# TROPICAL CONVECTION: COOLING THE ATMOSPHERE

## HOT TAKES

1. To understand our climate it is vital to understand convection, the tendency of hotter and therefore less dense material to rise.
2. Tropical convection leads to around 1,000 thunderstorms around the world at any one time, and without it the Earth would be unliveably hot.
3. If climate models understate its influence, they might overstate warming due to increasing $CO_2$.

**Tropical convection[1] in the form of thunderstorms and cyclones can be entertaining, awe inspiring, and even terrifying. Storms make a spectacle with towering clouds, intense rainfall, thunder, and lightning. It is rarely appreciated that such tropical convection is also the main driver of the general circulation of the atmosphere. It is the giant 'heat engine' driving the wind and weather. The engine's fuel is water vapour evaporating from the tropical and subtropical oceans.**

Convection drives energy from near the Earth–ocean surface, where the air is warm and humid, to the upper atmosphere where its stored energy can be radiated to space as thermal infrared (IR) emissions. This is one of the main energy transfer pathways that cool the atmosphere. So much heat can be removed in this way that without it the temperature of the surface of the Earth would be around 60°C.

## Tropical Convection & Thunderstorms

Once the temperature and humidity of the air gets above a critical point it only takes a small trigger to set off a thunderstorm – the air only needs to be lifted. As this air lifts, its pressure drops, and it cools. At first it cools at a rate of 9.8°C for every kilometre it rises. However, because tropical air is very humid, as it cools the water vapour it contains soon condenses, forming cloud and releasing latent heat[2]. When this heat is added to the rising air it cools more slowly than it otherwise would have – instead of 9.8°C per kilometre it now only cools at about 4–5°C per kilometre.

However, the still air surrounding the storm cell cools at roughly 6.5°C per kilometre, so the point is rapidly reached where the ascending centre of the storm is significantly hotter (and less dense) than the surrounding air. This hotter column of air consequently keeps rising – driven by this increasing density difference – condensing even more water, further heating the air column. It is a self-reinforcing process that propels the storm cell upward. Once this process has been triggered, it continues until the air reaches a height where its density is the same as that of the surrounding atmosphere.

The top of a storm cloud (Figure 1) can be well over 10 kilometres high and cooler than –50°C.

**Figure 1:** Tropical convection in the form of a thunderstorm[3]

The sprawling anvil cloud in this picture has formed from a main cumulonimbus tower. In this picture there are other 'fluffy' clouds at lower altitudes caused by rising air in minor convection cells.

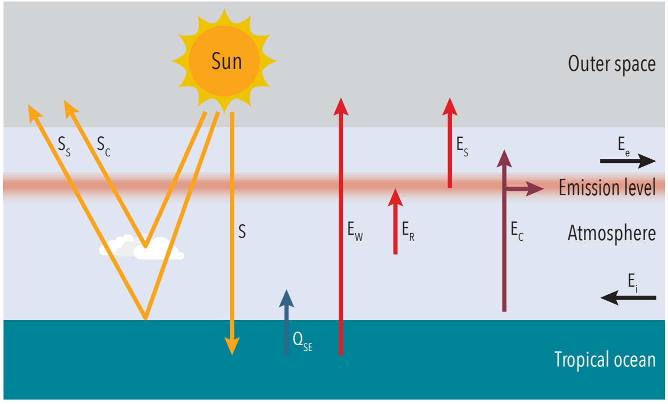
## Convection & Radiation: Working Together

Less than 60% of all solar radiation reaches and warms the Earth's surface. Around 30% is reflected, as shown in Figure 2, and some is absorbed directly by dust and water vapour in the atmosphere. But most heat energy enters the atmosphere via the sea and land by evaporation of water (latent heat), by direct thermal conduction, and by partial absorption of surface-emitted IR. It then makes its way upward through the atmosphere via two main pathways; *the convection pathway* ($E_C$), and the IR *radiation pathway* ($E_R$). When it reaches the *emission level*[4], high up in the atmosphere, this heat energy is emitted to space as IR.

In the convection pathway, heat-bearing air is transported upwards directly – keeping things *cooler* than otherwise. The radiation pathway, on the other hand, is partly choked off by greenhouse gases. These retard the transmission of IR radiation – keeping things *warmer* than otherwise.

In the 'greenhouse effect', greenhouse gases re-emit absorbed IR at all levels and in all directions but at any given level in the atmosphere there is always more IR going up than down because the air is always warmer below and colder above. Any increase in carbon dioxide ($CO_2$), a *trace* greenhouse gas, results in a *very slight* increase in the heat already retained in the atmosphere due to water vapour, the *main* greenhouse gas. This is because, in theory, a slightly higher temperature is needed for the same amount of IR to travel via the degraded radiation pathway, and be emitted to outer space, as was emitted before the $CO_2$ increase.

**Figure 2:** Schematic of the vertical fluxes of energy in the tropics [5]




Because of its large area, much of the Sun's energy (S) is absorbed by the sea. Some is reflected from clouds ($S_C$) and the surface ($S_S$).

Most of the Sun's energy is returned to the air via evaporation over the ocean ($Q_{SE}$) but some ($E_W$) is radiated directly back to outer space through the IR spectral 'windows' (parts of the IR spectrum that are not absorbed by greenhouse gases; see Fact Sheet 11 for more detailed illustrations).

Energy reaches the emission level either by IR radiation – the radiation pathway ($E_R$), or through the vertical updrafts in tropical convection – the convection pathway ($E_C$).

Once the energy has reached the upper atmosphere around the emission level, it is radiated to outer space ($E_S$); some is exported towards the poles as potential energy ($E_E$).

Energy is also imported in the form of latent heat from higher latitudes ($E_I$).

However, in tropical regions, the convection pathway transports almost twice the energy to the emission level as the radiation pathway[5]. This makes overall heat flows in the tropical regions relatively less sensitive to the effects of greenhouse gas changes on the radiation pathway.

In addition, if the Earth's temperature increases, increased evaporation over the oceans will fuel more convection and the surface cooling effect it drives. If this convection were an 'engine', it would run a little faster and more powerfully, becoming more powerful by about 10% per degree rise in temperature. This would drive more energy from the lower atmosphere, offsetting any slight warming from increasing trace greenhouse gases.

## Conclusions

Thunderstorms can be thought of as the giant pistons of an engine, driving warm humid air upwards and, ultimately, away from the tropics at high levels in the atmosphere.

Computer models seek to simulate the climate role of convection cells, and clouds, but most of these are smaller than the calculation interval possible in the models due to computing limitations. Their real-world effects can only ever be empirically approximated, or '*parameterised*'[6].

Parameterisation is unavoidable in climate modelling because of the unresolved uncertainties. Unless someone invents an entirely new form of mathematics, it is impossible to model the climate system accurately from purely mathematical first principles, even at larger scales, let alone down to the scale of individual thunderstorms. As a consequence, in order to resolve discrepancies between theory and observation, '*fiddle factors*' have to be arbitrarily inserted into the calculations to 'tune' out the discrepancies. The need for numerous parameterisation adjustments in today's complex computer models raises doubts as to how 'fit for purpose' they actually are.

Parameterisation demonstrates that the science of climate is not exact, irrespective of the enormous size and complexity of today's computer models. For example, if the climate models are understating the increase in the efficiency of tropical convection caused by possible greenhouse warming, as a result of flawed assumptions, then they will overstate the sensitivity of the climate to increasing $CO_2$.



SEE ALSO
FACT SHEET #11: THE IMPORTANT ROLE OF WATER AND WATER VAPOUR
FACT SHEET #13: REFLECTIONS ON THE IRIS EFFECT

Information in this fact sheet has been drawn from Climate Change: The Facts 2020 (IPA 2020), Chapter 12, by Dr Peter Ridd and Dr Marchant van der Walt. Fact Sheet series general editor: Dr Arthur Day

1. Convection is vertical motion driven by buoyancy forces arising from differences in air density, such as when warm or moist air is displaced and pushed upwards by denser colder or drier air.
2. Latent Heat is 'hidden heat'. It is the heat energy absorbed when water evaporates – for instance the cooling effect of sweat evaporating from our skin. This heat is released again when water vapour condenses back to liquid. Evaporation cools the air but condensation heats it.
3. Source: NASA/Tsado, image ID: KFCWA2 https://www.alamy.com/stock-image-anvil-thunderstormcloud-formation-africa-cumulonimbus-cloud-over-164396458.html
4. The emission level is a crude measure of the level above the ground from which IR radiation is emitted to space. In reality, emission of IR to space occurs from all levels but, on average, most heat energy ultimately escapes from high up in the atmosphere.
5. Riehl, H & Simpson, J 1979, 'The heat balance of the equatorial trough zone revisited', *Contributions to Atmospheric Physics*, vol. 52, pp. 287–305.
6. See: Curry, J 2017, '*Climate Models for the Layman*', GWPF Briefing 24. https://www.thegwpf.org/content/uploads/2017/02/Curry-2017.pdf