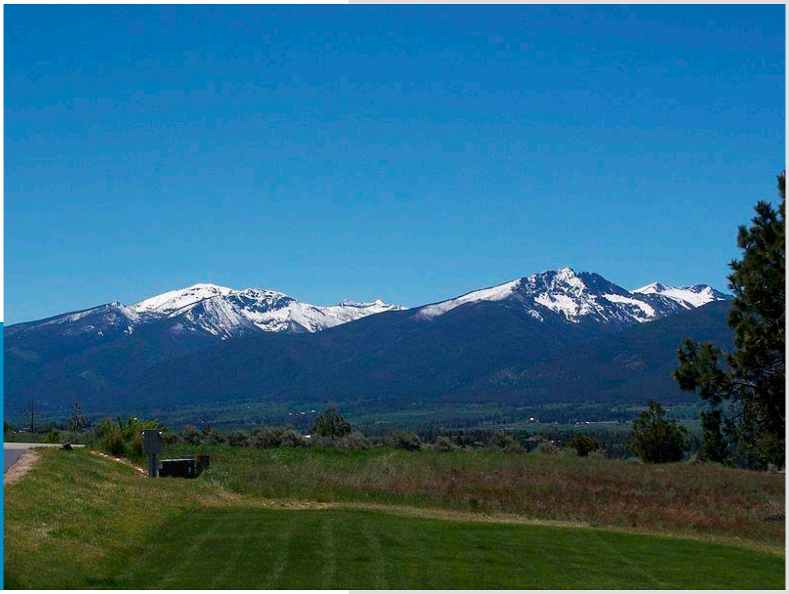
Cooler in the Mountains



Summer snow in the mountains and green crops in the valley illustrate the temperature differences that occur in mountainous regions.

Here's a riddle: If heat rises, and mountains are closer to the sun, why are they always colder?

The answer may surprise you.

The heat of the sun can't actually radiate through space. There would need to be particles of some element to conduct its heat; but space is a vacuum.

Instead, the sun emits electromagnetic energy: ultraviolet, visible and infrared light, X-rays, and radio waves.

When this solar radiation finally meets Earth's surface, it warms it. And that radiates heat back upward, warming the atmosphere from the bottom up.

So is that why it's warmer lower and cooler higher?

Not exactly. It has more to do with air pressure.

Like all gases, the air in our atmosphere is a poor conductor—because it's not dense with particles.

However, the atmosphere does have mass. And its weight bearing down on the air at the surface compresses it more than the air at altitude.

The compressed air is denser with molecules, which are more likely to collide, and these collisions produce heat.

That means the air near the surface is not only better able to conduct Earth's reflected heat but generates its own heat because it's dense.

This hot air can indeed rise. But as it does, the atmospheric pressure decreases, the air expands, and it cools.

So, even though they're closer to the sun, thin air in the mountains keeps them colder than the thicker air in the lowlands surrounding them.

Bureau of Economic Geology

Background: Cooler in the Mountains

Synopsis: During the summer heat, many vacationers head to the mountains to cool off. But if heat rises and mountains are closer to the sun, why is it cooler at elevation?

- The sun is extremely hot, but it can't radiate its heat through the vacuum of space; without particles colliding, heat can't be conducted.
    - Instead, the sun emits solar radiation as electromagnetic energy such as X-rays; radio waves; and ultraviolet, infrared, and visible light. This radiation makes its way to Earth as the constant solar wind and in pulses of energy called *coronal mass ejections*.
    - Some heat is generated as particles in Earth's middle and upper atmosphere interact with shorter-wavelength solar radiation (like X-rays and UVc rays) to produce the thermosphere's ionosphere and the stratosphere's ozone layer. However, most of the sun's energy passes right through these layers to warm Earth's surface.
    - The heat radiates back into the atmosphere, warming the lower atmosphere—the troposphere—from the bottom up, thus driving Earth's weather.
    - Our atmosphere is made up of a mixture of gases: 78 percent nitrogen; 21 percent oxygen; 0.93 percent argon; and smaller amounts of carbon dioxide, water vapor, neon, helium, methane, krypton, and hydrogen.
        - Like most gases, air is a pretty poor conductor of heat because its particles are far apart, limiting collisions that transfer heat.
- The ideal gas law, $PV=nRT$, defines the relationship among atmospheric pressure, volume, and temperature.
    - When temperature increases, it increases the kinetic energy of the gas so that its particles collide more frequently, thus increasing pressure.
    - When gas is compressed into a smaller volume, pressure increases. Since compression forces particles closer together, there are more collisions, causing temperature to rise. (Recall how bike pumps heat up when you inflate a tire.)
    - Conversely, if a gas is allowed to expand, its pressure drops so there are fewer collisions, causing temperature to drop. (When you let air out of a bike tire, the stem gets cold as the air expands through it to occupy a larger volume.)
    - The same volume of gas will have a higher temperature under high pressure than under low pressure.
- The adage that "hot air rises" should really be restated as "less dense gas rises."
    - Atmospheric pressure, which is greatest at the surface of Earth, forces more-buoyant objects upward toward lower pressure until gravity overwhelms the force of their buoyancy.
    - Hot air rises because it is more buoyant than cold air, like oil rises to the top of water.
    - Hot-air balloons have very light containers that enable the buoyant force to overcome gravity. A lighter gas like helium is even more effective.
    - As hot air rises, unconfined, into cooler air that buoys it upward, it expands rapidly, losing pressure and driving temperature lower, so the effect of "hot air rising" tends to be short-lived and localized.
- At more than 29,000 ft (8,848 m), Mount Everest is Earth's highest mountain above sea level; it is the closest point on Earth to the sun.
    - Its average temperature ranges from -2°F (-19°C) in July to -33°F (-36°C) in January; at times it can get as cold as -76°F (-60°C).
    - The crest of Mount Everest may be almost 5.5 mi (8.848 km) closer to the sun than Miami, but the sun is about 93,000,000 mi (150 million km) from Earth, rendering elevation differences on Earth negligible.

References: Cooler in the Mountains

Why Is It Cooler Up in the Mountains? | ABC (Australia) Science
Why Is It Colder at the Top of a Mountain Than It Is at Sea Level? | Howstuffworks.com
Why Does Air Expand When You Heat It, and Why Does Hot Air Rise? | NTSA
Why Is It Colder at a Higher Altitude When Technically It Is Closer to the Sun? | UCSB ScienceLine

Contributors: Juli Hennings, Harry Lynch

Background: Cooler in the Mountains

- What actually makes mountains cooler?
  - Where atmospheric pressures are higher, temperatures are higher.
    - If you are at sea level, every square inch of you supports 14.7 lbs of air. At a ski resort at 10,000 ft altitude, that number drops to 10.1 pounds, and you may be able to feel the decreased oxygen in the air you breathe. (In a passenger jet at 40,000 ft, the air above you only weighs 2.7 pounds per square inch, so the plane must supply oxygen for its passengers' survival.)
    - Atmospheric temperatures decrease at the rate of 3–5°F (2–3°C) per 1,000 ft.
    - Valleys are almost always warmer than nearby mountaintops, and coastal cities are warmer than mountains.
    - High-pressure weather systems bring warmer days than low-pressure systems.
    - An additional cooling mechanism in the mountains is adiabatic cooling. When winds drive air up into the mountains, the air expands into the lower pressures at high elevations and cools the higher elevations.
    - In mountainous areas, cold may be further accentuated by snow coverage, which reflects solar radiation. The warmest places in mountainous areas are broad high plateaus, which have larger land area to absorb and re-radiate solar radiation. However, any heat generated at high elevation quickly dissipates in the thin air.
  - There is one exception to mountains "always" being cooler: temperature inversions may occur when cold dense air becomes trapped in mountain valleys below regional-scale warmer air masses.

References: Cooler in the Mountains

Why Is It Cooler Up in the Mountains? I ABC (Australia) Science
Why Is It Colder at the Top of a Mountain Than It Is at Sea Level? I Howstuffworks.com
Why Does Air Expand When You Heat It, and Why Does Hot Air Rise? I NTSA
Why Is It Colder at a Higher Altitude When Technically It Is Closer to the Sun? I UCSB ScienceLine

Contributors: Juli Hennings, Harry Lynch