ESPERE Climate Encyclopaedia

Topic: Upper Atmosphere

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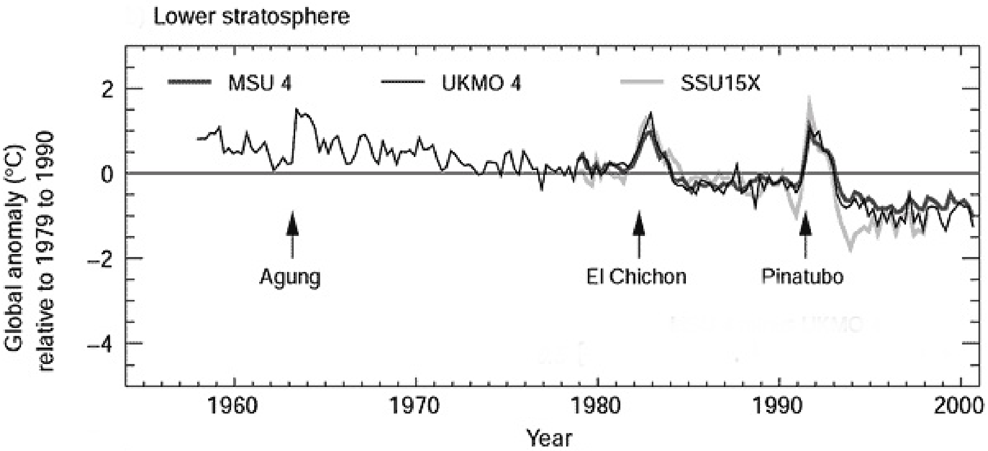
Part 5: Cooling

Stratospheric cooling

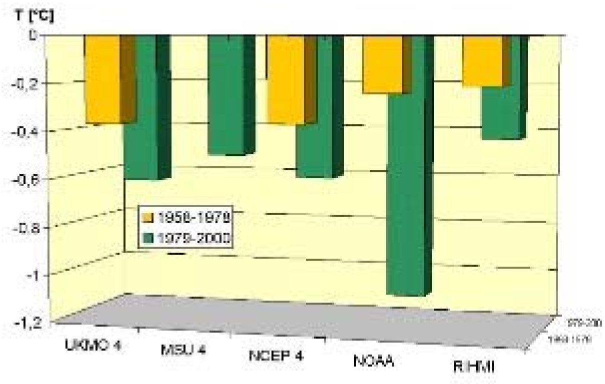
Cooling of the stratosphere isn't just the result of ozone destruction but is also caused by the release of carbon dioxide in the troposphere. Therefore, global warming in the troposphere and stratospheric cooling due to ozone loss are parallel effects. As cooling increases, development of the ozone layer can be affected because a cold stratosphere is necessary for ozone depletion.
So releasing more carbon dioxide may not only increase global warming but may also contribute to the formation of the ozone hole. The system is pretty complicated and so we try to give just an overview of it here.

Is the stratosphere cooling?

It's, of course, harder to measure the temperature in the stratosphere than in the troposphere where we have a network of measurement stations. Stratospheric temperature measurements do exist. They have been made using weather balloons, microwave sounding units, rocketsondes, LIDAR and satellites. Most of these readings only go back two or three decades at most and there are large uncertainities associated with the data.



1. Seasonal anomalies of global average temperature (°C), 1958 to 2000, relative to 1979 to 1990 for the lower stratosphere, as observed from satellites (MSU 4 and SSU 15X) and balloons (UKMO 4). The times of the major explosive eruptions of the Agung, El Chichon and Mt. Pinatubo volcanoes are marked. Image adapted from IPCC TAR 2001.



2. Calculated stratospheric cooling. Values from IPCC TAR Tab. 2.3.

The lower stratosphere appears to be cooling by about 0.5°C per decade. This cooling trend is interrupted by large volcanic eruptions which lead to a temporary warming of the stratosphere and last for one to two years. Calculations from many research institutes generally estimate the cooling trend for the last two decades (1979-2000) to be greater than for the previous period (1958-1978).

Why does the stratosphere cool?

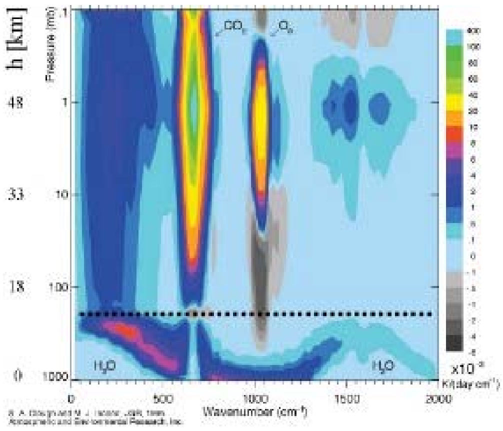
There are several reasons why the stratosphere is cooling. The two best understood are:
1) depletion of stratospheric ozone
2) increase in atmospheric carbon dioxide.

Cooling due to ozone depletion

The first effect is easy to understand. Less ozone leads to less absorption of ultra-violet radiation from the Sun. As a result, solar radiation is not converted into heat radiation in the stratosphere. So cooling due to ozone depletion is simply reduced heating as a consequence of reduced absorption of ultra-violet radiation. Ozone also acts as a greenhouse gas in the lower stratosphere. Less ozone means less absorption of infra-red heat radiation and therefore less heat trapping.
At an altitude of about 20 km, the effects of ultra-violet and infra-red radiation are about the same. Ozone levels decrease the higher we go in the atmosphere but there are other greenhouse gases present in the air which we have to consider.

Cooling due to the greenhouse effect

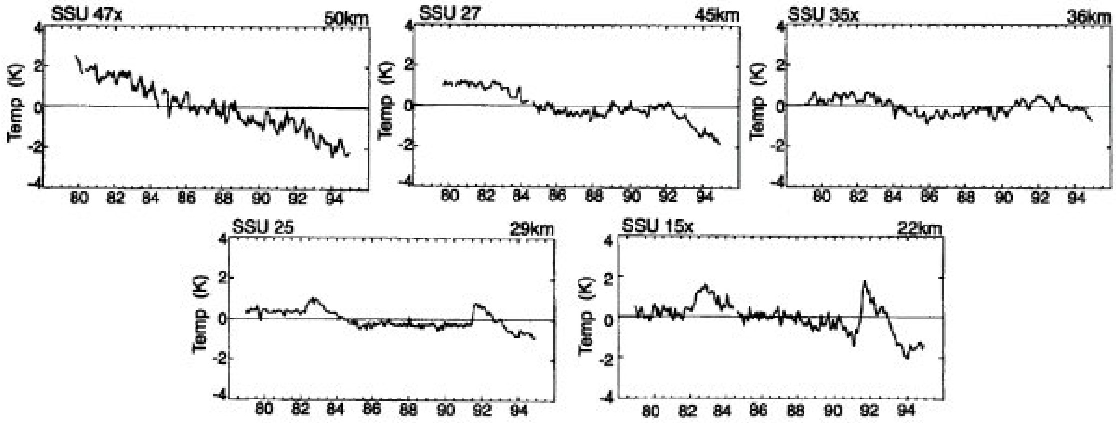
The second effect is more complicated. Greenhouse gases (CO_2, O_3, CFC) absorb infra-red radiation from the surface of the Earth and trap the heat in the troposphere. If this absorption is really strong, the greenhouse gas blocks most of the outgoing infra-red radiation close to the Earth's surface. This means that only a small amount of outgoing infra-red radiation reaches carbon dioxide in the upper troposphere and the lower stratosphere. On the other hand, carbon dioxide emits heat radiation, which is lost from the stratosphere into space. In the stratosphere, this emission of heat becomes larger than the energy received from below by absorption and, as a result, there is a net energy loss from the stratosphere and a resulting cooling. Other greenhouse gases, such as ozone and chlorofluorocarbons (CFC's), have a weaker impact because their concentrations in the troposphere are smaller. They do not entirely block the whole radiation in their wavelength regime so some reaches the stratosphere where it can be absorbed and, as a consequence, heat this region of the atmosphere.



3. Stratospheric cooling rates: The picture shows how water, cabon dioxide and ozone contribute to longwave cooling in the stratosphere. Colours from blue through red, yellow and to green show increasing cooling, grey areas show warming of the stratosphere. The tropopause is shown as dotted line (the troposphere below and the stratosphere above). For CO_2 it is obvious that there is no cooling in the troposphere, but a strong cooling effect in the stratosphere. Ozone, on the other hand, cools the upper stratosphere but warms the lower stratosphere. Figure from: Clough and Iacono, JGR, 1995; adapted from the SPARC Website.

Where does cooling take place?

The impact of decreasing ozone concentrations is largest in the lower stratosphere, at an altitude of around 20 km, whereas increases in carbon dioxide lead to highest cooling at altitudes between 40 and 50 km (Figure 3). All these different effects mean that some parts of the stratosphere are cooling more than others.



4. Cooling trends at different altitudes in the stratosphere. source: Ramaswamy et al., Reviews of Geophysics, Feb. 2001.

Other influences

It is possible that greenhouse warming could disturb the heating of the Arctic stratosphere by changing planetary waves. These waves are triggered by the surface structure in the Northern Hemisphere (mountain ranges like the Himalayas, or the alternation of land and sea). Recent studies show that increases in the stratospheric water vapour concentration could also have a strong cooling effect, comparable to the effect of ozone loss.

Conclusions

We now know that stratospheric cooling and tropospheric warming are intimately connected and that carbon dioxide plays a part in both processes. At present, however, our understanding of stratospheric cooling is not complete and further research has to be done. We do, however, already know that observed and predicted cooling in the stratosphere makes the formation of an Arctic ozone hole more likely.