Global Cooling by Injecting Black Carbon into the Stratosphere?

Thomas Prevenslik
QED Radiations, Berlin, Germany

Abstract Global cooling by injecting black carbon (BC) aerosols into the stratosphere is currently not considered a viable geoengineering solution to compensate for global warming. However, geoengineering analysis methods assume the BC particles upon under absorbing solar radiation follow classical physics and increase in temperature. But for sub-micron nanoparticles (NPs) the Planck law denies atoms in BC particles the heat capacity to increase in temperature in absorbing solar radiation, the consequence of which allows BC to be effective in compensating for global warming. In thus paper, classical physics is superseded by simple QED - a nanoscale heat transfer process based on the Planck law - is used to show the advantages of radiative forcing by BC absorption compared to reflective aerosols. The analysis uses the simple QED heat transfer process based on the Planck law that conserves heat by creating standing EM radiation inside the BC particle having wavelength $\lambda = 2nd$, where n and d are the refractive index and diameter of the spherical BC particle. For BC having n = 2.4, the desired λ = 10-micron wavelength for emission through the 8-12 microns atmospheric window requires d ~ 2 microns. The BC particles injected at the top of the stratosphere having high absorb all incident UV-VIS-NIR solar radiation. For a 1% absorption of solar radiation in the stratosphere or negative radiative forcing of -1.6 W/m^2 at the Earth's surface, 3.4×10^6 tons of BC are required at a cost from $ 1-2 trillion. Alternative geoengineering using Earth based BC mirrors is discussed.

Keywords: Global cooling, Black carbon, geoengineering, Classical physics, Planck law,

I. INTRODUCTION

Global warming over the past decades has primarily concentrated on scientific research directed to the control of greenhouse gases, and specifically limiting carbon dioxide in emissions from burning fossil fuels. Despite controls on carbon dioxide, global temperatures continued to increase suggesting research on other ways to limit the rise in global temperature. One promising area of research [1-3] was to inject aerosols of sulfates into the stratosphere that reflect solar radiation back into space and thereby cooling the Earth surface even though carbon emissions do not decrease.

Indeed, the dispersion of submicron nanoparticles (NPs) in the atmosphere was proposed [1] to scatter solar irradiation while being transparent IR radiation at 10 microns emitted by the Earth. In effect, the feasibility of controlling the global temperature without reducing the emission of greenhouse gases was studied. NPs of inexpensive alumina (Al_2O_3) that do not absorb solar irradiation. By Mie scattering theory, the NPs in the stratosphere scatter solar irradiation having wavelengths ranging from 0.2 to 4.0 micron. The NPs having an optimum size of 350-450 nm were assumed dispersed in the stratosphere at an altitude of 30 km. The total NP mass of 3×10^7 tons in the stratosphere was found to reduce 3% of the solar irradiation.

Because of high scattering efficiency, titania was proposed [2] as an alternate to alumina aerosols over 2020-2100 period. However, titania efficiently absorbs solar UV radiation producing a significant stratospheric warming > 20 C offering little benefit when compared to sulfate aerosols from the injection of sulfur dioxide. In this regard, black carbon (BC) having high absorption was shown to have a much lower injection rate than titania produced stratospheric temperature changes > 70 C. BC more commonly known as soot that like carbon dioxide is produced in the combustion of fuels. Because of atmospheric heating, BC aerosols were considered [2] excluded from geoengineering.

Similarly, earlier [3] studies of BC aerosols showed 1 Tg/year of BC injected into the lower stratosphere would cause little surface cooling for 0.3-micron NPs while 0.16-micron NPs produced large surface cooling, but stratospheric warming of over 60 C. Stratospheric warming caused global ozone loss by up to 50% for 0.16 micron NPs. Using diesel fuel to produce the aerosols is also prohibitively expensive. Compared to reflecting sulfate aerosols, absorbing BC aerosols carry too many problems to be a viable option for climate control.

However, there is a dark side to sulfate aerosols because they are not totally reflective, and in fact are absorptive [4] because the sulfate aerosols also contain BC. Contrarily, the sulfate aerosol particles actually heat the atmosphere.

II. PROBLEM

Prior studies of aerosols containing alumina, titania, and BC NPs in the atmosphere based on Mie theory and classical physics are questionable because the Planck law denies NPs the heat capacity to conserve absorbed solar radiation by an increase in temperature. Instead, solar radiation is conserved by the NPs creating EM radiation that is emitted to the atmosphere. The Planck law depends on NP temperature and maximum size. NPs larger than the maximum are macroscopic particles that follow classical physics and increase in temperature upon absorption of solar radiation.

III. PROPOSAL

To propose absorptive BC aerosols injected into the stratosphere provide geoengineering with a means to reduce solar radiation at the Earth surface to compensate for increasing carbon dioxide levels. Specifically, 2-micron spherical NPs of graphite comparable to BC injected at the top of the stratosphere. The solar radiation spectrum from UV to near IR is absorbed and converted to 10-micron radiation that escapes to space through the 8-10 micron atmospheric window. The graphite NPs produce 10-micron IR radiation without heating the atmosphere.

IV. METHOD

The analysis method is based on simple QED which is a nanoscale heat transfer process (nothing to do with Feynman's QED). Unlike elastic Mie theory having the emission frequency to be the same as the excitation frequency, simple QED changes the frequency of absorbed light in size dependent EM quantum states of the nanostructure. Since NPs are small compared the wavelength of incident light, simple QED assumes light is absorbed over the NP surface consistent with the high surface surface-to-volume ratio of NPs. But the Planck law precludes conservation of absorbed light by a temperature increase, and therefore simple QED asserts standing EM radiation is created inside the NP, the absorbed surface heat itself providing the EM confinement to constrain standing EM radiation inside and across the NP diameter. In effect, simple QED conserves EM heat in nanoscale regions by creating EM radiation - not temperature.

Simple QED energy E is quantized by the dimension d of the nanostructure that defines the half-wavelength $\lambda/2$ of the nanostructure. Fig. 1 illustrates the standing EM radiation in a spherical NP has a single quantum state corresponding to NP diameter d, but NP atoms still follow their quantized electron energy levels.

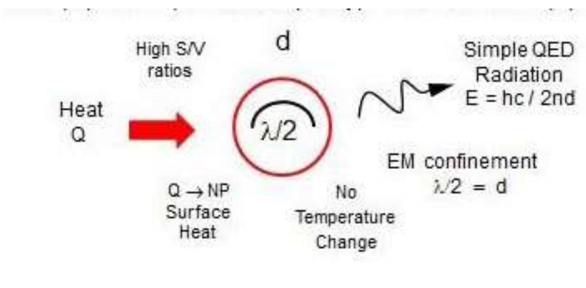

Fig. 1: Planck Energy of EM Radiation

In a rectangular NP with different dimensions of width, thickness, and length there are 3 simple QED quantum states corresponding to the different dimensions of the NP. Continuous variation in internal nanoscopic dimensions produces a broadband spectrum of simple QED quantum states. Fig. 1 shows simple QED absorbs heat Q in the NP surface because of the high EM confinement. Unable to conserve the surface heat by a change in temperature, conservation requires the creation of simple QED radiation. The Planck energy $E = h \cdot c/2nd$, where h is Planck's constant and c the velocity of light. The refractive index n of the NP corrects for the velocity c of light within the NP.

V. ANALYSIS

Solar radiation at 1365 W/m^2 at the Earth's surface is reduced by a factor of 4 to 340 W/m^2 as only a quarter of the Earth is illuminated at any time. Of the 340 W/m^2, Figure 1 shows reflected radiation is 29% while radiation absorbed in the atmosphere is 23%. Radiation that is absorbed by the Earth surface is 48%.

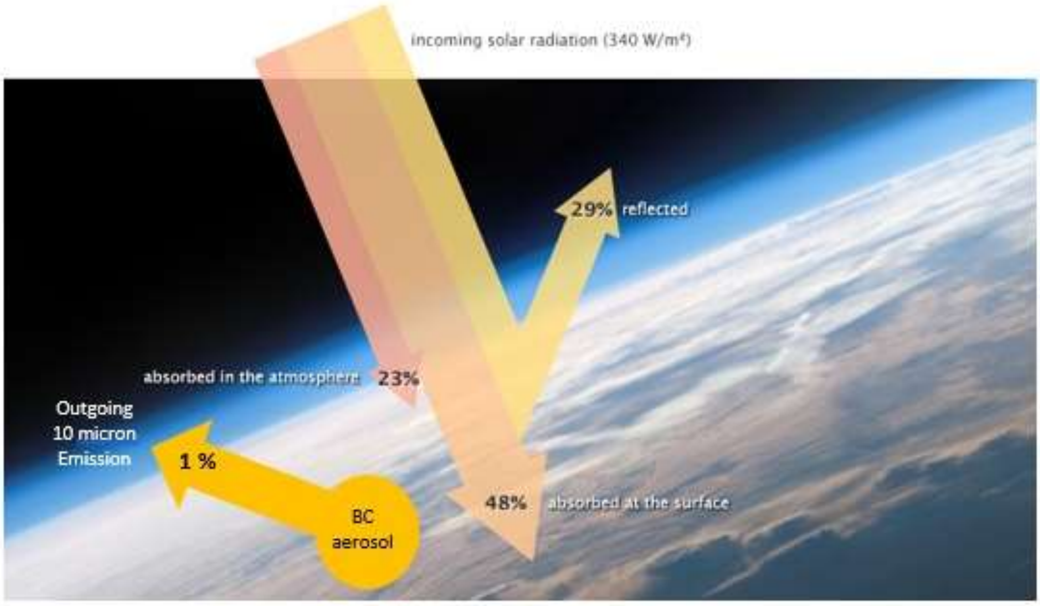

Figure 1. Distribution of Solar Radiation on Earth

In this analysis, the BC aerosol absorbs 1 % of the incoming solar radiation 340 W/m^2 or 3.4 W/m^2. Hence, 48 % of 3.4 W/m^2 or 1.6 W/m^2 that otherwise would have increased Earth temperature can correct for limited global warming.

Simple QED gives the emission wavelength λ = 2nd. Since λ = 10 microns, the particle diameter d = 5/n. From [5] the BC refractive index n at 10 microns is, n = 2.4. Hence, d ~ 2 microns. As discussed later, simple QED converts the heat from broadband UV-VIS-NIR solar radiation to 10-micron IR that is radiated back into space as 10-micron radiation through the 8-12 microns atmospheric window.

1. Number of BC Particles

For the Earth as a sphere of radius R and N spherical BC particles of diameter d, the ratio of solar radiation absorbed is,

$$\frac{\mathrm{NA_p}}{\mathrm{A}/4} = \frac{1.6}{340 * 0.48} = 0.01$$

where, $\mathrm{A} = 4\pi\mathrm{R}^2$ and $A_p = \pi d^2/4$.

Taking R = 6.37x10^6 m and d = 2 microns, A = 5.1x10^{14} m^2 and A_p = 3.1x10^{-12} m^2 giving, N = 4.1x10^{23}. The BC particle weight w = $\pi\rho d^3/6$ and total BC mass W = w·N that for ρ = 2000 kg/m3, w = 8.4x10^{-15} kg and W = 3.4x10^9 kg or 3.4x10^6 tons for the BC aerosol absorbing 1 % of the solar radiation. In comparison, 3 % reflection of solar radiation [1] required 3x10^7 tons of alumina, about 10x more mass than the BC aerosol.

2. Simple QED and the Planck law

The 2-micron BC particle chosen for the aerosol was selected to have the 10-micron emission and allow the solar radiation from the UV to near IR to dissipated to space, but only if BC particle heat capacity vanishes. Otherwise, the particle temperature increases to heat the atmosphere. For the stratosphere having temperatures at top and bottom of the stratosphere of 220 and 270 K, the Planck law for atoms in the BC particle is shown in Fig. 2.

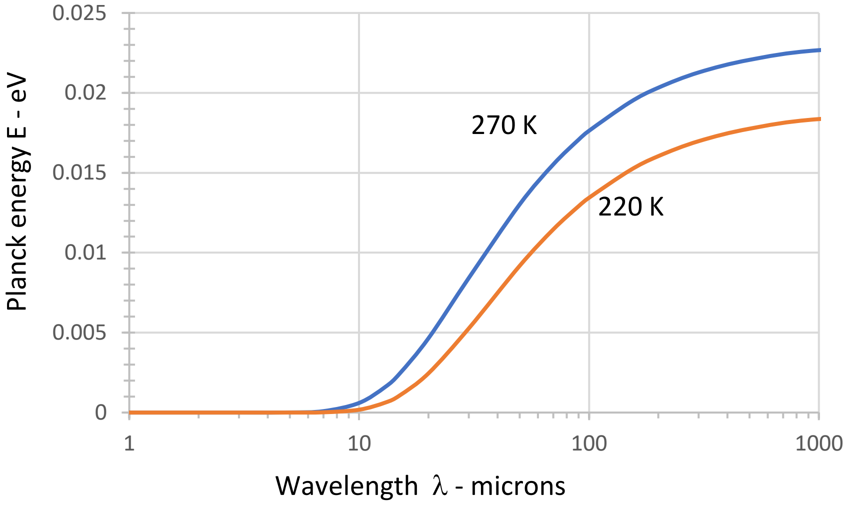

Figure 2. Planck law at 220 and 270 K

The Planck law shows the kT energy of the atoms in the BC particle at both 220 and 270 K vanishes to E < 400 μeV at wavelengths λ < 10 microns. What this means is all solar radiation from the UV to the near IR absorbed as heat by the 2-micron BC particle is emitted back into space at 10 microns.

VI. DISCUSSION

1. Classical Physics vs. Simple QED

Classically, the 2-micron BC particle atoms have heat capacity by the Planck law. The increase in temperature ΔT upon absorption of 1.6 W/m^2 solar radiation is,

$$\Delta T = \frac{1.6A_p}{wC}$$

where, w and C are mass and specific heat of the BC particle. For BC specific heat C = 708 J/kg-°C, the temperature rate is, ΔT = 0.83 °C/s.

In contrast, simple QED creates photons isothermally. The number Np of 10-micron IR photons emitted to space is,

$$N_p = \frac{1.6A_p}{E}$$

where, E = hc/λ. For λ = 2nd = 10 microns, E = 1.98x10^{-20} J, the rate of 10-micron photons emitted to space through the 8-12 microns atmospheric window is, N_p = 253x10^6 /s.

2. Health Concerns

The BC aerosol proposal to block 1 % of solar radiation carries the danger of health concerns. Indeed, BC geoengineering is thought [3] not viable as a means of modifying the climate. The problem with BC is soot is considered a major factor in respiratory illness and has been labeled as carcinogenic. The World Health Organization has estimated that up to 500,000 globally each year may be associated air quality exceeding the PM2.5 soot standard.

However, the PM2.5 standard includes not only micron sized particles, but also NPs. PM stands for particulate matter. By simple QED, the NPs emit EM radiation in the UV that causes inflammation and DNA damage leading to health problems. Micron sized particles in the PM2.5 standard emit EM radiation in the Near and far IR which does not cause health problems. In vaccinations, adjuvants to stimulate activation of the immune system antigens, the adjuvants comprising < 100 nm aluminum NPs. Upon vaccine injection, the adjuvant accumulates in the brain. Simple QED converts heat from the brain tissue [6] into UV radiation that activates the immune system, but also damages DNA leading to neuro-degenerative disease and autism. approved by the FDA about a century ago. Similarly, soot NPs cause health problems and micron sized particles are benign. Fig. 3 shows a typical PM2.5 soot particle extends over a few microns and meets the PM2.5 standard. However, the soot particle consists of numerous nanoscopic filaments noted in white circles. Simple QED induced EM radiation E is shown emitted from the filaments that cause health problems - not the micron agglomerate. Coating 2-micron solid spherical BC particles not only avoids health effects, but also ozone loss from chemical reactions between BC and ozone.

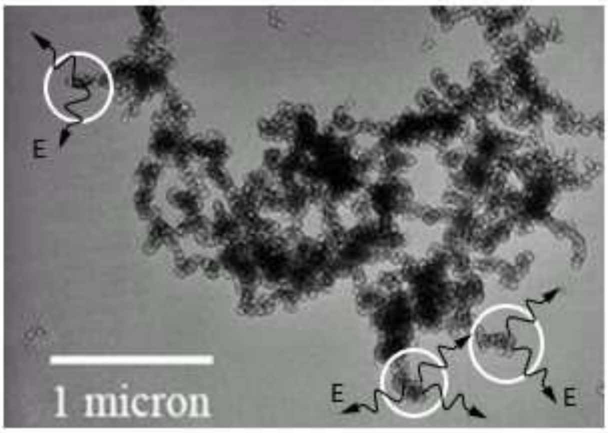

Figure 3. PM2.5 Soot - Micron Particles and NPs

3. Thermal Ozone Damage

Based on classical physics, injecting BC aerosols in the stratosphere [3,7] will cause stratospheric heating estimated above for 1.6 W/m2 as about 1°/s. Nuclear winter simulations [8] suggest catastrophic ozone losses would rapidly destabilize the stratosphere.

In contrast, the Planck law at stratosphere temperatures shows the atoms in 2-micron BC particles are denied the thermal kT heat capacity to increase in temperature as shown in Fig. 2. Contrary to classical physics, the BC particles do not increase in temperature at all, let alone cause stratospheric heating. At 1.6 W/m^2, there is no loss of ozone due to excessive stratosphere temperatures. However, the BC particles absorb UV radiation and preclude ozone formation, but comprising only 1 % of the Earth's surface area allow ozone formation without any significant difference.

4. BC Cost

Geoengineering with BC aerosols is usually based on NPs < 100 nm produced from soot in the burning of diesel fuel. Carbon black (CB) differs by being produced from combustion of heavy fuel oil in low oxygen. Both BC and CB therefore have similar density and refractive indices. However, a typical BC particle aerosol is approximately 0.1 micron while CB particles are larger of few mm. Hence, grinding mm size CB particles down to the 2-micron BC size is necessary. Either way, the annual cost of BC or CB aerosol is estimated [3] at about 2 trillion USD.

VII. CONCLUSION

The injection of BC aerosols into the stratosphere to absorb solar radiation and provide obtain negative -1.6 W/m^2 radiative forcing avoids the problem that reflection of solar radiation also includes an absorptive fraction that increases stratosphere temperature. Regardless of whether absorptive or reflective forcing surpass each other, the problem is the practicality of injecting 3 million tons of BC or sulfur aerosols in the stratosphere. A more practical BC global cooling alternative is suggested.

VIII. ALTERNATIVES

One alternative to injecting BC particles into the stratosphere is an Earth based extension of placing a number space mirrors in orbit [10,11] to reflect solar radiation back into space. The mirrors having an area of a square kilometer made of thin plastic reflective films to illuminate photovoltaic devices producing electricity.

Another alternative extends the injection of 2-micron BC particle aerosols into the stratosphere by providing a large number of flat 100 m square BC mirrors on the Earth surface. Although avoiding the difficulty of injecting BC particles into the stratosphere, geoengineering of many Earth based BC mirrors is still formidable. The BC mirrors are flat having a 2-micron BC layer on a silicon substrate, the BC layer facing the sun and the back-silicon surface facing the Earth surface as shown in Fig. 4.

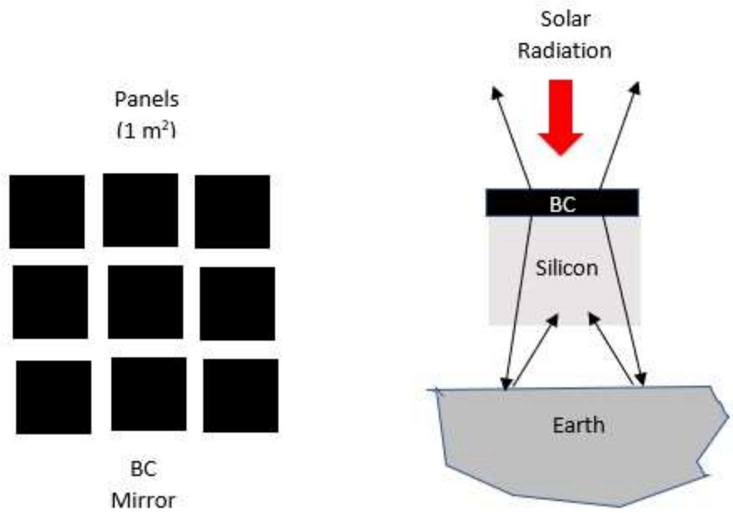

Fig. 4 Earth based Global Cooling BC Mirrors

Similar to BC particles, the BC mirrors have thickness of 2 microns, consistent with the same simple QED emission wavelength λ = 2nd $\sim$ 10 microns. Hence, simple QED converts the heat from the absorption of all UV-VIS-NIR solar radiation at the Earth's surface to 10-micron radiation that escapes the Earth through the 8-12 microns atmospheric window.

From the above 2-micron spherical BC particle design, the total BC mirror area $A_T = N \cdot A_p = 1.23 \times 10^{12}$ m^2 required is distributed with many BC mirrors spread over the Earth's surface. Each mirror area A_m is 100 m on a side having $A_m = 1 \times 10^4$ m^2 comprised of 1 m^2 panels, each panel consisting of a 2-micron

BC front surface on a supporting substrate transparent to 10-micron radiation, e.g., silicon. What this means is a very large number 123 million BC mirrors are required, the economic feasibility of which is yet to be determined. Nevertheless, the Earth based BC mirrors offer advantages over injecting 2-micron spherical BC particles into the stratosphere as health effects and the cost of continual BC particle injection into the stratosphere are avoided. Moreover, Earth based BC mirrors are more feasible than reflective mirrors deployed in space. Indeed, earth-based BC mirrors are more feasible than injection of BC or any reflective aerosol into the stratosphere and would be even more attractive if IR photocells are developed to utilize the 10-micron emission from the silicon substrate.

Nevertheless, geoengineering with BC mirrors is still prohibitively expensive, but may be necessary for the survival of the human species. Since removing carbon dioxide from the atmosphere is a decades long solution, the recommendation here follows [4] in that the near-term BC emissions be immediately reduced while Earth-based BC mirror technology is developed.

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