Terrestrial application of reflectors to arrest global warming.

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With the topic of climate change occupying an ever increasing share of the media, it is hardly surprising that a diverse range of ideas to solve the problem is being aired. There are two general approaches which can be adopted: (i) reduce and/or sequester CO_2 from the atmosphere, and (ii) reduce the intensity of the sun's radiation at the Earths surface. There is considerable advice available to the public regarding the first approach. The various ways to reduce our CO_2 output are indeed numerous and are effective to varying degrees.

With all the efforts to minimise the concentration of CO_2 in the atmosphere there are a number of less well known solutions which would be categorized under the second approach. These include: placing space based reflectors, either in orbit or at the inner Lagrange point[1], sulphur pumping where millions of tonnes of sulphur are injected into the upper atmosphere to create reflective aerosol particles, and detonating nuclear devices in low Earth orbit to irradiate the high atmosphere - the resulting radioactivity would in turn catalyse increased cloud formation. Such ideas, of course, generate their own problems, while space based reflectors incur high launch costs.

Another way forward also involves manufactured reflectors, but this time at the Earth's surface. A source[2] which suggests that it may be possible for individuals to have an effect is frankly naïve, although it is based on a sound idea. The reason being that the calculation on which it is based takes account only of the mass and specific heat capacity of the atmosphere, while much of the heat in the environment is in the oceans and the land masses.

This being the case a question arises as to the effective depth of the oceans and the land that is affected by environmental warming. Here we are assuming that the depths affected by seasonal temperature changes are a good approximation to this. It turns out that the effective ocean depth, on this basis, is around 300 m[3], and the similarly defined depth for land is surprisingly small at around 20 m[4,5]. The analysis to follow is based on these estimates.

If we first consider our objective of offsetting global warming, the expression for change in temperature, Θ, after a given time period, Δt, is given by

$$\Theta = \Delta t \frac{dT}{dt} - \Delta T \tag{1}$$

where dT/dt is the current rate of global warming and ΔT is the temperature offset which we need to generate. To keep global warming in check we need Θ to be zero or negative, that is

$$\Delta T \geq \Delta t \frac{dT}{dt}. \tag{2}$$

ΔT is related to the corresponding change in thermal energy, ΔE, of the environment by the relation

$$\Delta E = \left(m_a C_a + m_o C_o + m_l C_l \right) \Delta T \tag{3}$$

where m_a, m_o and m_l are the seasonally affected masses of the atmosphere, oceans and land respectively, and C_a, C_o and C_l are similarly their specific heat capacities. Importantly ΔE

is the energy which would be absorbed by the environment over the time Δt if we don't reflect it back.

The time period of interest, Δt, is related to the energy we reflect back by $P\Delta t = \Delta E$ where P is the averaged total power reflected back. This power is given by the intensity, *I*, of solar radiation at the Earth's surface and the effective area, *A*, of ideal reflectors on the daylight side of the planet, by the relation $P = IA$. It is this area, *A*, over which we have control.

Given a little algebra we now have sufficient information to right down equation (1) as

$$\Theta = \Delta T\left[\frac{\left(m_a C_a + m_o C_o + m_l C_l\right)}{IA}\frac{dT}{dt} - 1\right]. \tag{4}$$

So to maintain the averaged atmospheric temperature at a constant value ($\Theta = 0$), the minimum reflective area required to do this is given by

$$A = \frac{\left(m_a C_a + m_o C_o + m_l C_l\right)}{I}\frac{dT}{dt}. \tag{5}$$

Values on the right hand side of equation (5) are given by

$m_a = 5\times10^{18}$ kg
$m_o = 1.1\times10^{20}$ kg
$m_l = 1.5\times10^{19}$ kg
$C_a = 990$ $\mathrm{Jkg^{-1}K^{-1}}$
$C_o = 4186$ $\mathrm{Jkg^{-1}K^{-1}}$
$C_l \approx 500$ $\mathrm{Jkg^{-1}K^{-1}}$
$I = 630$ W (Calculated from [6])
$\frac{dT}{dt} = 6.7\times10^{-10}$ $\mathrm{Ks^{-1}}$ (About 2 $^{\circ}$C per century).

This gives $A = 5.03\times10^{11}$ $\mathrm{m^2}$. Of course *A* is the total reflector area on the daylight side only, so the total required area, globally, is $2A \simeq 1$ million $\mathrm{km^2}$.

To achieve a cooling we would need to exceed this. Suppose we wanted to reduce the time averaged global temperature by 1 $^{\circ}$C over a 20 year period. Then in equation (1) we have $\Theta = -1$ and $\Delta t = 20$ years. We then solve for ΔT and use equation (3) to obtain ΔE. For convenience, if we use the symbol $\Sigma mC = m_a C_a + m_o C_o + m_l C_l$ for the total heat capacity of the environment, then after a little algebra we have the required daylight side reflector area

$$A = \frac{\Delta T \Sigma mC}{I\Delta t}. \tag{6}$$

From equation (1) we have $\Delta T = 1.4$ K and from the data above $\Sigma mC = 4.73\times10^{23}$ $\mathrm{JK^{-1}}$. This gives $2A \simeq 3.33\times10^{12}$ $\mathrm{m^2}$.

It is interesting that these values for A are of a similar order of magnitude to those implied in Schirber's article[1]. In one case a single disc shaped space based reflector with a diameter of 2000 km is considered. Another solution involves an array of 1.6×10^{12} smaller reflectors positioned at the Lagrange point. These would each have a diameter of 0.6 m. The cost of launching such a large area of reflectors is likely to be prohibitive. So the question is, why not just site them on the Earth's surface? The obvious and most effective places for such installations would be the deserts.

The Sahara desert with an area of around 9.1 million km^2 is a good place to start, at least on a practical level. To reach the 'break even' point (equation (5)) would require about 10% of this area. A much greater barrier to this is likely to be due to the political instability of the area. However, the USA and Australia also have extensive desert expanses. Surely some inroads could be made there.

References

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