3 Human Impacts on the Planet

Visualising Change over Time

Human interactions with the environment leave many traces. For much of human history, human impact on the Earth's surface has been relatively minor. In the last several hundred years, however, that impact has grown tremendously. Change brought about by human activities can now be objectively measured; it can even be seen from space. A study by the National Aeronautics and Space Administration (NASA 2003a) known as The Human Footprint (Figure 3.1) is a quantitative analysis of human influence across the globe that illustrates the impact of people and their activities on the Earth.

Evidence of change is not always visible on the landscape. Change also occurs in the atmosphere, in the soil, and in the oceans and other water bodies. In these environments, evidence of change can still be "seen," however, by detecting and measuring things such as rising average global temperatures, the concentrations of certain gases in the atmosphere, and various chemical contaminants in water.

Change alone is not the only problem. It is the degree to which human activities are changing the Earth that is also cause for growing concern. For instance, the results of a recent ten-year study concerning the ecological effects of industrialized fishing in the world's oceans reveals that large predatory fish species including tuna, marlin, sharks, cod, and halibut have declined by an estimated 90 per cent from pre-industrial levels (Myers and Warm 2003). Furthermore, the average size of surviving individuals among these species is only one-fifth to one-half what it was previously.

The composition of the Earth's atmosphere is also undergoing rapid change. Since life began on Earth, changes in climate have ordered the distribution of

Map of the Human Footprint

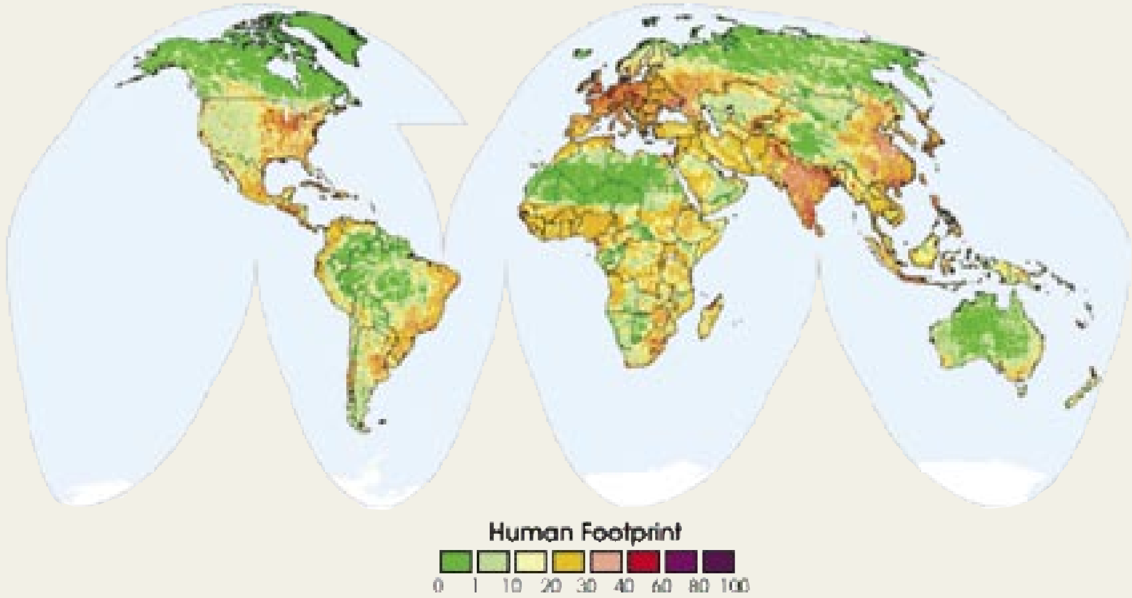


Figure 3.1: The Human Footprint is a quantitative analysis of human influence on the Earth's surface. In this map, human impact is rated on a scale from 0 (minimum) to 100 (maximum) for each terrestrial biome. The color green indicates areas of minimal impact while purple indicates areas of major impact. *Credit: Scott, Michon 2003. The Human Footprint. NASA: Socioeconomic Data and Applications Center. Source: http://earthobservatory.nasa.gov/Newsroom/NewImages/Images/human_footprint.gif*

Credit: Apollo Mbabaz/UNEP/Topfoto

Credit: Paiboon Pattanasitubol /UNEP/Topfoto

organisms and their behavior. Today, increases in atmospheric concentrations of greenhouse gases are expected to cause more rapid changes in the Earth's climate than have been experienced for millennia (Figure 3.2). At least some of the increase globally is due to human activity, and certainly, local impacts such as urban heat islands have profound effects on regional climatic conditions. As shown in Figure 3.2, waste generation and disposal is one of the ways in which humans contribute greenhouse gases to the atmosphere.

An emerging global impact issue is that of electronic or E-waste—a collective term for discarded electronic devices. Over the past decade, E-waste has become one of the world's fastest growing waste streams and—due to the presence of lead, mercury, brominated flame retardants, and other hazardous substances—one of the most toxic. The disposal of computer waste in particular is becoming a difficult issue as millions of computers and other electronic devices are rapidly becoming obsolete as each year the industry produces ever-greater quantities of less-expensive equipment. There are an estimated 300 million obsolete computers in the United States, with fewer that ten per cent destined for recycling each year. Even when a computer is sold to a secondhand parts dealer, however, there is a good chance it will end up in a dump in the developing world (Figure 3.3).

The Earth's forests are also under pressure. Tropical forests are now being subjected to the same heavy exploitation as were temperate forests a few generations ago. Pressures from logging, mining, hydropower, and a hunger for land are

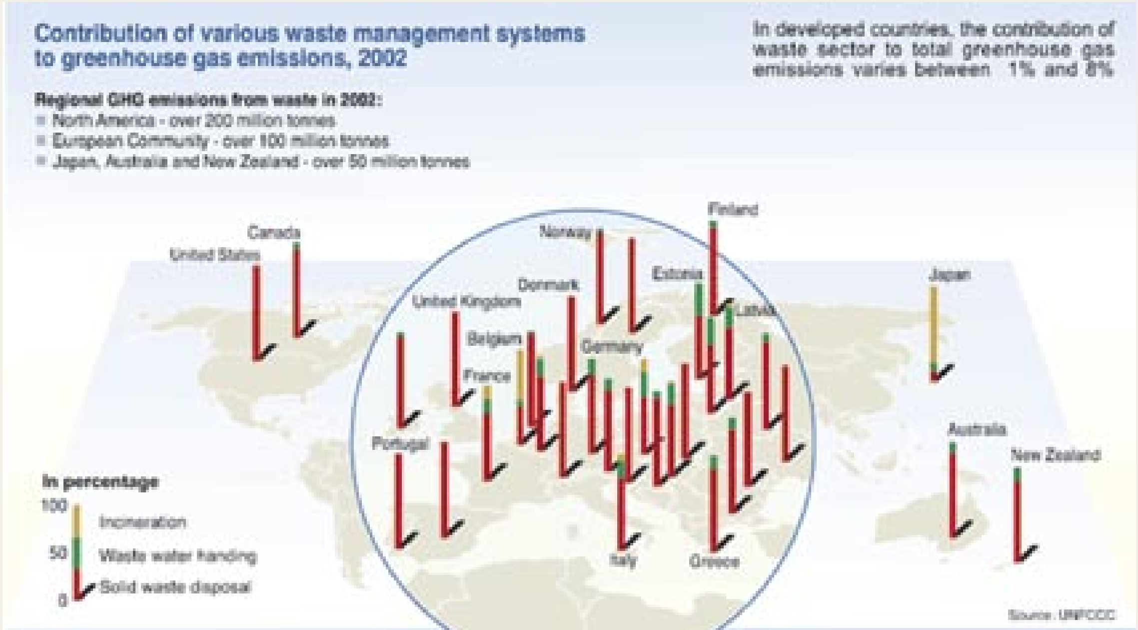


Figure 3.2: The disposal and treatment of waste can produce emissions of several greenhouse gases that contribute to global climate change. Even the recycling of waste produces some emissions, although these are offset by the reduction in fossil fuels that would be required to obtain new raw materials. Both waste prevention and recycling help address global climate change by decreasing greenhouse gas emissions and saving energy (Environmental Protection Agency). *Source: http://www.grid.unep.ch/waste/html_file/42-43_climate_change.html*

leading to large areas of forest being converted to serve other purposes. The integrity of forest ecosystems is being affected as the timber and paper industries remove vast areas of mature tropical and temperate forests. As a consequence, forest ecosystems lose their ability to support complex biodiversity and thousands of plant and animal species disappear forever.

Several globally significant environmental trends that have occurred between 1980 and 2000 may also be contributing to loss of forest ecosystems, including global warming (the two warmest decades on record are the 1980s and 1990s), three intense El Niño events, changes in cloudiness and monsoon dynamics, and a 9.3 per cent increase in atmospheric CO_2. Although these factors, along with others, are thought to exert their influence globally, their relative roles are still unclear.

An observed decline in tropical cloud cover is probably one of the more important recent climatic changes, although none of the existing climate models can accurately simulate this effect. It is known that continued reductions in tropical cloud cover, if accompanied by reduced rainfall, will have profound implications for tropical ecosystems in terms of water stress, productivity, ecological community composition, and disturbance patterns.

Images of Change

Various types of ground-based instruments, together with *in situ* surveys and analyses, can measure many of the changes being brought about on the Earth as a result of human activities. But such changes can also be observed—in more detail and with a "big picture" perspective—from space by Earth-orbiting satellites that gather images of the Earth's surface at regular intervals. The Landsat series of Earth-observing satellites has compiled a data record of the planet's land surfaces that spans the past thirty years and continues today.

By comparing two images of the same area taken ten, twenty, or even thirty years apart, it is often easy to see human-induced changes in a particular landscape. Few places remain on our planet that do not show at least some impact from human activities.

The focus of this chapter is a set of specific case studies in which satellite images, taken at different times, are paired so as to reveal changes and human impacts on the atmosphere, oceans and coastal zones, freshwater ecosystems and wetlands, forests, croplands, grasslands, urban areas, and the tundra regions.

The changes that we see in pairs of satellite images should make us cautious. Some are positive changes. But many more are negative. These images could be seen as warning signs. At the least they should provide us with food for thought and prompt us to ask pointed questions: How can we be more protective of our environment? How can we use the environment in ways that will not reduce the ability of the Earth to support us in perpetuity?

Figure 3.3: The high tech boom has been accompanied by E-waste, which represents the largest and fastest-growing type of manufacturing waste product. Recycling E-waste involves major producers and users, and the shipping of obsolete equipment and other products to Asia, Eastern Europe, and Africa where recyclers, such as the people in this photo, are exposed to toxic substances. *Source: http://www.grid.unep.ch/waste/html_file/36-37_ewaste.html*

Credit: Unknown/UNEP/Basel Action Network

Credit: Unknown/UNEP/Morgue File

3.1 Atmosphere

The Earth's atmosphere is a collection of gases, vapor, and particulates that together form a blanket of "air" that surrounds the planet. The atmosphere extends over 560 km (348 miles) from the surface of the Earth out toward space, and can be roughly divided into five major layers or sections (Figure 3.4). The primary components of the atmosphere are three gases: nitrogen (N_2, 78 per cent), oxygen (O_2, 21 per cent), and argon (Ar, 1 per cent). Other components, present in smaller amounts, include water vapor (H_2O, 0-7 per cent), ozone (O_3, 0-0.01 per cent), and carbon dioxide (CO_2, 0.01-0.1 per cent) (Phillips 1995).

The Earth's atmosphere plays many vital roles essential to sustaining life on the planet. The air we breathe circulates through its lowest level. The chemical elements carbon, nitrogen, oxygen, and hydrogen, which are constituents of all living things, are cycled and recycled in the atmosphere. Organisms convert these elements into carbohydrates, proteins, and other chemical compounds. The atmosphere also shields life on the planet's surface from harmful solar radiation, and—for the most part—from the threat of meteorites, which typically burn up as they go through the atmosphere (UNEP 1999a).

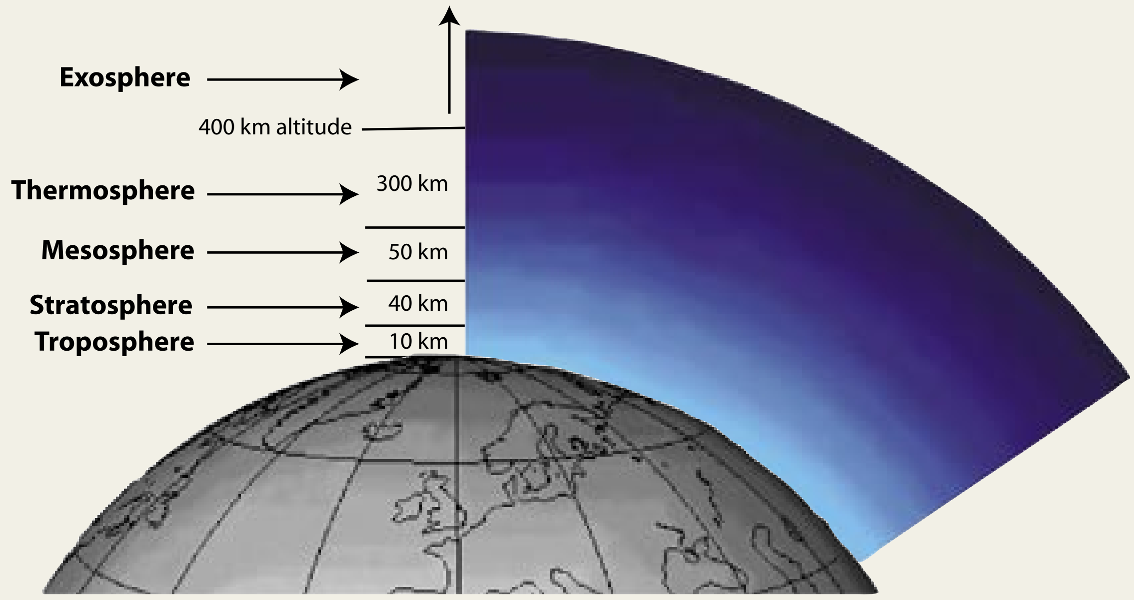


Figure 3.4: The Earth's atmosphere *Credit: Used with permission from Centre for Atmospheric Science, University of Cambridge, UK. Source: http://www.atm.ch.cam.ac.uk/tour/atmosphere.html*

Human activities impact the Earth's atmosphere in many ways. Some activities produce a quite direct effect, such as generating and releasing pollutants that foul the air, and adding carbon dioxide and other greenhouse gases to the atmosphere that induce global warming and climate change. Other human impacts, such as water pollution, land degradation, and human-induced loss of biodiversity, can indirectly affect the atmosphere, as well as the water and land.

In this section, four major issues that involve human impacts on the atmosphere—ozone depletion, global warming, climate change, and air pollution—are addressed.

Ozone Depletion

Ozone is a relatively unstable molecule, made up of three oxygen atoms (O_3). In the atmosphere, ozone is formed naturally in the stratosphere. It is concentrated there as an "ozone layer" that acts as a protective shield against harmful ultraviolet (UV) radiation coming from the Sun. The loss of stratospheric ozone allows more UV radiation to reach the Earth's surface, where it can cause skin cancer and cataracts in people and negatively affect other living things as well.

Ozone is also found in the troposphere, the layer of the Earth's atmosphere that is closest to the planet's surface. Ozone can

Credit: Image Analysis Laboratory/UNEP/NASA Johnson Space Center

Credit: Image Analysis Laboratory/UNEP/NASA Johnson Space Center

be formed naturally in the troposphere—for example, by lightning. However, tropospheric ozone is also a byproduct of certain human activities. Vehicle exhaust contributes large quantities of ozone to the troposphere each year.

Depending on where ozone resides, it can protect or harm life on the Earth (Figure 3.5). In the stratosphere, ozone is "good" as it shields life on the surface from harmful solar radiation. In the troposphere, ozone can be "bad" as it becomes a type of air pollution. Changes in the amount of ozone in either the stratosphere or the troposphere can have serious consequences for life on the Earth. For several decades, "bad" tropospheric ozone has been increasing in the air we breathe, while "good" stratospheric ozone has been decreasing, gradually eroding the Earth's protective ozone shield (Thompson 1996).

Since the late 1970s, scientists have detected a slow but steady decline in the amount of ozone in the stratospheric ozone layer. This ozone destruction results from the presence of certain types of chemicals in the atmosphere, especially chlorofluorocarbons (CFCs) and other chlorine- and bromine-containing compounds, coupled with fluctuations in stratospheric temperature.

In polar regions, particularly the area of the atmosphere that overlies Antarctica, ozone depletion is so great that an "ozone hole" forms in the stratosphere there every

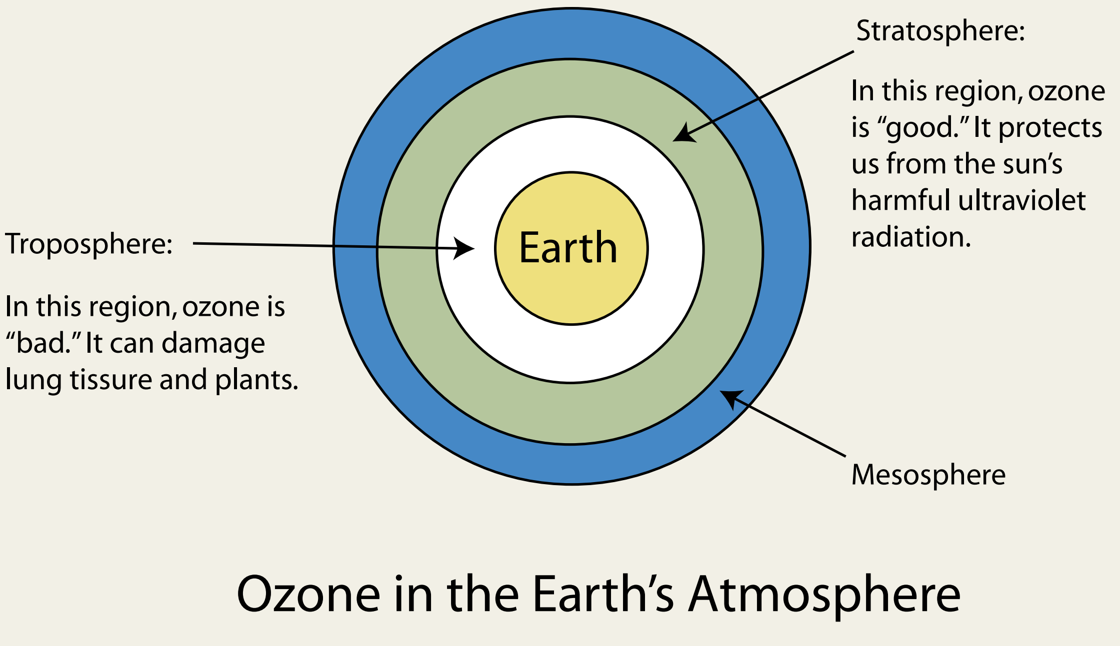
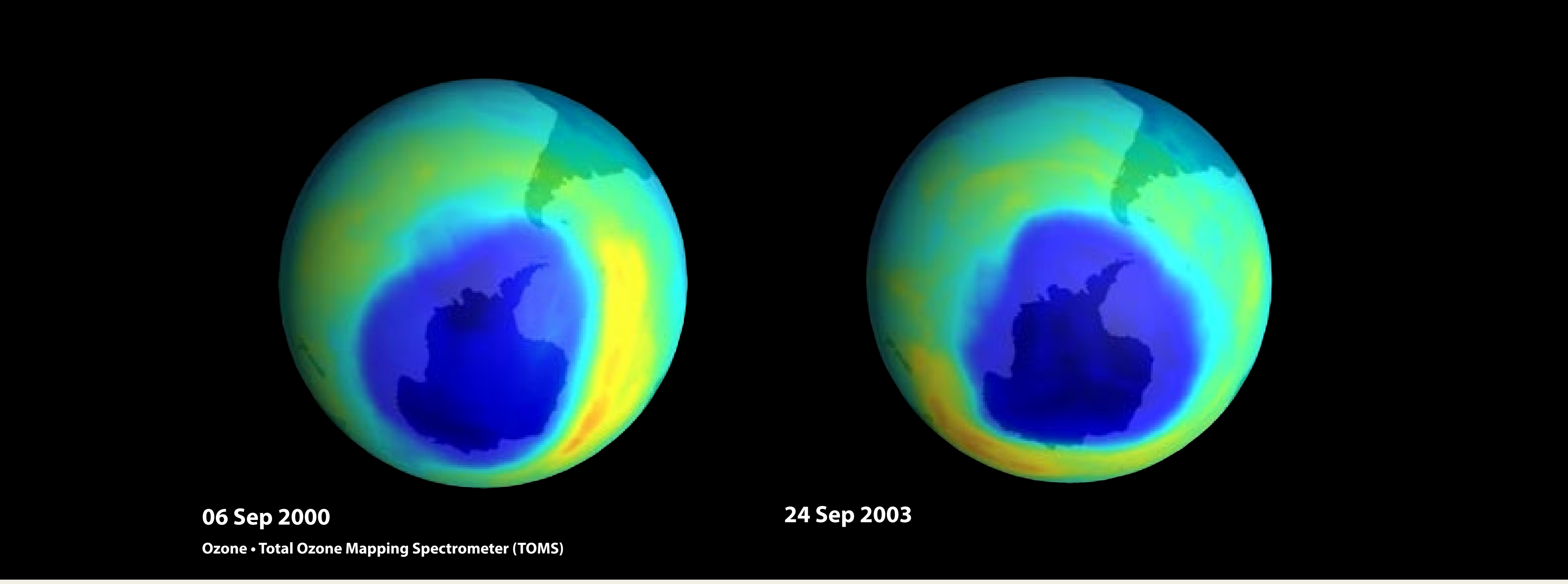


Figure 3.5: Ozone in the stratosphere forms the protective ozone layer that shields the Earth's surface from harmful solar radiation. Ozone in the troposphere, the lowest part of the atmosphere, can be a form of air pollution. *Source: http://www.atmos.umd.edu/~owen/CHPI/IMAGES/ozonefig1.html*



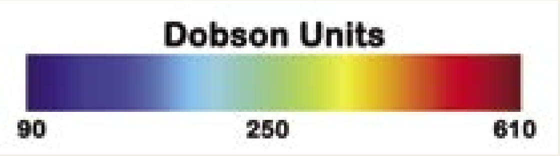


Figure 3.6: Every austral spring, an area of severe stratospheric ozone depletion— an "ozone hole"—forms in the atmosphere over Antarctica. The ozone holes that formed in 2000 and 2003 were the largest and second largest on record, respectively. *Source: http://www.gsfc.nasa.gov/gsfc/earth/pictures/2003/0925ozonehole/still_hires_24Sept2003.tif and http://www.gsfc.nasa.gov/ftp/pub/ozone/ozone_still_2000_09_06.tif (NASA 2004a)*

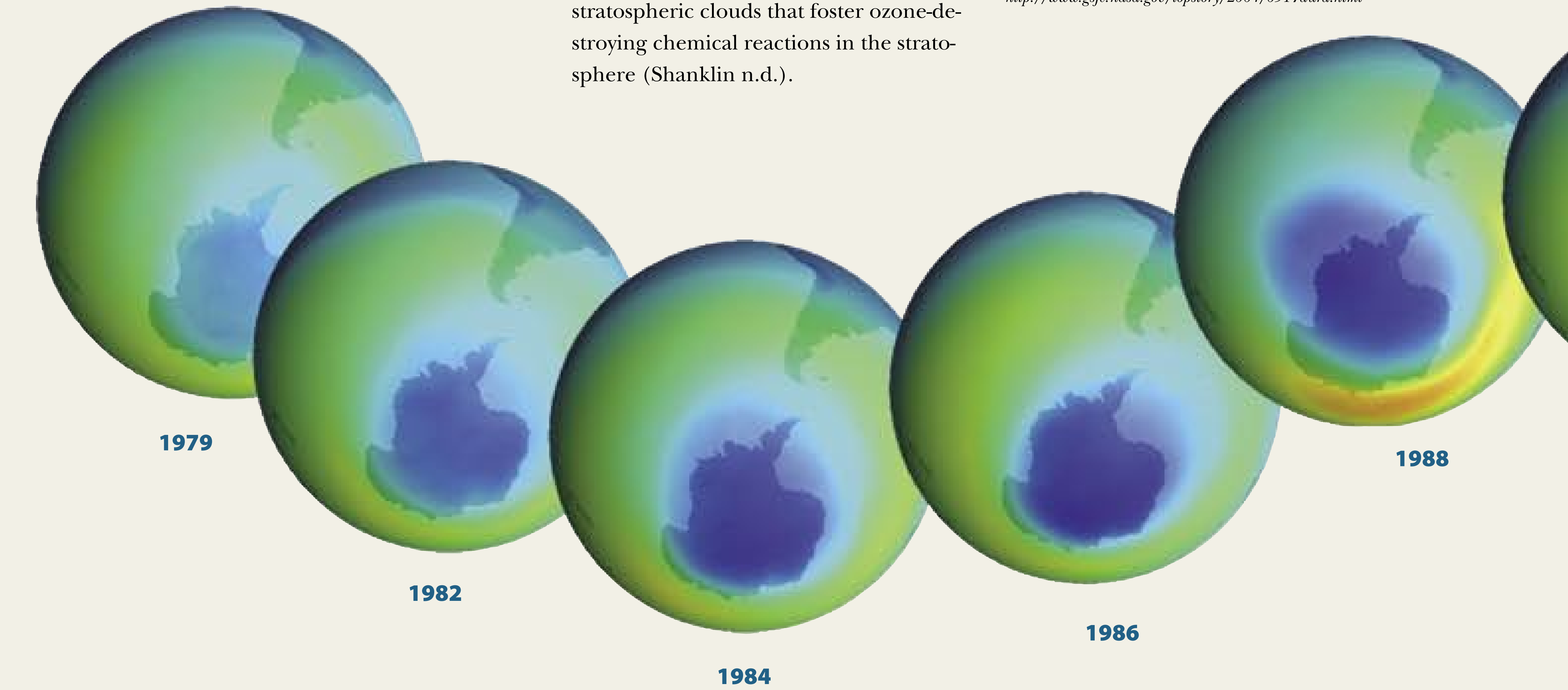
austral spring (late August through early October). In the past few years, the Antarctic ozone hole has been about the size of North America. In 2000, the Antarctic ozone hole was the largest on record, covering 29.6 million km^2 (11.4 million square miles). In the austral spring of 2003, it was almost as large, covering 28.9 million km^2 (11.1 million square miles) (Figure 3.6).

Seasonal ozone depletion is also noticeable around the North Pole. More than 60 per cent of stratospheric ozone north of the Arctic Circle was lost during the winter and early spring of 1999-2000 (Shah 2002).

Some ozone-depleting chemicals, such as CFCs, also contribute to global warming. Like carbon dioxide and methane, CFCs are powerful greenhouse gases that trap heat radiating from the Earth's surface and prevent it from immediately escaping into space. This causes the part of the atmosphere nearest the Earth's surface to warm, resulting in global warming. This warming in the troposphere, however, leads to colder-than-normal temperatures in the stratosphere. This, in turn, enhances the formation of certain types of stratospheric clouds that foster ozone-destroying chemical reactions in the stratosphere (Shanklin n.d.).

Fortunately, bans against the production and use of CFCs and other stratospheric ozone-destroying chemicals appear to be working to reverse the damage that has been done to the ozone layer. In the past few years, the Antarctic ozone hole has not increased significantly in size

Figure 3.7: Growth of the Antarctic ozone hole over 20 years, as observed by the satellite-borne Total Ozone Mapping Spectrometer (TOMS). Darkest blue areas represent regions of maximum ozone depletion. Atmospheric ozone concentration is measured in Dobson Units. A "normal" stratospheric ozone measurement is approximately 300 Dobson Units. Measurements of 220 Dobson Units and below represent significant ozone depletion. *Source: http://www.gsfc.nasa.gov/topstory/2004/0517aura.html*



Credit: John Bortniak/UNEP/NOAA

or intensity. Some researchers predict that if atmospheric concentrations of ozone-destroying chemicals drop to pre-ozone-hole levels, the Antarctic ozone hole should disappear in approximately 50 years (Figure 3.7) (WMO-UNEP 2002).

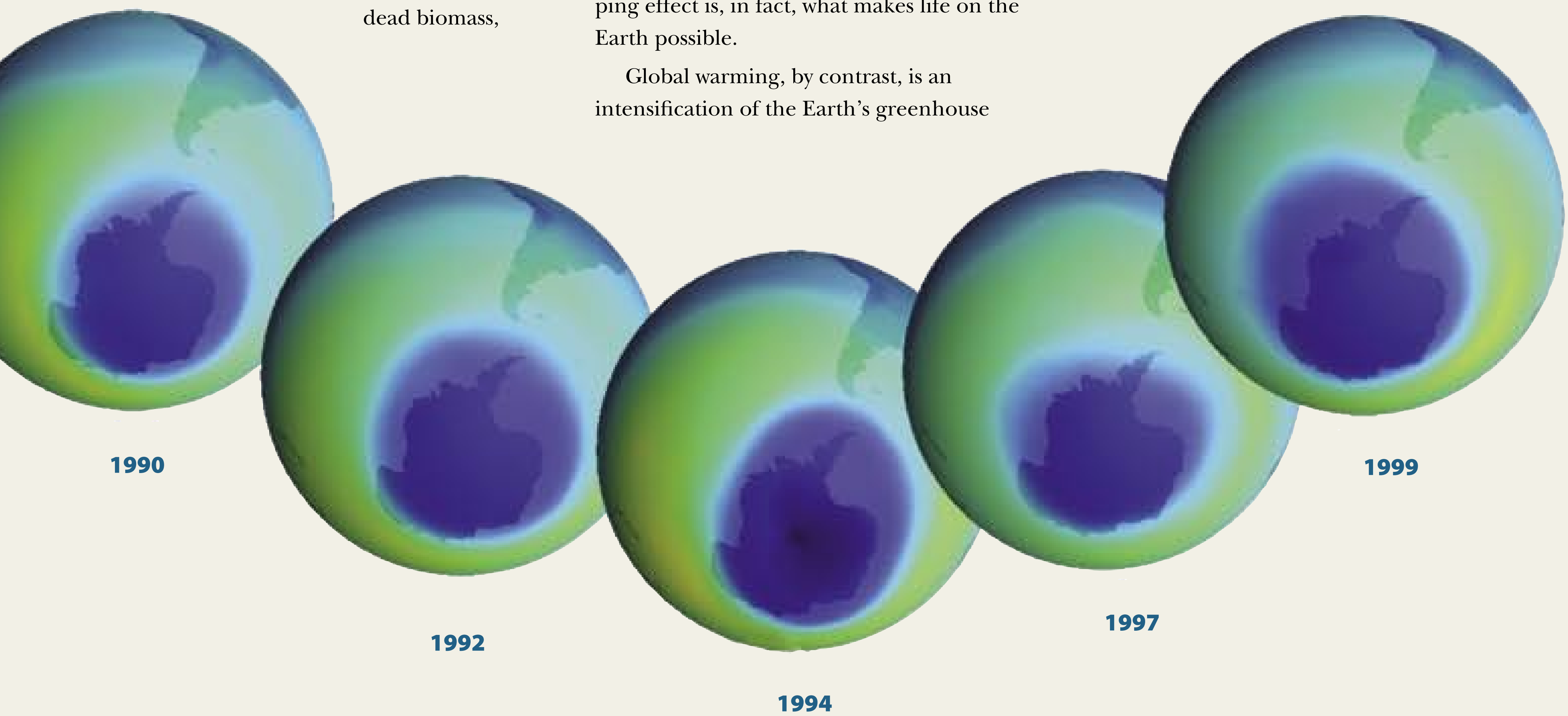
Global Warming

Atmospheric temperature and chemistry are strongly influenced by the amount and types of trace gases present in the atmosphere. Examples of human-made trace gases are chlorofluorocarbons, such as CFC-11, CFC-12, and halons. Carbon dioxide, nitrous oxide, and methane (CH_4) are naturally formed trace gases produced by the burning of fossil fuels, released by living and dead biomass, and resulting from various metabolic processes of microorganisms in the soil, wetlands, and oceans. There is increasing evidence that the percentages of environmentally significant trace gases (greenhouse gases) are changing due to both natural and human factors, and contributing to global warming.

Global warming is recognized as one of the greatest environmental threats facing the world today. Global warming is the gradual rise of the Earth's average surface temperature caused by an enhancing of the planet's natural greenhouse effect. Radiant energy leaving the planet is naturally retained in the atmosphere thanks to the presence of certain gases such as water vapor and carbon dioxide. This heat-trapping effect is, in fact, what makes life on the Earth possible.

Global warming, by contrast, is an intensification of the Earth's greenhouse effect. The Earth's average surface temperature, which has been relatively stable for more than 1 000 years, has risen by about 0.5 degrees Celsius in the past 100 years (Figure 3.8). The nine warmest years in the 20th century have all occurred since 1980; the 1990s were probably the warmest decade of the second millennium (IPCC 2001).

Global warming has occurred in the distant past as the result of natural influences. However, since the industrial era, the term is most often used to refer to the current warming predicted as a result of increases in the atmospheric concentrations of certain heat-trapping greenhouse gases generated by human activities (Figure 3.9). Most scientists



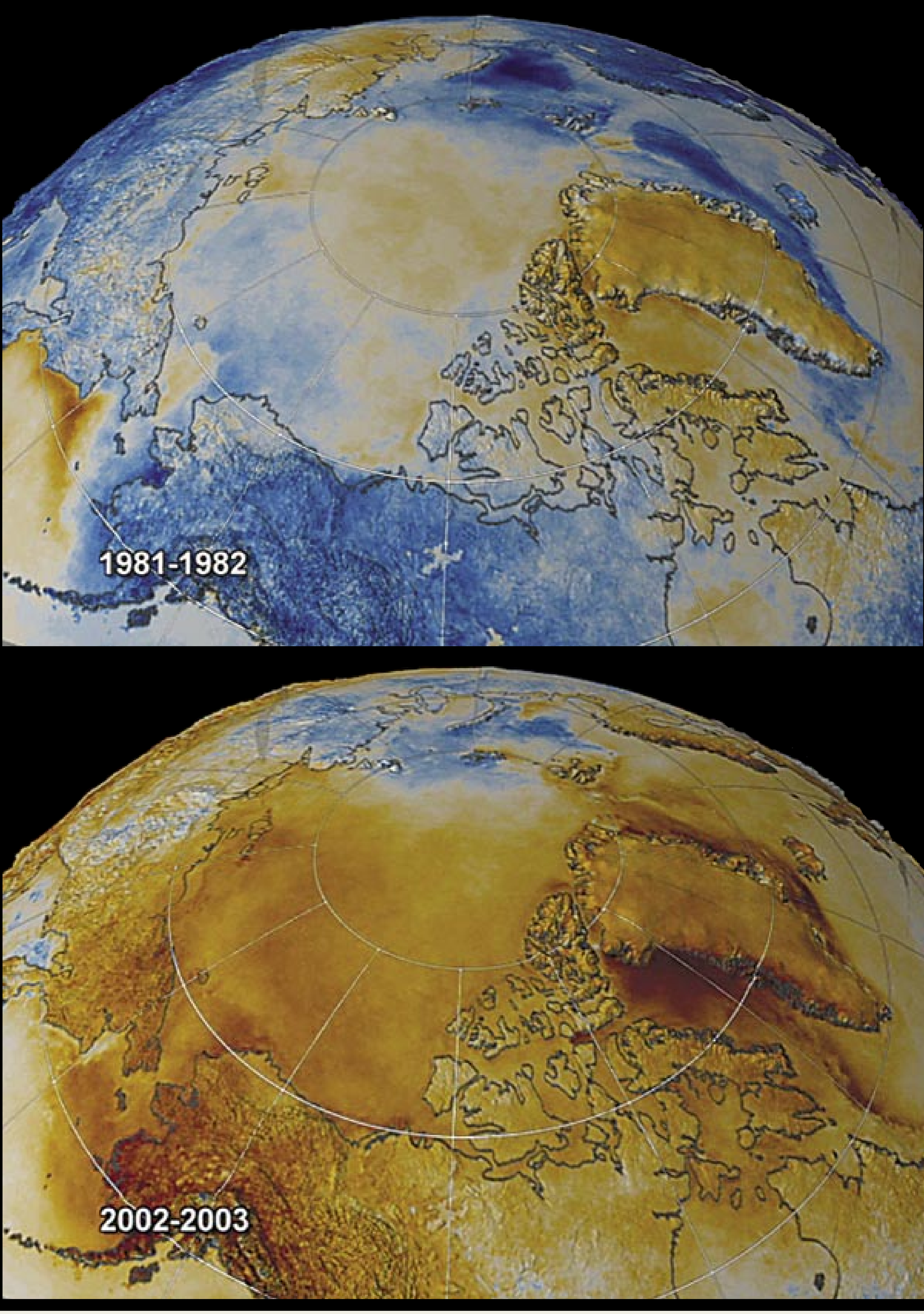


Figure 3.8: Satellite data of Arctic regions show warming is taking place there at an accelerating rate. These two maps show temperature anomalies in the Arctic in 1981 and in 2003. The anomalies range from 7°C (12.6°F) below normal to 7°C (12.6°F) above normal. Shades of orange and red show areas of warming; shades of blue shows areas of cooling; white represents little or no change (map adapted from Comiso). The data reveal that some regions are warming faster than 2.5°C (4.5°F) per decade (NASA 2003b).

Source: http://svs.gsfc.nasa.gov/vis/a000000/a002800/a002830/

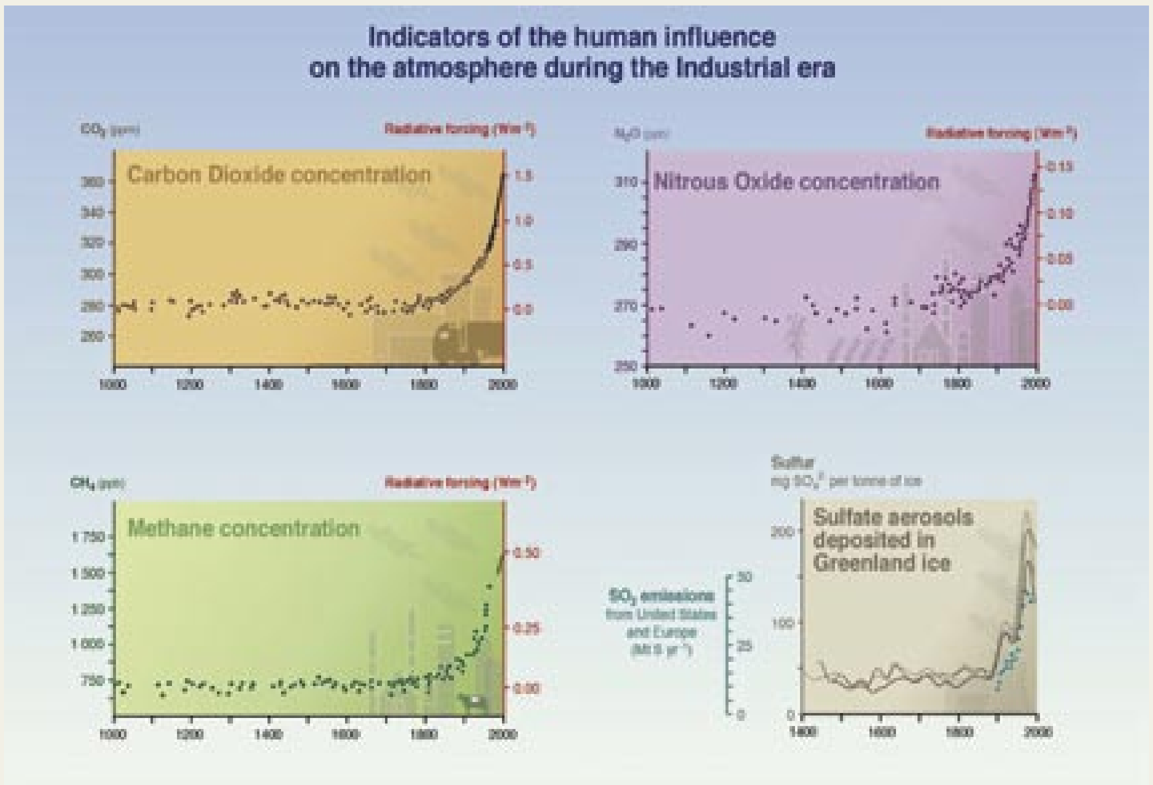


Figure 3.9: Human activities directly influence the abundance of greenhouse gases and aerosols in the atmosphere. Carbon dioxide, nitrous oxide, methane, and sulfur aerosols have all increased significantly in the past 50 years. *Source: Intergovernmental Panel on Climate Change, IPCC (2001)*

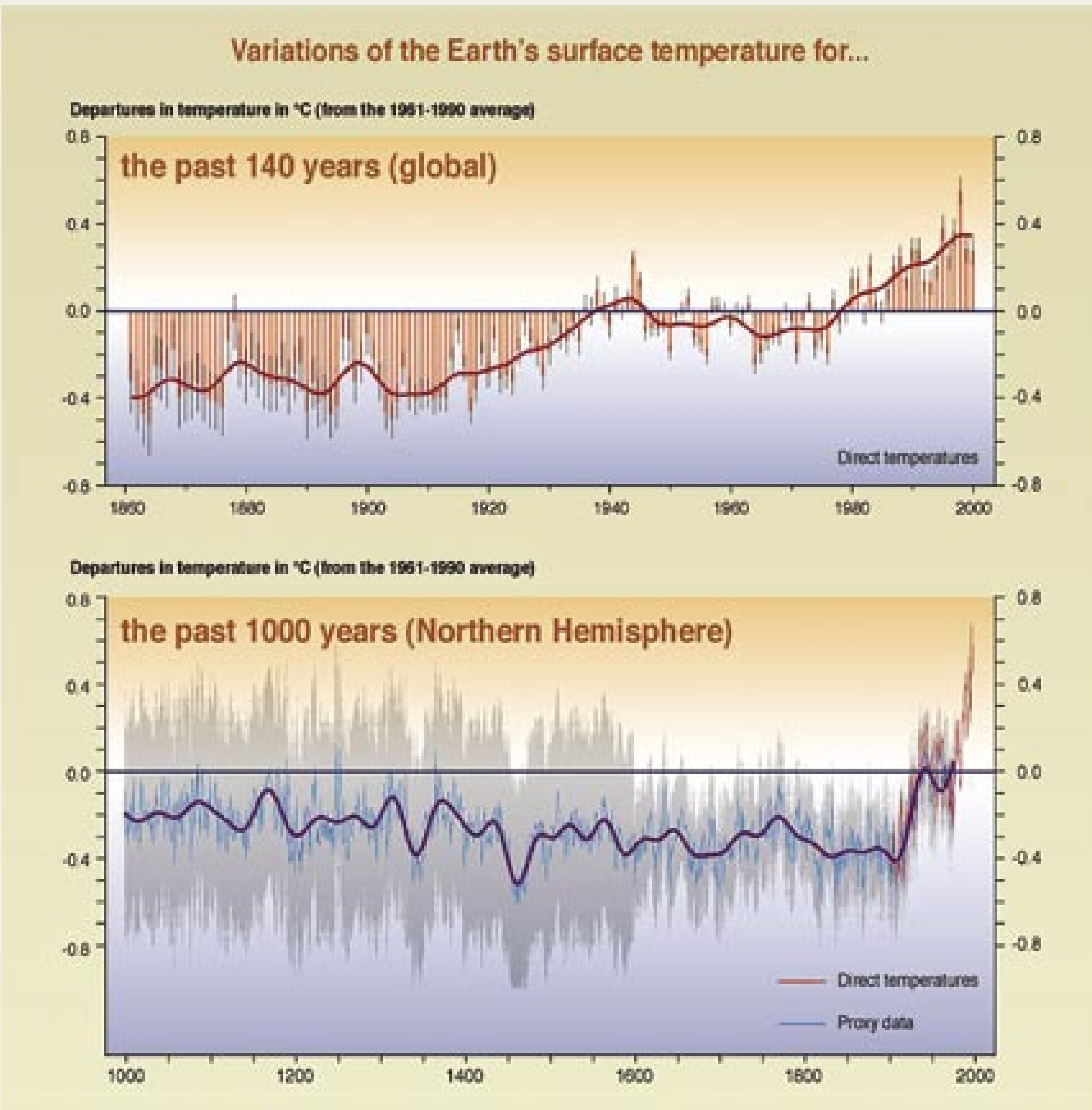


Figure 3.10: Variations in the Earth's temperature for the past 140 years (global) and for the past 1 000 years (Northern Hemisphere). *Source: IPCC (2001)*

believe that much of this global temperature increase is due to increased use of fossil fuels, which when burned, release carbon dioxide into the atmosphere where it absorbs infrared radiation that normally would pass through the atmosphere and travel out into space (Brehm 2003).

The planet is not as warm as it was approximately 1 000 years ago (Figure 3.10). Nevertheless, CO_2 currently accounts for the greatest proportion of greenhouse gas emissions. Much of the CO_2 added to the atmosphere comes from the burning of fossil fuels in vehicles, for heating, and for the production of electricity (Figure 3.11).

In addition to carbon dioxide, rising levels of methane in the atmosphere are also of concern. The relative rate of increase of methane has greatly exceeded that of carbon dioxide in the last several decades. Methane is released into the atmosphere in many ways: as a result of agriculture and ranching activities; through the decay of organic matter, including waste dumps; through deforestation; and as a by-product of the hydrocarbon economy. None of these sources are anticipated to decrease in the future. On the contrary, methane emissions are expected to increase, as each year an additional 100 million people require food and fuel as world population expands (Figure 3.12).

Most scientists believe that recent global warming is mainly due to human activities and related increases in concentrations of greenhouse gases (Figure 3.13), primarily CO_2, CH_4, nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). These changes are driven by worldwide population and economic growth, and the underlying production and consumption of fossil fuels, as well as by the intensification of agricultural activity and changes in land use and land cover. Energy production and use, the largest sole source of CO_2 emissions and a large contributor of CH_4 and N_2O emissions, accounted for 81.7 per cent of emissions in industrialised countries in 1998 (UNFCCC 2000).

From far out in space, instruments carried aboard satellites, such as NASA's

Moderate Resolution Imaging Spectroradiometre (MODIS) sensor, are taking the temperature of the Earth's surface. Satellite data confirm that the Earth's average surface temperature has been slowly rising for the past few decades (Figure 3.14). Satellite records are more detailed and comprehensive than previously available ground measurements, and are essential for improving climate analyses and computer modeling.

One of the more predictable effects of global warming will be a rise in sea levels (Figure 3.15). It is already under way at a pace of about a millimetre a year—a consequence of both melting land ice and the thermal expansion of the oceans (Harrison and Pearce 2001). Predictions as to how much global sea levels may rise over the next century range from half a metre (1.5 feet) (Houghton et al. 2001) to between 1 and 2 m (3 to 6 feet) (Nicholls et al. 1999). Such an increase would drown many coastal areas and atoll islands. Unless countries take action to address rising sea levels, the resulting flooding is expected to impact some 200 million people worldwide by the 2080s. In addition, around 25 per cent of the world's coastal wetlands could be lost by this time due to sea-level rise (DETR 1997).

Global warming may have some positive impacts. It could, for example, open

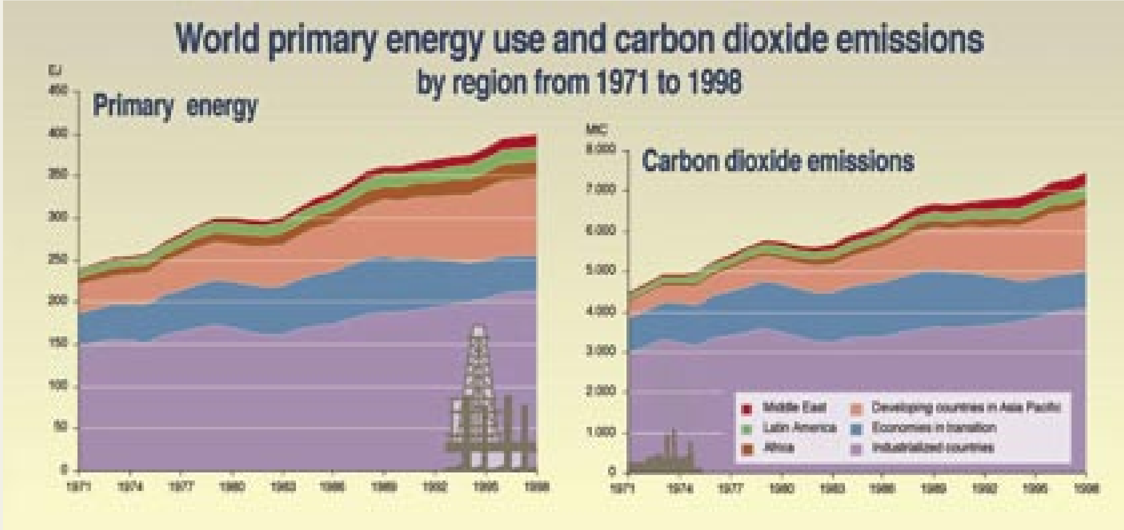


Figure 3.11: Between 1971 and 1998, energy use and carbon dioxide emissions both increased significantly, contributing to the likelihood of global warming. *Source: IPCC (2001)*

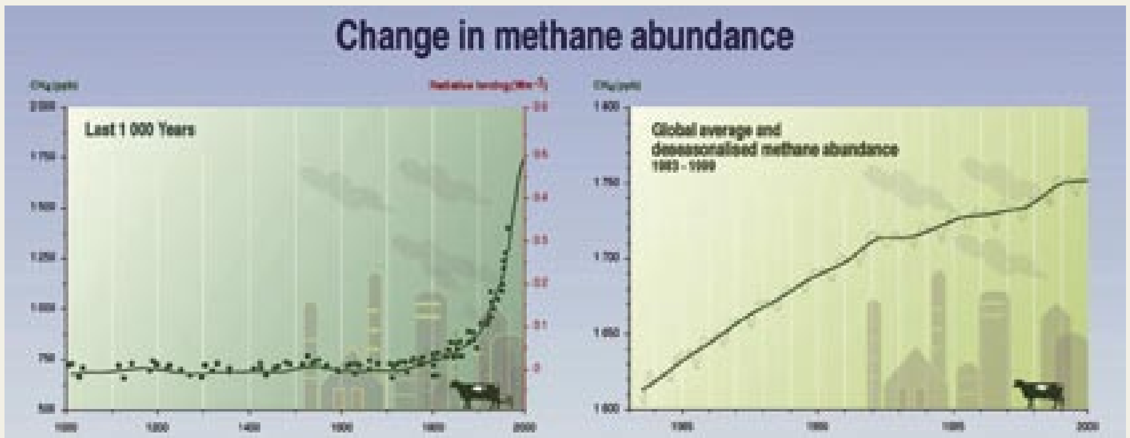


Figure 3.12: Methane is the second largest contributor to global warming and its atmospheric concentration has increased significantly over the last two decades. Methane emissions from human-related activities now represent about 70 per cent of total emissions, as opposed to less than 10 per cent 200 years ago. *Source: IPCC (2001)*

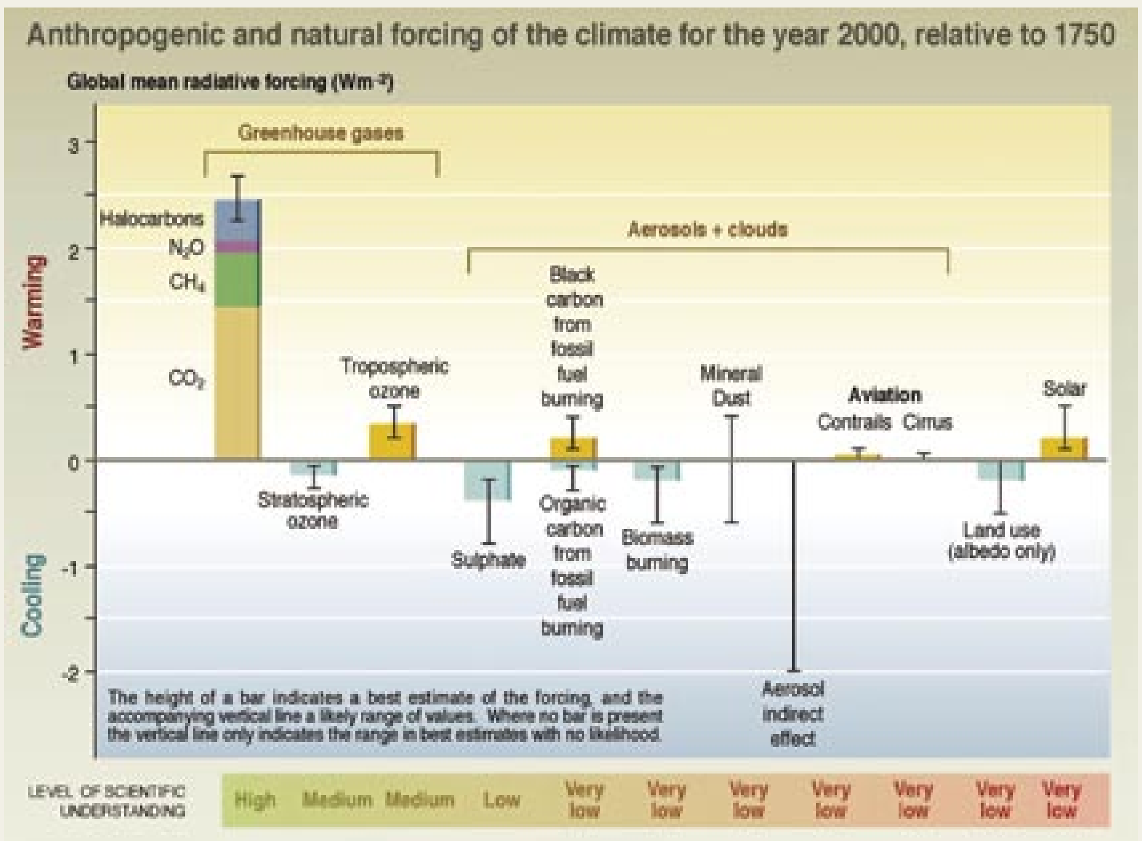


Figure 3.13: The role of different gases and aerosols in global warming. *Source: IPCC (2001)*

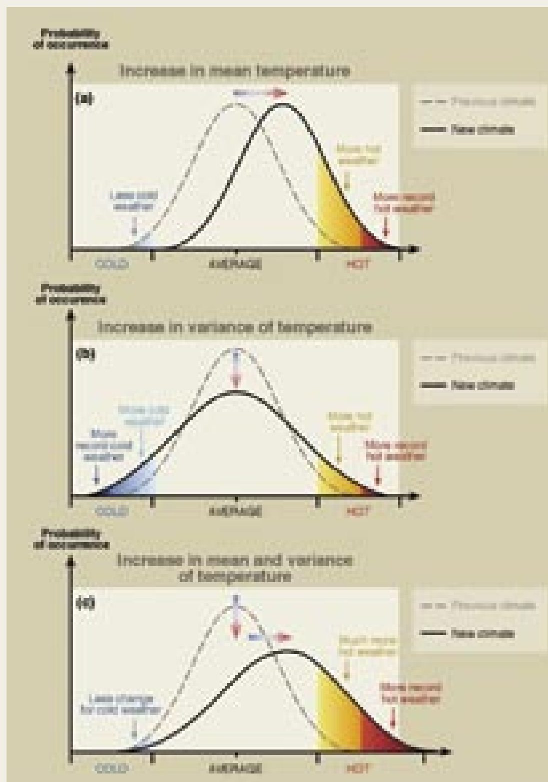


Figure 3.14: Global warming is an increase in the Earth's average surface temperature. These graphs illustrate how a shift in the mean temperature and its variance can affect weather. *Source: IPCC (2001)*

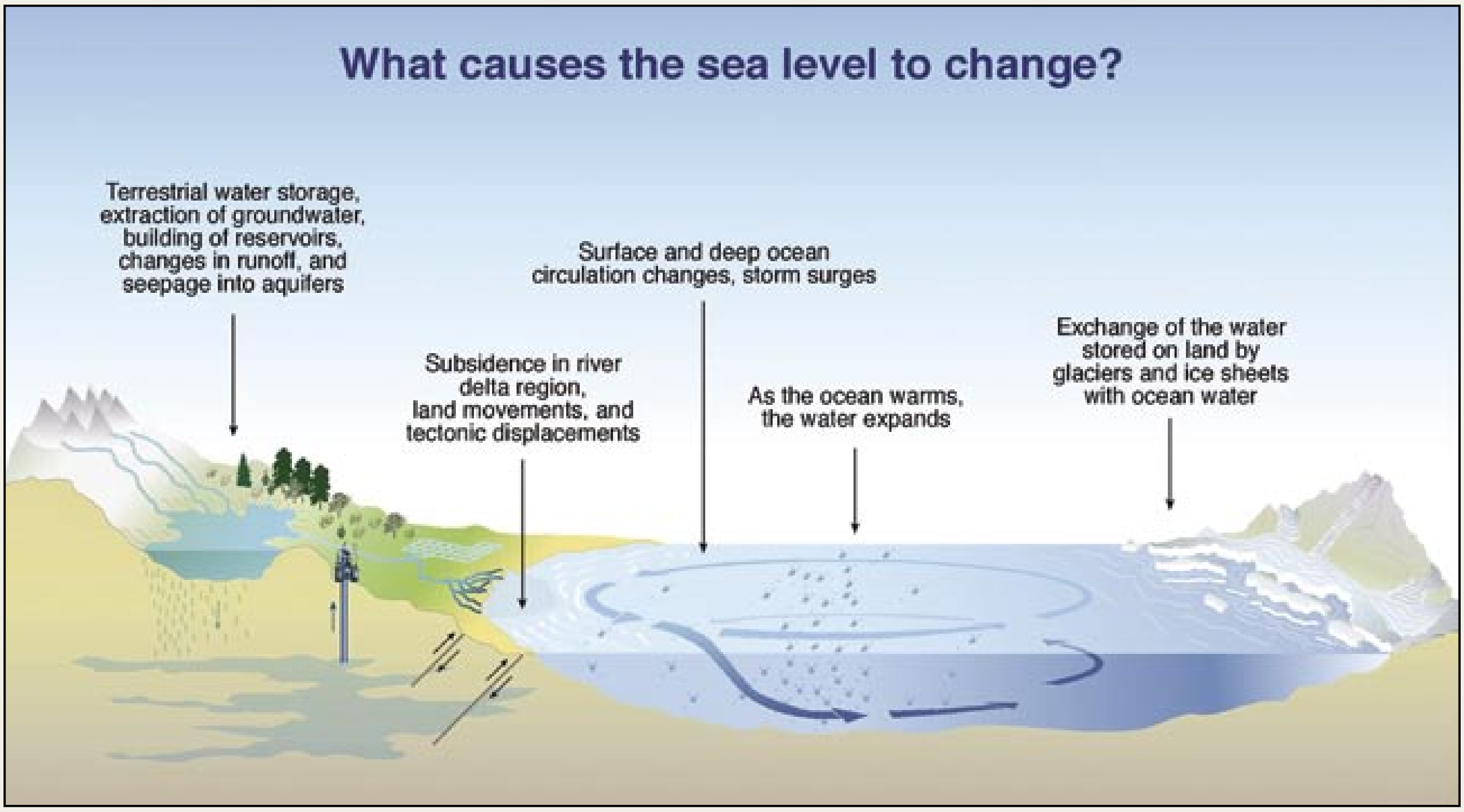
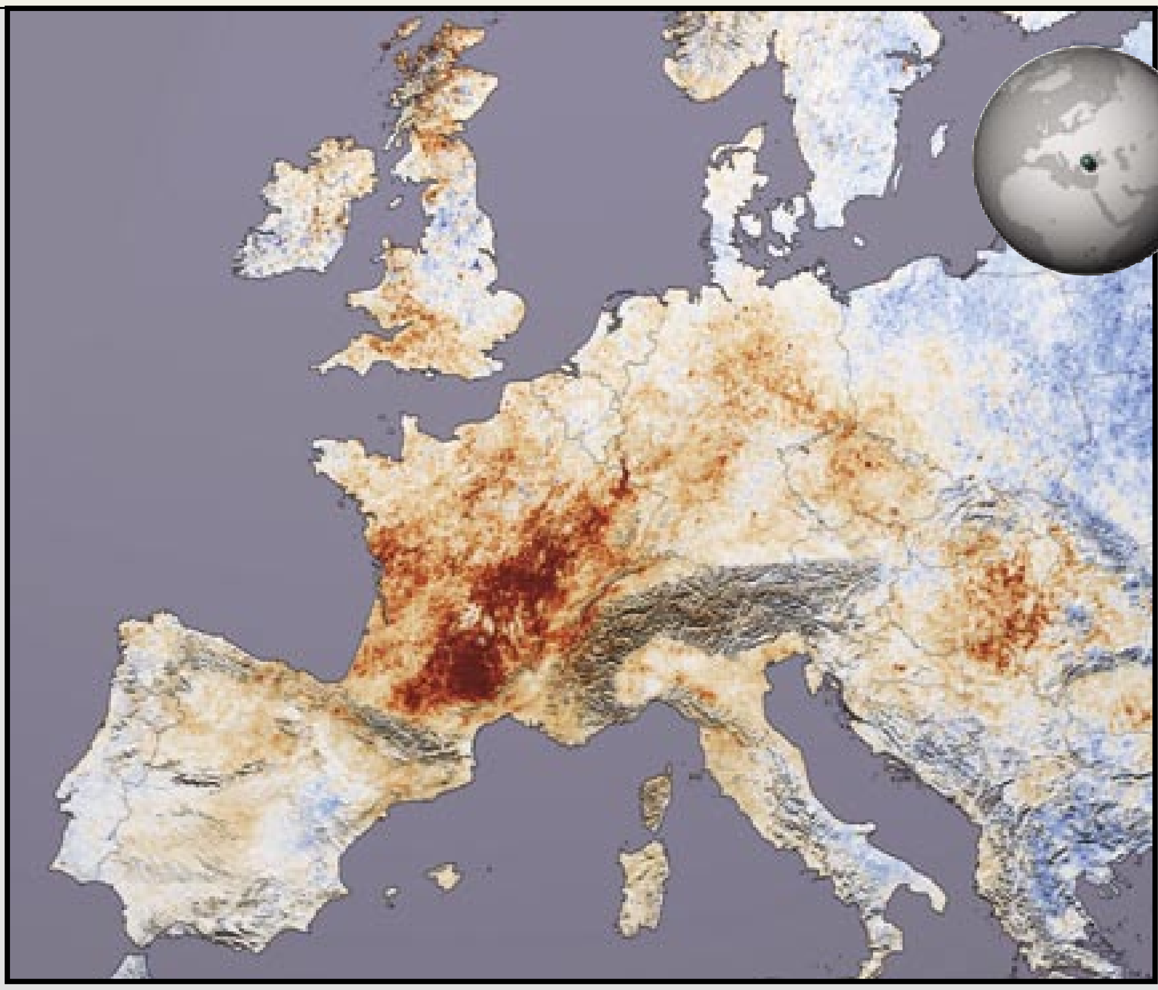


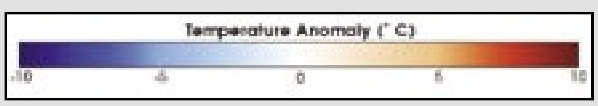
Figure 3.15: Reasons for sea level change *Source: IPCC (2001)*

new lands for agriculture and forestry in the far north. During the past 30 years in Iceland, old farmlands have been exposed, and are being used, as the Breidamerkurjökull Glacier has receded. All told, however, the negative impacts of unchecked global warming outweigh any positive benefits.

Climate Change

Climate is the statistical description in terms of the mean and variability of relevant measures of the atmosphere-ocean system over periods of time ranging from weeks to thousands or millions of years. Climate change is defined as a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or to external forcing (Figure 3.16). Volcanic gases and dust, changes in ocean circulation, fluctuations in solar output, and increased concentrations of greenhouse gases in the





European Heat Wave, July 2003 *Credit: NASA—Satellite Thermometers Show Earth Has a Fever (2004)*

Case Study: European Heat Wave July 2003

This image shows the differences in daytime land surface temperatures (temperature anomalies) collected over Europe between July 2001 and July 2003 by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite. A blanket of deep red across southern and eastern France (left of image center) reveals that temperatures in this region were 10ºC (18ºF) hotter during 2003 than in 2001. Temperatures were similar in white areas and cooler in blue areas. Although models predict an overall increase in global average temperatures, regional differences may be pronounced, and some areas, such as mid-continental zones in North America and Asia, may actualy experience some degree of cooling (NASA 2003c).

atmosphere can all cause climate changes (USCCSP 2003).

Global warming, whatever its underlying causes, is expected to have adverse, possibly irreversible effects on the Earth's climate, including changes in regional temperature and rainfall patterns and more frequent extreme weather events. Climate change will affect the ecology of the planet by impacting biodiversity, causing species extinctions, altering migratory patterns, and disturbing ecosystems in countless ways. Climate change will impact human societies by affecting agriculture, water supplies, water quality, settlement patterns, and health.

Overall, climate change is likely to intensify the already increasing pressures on various sectors. Although the impact of climate change may, in some cases, be smaller than other stresses on the environment, even relatively small changes can have serious adverse effects, especially where there may be critical thresholds, where development is already marginal, or where a region is less able to implement adaptation measures (DETR 1997).

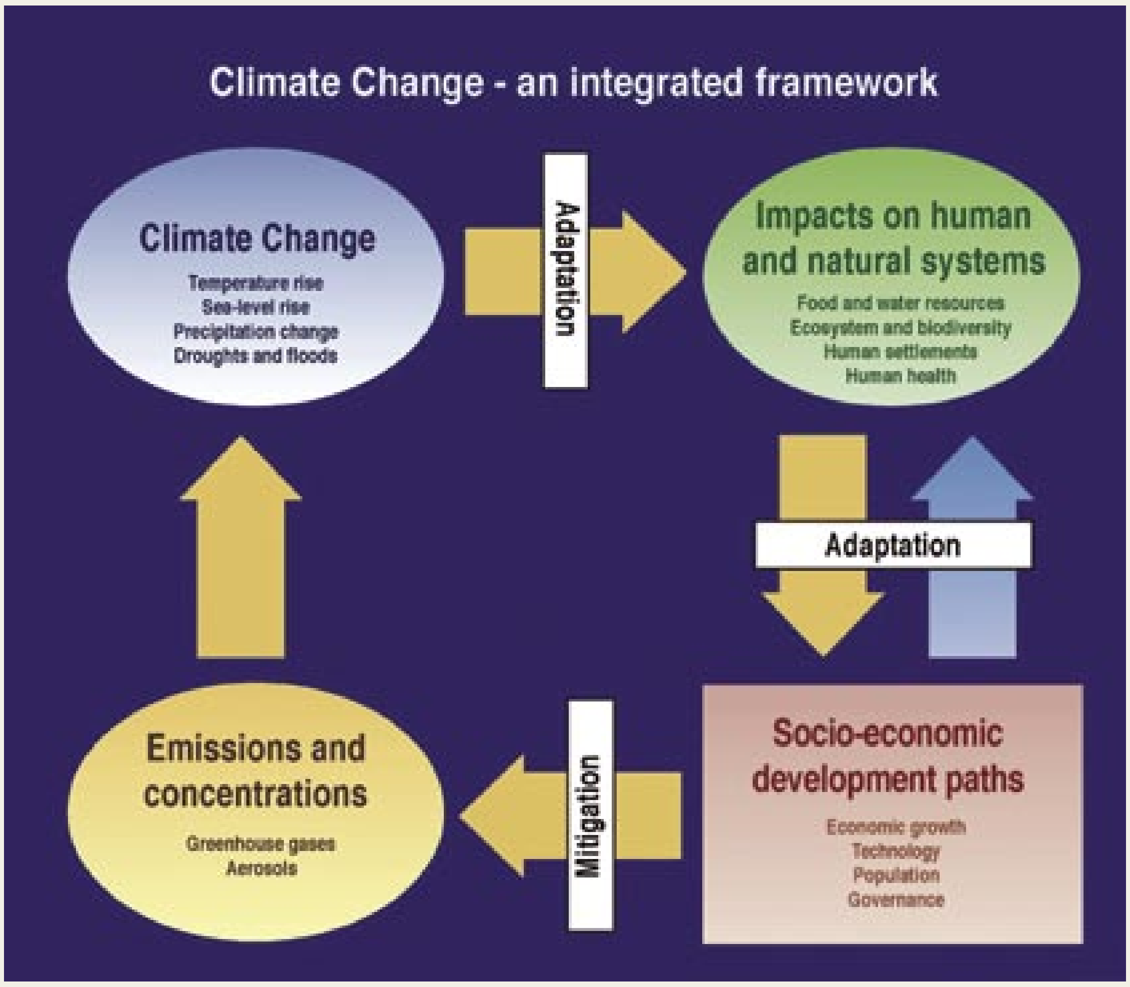


Figure 3.16: Climate change is the result of complex interactions among many factors. *Source: IPCC (2001)*

For example, climate change is likely to exacerbate already increasing pressure being put on water resources by a growing global population, particularly in Africa, Central America, the Indian subcontinent, and southern Europe. By the 2050s, models indicate that there may be an additional 100 million people living in countries with extreme water stress due to climate change alone (DETR 1997).

Credit: Unknown/UNEP/Topfoto

Carbon dioxide, the gas largely blamed for global warming, has reached record-high levels in the atmosphere (Hanley 2004). Carbon dioxide levels have risen by 30 per cent in the last 200 years as a result of industrial emissions, automobiles, and rapid forest burning, especially in the tropics. Much of this increase has occurred since 1960. This increase in CO_2 is thought to enhance the Earth's natural greenhouse effect and thus increase global temperatures (Figure 3.17).

The Intergovernmental Panel on Climate Change projects that, if unchecked, atmospheric carbon dioxide concentrations will range from 650 to 970 ppm by 2100. As a result, the panel estimates, average global temperature may rise by 1.4°C (2.5°F) to 5.8°C (10.4°F) between 1990 and 2100 (Hanley 2004).

Interestingly, increased levels of atmospheric CO_2 may stimulate the growth of some kinds of plants. Researchers in the Amazon have noted increased growth rates in several species of trees (Laurance et al. 2004). The forests are also becoming more dynamic, with existing trees dying and being replaced by new trees at a more rapid pace. In addition, the species composition of the forest is changing. Rising atmospheric CO_2 concentrations may explain these changes, although the effects of this and other large-scale environmental alterations remain uncertain.

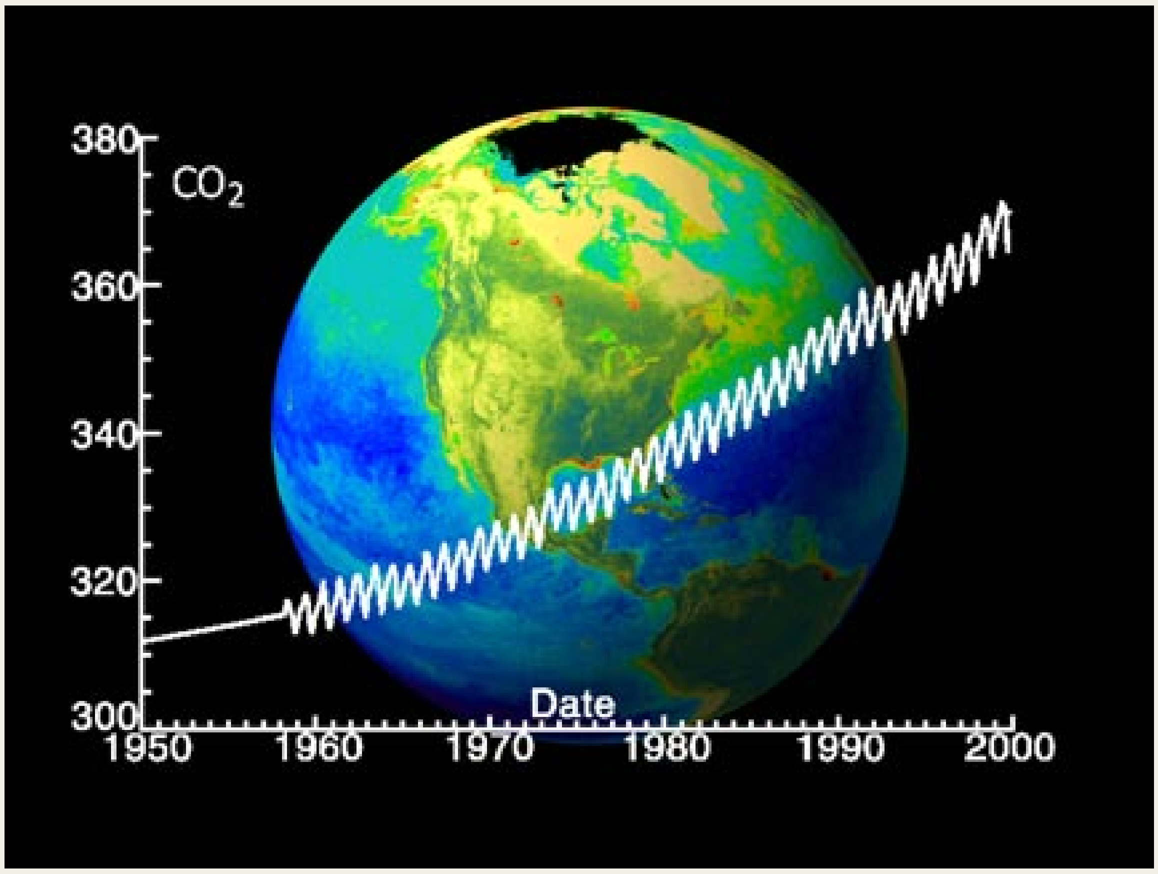


Figure 3.17: For more than 40 years, researchers at Mauna Loa Observatory, Hawaii, have tracked the steady increase of atmospheric carbon dioxide (concentration expressed in parts per million, or ppm). *Source: SIO (2004) and SeaWiFS: NASA Carbon Cycle Initiative, NASA/Goddard Space Flight Center Scientific Visualization Studio (2004). Source: NASA (2004b)*

Air Pollution

Air pollution is the presence of contaminants or pollutant substances in the air that interfere with human health or welfare or produce other harmful environmental effects (EEA 2004). The term "smog"—first coined in London, England, to describe a combination of smoke and fog—is now used in reference to a specific combination of airborne particles, gases, and chemicals that together affect peoples' health and their natural environment (Health Canada 2003).

Aerosols are tiny particles suspended in the air. Some occur naturally, originating from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray. Human activities, such as the burning of fossil fuels and the alteration of natural land cover, also generate aerosols. Averaged over the globe, human-generated aerosols currently account for about ten per cent of total atmospheric aerosols. Most of those aerosols are concentrated in the Northern Hemisphere, especially downwind of industrial sites, slash-and-burn agricultural regions, and overgrazed grasslands (Figure 3.18).

As the composition of Earth's atmosphere changes, so does its ability to absorb, reflect and retain solar energy. Greenhouse gases, including water vapor, trap heat in the atmosphere. Airborne aerosols from human and natural sources absorb or reflect solar energy based on colour, shape, size, and substance. The impact of aerosols, tropospheric ozone, and upper tropospheric water vapor on Earth's climate remains largely unquantified (NASA 1989).

About 25 per cent of the world's population is exposed to potentially harmful amounts of SO_2, O_3, and particulate matter in smog (Schwela 1995). Globally, some 50 per cent of cases of chronic respiratory illness are now thought to be associated with air pollution (UNEP 1999b).

Some pollutants travel long distances on the wind, causing acid deposition in the surrounding countryside and even in neighboring countries. In the 1980s, "acid rain" was identified as a major international environmental problem, moving from

Figure 3.18: Aerosol particles larger than 1 micrometre are composed primarily of windblown dust and sea salt from sea spray. Aerosols smaller than 1 micrometre are mostly formed by condensation processes, such as the conversion of SO_2 gas released by volcanic eruptions to sulfate particles and by formation of soot and smoke during burning processes. After aerosols form, they are mixed and transported throughout the atmosphere by wind and weather; they are removed from the atmosphere primarily through cloud formation and precipitation. *Source: http://earthobservatory.nasa.gov/Library/Aerosols/ (NASA 2004c)*

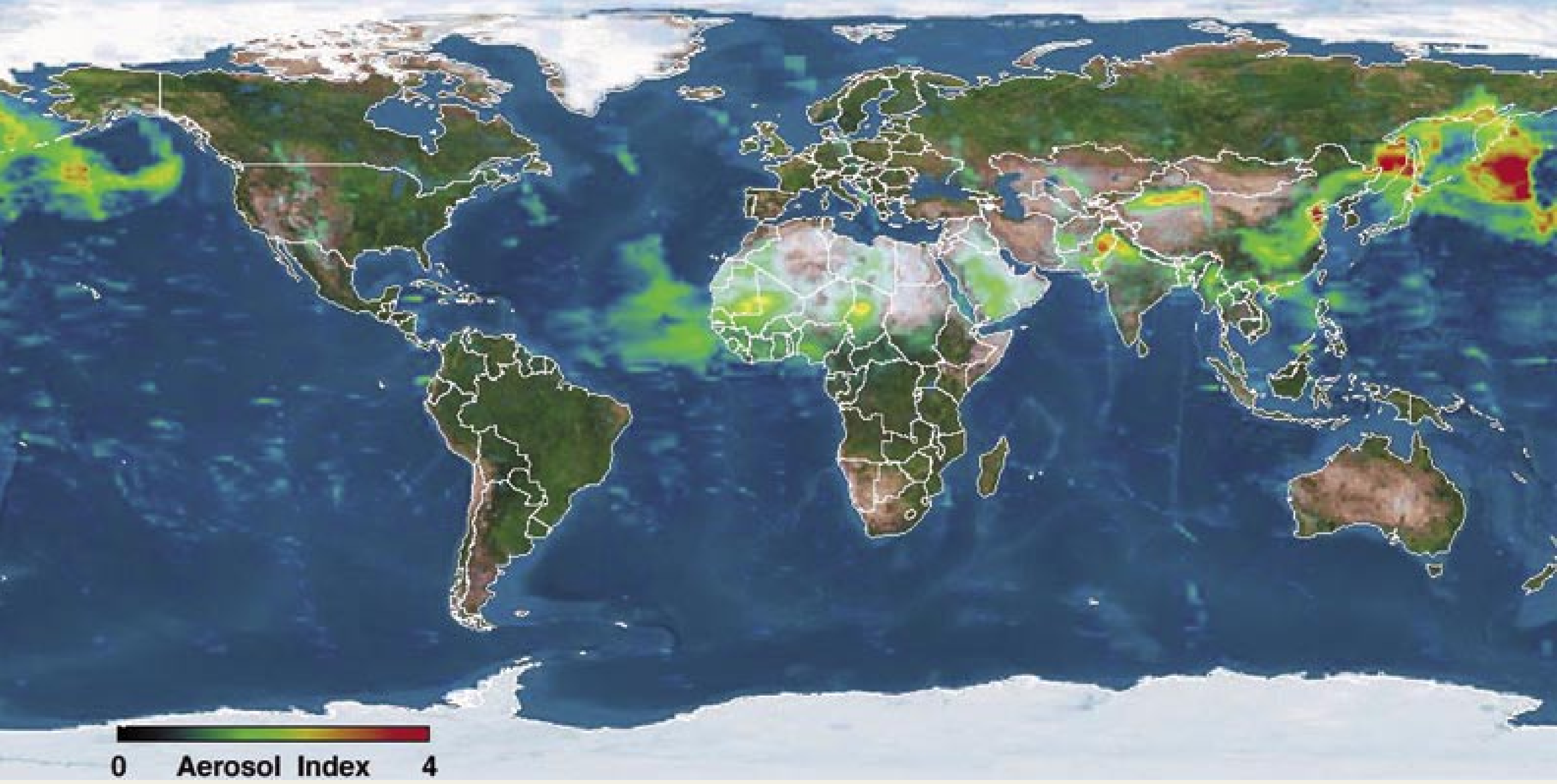


Fig.3.19: Aerosols affect climate both directly by reflecting and absorbing sunlight and indirectly by modifying clouds. The Total Ozone Mapping Spectrometer (TOMS) aerosol index is an indicator of smoke and dust absorption. This figure shows aerosols—the hazy green, yellow, and red patches—crossing the Atlantic and Pacific Oceans. Dust from the Sahara Desert is carried westward toward the Americas and provides nutrients for Amazon forests. Asian dust and pollution travel to the Pacific Northwest. *Source: NASA (http://www.gsfc.nasa.gov/topstory/2004/0517aura.html) (NASA 2004a)*

heavily industrialized areas of both Europe and North America into prime agricultural areas that lay downwind. Mountain regions suffered the most because their higher rainfall increased the volume of acid deposition and their often thin soils could not neutralize the acid. Lakes and streams in pristine parts of Scandinavia and Scotland became acidified, and fish populations were decimated in some areas. The most intense acid rain fallout occurred in the so-called Black Triangle region bordered by Germany, Czech Republic, and Poland (Harrison and Pearce 2001) (Figure 3.19).

Acid precipitation decreased throughout the 1980s and 1990s across large portions of North America and Europe. Many recent studies have attributed observed reversals in surface-water acidification at national and regional scales to this decline (Stoddard et al. 1999; Larssen 2004). Decreases in acid precipitation have been achieved largely through improved flue gas treatments, fuel switching, use of low-sulfur fuels in power stations, and use of catalytic converters in automobiles. Since 1985, international treaties and heavy investment in desulphurization equipment by power station operators have cut sulfur pollution in Europe and North America by as much as 80 per cent (Harrison and Pearce 2001).

Although significant progress has been made in controlling acid-forming emissions in some countries, the global threat from acid precipitation still remains. In fact, the problem is growing rapidly in Asia, where 1990s-level SO_2 emissions could triple by 2010 if current trends continue. Curtailing the already substantial acid precipitation damage in Asia, and avoiding much more severe damage in the future, will require investments in pollution control similiar to those made in Europe and North America over the past 20 years (Downing 1997; WRI 1998).

Nitrogen dioxide is the orange gas that is the most visible component of most air pollution. In many cities, NO_2 and other pollutants are suspended in the air to form a brownish haze commonly called smog. Nitrogen dioxide is formed when oxygen in the air combines with nitric oxide. Nitric oxide comes from automobiles, aerosols, and industrial emissions, and contributes to the formation of acid rain. In addition, this pollutant can cause a wide range of environmental damage, including eutrophication of water bodies—explosive algae growth that can deplete oxygen and kill aquatic organisms.

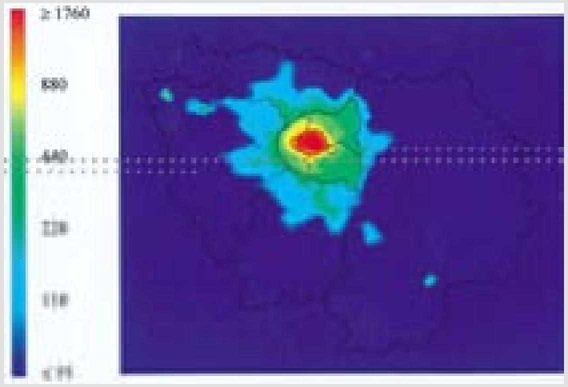
Case Study: Emissions in Paris 1999-2003

Paris, France, lies on a relatively flat plain. Most of the time, Paris benefits from a wet and windswept oceanic climate that encourages the dispersal of air pollution and thus cleans the air. However, under certain meteorological conditions (anticyclones and a lack of wind), pollutants can remain trapped in the atmosphere above the city, where they become concentrated, resulting in significantly higher levels of pollution. Thus, for equivalent pollutant emissions in terms of location and intensity, the levels of pollutants recorded in the atmosphere can vary by a factor of 20 according to meteorological conditions.

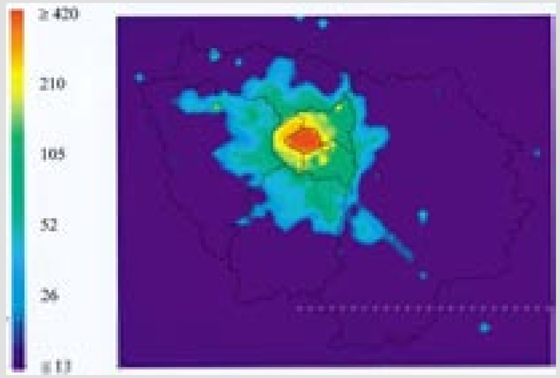
This explains why peaks in secondary pollutants often affect wider areas than peaks in primary pollutants. For example, when the wind blows from the city in a certain direction, the rural area surrounding the Paris region is also subject to ozone pollution. Indeed, ozone levels registered in these areas are often much higher than those in the centre of Paris itself.

In 1994, according to the Centre Interprofessionnel Technique d'Etude de la Pollution Atmosphérique (CITEPA, Inter-professional Technical Centre for Research into Air Pollution) SO_2 emissions in the Paris region corresponded to eight per cent of national emissions (mainland France and overseas territories), oxides of nitrogen (NOx) emissions to 10 per cent, Volatile Organic Compound (non-methane) (VOCNM) emissions to 12 per cent, carbon monoxide (CO) emissions to 15 per cent, and CO_2 emissions to 14 per cent. Given that 19 per cent of the population lives in the Paris region, emissions per inhabitant in this area are less than the national average for all substances (CITEPA 1994).

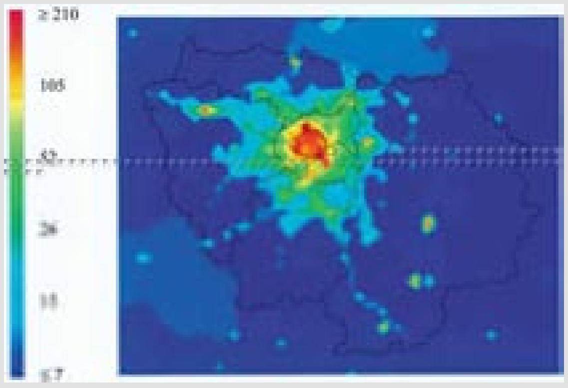
Annual SO_2 emmissions in the Paris region



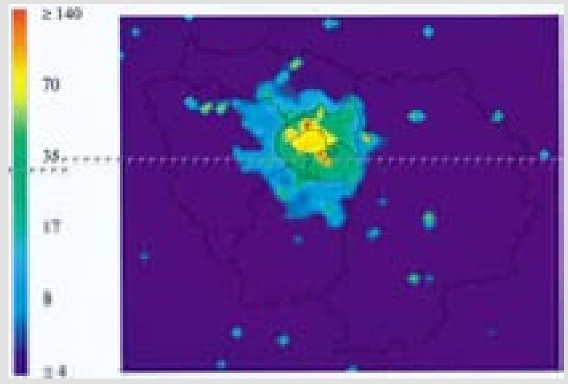
Annual NOx emmissions in the Paris region



Annual CO emmissions in the Paris region

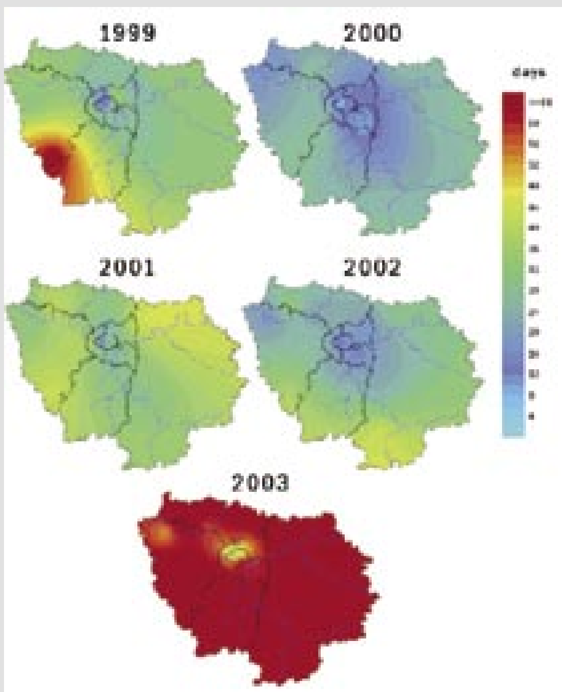


Annual VOC emmissions in the Paris region

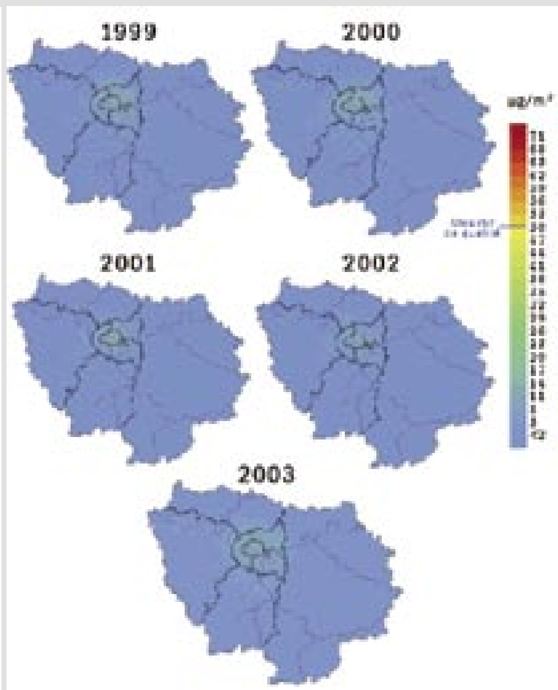


Concentrations of SO_2, NOx, CO, and VOC over Paris. *Source: http://www.airparif.asso.fr/english/polluants/default.htm*

Annual averages of SO_2 in Ile-de-France from 1999 to 2003



Regional cartography of the annual level of benzene evaluated within the framework of the European project LIFE "RESOLUTION"



Air quality dynamics over the region of Paris, France, from 1999 to 2003. *Source: http://www.airparif.asso.fr/english/polluants/default.htm*

Existing air-quality-monitoring tools in the greater region of Paris provide a constant indication of air pollution levels at specific background and roadside locations. In addition to standard monitoring, specific modeling applications give extensive descriptions of air-quality patterns for several significant pollutants. Despite the involvement of the transport sector in monitoring local atmospheric emissions, there is no direct and constant traffic data feed. Recently, a project known as HEAVEN (Healthier Environment through the Abatement of Vehicle Emissions and Noise) was implemented in Paris. Its main objective was to integrate real-time traffic information with the air quality monitoring tools. HEAVEN helped develop and demonstrate new concepts and tools to allow cities to estimate emissions from traffic in near-real time. This enhanced the identification and evaluation of the best strategies for transport demand management.

Souce: http://heaven.rec.org

Case Study: Pollution from Wild Fires 2003–2004

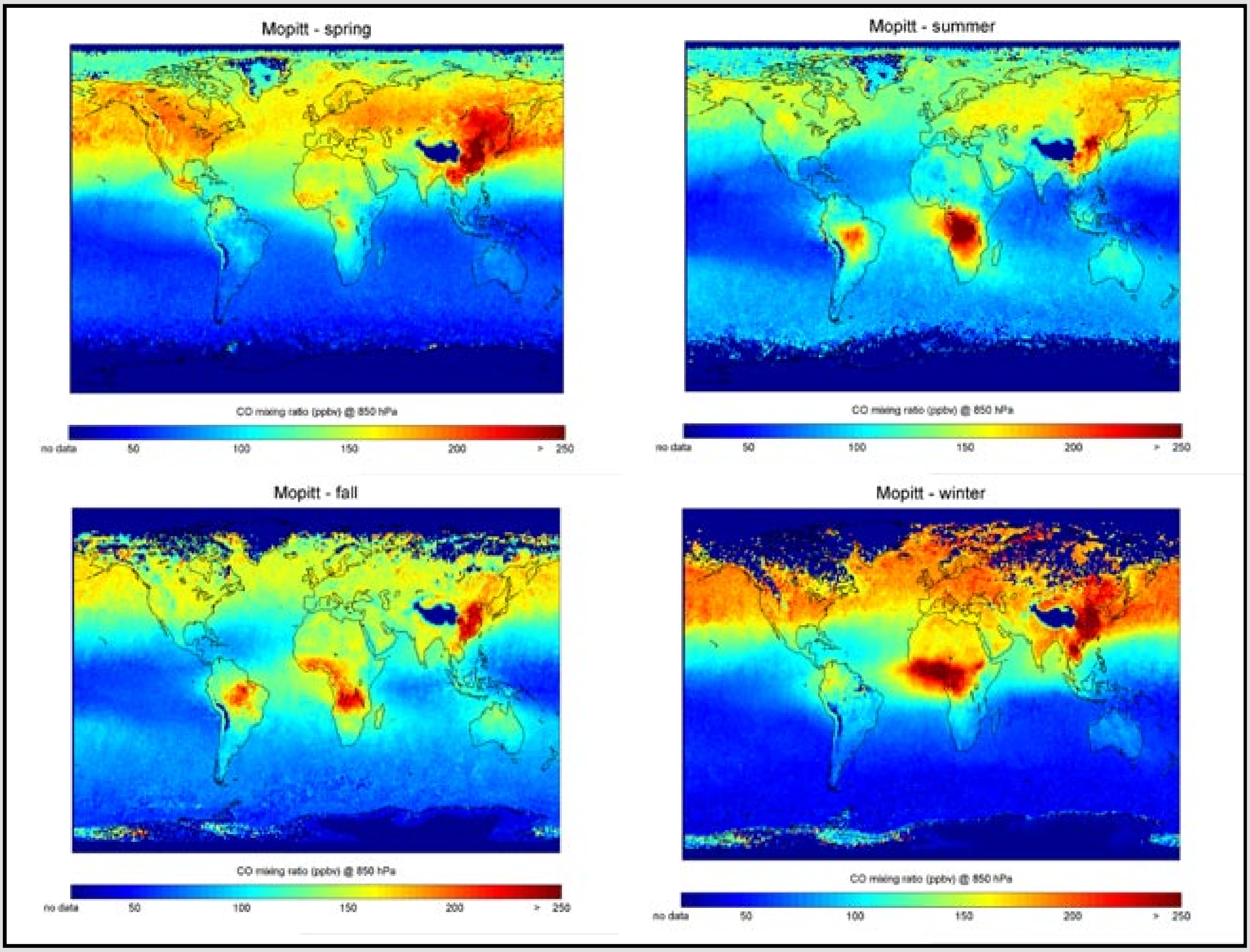
Whether started by people or natural events, fires add large quantities of pollutants to the atmosphere every year, primarily in the form of CO and aerosols. Satellite sensors can help researchers distinguish between wildfires and urban or industrial fires. Some can also distinguish different types of fire-generated pollutants. For instance, two sensors aboard NASA's Terra satellite—the Measurements of Pollution in the Troposphere (MOPITT) instrument and the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument—gather data on CO and aerosols, respectively.

Carbon monoxide is one of the more easily mapped air pollutants. In the MOPITT-generated series of maps shown below, global seasonal variations in CO concentration are clearly visible (highest concentrations of CO appear as red). Major concentrations of CO during different seasons can be easily identified and tracked over time on such images, leading to better understanding of sources of CO pollution and its transcontinental transport (NASA 2004d). For example, in the summer image of this series, a very high concentration of CO appears over west central Africa, largely due to forest fires.

Wildfires in southern Africa are a major source of carbon monoxide pollution. Every August in southern Africa, thousands of people equipped with lighters or torches travel out onto the savanna and intentionally set the dry grasslands ablaze. Burned grasses send up tender new growth that is ideal for cattle consumption. The fires typically scorch an area the size of Montana, Wyoming, Idaho, and the Dakotas combined. Long plumes of smoke rise like hundreds of billowing smokestacks, and herds of animals are sent scurrying across open grassland.

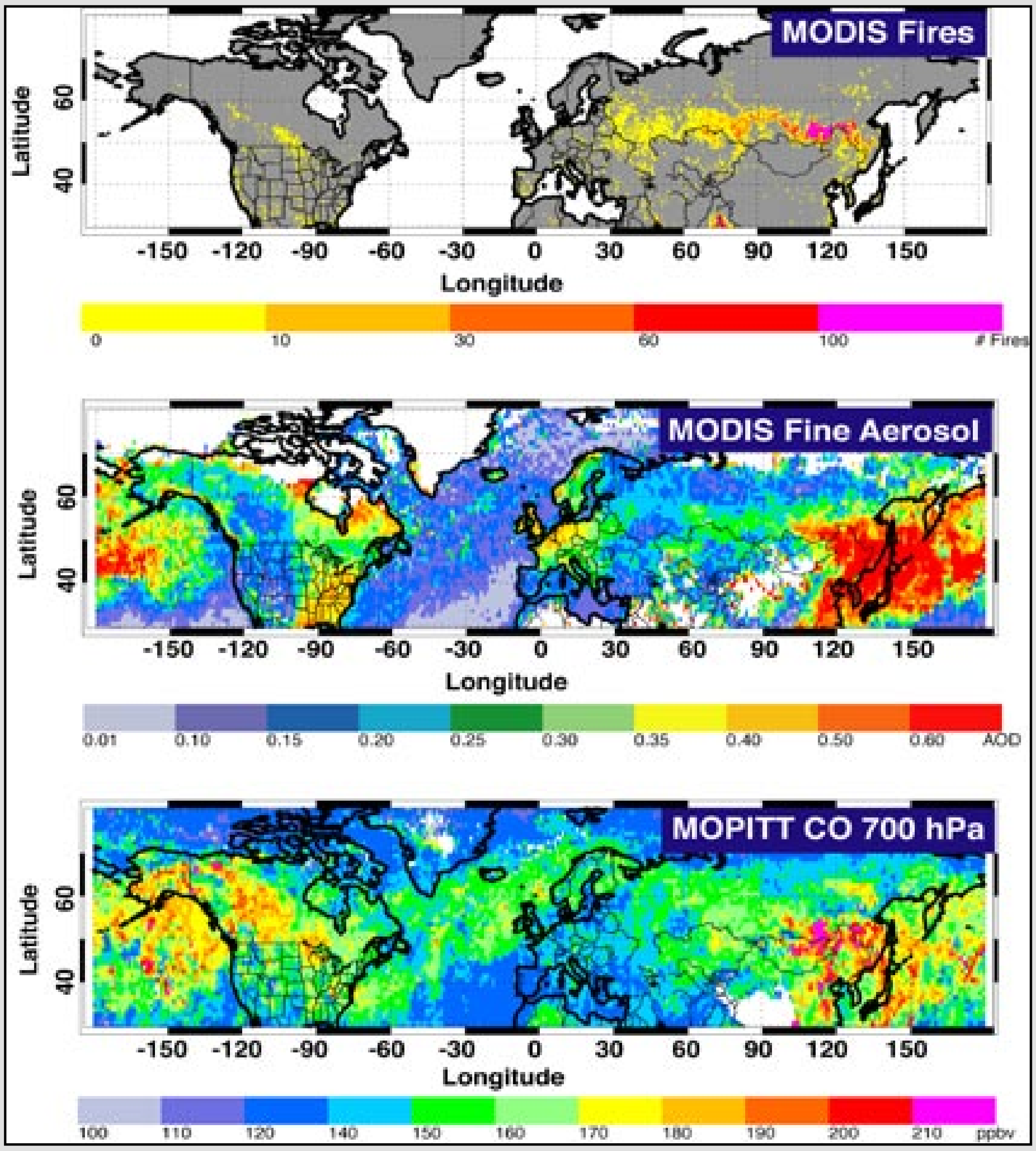
During this fire season, a thick pall of smoke clouds the sky for many weeks. The smoke is laced with a number of pollutants, including nitrogen oxides, carbon monoxide, and hydrocarbons. Some of these substances react with the intense heat and sunlight to form ozone. Ground-level ozone contributes to respiratory diseases and can seriously damage crops. At higher levels in the troposphere, ozone molecules trap thermal radiation emanating from the Earth's surface in the same way as carbon dioxide and other greenhouse gases do. In fact, up to 20 per cent of the global warming experienced by the Earth over the past 150 years is thought to be from ozone.

In the spring of 2003, the MODIS and MOPITT instruments were used to monitor fires and fire-produced air pollutants in Siberia, especially in the Baikal region. These fires produced large amounts of fine carbon aerosols that spread out over the Pacific Ocean and remained suspended in the atmosphere for a few days. Carbon monoxide was also produced by the fires,



Northern Hemisphere seasonal variation in atmospheric carbon monoxide and its global distribution. *Source: http://svs.gsfc.nasa.gov/vis/a000000/a002100/a002150/ (NASA 2004d)* but unlike the aerosols, remained airborne for a much longer period of time, allowing it to cross the Pacific Ocean and reduce air quality over North America before continuing on around the globe.

Gas and particle emissions produced as a result of fires in forests and other vegetation impact the composition of the atmosphere (WHO 2000). These gases and particles interact with those generated by fossil-fuel combustion or other technological processes, and are major causes of urban air pollution. They also create ambient pollution in rural areas. When biomass fuel is burned, the process of combustion is not complete and pollutants released include particulate matter, carbon monoxide, oxides of nitrogen, sulfur dioxide and organic compounds. Once emitted, the pollutants may undergo physical and chemical changes. Thus, vegetation fires are major contributors of toxic gaseous and particle air pollutants into the atmosphere. These fires are also sources of "greenhouse" and reactive gases. Particulate pollution affects more people globally on a continuing basis than any other type of air pollution. In 1997/98, forest fires in Southeast Asia affected at least 70 million people in Brunei Darussalam, Indonesia, Malaysia, the Philippines, Singapore, and Thailand. Thousands of people fled the fires and smoke and the increase in the number of emergency visits to hospitals demonstrated the severity of the fires and pollution they caused (WHO 2000).



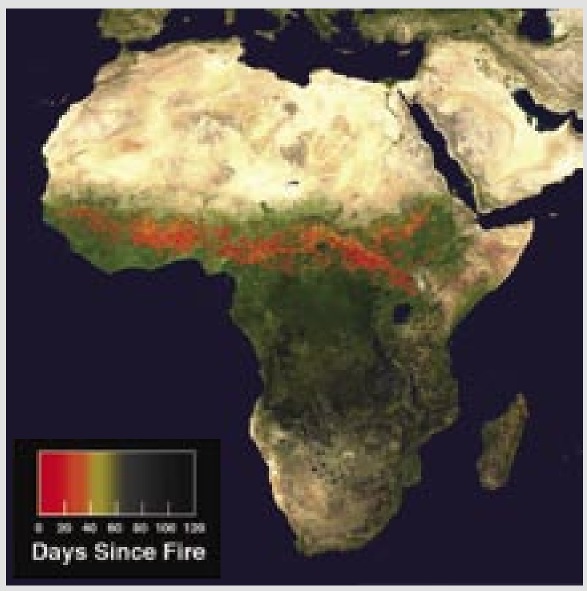
Pollution outflow from spring 2003 fires in Siberia can be seen in the top and middle image. These fires produced large amounts of fine carbon aerosol detected by MODIS instrument (bright colours) on the Terra satellite, which spread over the Pacific Ocean but lasted only a few days. They also produced carbon monoxide, which was detected by the MOPITT instrument on the Terra satellite (bottom image). This gas can last over a month, which allowed it to cross the Pacific Ocean and reduce air quality over North America before continuing on around the globe.
Credit: David Edwards, The National Center for Atmospheric Research (NCAR) (NASA 2004e)

Case Study: African Fires 2002

Wildfires—from forest fires and brush fires to grass fires and slash-and-burn agriculture—can be sweeping and destructive conflagrations, especially in wilderness or rural areas. As biomass burns, particulates, black carbon, and gases including CO_2, CO, NOx, CH_4, and CH_3Cl are produced in great quantities. All of these pollutants can be lofted relatively high in the atmosphere due to the convective heating of a raging fire (Graedel and Crutzen 1993).

The image at right shows fire activity in Africa from 1 January 2002 to 31 December 2002. The fires are shown as tiny dots with each dot depicting the geographic region in which fire was detected. The color of a dot represents the number of days since a sizable amount of fire was detected in that region, with red-orange representing less than 20 days, orange representing 20 to 40 days, yellow representing 40 to 60 days, and gray to black representing more than 60 days. These data were gathered by the MODIS instrument on the Terra satellite. MODIS detects fires by measuring the brightness temperature of a region in several frequency bands and looking for hot spots where this temperature is greater than the surrounding region.

Global statistics on the amount of land burned worldwide every year vary considerably. It has been estimated that from 7.5 million to 8.2 million km^2 (4.6 million to 5.1 million square miles) are burned and between 1 800 million and 10 000 million metric tonnes of dry biomass are consumed in fires annually. Global change scenarios predict an increase in total area burned, with an increase in very large and intense fires.



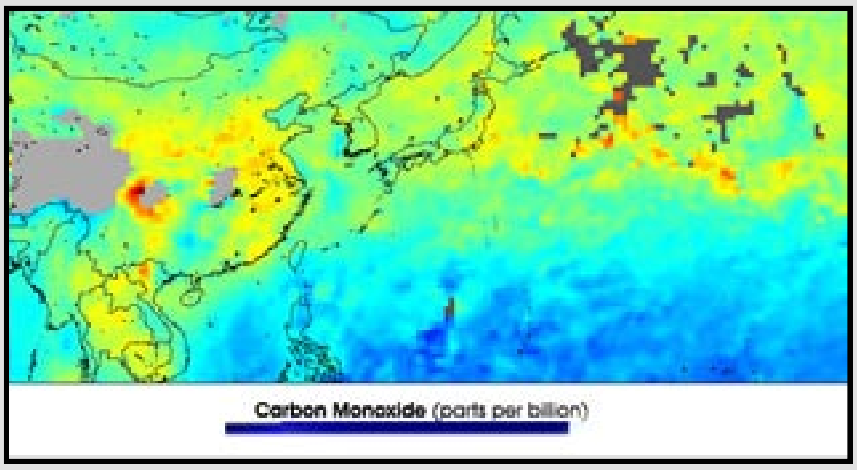
African Fires during 2002 *Credit: http://svs.gsfc.nasa.gov/vis/a000000/a002800/a002890/index.html (NASA 2004f)*

Case Study: Pollution in China 2001 and 2004

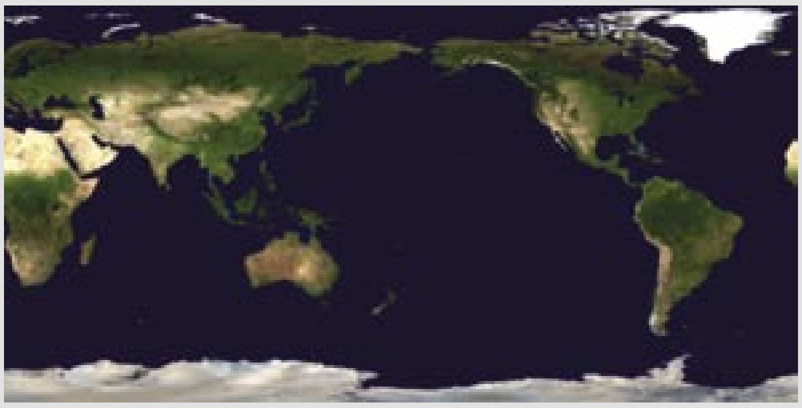
During February 2004, a considerable outflow of pollution stemmed from China and Southeast Asia. The image at right shows atmospheric concentrations of carbon monoxide at an altitude of roughly 3 km (1.9 miles) over this region that were moving across the Pacific Ocean and at some points reaching the western coast of the United States.

Carbon monoxide is a good indicator of air pollution since it is produced during combustion processes, such as the burning of fossil fuels in urban and industrial areas, as well as by wildfires and biomass burning in more rural areas. Industrial emissions were mainly responsible for the high levels of carbon monoxide over China in this image, whereas emissions in Southeast Asia were due primarily to agricultural fires.

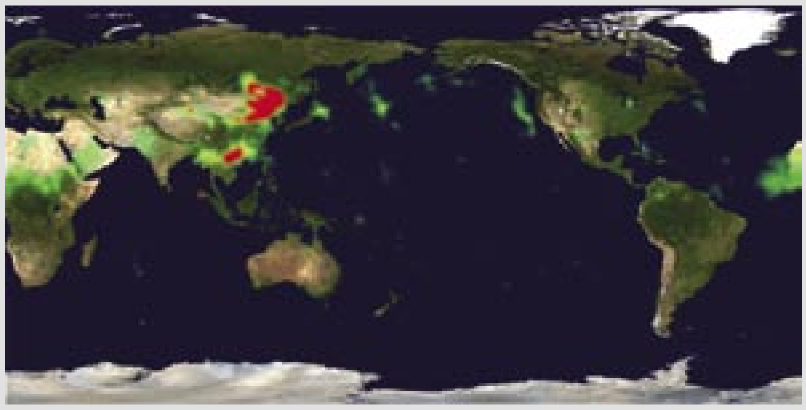
Natural processes and events can also be a source of transcontinental air pollution. In 2001, a large dust storm developed over China (see below). Prevailing winds swept particulates from this storm all the way to the eastern coast of North America.



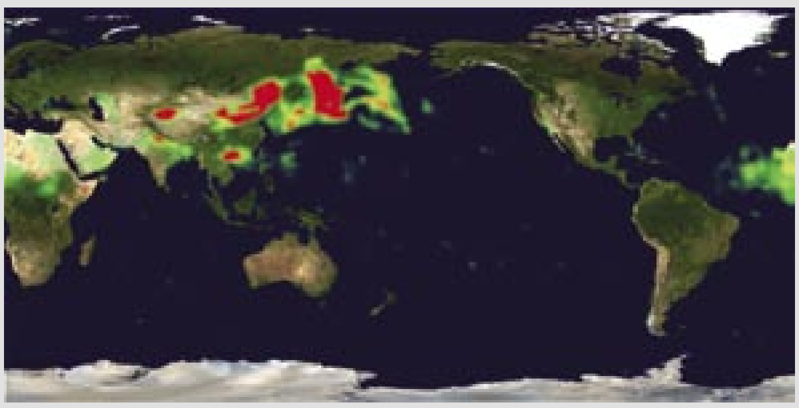
This image was developed from a composite of carbon monoxide data collected over China and Southeast Asia from 1-25 February 2004, by the Measurements of Pollution in the Troposphere (MOPITT) instrument aboard NASA's Terra satellite. The colors represent the mixing ratios of carbon monoxide in the air, given in parts per billion by volume. The grey areas show where no data were collected due to persistent cloud cover. *Source: http://earthobservatory.nasa.gov/Natural (NASA 2004g)*



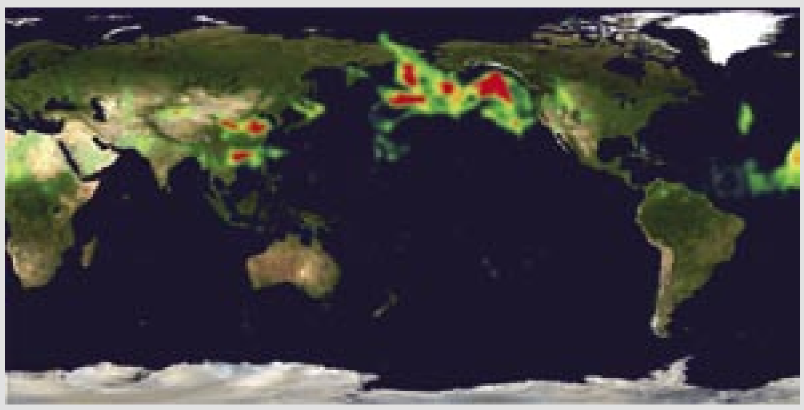
6 April 2001 normal aerosol levels are apparent on the first day of the dust storm.



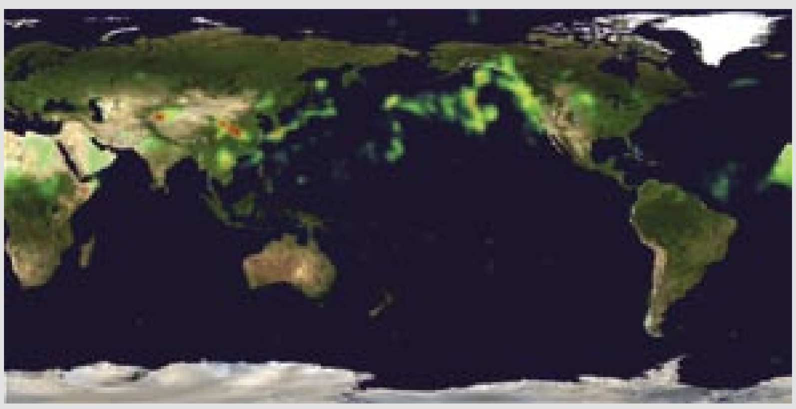
7 April 2001 - Blue represents just slightly higher-than-normal aerosols and red represents the highest concentration of aerosols.



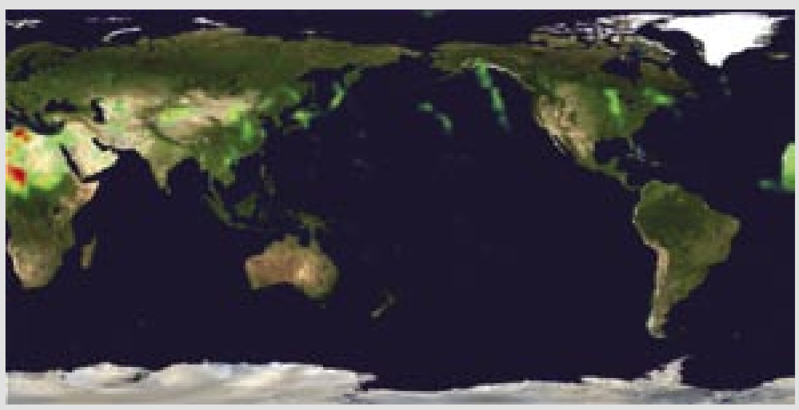
10 April 2001 - The aerosol impact from the dust storm can clearly be seen over China, Mongolia, Russia, Korea, Japan, and the Pacific Ocean.



13 April 2001 - The aerosol impact from the dust storm can clearly be seen over Japan, the Pacific Ocean, Alaska, and the United States.



14 April 2001 - The aerosol impact from the dust storm can clearly be seen in the Pacific Ocean, and the United States.



17 April 2001 - High levels of aerosols are visible over the East Coast of the United States, especially Maine.

A large dust storm developed over China on 6-7 April 2001. This series of images shows air-borne dust from the storm moving over China, Russia, Japan, the Pacific Ocean, Canada, and ultimately over the United States on 17 April 2001 (NASA 2004g). *Visualization Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio Source: http://svs.gsfc.nasa.gov/vis/a000000/a002900/a002957/index.html*

Credit: Chia/UNEP/Morgue File