The atmosphere and the greenhouse effect

The Earth's gravitational force retains the various gases that envelop the planet and constitute the atmosphere. The atmosphere has no real boundary, it simply fades into space, but about three quarters of its mass is found close to the surface in the lower layer, the troposphere, where most weather occurs and which extends upwards about 11 km on average. The British astronomer Sir Fred Hoyle remarked about the extent of the atmosphere: *Space isn't remote at all. It's only an hour's drive away if your car could go straight upwards*. The height of the atmosphere varies but based on distinct temperature profiles for different regions it is divided into the troposphere (up to 17 km above ground), the stratosphere (from the troposphere to about 50 km out), the mesosphere (up to 90 km), and the thermosphere (above 90 km). The region furthest out beyond the thermosphere is called the exosphere.

In the thermosphere gravitation is weak and atoms escape to space – in the mesosphere the strong sunlight breaks down molecules into atoms. The stratosphere is a layered, or stratified, region where there is little mixing of the air (thus it acts as a 'lid' on top of the troposphere). The stratosphere contains most of Earth's ozone which protects us by filtering out some of the damaging ultraviolet light from the Sun. The troposphere is different from the other atmospheric regions because it is well mixed by convection – the energy emitted from the Earth's surface warms up the overlying air which transfers the heat energy by upward circulation. Close to the surface the IR radiation emitted by the Earth is absorbed by greenhouse gasses and by clouds. Convection carries the heat energy to an altitude where the atmosphere is transparent to IR radiation and eventually the energy radiates to space.

The composition of the atmosphere determines the magnitude of the greenhouse effect – as we have seen, the Earth would be approximately 33 ºC cooler without the presence of gases that absorb IR radiation. The three major constituents of Earth's atmosphere, nitrogen, N_2 (78% by volume), oxygen, O_2 (21%), and argon, Ar (0.9%), are not greenhouse gases. Although these three gases together make up almost the entire volume of the atmosphere there is a wealth of minor gases, or trace gases, that are very important to climate and atmospheric chemistry. When we describe the concentration of such small quantities we use the measure *parts per million*, or *ppm*, which means that there is one molecule of a certain gas in every million air molecules (here we use ppm to denote parts per million by volume). If we describe the presence of nitrogen in the atmosphere in this way we thus get a value of 780000 ppm. The most abundant greenhouse gases are water vapour, H_2O (0.1-40,000 ppm depending on latitude), carbon dioxide, CO_2 (385 ppm), methane, CH_4 (1.75 ppm), nitrous oxide, N_2O (0.3 ppm), ozone, O_3 (0.01-0.07 ppm depending on altitude), and chlorofluorocarbons, CFCs (e.g. Freon-11, CCl_3F, 0.00026 ppm). The contribution of a gas to the greenhouse effect depends on its abundance as well as its molecular structure. Methane is a more potent greenhouse gas than carbon dioxide but its overall contribution is smaller because it is less voluminous.

The electromagnetic energy emitted from the Sun is often described as waves, and we can think if it as moving like a wave through a still surface in a lake. The space between two crests is the wavelength. The Sun emits about 50% of its energy in the form of visible light, wavelengths shorter than this are ultraviolet light, X-rays and Gamma rays, longer wavelengths are infrared, microwaves and radio waves. Different gases absorb radiation at different wavelengths across the electromagnetic spectrum. This means that gases which are only present in small quantities can have a large warming effect, e.g. freon-11 absorbs radiation in a region where carbon dioxide does not, and in this way one freon-11 molecule contributes more to the greenhouse effect than does one molecule of carbon dioxide. So the influence of greenhouse gases is not additive. The most important greenhouse gases ranked in terms of their contribution to the greenhouse effect are water vapour (36-78%), carbon dioxide (9-26%), methane (4-9%), and ozone (3-7%). The lifetimes of all these gases vary. Atmospheric lifetime is a measure of how long it takes a gas to decay – effectively how long it stays in the atmosphere. CO_2 has a lifetime of about 100 years, CH_4 12 years, N_2O 114 years, Ozone from a couple of hours to days, CFCs up to 100 years.

A useful concept for understanding the greenhouse effect and the contributions of different gases is that of *radiative forcing*. In the scientific literature radiative forcing is defined as "net downward radiation at the tropopause [the boundary between the troposphere and the atmosphere] after allowing for adjustment of stratospheric temperatures only". We can think of this simply as the difference between the energy received from the Sun and the energy emitted back into space. The amount of radiative forcing determines the rate of change in surface temperature. Greenhouse gases thus contribute to a greater radiative forcing and we can estimate this contribution for individual gases. One way of doing this is measuring, on the basis of the characteristics of each gas, its radiative forcing in relation to CO_2 which is set to have a 'global warming potential' of 1. On this scale methane for example has a global warming potential of 25 and freon-11 4600. This means that one molecule of methane would increase radiative forcing by 25 times that of one molecule of CO_2 (over 100 years). This shows how greenhouse gases differ in their 'warming effect'.

The IPCC has created an index of the 'radiative forcing components' which illustrates how different factors, including greenhouse gases, albedo, cloud cover, aerosols and solar irradiance, influence overall radiative forcing. Some components, like aerosols and albedo, have a negative impact, which is to say they have a 'cooling effect' in the global energy budget. The presence of aerosols in the atmosphere has important implications for atmospheric chemistry and the greenhouse effect. This is what has become known as 'global cooling', and it lowers global temperatures considerably. Unfortunately, this cooling is effective only as long as we keep emitting aerosols into the atmosphere because they have a very short lifetime. The combined radiative forcing of all these components determines the magnitude of the warming.

The technicalities of the greenhouse effect are not important to remember. The meaning of some of these terms will also become clearer when we look at the influence that humans have on the atmosphere. However, it should be clear that climate change is not simply a matter of how much CO_2 there is in the atmosphere. There are many influences, both in the positive and negative direction, on the greenhouse effect. Although some of the gases involved appear in the stratosphere, e.g. ozone, most of the processes involved take place in the troposphere where the air is well-mixed by the winds. The greenhouse effect is the overall effect of those atmospheric gases that allow radiation from the sun to reach the surface but absorb the IR-radiation emitted back from the Earth. This reduces the loss of energy to space and keeps the planet warmer than it would otherwise have been: the surface warms until the emitted radiation balances the incoming radiation and the system reaches an equilibrium.