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P2_7 Outrunning Climate Change

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Abstract

In this paper we investigate the rate at which you would have to move Earth away from the Sun to combat the global temperature increase due to climate change. By assuming the average global temperature increases linearly between 0.200 $°C$ or 4.80 $°C$ by the year 2100, we found that the Earth would need to be moved between 5.44×10^6 and 1.31×10^8 meters per year.

Introduction

One of the biggest challenges currently facing humanity is climate change. Our global reliance on coal, oil and natural gas means we are emitting billions of tons of greenhouse gases per year into the atmosphere. Even with our increasing understanding of the problem and efforts to reduce emissions, this is only expected to increase as energy demands increase. The Intergovernmental Panel on Climate Change (IPCC) have predicted global warming to be 0.200 $°C$ by 2100 (from 2021) in a "low-emissions" scenario (0.2 Case) [1]. The second, "high-emissions", scenario (4.8 Case) gives an upper bound of 4.80 $°C$. To illustrate the severity of global warming, we calculated the rate at which the Earth would have to be moved away from the Sun to keep the surface temperature of Earth constant at it's present-day value.

Theory and Method

Firstly, by assuming the Sun emits radiation as a black-body, the flux radiated by the Sun can be calculated using the Stefan-Boltzman Law,

$$F_{sun} = \sigma T_{sun}^4, \tag{1}$$

where σ is the Stefan-Boltzman constant and the effective temperature of the solar atmosphere, T_{sun}, is 5770 K [2]. This gives a value of $6.29 \times 10^7 \ Wm^{-2}$. This can then be used to find the global mean insolation, S - the irradiance that reaches Earth - assuming Earth's orbit is circular with radius, $a = 1.50 \times 10^{11} \ m$ ($1AU$).

$$S = \frac{(4\pi R_s^2) F_{sun}}{4\pi a^2}, \tag{2}$$

where $R_s = 6.96 \times 10^8 \ m$, the radius of the Sun. S is an average which covers days, nights and seasons. This result can be used to find the surface temperature of Earth. To do this we assume that the atmosphere is transparent to shortwave solar radiation but longwave, terrestrial radiation is absorbed by each greenhouse gas in the atmosphere. To find the surface temperature, T_{surf} we use

$$T_{surf} = \sqrt[4]{\frac{(n+1)S(1-\alpha)}{4\epsilon_s \sigma}}, \tag{3}$$

assuming Earth's albedo is $\alpha = 0.30$ and emissivity is $\epsilon = 1.00$ [3]. We have chosen the number of layers for Earth's atmosphere, n, to be 5 to represent the major greenhouse gases in the atmosphere. These are H_2O, CO_2, CH_4, N_2O and O_3 [3]. By substituting (1) into (2), and substituting this into (3), we have the surface temperature of Earth as a function of distance from the Sun which is plotted in Figure 1.

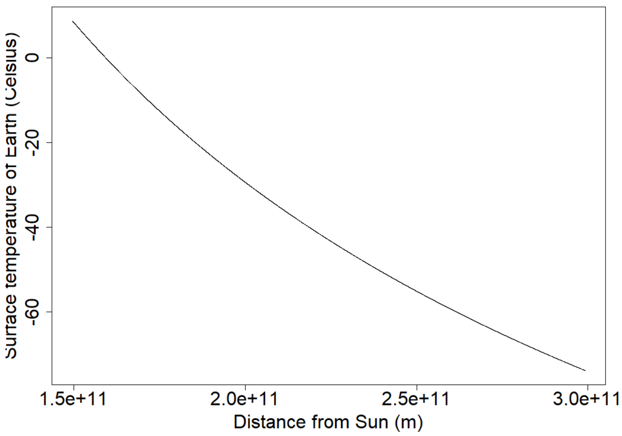

Figure 1: How the surface temperature of Earth would change with distance from the Sun.

Assuming the temperature increase projected by the IPCC is linear, we calculated the temperature increase each year to be 0.00256 $°C$ for the 0.2 Case, and 0.0615 $°C$ for the 4.8 Case. To calculate how much the Earth would have to move to counteract this heating, we rearranged Eq. (3) to find the derivative of a with respect to T_{surf}. The chain rule can then be used to find the rate the Earth would need to move to keep the surface temperature constant.

Discussion

Using the gradients from Figure 2 we found that the distance Earth would have to be moved each year in the 0.2 Case is 5.44×10^6 m and 1.31×10^8 m for the 4.8 Case. This is based on the assumption that global warming is linear, however measurements of previous decades have shown that warming has accelerated [4] meaning the rate at which Earth would need to move would also accelerate. Also, other heating sources of Earth have not been considered (such as from radioactivity) meaning the calculated surface temperatures are an underestimate.

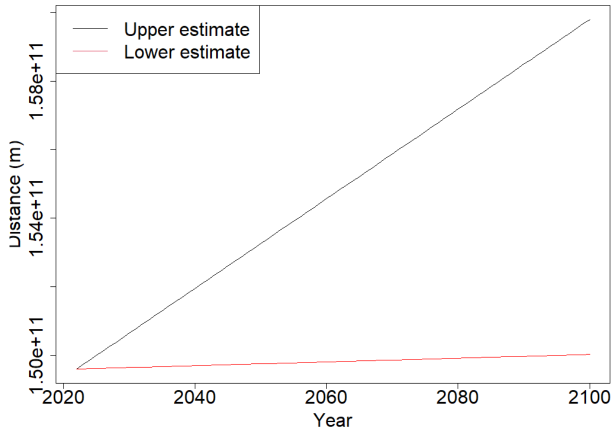

Figure 2: Distance Earth would need to be from the Sun to keep the temperature of the surface constant from 2022 to 2100.

Conclusion

In conclusion, the rate at which Earth would need to be moved was calculated to be 5.44×10^6 m per year for the 0.2 Case and 1.31×10^8 m per year for the 4.8 Case. However, this is likely an underestimate. Further work on this could include considering the change in atmosphere composition over time, but this is out of the scope of this paper. Clearly, this is not a feasible solution to combating climate change, however this does illustrate the severity of the climate crisis.

References

[1] `https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-4/` [Accessed 25 October 2022]

[2] `https://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html` [Accessed 25 October 2022]

[3] Dr Michael Barkley. Planetary Physics Unit 2. University of Leicester, PA3606, 2021-2022. Course taken 2021.

[4] `https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-1/` [Accessed 25 October 2022]