

How can a cloud stay in the air?

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QUE · Article 014 · Simple Questions, Deep Answers · Version 0.1 EN

A cloud is not a weightless object. Its visible parts contain liquid water droplets, ice particles or both. Many of those particles are falling relative to the surrounding air. A cloud can nevertheless remain visible because small particles settle slowly, air moves, and condensation and evaporation continually change which particles exist.

The question becomes much easier once we stop imagining a cloud as one solid body suspended above the landscape. The visible outline marks a changing region in which condensed water is present. It need not enclose the same collection of droplets from one moment to the next.

1. What is visible is not the water vapour

Water vapour is the gas phase of water and is not itself the white material we see. Droplets and ice particles scatter light and make a cloud visible. The National Weather Service describes ordinary terrestrial clouds as condensed liquid or solid water, with atmospheric particles often providing sites for droplet formation [1].

Cooling an air parcel can bring its water vapour to saturation and permit condensation. Rising air often expands and cools, which is one important route to cloud formation. It is not the only one: the required change in temperature and moisture can occur in different meteorological settings.

Saturation concerns the relation between vapour pressure and temperature. Saying that cold air simply has fewer empty spaces in which to hold water supplies the wrong microscopic picture. Air is not a sponge with temperature-controlled holes. Nor does every small cooling of any air parcel immediately create a cloud; its initial moisture state matters.

Particles on which droplets form also matter, so cloud development is not determined by temperature alone. The detailed activation of particles and growth of droplets is a microphysical problem. For the present question, the essential result is that a visible cloud contains many small condensed particles rather than one enormous drop.

2. Small droplets have small settling speeds

A falling droplet experiences gravity, buoyancy and aerodynamic drag. After a short adjustment, drag can balance its effective weight, giving a terminal speed relative to the air. Terminal does not mean the droplet has stopped; it means its falling speed is no longer increasing under the stated conditions.

For a small spherical particle moving slowly through a viscous fluid, Stokes' law gives drag magnitude $6\pi\mu rv$, where μ is dynamic viscosity, r particle radius and v speed relative to the fluid [2]. Equating this to effective weight, $(4\pi r^3/3)(\rho_w - \rho_a)g$, gives $v = 2(\rho_w - \rho_a)gr^2/(9\mu)$. Here ρ_w and ρ_a are water and air densities, and g is gravitational acceleration.

The radius-squared dependence is the crucial result. Weight scales with volume, hence r^3 , while this low-speed drag scales with r . Small particles therefore reach a balance at low speed. The formula is a low-Reynolds-number approximation for an isolated sphere, not a law for all raindrops, ice crystals or turbulent interactions.

Use illustrative near-surface inputs: $\rho_w = 1,000 \text{ kg/m}^3$, $\rho_a = 1.2 \text{ kg/m}^3$, $\mu = 1.8 \times 10^{-5} \text{ Pa s}$ and $g = 9.81 \text{ m/s}^2$. A radius of 10 micrometres then gives about 0.0121 m/s, or 1.21 centimetres per second. These are specified model inputs, not a measurement of every droplet in a cloud.

The associated Reynolds number, $\rho_a v(2r)/\mu$, is about 0.016, consistent with using the slow-flow approximation. Doubling the radius gives four times the model speed, about 0.0484 m/s, and a Reynolds number near 0.13. As particles grow further, extrapolating the same formula without checking its regime becomes inappropriate.

3. Falling through air is not necessarily falling towards the ground

Velocity relative to the air differs from velocity relative to the ground. If air moves upward faster than a droplet settles through it, the droplet rises relative to the ground. If the upward motion is weaker, the droplet may still descend, but slowly. A cloud need not contain a force that cancels gravity directly for every particle.

For the 10-micrometre example, a hypothetical upward air speed of 0.020 m/s would exceed the calculated settling speed. The droplet's net vertical speed would be about 0.0079 m/s upward in this simple steady comparison. This is an illustration of adding velocities, not a statement that a particular cloud has that uniform updraft.

In perfectly still air, the same terminal speed would require roughly 2.3 hours to fall 100 metres. That calculation does not establish a cloud lifetime. Real droplets can evaporate, grow, collide or enter different air motions during the interval. It only demonstrates why a small falling particle does not immediately leave a deep cloud.

Buoyancy also needs careful wording. A liquid droplet is much denser than air and is not individually buoyant like a helium balloon. Buoyant motion of a moist air parcel is a separate matter involving the parcel's density relative to its surroundings. The cloud can be associated with rising air even though its droplets have downward settling velocities relative to that air.

4. The boundary is being rebuilt

A droplet entering sufficiently unsaturated air can evaporate. Water vapour entering a region favourable to condensation can contribute to droplets. Consequently, the edge of a cloud can remain near a location while particles pass through it and change phase. Its outline is evidence of current conditions, not a permanent material surface.

A useful analogy is a visible wave pattern in flowing water: the pattern and the material passing through it need not share one velocity. The analogy concerns identity and motion, not a claim that clouds obey exactly the same equations as water waves.

Cooling during ascent and warming during descent help explain why formation and disappearance can occur along different parts of an air flow [1]. Mixing with surrounding air complicates that picture. A cloud's persistence therefore combines microphysics with motion and thermodynamics, rather than reducing to one comparison between weight and a single supporting force.

The total mass can still be large. A hypothetical cloud region of one cubic kilometre with a uniform liquid water content of 0.5 grams per cubic metre would contain 500,000 kilograms of liquid water. The water content is a chosen example, not a universal value. A large total distributed among many tiny droplets does not have the settling speed of one compact object of the same mass.

5. Why some water eventually becomes precipitation

Particle growth changes the balance. Droplets can collide and merge; ice processes provide other routes to particles large enough to fall out efficiently. The National Weather Service distinguishes warm-cloud collision processes and pathways involving ice [1]. Which dominates depends on the cloud's temperature, particle population and dynamics.

Condensation alone is not a complete explanation for every raindrop. Nor is every cloud required to precipitate. Some lose their condensed water by evaporation before a substantial population of rapidly settling particles develops. Predicting precipitation requires a distribution of sizes and a history of growth and motion, not merely the presence of visible white material.

Observations that constrain such an account include particle sizes, liquid water content and air velocity. Their combination matters: a photograph can reveal a cloud outline while leaving these quantities poorly determined. The settling calculation tests a mechanism; it does not infer all its inputs from appearance.

The secure answer is that small particles fall slowly relative to air, moving air can carry them, and cloud particles continually form and disappear. The uncertain details concern a particular cloud's evolving population and flow. The conceptual error is to demand a single support mechanism for an object whose identity is changing while we look at it.

References

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