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Optimum Solution to Global Warming

In the Control of CO_2, Hotspots, & Hydro-Hotspots Forcing Due to the Albedo-GHG Interaction

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Abstract

The albedo solution can be vital in global warming as results can reverse trends and reduce the probability of the tipping point. Furthermore, when considering the albedo-GHG interactions, the albedo solution is certainly an optimum way to mitigate global warming if all known forcing issues are conservatively considered significant. As well, given the current difficulty in CO_2 reverse forcing and the threat of the tipping point occurring, an additional approach to reducing climate change is now needed. Therefore, it is important to clarify and model the GHG-albedo interaction strength to aid in solar geoengineering estimates. This requires a different approach than traditional CO_2 doubling theory. Our results are directed toward influencing climate policy, demonstrating the important immediate need for albedo controls and solutions.

1. Introduction

Although albedo solutions have been recommended in helping to mitigate climate change [1] and likely a vital supplement to CO_2 efforts, little work is being done in this area. There have been a number of proposed albedo solutions, both surface and atmospheric methods [1-3] to reduce climate change. Such techniques have not been widely adopted by governments [2] and unfortunately are typically given little funding consideration by climate groups.

In this paper, we describe the albedo-GHG interactions that applies to three observed forcing issues and using historical information, model its strength and discuss its unique role for potential albedo solutions in climate controls [4,5]. That is, if only one solution were available in climate change, the albedo solution would conservatively be the optimum method as the only control that has strong interaction in mitigating all three types of forcing. Thus, this interaction strength is important in solar geoengineering for assessing such climate controls and directing climate policy. The cumulative effect of widespread select [4] albedo-GHG mitigation areas could potentially have important influence both to the Earth's solar surface heat absorption and associated GHG re-radiation power. Therefore, we describe the albedo solution as vital and suggest that its implementation is needed in the immediate future. Although there remains a lack of knowledge for it in the public domain, we are hopeful this work may help contribute to climate policy and its funding.

2. Method

It is helpful to describe the albedo-GHG interactions and associated historical information for three types of observed Goble Warming (GW) forcing issues:

- CO_2 (ignoring other GHGs)
- Hotspots (such as Urban Heat Islands and Roads)
- Hydro-hotspots

> We term a hydro-hotspot [6] as a solar hot impermeable surface common in cities and roads that creates atmospheric moisture in the presence of precipitation. This moisture increase can act as a local greenhouse gas. A possible mechanism includes warmer expanded air-surface temperatures due to the initial hotspot, and then during precipitation, evaporation increases the local atmosphere humidity GHG (as warm air holds more water vapor). The level of hydro-hotspot significance in climate change is currently unknown.
>
> However observations of this effect are reasonably well established. For example, Zhao et al. [7] observed that Urban Heat Islands (UHI) temperatures increase in daytime ΔT by $3.0^{o}C$ in humid climates but decrease ΔT by $1.5^{o}C$ in dry climates. They found a strong correlation between ΔT increase and daytime precipitation. Their results concluded that albedo management would be a viable means of reducing ΔT on large scales.

A major benefit of the albedo solution often overlooked is the interaction strength with the greenhouse gas mechanism which arises from the simple fact that

- *Increasing the reflectivity of a hotspot surface reduces its greenhouse gas effect*
- *Decreasing the reflectivity of a hotspot surface increases its greenhouse gas effect*
- *The Global Warming (GW) change associated with a reflectivity hotspot modification is given by the albedo-GHG radiation factor having an approximate inherent value of 1.6 (Sec. 2.2).*

This additional benefit means that albedo solutions [1-4] are proficient, ***and the only climate control having strong distinct mitigation interactions with all three forcing mechanisms***. Such simple knowledge could be helpful in educating policy makers on realizing the value of the albedo solution.

- In Section 2.2, we detail this 1.6 average albedo-GHG interaction strength for geoengineering and provide estimates of this additional GHG heat exchange in two different time periods, 1950 and 2019.
- In Section 4, we specifically show how practical the albedo solution is for even mitigating increases in CO_2 levels (see also Eq. 23).

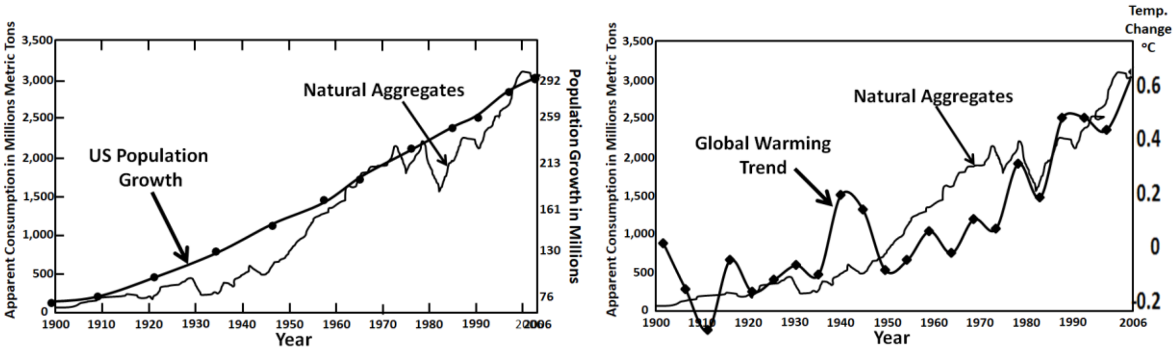
It is important to note that the albedo-GHG heat exchange is often dominated with water vapor and clouds GHG, 36-72% compared with CO_2 GHG 9-26% [8]. This provides a possible breakdown of the GHG power, but not the forcing strengths [9, 10]. Due to this interaction, albedo solutions would decrease risks of GHG effects, hydro-hotspot forcing as well as the possible significance of hotspots. Since hydro-hotspots create higher warming impact in humid climates, these select widespread urban surface areas generally have higher GW impact and mitigating albedo solutions in these regions would be desirable.

The significance of hotspot forcing has been somewhat controversial in global warming as it relates to UHIs. Measurements and their assessments have been described by a number of authors [11-21] and more recently in modeling [4, 23]. One key work often referred to is by McKitrick and Michaels [11, 12] who found that the net warming bias at the global level may explain as much as half the observed land-based warming. Although this study was criticized by Schmidt [23] and defended successfully by Mckitrick [12] over many years, the research still remains apparently difficult to accept. As well, these results [11-21] completed over 10 years ago, still have not been influential for implementing worldwide albedo controls and solutions. For example, such solutions were not part of the Paris Climate Accord [24]. In modeling recently, by the author [4, 22], UHI amplification factors were estimated (for solar area, heat capacity, canyon effect, etc.) with the help of UHI footprint and dome estimates that extended the UHI effect beyond its own area and applied to albedo modeling. Results showed reasonable support for these authors' findings [11-21] that UHIs can significantly contribute to GW with one model showing 4.5%-38% [22] and a second model showing 6%-82% [4] of GW could be due to UHIs. These large variations are due to uncertainties in UHI amplification factors and estimates of how much of the Earth is urbanized.

- ***Policy makers should realize that albedo controls can serve two purposes 1) In the event that hotspots and hydro-hotspots are truly significant and by 2) Offset CO_2 GW effects through enhanced albedo (high reflectivity) solutions (See Sec. 4 for a CO_2 albedo mitigation example)***

Little is understood about hydro-hotspot GW forcing significance. However, since the industrial revolution, impermeable surfaces have increased at a high rate (like CO_2) correlated to population growth and thus, GW increases [22]. This is illustrated in Figure 1 that shows correlations to both GW and population growth to natural aggregates that are used to build cities and roads.

- ***This is coupled with the fact that there has been a lack of hotspot controls in terms of solar considerations in their construction of UHIs, rooftops, roads, parking lots, car colors, and so forth by policymakers.***



(a) **(b)**

Figure 1. a) Natural aggregates [25] correlated to U.S. Population Growth (USGS [26]) **b)** Natural aggregates [25] correlated to global warming (NASA [27])

In terms of amplification effects, hydro-hotspots would likely have both local water-vapor GHG interactions and the additional 1.6 warming influence on GW (with UHI heat capacity also playing an important role).

- ***Therefore, albedo solutions should have higher interests for policy makers as they would greatly reduce risks and significantly add to CO_2 reduction efforts when implemented in parallel, since the interactive albedo-GHG is the only method to help mitigate all three types of forcing.***

Furthermore, there are growing concerns regarding the:

- slow progress reported in CO_2 reduction
- yearly increases in reports on large desertification and deforestation occurring [28]
- lack of hotspot and hydro-hotspot albedo controls [6] that are continually increasing
- threat of the tipping point occurring as we are running out of time

Regarding the interactive strength, it is helpful to determine the geoengineering albedo-GHG re-radiation inherent 1.6 factor [4] and its change since the pre-industrial revolution. Such values relate to the effective emissivity constant of the planetary system. Results will also help to demonstrate how albedo solution can offset CO_2 forcing (see Sec. 4). Furthermore, assessment may help strengthen interests in the albedo solution.

2.1 Albedo-GHG Radiation Factor

In geoengineering the albedo-GHG interaction requires a different approach compared to CO_2 doubling theory. When initial solar absorption occurs, part of the long wavelength radiation given off is re-radiated back to Earth. In the absence of forcing we denote this fraction as f_1. This presents a simplistic but effective model

$$P_{\Pr e-Industrial} = P_\alpha + P_{GHG} = P_\alpha + f_1 P_\alpha = P_\alpha\left(1+f_1\right) = \sigma T_S^4 \text{ where } P_\alpha = \frac{S_o}{4}(1-\alpha) \tag{1}$$

and T_s is the surface temperature, $P_{\text{pre-industrial}}$, P_α, and P_{GHG} are the total pre-industrial warming, albedo warming and GHG warming in W/m^2, respectively. As one might suspect, f_1 turns out to be exactly β^4 in the absence of forcing, so that f_1 is a redefined variable taken from the effective emissivity constant of the planetary system. We identify $1+f_1=1.618034$ (see Section 2.2) as the pre-industrial albedo-GHG radiation factor (Table 1).

We identify the re-radiation 2019 having a value of $1+f_2=1.6276$ (Table 1). That is, in 2019, due to increases in GHGs, an increase in the re-radiation fraction occurs

$$f_2 = f_{2019} = f_1 + \Delta f = \beta_1^4 + \Delta f \approx \beta_2^4 + \Delta f \tag{2}$$

In this way $f_{2019} = f_2$ is a function of f_1. The RHS of Eq. 2 indicates that $\beta_1 \approx \beta_2$ (see verification results in Eq. 18 and 19). We find that $\Delta f=0.0096$ is relatively small compared to $(1+f_1)$ which we show can fairly accurately be assessed in geoengineering.

2.2 Estimating the Pre-industrial Albedo-GHG Interaction Strength

In geoengineering, we are working with absorption and re-radiation, we define

$$P_{Total} = \sigma T_S^4 = \sigma\left(\frac{T_e}{\beta}\right)^4 \text{ and } P_\alpha = \sigma T_\alpha^4 = \sigma\left(\beta T_S\right)^4 \tag{3}$$

The definitions of $T_\alpha=T_e$, T_S and β are the emission temperature, surface temperature and typically $\beta \approx 0.887$, respectively. Consider a time when there is ***no forcing issues*** causing warming trends. Then by conservation of energy, the equivalent power re-radiated from GHGs in this model is dependent on P_α with

$$P_{GHG} = P_{Total} - P_\alpha = \sigma T_S^4 - \sigma T_\alpha^4 \tag{4}$$

To be consistent with $T_\alpha=T_e$, since typically $T_\alpha \approx 255^oK$ and $T_s \approx 288^oK$, then in keeping with a common definition of the global beta (the proportionality between surface temperature and emission temperature) for the moment $\beta=T_\alpha/T_s=T_e/T_S$.

This allows us to write the dependence

$$P_{GHG} = \sigma T_S^4 - \sigma T_\alpha^4 = \frac{\sigma T_\alpha^4}{\beta^4} - \sigma T_\alpha^4 = \sigma T_\alpha^4\left(\frac{1}{\beta^4} - 1\right) = \sigma T_\alpha^4\left(\frac{1}{f} - 1\right) \tag{5}$$

Note that when $\beta^4=1$, there are no GHG contributions. We note that f, the re-radiation parameter equals β^4 in the absence of forcing.

We can also define the blackbody re-radiated by GHGs given by some fraction f_1 such that

$$P_{GHG} = f_1 P_\alpha = f_1 \sigma T_\alpha^4 \tag{6}$$

Consider f=f$_1$, in this case according to Equations 5 and 6, it requires

$$P_{GHG} = \sigma T_\alpha^4 \left(\frac{1}{f_1} - 1 \right) = f_1 \sigma T_\alpha^4 \tag{7}$$

This dependence leads us to the solution of the quadratic expression

$$f_1^2 + f_1 - 1 = 0 \text{ yielding } f_1 = 0.618034 = \beta^4 \text{, } \beta = (0.618034)^{1/4} = 0.886652 \tag{8}$$

This is very close to the common value estimated for β and this has been obtained through energy balance in the planetary system providing a self-determining assessment. In geoengineering we can view the re-radiation as part of the albedo effect. Consistency with the Planck parameter is shown in Section 3.1. We note that the assumption f=f$_1$ only works if planetary energy is in balance without forcing. In the next section, we double check this model in another way by balancing energy in and out of our global system.

2.3 Balancing Pout and Pin in 1950

In equilibrium the radiation that leaves must balance P$_\alpha$, the energy absorbed, so that

$$\begin{aligned} Energy_{Out} &= (1-f_1)P_\alpha + (1-f_1)P_{Total} = (1-f_1)P_\alpha + (1-f_1)\{P_\alpha + f_1 P_\alpha\} \\ &= 2P_\alpha - f_1 P_\alpha - f_1^2 P_\alpha = Energy_{In} = P_\alpha \end{aligned} \tag{9}$$

This is consistent, so that in 1950, Eq. 9 requires the same quadratic solution as Eq. 8. It is also apparent that

$$P_\alpha = f_1 P_{Total\_1950} = \beta_1^4 P_{Total\_1950} \tag{10}$$

since

$$P_\alpha = f_1(P_\alpha + f_1 P_\alpha) \;\; or \;\; 1 = f_1(1 + f_1) \tag{11}$$

The RHS of Eq. 11 is Eq. 8. This illustrates f$_1$ from another perspective as the fractional amount of total radiation in equilibrium. As a final check, the application in the Section 3, in Table 1, illustrates that f$_1$ provides reasonable results.

2.4 Re-radiation Model Applied to 2019

In 2019 due to global warming trends, to apply the model we assume that feedback can be applied as a separate term and we make use of some IPCC estimates for GHG forcing as a way to calibrate our model. In the traditional sense of forcing, we assume some small change to the albedo and most of the forcing due to IPCC estimates for GHGs where

$$P_{Total\,2019} = P_{\alpha'} + P_{GHG'} = P_{\alpha'}(1 + f_2) \tag{12}$$

Then we introduce feedback through an amplification factor A$_F$ as follows

$$P_{Total\,2019\&Feedback} = P_{1950} + (\Delta P)A_F = P_{1950} + (P_{2019} - P_{1950})A_F = \sigma T_S^4 \tag{13}$$

Here, we assume a small change in the albedo denoted as P$_\alpha$′ and f$_2$ is adjusted to the IPCC GHG forcing value estimated between 1950 and 2019 of 2.38W/m^2 [10]. Although this value does not include hydro-hotspot forcing assessment described in the introduction, it possibly may be effectively included since forcing estimates also relate to accurate GW temperature changes. Then the feedback amplification factor, is calibrated so that T$_S$=T$_{2019}$ (see Table 1) yielding A$_F$ =2.022 [also see ref. 29]. The main difference in our model is that the forcing is about 6% higher than the IPCC for this period. Here, we take into account a small albedo decline of 0.15% that the author has estimated in another study due to likely issues from UHIs [22] and their coverage. We note that unlike f_1, f_2 is not a strict measure of the emissivity due to the increase in GHGs.

3. Results Applied to 1950 and 2019 with an Estimate for f_2

In 1950 we will simplify estimates by assuming the re-radiation parameter is fixed and reasonable close to the pre-industrial level of f_1=0.618034. Then, to obtain the average surface temperature T_{1950}=13.89°C (287.04°K), the only adjustable parameter left in our basic model is the global albedo (see also Eq. 1). This requires an albedo value of 0.3008 (see Table 1) to obtain the T_{1950}.=287.04°K. This albedo number is reasonable and similar to values cited in the literature [30].

In 2019, the average temperature of the Earth is T_{2019}=14.84°C (287.99°K) given in Eq. 15. We have assumed a small change in the Earth's albedo due to UHIs [22]. The f_2 parameter is adjusted to 0.6276 to obtain the GHG forcing shown in Column 7 of 2.38W/m^2 [10]. Therefore the next to last row in Table 1 is a summary without feedback, and the last row incorporates the A_F=2.022 feedback amplification factor.

Table 1 Model Results

Year	**T_S(°K)**	**T_α(°K)**	***f_1, f_2***	**α, α'**	**Power Absorbed W/m^2**	**$P_{GHG'}$ P_{GHG}**	**P_{Total} W/m^2**
2019	287.5107	254.55	0.6276	30.03488	238.056	149.4041	387.4605
1950	287.04	254.51	0.6180	30.08	237.9028	147.024	384.9267
Δ2019-1950	0.471	0.041	0.0096	(0.15%)	0.15352	2.38	2.53
$\Delta_{Feedback}$ A_F=2.022	0.95	0.083	-	-	0.3104	4.81	5.12

From Table 1 we now have identified the reverse forcing at the surface needed since

$$P_{Total\,2019\_Feedback\,Amp} = P_{1950} + \left(P_{2019} - P_{1950}\right)A_F = 384.927W/m^2 + (2.5337W/m^2)2.022 = 390.05W/m^2 \quad (14)$$

and

$$\Delta T_S = T_{2019} - T_{1950} = \left(390.05/\sigma\right)^{1/4} - 287.04°K = 287.9899°K - 287.04°K = 0.95°K \quad (15)$$

as modeled. We also note an estimate has now been obtained in Table 1 for f_2=0.6276, A_F=2.022, and $\Delta P_{Total\_Feedback\_amp}$=5.12W/m^2.

3.1 Model Consistency with the Planck Parameter

As a measure of model consistency, the forcing change with feedback, and resulting temperatures T_{1950} and T_{2019}, should be in agreement with expected results using the Planck feedback parameter. From the definition of the Planck parameter λ_o and results in Table 1, we estimate [31]

$$\lambda_o = -4\frac{\Delta R_{OLW}}{T_S} = -4\left(\frac{237.9028W/m^2}{287.041°K}\right)_{1950} = -3.31524W/m^2/°K \quad (16)$$

and

$$\lambda_o = -4\frac{\Delta R_{OLW}}{T_S} = -4\left(\frac{238.056W/m^2}{287.99°K}\right)_{2019} = -3.306W/m^2/°K \quad (17)$$

Here ΔR_{OLW} is the outgoing long wave radiation change. We note these are very close in value showing miner error and consistency with Planck parameter value, often taken as 3.3W/m^2/°K.

Also note the Betas are very consistent with Eq. 8 for the two different time periods since from Table 1

$$\beta_{1950} = \frac{T_\alpha}{T_S} = \frac{T_e}{T_S} = \frac{254.51}{287.041} = 0.88667 \textit{ and } \beta_{1950}^4 = 0.6180785 \tag{18}$$

and

$$\beta_{2019} = \frac{T_\alpha}{T_S} = \frac{T_e}{T_S} = \frac{254.55}{287.5107} = 0.88526 \textit{ and } \beta_{2019}^4 = 0.6144 \tag{19}$$

3.2 Hotspot Versus GHG Forcing Equivalency

From Equation 1 and 12 we can estimate the effect in a change in hotspot forcing as

$$\left(\frac{dP_{Total}}{dP_\alpha}\right)_{1950} = (1+f_1) = 1.618 \text{ and } \left(\frac{dP_{Total}}{dP_\alpha}\right)_{2019} = (1+f_2) = 1.6276 \tag{20}$$

However, we note a change in GHGs is only a factor of 1 by comparison

$$\frac{dP_{Total}}{dP_{GHG}} = \frac{d(P_\alpha + P_{GHG})}{dP_{GHG}} = 1 \tag{21}$$

or from Table 1 data

$$\frac{dP_{Total}}{dP_{GHG}} = \frac{2.53}{2.38} = 1.063 \tag{22}$$

This indicates 1 W/m^2 of albedo forcing generally requires 1.6 W/m^2 of GHG forcing to have the same global warming effect. Alternately, form Eq. 22 and Table 1 data this is about 1.53. This result should be helpful in albedo forcing estimates.

4. Discussion

From Table 1 we used two key forcing changes that are responsible for climate change since 1950

- Δf and $\Delta\alpha$

We know that $\Delta\alpha$ can only be controlled by albedo controls. However, in Table 1, the albedo effect used was fairly minimal contributing only a 0.15 W/m^2 (6%) to the warming. However, if we were to implement a worldwide albedo surface solution of select areas, for example, the following albedo amplification factors can potentially be realized

Table 2 Albedo Surface Solution Factors

Amplification Type	Factor
Albedo enhancement	4
Reduction of heat storage targets	6
Re-radiation reduction	1.6
Total Product	**38**

Here, selecting surfaces with high heat storage capacity, such as buildings (or possibly mountains) are likely good strategic targets. These areas are a function of heat capacity, surface albedo, mass, temperature storage, solar irradiance and humid environments, which can yield amplification factors between 3.1-8.4 (averaging 6) [4, 21]. These estimates are not unreasonable for UHIs. As well there are atmospheric albedo solutions [1].

Consider how this applies to Table 1 GHGs. In Table 1, Δf is controlled by GHGs assumed to be dominated by CO_2 forcing (recall that part of this may actually intrinsically include hydro-hotspots which are mitigated only by albedo methods). The reverse forcing albedo reduction to mitigate Δf when considering albedo amplification factors in Table 2 on GHG forcing in Table 1

$$\text{Reverse Forcing Mitigation Requirement} = 2.38\ \text{W/m}^2/38 = 0.063\ \text{W/m}^2 \tag{23}$$

The amount of Earth that would have to be modify with reflectivity factor between 4-7.5 has been assessed by the author in Reference [4] for this particular problem, yielding a

- Modification area of about 0.2% to 1% of the Earth, depending on the selected target types

Therefore, we note by employing albedo solutions, reverse cooling results would help compensate for CO_2 forcing, and conservatively include hotspots and hydro-hotspots mitigation. In the event that hotspots and hydro-hotspot are truly significant, this would be the optimum approach.

- ***This should help to clarify the benefit and need for including albedo controls and solutions in climate change policies***

5. Summary

In this paper we have focused on the albedo-GHG interaction to show how the albedo solution, could be a vital method to help mitigate global warming when three types of forcing issues are considered. Such implementation would greatly supplement CO_2 solutions. Results can improve the speed in helping to prevent a tipping point from occurring (especially with desertification and deforestation occurring). Furthermore, analysis showed that the albedo solution can effectively compensate for CO_2 forcing without having to modify an unreasonable area of the Earth. Furthermore other albedo solutions are available.

The GHG-albedo interaction strength due to the re-radiation factor has been fully described in application to two time periods. Results show that the re-radiation factor for 1950 when taken as a pre-industrial value is 1.6181 which is directly given by β^4 (the emissivity constant of the planetary system). However in present day, this factor has increase to 1.6276 due to the increase in GHGs. In order to make the present day assessment, we assumed a small planetary albedo decrease from 1950 of 0.15% and GHG forcing of about 2.38 W/m^2 (in accordance with IPCC estimates). In terms of geoengineering albedo modification estimates, the interactive value of 1.62 should to be a good approximation.

Below we provide suggestions and corrective actions which include:

- Modification of the Paris Climate Agreement to include albedo controls and solutions
- Albedo guidelines for both UHIs and roads similar to on-going CO_2 efforts
- Guidelines for future albedo design considerations of cities
- Government money allocation for geoengineering and implement albedo solutions
- Recommend an agency like NASA to be tasked with finding applicable albedo solutions and implementing them
- Recommendation for cars to be more reflective. Although world-wide vehicles likely do not embody much of the Earth's area, recommending that all new manufactured cars be higher in reflectivity (e.g., silver or white) would help raise awareness of this issue similar to electric automobiles that help improve CO_2 emissions.

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