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Solutions for Fermi Questions, October 2022 Cloud Ripple Pattern

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Fermi Questions

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Cloud Ripple Pattern

Question 1:

Last summer, as I was walking across campus I noticed the above cloud with wave-like structure. This cloud is most likely an isolated example of *altocumulus undulatus*, which most commonly occurs in the altitude range of 2.5 – 6 km. This cloud was at approximately a 45-degree elevation, and the wavelength (or crest-to-crest distance) was about the width of my index finger held at arm's length. Estimate this wavelength.

Solution: If we take the altitude of the cloud to be approximately 5 km, then the line-of-sight distance is $\approx 5\sqrt{2}$ km. Let the average wavelength of the billow pattern be d km. It is this length that we wish to find. The length of my outstretched arm is about ½ m, and my forefinger width is ≈ 2 cm. Therefore, by simple proportion (d km)/(2 cm = [$(5\sqrt{2})$ km)/(50 cm)]; hence $d = 0.3$; the wavelength is very small, about 300 m. This type of cloud can be generated by the Kelvin-Helmholtz shear instability.
Link for Kelvin-Helmholtz instability:

https://www.eoas.ubc.ca/courses/atsc113/flying/met_concepts/01-met_concepts/01b-special-clouds/billow.html#:~:text=Because%20these%20waves%20happen%20in,cloud%20layer%20

A word about foreshortening: If the ripples were parallel to my line of sight there would be no foreshortening of the wavelength. If they were perpendicular to this direction, there would be a foreshortening factor (at 45-degree elevation angle) of $1/\sqrt{2}$. At any other intermediate ripple angle to my line of sight, the corresponding factor would be smaller. Given the uncertainties inherent in my observations, this factor can be ignored.

Question 2:

Estimate the area of the shadow cast on the ground by the cloud.

Solution: I can count about 14 wavelengths, so the cloud width from left to right is approximately 5 km. Treating the cloud as approximately rectangular in shape, with area 5 km × 1 km, the shadow area is approximately 5 km^2. (Note that this is independent of the Sun's altitude.)