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ENVIRONMENTAL PROBLEMS CONNECTED TO EMISSIONS OF OZONE DEPLETING AND CLIMATE GASES

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INTRODUCTION

The ozone depletion and climate change problems have been given thorough scientific evaluations through the international assessments on the two issues. A schematic overview of the two problems and their relation to the atmosphere and pollutants emitted is given in **Figure 1**.

Stratospheric ozone depletion is linked to man made emissions of CFCs. The emissions of CFCs and other ozone depleting substances (ODS) are now controlled by the agreement outlined in the Montreal Protocol. The agreement has led to a significant reduction in emission of ODS during the last 5 years. Nevertheless, observations at mid and high northern latitudes (**Figure 2**) show significant ozone decreases during this time period, giving large increases in harmful ultraviolet (UV-B) solar radiation. The change in UV-B radiation is a consequence of changes in ozone, as ozone protects the Earth from harmful UV-B radiation.

Climate change is first of all linked to enhanced concentrations of climate gases in the lower atmosphere (troposphere) which leads to enhanced heating of the Earth's surface. The main man made greenhouse gases are carbon dioxide, methane and nitrous oxide, and their increases are global and lead to a **global warming**.

Pollutants emitted on a local or regional scale will often undergo chemical transformation in the atmosphere and form compounds which will have **regional climate effects**. Pollutants like carbon monoxide, nitrogen oxides and hydrocarbons will form ozone, which is a greenhouse gas, in regional areas. Sulfur dioxide will form sulfate particles, which have a cooling effect on the lower atmosphere.

Temperatures have increased significantly on a global scale during the last century as shown in **Figure 3**. Exceptionally high global average temperatures have been observed for more than a decade, although there are large regional variations in the temperature trend.

CHANGES IN ATMOSPHERIC COMPOSITION AND THE CONSEQUENCES

The IPCC (Intergovernmental Panel for Climate Change) assessment has demonstrated that all major climate gases continue to increase on a global scale, and it is evident that the increase eventually will lead to significant changes in the Earth's climate. The increase has been thoroughly documented through worldwide observations over several decades as shown in **Figure 4 a-b** for carbon dioxide and methane respectively. Carbon dioxide has increased with approximately 30 %, methane with more than 100 % and nitrous oxide with 15 % since pre-industrial time.

CO₂ is the major greenhouse gas contributing probably more than 60 % to the increasing global warming at present. Its increase in the atmosphere is mainly due to the use of fossil fuels. For instance in China, with its rapid economic growth and the key role coal has as energy supply, the efficiency of coal use is a key issue in the discussion of how to limit the growth in the emission of greenhouse gases. Methane plays a special role in the climate system since it interacts chemically in the atmosphere. Through the interactions which are demonstrated in **Figure 5** its climate impact is twice as large as it would have been if it had not been interacting

chemically with other compounds in the atmosphere. As a whole its contribution to enhanced climate warming could be as much as 20 %. Methane is therefore a significant contributor to the greenhouse process, and measures to reduce the emissions should be taken. It has a large number of sources as indicated in Figure 5, of which a majority is affected by human activities. Furthermore, its lifetime in the atmosphere is 8 to 10 years, substantially less than for other greenhouse gases. Atmospheric growth of methane will respond more rapidly to reduced emission than more longlived climate gases like CO₂ and N₂O. The result of a reduction in methane emissions could therefore have a significant impact on climate on a time scale of a few decades.

Increases have also been measured in free tropospheric ozone and in the loading of sulfate particles over industrial regions as shown in **Figure 6**. Since sulfate particles cool the Earth's surface they will counteract the warming from climate gases in polluted regions. In fact, this cooling may dominate temperature trends in regions where sulfur emissions are increasing rapidly (e. g. China).

It is expected that the key climate gases carbon dioxide, methane, and nitrous oxide will continue to increase on a global scale, and that ozone and sulfate particles are likely to increase rapidly in regions with rapid economic growth. The regional increase in ozone and sulfate particles in a region like China will be dictated by the rapid regional increase in emissions of pollutants and will therefore be much faster than the global increases. This development represents a vast challenge to the society as there are already signs in the climate records which can be interpreted as changes due to man made activities.

Thanks to the Montreal Protocol there has been effective reduction in CFCs emissions, and a slower growth in stratospheric chlorine loading than in previous years. It is expected that the stratospheric chlorine loading will peak within the next 10 years, depending on how well the CFC phaseout agreement is complied with.

Measurements have shown continuous ozone reduction in the ozone layer for nearly two decades as demonstrated in **Figure 7**. The pronounced reductions at mid- and high- northern latitudes after 1990 can be linked to man made emissions of CFCs and bromine compounds. There are no signs of less ozone reductions during the last couple of years in response to the Montreal Protocol compliance. It is therefore important that the phaseout plan for CFCs and other ODS is continued, and that the developing countries are given the possibility to comply fully with the Montreal Protocol.

REGIONAL IMPACT

The IPCC assessment has demonstrated that climate impact on a regional scale can be significant due to chemical conversion of pollutants which are emitted in the region and converted to climate components like ozone and sulfate particles as demonstrated in **Figure 1**. An important issue here is that the chemical conversion and the impact occur in the region where the emission takes place. **Figure 8** gives an outline of the type of regional perturbations which are of importance from a climate point of view.

Sulfate particles formed over regions with large emissions of pollutants (shown in **Figure 6**) reflect solar radiation and cool the surface.

Emission of pollutants like nitrogen oxides (NO_x), carbon monoxide (CO) and hydrocarbons (HC) leads to regional formation of ozone. The pollutants are transported to the upper troposphere (10 to 12 km) where ozone levels are enhanced. The significance of this is an impact on regional climate, since surface temperatures are sensitive to changes in this height region. This type of climate impact is important in regions where there are efficient vertical transport as in the monsoon region in South East Asia.

Another type of regional environmental impact which has obtained large attention lately is represented by the emissions from aircraft. Emissions from aircraft in the 8 to 12 km region will enhance climate compounds like ozone, sulfate particles and water vapour.

The emissions of pollutants are increasing rapidly in China and several other countries in South East Asia. The increases are expected to continue at a high rate also in the future as a result of rapid economic growth. We therefore expect to see a much more rapid growth in the regional climate impact than in global impact. Therefore, unless measures are taken to reduce emissions significantly regional impacts are expected in the future.

LINKS TO OTHER ENVIRONMENTAL PROBLEMS

The regional component of climate change which is discussed above is strongly linked to regional air pollution in general. A brief outline of the links between regional environmental components is given in **Figure 9**. The same type of processes are responsible for forming climate compounds, acid precipitation and regional photochemical smog. The links are through chemical conversion of pollutants in the atmosphere: sulfate particles are formed from SO_2 and ozone from NO_x , CO and hydrocarbons.

A consequence of the links between regional environmental problems is that measures which are taken to limit the climate impact also will affect the impact from acid rain and photochemical formation in the region.

EMISSION CONTROL

An overview of the main sources for the climate components is given in **Figure 10** for components acting on a global scale (CO_2 and CH_4), and in **Figure 11** for

climate components acting on a regional scale (O_3 and sulfate particles).

The sulfate concentrations are strongly linked to the use of coal as energy source.

With the rapid growth in fossil fuel use in China, particularly the use of coal, CO_2 emission is likely to show significant growth, thereby enhancing the contribution to the global climate warming.

Reduced growth in CO_2 emissions could be achieved through more efficient energy use, or to the switch to non fossil fuel energy like hydropower and wind power, which have large potentials in China. Such transitions would also reduce local and regional pollution leading to climate impact through ozone formation and the formation sulfate particles (see Figure 11). It will also reduce the formation of photochemical smog and acid rain.

Transition from coal to gas in the industry offers obvious advantages. Firstly, CO_2 emissions will be reduced since gas is a more efficient energy source than coal. Secondly, the emission of other pollutants will be strongly reduced. NO_x levels can be reduced to a minimum, and there will be no emission of SO_2 .

Methane has several sources of which energy use stands for only one part. In China, two other sources are important, emissions from rice paddies and from human waste. In the latter case methane can be collected and used as energy source, thereby reducing the demand for energy. At the same time there will be reduced methane emission to the atmosphere, and thereby less impact on climate.

One caution should be raised, since gas predominantly contains methane.

According to the IPCC assessment methane is more than 20 times as efficient as a climate gas as CO_2 . If therefore only a small fraction (a few %) of methane leaks out during transport and use it could have significant climatic consequences. The

use of natural gas or methane from waste as energy source requires that the gas can be transported with a minimum of loss.

Two additional sources are likely to contribute significantly in the future to man made impact on regional pollution and regional climate change in the South East Asian region:

- 1) emission from motor traffic, and
- 2) emission from a fast growing fleet of commercial aircraft.

Both areas are expected to grow rapidly in the future. The main pollutants from cars are NO_x , CO and hydrocarbons, which will contribute significantly to local pollution in urban areas in the same way as has been seen in a number of large cities in countries around the world. The traffic will also contribute to ozone generation on a regional scale and thereby to the regional climate impact. Significant amounts of CO_2 will also be emitted.

There are at present extensive ongoing research programmes in the US and in Europe to study the impact of future aircraft emissions of NO_x , SO_2 and water vapor in order to recommend measures to be taken to reduce emissions.

The regional aspect of climate change combined with rapid growing emission of sulfur dioxide and ozone precursors (NO_x , CO, and hydrocarbons), in contrast to what is seen in Europe and the US, makes it more urgent with specific regional solutions to reduce the climate impact.

RESEARCH ON A REGIONAL SCALE OF ENVIRONMENTAL IMPACT

A main reason for performing research on climate issues is to contribute to the

IPCC process about regional climate changes. Studies of other environmental issues (ozone layer depletion, regional pollution, acid rain) is important as they are linked to changes in climate components (e.g. ozone, sulfate particles). There are several areas where research contributions are needed:

- a) Establish a programme to study climate gases.
- b) Study the impact on climate.

Such a programme is already under way as part of international meteorological collaboration.

- c) A program for studies of pollutants in regional areas.

Such studies will help estimate the emission of pollutants, and the regional impact of pollutants.

- d) Inventories of emissions of greenhouse gases and other pollutants.

These studies should be linked to the measurements described under points a) and c). Of particular importance is the emission of methane which comes from a large number of sources, of which several are poorly known (for instance the emission from rice paddies).

- e) Modelling of pollutants, the greenhouse gases and their impact on climate on a regional scale.

The modelling studies is important for estimating the effect of emissions on the chemical composition of the atmosphere, and through this the impact on climate. It will also help select control strategy for emission control.

- f) A network for detection of UV-B changes due to changes in the stratospheric ozone layer.
- g) Capacity building on climate issues, improved participation in international programmes.

CONCLUSIONS

China and several other countries in the region are characterized by a fast growing economy with increasing demand for energy and rapid increase in the emission of greenhouse gases and other pollutants.

It is expected that the increase in emission of pollutants will continue with increasing economic development in the industrial sector, with the increases in motor vehicles and in air traffic unless strong measures are taken to reduce emissions.

Future regional emissions could lead to, not only rapid increases in local and regional pollution, but also strong regional impact on climate through regional perturbation of sulfate particles and ozone.

The regional climate impact can be limited if appropriate measures are taken to remove pollutants like SO₂, NO_x, CO, and hydrocarbons from the emissions. Such measures will also reduce local and regional pollution.

The global impact is strongly linked to the use of energy (coal) and the emission of CO₂. Emission of methane is probably also an important contributor, and there are potentials for significant reductions of the climate impact from methane.

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Figure 1

Climate Change and Ozone Depletion

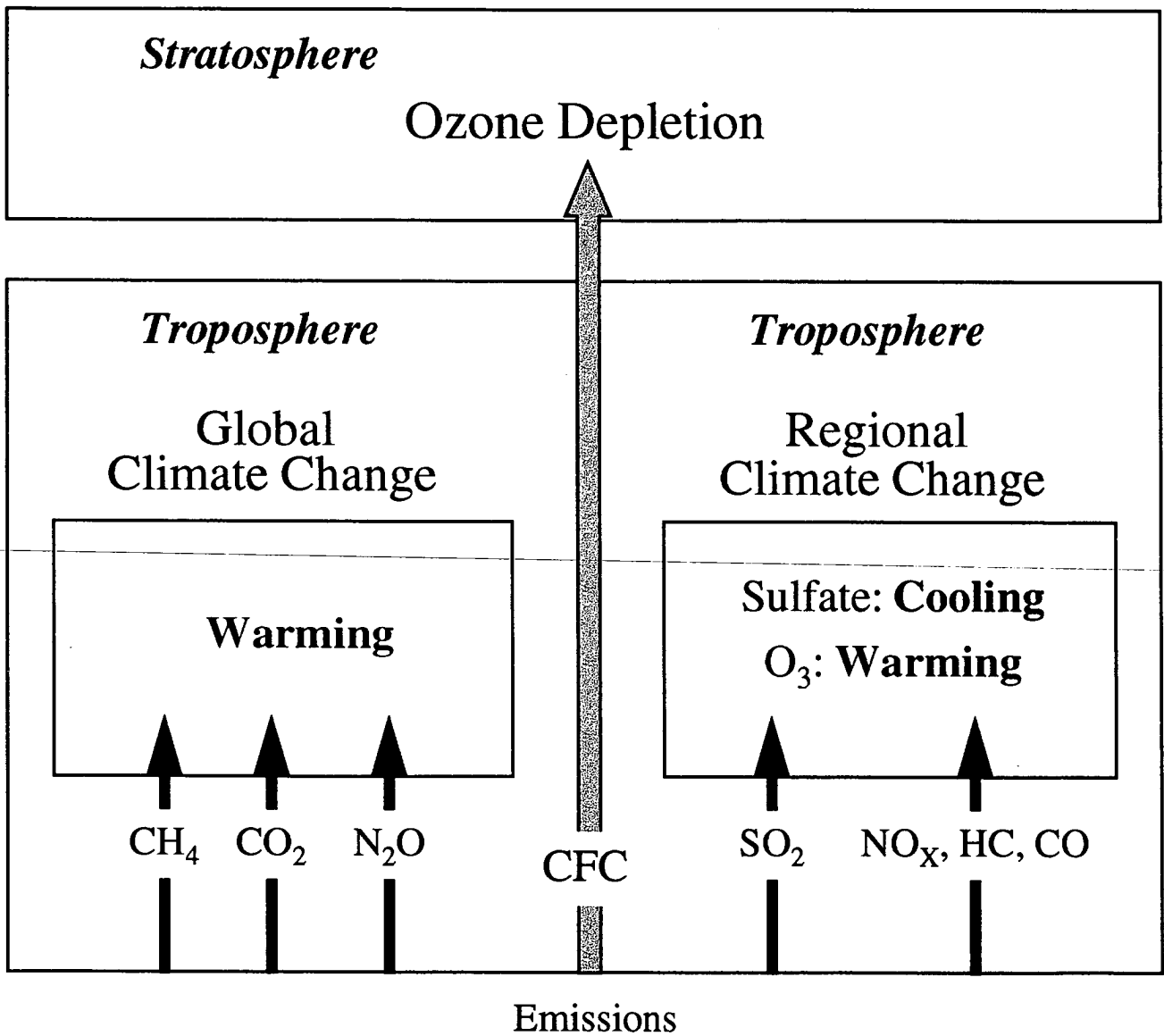
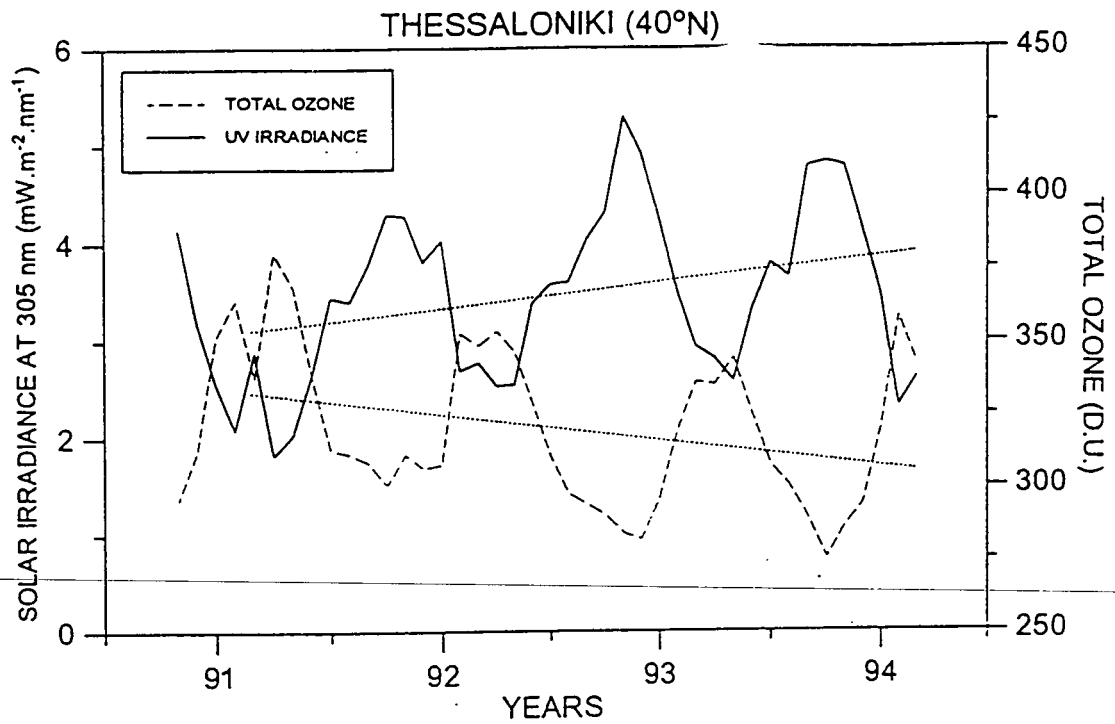
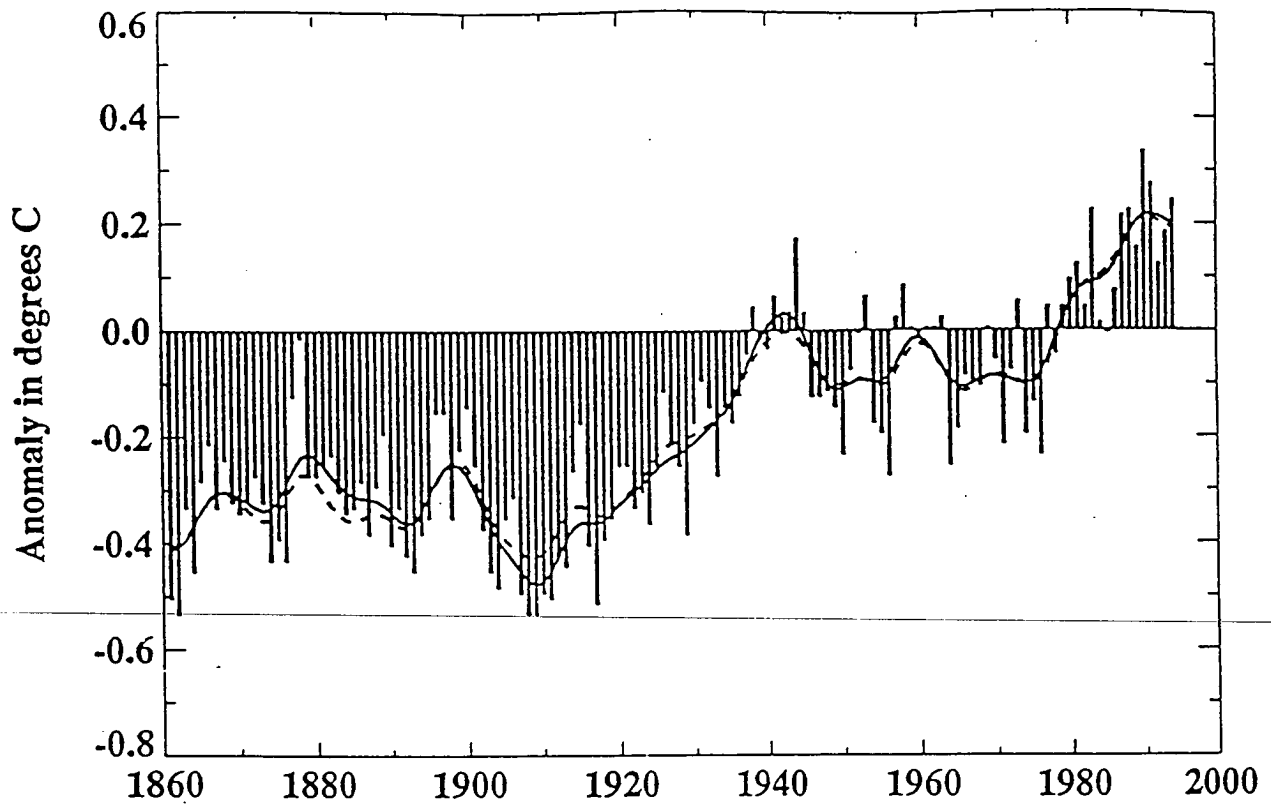


Figure 2



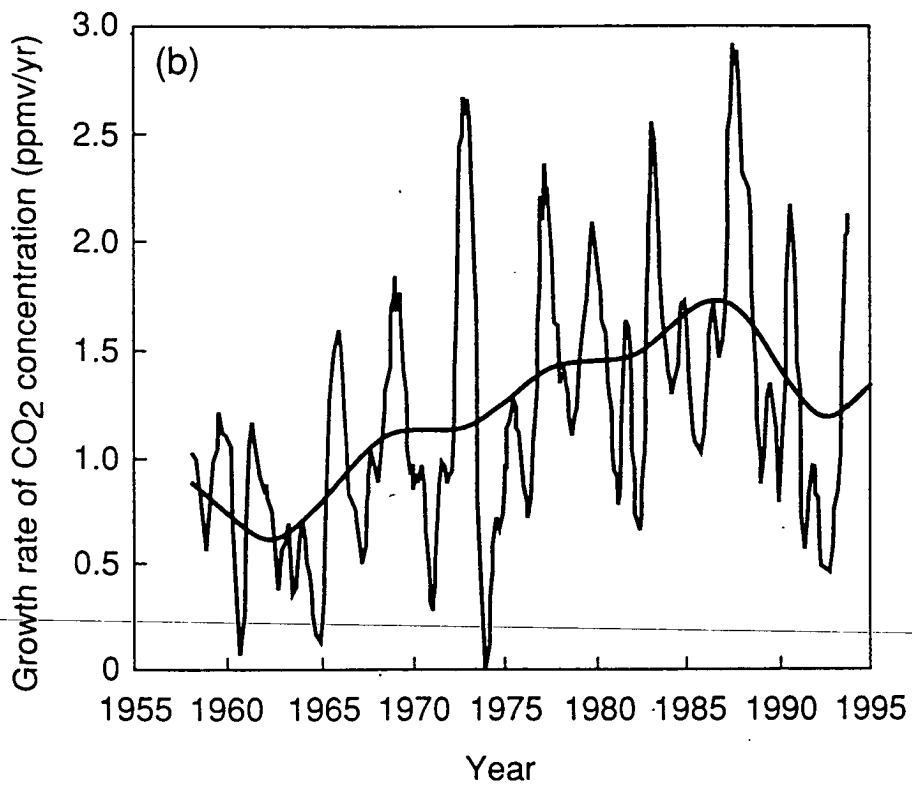
Changes in Total Ozone and UV-B Radiation

Figure 3



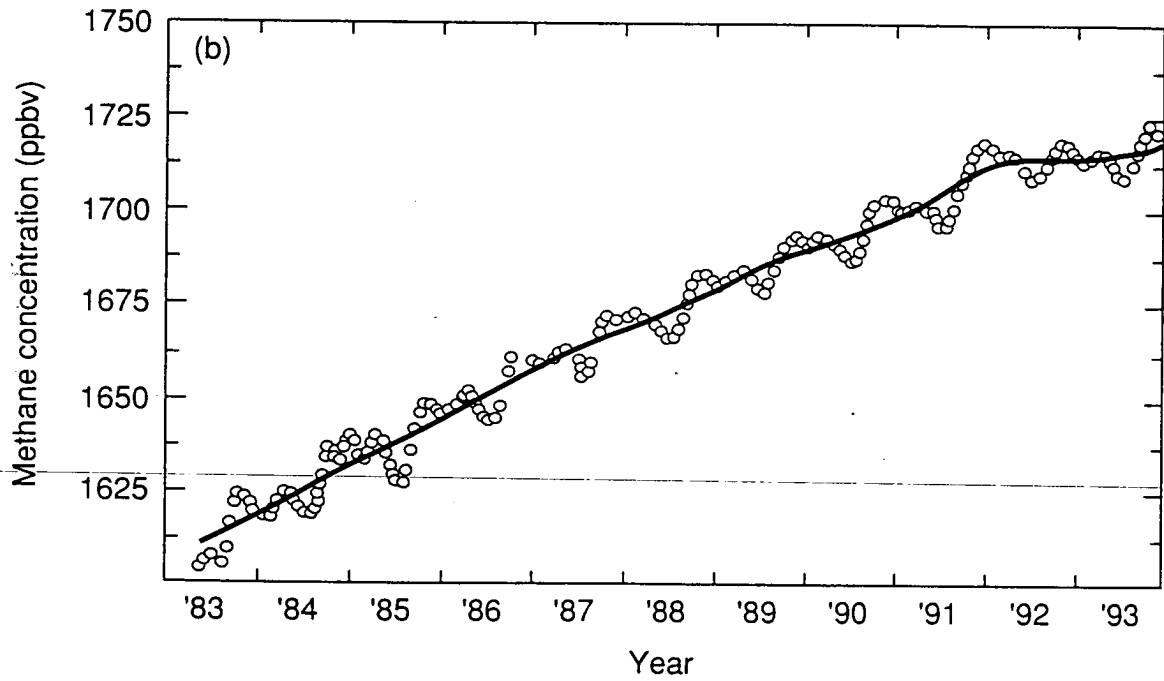
Global Temperature Trend

Figure 4a



Yearly Growth Rate of CO₂

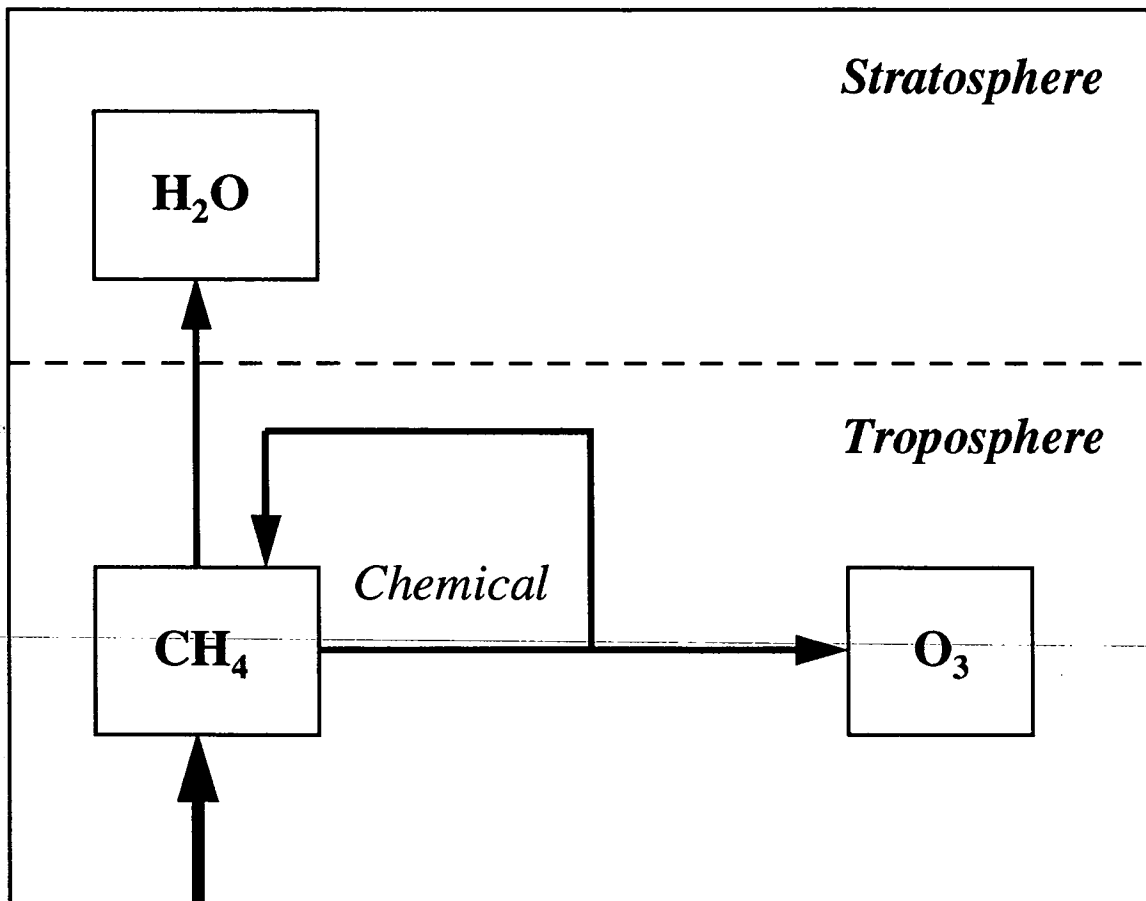
Figure 4b



Global CH₄ Concentration

Figure 5

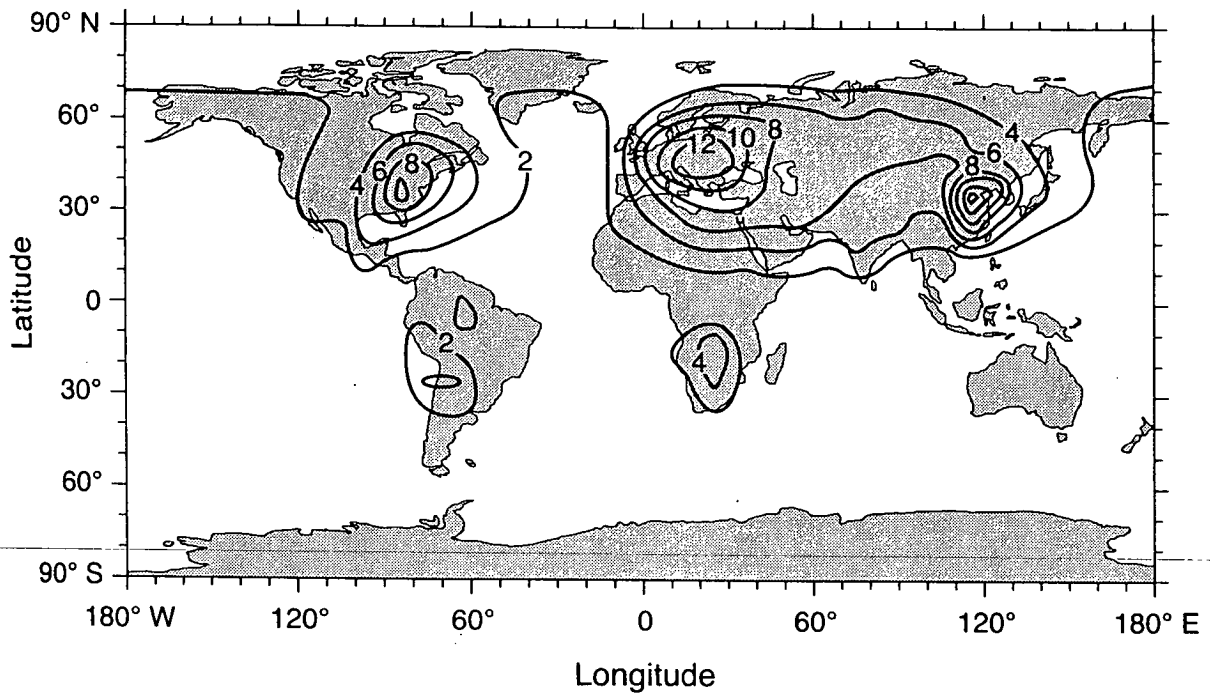
Methane-Climate Relations



CH₄ Emissions:

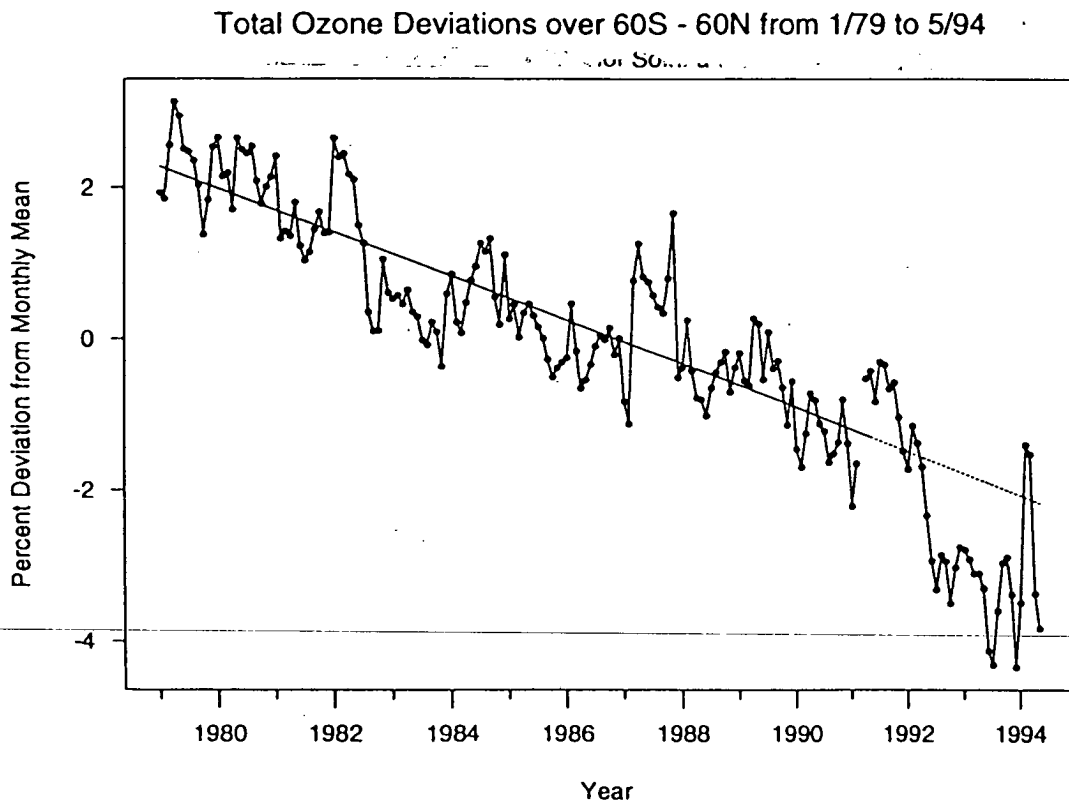
- Animals
- Rice Paddies
- Human Waste
- Biomass Burning
- Fossil Fuel
- Wet Land

Figure 6



Sulfate Loading (mg/m^2)

Figure 7



Global Ozone Reduction

Figure 8

Regional Climate Problems

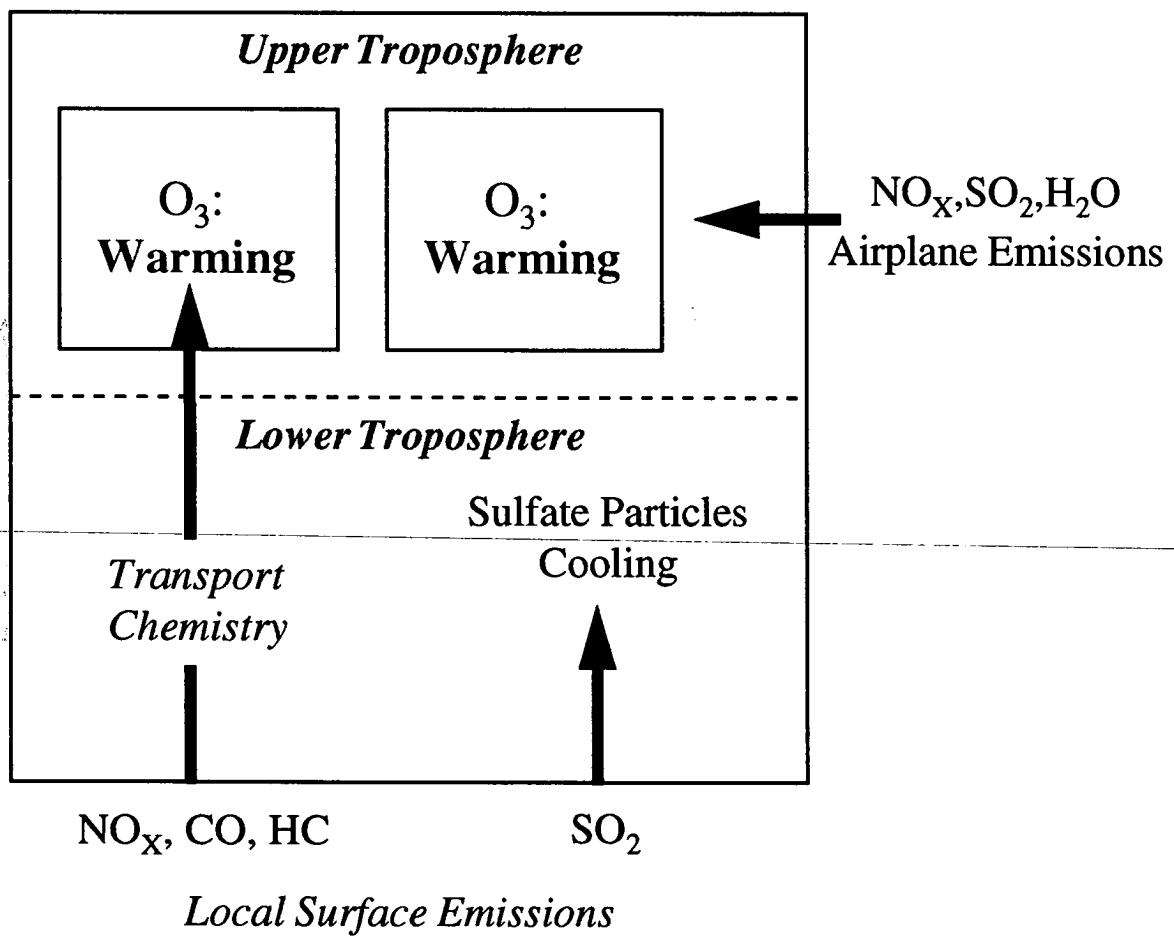
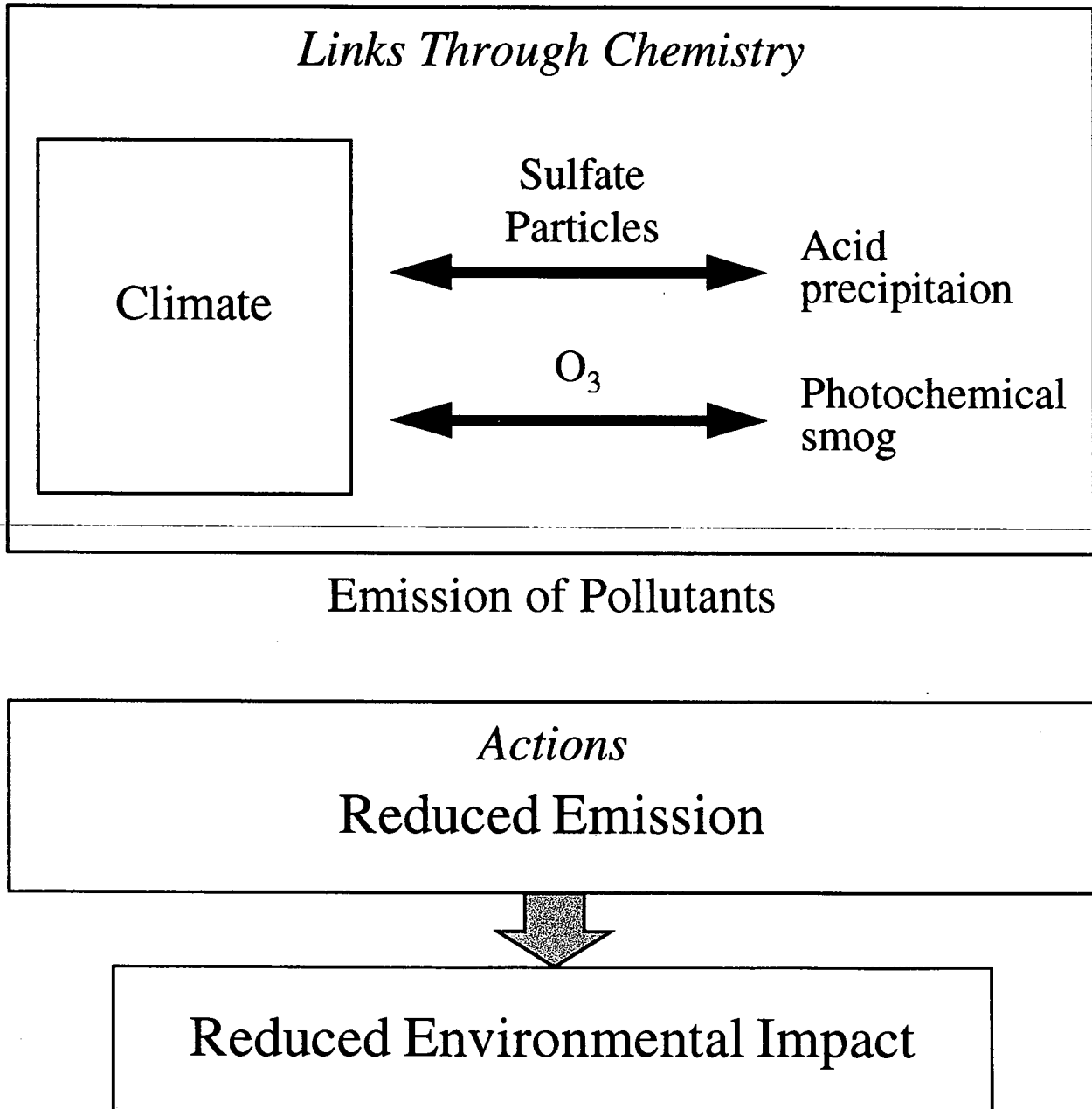


Figure 9

Regional Environmental Impact



Global Climate Impact

Sources of Emission

Actions to Reduce Emission

<p>CO₂</p> <ul style="list-style-type: none">• Industry Coal• Transport	<ul style="list-style-type: none">• Energy Efficiency, Less Coal. Transition Coal → Gas. Switch to Hydro-Electrical and Wind Power.• Energy Efficiency
<p>CH₄</p> <ul style="list-style-type: none">• Rice• Human waste• Fuel consumption	<ul style="list-style-type: none">• Improve Growing Practices• Use Waste As Energy, Reduce CH₄• Control of emissions

Regional Climate Impact

Sources of Emission

Actions to Reduce Emission

NO_x, CO, HC → O₃	
<ul style="list-style-type: none">• Industry (Coal)• Cars• Aircraft	<ul style="list-style-type: none">• Emission Control on Cars, Industry and Aircraft.
SO₂ → Sulfate	
<ul style="list-style-type: none">• Industry (Coal)	<ul style="list-style-type: none">• Remove SO₂ in Emission

Research on Environmental Impact

- A programme to study climate gases.
- Study the impact on climate.
- A programme for studies of regional pollution.
- Emission inventories.
- Modelling of pollutants and climate impact.
- A network for detection of UV-B changes.
- Capacity building.

Summary

- Carbon dioxide and methane emissions important for the global climate impact.
- Less impact through energy efficiency (CO_2) and better control of CH_4 emissions.
- Rapid increase in emission of pollutants.
- Rapid increase in regional pollution.
- Future increase gives regional impact on climate.
- The regional impact can be reduced by removing pollutant like SO_2 , NO_2 , CO and hydrocarbons from the emissions