Atmosphere: An Ocean of Air

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Introduction

The atmosphere is very accessible in some ways, and extremely inaccessible in others. We all walk around in it, breathe it, and directly experience the weather that happens inside it. But unlike the ground or the ocean, which any curious human can investigate by digging a hole, going swimming or sending down a fishing line, the innards of the atmosphere were almost completely inaccessible until the invention of hot air balloons. Even then, scientists looking for money to fund science by balloon had to confront the widespread feeling that a balloon trip was a vulgar spectacle to entertain the mob, not something a serious and diligent scientist should be associated with. Balloons were also hard to control, and highly weather-dependent. A few hardy scientists did venture upward in the mid-late 1800s but even now, atmospheric science is mostly done at a distance. What did start to fly was the idea that the atmosphere is important and worthy of study, not just to generate weather forecasts but because it's a critical part of the whole Earth system.

What is the atmosphere?

The atmosphere is a soup of gas molecules, bound to Earth by gravity. It's mostly made up of just two gases: 78.084% nitrogen and 20.946% oxygen, very slightly diluted by 0.9340% of argon, an inert noble gas. Their relative proportions are the exactly the same everywhere around the world, although up to 3% of the atmosphere can be made up of water molecules and the water fraction varies a lot from place to place. Everything else in the atmosphere makes up only a tiny proportion – around 0.04% of the total. But it's these "trace gases", miniscule quantities of carbon dioxide, volatile organic compounds produced by life, nitrous oxides and other pollutants and a huge menu of other potential components that give each part of the atmosphere a distinctive signature. Even though they're present in very small quantities, they can have a significant effect on life and how the chemistry of the atmosphere works.

The spatial patterns in these trace gases depend on their lifetimes in the atmosphere. Short-lived chemical species like the hydroxyl radical and ozone will often react with them and oxidise almost everything to much simpler gases. If a gas has a short lifetime, we will see strong patterns in its distribution because it won't be able to travel very far from its source. Gases with long lifetimes get thoroughly mixed in and so few patterns are apparent. Increasingly, we are using satellites to map out these short-lived gases. Until recently most of these satellites scanned the whole globe, seeing the big picture but not able to follow the details. But now there is a new generation of geostationary satellites that are permanently monitoring regions in much more detail. The most recent is Sentinel-4, operated by Copernicus and launched in July 2025. It has only just started to produce calibrated data, but it will provide hourly measurements of pollutants like nitrogen dioxide, sulphur dioxide and ozone across Europe.

The atmosphere also has an important physical presence. It weighs around 5 quadrillion tons, and as gravity squeezes it on to Earth's surface it exerts significant pressure. A liquid ocean would not be possible without this external pressure. And of course, what we notice most is the weather – the forces we experience as this air pushes on the world around us, and the energy and water that it moves around.

How does the atmosphere interact with what's around it?

The atmosphere is a huge reservoir that is constantly exchanging molecules, heat, and momentum with the land, ocean and ice. This reservoir is incredibly thin compared to its horizontal size, so it has a huge surface area to volume ratio. That makes very large fluxes into and out of the atmosphere possible, and so the atmosphere has a huge influence on what's happening beneath it. The lowest layer of the atmosphere (the troposphere) interacts relatively little with the layer above it (the stratosphere), because the denser troposphere cannot mix upwards into the less dense stratosphere.

The most consequential interaction the atmosphere has is with light. We assume that the atmosphere is transparent because we can see things that are a long way away. But our eyes are only sensitive to a tiny part of the electromagnetic spectrum, where the atmosphere does happen to be transparent. The frequency bands which are transparent are known as "atmospheric windows" because light can pass through them. But the windows are the exceptions. If you look at the bigger picture, the atmosphere is more like a gatekeeper, blocking a lot of the light that could pass through. Light carries energy, and so the atmosphere controls the most important flow on Earth: the flow of energy into our planet and back out into space. The way that this (mostly invisible) energy flows structures our planet and our lives.

How is the atmosphere changing?

Humans have not changed the oxygen or nitrogen in the atmosphere in any significant way, but we have changed the trace gases that are present. We are also adding aerosol particles, which are tiny liquid or solid drops that are far too small to see. Some exist naturally, but we have increased their numbers dramatically. A subset of the additional trace gases are particularly significant because they absorb infrared radiation, and this means that they change the shape of the atmospheric windows, making them smaller and more opaque. These are the greenhouse gases, and they are responsible for a slow accumulation of additional energy in the Earth system. Some of this additional energy ends up in the atmosphere, but the vast majority of it (>90%) is stored in the ocean. The Global Carbon Budget and others are monitoring yearly emissions of greenhouse gases, so that we can calculate their consequences for our world. This year, for the first time, it looks as though the emissions of one of the world's largest emitters – China – may be about to peak. Yearly global emissions are still very large, but we may be getting close to the point where that large number isn't growing every year. That still leaves a lot of work to do in reducing our emissions, but it is at least a sign that the huge growth in renewable energy generation can help us turn the ship around.

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