Melting the Antarctic Ice

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Abstract

The melting of the polar ice caps is widely discussed; this article considers the repercussions of the ice shelf in Antarctica melting and the prospect of using an array of lasers to do so. The energy required to melt the $3 \times 10^7 \text{km}^3$ of ice was found to be $1.12 \times 10^{25} \text{J}$, it was found to take 22.2 hours for an array of $1.4 \times 10^{11}$ lasers to melt the ice. The melting of this much ice would cause the sea level to rise 77m above its current level.

Introduction

The melting of the polar ice caps is a well-known scenario that has been featured in films such as Waterworld in 1995 [1]. The aim of this article is to estimate the energy that would be required to melt the ice shelf of Antarctica and the repercussions of such a scenario on the sea level around the globe. Additionally the time required for an array of free electron lasers to melt the ice is estimated.

Antarctica is the fifth largest continent on Earth, covering 14 million km$^2$ and containing 30 million km$^3$ ($3 \times 10^{16} \text{m}^3$) of ice, with a density of 0.92 $\times$ $10^3 \text{kgm}^{-3}$ [2], around 90% of the planet’s fresh water [3]. It is classified as a desert and is nearly inhospitable, with an average temperature of $-34.4^\circ\text{C}$ [4] during the winter.

Theory

The energy required, $Q$, to raise the temperature of a substance of mass, $m$, specific heat, $c$, by an amount $\Delta T$ and melt the substance of latent heat of fusion, $L_f$, is given by

$$Q = mc\Delta T + mL_f. \quad (1)$$

Putting values into this equation the total energy required to melt the ice can be found.

In order to calculate the volume of a shell in a sphere, $V_{\text{shell}}$, the following equation can be used,

$$V_{\text{shell}} = \alpha \left( \frac{4}{3} \pi R_E^3 - \frac{4}{3} \pi r^3 \right). \quad (2)$$

This is used to calculate the volume of water on the Earth, where $R_E$ is the radius of the Earth and $r$ is the radius of the Earth when neglecting the average ocean depth, as depicted in figure 1. It is also necessary to account for only a portion of the Earth’s surface being covered in water, $\alpha$, which is taken to be 0.7.

![Figure 1: Illustration of the Earth-ocean model, where $R_E$ is the radius of the Earth and $r$ is $R_E$ minus $D$, where $D$ is average ocean depth.](image)

The time required for an array of lasers to melt the ice, $t_{\text{melt}}$, can be found by assuming each laser in the array melts an area of 1m$^2$, $A_v$, with all energy going into melting the ice, using

$$t_{\text{melt}} = \frac{QA_l}{AP_l}, \quad (3)$$
where $A$ is the area of Antarctica and $P_l$ is the power of the laser.

Results

The total mass of ice in the Antarctic ice shelf was found to be $2.76 \times 10^{20}$ kg. It was assumed that the average temperature of Antarctica, stated above, is the temperature across the whole of the continent. The value 34.4°C was used for $\Delta T$ as this is the change in temperature required to bring the ice to its melting point. The specific heat of ice is $2.05 \times 10^3$ J kg$^{-1}$ K$^{-1}$ [5], whilst the latent heat of fusion of ice was is $334$ kJ kg$^{-1}$ [6]. The values were substituted into equation 1 and the total energy required to melt the ice was found to be $1.12 \times 10^{25}$ J.

The average depth of the ocean is $4.3 \times 10^3$ m [7] and the radius of Earth is $6378 \times 10^3$ m [8]. The current volume of water on Earth found using equation 2 is $1.54 \times 10^{18}$ m$^3$.

The volume of water from the melted ice was calculated by using the mass of ice and the density of water, $1000$ kg m$^{-3}$ [4], and was found to be $2.76 \times 10^{16}$ m$^3$. In order to find the new volume of water on the Earth it is necessary to add the current volume of water and the melted ice. This gave a total volume of $1.56 \times 10^{18}$ m$^3$. Rearranging equation 2 and using the new total volume, the rise in global sea level was found to be $77$ m.

A free electron laser is capable of producing a power, $P_l$, of $10^8$ W [9], and the area of Antarctica, $A$, is $1.4 \times 10^{17}$ m$^2$. When these values and $Q$, calculated above, were put into equation 3 the time taken to melt the ice was found to be $22.2$ hours.

Conclusion

A rise in the sea level of 77 m would flood coastal regions all around the globe, an example of this is shown in figure 2 where a rise in sea level of 77 m has been applied to a map of Europe. The figure shows many major cities are submerged including Amsterdam and Helsinki, with around 1.2 million people [11] occupying these two cities alone. Additionally a large portion of Britain, approximately a third, is submerged destroying coastal towns and cities, impacting the entire country.

The laser array would be incredibly difficult to build and power, as $1.4 \times 10^{21}$ lasers would be needed. These lasers possess efficiencies of around 5% [9] suggesting 20 times the energy required to melt the ice must be provided. Additionally, the peak power has been used but in reality the laser could only provide a smaller continuous power.

References

[1] “Waterworld”, 2005, Kevin Reynolds (Director), Universal Pictures, USA.