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P3_9 The Loudest Sound

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Abstract

Two of the most prominent natural explosions in history were the Tunguska event and the Krakatoa eruption, using the decibel levels of each sound to estimate the pressure, and thus the energies of each eruptions reveals their values to be $1.37 \cdot 10^{29} J$ and $5.09 \cdot 10^{29} J$ respectively, which are found to be drastic over-estimates. The reasons for this are discussed.

Introduction

On June 30^{th}, 1908, an enormous explosion rang out across the Siberian taiga. The Tunguska event, famous for being one of the loudest recorded sounds on Earth, happened when a meteor entering the Earth's atmosphere exploded around 15 miles ($24km$) off the ground. The resulting shockwave was powerful enough to knock people off their feet kilometers away. The sound from this explosion measured at between $300 - 315dB$, and is rivalled in magnitude only by one other event [1].

The Krakatoa explosion in 1883 was so catastrophic that it destroyed the island at its epicenter. The sounds of its eruption were heard 50 miles ($80km$) away, and the cloud of ash darkened the skies in the area for several days. The eruption measured at $187dB$ at a distance of 100 miles away [2].

Theory

The sound intensity level is given by [3]

$$\beta = 10log_{10}(\frac{I}{I_0}) \tag{1}$$

where β is measured in dB, I is the intensity of the sound in Watts per square meter, and I_0 is the reference intensity (in air this is around $10^{-12}Wm^{-2}$ [3]).This can be rearranged for the intensity as

$$I = I_0 10^{(\frac{\beta}{10})} \tag{2}$$

The sound intensity can also be related to sound pressure [4], as

$$I = pv \tag{3}$$

where v is the velocity of the spherical pressure wave (in this case this is the speed of sound in air, or $343ms^{-1}$), and finally this can be used to calculate the energy of the wave simply by

$$E = pV \tag{4}$$

where V is the volume of the pressure sphere.

The Tunguska event had an average intensity level of $307.5dB$, and flattened trees for approximately $1994km^2$. Meanwhile, Krakatoa was measured at $187dB$ $160km$ from the source, and is projected to have peaked at around $310dB$ at the source. Since the energy was diminished by the time the sound level was measured $160km$ away, this paper will calculate two values, one at the further distance, and one at a distance of $16km$ from the source, where it is estimated the pressure would have been sufficient to instantly deafen any onlookers.

Results

The Intensity of the Tunguska blast was around $5.62 \cdot 10^{18} Wm^{-2}$ from equation (2), giving a sound pressure of $1.64 \cdot 10^{16} Pa$, and a total energy release of $1.373 \cdot 10^{29} J$.

Meanwhile, the Krakatoa eruption at a distance of $160km$ had an intensity level of $5.011 \cdot 10^{6} Wm^{-2}$, and therefore had an associated pressure of $1.46 \cdot 10^{4} Pa$, giving an energy of $1.57 \cdot 10^{15} J$, while at a closer distance of only $16km$ (with a reading of $310dB$), the intensity is much higher at $1 \cdot 10^{19} Wm^{-2}$, giving a sound pressure of $2.92 \cdot 10^{16} Pa$, and an energy release of $5.09 \cdot 10^{29} J$.

Discussion and Conclusion

From these values it is clear that the two explosions were roughly equivalent in terms of power released, however the Krakatoa eruption was slightly more energetic. The energies of explosions are traditionally quoted in megatons of TNT rather than Joules, and doing so reveals that Tunguska was equivalent to $32.8 \cdot 10^{12}$ Megatons, while Krakatoa measures at $121 \cdot 10^{12}$ Megatons. In truth, Tunguska was estimated to be equivalent to between ten and forty Megatons of TNT (most estimates put it at around fifteen [5]), while Krakatoa was supposedly around two hundred Megatons [6].

The reason for this discrepancy in results is likely due to the fact that these calculations don't account for the damping of energy as the pressure wave travels. As shown by the two different results obtained for the Krakatoa eruption, the energy falls off quite quickly with distance (as $\frac{1}{r^2}$). Since the calculations have used values for the epicentre of each blast, the estimated radius of each blast is likely much larger than the true value for the epicentre size, and the reading would have already dropped significantly by this radius.

There are two ways to counter this error. First, the calculations could be done with a radius of the initial blast. But the issue then becomes a question of what that radius should be. For the Tunguska event, it may be reasonable to use the radius of the meteorite itself, though since no samples of it have been found, its true size remains an estimate and nothing more. Krakatoa is an altogether different problem. How does one decide the radius of a volcanic eruption? There is no clearly defined size of the eruption, and because it happened in the 1800s, nobody had taken any detailed topography of the island. Since the island was destroyed, it is impossible to reasonably estimate the size of the volcano. The other solution would be to introduce some reduction factor to the calculation to account for the energy lost as sound travels, however doing so would require extensive research into the topic, the likes of which cannot be covered in so short a paper.

References

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[5] The Tunguska Meteorite Problem Today, N.V. Vasilyev, July 1997

[6] `https://www.history.com/topics/natural-disasters-and-environment/krakatoa`[Accessed 26/11/2020]