

Lower Atmosphere

Basics

Unit 1

An introduction to the troposphere

The troposphere is the layer of the atmosphere closest to the ground. It is where plants and animals live and where our weather takes place. If we look towards the sky, the air seems to be endless. However, the layer of air surrounding our planet, protecting us and making life possible, is really very thin.

When we travel by aeroplane, 80% of the air mass is below us. In this unit we look at how the composition and properties of the air vary with altitude. We compare the dimensions of the Earth's surface with the dimensions of the troposphere and look at how the properties of the troposphere change depending on where we are on Earth. Finally, we look at the composition of the air and see how very small amounts of certain chemicals affect our climate.



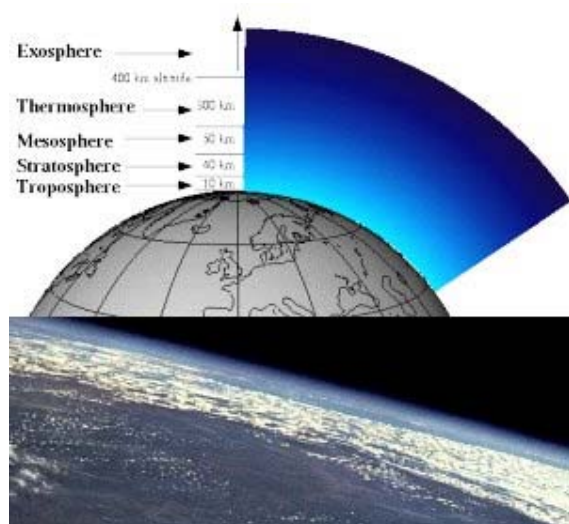
1. The atmosphere from space - source: NASA



Part 1 - Vertical

The Troposphere - variations with height and temperature

The lowest layer of our atmosphere, next to the Earth's surface, is called the 'troposphere'. It reaches from the ground to the highest clouds we can see. If we look into the sky, this layer seems endless but it is really just a thin cover. However it's really important to us, it protects us from the damaging rays of the Sun, contains oxygen so we can breathe and allows life to exist on Earth.



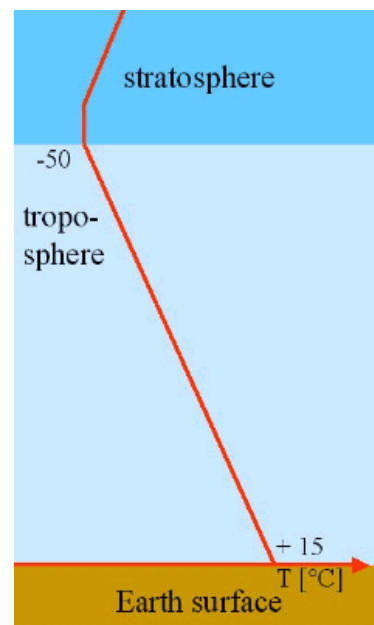
1. The atmosphere (shown in blue) consists of several layers. The lowest layer is the troposphere. In this figure, the atmosphere is shown much thicker than it is in reality. source: freeware STRATO, scheme: University of Cambridge. <http://www.atm.ch.cam.ac.uk/tour>

The temperature profile and the transport of air

In the troposphere, the temperature decreases with increasing altitude, it becomes colder, the higher you go. You can feel this temperature change if you hike in the mountains. There is, however, a point in the atmosphere where this trend changes. This is the tropopause, a temperature minimum in the atmosphere. Some scientists call it a cold trap because this is a point where rising air can't go higher and it gets trapped. The tropopause is very important for air movement and for chemistry in the troposphere, for cloud formation and for weather. Warm air is lighter than cold air. If you open the door in winter you feel the cold air first at your feet, as it's heavier and sinks to the floor. Similarly, when the morning Sun heats the ground, the air starts rising. As long as the air around it is colder (= heavier) the warm air continues to rise. At the tropopause this travel stops as the air above is warmer and lighter. This is the reason why it's difficult for water (clouds) and chemical

Dimensions of the troposphere

Although the troposphere is the thinnest layer of the atmosphere, about 11 kilometers in height around a planet of 12,800 km in diameter, it contains about 90% of the mass of the atmosphere, i.e. 90% of the molecules of the air. The troposphere reaches an altitude of about seven kilometers at the poles and about 17 kilometers at the Equator. The layer above the troposphere is known as the stratosphere and the border between the two layers is called the tropopause. How do we know where the troposphere ends? Changes in the temperature trend give us the answer.



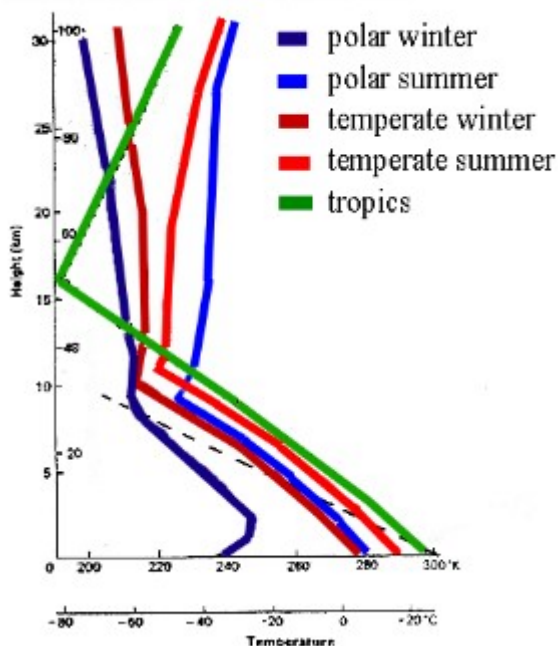
2. Rising air. A parcel of warm tropospheric air (red) rises and expands. It becomes cooler (as shown by the disappearing red color), but is always warmer than the surrounding air. When it gets



compounds in the air to cross the tropopause, it acts as an invisible temperature barrier. It's also why most of the chemistry and weather takes place in the troposphere.

The animation shows average temperatures at the ground (15°C) and at the tropopause (-50°C) and a rather simple temperature profile.

the surrounding air. When it gets to the tropopause it can't rise further but can only expand horizontally. Author: Elmar Uherek.



3. Temperature profiles in the troposphere and lower stratosphere. Temperatures are given in Kelvin (K) and in Celsius (°C). Source: unknown. Adapted by Elmar Uherek from a lecture at Harvard University. icg.harvard.edu/~eps132/lecture.dir/lecture3a/notes.htm

The real world is, however, a little bit more complicated. It isn't the same temperature everywhere at the ground or at the tropopause and temperatures change with season (although this change is only small in the tropics). This figure gives an idea how the temperature profiles look at different latitudes in the summer and the winter.

The temperature profile in the tropics is shown in green. Here the tropopause is at altitudes greater than 15 kilometers. In temperate regions (light red for summer, dark red for winter) the tropopause occurs at altitudes greater than 10 kilometers. In the polar regions (light blue for summer, dark blue for winter) the tropopause is at altitudes of less than 10 kilometers.

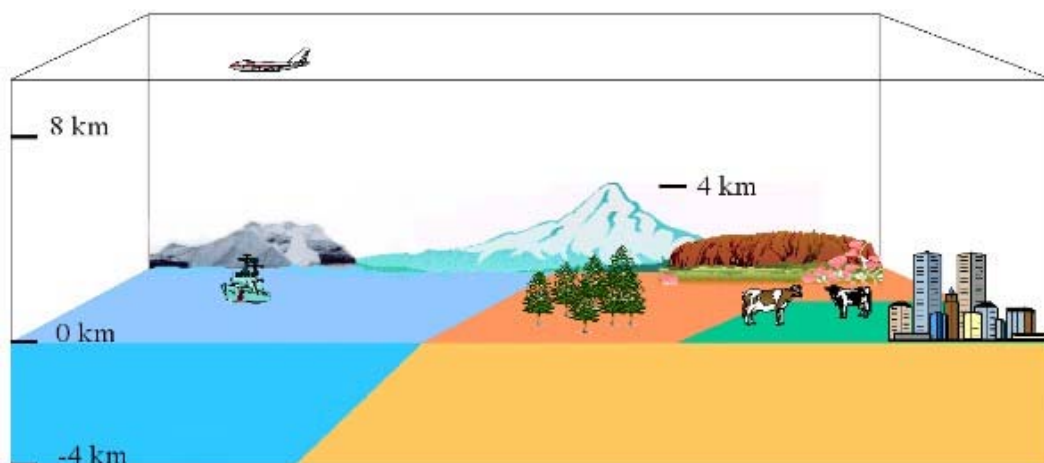
We divide the troposphere further into two sublayers, a layer which is directly influenced by the surface of the Earth known as the planetary boundary layer, and the free troposphere above. In the planetary boundary layer, processes such as friction, heat transport, evaporation, and air pollution lead to changes in conditions which occur within one hour. The thickness of this layer varies between a few hundred meters and about two kilometers. Mixing of air as warm air rises from the ground is the most important process which occurs in this layer.



Part 2 – Horizontal

Different landscapes - the horizontal extension

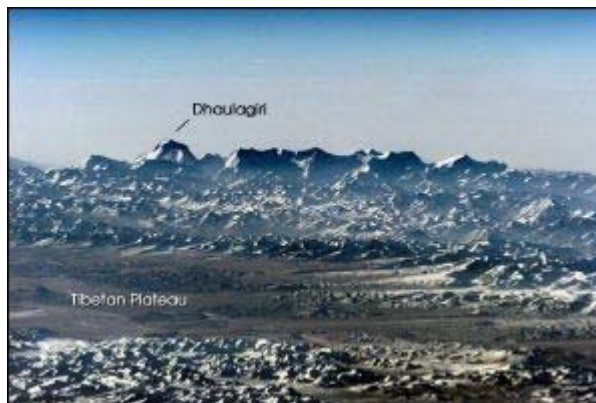
The troposphere is much more than just a shell around a sphere. The surface of the Earth is rough and structured. The depth of the ocean is between two and six kilometers, in some places even deeper. The highest mountains are greater than six kilometers in height. That's about half the altitude of the troposphere!



1. The troposphere - a very structured place. Author: Elmar Uherek.

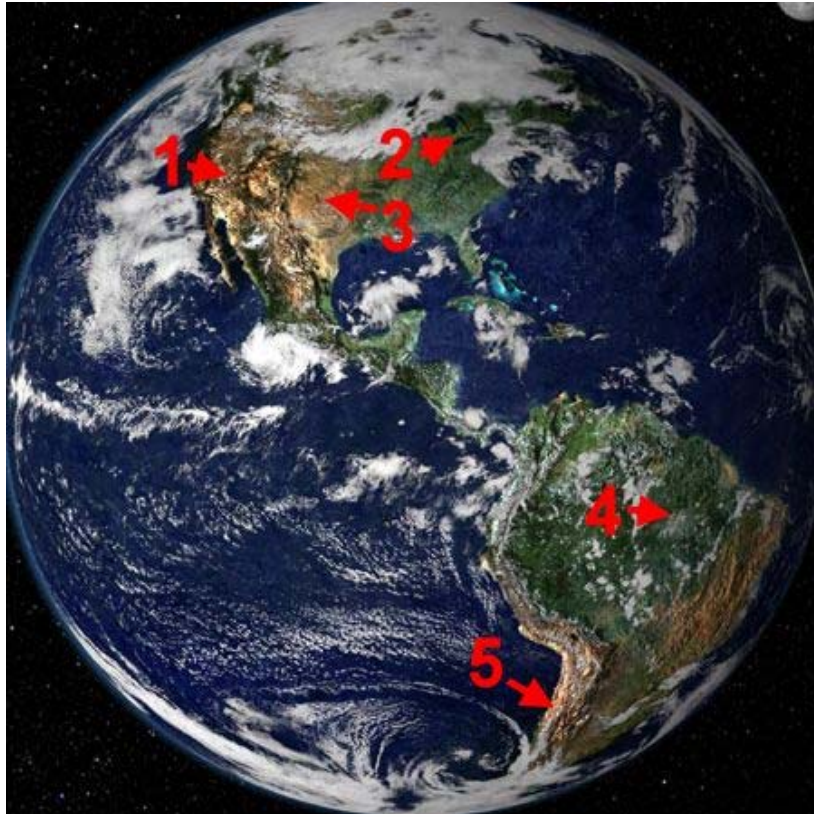
Different landscapes

Have a look at the Earth and the two American continents below and explore our planet a bit: Look up the numbered places in an atlas! What is the landscape like? Is the climate dry or wet? What latitudes are dry, where is it wet? Which climate zones do the places belong? What temperatures would you expect in the winter and the summer? How much rain falls? The troposphere is in contact with many different landscapes and climate zones: dry deserts, snowy mountain peaks, humid rain forests and don't forget the oceans, these make up 71% of the contact area.



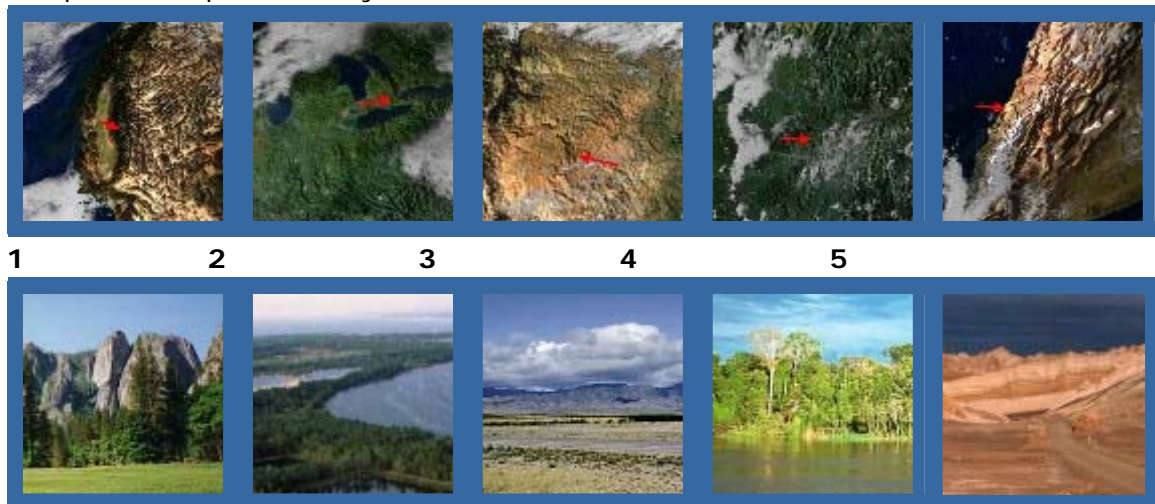
2. Mountains reaching high into the troposphere. The photograph shows a view across the Tibetan Plateau. The Dhaulagiri Peak (8167 m) is higher than the troposphere at the poles. Source: NASA Earth Sciences and Image Analysis. <http://visibleearth.nasa.gov/cgi-bin/viewrecord?783>





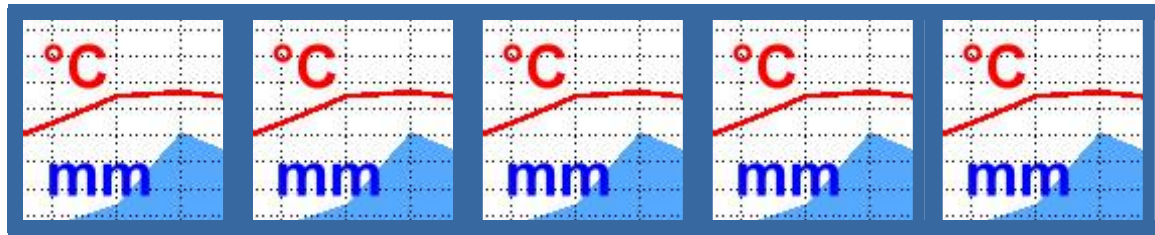
3. Our planet Earth from space. Author: Reto Stockli, Nazmi El Saleous, and Marit Jentoft-Nilsen, NASA GSFC. To see the detailed structure of the landscape.

Below are three pieces of information about the places marked on the globe above: 1) A modified image from space (75 KB per image); 2) a photograph of the landscape (50 KB); 3) annual average temperatures and precipitation from this place or a place nearby.



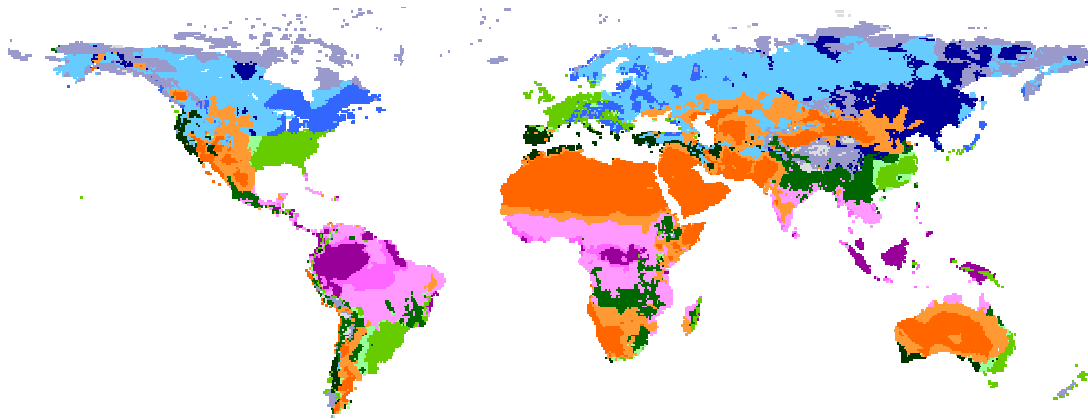
4. Locations: 1) Yosemite Park, Rocky Mountains (USA) - 2) Erie Lake Area, Pennsylvania (USA) - 3) Landscape near El Paso, Mexican boarder (USA) - 4) Amazonian rainforest (Brazil) - 5) Atacama desert (Chile).





1 2 3 4 5

Please note: Summer is always in the middle of the graph, i.e. the month time scale is not the same for the northern and southern hemispheres. Source: www.klimadiagramme.de - Bernhard Mühr.



Koeppen's Climate Classification
by FAO - SDRN - Agrometeorology Group - 1997



5. Koeppen's climate map - This shows which climate zone the places above belong to.

The human population on Earth

The examples above show different natural landscapes from space and from photographs. These images and the climate diagrams give us an impression of their climate. The composition of the troposphere is not, however, just governed by natural processes. Humans also affect the troposphere through energy release and emissions of chemicals. The view of city lights at night over the globe shows that human activities, other than agriculture, are concentrated in particular regions of our planet, the big urban areas.



6. The world at night. Authors: AVHRR and Seawifs texture: Reto Stockli; Visualization: Marit Jentoft-Nilsen, VAL, NASA GSFC.

Data: AVHRR, NDVI, Seawifs, MODIS, NCEP, DMSP and Sky2000 star catalogue.



How large is the area covered by the troposphere?

People sometimes think that if it is unusually cold or warm or that there is too much rain or too little snow in our country for a few days or weeks then this is a sign that the climate is changing. But what does it really mean if such unusual events take place in our country? How big is, for example, Poland compared to the area of our planet?

Let's have a look:

Area of the Earth's surface: 510,000,000 km² (29.2% land, 70.8% water)

Surface area of Poland: 312,000 km²

The Earth's surface is 1637 times bigger.

Here you can see this relationship (land is shown in brown, water in blue and Poland in red).



7. Imagine the total size of land (in brown) and water (in blue) on Earth compared to the size of Poland.

For global climate change to be real, changes should be seen over a period of at least 30 years (1560 weeks). If you observe unusual weather for one week in Poland, you only see it on 1/1637 of the Earth's surface and for just 1/1560 of the time recommended.

How do you think we can observe climate change in an objective way? Ask your parents and grandparents about the climate when they were young. Is it different from nowadays? Think about how your perception of average weather conditions are influenced by the environment, by where you live and your personal feelings.

Part 3: Components

What does tropospheric air consist of?

Tropospheric air is a mixture of a few dominant gases and many many trace gases, some of which are rather important for our climate.





1. Dew rising in the morning - Virgen valley Osttirol. Photograph: Elmar Uherek.

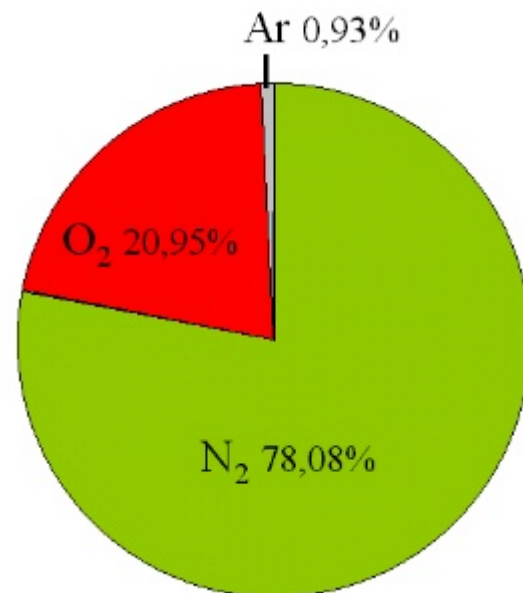
The gas phase

The most obvious problem we have with air is that we cannot see it! But if something is invisible this does not mean that it does not exist. Dew on the grass in the morning disappears as the sun comes up. The water droplets don't disappear by magic, they simply evaporate and change from the liquid phase to the gas phase. This change between a visible and an invisible state is most easily understandable for water.

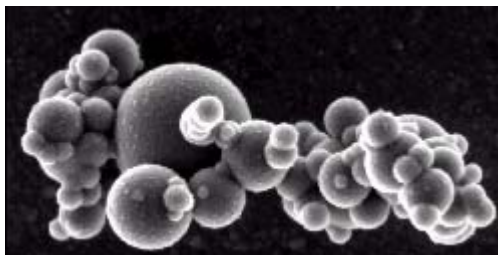
Dry air is made up of about 78% nitrogen, 21% oxygen and 1% Argon. These gases can also be occur as liquids but it takes temperatures below -150°C for this to happen and we never observe such low temperatures naturally. So air always exists as a gas and is invisible to our eyes.

Particles

When we see pictures of sand storms in the Sahara it's very obvious that there is a lot of sand and dust particles in the air. The same is true in cities where industrial processes and car exhausts emit particles into the air. Little particles are even found in air over really remote places such as Antarctica or over the middle of the oceans.



2. The major components of the atmosphere - nitrogen (N₂), oxygen (O₂) and argon (Ar). Author: Elmar Uherek.



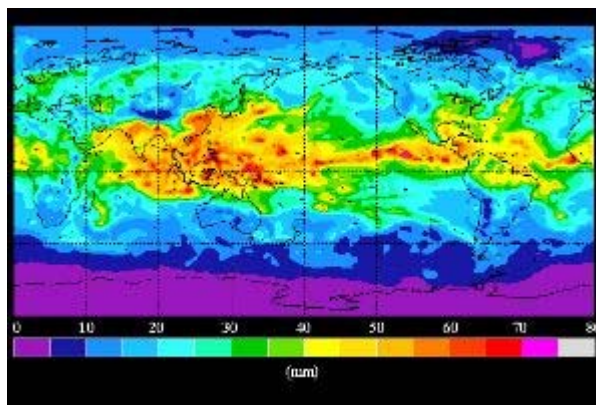
3. Electron microscope image of aerosol particles collected from the atmosphere above the Mediterranean Sea. Author: Research Group Dr. Helas, MPI Mainz. <http://www.mpch-mainz.mpg.de/~kosmo/remgallery/medsea/medsea.htm>

Particles can either be directly emitted into the atmosphere or can be formed by chemical reactions in the air. They are extremely important to our climate, they are essential for cloud formation and they can prevent solar radiation from reaching the surface of the Earth.



Water vapour

When we talk about the composition of air we generally mean dry air and ignore any water it contains. The main gases (nitrogen, oxygen, and argon) make up nearly 100% of the composition of dry air. The most important of the **trace gases** is carbon dioxide which makes up 0.037% of the air, other gases occur in much smaller amounts. The amount of water vapour in the air is really variable, making up between 0.1% and 4% of tropospheric air, depending on the climatic conditions. Cold air can hold much less water vapour than warm air.



4. Global overview of the total water vapour column in July 1989. Source: NASA water vapour project NVAP. <http://www.cira.colostate.edu/climate/NVAP/nvapcira.html>

Trace gases

Many climate processes are controlled by the levels of trace gases in the atmosphere, rather than the major constituents. These gases are present in very low amounts, i.e. a few molecules in one million or even one billion air molecules. To describe this, we often use the unit ppm (parts per million) so a trace gas with a concentration of 1 ppm means that there is just one molecule of the gas in every 1,000,000 air molecules (the more scientific unit is $1 \mu\text{mol mol}^{-1}$, we will talk more about atmospheric gas concentration units later). Levels of carbon dioxide, a very important greenhouse gas have increased from 280 ppm in preindustrial times to about 370 ppm now and predictions are that these concentrations will continue to rise due to human activities, the most important of which is fossil fuel combustion. Two other important greenhouse gases are methane (1.7 ppm) and ozone (varying around about 0.04 ppm). In addition, there are thousands of organic and inorganic gases which are emitted into the air from plants (imagine the smell of flowers) or during industrial procedures (think about solvents) or are formed during chemical processes in the atmosphere. These gases all play a part in the complex chemistry which goes on in the lowest layer of the atmosphere, the troposphere.

