is about 0.12 [11]. Reversing just warming due to UHI would require changing the albedo to 0.2 [5]. This is not a lot of change, but can pose difficulties as this would be an effective albedo for the entire UHI. Nevertheless, certainly much higher reflective surfaces can be realized. Furthermore, 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 changes to occur from increases of snow fall and ice formations. Albedo changes could be done in summer months, and then in winter months, any compounding effects can be assessed.

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.

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
- Selecting proper target areas can reduce the required area to 3.3-17.3 times smaller than current occupied urbanized area estimates
- Likely target areas may include problematic hotspots including UHI with urbanized areas and mountains

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 increase to obtain the 1950 temperature is about 385W/m^2. This implies the reemission must be

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

Appendix B Estimating the Amplification Factor

In this appendix we suggest the candidate amplification factor $H_{T\text{-}N}$ described in Section 2. We provide it in this appendix since it is a rough overview to aid the reader in clarifying our suggested method in Section 2. Using this methodology, it is likely more rigorous solutions can be developed. Such solutions are outside the scope of this paper.

In this keeping with the suggested method in Section 2, we consider a ratio for a target (T) area compared to a nominal (N) area. Then the sensible heat storage q due to a mass *m*, having specific heat capacity *Cp* experiencing a heat day-night *ΔT* change, then the suggested amplification factor $H_{T\text{-}N}$ 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 40% [12]. Then the irradiance ratio is

$$\frac{I\%_T}{I\%_N} = \frac{90\%_T}{70\%_N} = 1.3 \tag{B-2}$$

For the sensible heat numeric portion we consider a target rocky area (such as Flaming mountain) 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].

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

Then including irradiance

$$H_{T-N} \approx 9 \tag{B-4}$$

Appendix C Planck-Albedo Feedback Parameter

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

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

where Eo=340 W/m^2 and we see the closer that α_1 is to 29.4118%, the nearer a value of 1W/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°K change [2,3] where

$$\lambda_{\%\Delta\alpha\Delta T} = 1W / m^2 / \%\Delta albedo / {}^\circ K \tag{C-2}$$

Therefore, one can estimate the feedback parameter

$$\lambda_\alpha = \lambda_{\%\Delta\alpha}\ x\ \%\Delta\alpha \tag{C-3}$$

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