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A2_8 Sunshades for the Earth

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Abstract

This article examines the theoretical size of a sunshade that could be employed to combat the heating effects of climate change. It is found that a change in emissivity of as little as 0.06 could result in a global mean temperature change of around 4 K. To counteract this temperature change, a sunshade of area 7.45×10^{12} m^2 placed at the L_1 point would be required.

Introduction

The Earth absorbs radiation from the sun and reemits it as radiation in the infra red band. A body in space can maintain a constant temperature by emitting the same amount of energy as it absorbs. However if the body has a mechanism of absorbing some of the energy it emits, then its temperature will rise. On Earth, greenhouse gases in the atmosphere can absorb infra red radiation, trapping heat in the atmosphere of the planet.

Analysis

Using a simplified radiative balance model of the Earth [1] whereby the planet's absorption and emission of radiation are in equilibrium, we can say

$$T = \left(\frac{S(1-A)}{4\varepsilon\sigma}\right)^{\frac{1}{4}}, \qquad (1)$$

where A is the average albedo (a measure of reflectivity) of the Earth which takes a value of 0.3 [2] and is assumed independent of wavelength, σ is the Stefan-Boltzmann constant, ε is the mean emissivity of the Earth, to which we are assigning a value of 1 [1], T is the mean temperature of the planet and S is the solar flux at Earth found by dividing the bolometric power output of the Sun, 3.9×10^{26} W, by the surface area of a sphere with radius of 1 AU (1.5×10^{11} m).

Using these figures, the mean temperature of the Earth is found to be ~255 K. This equation assumes that ε is independent of wavelength in order to equate its effects to those of absorption, controlled by A. As greenhouse gases are released into the atmosphere, the emissivity of the planet will decrease, effectively trapping more heat.

If we rearrange (1) for S and multiply by the cross sectional area of the Earth, we get

$$P = \frac{4\pi {R_E}^2\varepsilon\sigma T^4}{1-A}, \qquad (2)$$

where P is the net power incident on the Earth and R_E is the Earth's radius. Now, by setting the temperature to a constant 255 K and decreasing the emissivity, we can find a value for the power that would have to be incident upon the Earth to maintain this temperature when more heat is trapped by greenhouse gases. Subtracting this from the original power incident upon the Earth we get

$$\Delta P = \frac{4\pi {R_E}^2 \sigma T^4}{1-A} \Delta\varepsilon, \qquad (3)$$

which is the amount of power that must be stopped to maintain the temperature with a change in emissivity of $\Delta\varepsilon$.

If a solar shade were to be employed to effect this change then it would have to be constantly between the Earth and the Sun. This could be achieved by placing it at the L_1 point, the point between the Earth and the Sun where the combined effect of the gravitational pull of the two bodies equals the centripetal force required for the shade to orbit the Sun with the same period of the Earth. This is about 1.5 x10^9 m from the Earth [3].

Dividing the power difference by the flux at the L_1 point gives us an area that would need to be blocked in order to maintain a constant temperature.

$$a = \frac{4\pi {R_E}^2 \sigma T^4}{S_{L_1}(1-A)} \Delta\varepsilon. \qquad (4)$$

As we are maintaining *T* at 255 K, the only variable in (4) is $\Delta\varepsilon$. If we substitute in the values of the constants then we arrive at

$$a = 1.24 \times 10^{14} \, \Delta\varepsilon. \quad (5)$$

Conclusion

Equation (5) shows the necessary area of the sunshade as a function of $\Delta\varepsilon$. It is clear that, for even a small change in emissivity, a huge structure would be required to maintain a constant temperature. A change of just 0.06 in the emissivity would result in a mean temperature rise of just over 4 K (from equation (1)). This level of global temperature change could be considered catastrophic for many occupants of the planet. In order to negate this change, according to this model, a solar shade of area 7.45x10^{12} m^2 would be required. Such a structure would represent the largest construction project ever undertaken by mankind and would probably require new building materials or techniques to be implemented as it is unclear that a construction of this size could support itself adequately. It would also be advisable to erect the shade in situ at the L_1 point, as transport of the completed shade would be likely to place unnecessarily large structural stresses upon it.

This method does have limitations, such as assuming that *A* and ε are wavelength independent. In reality the emissivity used here is effective in the infra red band and the albedo is effective in the UV and visible bands. It has also been assumed that greenhouse gases will have no effect on the planet's albedo. Should the albedo increase, more of the incident radiation would be reflected into space. The concept of a sunshade itself has limitations. It is, for example, impractical to replace such a large structure in response to changes in the planet's emissivity on short time scales of years or even decades. With this in mind, a structure whose area can be expanded or shrunk in response to a mean emissivity change would be preferable to a rigid one.

References

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[2] P. R. Goode *et al.*, *Geophys. Res. Lett.* **28**, 1671 (2001).
[3] *http://www.esa.int/esaSC/SEMC4QS1VED_index_0.html*