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P3_4 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 x 10^7km^3 of ice was found to be 1.12 x 10^{25}J, it was found to take 22.2 hours for an array of 1.4 x 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 x 10^{16}m^3) of ice, with a density of 0.92 x 10^3kgm^{-3} [2], around 90% of the planets fresh water [3]. It is classified as a desert and is nearly inhospitable, with an average temperature of -34.4°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 ΔT and melt the substance of latent heat of fusion, L_f, is given by

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

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_{shell}, the following equation can be used,

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

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, α, which is taken to be 0.7.

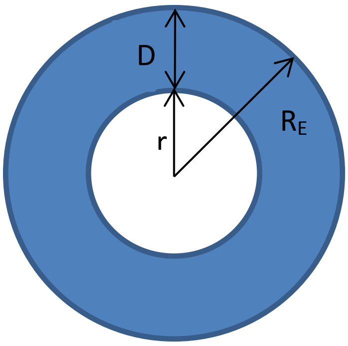

Figure 1: Illustration of the Earth-ocean model, where R_E is the radius of the Earth and r is R_E minus D, where D is average ocean depth.

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

$$t_{melt} = \frac{QA_l}{AP_l}, \qquad (3)$$

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 x 10^{19}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 ΔT as this is the change in temperature required to bring the ice to its melting point. The specific heat of ice is 2.05 x 10^3Jkg^{-1}K^{-1} [5], whilst the latent heat of fusion of ice was is 334kJkg^{-1} [6]. The values were substituted into equation 1 and the total energy required to melt the ice was found to be 1.12 x 10^{25}J.

The average depth of the ocean is 4.3 x 10^3m [7] and the radius of Earth is 6378 x 10^3m [8]. The current volume of water on Earth found using equation 2 is 1.54 x 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, 1000kgm^{-3} [4], and was found to be 2.76 x 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 x 10^{18}m^3. Rearranging equation 2 and using the new total volume, the rise in global sea level was found to be 77m.

A free electron laser is capable of producing a power, P_l, of 10^9W [9], and the area of Antarctica, A, is 1.4 x 10^{11}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 77m would flood coastal regions all around the globe, an example of this is shown in figure 2 where a rise in sea level of 77m 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.

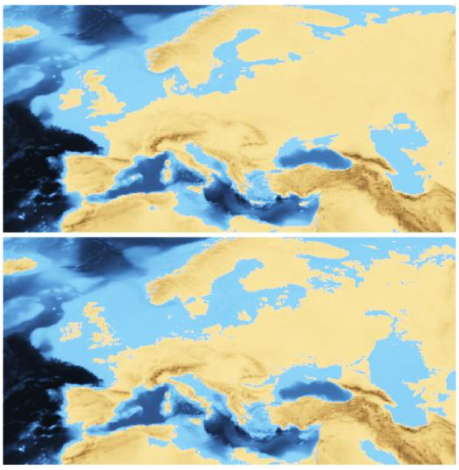

Figure 2: Map of Europe showing current sea levels (top) and sea levels after a 77m rise (bottom) [10].

The laser array would be incredibly difficult to build and power, as 1.4 x 10^{11} 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.
[2]P. Tipler, *Physics For Scientists and Engineers* (2008), Ed. 6, p. 424.
[3]www.antarctica.ac.uk/about_antarctica/geography/ice/sheets.php accessed on 28/10/12.
[4]www.nasa.gov/audience/forstudents/5-8/features/what-is-antarctica-58.html accessed on 28/10/12.
[5] P. Tipler, *Physics For Scientists and Engineers* (2008), Ed. 6, p. 592.
[6]www.engineeringtoolbox.com/latent-heat-melting-solids-d_96.html accessed on 28/10/12.
[7]www.oceanservice.noaa.gov/facts/oceandepth.html accessed on 28/10/12.
[8]www.nssdc.gsfc.nasa.gov/planetary/factsheet/Earthfact.html accessed on 28/10/12.
[9]P. O'Shea and H. Freund, *Free-Electron Lasers: Status and Applications* (Science, 2001), Vol. 292, p. 1853.
[10]merkel.zoneo.net/Topo/Applet/ accessed on 13/11/2012.
[11]www.worldatlas.com/capcitys.htm accessed on 27/11/2012.