A Comprehensive Study on

Problems arising from Exploitation of Natural Resources

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Introduction

Timber

Some **exploitation of natural resources** is an essential condition of the human existence. This refers primarily to food production and necessities. The exploitation of nature is often done unsustainably and is of increasing concern as the depletion of natural resources from economic growth and population growth ultimately threatens human existence.

Why resources are under pressure

- Increase in sophistication of technology enabling natural resources to be extracted quickly and efficiently. *For Example*: In the past, it could take long hours just to

cut down one tree only using saws. Due to increased technology, rates of deforestation have greatly increased

- A rapidly increasing population. This leads to greater demand for natural resources.
- Cultures of consumerism. Materialistic views lead to gold and diamonds mined and used for jewelry—something unnecessary for human life or advancement.
- Excessive demand often leads to conflicts due to intense competition. Organizations, such as Global Witness and the United Nations have documented the connections.
- Another reason maybe because of non-equitable distribution of resources.

Chapter- 1

Deforestation

Jungle burned for agriculture in southern Mexico.

Deforestation in the Gran Chaco, Paraguay

Deforestation and increased road-building in the Amazon Rainforest are a significant concern because of increased human encroachment upon wild areas, increased resource extraction and further threats to biodiversity.

Deforestation is the removal of a forest or stand of trees where the land is thereafter converted to a nonforest use. Examples of deforestation include conversion of forestland to agriculture or urban use.

The term *deforestation* is often misused to describe any activity where all trees in an area are removed. However in temperate mesic climates, the removal of all trees in an area—in conformance with sustainable forestry practices—is correctly described as *regeneration harvest*. In temperate mesic climates, natural regeneration of forest stands often will not occur in the absence of disturbance, whether natural or anthropogenic. Furthermore, biodiversity after regeneration harvest often mimics that found after natural disturbance, including biodiversity loss after naturally occurring rainforest destruction.

Deforestation occurs for many reasons: trees or derived charcoal are used as, or sold, for fuel or as lumber, while cleared land is used as pasture for livestock, plantations of commodities, and settlements. The removal of trees without sufficient reforestation has resulted in damage to habitat, biodiversity loss and aridity. It has adverse impacts on

biosequestration of atmospheric carbon dioxide. Deforested regions typically incur significant adverse soil erosion and frequently degrade into wasteland.

Disregard or ignorance of intrinsic value, lack of ascribed value, lax forest management and deficient environmental laws are some of the factors that allow deforestation to occur on a large scale. In many countries, deforestation, both naturally occurring and human induced, is an ongoing issue. Deforestation causes extinction, changes to climatic conditions, desertification, and displacement of populations as observed by current conditions and in the past through the fossil record.

Among countries with a per capita GDP of at least US$4,600, net deforestation rates have ceased to increase.

Causes

There are many causes of contemporary deforestation, including corruption of government institutions, the inequitable distribution of wealth and power, population growth and overpopulation, and urbanization. Globalization is often viewed as another root cause of deforestation, though there are cases in which the impacts of globalization (new flows of labor, capital, commodities, and ideas) have promoted localized forest recovery.

In 2000 the United Nations Food and Agriculture Organization (FAO) found that "the role of population dynamics in a local setting may vary from decisive to negligible," and that deforestation can result from "a combination of population pressure and stagnating economic, social and technological conditions."

According to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat, the overwhelming direct cause of deforestation is agriculture. Subsistence farming is responsible for 48% of deforestation; commercial agriculture is responsible for 32% of deforestation; logging is responsible for 14% of deforestation and fuel wood removals make up 5% of deforestation.

The degradation of forest ecosystems has also been traced to economic incentives that make forest conversion appear more profitable than forest conservation. Many important forest functions have no markets, and hence, no economic value that is readily apparent to the forests' owners or the communities that rely on forests for their well-being. From the perspective of the developing world, the benefits of forest as carbon sinks or biodiversity reserves go primarily to richer developed nations and there is insufficient compensation for these services. Developing countries feel that some countries in the developed world, such as the United States of America, cut down their forests centuries ago and benefited greatly from this deforestation, and that it is hypocritical to deny developing countries the same opportunities: that the poor shouldn't have to bear the cost of preservation when the rich created the problem.

Experts do not agree on whether industrial logging is an important contributor to global deforestation. Some argue that poor people are more likely to clear forest because they have no alternatives, others that the poor lack the ability to pay for the materials and labour needed to clear forest. One study found that population increases due to high fertility rates were a primary driver of tropical deforestation in only 8% of cases.

Some commentators have noted a shift in the drivers of deforestation over the past 30 years. Whereas deforestation was primarily driven by subsistence activities and government-sponsored development projects like transmigration in countries like Indonesia and colonization in Latin America, India, Java etc. during late 19th century and the earlier half of the 20th century. By the 1990s the majority of deforestation was caused by industrial factors, including extractive industries, large-scale cattle ranching, and extensive agriculture.

Environmental problems

Atmospheric

Deforestation is ongoing and is shaping climate and geography.

Deforestation is a contributor to global warming, and is often cited as one of the major causes of the enhanced greenhouse effect. Tropical deforestation is responsible for approximately 20% of world greenhouse gas emissions. According to the Intergovernmental Panel on Climate Change deforestation, mainly in tropical areas, could account for up to one-third of total anthropogenic carbon dioxide emissions. But recent calculations suggest that carbon dioxide emissions from deforestation and forest degradation (excluding peatland emissions) contribute about 12% of total anthropogenic carbon dioxide emissions with a range from 6 to 17%. Trees and other plants remove carbon (in the form of carbon dioxide) from the atmosphere during the process of photosynthesis and release oxygen back into the atmosphere during normal respiration. Only when actively growing can a tree or forest remove carbon over an annual or longer timeframe. Both the decay and burning of wood releases much of this stored carbon back to the atmosphere. In order for forests to take up carbon, the wood must be harvested and turned into long-lived products and trees must be re-planted. Deforestation may cause carbon stores held in soil to be released. Forests are stores of carbon and can be either sinks or sources depending upon environmental circumstances. Mature forests alternate between being net sinks and net sources of carbon dioxide.

Reducing emissions from the tropical deforestation and forest degradation (REDD) in developing countries has emerged as new potential to complement ongoing climate policies. The idea consists in providing financial compensations for the reduction of greenhouse gas (GHG) emissions from deforestation and forest degradation".

Rainforests are widely believed by laymen to contribute a significant amount of world's oxygen, although it is now accepted by scientists that rainforests contribute little net oxygen to the atmosphere and deforestation will have no effect on atmospheric oxygen

levels. However, the incineration and burning of forest plants to clear land releases large amounts of CO_2, which contributes to global warming.

Forests are also able to extract carbon dioxide and pollutants from the air, thus contributing to biosphere stability.

Hydrological

The water cycle is also affected by deforestation. Trees extract groundwater through their roots and release it into the atmosphere. When part of a forest is removed, the trees no longer evaporate away this water, resulting in a much drier climate. Deforestation reduces the content of water in the soil and groundwater as well as atmospheric moisture. Deforestation reduces soil cohesion, so that erosion, flooding and landslides ensue. Forests enhance the recharge of aquifers in some locales, however, forests are a major source of aquifer depletion on most locales.

Shrinking forest cover lessens the landscape's capacity to intercept, retain and transpire precipitation. Instead of trapping precipitation, which then percolates to groundwater systems, deforested areas become sources of surface water runoff, which moves much faster than subsurface flows. That quicker transport of surface water can translate into flash flooding and more localized floods than would occur with the forest cover. Deforestation also contributes to decreased evapotranspiration, which lessens atmospheric moisture which in some cases affects precipitation levels downwind from the deforested area, as water is not recycled to downwind forests, but is lost in runoff and returns directly to the oceans. According to one study, in deforested north and northwest China, the average annual precipitation decreased by one third between the 1950s and the 1980s.

Trees, and plants in general, affect the water cycle significantly:

- their canopies intercept a proportion of precipitation, which is then evaporated back to the atmosphere (canopy interception);
- their litter, stems and trunks slow down surface runoff;
- their roots create macropores - large conduits - in the soil that increase infiltration of water;
- they contribute to terrestrial evaporation and reduce soil moisture via transpiration;
- their litter and other organic residue change soil properties that affect the capacity of soil to store water.
- their leaves control the humidity of the atmosphere by transpiring. 99% of the water absorbed by the roots moves up to the leaves and is transpired.

As a result, the presence or absence of trees can change the quantity of water on the surface, in the soil or groundwater, or in the atmosphere. This in turn changes erosion rates and the availability of water for either ecosystem functions or human services.

The forest may have little impact on flooding in the case of large rainfall events, which overwhelm the storage capacity of forest soil if the soils are at or close to saturation.

Tropical rainforests produce about 30% of our planet's fresh water.

Soil

Deforestation for the use of clay in the Brazilian city of Rio de Janeiro. The hill depicted is Morro da Covanca, in Jacarepaguá

Undisturbed forests have a very low rate of soil loss, approximately 2 metric tons per square kilometer (6 short tons per square mile). Deforestation generally increases rates of soil erosion, by increasing the amount of runoff and reducing the protection of the soil from tree litter. This can be an advantage in excessively leached tropical rain forest soils. Forestry operations themselves also increase erosion through the development of roads and the use of mechanized equipment.

China's Loess Plateau was cleared of forest millennia ago. Since then it has been eroding, creating dramatic incised valleys, and providing the sediment that gives the Yellow River its yellow color and that causes the flooding of the river in the lower reaches (hence the river's nickname 'China's sorrow').

Removal of trees does not always increase erosion rates. In certain regions of southwest US, shrubs and trees have been encroaching on grassland. The trees themselves enhance the loss of grass between tree canopies. The bare intercanopy areas become highly

erodible. The US Forest Service, in Bandelier National Monument for example, is studying how to restore the former ecosystem, and reduce erosion, by removing the trees.

Tree roots bind soil together, and if the soil is sufficiently shallow they act to keep the soil in place by also binding with underlying bedrock. Tree removal on steep slopes with shallow soil thus increases the risk of landslides, which can threaten people living nearby. However most deforestation only affects the trunks of trees, allowing for the roots to stay rooted, negating the landslide.

Ecological

Deforestation results in declines in biodiversity. The removal or destruction of areas of forest cover has resulted in a degraded environment with reduced biodiversity. Forests support biodiversity, providing habitat for wildlife; moreover, forests foster medicinal conservation. With forest biotopes being irreplaceable source of new drugs (such as taxol), deforestation can destroy genetic variations (such as crop resistance) irretrievably.

Since the tropical rainforests are the most diverse ecosystems on Earth and about 80% of the world's known biodiversity could be found in tropical rainforests, removal or destruction of significant areas of forest cover has resulted in a degraded environment with reduced biodiversity.

It has been estimated that we are losing 137 plant, animal and insect species every single day due to rainforest deforestation, which equates to 50,000 species a year. Others state that tropical rainforest deforestation is contributing to the ongoing Holocene mass extinction. The known extinction rates from deforestation rates are very low, approximately 1 species per year from mammals and birds which extrapolates to approximately 23,000 species per year for all species. Predictions have been made that more than 40% of the animal and plant species in Southeast Asia could be wiped out in the 21st century. Such predictions were called into question by 1995 data that show that within regions of Southeast Asia much of the original forest has been converted to monospecific plantations, but that potentially endangered species are few and tree flora remains widespread and stable.

Scientific understanding of the process of extinction is insufficient to accurately make predictions about the impact of deforestation on biodiversity. Most predictions of forestry related biodiversity loss are based on species-area models, with an underlying assumption that as the forest declines species diversity will decline similarly. However, many such models have been proven to be wrong and loss of habitat does not necessarily lead to large scale loss of species. Species-area models are known to overpredict the number of species known to be threatened in areas where actual deforestation is ongoing, and greatly overpredict the number of threatened species that are widespread.

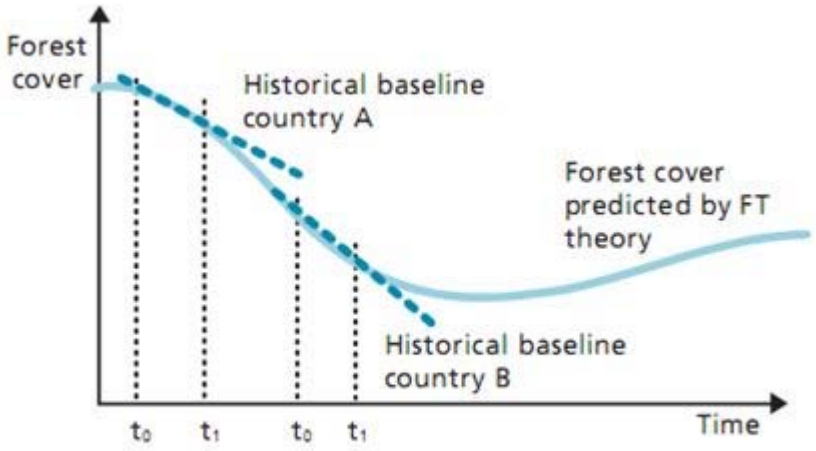
Economic impact

Damage to forests and other aspects of nature could halve living standards for the world's poor and reduce global GDP by about 7% by 2050, a major report concluded at the Convention on Biological Diversity (CBD) meeting in Bonn. Historically utilization of forest products, including timber and fuel wood, have played a key role in human societies, comparable to the roles of water and cultivable land. Today, developed countries continue to utilize timber for building houses, and wood pulp for paper. In developing countries almost three billion people rely on wood for heating and cooking.

The forest products industry is a large part of the economy in both developed and developing countries. Short-term economic gains made by conversion of forest to agriculture, or over-exploitation of wood products, typically leads to loss of long-term income and long term biological productivity (hence reduction in nature's services). West Africa, Madagascar, Southeast Asia and many other regions have experienced lower revenue because of declining timber harvests. Illegal logging causes billions of dollars of losses to national economies annually.

The new procedures to get amounts of wood are causing more harm to the economy and overpowers the amount of money spent by people employed in logging. According to a study, "in most areas studied, the various ventures that prompted deforestation rarely generated more than US$5 for every ton of carbon they released and frequently returned far less than US$1". The price on the European market for an offset tied to a one-ton reduction in carbon is 23 euro (about US$35).

Forest transition theory



Source: Angelsen 2008.

The forest transition and historical baselines.

The forest area change may follow a pattern suggested by the forest transition (FT) theory, whereby at early stages in its development a country is characterized by high forest cover and low deforestation rates (HFLD countries).

Then deforestation rates accelerate (HFHD, high forest cover - high deforestation rate), and forest cover is reduced (LFHD. low forest cover - high deforestation rate), before the deforestation rate slows (LFLD, low forest cover - low deforestation rate), after which forest cover stabilizes and eventually starts recovering. FT is not a “law of nature,” and the pattern is influenced by national context (e.g., human population density, stage of development, structure of the economy), global economic forces, and government policies. A country may reach very low levels of forest cover before it stabilizes, or it might through good policies be able to “bridge” the forest transition.

FT depicts a broad trend, and an extrapolation of historical rates therefore tends to underestimate future BAU deforestation for counties at the early stages in the transition (HFLD), while it tends to overestimate BAU deforestation for countries at the later stages (LFHD and LFLD).

Countries with high forest cover can be expected to be at early stages of the FT. GDP per capita captures the stage in a country’s economic development, which is linked to the pattern of natural resource use, including forests. The choice of forest cover and GDP per capita also fits well with the two key scenarios in the FT:

(i) a forest scarcity path, where forest scarcity triggers forces (e.g., higher prices of forest products) that lead to forest cover stabilization; and

(ii) an economic development path, where new and better off-farm employment opportunities associated with economic growth (= increasing GDP per capita) reduce profitability of frontier agriculture and slows deforestation.

Historical causes

Prehistory

The Carboniferous Rainforest Collapse, was an event that occurred 300 million years ago. Climate change devastated tropical rainforests causing the extinction of many plant and animal species. The change was abrupt, specifically, at this time climate became cooler and drier, conditions that are not favourable to the growth of rainforests and much of the biodiversity within them. Rainforests were fragmented forming shrinking 'islands' further and further apart. This sudden collapse affected several large groups, effects on amphibians were particularly devastating, while reptiles fared better, being ecologically adapted to the drier conditions that followed.

An array of Neolithic artifacts, including bracelets, axe heads, chisels, and polishing tools.

Small scale deforestation was practiced by some societies for tens of thousands of years before the beginnings of civilization. The first evidence of deforestation appears in the Mesolithic period. It was probably used to convert closed forests into more open ecosystems favourable to game animals. With the advent of agriculture, larger areas began to be deforested, and fire became the prime tool to clear land for crops. In Europe there is little solid evidence before 7000 BC. Mesolithic foragers used fire to create openings for red deer and wild boar. In Great Britain, shade-tolerant species such as oak and ash are replaced in the pollen record by hazels, brambles, grasses and nettles. Removal of the forests led to decreased transpiration, resulting in the formation of upland peat bogs. Widespread decrease in elm pollen across Europe between 8400-8300 BC and 7200-7000 BC, starting in southern Europe and gradually moving north to Great Britain, may represent land clearing by fire at the onset of Neolithic agriculture.

The Neolithic period saw extensive deforestation for farming land. Stone axes were being made from about 3000 BC not just from flint, but from a wide variety of hard rocks from across Britain and North America as well. They include the noted Langdale axe industry in the English Lake District, quarries developed at Penmaenmawr in North Wales and numerous other locations. Rough-outs were made locally near the quarries, and some were polished locally to give a fine finish. This step not only increased the mechanical strength of the axe, but also made penetration of wood easier. Flint was still used from sources such as Grimes Graves but from many other mines across Europe.

Evidence of deforestation has been found in Minoan Crete; for example the environs of the Palace of Knossos were severely deforested in the Bronze Age.

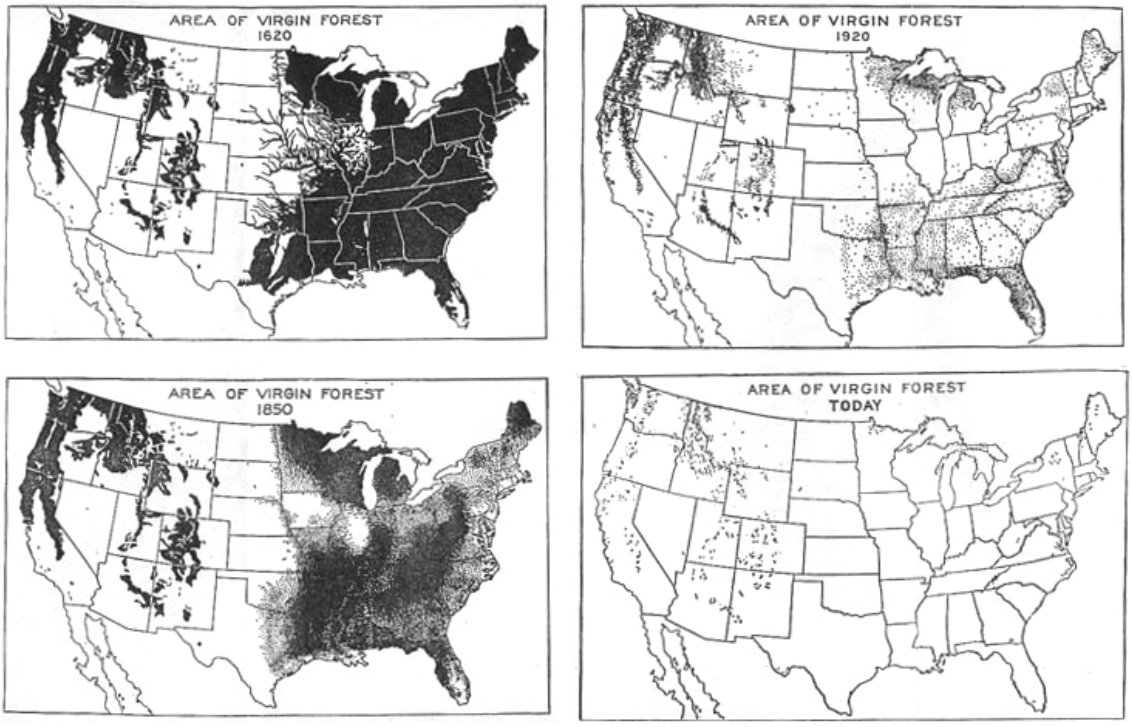
Pre-industrial history

Throughout most of history, humans were hunter gatherers who hunted within forests. In most areas, such as the Amazon, the tropics, Central America, and the Caribbean, only after shortages of wood and other forest products occur are policies implemented to ensure forest resources are used in a sustainable manner.

In ancient Greece, Tjeered van Andel and co-writers summarized three regional studies of historic erosion and alluviation and found that, wherever adequate evidence exists, a major phase of erosion follows, by about 500-1,000 years the introduction of farming in the various regions of Greece, ranging from the later Neolithic to the Early Bronze Age. The thousand years following the mid-first millennium BCE saw serious, intermittent pulses of soil erosion in numerous places. The historic silting of ports along the southern coasts of Asia Minor (*e.g.* Clarus, and the examples of Ephesus, Priene and Miletus, where harbors had to be abandoned because of the silt deposited by the Meander) and in coastal Syria during the last centuries BC.

Easter Island has suffered from heavy soil erosion in recent centuries, aggravated by agriculture and deforestation. Jared Diamond gives an extensive look into the collapse of the ancient Easter Islanders in his book *Collapse*. The disappearance of the island's trees seems to coincide with a decline of its civilization around the 17th and 18th century. He attributed the collapse to deforestation and over-exploitation of all resources.

The famous silting up of the harbor for Bruges, which moved port commerce to Antwerp, also followed a period of increased settlement growth (and apparently of deforestation) in the upper river basins. In early medieval Riez in upper Provence, alluvial silt from two small rivers raised the riverbeds and widened the floodplain, which slowly buried the Roman settlement in alluvium and gradually moved new construction to higher ground; concurrently the headwater valleys above Riez were being opened to pasturage.



Loss of old growth forest in the United States; 1620, 1850, and 1920 maps: *From William B. Greeley's, The Relation of Geography to Timber Supply, Economic Geography, 1925, vol. 1, p. 1-11. Source of "Today" map: compiled by George Draffan from roadless area map in The Big Outside: A Descriptive Inventory of the Big Wilderness Areas of the United States, by Dave Foreman and Howie Wolke (Harmony Books, 1992)*. These maps represent only virgin forest lost. Some regrowth has occurred but not to the age, size or extent of 1620 due to population increases and food cultivation.

A typical progress trap was that cities were often built in a forested area, which would provide wood for some industry (e.g. construction, shipbuilding, pottery). When deforestation occurs without proper replanting, however; local wood supplies become difficult to obtain near enough to remain competitive, leading to the city's abandonment, as happened repeatedly in Ancient Asia Minor. Because of fuel needs, mining and metallurgy often led to deforestation and city abandonment.

With most of the population remaining active in (or indirectly dependent on) the agricultural sector, the main pressure in most areas remained land clearing for crop and cattle farming. Enough wild green was usually left standing (and partially used, e.g. to collect firewood, timber and fruits, or to graze pigs) for wildlife to remain viable. The elite's (nobility and higher clergy) protection of their own hunting privileges and game often protected significant woodlands.

Major parts in the spread (and thus more durable growth) of the population were played by monastical 'pioneering' (especially by the Benedictine and Commercial orders) and some feudal lords' recruiting farmers to settle (and become tax payers) by offering

relatively good legal and fiscal conditions. Even when speculators sought to encourage towns, settlers needed an agricultural belt around or sometimes within defensive walls. When populations were quickly decreased by causes such as the Black Death or devastating warfare (e.g. Genghis Khan's Mongol hordes in eastern and central Europe, Thirty Years' War in Germany), this could lead to settlements being abandoned. The land was reclaimed by nature, but the secondary forests usually lacked the original biodiversity.

From 1100 to 1500 AD, significant deforestation took place in Western Europe as a result of the expanding human population. The large-scale building of wooden sailing ships by European (coastal) naval owners since the 15th century for exploration, colonisation, slave trade–and other trade on the high seas consumed many forest resources. Piracy also contributed to the over harvesting of forests, as in Spain. This led to a weakening of the domestic economy after Columbus' discovery of America, as the economy became dependent on colonial activities (plundering, mining, cattle, plantations, trade, etc.)

In *Changes in the Land* (1983), William Cronon analyzed and documented 17th-century English colonists' reports of increased seasonal flooding in New England during the period when new settlers initially cleared the forests for agriculture. They believed flooding was linked to widespread forest clearing upstream.

The massive use of charcoal on an industrial scale in Early Modern Europe was a new type of consumption of western forests; even in Stuart England, the relatively primitive production of charcoal has already reached an impressive level. Stuart England was so widely deforested that it depended on the Baltic trade for ship timbers, and looked to the untapped forests of New England to supply the need. Each of Nelson's Royal Navy war ships at Trafalgar (1805) required 6,000 mature oaks for its construction. In France, Colbert planted oak forests to supply the French navy in the future. When the oak plantations matured in the mid-19th century, the masts were no longer required because shipping had changed.

Norman F. Cantor's summary of the effects of late medieval deforestation applies equally well to Early Modern Europe:

Europeans had lived in the midst of vast forests throughout the earlier medieval centuries. After 1250 they became so skilled at deforestation that by 1500 they were running short of wood for heating and cooking. They were faced with a nutritional decline because of the elimination of the generous supply of wild game that had inhabited the now-disappearing forests, which throughout medieval times had provided the staple of their carnivorous high-protein diet. By 1500 Europe was on the edge of a fuel and nutritional disaster [from] which it was saved in the sixteenth century only by the burning of soft coal and the cultivation of potatoes and maize.

Industrial era

In the 19th century, introduction of steamboats in the United States was the cause of deforestation of banks of major rivers, such as the Mississippi River, with increased and more severe flooding one of the environmental results. The steamboat crews cut wood every day from the riverbanks to fuel the steam engines. Between St. Louis and the confluence with the Ohio River to the south, the Mississippi became more wide and shallow, and changed its channel laterally. Attempts to improve navigation by the use of snagpullers often resulted in crews' clearing large trees 100 to 200 feet (61 m) back from the banks. Several French colonial towns of the Illinois Country, such as Kaskaskia, Cahokia and St. Philippe, Illinois were flooded and abandoned in the late 19th century, with a loss to the cultural record of their archeology.

The wholescale clearance of woodland to create agricultural land can be seen in many parts of the world, such as the Central forest-grasslands transition and other areas of the Great Plains of the United States. Specific parallels are seen in the 20th-century deforestation occurring in many developing nations.

Rates

Orbital photograph of human deforestation in progress in the Tierras Bajas project in eastern Bolivia

Global deforestation sharply accelerated around 1852. It has been estimated that about half of the Earth's mature tropical forests—between 7.5 million and 8 million km^2 (2.9 million to 3 million sq mi) of the original 15 million to 16 million km^2 (5.8 million to 6.2 million sq mi) that until 1947 covered the planet—have now been cleared. Some

scientists have predicted that unless significant measures (such as seeking out and protecting old growth forests that have not been disturbed) are taken on a worldwide basis, by 2030 there will only be ten percent remaining, with another ten percent in a degraded condition. 80% will have been lost, and with them hundreds of thousands of irreplaceable species.

Estimates vary widely as to the extent of tropical deforestation. Scientists estimate that one fifth of the world's tropical rainforest was destroyed between 1960 and 1990. They claim that that rainforests 50 years ago covered 14% of the world's land surface, now only cover 5-7%, and that all tropical forests will be gone by the middle of the 21st century.

A 2002 analysis of satellite imagery suggested that the rate of deforestation in the humid tropics (approximately 5.8 million hectares per year) was roughly 23% lower than the most commonly quoted rates. Conversely, a newer analysis of satellite images reveals that deforestation of the Amazon rainforest is twice as fast as scientists previously estimated.

Some have argued that deforestation trends may follow a Kuznets curve, which if true would nonetheless fail to eliminate the risk of irreversible loss of non-economic forest values (e.g., the extinction of species).

A 2005 report by the United Nations Food and Agriculture Organization (FAO) estimates that although the Earth's total forest area continues to decrease at about 13 million hectares per year, the global rate of deforestation has recently been slowing. Still others claim that rainforests are being destroyed at an ever-quickening pace. The London-based Rainforest Foundation notes that "the UN figure is based on a definition of forest as being an area with as little as 10% actual tree cover, which would therefore include areas that are actually savannah-like ecosystems and badly damaged forests." Other critics of the FAO data point out that they do not distinguish between forest types, and that they are based largely on reporting from forestry departments of individual countries, which do not take into account unofficial activities like illegal logging.

Despite these uncertainties, there is agreement that destruction of rainforests remains a significant environmental problem. Up to 90% of West Africa's coastal rainforests have disappeared since 1900. In South Asia, about 88% of the rainforests have been lost. Much of what remains of the world's rainforests is in the Amazon basin, where the Amazon Rainforest covers approximately 4 million square kilometres. The regions with the highest tropical deforestation rate between 2000 and 2005 were Central America—which lost 1.3% of its forests each year—and tropical Asia. In Central America, two-thirds of lowland tropical forests have been turned into pasture since 1950 and 40% of all the rainforests have been lost in the last 40 years. Brazil has lost 90-95% of its Mata Atlântica forest. Madagascar has lost 90% of its eastern rainforests. As of 2007, less than 1% of Haiti's forests remained. Mexico, India, the Philippines, Indonesia, Thailand, Myanmar, Malaysia, Bangladesh, China, Sri Lanka, Laos, Nigeria, the Democratic Republic of the Congo, Liberia, Guinea, Ghana and the Côte d'Ivoire, have lost large

areas of their rainforest. Several countries, notably Brazil, have declared their deforestation a national emergency. The World Wildlife Fund's ecoregion project catalogues habitat types throughout the world, including habitat loss such as deforestation, showing for example that even in the rich forests of parts of Canada such as the Mid-Continental Canadian forests of the prairie provinces half of the forest cover has been lost or altered.

Regions

Rates of deforestation vary around the world. Southeast Asia and parts of South America are among the regions of highest concern to environmentalists.

Control

Reducing emissions

Major international organizations, including the United Nations and the World Bank, have begun to develop programs aimed at curbing deforestation. The blanket term Reducing Emissions from Deforestation and Forest Degradation (REDD) describes these sorts of programs, which use direct monetary or other incentives to encourage developing countries to limit and/or roll back deforestation. Funding has been an issue, but at the UN Framework Convention on Climate Change (UNFCCC) Conference of the Parties-15 (COP-15) in Copenhagen in December 2009, an accord was reached with a collective commitment by developed countries for new and additional resources, including forestry and investments through international institutions, that will approach USD 30 billion for the period 2010 - 2012. Significant work is underway on tools for use in monitoring developing country adherence to their agreed REDD targets. These tools, which rely on remote forest monitoring using satellite imagery and other data sources, include the Center for Global Development's FORMA (Forest Monitoring for Action) initiative and the Group on Earth Observations' Forest Carbon Tracking Portal. Methodological guidance for forest monitoring was also emphasized at COP-15 The environmental organization Avoided Deforestation Partners leads the campaign for development of REDD through funding from the U.S. government.

Farming

New methods are being developed to farm more intensively, such as high-yield hybrid crops, greenhouse, autonomous building gardens, and hydroponics. These methods are often dependent on chemical inputs to maintain necessary yields. In cyclic agriculture, cattle are grazed on farm land that is resting and rejuvenating. Cyclic agriculture actually increases the fertility of the soil. Intensive farming can also decrease soil nutrients by consuming at an accelerated rate the trace minerals needed for crop growth.The most promising approach, however, is the concept of food forests in permaculture, which consists of agroforestal systems carefully designed to mimic natural forests, with an emphasis on plant and animal species of interest for food, timber and other uses. These systems have low dependence on fossil fuels and agro-chemicals, are highly self-

maintaining, highly productive, and with strong positive impact on soil and water quality, and biodiversity.

Forest management

Efforts to stop or slow deforestation have been attempted for many centuries because it has long been known that deforestation can cause environmental damage sufficient in some cases to cause societies to collapse. In Tonga, paramount rulers developed policies designed to prevent conflicts between short-term gains from converting forest to farmland and long-term problems forest loss would cause, while during the seventeenth and 18th centuries in Tokugawa, Japan, the shoguns developed a highly sophisticated system of long-term planning to stop and even reverse deforestation of the preceding centuries through substituting timber by other products and more efficient use of land that had been farmed for many centuries. In 16th century Germany landowners also developed silviculture to deal with the problem of deforestation. However, these policies tend to be limited to environments with *good rainfall*, *no dry season* and *very young soils* (through volcanism or glaciation). This is because on older and less fertile soils trees grow too slowly for silviculture to be economic, whilst in areas with a strong dry season there is always a risk of forest fires destroying a tree crop before it matures.

In the areas where "slash-and-burn" is practiced, switching to "slash-and-char" would prevent the rapid deforestation and subsequent degradation of soils. The biochar thus created, given back to the soil, is not only a durable carbon sequestration method, but it also is an extremely beneficial amendment to the soil. Mixed with biomass it brings the creation of terra preta, one of the richest soils on the planet and the only one known to regenerate itself.

Sustainable practices

Certification, as provided by global certification systems such as PEFC and FSC, contributes to tackling deforestation by creating market demand for timber from sustainably managed forests. According to the United Nations Food and Agriculture Organization (FAO), "A major condition for the adoption of sustainable forest management is a demand for products that are produced sustainably and consumer willingness to pay for the higher costs entailed. Certification represents a shift from regulatory approaches to market incentives to promote sustainable forest management. By promoting the positive attributes of forest products from sustainably managed forests, certification focuses on the demand side of environmental conservation."

Reforestation

In many parts of the world, especially in East Asian countries, reforestation and afforestation are increasing the area of forested lands. The amount of woodland has increased in 22 of the world's 50 most forested nations. Asia as a whole gained 1 million hectares of forest between 2000 and 2005. Tropical forest in El Salvador expanded more

than 20% between 1992 and 2001. Based on these trends, one study projects that global forest will increase by 10%—an area the size of India—by 2050.

In the People's Republic of China, where large scale destruction of forests has occurred, the government has in the past required that every able-bodied citizen between the ages of 11 and 60 plant three to five trees per year or do the equivalent amount of work in other forest services. The government claims that at least 1 billion trees have been planted in China every year since 1982. This is no longer required today, but March 12 of every year in China is the Planting Holiday. Also, it has introduced the Green Wall of China project, which aims to halt the expansion of the Gobi desert through the planting of trees. However, due to the large percentage of trees dying off after planting (up to 75%), the project is not very successful. There has been a 47-million-hectare increase in forest area in China since the 1970s. The total number of trees amounted to be about 35 billion and 4.55% of China's land mass increased in forest coverage. The forest coverage was 12% two decades ago and now is 16.55%.

An ambitious proposal for China is the Aerially Delivered Re-forestation and Erosion Control System and the Proposed sahara forest project coupled with the Seawater Greenhouse.

In Western countries, increasing consumer demand for wood products that have been produced and harvested in a sustainable manner is causing forest landowners and forest industries to become increasingly accountable for their forest management and timber harvesting practices.

The Arbor Day Foundation's Rain Forest Rescue program is a charity that helps to prevent deforestation. The charity uses donated money to buy up and preserve rainforest land before the lumber companies can buy it. The Arbor Day Foundation then protects the land from deforestation. This also locks in the way of life of the primitive tribes living on the forest land. Organizations such as Community Forestry International, Cool Earth, The Nature Conservancy, World Wide Fund for Nature, Conservation International, African Conservation Foundation and Greenpeace also focus on preserving forest habitats. Greenpeace in particular has also mapped out the forests that are still intact and published this information on the internet. World Resources Institute in turn has made a simpler thematic map showing the amount of forests present just before the age of man (8000 years ago) and the current (reduced) levels of forest. These maps mark the amount of afforestation required to repair the damage caused by people.

Forest plantations

To meet the world's demand for wood, it has been suggested by forestry writers Botkins and Sedjo that high-yielding forest plantations are suitable. It has been calculated that plantations yielding 10 cubic meters per hectare annually could supply all the timber required for international trade on 5% of the world's existing forestland. By contrast, natural forests produce about 1-2 cubic meters per hectare; therefore, 5-10 times more

forestland would be required to meet demand. Forester Chad Oliver has suggested a forest mosaic with high-yield forest lands interpersed with conservation land.

One analysis of FAO data suggests that afforestation and reforestation projects "could reverse the global decline in woodlands within 30 years."

Reforestation through tree planting could take advantage of changing precipitation patterns due to climate change. This would be done by studying where precipitation is projected to increase and setting up reforestation projects in these locations. Areas such as Niger, Sierra Leone and Liberia are especially important candidates because they also suffer from an expanding desert (the Sahara) and decreasing biodiversity (while being important biodiversity hotspots).

Military context

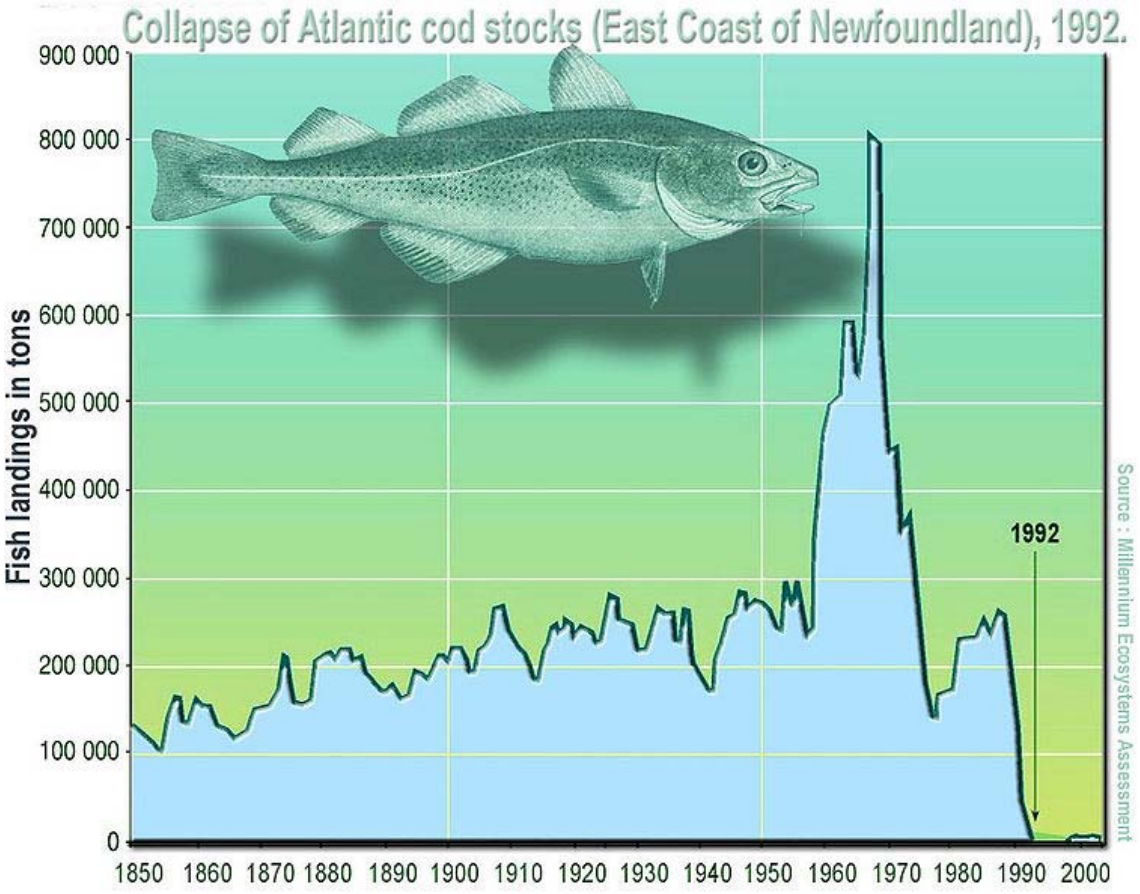
American Sherman tanks knocked out by Japanese artillery on Okinawa.

While the preponderance of deforestation is due to demands for agricultural and urban use for the human population, there are some examples of military causes. One example of deliberate deforestation is that which took place in the U.S. zone of occupation in Germany after World War II. Before the onset of the Cold War defeated Germany was still considered a potential future threat rather than potential future ally. To address this threat, attempts were made to lower German industrial potential, of which forests were deemed an element. Sources in the U.S. government admitted that the purpose of this was the "ultimate destruction of the war potential of German forests." As a consequence of the practice of clear-felling, deforestation resulted which could "be replaced only by long forestry development over perhaps a century."

War can also be a cause of deforestation, either deliberately such as through the use of Agent Orange during the Vietnam War where, together with bombs and bulldozers, it contributed to the destruction of 44% of the forest cover, or inadvertently such as in the 1945 Battle of Okinawa where bombardment and other combat operations reduced the lush tropical landscape into "a vast field of mud, lead, decay and maggots".

Chapter- 2

Overexploitation



Atlantic cod stocks were severely overexploited in the 1970s and 1980s, leading to their abrupt collapse in 1992

Overexploitation, also called **overharvesting**, refers to harvesting a renewable resource to the point of diminishing returns. Sustained overexploitation can lead to the destruction of the resource. The term applies to natural resources such as: wild medicinal plants, grazing pastures, fish stocks, forests and water aquifers.

In ecology, overexploitation describes one of the five main activities threatening global biodiversity. Ecologists use the term to describe populations that are harvested at a rate that is unsustainable, given their natural rates of mortality and capacities for reproduction. This can result in extinction at the population level and even extinction of whole species. In conservation biology the term is usually used in the context of human economic activity that involves the taking of biological resources, or organisms, in larger numbers than their populations can withstand. The term is also used and defined somewhat differently in fisheries, hydrology and natural resource management.

Overexploitation can lead to resource destruction, including extinctions. However it is also possible for overexploitation to be sustainable, as discussed below in the section on fisheries. In the context of fishing, the term overfishing can be used instead of overexploitation, as can overgrazing in stock management, overlogging in forest management, overdrafting in aquifer management, and endangered species in species monitoring. Overexploitation is not an activity limited to humans. Introduced predators and herbivores, for example, can overexploit native flora and fauna.

History

When the giant flightless birds called moa were overexploited to the point of extinction, the giant Haast's eagle that preyed on them also became extinct

Overexploitation is not a new phenomenon. It has been observed for millennia. For example, ceremonial cloaks worn by the Hawaiian kings were made from the mamo bird; a single cloak used the feathers of 70,000 birds of this now-extinct species. The dodo, a flightless bird from Mauritius, is another well known example of overexploitation. As with many island species, it was naive about certain predators, allowing humans to approach and kill it with ease.

From the earliest of times, hunting for wild mammals and birds has been an important human activity as a means of survival. There is a whole history of overexploitation in the form of overhunting. The overkill hypothesis (Quaternary extinction events) explains why the megafaunal extinctions occurred within a relatively short period of time. This can be traced with human migration. The most convincing evidence of this theory is that 80% of the North American large mammal species disappeared within 1000 years of the arrival of humans on the western hemisphere continents. Again, in New Zealand, ten species of the giant moa birds were hunted to extinction by the Māori by 1500 AD. A second wave of extinctions occurred later with European settlement.

In more recent times, overexploitation has resulted in the gradual emergence of the concepts of sustainability and sustainable development, which has built on other concepts, such as sustainable yield, eco-development and deep ecology.

Overview

Overexploitation need not necessarily lead to the destruction of the resource, nor is it necessarily unsustainable. However, depleting the numbers or amount of the resource can change its quality. For example, footstool palm is a wild palm tree found in Southeast Asia. Its leaves are used for thatching and food wrapping, and overharvesting has resulted in its leaf size becoming smaller.

Tragedy of the commons

Cows on Selsley Common. The tragedy of the commons is a useful parable for understanding how overexploitation can occur

The tragedy of the commons refers to a dilemma described in an article by that name written by Garrett Hardin and first published in the journal *Science* in 1968.

Central to Hardin's essay is an example which is a useful parable for understanding how overexploitation can occur. This example was first sketched in an 1833 pamphlet by William Forster Lloyd, as a hypothetical and simplified situation based on medieval land tenure in Europe, of herders sharing a commons on which they are each entitled to let their cows graze. In Hardin's example, it is in each herder's interest to put each succeeding cow he acquires onto the land, even if the carrying capacity of the common is exceeded and it is temporarily or permanently damaged for all as a result. The herder receives all of the benefits from an additional cow, while the damage to the common is shared by the entire group. If all herders make this individually rational economic decision, the common will be overexploited or even destroyed to the detriment of all. However, since all herders reach the same rational conclusion, overexploitation in the form of overgrazing occurs, with immediate losses, and the pasture may be degraded to the point where it gives very little return.

"Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit - in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own interest in a society that believes in the freedom of the commons." (Hardin, 1968)

In the course of his essay, Hardin develops the theme, drawing in many examples of latter day commons, such as national parks, the atmosphere, oceans, rivers and fish stocks. The example of fish stocks had led some to call this the "tragedy of the fishers". A major theme running through the essay is the growth of human populations, with the Earth's finite resources being the general common.

The tragedy of the commons has intellectual roots tracing back to Aristotle, who noted that "what is common to the greatest number has the least care bestowed upon it", as well as to Hobbes and his leviathan. The opposite situation to a tragedy of the commons is sometimes referred to as a tragedy of the anticommons: a situation in which rational individuals, acting separately, collectively waste a given resource by underutilizing it.

The tragedy of the commons can be avoided if it is appropriately regulated. Hardin's use of "commons" has frequently been misunderstood, leading Hardin to later remark that he should have titled his work "The tragedy of the unregulated commons".

Fisheries

The northern bluefin tuna is currently seriously overexploited. Scientists say 7,500 tons annually is the sustainable limit, yet the fishing industry continue to harvest 60,000 tons.

In wild fisheries, overexploitation or overfishing occurs when a fish stock has been fished down "below the size that, on average, would support the long-term maximum sustainable yield of the fishery". However, overexploitation can be sustainable.

When a fishery starts harvesting fish from a previously unexploited stock, the biomass of the fish stock will decrease, since harvesting means fish are being removed. For sustainability, the rate at which the fish replenish biomass through reproduction must balance the rate at which the fish are being harvested. If the harvest rate is increased, then the stock biomass will further decrease. At a certain point, the maximum harvest yield that can be sustained will be reached, and further attempts to increase the harvest rate will result in the collapse of the fishery. This point is called the maximum sustainable yield, and in practice, usually occurs when the fishery has been fished down to about 30% of the biomass it had before harvesting started.

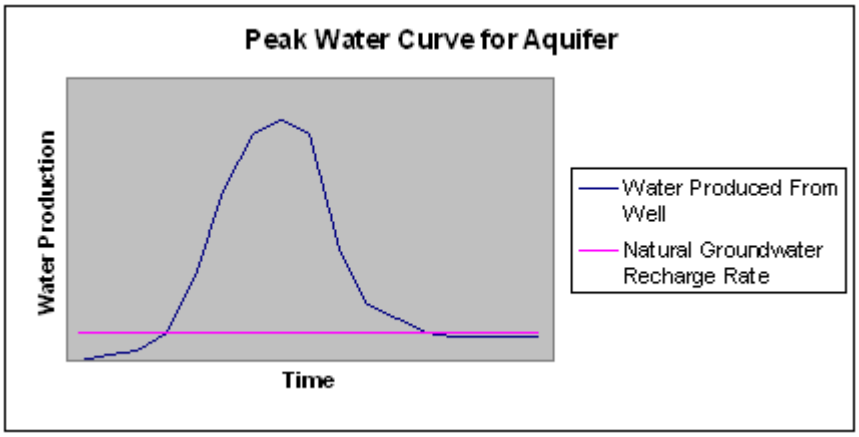
It is possible to fish the stock down further, to say 15% of the pre-harvest biomass, and then adjust the harvest rate so the biomass remains at that level. In this case, the fishery is sustainable, but is now overexploited, because the stock has been run down to the point where the sustainable yield is less than it could be.

Fish stocks are said to "collapse" if their biomass declines by more than 95 percent of their maximum historical biomass. Atlantic cod stocks were severely overexploited in the 1970s and 1980s, leading to their abrupt collapse in 1992. Even though fishing has ceased, the cod stocks have failed to recover. The absence of cod as the apex predator in many areas has led to trophic cascades.

About 25% of world fisheries are now overexploited to the point where their current biomass is less than the level that maximizes their sustainable yield. These depleted fisheries can often recover if fishing pressure is reduced until the stock biomass returns to the optimal biomass. At this point, harvesting can be resumed near the maximum sustainable yield.

The tragedy of the commons can be avoided within the context of fisheries if fishing effort and practices are regulated appropriately by fisheries management. One effective approach may be assigning some measure of ownership in the form of individual transferable quotas (ITQs) to fishermen. In 2008, a large scale study of fisheries that used ITQs, and ones that didn't, provided strong evidence that ITQs help prevent collapses and restore fisheries that appear to be in decline.

Water resources



Overexploitation of groundwater from an aquifer can result in a peak water curve.

Water resource, such as lakes and aquifers, are usually renewable resources which naturally recharge (the term fossil water is sometimes used to describe aquifers which don't recharge). Overexploitation occurs if a water resource, such as the Ogallala Aquifer, is mined or extracted at a rate that exceeds the recharge rate, that is, at a rate that exceeds the practical sustained yield. Recharge usually comes from area streams, rivers and lakes. An aquifer which has been overexploited is said to be overdrafted or depleted. Forests enhance the recharge of aquifers in some locales, although generally forests are a major source of aquifer depletion. Depleted aquifers can become polluted with contaminants such as nitrates, or permanently damaged through subsidence or through saline intrusion from the ocean.

This turns much of the world's underground water and lakes into finite resources with peak usage debates similar to oil. These debates usually centre around agriculture and suburban water usage but generation of electricity from nuclear energy or coal and tar sands mining is also water resource intensive. A modified Hubbert curve applies to any resource that can be harvested faster than it can be replaced. Though Hubbert's original analysis did not apply to renewable resources, their overexploitation can result in a Hubbert-like peak. This has led to the concept of peak water.

Forest resources

Beech forest – Grib Skov, Denmark

Forests are overexploited when they are logged at a rate faster than reforestation takes place. Reforestation competes with other land uses such as food production, livestock grazing, and living space for further economic growth. Historically utilization of forest products, including timber and fuel wood, have played a key role in human societies, comparable to the roles of water and cultivable land. Today, developed countries continue to utilize timber for building houses, and wood pulp for paper. In developing countries almost three billion people rely on wood for heating and cooking. Short-term economic gains made by conversion of forest to agriculture, or overexploitation of wood products, typically leads to loss of long-term income and long term biological productivity (hence reduction in nature's services). West Africa, Madagascar, Southeast Asia and many other regions have experienced lower revenue because of overexploitation and the consequent declining timber harvests.

Biodiversity

The rich diversity of marine life inhabiting coral reefs attracts bioprospectors. Many coral reefs are overexploited

Overexploitation is one of the five main activities threatening global biodiversity. The other four activities are pollution, introduced species, habitat fragmentation and habitat destruction.

One of the key health issues associated with biodiversity is drug discovery and the availability of medicinal resources. A significant proportion of drugs are derived, directly or indirectly, from biological sources. Marine ecosystems are of particular interest in this regard. However unregulated and inappropriate bioprospecting can be considered a form of overexploitation which has the potential to degrade ecosystems and increase biodiversity loss, as well as impacting on the rights of the communities and states from which the resources are taken.

Endangered species

It is not just humans that overexploit their resources. Overgrazing can occur naturally, caused by native fauna, as shown in the upper right.

Overexploitation threatens one-third of endangered vertebrates, as well as other groups. Excluding edible fish, the illegal trade in wildlife is valued at $10 billion per year. Industries responsible for this include the trade in bushmeat, the trade in Chinese medicine, and the fur trade. The Convention for International Trade in Endangered Species of Wild Fauna and Flora, or CITES was set up in order to control and regulate the trade in endangered animals. It currently protects, to a varying degree, some 33,000 species of animals and plants. It is estimated that a quarter of the endangered vertebrates in the United States of America and half of the endangered mammals is attributed to overexploitation

All living organisms require resources to survive. Overexploitation of these resources for protracted periods can deplete natural stocks to the point where they are unable to recover within a short time frame. Humans have always harvested food and other resources they have needed to survive. Human populations, historically, were small, and methods of collection limited to small quantities. With an exponential increase in human population, expanding markets and increasing demand, combined with improved access and

techniques for capture, are causing the exploitation of many species beyond sustainable levels. In practical terms, if continued, it reduces valuable resources to such low levels that their exploitation is no longer sustainable and can lead to the extinction of a species, in addition to having dramatic, unforeseen effects, on the ecosystem. Overexploitation often occurs rapidly as markets open, utilising previously untapped resources, or locally used species.

The Carolina parakeet was hunted to extinction.

Today, overexploitation and misuse of natural resources is an ever present threat for species richness. This is more prevalent when looking at island ecology and the species that inhabit them, as islands can be viewed as the world in miniature. Island endemic populations are more prone to extinction from overexploitation, as they often exist at low

densities with reduced reproductive rates. A good example of this are island snails, such as the Hawaiian *Achatinella* and the French Polynesian *Partula*. Achatinelline snails have 15 species listed as extinct and 24 critically endangered while 60 species of partulidae are considered extinct with 14 listed as critically endangered. The WCMC have attributed over-collecting and very low lifetime fecundity for the extreme vulnerability exhibited among these species.

As another example, when the humble hedgehog was introduced to the Scottish island of Uist, the population greatly expanded and took to consuming and overexploiting shorebird eggs, with drastic consequences for their breeding success. Twelve species of avifauna are affected, with some species numbers being reduced by 39%.

Where there is substantial human migration, civil unrest, or war, controls may no longer exist. With civil unrest, for example in the Congo and Rwanda, firearms have become common place and the breakdown of food distribution networks in such countries leaves the resources of the natural environment vulnerable to whoever can exploit them. Animals are even killed as target practice sometimes, or simply to spite the government. Populations of large primates, such as gorillas and chimpanzees, ungulates and other mammals, may be reduced by 80% or more by hunting and certain species may be eliminated all together. This decline has been called the bushmeat crisis.

Overall, 50 bird species that have become extinct since 1500 (approximately 40% of the total) have been subject to overexploitation, including:

- Great Auk- The penguin-like bird of the north, hunted for its feathers, meat, fat and oil.
- Carolina parakeet - The only parrot species native to the eastern United States, was hunted for crop protection and its feathers.

Other species affected by overexploitation include:

- The international trade in fur: chinchilla, vicuña, giant otter and numerous cat species.
- Insect collectors: butterflies
- Horticulturists: New Zealand mistletoe (*Trilepidia adamsii*), orchids, cacti and many other plant species.
- Shell collectors: Marine molluscs
- Aquarium hobbyists: tropical fish
- Chinese medicine: bears, tigers
- Novelty pets: snakes, parrots and primates

Cascade effects

Overexploiting sea otters resulted in cascade effects which destroyed kelp forest ecosystems

Overexploitation of species can result in knock-on or cascade effects. This can particularly apply if, through overexploitation, a habitat loses its apex predator. Because of the loss of the top predator, a dramatic increase in their prey species can occur. In turn, the unchecked prey can then overexploit their own food resources until population numbers dwindle, possibly to the point of extinction.

A classic example of cascade effects occurred with sea otters. Starting before the 17th century and not phased out until 1911, sea otters were hunted aggressively for their exceptionally warm and valuable pelts, which could fetch up to $2500 US. This caused cascade effects through the kelp forest ecosystems along the Pacific Coast of North America.

One of the sea otters' primary food sources is the sea urchin. When hunters caused sea otter populations to decline, an ecological release of sea urchin populations occurred. The sea urchins then overexploited their main food source, kelp, creating urchin barrens, areas of seabed denuded of kelp, but carpeted with urchins. No longer having food to eat, the sea urchin became locally extinct as well. Also, since kelp forest ecosystems are homes to many other species, the loss of the kelp caused other cascade effects of secondary extinctions.

In 1911, when only one small group of 32 sea otters survived in a remote cove, an international treaty was signed to prevent further exploitation of the sea otters. Under heavy protection, the otters multiplied and repopulated the depleted areas, which slowly

recovered. More recently, with declining numbers of fish stocks, again due to overexploitation, killer whales have experienced a food shortage and have been observed feeding on sea otters, again reducing their numbers.

Chapter- 3

Desertification

Goat husbandry is common through the Norte Chico of Chile, however it produces severe erosion and desertification. Image from upper Limarí River

Desertification is the degradation of land in arid and dry sub-humid areas due to various factors: including climatic variations and human activities.

A major impact of desertification is reduced biodiversity and diminished productive capacity, for example, by transition from land dominated by shrublands to non-native grasslands. For example, in the semi-arid regions of southern California, many coastal sage scrub and chaparral ecosystems have been replaced by non-native, invasive grasses

due to the shortening of fire return intervals. This can create a monoculture of annual grass that cannot support the wide range of animals once found in the original ecosystem. In Madagascar's central highland plateau, 10% of the entire country has desertified due to slash and burn agriculture by indigenous peoples.

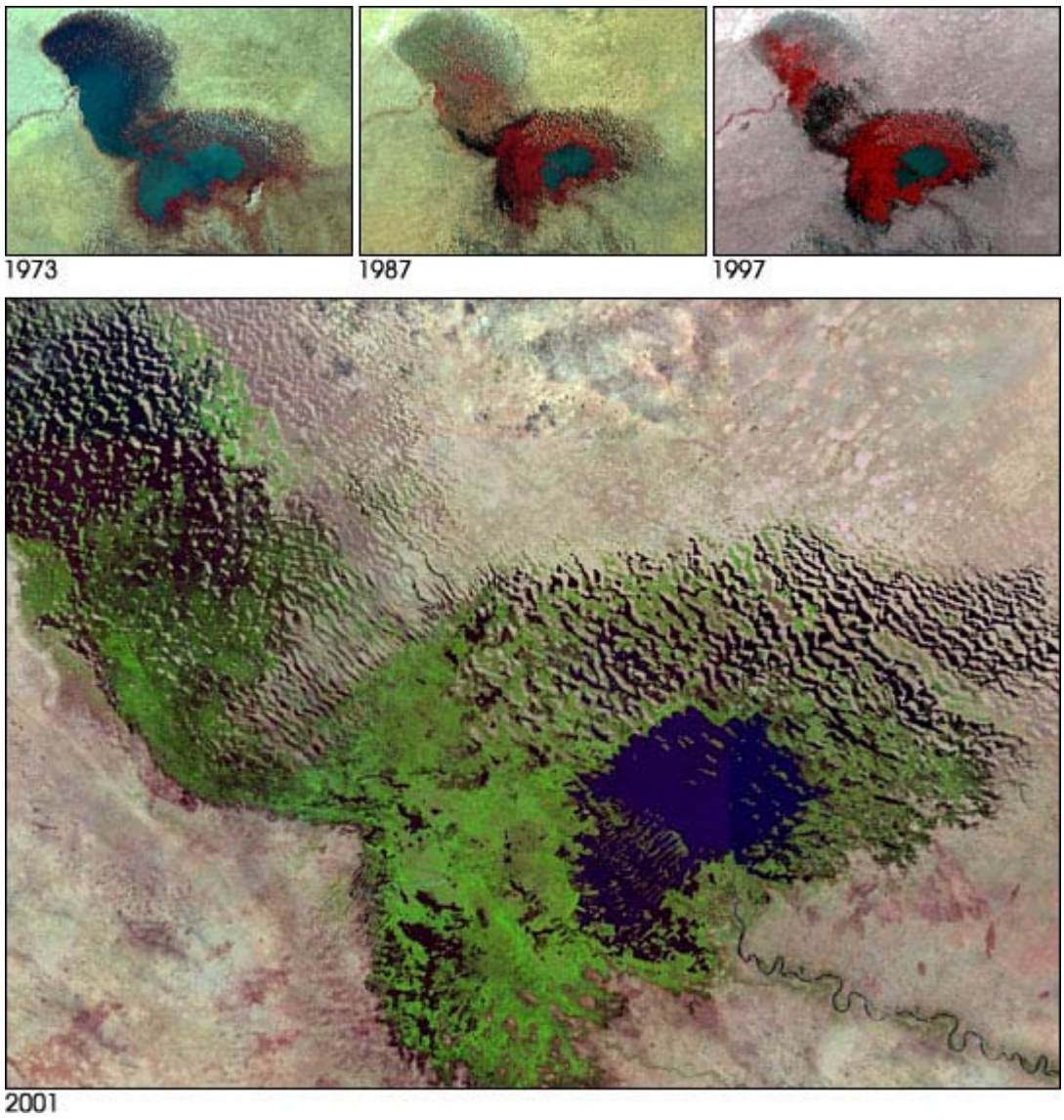
Prehistoric patterns

Desertification is a historic phenomenon; the world's great deserts were formed by natural processes interacting over long intervals of time. During most of these times, deserts have grown and shrunk independent of human activities. Paleodeserts are large sand seas now inactive because they are stabilized by vegetation, some extending beyond the present margins of core deserts, such as the Sahara. Many deserts in western Asia arose because of an overpopulation of prehistoric species and subspecies during the late Cretaceous era.

Dated fossil pollen indicates that today's Sahara desert has been changing between desert and fertile savanna. Studies also show that prehistorically the advance and retreat of deserts tracked yearly rainfall, whereas a pattern of increasing amounts of desert began with human-driven activities of overgrazing and deforestation.

A chief difference of prehistoric versus present desertification is the much greater rate of desertification than in prehistoric and geologic time scales, due to anthropogenic influences. Also another reason for desertification is the Sahara Desert. This desert is spreading at its fastest rate.

Historical and current desertification



Lake Chad in a 2001 satellite image, with the actual lake in blue. The lake has shrunk by 95% since the 1960s.

Overgrazing and to a lesser extent drought in the 1930s transformed parts of the Great Plains in the United States into the "Dust Bowl". During that time, a considerable fraction of the plains population abandoned their homes to escape the unproductive lands. Improved agricultural and water management have prevented a disaster of the earlier magnitude from recurring, but desertification presently affects tens of millions of people with primary occurrence in the lesser developed countries.

Desertification is widespread in many areas of the People's Republic of China. The populations of rural areas have increased since 1949 for economic reasons as more people have settled there. While there has been an increase in livestock, the land available for grazing has decreased. Also the importing of European cattle such as Friesian and Simmental, which have higher grazing intensity, has exacerbated matters.

Human overpopulation is leading to destruction of tropical wet forests and tropical dry forests, due to widening practices of slash-and-burn and other methods of subsistence farming in lesser developed countries. A sequel to the deforestation is typically large scale erosion, loss of soil nutrients and sometimes total desertification. Examples of this extreme outcome can be seen on Madagascar's central highland plateau, where about seven percent of the country's total land mass has become barren, sterile land.

Overgrazing has made the Rio Puerco Basin of central New Mexico one of the most eroded river basins of the western United States and has increased the high sediment content of the river. Overgrazing is also contributing to desertification in some parts of Chile, Ethiopia, Morocco and other countries. Overgrazing is also an issue with some regions of South Africa such as the Waterberg Massif, although restoration of native habitat and game has been pursued vigorously since about 1980.

Another example of desertification occurring is in the Sahel. The chief cause of desertification in the Sahel is described to be slash-and-burn farming in which soil degration is increased do to winds removing unprotected topsoil. Decreases in rainfall are also a cause as well as destruction of local perennials. The Sahara is expanding south at a rate of up to 48 kilometres per year.

Ghana and Nigeria currently experience desertification; in the latter, desertification overtakes about 1,355 square miles (3,510 km^2) of land per year. The Central Asian countries, Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, and Uzbekistan, are also affected. More than 80% of Afghanistan's and Pakistan's land could be subject to soil erosion and desertification. In Kazakhstan, nearly half of the cropland has been abandoned since 1980. In Iran, sand storms were said to have buried 124 villages in Sistan and Baluchestan Province in 2002, and they had to be abandoned. In Latin America, Mexico and Brazil are affected by desertification.

Desertification and poverty

Numerous authors underline the strong link between desertification and poverty. The proportion of poor people among populations is noticeably higher in dryland zones, especially among rural populations. This situation increases yet further as a function of land degradation because of the reduction in productivity, the precariousness of living conditions and difficulty of access to resources and opportunities.

A downward spiral is created in many underdeveloped countries by overgrazing, land exhaustion and overdrafting of groundwater in many of the marginally productive world regions due to overpopulation pressures to exploit marginal drylands for farming. Decision-makers are understandably averse to invest in arid zones with low potential. This absence of investment contributes to the marginalisation of these zones.When unfavourable agro-climatic conditions are combined with an absence of infrastructure and access to markets, as well as poorly adapted production techniques and an underfed and undereducated population, most such zones are excluded from development.

Countering desertification

Trees are planted instead of sand fences to reduce sand accumulating in a UAE highway.

Anti-sand shields in north Sahara, Tunisia.

Desertification is recognized as a major threat to biodiversity. Some countries have developed Biodiversity Action Plans to counter its effects, particularly in relation to the protection of endangered flora and fauna.

Reforestation gets at one of the root causes of desertification and isn't just a treatment of the symptoms. Environmental organizations work in places where deforestation and desertification are contributing to extreme poverty. There they focus primarily on educating the local population about the dangers of deforestation and sometimes employ them to grow seedlings, which they transfer to severely deforested areas during the rainy season.

Techniques focus on two aspects: provisioning of water and fixation and hyper-fertilising soil.

A recent development is the Seawater Greenhouse and Seawater Forest. This proposal is to construct these devices on coastal deserts in order to create freshwater and grow food A similar approach is the Desert Rose concept. These approaches are of widespread applicability, since the relative costs of pumping large quantities of seawater inland are low.

Fixating the soil is often done through the use of shelter belts, woodlots and windbreaks. Windbreaks are made from trees and bushes and are used to reduce soil erosion and evapotranspiration. They were widely encouraged by development agencies from the middle of the 1980s in the Sahel area of Africa. Another approach is the spraying of petroleum or nano clay over semi-arid cropland. This is often done in areas where either petroleum or nano clay is easily and cheaply obtainable (e.g. Iran). In both cases, the application of the material coats seedlings to prevent moisture loss and stop them being blown away.

Some soils (e.g. clay), due to lack of water can become consolidated rather than porous (as in the case of sandy soils). Some techniques as zaï or tillage are then used to still allow the planting of crops. Notably, in Burkina Faso farmer Yacouba Sawadogo has adapted the zai method with remarkable results. His story is the subject of the documentary 'The Man Who Stopped the Desert'

Enriching of the soil and restoration of its fertility is often done by plants. Of these, the Leguminous plants which extract nitrogen from the air and fixes it in the soil, and food crops/trees as grains, barley, beans and dates are the most important. A related concept is ADRECS - a system for rapidly delivering soil stabilisation and re-forestation techniques coupled with renewable energy generation. Sand fences can also be used to control drifting of soil and sand erosion.

Finally, some approaches as stacking stones around the base of trees and artificial groove-digging also help increase the local success of crop survival. Stacked stones help to collect morning dew and retain soil moisture. Artificial grooves are dug in the ground as to retain rainfall and trap wind-blown seeds.

In order to solve the problem of cutting trees for personal energy requirements, solutions as Solar ovens and efficient wood burning cook stoves are advocated as a means to relieve pressure upon the environment; however, these techniques are generally prohibitively expensive in the very regions where they are needed.

While desertification has received some publicity by the news media, most people are unaware of the extent of environmental degradation of productive lands and the expansion of deserts. In 1988 Ridley Nelson pointed out that desertification is a subtle and complex process of deterioration.

At the local level, individuals and governments can temporarily forestall desertification. Sand fences are used throughout the Middle East and the US, in the same way snow fences are used in the north. Placement of straw grids, each up to a square meter in area, will also decrease the surface wind velocity. Shrubs and trees planted within the grids are protected by the straw until they take root. However, some studies suggest that planting of trees depletes water supplies in the area. In areas where some water is available for irrigation, shrubs planted on the lower one-third of a dune's windward side will stabilize the dune. This vegetation decreases the wind velocity near the base of the dune and prevents much of the sand from moving. Higher velocity winds at the top of the dune level it off and trees can be planted atop these flattened surfaces.

Jojoba plantations, such as those shown, have played a role in combating edge effects of desertification in the Thar Desert, India.

Oases and farmlands in windy regions are often protected by the approach described above by planting tree fences or grass belts in order to reduce erosion and walking dunes. Also, small projects as oases often section their plot of land by placing a barrier of thorny bushes or other obstacles to keep grazing animals away from the food crops. Instead, they provide water provisioning (e.g. from a well, ...) outside this barrier. They provide this service mainly to accommodate the animals of travelers (e.g. camels, ...). Sand that manages to pass through the grass belts can be caught in strips of trees planted as wind breaks 50 to 100 meters apart adjacent to the belts. Small plots of trees may also be scattered inside oases to stabilize the area. On a much larger scale, a "Green Wall of China", which will eventually stretch more than 5,700 kilometers in length, nearly as long as the Great Wall of China, is being planted in north-eastern China to protect "sandy lands" – deserts created by human activity.

There is another technique, which is controversial, that involves using livestock to rehabilitate land. This is based on the fact that many areas in the world which are heavily desertified were once grasslands and similar environments (the Sahara, areas in the USA that were affected by the Dust Bowl years) and where substantial populations of large herbivores were once supported. By using livestock (which is contained within a portable fence so that they cannot wander away from the site) along with hay and seeds contained within, the land can be restored effectively, even on mine dumps. In addition, people that hold livestock and that have a semi-nomadic livestyle (moving between fixed homes) such as nomadic pastoralists have significant interest in combating desertification of these areas. Having these people to plant shelterbelts, windbreaks, trees or nitrogen-fixating crops in the vicinity of their homes would also help a lot.

Africa, with coordination from Senegal, has launched its own "green wall" project. Trees will be planted on a 15 km wide land strip from Senegal to Djibouti. Aside from countering desert progression, the project is also aimed at creating new economic activities, especially thanks to tree products such as gum arabic

More efficient use of existing water resources and control of salinization are other tools for mitigating arid lands. A recent development is the Seawater Greenhouse and Seawater Forest. This proposal is to construct these devices on coastal deserts in order to create freshwater and grow food A similar approach is the Desert Rose concept. These approaches are of widespread applicability, since the relative costs of pumping large quantities of seawater inland are low.

New ways are also being sought to find groundwater resources and to develop more effective ways of irrigating arid and semiarid lands. Research on the reclamation of deserts is also focusing on discovering proper crop rotation to protect fragile soil, on understanding how sand-fixing plants can be adapted to local environments, and on how overgrazing can be addressed. A proposal combining desert stabilization and renewable energy is Aerially Delivered Re-forestation and Erosion Control System -

Architecture student Magnus Larsson won the 2008 Holcim Awards "Next Generation" 1st prize for region Africa Middle East for his project "Dune anti-desertification

architecture, Sokoto, Nigeria" and his design of a habitable wall using a microorganism with the ability to by solidifying the sand with the bacteria Bacillus pasteurii. Larssons also presented the design at TED.

Mitigation

Analyses of satellite images have revealed a retreat of the Sahara Desert on its southern border, throughout the Sahel region. One such analysis, dating from September 2002, showed a greening of the Desert from the mid-1980s onwards. Pointing to the significance of the phenomenon, families had been observed to be returning home to previously drought stricken areas in countries such as Burkina Faso.

As a result of these analyses, along with the results obtained from scientific models, a number of scientists now predict that rainfall may be increasing in the region, possibly as a result of global warming.

Chapter- 4

Holocene Extinction

The dodo, a bird of Mauritius, became extinct during the mid-late seventeenth century after humans destroyed the forests where the birds made their homes and introduced mammals that ate their eggs.

The **Holocene extinction** is the widespread, ongoing extinction of species during the present Holocene epoch (since around 10,000 BC). The large number of extinctions span numerous families of plants and animals including mammals, birds, amphibians, reptiles and arthropods; a sizeable fraction of these extinctions are occurring in the rainforests. Between 1500 and 2009, 875 extinctions have been documented by the International Union for Conservation of Nature and Natural Resources. However, most extinctions go undocumented. According to the Species-area theory and based on upper-bound estimating, up to 140,000 species per year may be the present rate of extinction.

In broad usage, Holocene extinction includes the notable disappearance of large mammals, known as megafauna, starting roughly 11,500 years ago as humans developed and spread. Such disappearances have normally been considered as either a result of global warming (the current climate change), a result of the proliferation of modern humans, or both; however in 2007 a cometary impact hypothesis was presented, but has not been broadly accepted. These extinctions, occurring near the Pleistocene–Holocene boundary, are sometimes referred to as the Quaternary extinction event or Ice Age

extinction. However, the Holocene extinction may be regarded as continuing into the 21st century.

There is no general agreement on whether to consider more recent extinctions as a distinct event or merely part of the Quaternary extinction event. Only during these most recent parts of the extinction have plants also suffered large losses. Overall, the Holocene extinction is most significantly characterised by the presence of human-made driving factors and climate change.

The prehistoric extinction events

There was a limited debate as to the extent to which the disappearance of megafauna at the end of the last glacial period can also be attributed to human activities, directly, by hunting, or indirectly, by decimation of prey populations. While climate change is still cited as another important factor, anthropogenic explanations have become predominant.

The ongoing extinction seems more outstanding in light of separating recent extinctions (approximately since the industrial revolution) from the Pleistocene extinction near the end of the last glacial period. The latter is exemplified by the extinction of the woolly mammoth.

However, modern climatology suggests the current Holocene epoch is no more than the latest in a series of interglacial intervals. Furthermore, there is a continuum of extinctions since 11,000 BCE. If only considering human impact, the vulnerability and extinction rate of species simply rises with the increase in human population, so there would be no need to separate the Pleistocene extinction from the recent one. Nevertheless, the Pleistocene extinction event is large enough and has not been resolved completely.

Younger extinctions

New Zealand

c. 1500, several species became extinct after Polynesian settlers arrived, including:

- Ten species of Moa, giant flightless ratite birds.
- The giant Haast's Eagle, *Harpagornis*
- The flightless predatory Adzebills.

Pacific, including Hawaii

Recent research, based on archaeological and paleontological digs on 70 different islands, has shown that numerous species went extinct as people moved across the Pacific, starting 30,000 years ago in the Bismarck Archipelago and Solomon Islands (Steadman & Martin 2003). It is currently estimated that among the bird species of the Pacific some 2000 species have gone extinct since the arrival of humans (Steadman 1995). Among the extinctions were:

- The Moa-nalos, giant grazing ducks from Hawaii.
- The Nēnē-nui, or Woodwalking Goose, an extinct species of goose that once inhabited Maui.
- A giant megapode from New Caledonia.
- Mekosuchine crocodiles from New Caledonia, Fiji and Samoa.

Ten species or subspecies of birds have disappeared from the Hawaiian islands since the 1980s. These include the Kaua'i O'o, Nukupu'u, 'Akialoa, Kama'o, Po'ouli, and others.

Madagascar

Starting with the arrival of humans around 2000 years ago, nearly all of the island's megafauna became extinct, including:

- Eight or more species of elephant birds, giant flightless ratites in the genera *Aepyornis* and *Mullerornis*.
- 17 species of lemur, known as giant, subfossil lemurs, including:
  - Giant Aye-aye *(Daubentonia robusta)*
  - Sloth lemurs, including chimpanzee-sized *Palaeopropithecus* and gorilla-sized *Archaeoindris*
  - Koala lemurs (*Megaladapis*), a koala-like, orangutan-sized arboreal lemur
  - Monkey lemurs, most terrestrial of lemurs, often compared to baboons or macaques.
  - *Pachylemur*, a genus of giant ruffed lemurs
- Giant Fossa
- *Plesiorycteropus*, a genus containing two species of digging mammal unlike anything alive today
- Two species of Malagasy Hippopotamus

Indian Ocean Islands

Starting c. 1500, a number of species became extinct upon human settlement of the islands, including:

- several species of giant tortoise on the Seychelles and Mascarene Islands
- 14 species of birds on the Mascarene Islands, including the Dodo, the Rodrigues Solitaire, and the unrelated Réunion Solitaire.

Ongoing Holocene extinction

One scientist estimates the extinction may be 10,000 times the background extinction rate (the average between mass extinction events). Most scientists predict a much lower extinction rate than this outlying estimate.

Megafaunal extinctions continue into the 21st century. Modern extinctions are more directly attributable to human influences. Extinction rates are minimized in the popular

imagination by the survival of captive populations of animals that are *extinct in the wild* (Père David's Deer, etc.), by marginal survivals of highly-publicized megafauna that are *ecologically extinct* (the Giant Panda, Sumatran Rhinoceros, North American Black-Footed Ferret, etc.) and by extinctions among arthropods. Some examples of modern extinctions of "charismatic" mammal fauna include:

- Aurochs, Europe
- Tarpan, Europe
- Thylacine or Tasmanian Tiger, *Thylacinus cynocephalus*, Tasmania [*extinction disputed*]
- Quagga, a zebra relative, Southeast Africa
- Steller's Sea Cow
- Falkland Island Fox

Many birds have become extinct as a result of human activity, especially birds endemic to islands, including many flightless birds. Notable extinct birds include:

- the Dodo, the giant flightless pigeon of Mauritius, Indian Ocean
- the Great Auk of islands in the north Atlantic
- the Passenger Pigeon of North America
- several species of Moa, giant flightless birds from New Zealand
- the Carolina Parakeet of the American southeast

A 1998 poll conducted by the American Museum of Natural History found that seventy percent of biologists believe that we are in the midst of an anthropogenic extinction. Numerous scientific studies—such as a 2004 report published in *Nature*,, and papers authored by the 10,000 scientists who contribute to the IUCN's annual Red List of threatened species—have since reinforced this conviction. In *The Future of Life* (2002), E.O. Wilson of Harvard calculated that, if the current rate of human disruption of the biosphere continues, one-half of Earth's higher lifeforms will be extinct by 2100.

Peter Raven, past President of the American Association for the Advancement of Science, states in the foreword to their publication *AAAS Atlas of Population and Environment*: "We have driven the rate of biological extinction, the permanent loss of species, up several hundred times beyond its historical levels, and are threatened with the loss of a majority of all species by the end of the 21st century." Some of the human causes of the current extinctions include deforestation, hunting, pollution, climate change, and the introduction of non-native species

The Golden Toad of Costa Rica, extinct since around 1989. Its disappearance has been attributed to a confluence of several factors, including El Niño warming, fungus, and the introduction of invasive species.

189 countries which are signatory to the Rio Accord have committed to preparing a Biodiversity Action Plan, a first step at identifying specific endangered species and habitats, country by country.

Human influence on extinction

Extinction of animals and plants caused by human actions may go as far back as the late Pleistocene. Extinctions that are due to human activity (anthropogenic), particularly hypothesized future events, have also been labelled the *anthropocene extinction*. The Anthropocene is a term introduced in 2000.

Recent extinctions described are well-documented, but the nomenclature used varies. The term Anthropocene is a term that is used by few scientists, and some commentators may refer to the current and projected future extinctions as part of a longer Holocene extinction. The Holocene-Anthropocene boundary is contested, with some commentators asserting significant human influence on climate for much of what is normally regarded as the Holocene Epoch. Other commentators place the Holocene-Anthropocene boundary at the industrial revolution while also saying that "Formal adoption of this term in the near future will largely depend on its utility, particularly to earth scientists working on late Holocene successions."

The extinction of megaherbivores in the late Pleistocene is explained by one of two hypotheses, or a combination of the two: climate change, and the ecological impact of early humans. Not only hunting, but anthropogenic fire selected for the survival of ruminants more than the survival of browsing mammals, and against carnivores and scavengers which fed on both.

Chapter- 5

Erosion

Cliff erosion in Pacifica, California

Erosion is the process of weathering and transport of solids (sediment, soil, rock and other particles) in the natural environment or their source and deposits them elsewhere. It usually occurs due to transport by wind, water, or ice; by down-slope creep of soil and other material under the force of gravity; or by living organisms, such as burrowing animals, in the case of bioerosion.

Erosion is a natural process, but it has been increased dramatically by human land use, especially industrial agriculture, deforestation, and urban sprawl. Land that is used for industrial agriculture generally experiences a significantly greater rate of erosion than that of land under natural vegetation, or land used for sustainable agricultural practices. This is particularly true if tillage is used, which reduces vegetation cover on the surface of the soil and disturbs both soil structure and plant roots that would otherwise hold the soil in place. However, improved land use practices can limit erosion, using techniques such as terrace-building, conservation tillage practices, and tree planting.

A certain amount of erosion is natural and, in fact, healthy for the ecosystem. For example, gravels continuously move downstream in watercourses. Excessive erosion, however, causes serious problems, such as receiving water sedimentation, ecosystem damage and outright loss of soil.

Erosion is distinguished from weathering, which is the process of chemical or physical breakdown of the minerals in the rocks, although the two processes may occur concurrently.

Causes

Soil erosion exposing roots

A natural arch produced by erosion of differentially weathered rock in Jebel Kharaz (Jordan)

The rate of erosion depends on many factors. Climatic factors include the amount and intensity of precipitation, the average temperature, as well as the typical temperature range, and seasonality, the wind speed, storm frequency. The geologic factors include the sediment or rock type, its porosity and permeability, the slope (gradient) of the land, and whether the rocks are tilted, faulted, folded, or weathered. The biological factors include ground cover from vegetation or lack thereof, the type of organisms inhabiting the area, and the land use.

In general, given similar vegetation and ecosystems, areas with high-intensity precipitation, more frequent rainfall, more wind, or more storms are expected to have more erosion. Sediment with high sand or silt contents and areas with steep slopes erode more easily, as do areas with highly fractured or weathered rock. Porosity and permeability of the sediment or rock affect the speed with which the water can percolate into the ground. If the water moves underground, less runoff is generated, reducing the amount of surface erosion. Sediments containing more clay tend to erode less than those

with sand or silt. Here, however, the impact of atmospheric sodium on erodibility of clay should be considered.

The factor that is most subject to change is the amount and type of ground cover. In an undisturbed forest, the mineral soil is protected by a litter layer and an organic layer. These two layers protect the soil by absorbing the impact of rain drops. These layers and the underlying soil in a forest are porous and highly permeable to rainfall. Typically, only the most severe rainfall and large hailstorm events will lead to overland flow in a forest. If the trees are removed by fire or logging, infiltration rates become high and erosion low to the degree the forest floor remains intact. Severe fires can lead to significantly increased erosion if followed by heavy rainfall. In the case of construction or road building, when the litter layer is removed or compacted, the susceptibility of the soil to erosion is greatly increased.

Roads are especially likely to cause increased rates of erosion because, in addition to removing ground cover, they can significantly change drainage patterns, especially if an embankment has been made to support the road. A road that has a lot of rock and one that is "hydrologically invisible" (that gets the water off the road as quickly as possible, mimicking natural drainage patterns) has the best chance of not causing increased erosion.

Many human activities remove vegetation from an area, making the soil susceptible to erosion. Logging can cause increased erosion rates due to soil compaction, exposure of mineral soil, for example roads and landings. However it is the removal of or compromise to the forest floor not the removal of the canopy that can lead to erosion. This is because rain drops striking tree leaves coalesce with other rain drops creating larger drops. When these larger drops fall (called throughfall) they again may reach terminal velocity and strike the ground with more energy then had they fallen in the open. Terminal velocity of rain drops is reached in about 8 meters. Because forest canopies are usually higher than this, leaf drop can regain terminal velocity. However, the intact forest floor, with its layers of leaf litter and organic matter, absorbs the impact of the rainfall.

A Linxia City, China, farmer is gradually losing his land as the edge of the loess plateau is eroded away

Heavy grazing can reduce vegetation enough to increase erosion. Changes in the kind of vegetation in an area can also affect erosion rates. Different kinds of vegetation lead to different infiltration rates of rain into the soil. Forested areas have higher infiltration rates, so precipitation will result in less surface runoff, which erodes. Instead much of the water will go in subsurface flows, which are generally less erosive. Leaf litter and low shrubs are an important part of the high infiltration rates of forested systems, the removal of which can increase erosion rates. Leaf litter also shelters the soil from the impact of falling raindrops, which is a significant agent of erosion. Vegetation can also change the speed of surface runoff flows, so grasses and shrubs can also be instrumental in this aspect.

One of the main causes of erosive soil loss in the year 2006 is the result of slash and burn treatment of tropical forest. When the total ground surface is stripped of vegetation and then seared of all living organisms, the upper soils are vulnerable to both wind and water erosion. In a number of regions of the earth, entire sectors of a country have been rendered unproductive. For example, on the Madagascar high central plateau, comprising approximately ten percent of that country's land area, virtually the entire landscape is sterile of vegetation, with gully erosive furrows typically in excess of 50 meters deep and one kilometer wide. Shifting cultivation is a farming system which sometimes

incorporates the slash and burn method in some regions of the world. This degrades the soil and causes the soil to become less and less fertile.

Effects

Approximately 40% of the world's agricultural land is seriously degraded. According to the UN, an area of fertile soil the size of Ukraine is lost every year because of drought, deforestation and climate change. In Africa, if current trends of soil degradation continue, the continent might be able to feed just 25% of its population by 2025, according to UNU's Ghana-based Institute for Natural Resources in Africa.

Bank erosion started by four wheeler all-terrain vehicles, Yauhanna, South Carolina

When land is overused by animal activities (including humans), there can be mechanical erosion and also removal of vegetation leading to erosion. In the case of the animal kingdom, this effect would become material primarily with very large animal herds stampeding such as the Blue Wildebeest on the Serengeti plain. Even in this case there are broader material benefits to the ecosystem, such as continuing the survival of grasslands, that are indigenous to this region. This effect may be viewed as anomalous or a problem only when there is a significant imbalance or overpopulation of one species.

In the case of human use, the effects are also generally linked to overpopulation. When large number of hikers use trails or extensive off road vehicle use occurs, erosive effects often follow, arising from vegetation removal and furrowing of foot traffic and off road vehicle tires. These effects can also accumulate from a variety of outdoor human activities, again simply arising from too many people using a finite land resource.

One of the most serious and long-running water erosion problems worldwide is in the People's Republic of China, on the middle reaches of the Yellow River and the upper reaches of the Yangtze River. From the Yellow River, over 1.6 billion tons of sediment flows into the ocean each year. The sediment originates primarily from water erosion in the Loess Plateau region of the northwest.

Processes

Gravity

Wadi in Makhtesh Ramon, Israel, showing gravity collapse erosion on its banks.

Mass wasting is the down-slope movement of rock and sediments, mainly due to the force of gravity. Mass movement is an important part of the erosional process, as it moves material from higher elevations to lower elevations where other eroding agents such as streams and glaciers can then pick up the material and move it to even lower elevations. Mass-movement processes are always occurring continuously on all slopes; some mass-movement processes act very slowly; others occur very suddenly, often with disastrous results. Any perceptible down-slope movement of rock or sediment is often referred to in general terms as a landslide. However, landslides can be classified in a much more detailed way that reflects the mechanisms responsible for the movement and the velocity at which the movement occurs. One of the visible topographical manifestations of a very slow form of such activity is a scree slope.

Slumping happens on steep hillsides, occurring along distinct fracture zones, often within materials like clay that, once released, may move quite rapidly downhill. They will often show a spoon-shaped isostatic depression, in which the material has begun to slide downhill. In some cases, the slump is caused by water beneath the slope weakening it. In many cases it is simply the result of poor engineering along highways where it is a regular occurrence.

Surface creep is the slow movement of soil and rock debris by gravity which is usually not perceptible except through extended observation. However, the term can also describe the rolling of dislodged soil particles 0.5 to 1.0 mm in diameter by wind along the soil surface.

Water

Nearly perfect sphere in granite, Trégastel, Brittany.

Splash erosion is the detachment and airborne movement of small soil particles caused by the impact of raindrops on soil.

Sheet erosion is the detachment of soil particles by raindrop impact and their removal downslope by water flowing overland as a sheet instead of in definite channels or rills. The impact of the raindrop breaks apart the soil aggregate. Particles of clay, silt and sand fill the soil pores and reduce infiltration. After the surface pores are filled with sand, silt or clay, overland surface flow of water begins due to the lowering of infiltration rates. Once the rate of falling rain is faster than infiltration, runoff takes place. There are two stages of sheet erosion. The first is rain splash, in which soil particles are knocked into the air by raindrop impact. In the second stage, the loose particles are moved downslope by broad sheets of rapidly flowing water filled with sediment known as sheetfloods. This

stage of sheet erosion is generally produced by cloudbursts, sheetfloods commonly travel short distances and last only for a short time.

Rill erosion refers to the development of small, ephemeral concentrated flow paths, which function as both sediment source and sediment delivery systems for erosion on hillslopes. Generally, where water erosion rates on disturbed upland areas are greatest, rills are active. Flow depths in rills are typically on the order of a few centimeters or less and slopes may be quite steep. These conditions constitute a very different hydraulic environment than typically found in channels of streams and rivers. Eroding rills evolve morphologically in time and space. The rill bed surface changes as soil erodes, which in turn alters the hydraulics of the flow. The hydraulics is the driving mechanism for the erosion process, and therefore dynamically changing hydraulic patterns cause continually changing erosional patterns in the rill. Thus, the process of rill evolution involves a feedback loop between flow detachment, hydraulics, and bed form. Flow velocity, depth, width, hydraulic roughness, local bed slope, friction slope, and detachment rate are time and space variable functions of the rill evolutionary process. Superimposed on these interactive processes, the sediment load, or amount of sediment in the flow, has a large influence on soil detachment rates in rills. As sediment load increases, the ability of the flowing water to detach more sediment decreases.

Where precipitation rates exceed soil infiltration rates, *runoff* occurs. Surface runoff turbulence can often cause more erosion than the initial raindrop impact.

Gully erosion, also called *ephemeral gully erosion*, occurs when water flows in narrow channels during or immediately after heavy rains or melting snow. This is particularly noticeable in the formation of hollow ways, where, prior to being tarmacked, an old rural road has over many years become significantly lower than the surrounding fields.

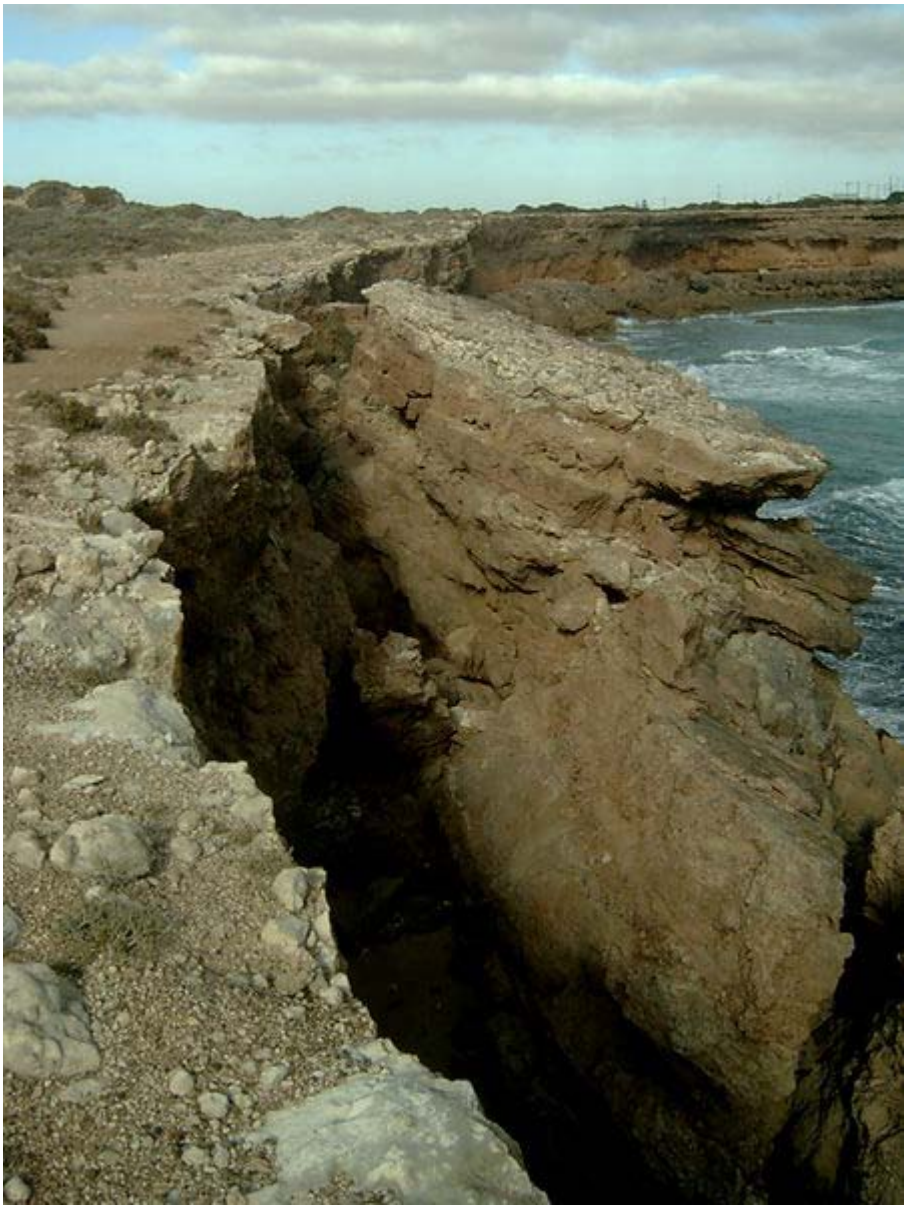
A gully is sufficiently deep that it would not be routinely destroyed by tillage operations, whereas rill erosion is smoothed by ordinary farm tillage. The narrow channels, or gullies, may be of considerable depth, ranging from 1 to 2 feet (0.61 m) to as much as 75 to 100 feet (30 m). Gully erosion is not accounted for in the revised universal soil loss equation.

Valley or *stream erosion* occurs with continued water flow along a linear feature. The erosion is both downward, deepening the valley, and headward, extending the valley into the hillside. In the earliest stage of stream erosion, the erosive activity is dominantly vertical, the valleys have a typical **V** cross-section and the stream gradient is relatively steep. When some base level is reached, the erosive activity switches to lateral erosion, which widens the valley floor and creates a narrow floodplain. The stream gradient becomes nearly flat, and lateral deposition of sediments becomes important as the stream meanders across the valley floor. In all stages of stream erosion, by far the most erosion occurs during times of flood, when more and faster-moving water is available to carry a larger sediment load. In such processes, it is not the water alone that erodes: suspended abrasive particles, pebbles and boulders can also act erosively as they traverse a surface.

At extremely high flows, kolks, or vortices are formed by large volumes of rapidly rushing water. Kolks cause extreme local erosion, plucking bedrock and creating pothole-type geographical features called Rock-cut basins. Examples can be seen in the flood regions result from glacial Lake Missoula, which created the channeled scablands in the Columbia Basin region of eastern Washington.

Bank erosion is the wearing away of the banks of a stream or river. This is distinguished from changes on the bed of the watercourse, which is referred to as *scour*. Erosion and changes in the form of river banks may be measured by inserting metal rods into the bank and marking the position of the bank surface along the rods at different times.

Shoreline



Erosion due to wave pounding at Venus Bay, South Australia.

Wave cut platform caused by erosion of cliffs by the sea, at Southerndown in South Wales

Shoreline erosion, which occurs on both exposed and sheltered coasts, primarily occurs through the action of currents and waves but sea level (tidal) change can also play a role.

Hydraulic action takes place when air in a joint is suddenly compressed by a wave closing the entrance of the joint. This then cracks it. *Wave pounding* is when the sheer energy of the wave hitting the cliff or rock breaks pieces off. *Abrasion* or *corrasion* is caused by waves launching seaload at the cliff. It is the most effective and rapid form of shoreline erosion. *Corrosion* is the dissolving of rock by carbonic acid in sea water. Limestone cliffs are particularly vulnerable to this kind of erosion. *Attrition* is where particles/seaload carried by the waves are worn down as they hit each other and the cliffs. This then makes the material easier to wash away. The material ends up as shingle and sand. Another significant source of erosion, particularly on carbonate coastlines, is the boring, scraping and grinding of organisms, a process termed *bioerosion*.

Sediment is transported along the coast in the direction of the prevailing current (longshore drift). When the upcurrent amount of sediment is less than the amount being carried away, erosion occurs. When the upcurrent amount of sediment is greater, sand or gravel banks will tend to form. These banks may slowly migrate along the coast in the direction of the longshore drift, alternately protecting and exposing parts of the coastline. Where there is a bend in the coastline, quite often a build up of eroded material occurs forming a long narrow bank (a spit). Armoured beaches and submerged offshore sandbanks may also protect parts of a coastline from erosion. Over the years, as the shoals gradually shift, the erosion may be redirected to attack different parts of the shore.

Ice

Ice erosion can take one of two forms. It can be caused by the movement of ice, typically as glaciers, in a process called *glacial erosion*. It can also be due to freeze-thaw processes in which water inside pores and fractures in rock may expand cause further cracking.

Glaciers erode predominantly by three different processes: abrasion/scouring, plucking, and ice thrusting. In an abrasion process, debris in the basal ice scrapes along the bed, polishing and gouging the underlying rocks, similar to sandpaper on wood. Glaciers can also cause pieces of bedrock to crack off in the process of plucking. In ice thrusting, the glacier freezes to its bed, then as it surges forward, it moves large sheets of frozen sediment at the base along with the glacier. This method produced some of the many thousands of lake basins that dot the edge of the Canadian Shield. These processes, combined with erosion and transport by the water network beneath the glacier, leave moraines, drumlins, ground moraine (till), kames, kame deltas, moulins, and glacial erratics in their wake, typically at the terminus or during glacier retreat.

Cold weather causes water trapped in tiny rock cracks to freeze and expand, breaking the rock into several pieces. This can lead to gravity erosion on steep slopes. The scree which forms at the bottom of a steep mountainside is mostly formed from pieces of rock (soil) broken away by this means. It is a common engineering problem wherever rock cliffs are alongside roads, because morning thaws can drop hazardous rock pieces onto the road.

In some places, water seeps into rocks during the daytime, then freezes at night. Ice expands, thus, creating a wedge in the rock. Over time, the repetition in the forming and melting of the ice causes fissures, which eventually breaks the rock down.

Wind

A rock formation in the Altiplano, Bolivia sculpted by wind erosion.

Wind-eroded alcove near Moab, Utah.

In arid climates, the main source of erosion is wind. The general wind circulation moves small particulates such as dust across wide oceans thousands of kilometers downwind of their point of origin, which is known as deflation. Erosion can be the result of material movement by the wind. There are two main effects. First, wind causes small particles to be lifted and therefore moved to another region. This is called deflation. Second, these suspended particles may impact on solid objects causing erosion by abrasion (ecological succession). Wind erosion generally occurs in areas with little or no vegetation, often in areas where there is insufficient rainfall to support vegetation. An example is the formation of sand dunes, on a beach or in a desert. Loess is a homogeneous, typically nonstratified, porous, friable, slightly coherent, often calcareous, fine-grained, silty, pale yellow or buff, windblown (aeolian) sediment. It generally occurs as a widespread blanket deposit that covers areas of hundreds of square kilometers and tens of meters thick. Loess often stands in either steep or vertical faces. Loess tends to develop into highly rich soils. Under appropriate climatic conditions, areas with loess are among the most agriculturally productive in the world. Loess deposits are geologically unstable by nature, and will erode very readily. Therefore, windbreaks (such as big trees and bushes) are often planted by farmers to reduce the wind erosion of loess.

Thermal

Thermal erosion is the result of melting and weakening permafrost due to moving water. It can occur both along rivers and at the coast. Rapid river channel migration observed in the Lena River of Siberia is due to thermal erosion, as these portions of the banks are composed of permafrost-cemented non-cohesive materials. Much of this erosion occurs as the weakened banks fail in large slumps. Thermal erosion also affects the Arctic coast, where wave action and near-shore temperatures combine to undercut permafrost bluffs along the shoreline and cause them to fail. Annual erosion rates along a 100-kilometer segment of the Beaufort Sea shoreline averaged 5.6 meters per year from 1955 to 2002.

Soil erosion and climate change

The warmer atmospheric temperatures observed over the past decades are expected to lead to a more vigorous hydrological cycle, including more extreme rainfall events. In 1998 Karl and Knight reported that from 1910 to 1996 total precipitation over the contiguous U.S. increased, and that 53% of the increase came from the upper 10% of precipitation events (the most intense precipitation). The percent of precipitation coming from days of precipitation in excess of 50 mm has also increased significantly.

Studies on soil erosion suggest that increased rainfall amounts and intensities will lead to greater rates of erosion. Thus, if rainfall amounts and intensities increase in many parts of the world as expected, erosion will also increase, unless amelioration measures are taken. Soil erosion rates are expected to change in response to changes in climate for a variety of reasons. The most direct is the change in the erosive power of rainfall. Other reasons include: a) changes in plant canopy caused by shifts in plant biomass production associated with moisture regime; b) changes in litter cover on the ground caused by changes in both plant residue decomposition rates driven by temperature and moisture dependent soil microbial activity as well as plant biomass production rates; c) changes in soil moisture due to shifting precipitation regimes and evapo-transpiration rates, which changes infiltration and runoff ratios; d) soil erodibility changes due to decrease in soil organic matter concentrations in soils that lead to a soil structure that is more susceptible to erosion and increased runoff due to increased soil surface sealing and crusting; e) a shift of winter precipitation from non-erosive snow to erosive rainfall due to increasing winter temperatures; f) melting of permafrost, which induces an erodible soil state from a previously non-erodible one; and g) shifts in land use made necessary to accommodate new climatic regimes.

Studies by Pruski and Nearing indicated that, other factors such as land use not considered, we can expect approximately a 1.7% change in soil erosion for each 1% change in total precipitation under climate change.

Tectonic effects

River eroding volcanic ash flow Alaska Southwest, Valley of Ten Thousand Smokes

The removal by erosion of large amounts of rock from a particular region, and its deposition elsewhere, can result in a lightening of the load on the lower crust and mantle. This can cause tectonic or isostatic uplift in the region. Research undertaken since the early 1990s suggests that the spatial distribution of erosion at the surface of an orogen can exert a key influence on its growth and its final internal structure.

Materials science

In materials science, erosion is the recession of surfaces by repeated localized mechanical trauma as, for example, by suspended abrasive particles within a moving fluid. Erosion can also occur from non-abrasive fluid mixtures. Cavitation is one example.

In hard particle erosion, the hardness of the impacted material is a large factor in the mechanics of the erosion. A soft material will typically erode fastest from glancing impacts. Harder material will typically erode fastest from perpendicular impacts. Hardness is a correlative factor for erosion resistance, but a higher hardness does not guarantee better resistance. Factors that affect the erosion rate also include impacting particle speed, size, density, hardness, and rotation. Coatings can be applied to retard erosion, but normally can only slow the removal of material. Erosion rate for solid particle impact is typically measured as mass of material removed divided by the mass of impacting material.

Figurative use

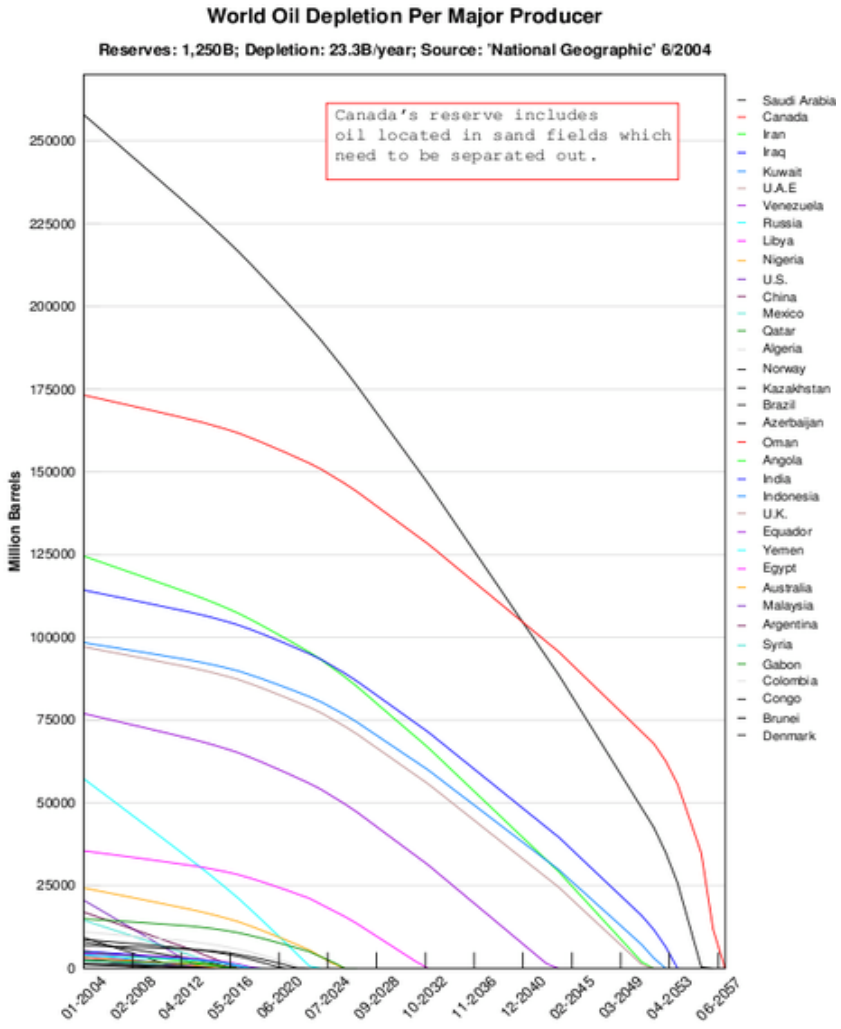
The concept of erosion is commonly employed by analogy to various forms of perceived or real homogenization (i.e. erosion of boundaries), "leveling out", collusion or even the decline of anything from morals to indigenous cultures. It is a common trope of the English language to describe as *erosion* the gradual, organic mutation of something thought of as distinct, more complex, harder to pronounce or more refined into something indistinct, less complex, easier to pronounce or (disparagingly) less refined.

Origin of term

The first known occurrence of the term "erosion" was in the 1541 translation by Robert Copland of Guy de Chauliac's medical text *The Questyonary of Cyrurygens*. Copland used erosion to describe how ulcers developed in the mouth. By 1774 'erosion' was used outside medical subjects. Oliver Goldsmith employed the term in the more contemporary geological context, in his book *Natural History*, with the quote

Chapter- 6

Oil Depletion



Oil depletion per major producing country. This model assumes world oil depletion remains constant at the 2004 level of 80 million barrels per day. However, world oil depletion is currently (as of 2008) at 85 million barrels per day. This model also assumes production will increase in the high-capacity countries as low-capacity countries become depleted.

Oil depletion occurs in the second half of the production curve of an oil well, oil field, or the average of total world oil production. The Hubbert peak theory makes predictions of production rates based on prior discovery rates and anticipated production rates. Hubbert curves predict that the production curves of non-renewing resources approximate a bell curve. Thus, when the peak of production is passed, production rates enter an exponential decline.

The American Petroleum Institute estimated in 1999 the world's oil supply would be depleted between 2062 and 2094, assuming total world oil reserves at between 1.4 and 2 trillion barrels and consumption at 80 million barrels per day. In 2004, total world reserves were estimated to be 1.25 trillion barrels and daily consumption was about 85 million barrels, shifting the estimated oil depletion year to 2057. A study published in the journal Energy Policy by researchers from Oxford University, however, predicted demand would surpass supply by 2015 (unless constrained by strong recession pressures caused by reduced supply or government intervention).

The United States Energy Information Administration predicted in 2006 that world consumption of oil will increase to 98.3 million barrels per day (mbd) in 2015 and 118 mbd in 2030. With 2009 world oil consumption at 84.4 mbd, reaching the projected 2015 level of consumption would represent an average annual increase between 2009 and 2015 of 2.7% per year while EIA's own figures show declining consumption and declining supplies during the 2005-2009 period.

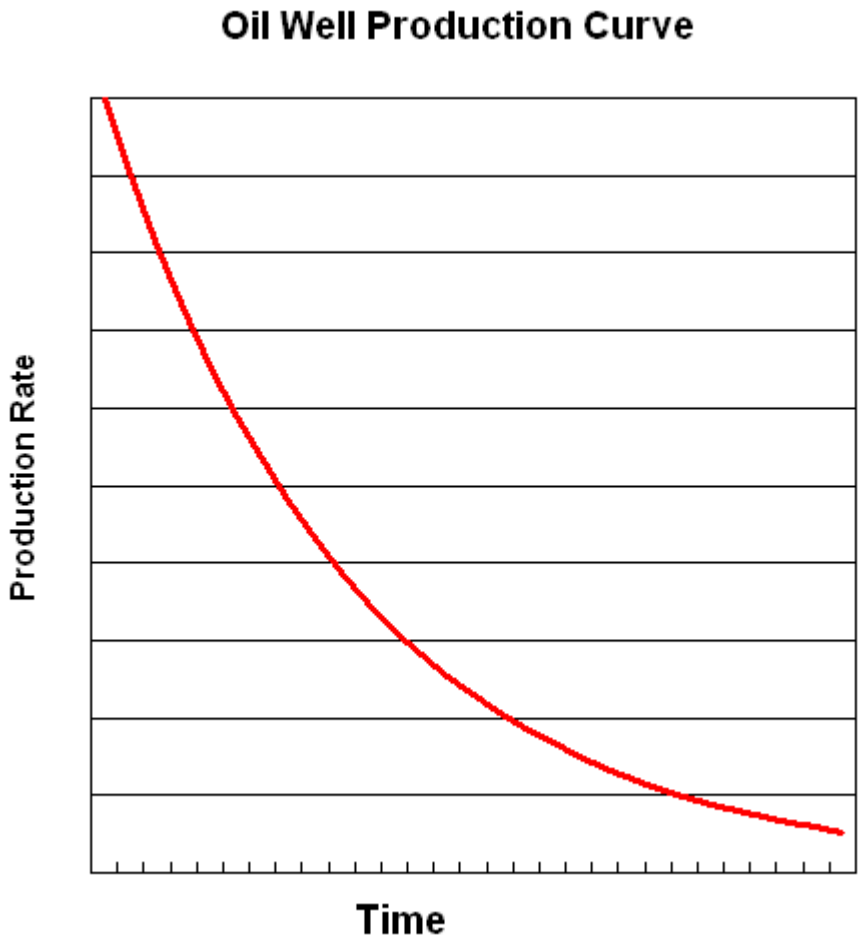
Resource availability

The world's oil supply is fixed because petroleum is naturally formed far too slowly to be replaced at the rate at which it is being extracted. Over many millions of years, plankton, bacteria, and other plant and animal matter become buried in sediments on the ocean floor. When conditions are right – a lack of oxygen for decomposition, and sufficient depth and temperature of burial – these organic remains are converted into petroleum compounds, while the sediment accompanying them is converted into sandstone, siltstone, and other porous sedimentary rock. When capped by impermeable rocks such as shale, salt, or igneous intrusions, they form the petroleum reservoirs which are exploited today.

Production decline models

Oil production decline occurs in a predictable manner based on geological circumstances, governmental policies, and engineering practices. The shape of the decline curve varies depending upon whether one considers a well, a field, a set of fields, or the world.

Oil well production decline



Theoretical oil well production curve.

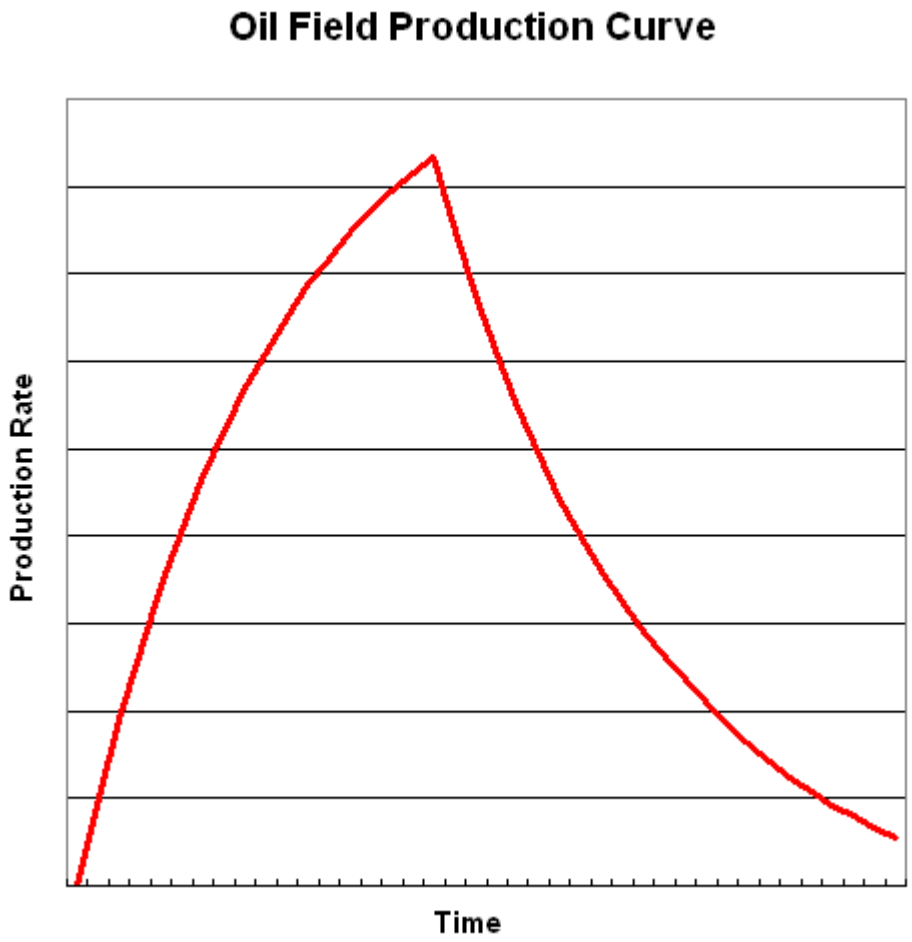
Oil well production curves typically end in an exponential decline. At natural rates, oil well production curves appear similar to a bell curve, a phenomenon known as the Hubbert curve. The typical decline is a rapid drop in production, and eventually a leveling off to a point at which they no longer produce profitable amounts. Such wells are referred to as marginal or stripper wells.

The shape of production curve of an oil well can be affected by a number of factors:

- Well may be restricted by choice by lack of market demand or government regulation. This flattens the peak of the curve, but will not change the well's total production significantly.
- Hydraulic fracturing (*fracing*) or acidizing may be used to cause a sharp spike in production, and may increase the recoverable reserves of a given well.

- The field may undergo a secondary or tertiary recovery project, discussed in the next section.

Oil field production decline



Typical oil field production curve.

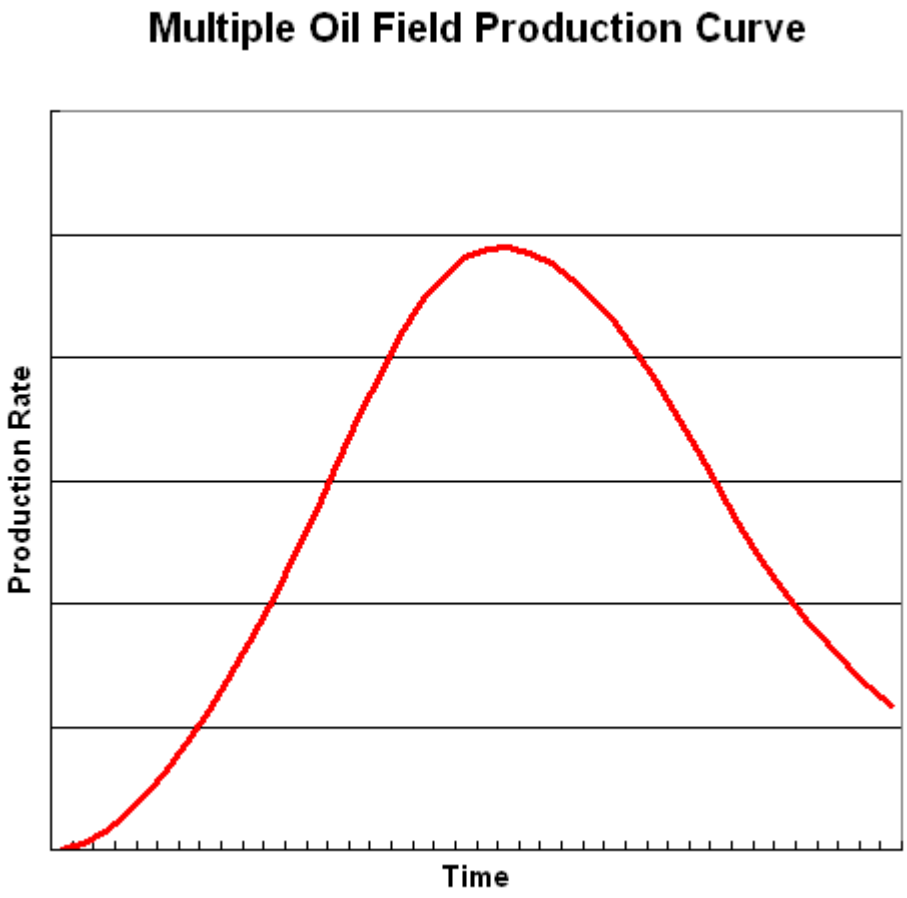
Each individual oil well is a portion of a larger fixed area oil field. As with individual wells, discovery and production amounts of oil fields generally average to a similar bell shaped production curve. Eventually, when the field is completely drilled out, a field's production goes into a sharp decline as the average production of its wells enter decline. As this decline levels off, production can continue at relatively low rates. A number of oil fields in the U.S. have been producing for over 100 years.

Oil field production curves can be modified by a number of factors:

- Production may be restricted by market conditions or government regulation.

- A secondary recovery project, such as water or gas injection, can repressurize the field and improve the production rate temporarily. However, it will not change the total production amount over the life of the field. Eventually the field will go into a steeper than normal decline.
- the field may undergo an enhanced oil recovery project, such as drilling of wells for injection of solvents, carbon dioxide, or steam. This can be very expensive but allows more oil to be coaxed out of the rock, increasing the ultimate production of the field.

Multi-field production decline



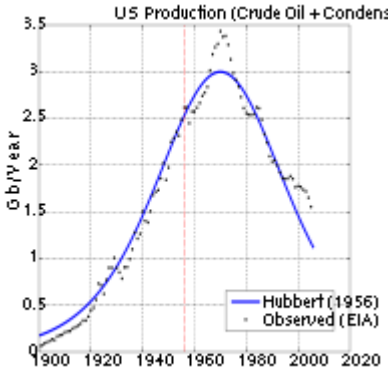
Multiple oil field production curve.

Most oil is found in a small number of very large oil fields. If oil fields are discovered at a constant rate until they have all been found, the combined production of fields will yield a curve such as the one at right. Production starts off slowly, rises faster and faster, then slows down and flattens until it reaches a peak. After the production peak, production enters an exponential decline, eventually flattening out. Oil production may

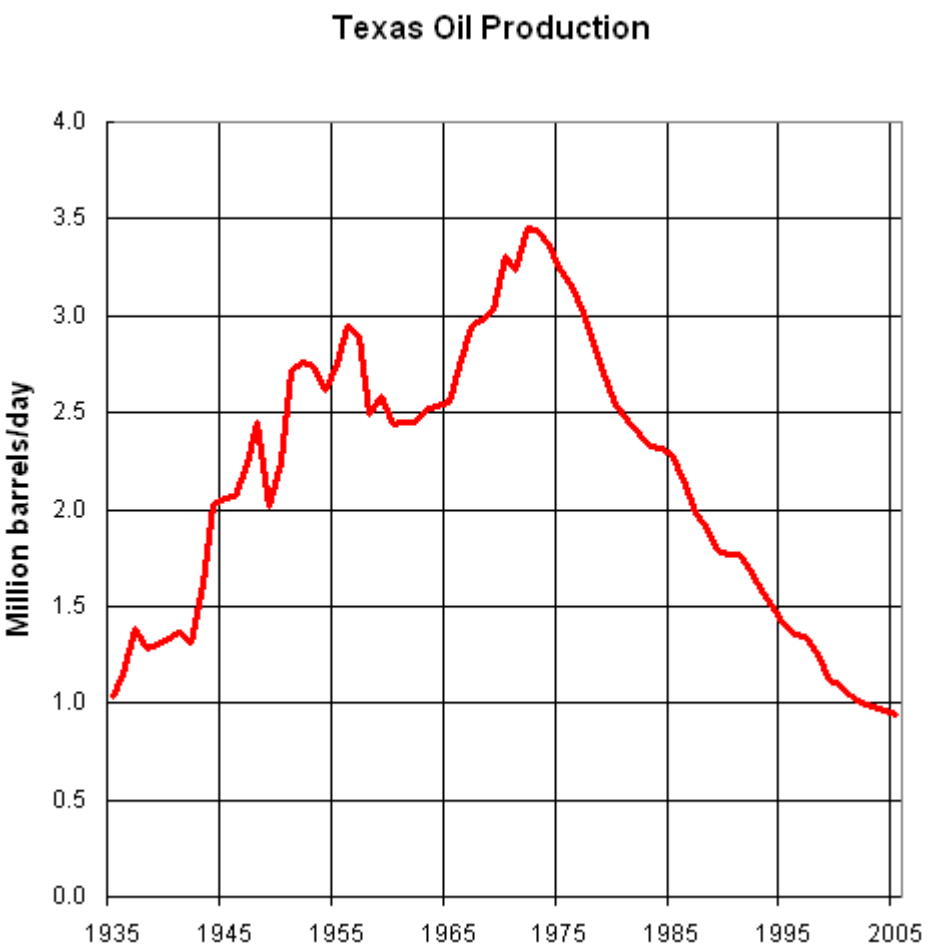
never actually reach zero, but eventually becomes very low. Factors which can modify this curve include:

- Inadequate demand for oil, which reduces steepness of the curve and pushes its peak into the future.
- Sharp price increases when the production peak is reached, as production fails to meet demand. If price increases cause a sharp drop in demand, a dip in the top of the curve may occur.
- Development of new drilling technology or marketing of unconventional oil can reduce the steepness of the decline as more oil is produced than initially anticipated.

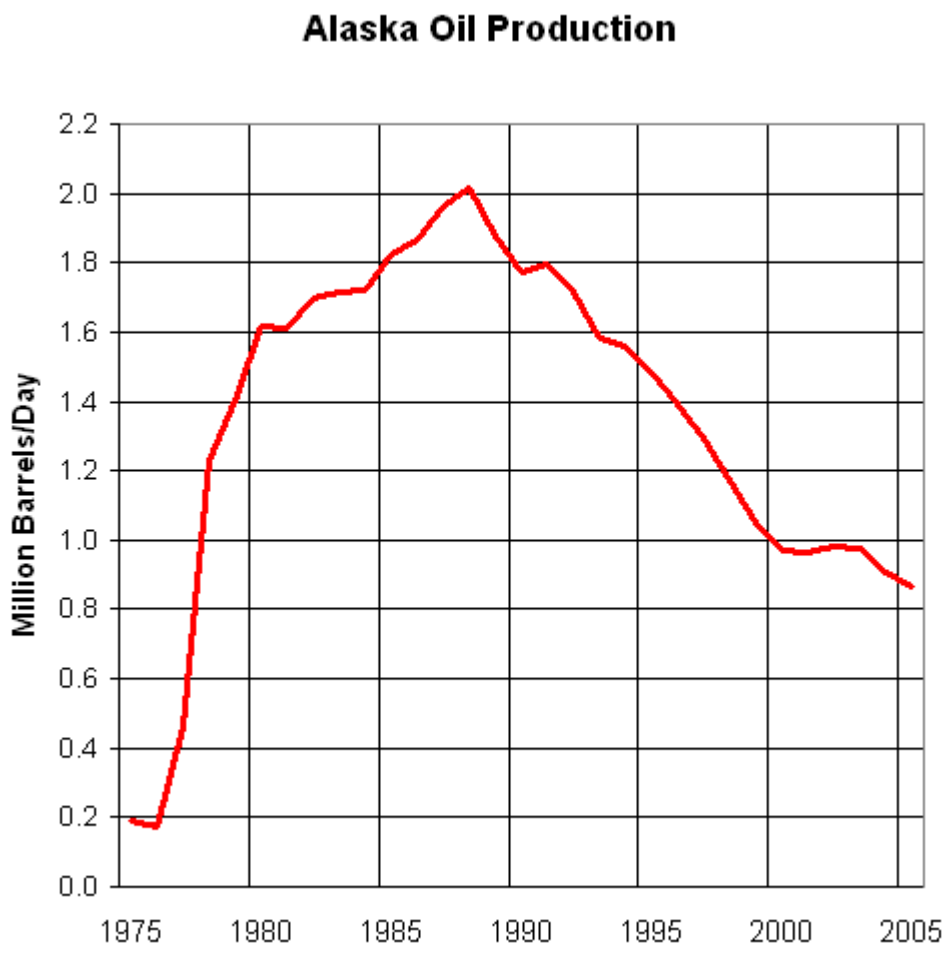
United States production decline



U.S. oil production (crude oil only) and Hubbert's high estimate (a multi-field projection)



Texas oil field production decline curve.



Alaska oil field production decline curve.

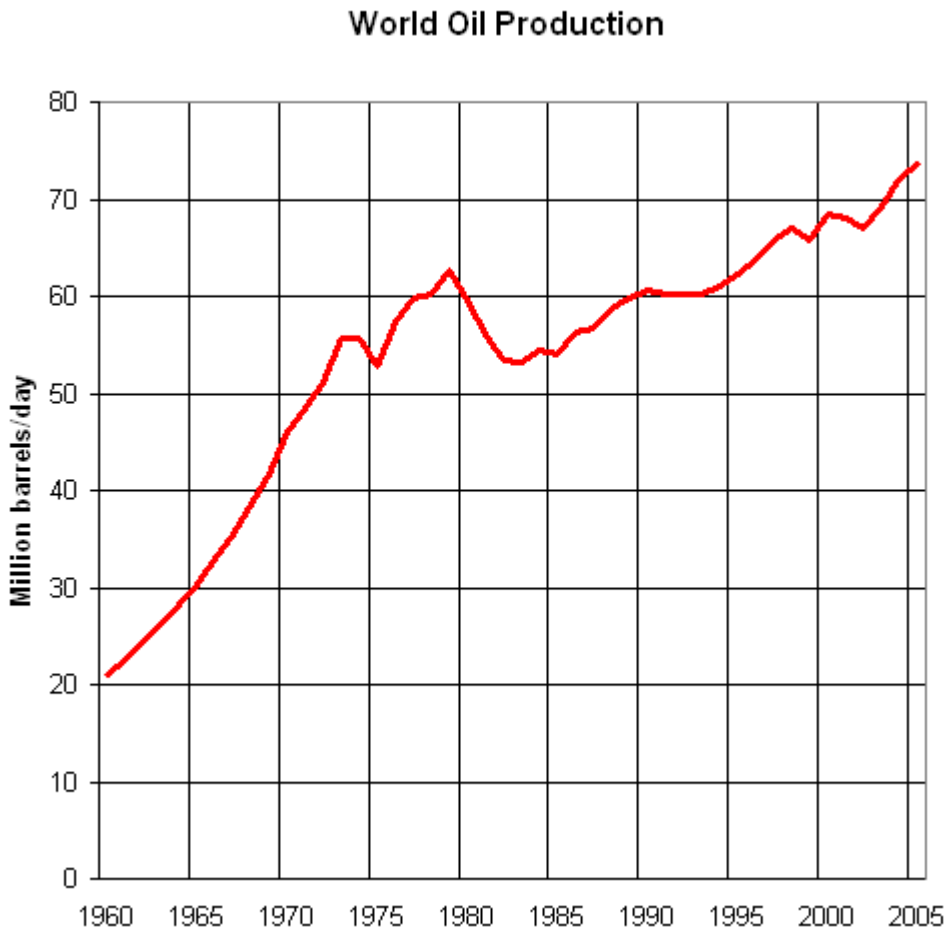
Oil production in the United States has followed the theoretical Hubbert curve. U.S. oil production reached its peak in 1970 and by the mid-2000s it had fallen to 1940s levels. In 1950, the United States produced over half the world's oil, but by 2005 that proportion had dropped to about 8%. In 2005, U.S. crude oil imports were twice as high as domestic production.

The production peak in 1970 was predicted in 1956 by Hubbert. By 1972 all import quotas and controls on U.S. domestic production had been removed. Oil companies began drilling large numbers of oil wells on a nationwide scale. Despite this, and despite the quadrupling of prices during the 1973 oil crisis, the production decline has, to date, proven irreversible.

The actual U.S. production curve does deviate from Hubbert's 1956 curve in some significant ways:

- When oil surpluses created a glut on the market and low prices began causing demand and production curves to rise, regulatory agencies such as the Texas Railroad Commission stepped in to restrain production.
- The curve peaked at a sharp point rather than gradually flattening out. This occurred because as consumption began to approach production limits, oil companies drilled out all their existing fields as fast as they could, and many of those fields peaked simultaneously.
- Production fell after 1970, but started to recover and reached a lower secondary peak in 1988. This occurred because the supergiant Prudhoe Bay field in Alaska was only discovered in 1968, and the Trans-Alaska Pipeline System (TAPS) was not completed until 1977. After 1988, Alaska production peaked and total U.S. production began to decline again. By 2005, Prudhoe Bay had produced over 75% of its oil.

World oil production



World oil field production curve.

World oil production has followed a typical Hubbert curve, rising over the past century with only a few dips. The 1970 production peak in the U.S. caused many people to begin to question when the world production peak would occur. The peak of world production is known as Peak oil. By the mid-2000s, all of the world's major oil producing countries except Saudi Arabia were producing at maximum capacity (many having peaked in production), and some experts such as Matthew Simmons were questioning whether even Saudi Arabia had any reserve capacity left.

Industry observers have pointed to the similarities between the global production curve in mid-2000s and that of the United States in the 1970s.

- The oil price increases since 2003 were preceded by a decade of production cutbacks in OPEC countries in an attempt to keep prices high despite an oil glut. This is similar to production cutbacks in Texas and other states to maintain prices despite an oil glut in the decade prior to the 1973 oil crisis.
- World oil prices reached record inflation adjusted highs beginning in 2008, but new oil did not appear on the market, as the theory of supply and demand would predict. This is reminiscent of price increases in the United States in the 1970s when U.S. oil production started to decline despite record high prices and record drilling by oil companies.
- There are serious doubts about whether OPEC countries really have the oil reserves they claim. This is similar to the illusionary oil reserves that U.S. oil companies claimed to have in the decade prior to the 1973 and 1979 oil crisis. In the 1970s, those companies were unable to produce as much oil as they had predicted, and production went down instead of up.

Implications of a world peak

A peak in oil production could result in a worldwide oil shortage, or it could not even be noticed as demand decreases in conjunction with increased prices. While past shortages stemmed from a temporary insufficiency of supply, crossing Hubbert's Peak would mean that the production of oil would continue to decline, and that demand for these products must be reduced to meet supply. The effects of such a shortage would depend on the rate of decline and the development and adoption of effective alternatives.

If alternatives were not forthcoming, it has been speculated that the numerous products produced with oil would become scarcer, leading to at the very least lower living standards in developed and developing countries alike, and possibly in the worst case to the collapse of the entire international banking system, which could not likely sustain itself without the prospect of growth. The political situation may change dramatically, with potential wars between countries over access to dwindling supplies. Accordingly, inequalities between various countries and regions of the world may become exacerbated.

Catastrophe

Economic growth and prosperity since the industrial revolution have, in large part, been due to increased efficiencies in the use of better and higher concentrations of energy in fossil fuels. The use of fossil fuels allows humans to participate in takedown, which is the consumption of energy at a greater rate than it is being replaced. Some believe that decreasing oil production portends a drastic impact on human culture and modern technological society, which is currently heavily dependent on oil as a fuel and chemical feedstock. For example, over 90% of transportation in the United States relies on oil.

Some envisage a Malthusian catastrophe occurring as oil becomes increasingly inefficient to produce, others have learned from the examples demonstrated in mature basins and applied those operational procedures to these basins to preserve their operational tempo. Since the 1940s, agriculture has dramatically increased its productivity, due largely to the use of chemical pesticides, fertilizers, and increased mechanisation. This process has been called the Green Revolution. The increase in food production has allowed world population to grow dramatically over the last 50 years. Pesticides rely upon oil as a critical ingredient, and fertilizers require natural gas. Farm machinery also requires oil.

Arguing that in today's world every joule one eats requires 5–15 joules to produce and deliver, some have speculated that decreasing supply of oil will cause modern industrial agriculture to collapse, leading to a drastic decline in food production, food shortages and possibly even mass starvation. However, most or all of the uses of fossil fuels in agriculture can be replaced with alternatives. For example, by far the biggest fossil fuel input to agriculture is the use of natural gas as a hydrogen source for the Haber-Bosch fertilizer-creation process. Natural gas is used simply because it is the cheapest currently-available source of hydrogen; were that to change, other sources, such as electrolysis powered by solar energy, could be used to provide the hydrogen for creating fertilizer without relying on fossil fuels.

Oil shortages may force a move to lower input "organic agriculture" methods, which may be more labor-intensive and require a population shift from urban to rural areas, reversing the trend towards urbanisation which has predominated in industrial societies; however, some organic farmers using modern organic-farming methods have reported yields as high as those available from conventional farming, but without the use of fossil-fuel-intensive artificial fertilizers or pesticides.

Another possible effect would derive from America's transportation and housing infrastructure. A majority of Americans live in suburbs, a type of low-density settlement designed with the automobile in mind. Commentators such as James Howard Kunstler argue that because of its reliance on the automobile, the suburb is an unsustainable living arrangement; the implications of peak oil would leave many Americans unable to afford fuel for their cars, and force them to move to higher density, more walkable areas. In effect, surburbia would comprise the "slums of the future." A movement to deal with this problem early, called "New Urbanism," seeks to develop the suburbs into higher density neighborhoods and use high density, mixed-use forms for new building projects.

Recession

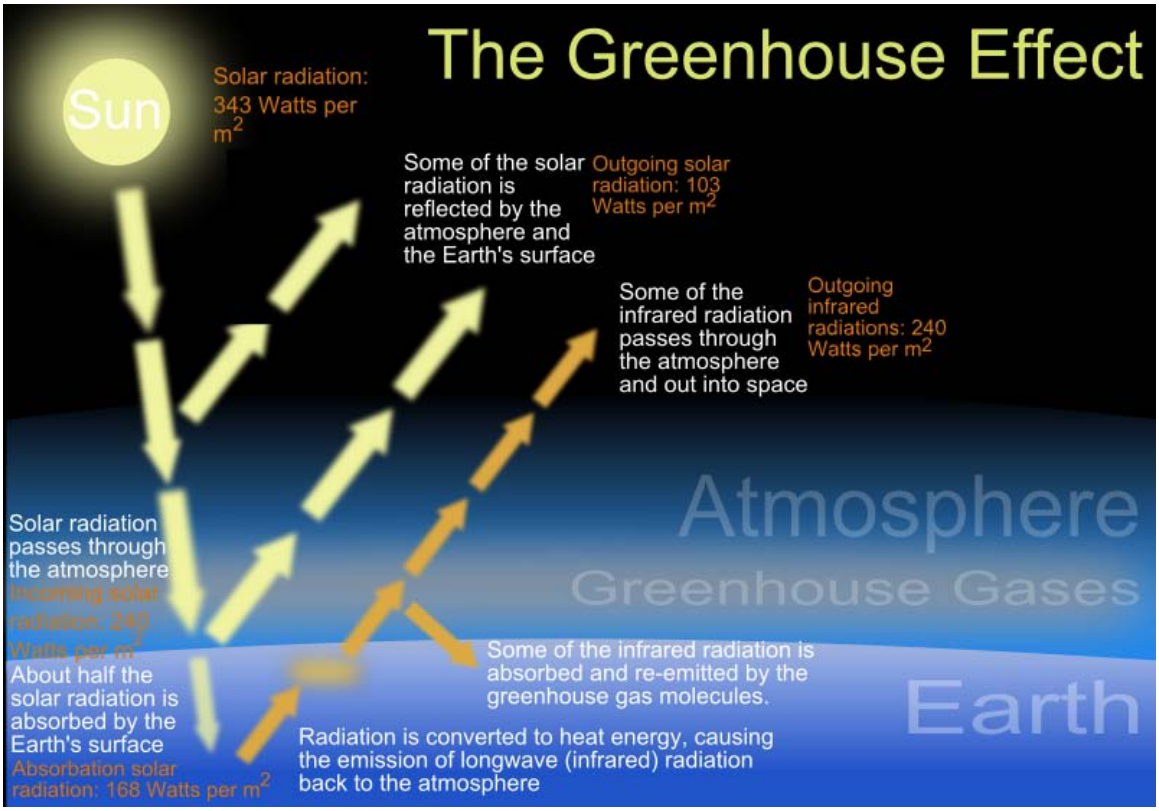
A more modest scenario, assuming a slower rate of depletion and a smooth transition to alternative energy sources could cause substantial economic hardship such as a recession or depression due to higher energy prices. Historically, there is a close correlation in the timing of oil price spikes and economic downturns. Inflation has also been linked to oil price spikes. However, economists disagree on the strength and causes of this association. The world economy may be less dependent on oil than during earlier oil crises. Conversely, the recessions of the early 1970s and early 1980s were associated with a relatively brief period of somewhat dwindling energy availability; the possible future increase in oil prices might be much higher and last longer.

Rising food prices

Rising oil prices cause rising food prices in three ways. First, increased equipment fuel costs drive higher prices. Second, transportation costs increase retail prices. Third, higher oil prices are causing farmers to switch from producing food crops to producing biofuel crops. The law of supply and demand predicts that if fewer farmers are producing food the price of food will rise.

Chapter- 7

Greenhouse Gas

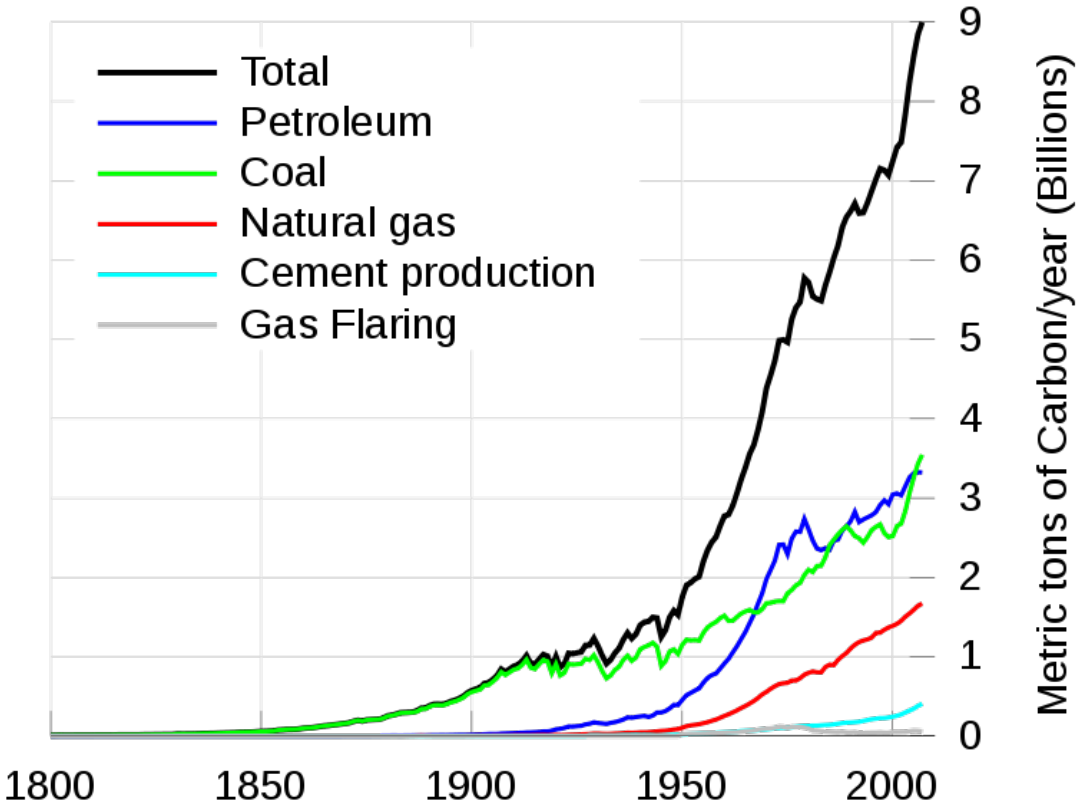


Simple diagram of greenhouse effect.

A **greenhouse gas** (sometimes abbreviated **GHG**) is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone. In the Solar System, the atmospheres of Venus, Mars, and Titan also contain gases that cause greenhouse effects. Greenhouse gases greatly affect the temperature of the Earth; without them, Earth's surface would be on average about 33 °C (59 °F) colder than at present.

Since the beginning of the Industrial revolution, the burning of fossil fuels has increased the levels of carbon dioxide in the atmosphere from 280ppm to 390ppm. Unlike other pollutants, carbon dioxide emissions do not result from inefficient combustion: CO2 is a product of ideal, stoichiometric combustion of carbon. The emissions of carbon are directly proportional to energy consumption.

Greenhouse effects in Earth's atmosphere



Modern global anthropogenic Carbon emissions.

In order, the most abundant greenhouse gases in Earth's atmosphere are:

- water vapor
- carbon dioxide
- methane
- nitrous oxide
- ozone
- chlorofluorocarbons

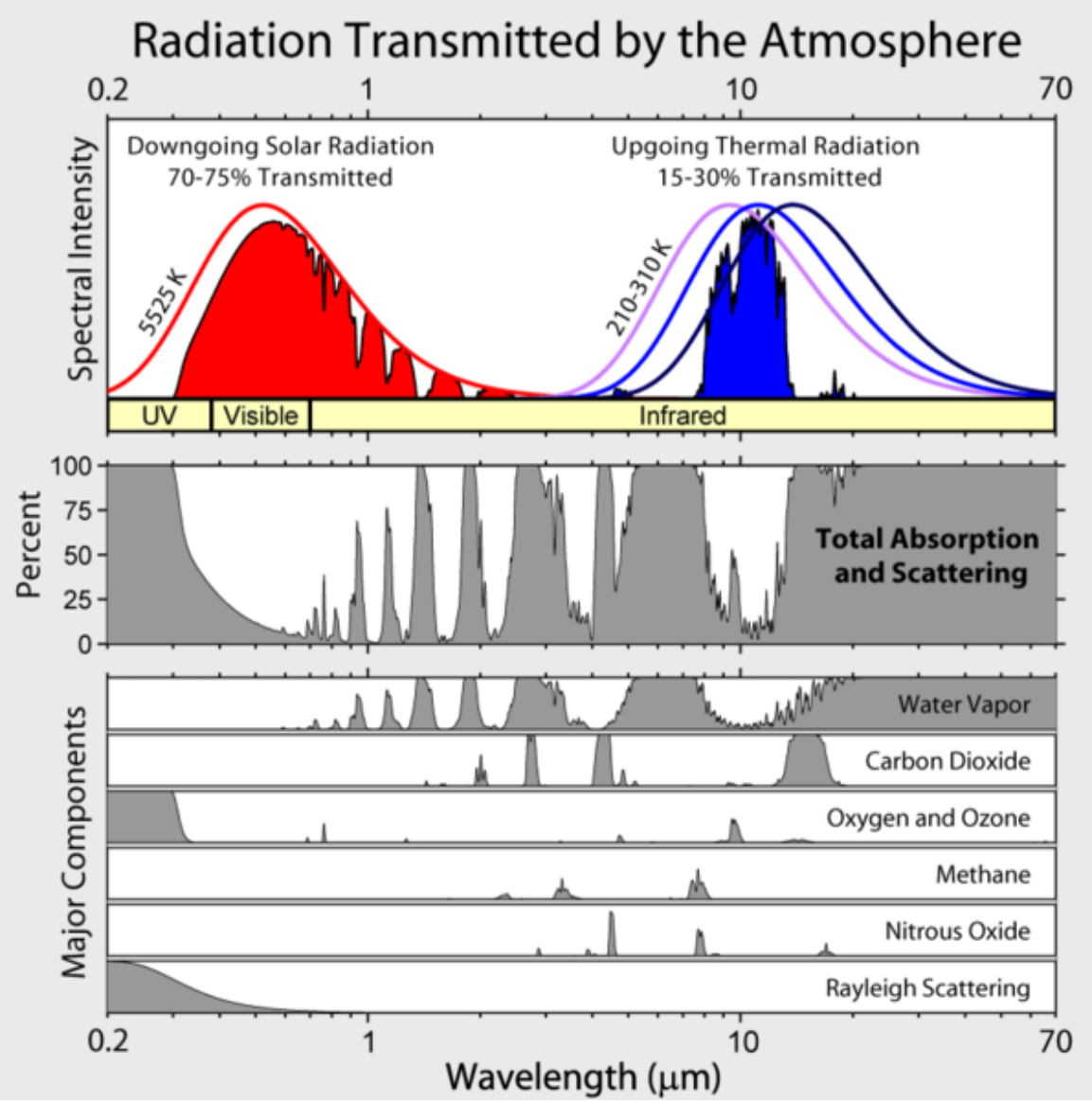
The contribution to the greenhouse effect by a gas is affected by both the characteristics of the gas and its abundance. For example, on a molecule-for-molecule basis methane is about eighty times stronger greenhouse gas than carbon dioxide , but it is present in much

smaller concentrations so that its total contribution is smaller. When these gases are ranked by their contribution to the greenhouse effect, the most important are:

Gas	Formula	Contribution (%)
Water Vapor	H_2O	36 – 72 %
Carbon Dioxide	CO_2	9 – 26 %
Methane	CH_4	4 – 9 %
Ozone	O_3	3 – 7 %

It is not possible to state that a certain gas causes an exact percentage of the greenhouse effect. This is because some of the gases absorb and emit radiation at the same frequencies as others, so that the total greenhouse effect is not simply the sum of the influence of each gas. The higher ends of the ranges quoted are for each gas alone; the lower ends account for overlaps with the other gases. The major non-gas contributor to the Earth's greenhouse effect, clouds, also absorb and emit infrared radiation and thus have an effect on radiative properties of the greenhouse gases.

In addition to the main greenhouse gases listed above, other greenhouse gases include sulfur hexafluoride, hydrofluorocarbons and perfluorocarbons. Some greenhouse gases are not often listed. For example, nitrogen trifluoride has a high global warming potential (GWP) but is only present in very small quantities.



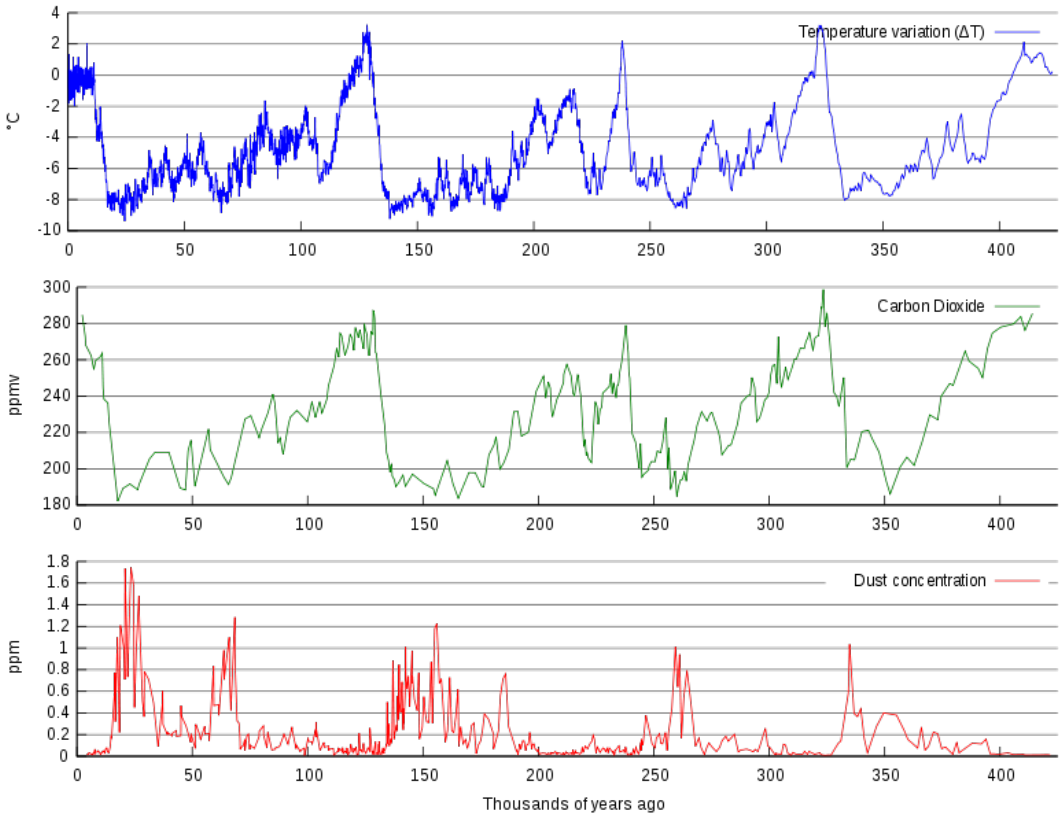
Atmospheric absorption and scattering at different electromagnetic wavelengths. The largest absorption band of carbon dioxide is in the infrared.

Scientists who have elaborated on Arrhenius' theory of global warming are concerned that increasing concentrations of greenhouse gases in the atmosphere are causing an unprecedented rise in global temperatures, with potentially harmful consequences for the environment and human health. Although contributing to many other physical and chemical reactions, the major atmospheric constituents, nitrogen (N_2), oxygen (O_2), and argon (Ar), are not greenhouse gases. This is because molecules containing two atoms of the same element such as N_2 and O_2 and monatomic molecules such as Ar have no net change in their dipole moment when they vibrate and hence are almost totally unaffected by infrared light. Although molecules containing two atoms of different elements such as carbon monoxide (CO) or hydrogen chloride (HCl) absorb IR, these molecules are short-lived in the atmosphere owing to their reactivity and solubility. As a consequence they do

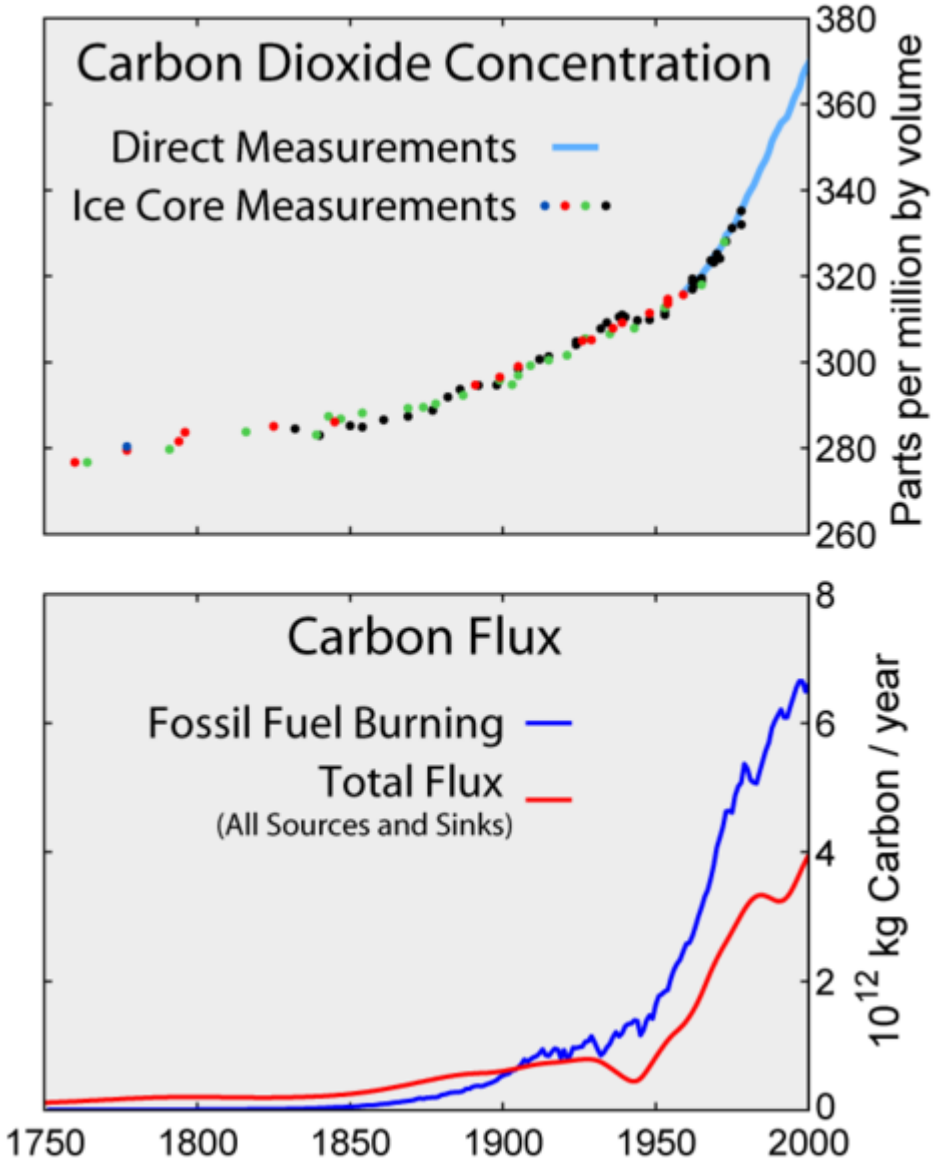
not contribute significantly to the greenhouse effect and are not often included when discussing greenhouse gases.

Late 19th century scientists experimentally discovered that N_2 and O_2 do not absorb infrared radiation (called, at that time, "dark radiation") while, at the contrary, water, as true vapour or condensed in the form of microscopic droplets suspended in clouds, CO_2 and other poly-atomic gaseous molecules do absorb infrared radiation. It was recognized in the early 20th century that the greenhouse gases in the atmosphere caused the Earth's overall temperature to be higher than what it would be without them.

Natural and anthropogenic sources



400,000 years of ice core data.



Top: Increasing atmospheric carbon dioxide levels as measured in the atmosphere and reflected in ice cores. Bottom: The amount of net carbon increase in the atmosphere, compared to carbon emissions from burning fossil fuel.

Aside from purely human-produced synthetic halocarbons, most greenhouse gases have both natural and human-caused sources. During the pre-industrial Holocene, concentrations of existing gases were roughly constant. In the industrial era, human activities have added greenhouse gases to the atmosphere, mainly through the burning of fossil fuels and clearing of forests.

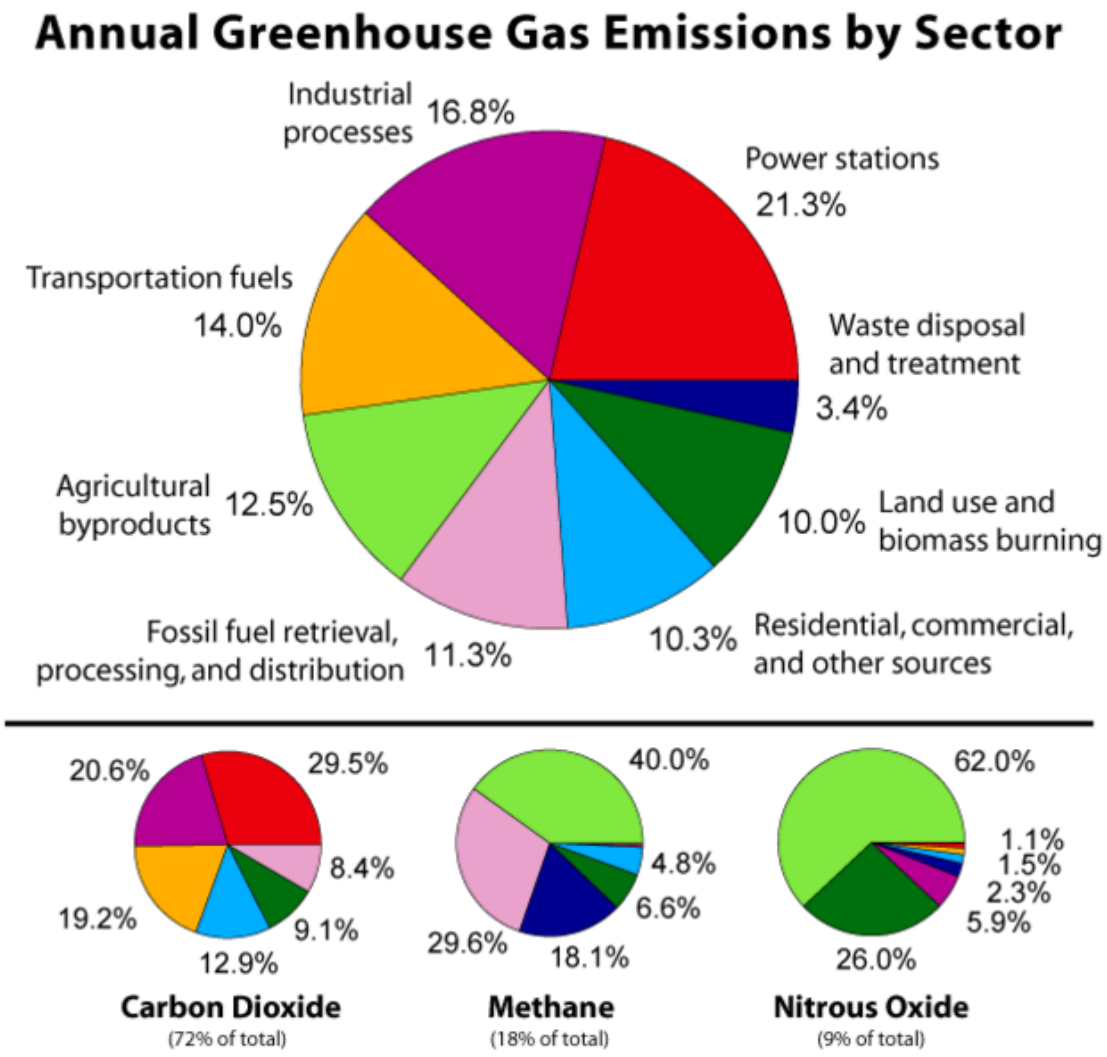
The 2007 Fourth Assessment Report compiled by the IPCC (AR4) noted that "changes in atmospheric concentrations of greenhouse gases and aerosols, land cover and solar radiation alter the energy balance of the climate system", and concluded that "increases in

anthropogenic greenhouse gas concentrations is very likely to have caused most of the increases in global average temperatures since the mid-20th century". In AR4, "most of" is defined as more than 50%.

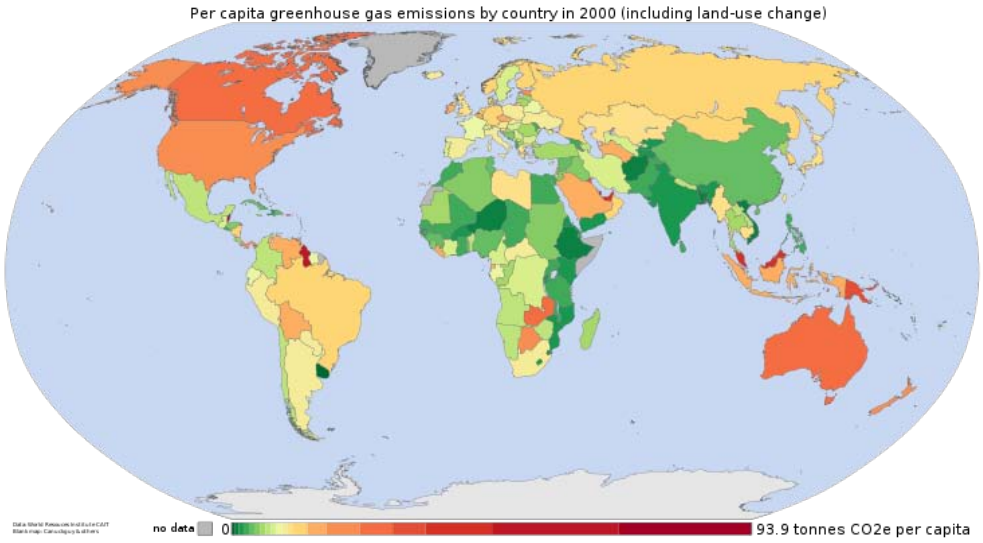
Gas	Preindustrial level	Current level	Increase since 1750	Radiative forcing (W/m^2)
Carbon dioxide	280 ppm	388 ppm	108 ppm	1.46
Methane	700 ppb	1745 ppb	1045 ppb	0.48
Nitrous oxide	270 ppb	314 ppb	44 ppb	0.15
CFC-12	0	533 ppt	533 ppt	0.17

Ice cores provide evidence for variation in greenhouse gas concentrations over the past 800,000 years. Both CO_2 and CH_4 vary between glacial and interglacial phases, and concentrations of these gases correlate strongly with temperature. Direct data does not exist for periods earlier than those represented in the ice core record, a record which indicates CO_2 levels staying within a range of between 180ppm and 280ppm throughout the last 800,000 years, until the increase of the last 250 years. However, various proxies and modeling suggests larger variations in past epochs; 500 million years ago CO_2 levels were likely 10 times higher than now. Indeed higher CO_2 concentrations are thought to have prevailed throughout most of the Phanerozoic eon, with concentrations four to six times current concentrations during the Mesozoic era, and ten to fifteen times current concentrations during the early Palaeozoic era until the middle of the Devonian period, about 400 Ma. The spread of land plants is thought to have reduced CO_2 concentrations during the late Devonian, and plant activities as both sources and sinks of CO_2 have since been important in providing stabilising feedbacks. Earlier still, a 200-million year period of intermittent, widespread glaciation extending close to the equator (Snowball Earth) appears to have been ended suddenly, about 550 Ma, by a colossal volcanic outgassing which raised the CO_2 concentration of the atmosphere abruptly to 12%, about 350 times modern levels, causing extreme greenhouse conditions and carbonate deposition as limestone at the rate of about 1 mm per day. This episode marked the close of the Precambrian eon, and was succeeded by the generally warmer conditions of the Phanerozoic, during which multicellular animal and plant life evolved. No volcanic carbon dioxide emission of comparable scale has occurred since. In the modern era, emissions to the atmosphere from volcanoes are only about 1% of emissions from human sources.

Anthropogenic greenhouse gases



Global anthropogenic greenhouse gas emissions broken down into 8 different sectors for the year 2000.



Per capita anthropogenic greenhouse gas emissions by country for the year 2000 including land-use change.

Since about 1750 human activity has increased the concentration of carbon dioxide and other greenhouse gases. Measured atmospheric concentrations of carbon dioxide are currently 100 ppmv higher than pre-industrial levels. Natural sources of carbon dioxide are more than 20 times greater than sources due to human activity, but over periods longer than a few years natural sources are closely balanced by natural sinks, mainly photosynthesis of carbon compounds by plants and marine plankton. As a result of this balance, the atmospheric concentration of carbon dioxide remained between 260 and 280 parts per million for the 10,000 years between the end of the last glacial maximum and the start of the industrial era.

It is likely that anthropogenic warming, such as that due to elevated greenhouse gas levels, has had a discernible influence on many physical and biological systems. Warming is projected to affect various issues such as freshwater resources, industry, food and health.

The main sources of greenhouse gases due to human activity are:

- burning of fossil fuels and deforestation leading to higher carbon dioxide concentrations in the air. Land use change (mainly deforestation in the tropics) account for up to one third of total anthropogenic CO_2 emissions.
- livestock enteric fermentation and manure management, paddy rice farming, land use and wetland changes, pipeline losses, and covered vented landfill emissions leading to higher methane atmospheric concentrations. Many of the newer style fully vented septic systems that enhance and target the fermentation process also are sources of atmospheric methane.
- use of chlorofluorocarbons (CFCs) in refrigeration systems, and use of CFCs and halons in fire suppression systems and manufacturing processes.

- agricultural activities, including the use of fertilizers, that lead to higher nitrous oxide (N_2O) concentrations.

The seven sources of CO_2 from fossil fuel combustion are (with percentage contributions for 2000–2004):

Seven main fossil fuel combustion sources	Contribution (%)
Liquid fuels (e.g., gasoline, fuel oil)	36 %
Solid fuels (e.g., coal)	35 %
Gaseous fuels (e.g., natural gas)	20 %
Cement production	3 %
Flaring gas industrially and at wells	< 1 %
Non-fuel hydrocarbons	< 1 %
"International bunker fuels" of transport not included in national inventories	4 %

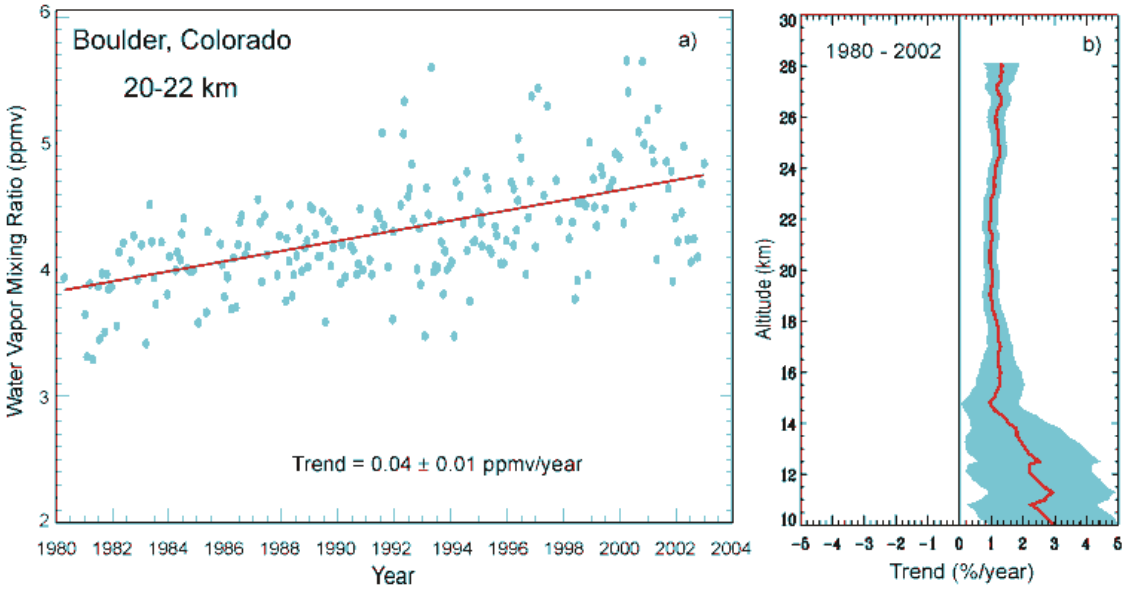
The US Environmental Protection Agency (EPA) ranks the major greenhouse gas contributing end-user sectors in the following order: industrial, transportation, residential, commercial and agricultural. Major sources of an individual's greenhouse gas include home heating and cooling, electricity consumption, and transportation. Corresponding conservation measures are improving home building insulation, installing geothermal heat pumps and compact fluorescent lamps, and choosing energy-efficient vehicles.

Carbon dioxide, methane, nitrous oxide and three groups of fluorinated gases (sulfur hexafluoride, HFCs, and PFCs) are the major greenhouse gases and the subject of the Kyoto Protocol, which came into force in 2005.

Although CFCs are greenhouse gases, they are regulated by the Montreal Protocol, which was motivated by CFCs' contribution to ozone depletion rather than by their contribution to global warming. Note that ozone depletion has only a minor role in greenhouse warming though the two processes often are confused in the media.

On December 7, 2009, the US Environmental Protection Agency released its final findings on greenhouse gases, declaring that "greenhouse gases (GHGs) threaten the public health and welfare of the American people". The finding applied to the same "six key well-mixed greenhouse gases" named in the Kyoto Protocol: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

Role of water vapor



Increasing water vapor in the stratosphere at Boulder, Colorado.

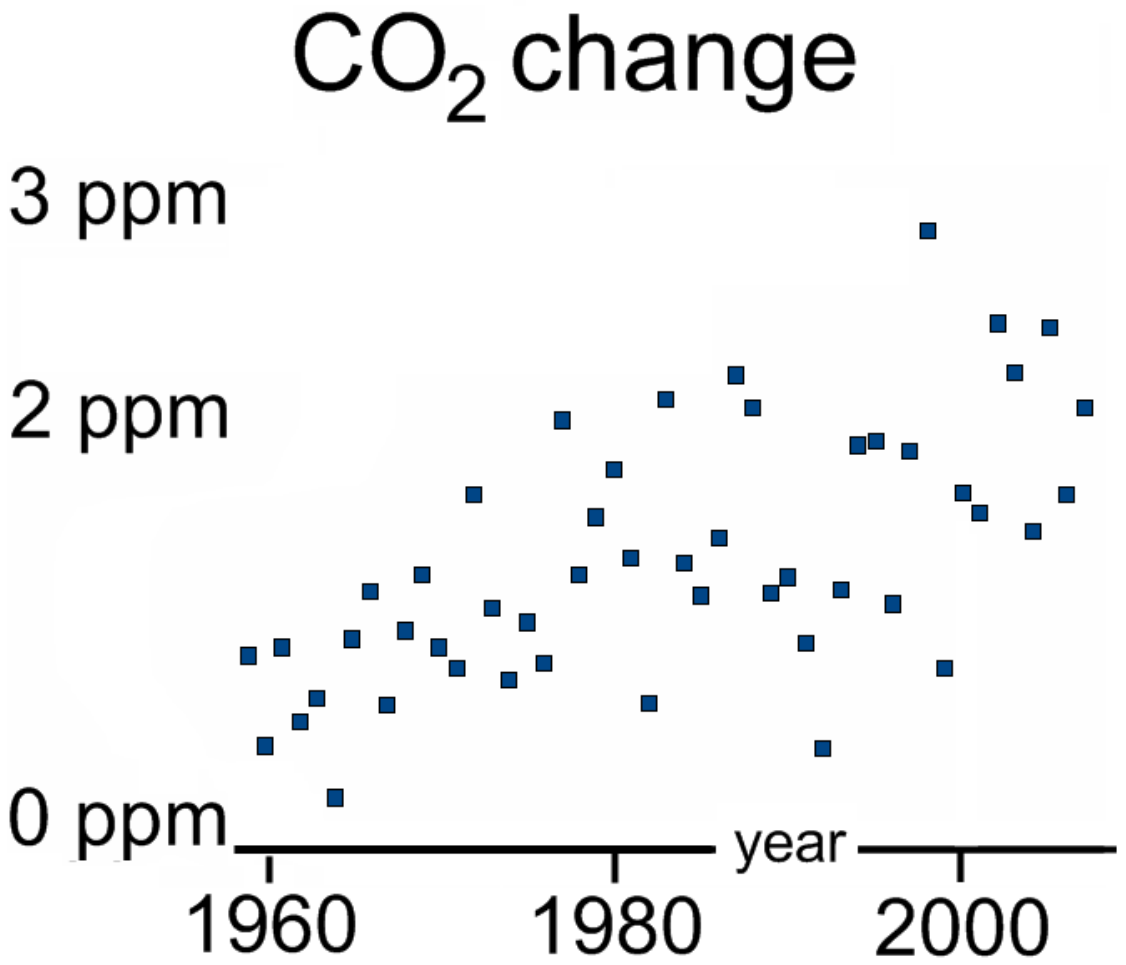
Water vapor accounts for the largest percentage of the greenhouse effect, between 36% and 66% for clear sky conditions and between 66% and 85% when including clouds. Water vapor concentrations fluctuate regionally, but human activity does not significantly affect water vapor concentrations except at local scales, such as near irrigated fields. According to the Environmental Health Center of the National Safety Council, water vapor constitutes as much as 2% of the atmosphere.

The Clausius-Clapeyron relation establishes that air can hold more water vapor per unit volume when it warms. This and other basic principles indicate that warming associated with increased concentrations of the other greenhouse gases also will increase the concentration of water vapor. Because water vapor is a greenhouse gas this results in further warming, a "positive feedback" that amplifies the original warming. This positive feedback does not result in runaway global warming because it is offset by other processes that induce negative feedbacks, which stabilizes average global temperatures.

Greenhouse gas emissions

Measurements from Antarctic ice cores show that before industrial emissions started atmospheric CO_2 levels were about 280 parts per million by volume (ppmv), and stayed between 260 and 280 during the preceding ten thousand years. Carbon dioxide concentrations in the atmosphere have gone up by approximately 35 percent since the 1900s, rising from 280 parts per million by volume to 387 parts per million in 2009. One study using evidence from stomata of fossilized leaves suggests greater variability, with carbon dioxide levels above 300 ppm during the period seven to ten thousand years ago, though others have argued that these findings more likely reflect calibration or contamination problems rather than actual CO_2 variability. Because of the way air is

trapped in ice (pores in the ice close off slowly to form bubbles deep within the firn) and the time period represented in each ice sample analyzed, these figures represent averages of atmospheric concentrations of up to a few centuries rather than annual or decadal levels.



Recent year-to-year increase of atmospheric CO_2.

Since the beginning of the Industrial Revolution, the concentrations of most of the greenhouse gases have increased. For example, the concentration of carbon dioxide has increased by about 36% to 380 ppmv, or 100 ppmv over modern pre-industrial levels. The first 50 ppmv increase took place in about 200 years, from the start of the Industrial Revolution to around 1973; however the next 50 ppmv increase took place in about 33 years, from 1973 to 2006.

Recent data also shows that the concentration is increasing at a higher rate. In the 1960s, the average annual increase was only 37% of what it was in 2000 through 2007.

The other greenhouse gases produced from human activity show similar increases in both amount and rate of increase. Many observations are available online in a variety of Atmospheric Chemistry Observational Databases.

Relevant to radiative forcing

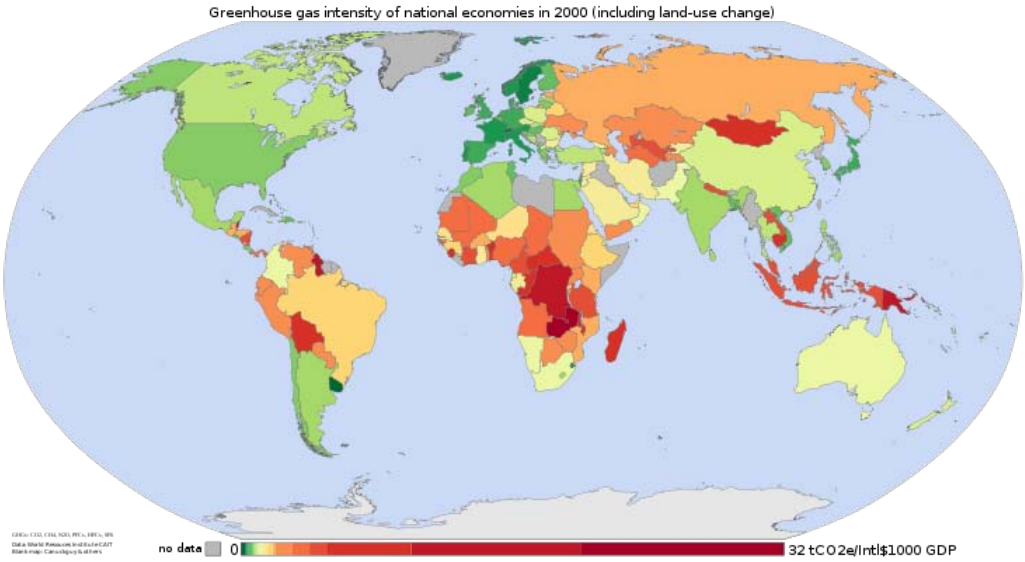
Gas	Current (1998) Amount by volume	Increase (absolute, ppm) over pre-industrial (1750)	Increase (relative, %) over pre-industrial (1750)	Radiative forcing (W/m^2)
Carbon dioxide	365 ppm (383 ppm, 2007.01)	87 ppm (105 ppm, 2007.01)	31 % (38 %, 2007.01)	1.46 (~1.53, 2007.01)
Methane	1745 ppb	1045 ppb	67 %	0.48
Nitrous oxide	314 ppb	44 ppb	16 %	0.15

Relevant to both radiative forcing and ozone depletion; all of the following have no natural sources and hence zero amounts pre-industrial

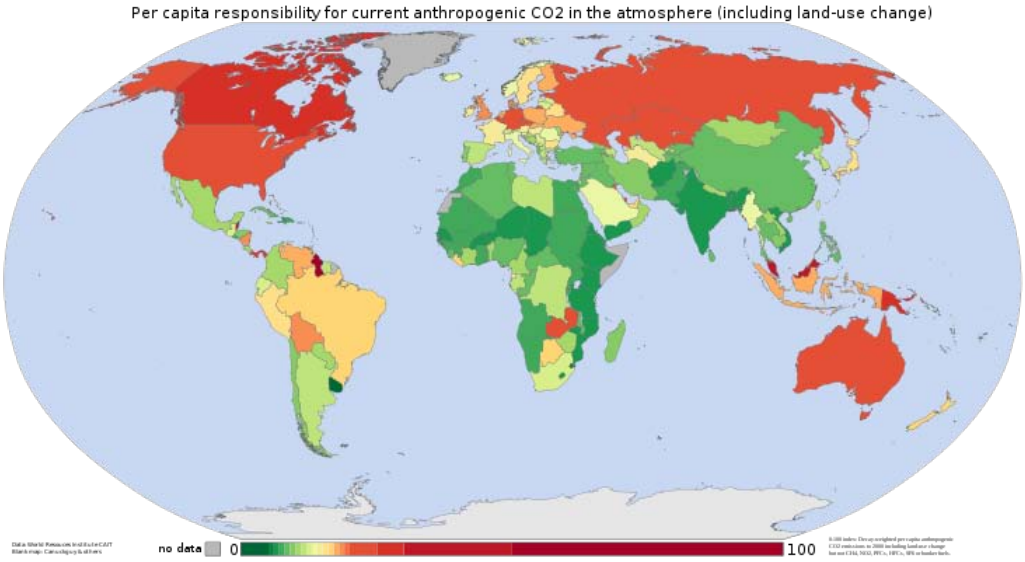
Gas	Current (1998) Amount by volume	Radiative forcing (W/m^2)
CFC-11	268 ppt	0.07
CFC-12	533 ppt	0.17
CFC-113	84 ppt	0.03
Carbon tetrachloride	102 ppt	0.01
HCFC-22	69 ppt	0.03

(Source: IPCC radiative forcing report 1994 updated (to 1998) by IPCC TAR table 6.1).

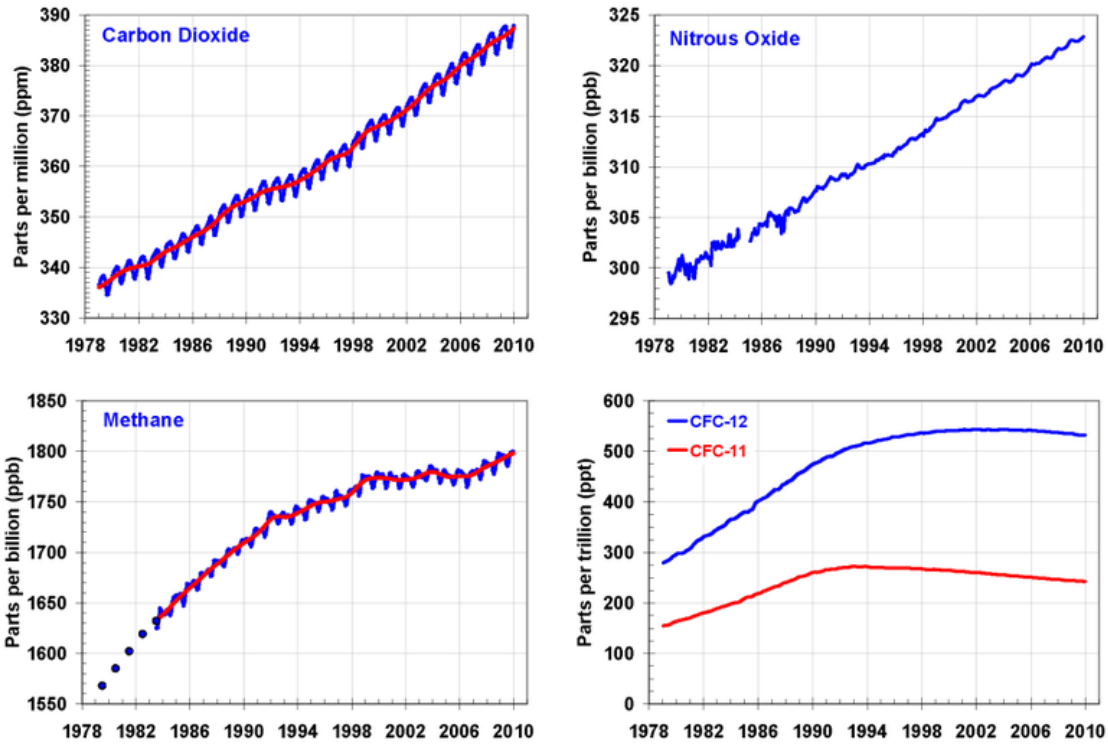
Regional and national attribution of emissions



Greenhouse gas intensity in 2000 including land-use change.



Per capita responsibility for current anthropogenic atmospheric CO_2.



Major greenhouse gas trends.

There are several different ways of measuring GHG emissions for a table of national emissions data).

Some variables that have been reported include:

- Definition of measurement boundaries. Emissions can be attributed geographically, to the area where they were emitted (the territory principle) or by the activity principle to the territory that caused the emissions to be produced. These two principles would result in different totals when measuring for example the importation of electricity from one country to another or the emissions at an international airport.
- The time horizon of different GHGs. Contribution of a given GHG is reported as a CO2 equivalent; the calculation to determine this takes into account how long that gas remains in the atmosphere. This is not always known accurately and calculations must be regularly updated to take into account new information.
- What sectors are included in the calculation (e.g. energy industries, industrical processes, agriculture etc.). There is often a conflict between transparency and availability of data.
- The measurement protocol itself. This may be via direct measurement or estimation; the four main methods are the emission factor-based method, the mass balance method, the predictive emissions monitoring system and the continuing

emissions monitoring systems. The methods differ in accuracy, but also in cost and usability.

The different measures are sometimes used by different countries in asserting various policy/ethical positions to do with climate change (Banuri *et al.*, 1996, p. 94). This use of different measures leads to a lack of comparability, which is problematic when monitoring progress towards targets. There are arguments for the adoption of a common measurement tool, or at least the development of communication between different tools.

Emissions may be measured over long time periods. This measurement type is called historical or cumulative emissions. Cumulative emissions give some indication of who is responsible for the build-up in the atmospheric concentration of GHGs (IEA, 2007, p. 199).

Emissions may also be measured across shorter time periods. Emissions changes may, for example, be measured against a base year of 1990. 1990 was used in the United Nations Framework Convention on Climate Change (UNFCCC) as the base year for emissions, and is also used in the Kyoto Protocol (some gases are also measured from the year 1995) (Grubb, 2003, pp. 146, 149). A country's emissions may also be reported as a proportion of global emissions for a particular year.

Another measurement is of per capita emissions. This divides a country's total annual emissions by its mid-year population (World Bank, 2010, p. 370). Per capita emissions may be based on historical or annual emissions (Banuri *et al.*, 1996, pp. 106–107).

Cumulative emissions

Over the 1900-2005 period, the US was the world's largest cumulative emitter of energy-related CO_2 emissions, and accounted for 30% of total cumulative emissions (IEA, 2007, p. 201). The second largest emitter was the EU, at 23%; the third largest was China, at 8%; fourth was Japan, at 4%; fifth was India, at 2%. The rest of the world accounted for 33% of global, cumulative, energy-related CO_2 emissions.

Changes since a particular base year

In total, Annex I Parties managed a cut of 3.3% in GHG emissions between 1990 and 2004 (UNFCCC, 2007, p. 11). Annex I Parties are those countries listed in Annex I of the UNFCCC, and are the industrialized countries. For non-Annex I Parties, emissions in several large developing countries and fast growing economies (China, India, Thailand, Indonesia, Egypt, and Iran) GHG emissions have increased rapidly over this period (PBL, 2009).

The sharp acceleration in CO_2 emissions since 2000 to more than a 3% increase per year (more than 2 ppm per year) from 1.1% per year during the 1990s is attributable to the lapse of formerly declining trends in carbon intensity of both developing and developed nations. China was responsible for most of global growth in emissions during this period.

Localised plummeting emissions associated with the collapse of the Soviet Union have been followed by slow emissions growth in this region due to more efficient energy use, made necessary by the increasing proportion of it that is exported. In comparison, methane has not increased appreciably, and N_2O by 0.25% y^{-1}.

Annual and per capita emissions

At the present time, total annual emissions of GHGs are rising (Rogner *et al.*, 2007). Between the period 1970 to 2004, emissions increased at an average rate of 1.6% per year, with CO_2 emissions from the use of fossil fuels growing at a rate of 1.9% per year.

Per capita emissions in the industrialized countries are typically as much as ten times the average in developing countries (Grubb, 2003, p. 144). Due to China's fast economic development, its per capita emissions are quickly approaching the levels of those in the Annex I group of the Kyoto Protocol (PBL, 2009). Other countries with fast growing emissions are South Korea, Iran, and Australia. On the other hand, per capita emissions of the EU-15 and the USA are gradually decreasing over time. Emissions in Russia and the Ukraine have decreased fastest since 1990 due to economic restructuring in these countries (Carbon Trust, 2009, p. 24).

Energy statistics for fast growing economies are less accurate than those for the industrialized countries. For China's annual emissions in 2008, PBL (2008) estimated an uncertainty range of about 10%.

Top emitters

In 2005, the world's top-20 emitters comprised 80% of total GHG emissions. Tabulated below are the top-5 emitters for the year 2005 (MNP, 2007). The second column is the country's or region's share of the global total of annual emissions. The third column is the country's or region's average annual per capita emissions, in tonnes of GHG per head of population:

Top-5 emitters for the year 2005

Country or region	% of global total annual emissions	Tonnes of GHG per capita
China[b]	17 %	5.8
United States[a]	16 %	24.1
European Union-27[a]	11 %	10.6
Indonesia[c]	6 %	12.9
India	5 %	2.1

Table footnotes:

- These values are for the GHG emissions from fossil fuel use and cement production. Calculations are for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and gases containing fluorine (the F-gases HFCs, PFCs and SF_6).
- These estimates are subject to large uncertainties regarding CO_2 emissions from deforestation; and the per country emissions of other GHGs (e.g., methane). There are also other large uncertainties which mean that small differences between countries are not significant. CO_2 emissions from the decay of remaining biomass after biomass burning/deforestation are not included.
- [a] Industrialised countries: official country data reported to UNFCCC.
- [b] Excluding underground fires.
- [c] Including an estimate of 2000 million tonnes CO_2 from peat fires and decomposition of peat soils after draining. However, the uncertainty range is very large.

Effect of policy

Rogner *et al.* (2007) assessed the effectiveness of policies to reduce emissions (mitigation of climate change). They concluded that mitigation policies undertaken by UNFCCC Parties were inadequate to reverse the trend of increasing GHG emissions. The impacts of population growth, economic development, technological investment, and consumption had overwhelmed improvements in energy intensities and efforts to decarbonize (energy intensity is a country's total primary energy supply (TPES) per unit of GDP (Rogner *et al.*, 2007). TPES is a measure of commercial energy consumption (World Bank, 2010, p. 371)).

Projections

Based on then-current energy policies, Rogner et al. (2007) projected that energy-related CO_2 emissions in 2030 would be 40-110% higher than in 2000. Two-thirds of this increase was projected to come from non-Annex I countries. Per capita emissions in Annex I countries were still projected to remain substantially higher than per capita emissions in non-Annex I countries. Projections consistently showed a 25-90% increase in the Kyoto gases (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride) compared to 2000.

Relative CO_2 emission from various fuels

One US gallon of gasoline, when used as a fuel, producess about 19.4 pounds of carbon dioxide, a greenhouse gas.

Mass of carbon dioxide emitted per quantity of energy for various fuels

Fuel name	CO_2 emitted (lbs/10^6 Btu)	CO_2 emitted (g/10^6 J)
Natural gas	117	50.30
Liquefied petroleum gas	139	59.76
Propane	139	59.76
Aviation gasoline	153	65.78

Automobile gasoline	156	67.07
Kerosene	159	68.36
Fuel oil	161	69.22
Tires/tire derived fuel	189	81.26
Wood and wood waste	195	83.83
Coal (bituminous)	205	88.13
Coal (subbituminous)	213	91.57
Coal (lignite)	215	92.43
Petroleum coke	225	96.73
Coal (anthracite)	227	97.59

Removal from the atmosphere and global warming potential

Natural processes

Greenhouse gases can be removed from the atmosphere by various processes, as a consequence of:

- a physical change (condensation and precipitation remove water vapor from the atmosphere).

"Internet forest" in the Netherlands, meant to compensate for the CO_2 emission caused by internet servers.

- a chemical reactions within the atmosphere. For example, methane is oxidized by reaction with naturally occurring hydroxyl radical, OH· and degraded to CO_2 and water vapor (CO_2 from the oxidation of methane is not included in the methane Global warming potential). Other chemical reactions include solution and solid phase chemistry occurring in atmospheric aerosols.
- a physical exchange between the atmosphere and the other compartments of the planet. An example is the mixing of atmospheric gases into the oceans.
- a chemical change at the interface between the atmosphere and the other compartments of the planet. This is the case for CO_2, which is reduced by photosynthesis of plants, and which, after dissolving in the oceans, reacts to form carbonic acid and bicarbonate and carbonate ions.
- a photochemical change. Halocarbons are dissociated by UV light releasing Cl· and F· as free radicals in the stratosphere with harmful effects on ozone (halocarbons are generally too stable to disappear by chemical reaction in the atmosphere).

Atmospheric lifetime

Aside from water vapor, which has a residence time of about nine days, major greenhouse gases are well-mixed, and take many years to leave the atmosphere. Although it is not easy to know with precision how long it takes greenhouse gases to leave the

atmosphere, there are estimates for the principal greenhouse gases. Jacob (1999) defines the lifetime τ of an atmospheric species X in a one-box model as the average time that a molecule of X remains in the box. Mathematically τ can be defined as the ratio of the mass *m* (in kg) of X in the box to its removal rate, which is the sum of the flow of X out of the box (F_{out}), chemical loss of X (*L*), and deposition of X (*D*) (all in kg/sec):

$$\tau = \frac{m}{F_{out} + L + D}$$

The atmospheric lifetime of a species therefore measures the time required to restore equilibrium following an increase in its concentration in the atmosphere. Individual atoms or molecules may be lost or deposited to sinks such as the soil, the oceans and other waters, or vegetation and other biological systems, reducing the excess to background concentrations. The average time taken to achieve this is the mean lifetime. The atmospheric lifetime of CO_2 is often incorrectly stated to be only a few years because that is the average time for any CO_2 molecule to stay in the atmosphere before being removed by mixing into the ocean, photosynthesis, or other processes. However, this ignores the balancing fluxes of CO_2 into the atmosphere from the other reservoirs. It is the net concentration changes of the various greenhouse gases by *all sources and sinks* that determines atmospheric lifetime, not just the removal processes.

Global warming potential

The global warming potential (GWP) depends on both the efficiency of the molecule as a greenhouse gas and its atmospheric lifetime. GWP is measured relative to the same **mass** of CO_2 and evaluated for a specific timescale. Thus, if a gas has a high radiative forcing but also a short lifetime, it will have a large GWP on a 20 year scale but a small one on a 100 year scale. Conversely, if a molecule has a longer atmospheric lifetime than CO_2 its GWP will increase with the timescale considered.

Carbon dioxide has a variable atmospheric lifetime, and cannot be specified precisely. Recent work indicates that recovery from a large input of atmospheric CO_2 from burning fossil fuels will result in an effective lifetime of tens of thousands of years. Carbon dioxide is defined to have a GWP of 1 over all time periods.

Methane has an atmospheric lifetime of 12 ± 3 years and a GWP of 72 over 20 years, 25 over 100 years and 7.6 over 500 years. The decrease in GWP at longer times is because methane is degraded to water and CO_2 through chemical reactions in the atmosphere.

Examples of the atmospheric lifetime and GWP relative to CO_2 for several greenhouse gases are given in the following table:

Atmospheric lifetime and GWP relative to CO_2 at different time horizon for various greenhouse gases.

Gas name	Chemical formula	Lifetime (years)	Global warming potential (GWP) for given time horizon

			20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See above	1	1	1
Methane	CH_4	12	72	25	7.6
Nitrous oxide	N_2O	114	289	298	153
CFC-12	CCl_2F_2	100	11 000	10 900	5 200
HCFC-22	$CHClF_2$	12	5 160	1 810	549
Tetrafluoromethane	CF_4	50 000	5 210	7 390	11 200
Hexafluoroethane	C_2F_6	10 000	8 630	12 200	18 200
Sulphur hexafluoride	SF_6	3 200	16 300	22 800	32 600
Nitrogen trifluoride	NF_3	740	12 300	17 200	20 700

The use of CFC-12 (except some essential uses) has been phased out due to its ozone depleting properties. The phasing-out of less active HCFC-compounds will be completed in 2030.

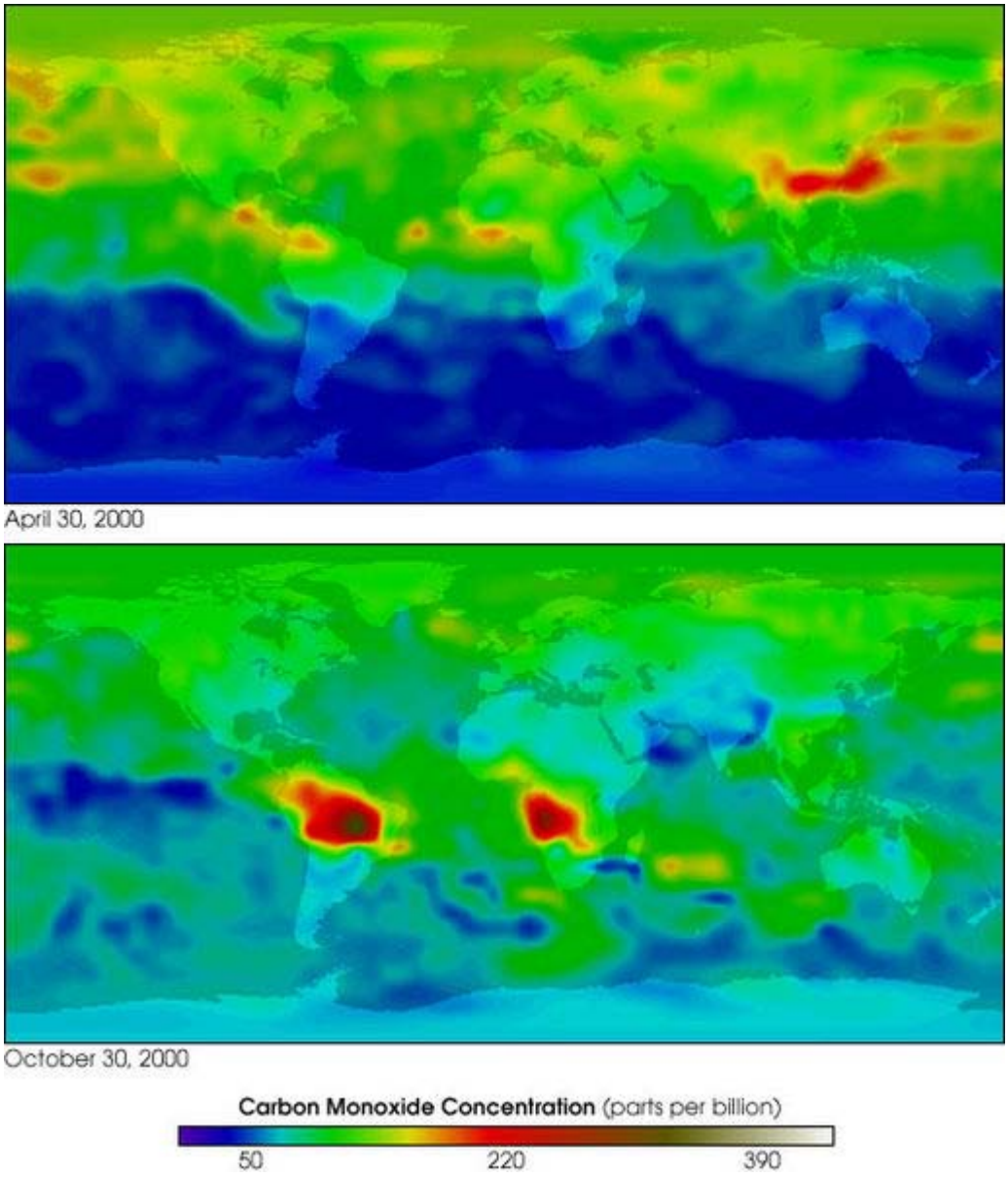
Airborne fraction

Airborne fraction (AF) is the proportion of an emission (e.g. CO_2) remaining in the atmosphere after a specified time. Canadell (2007) define the annual AF as the ratio of the atmospheric CO_2 increase in a given year to that year's total emissions, and calculate that of the average 9.1 PgC y^{-1} of total anthropogenic emissions from 2000 to 2006, the AF was 0.45. For CO_2 the AF over the last 50 years (1956–2006) has been increasing at 0.25 ± 0.21%/year.

Negative emissions

There exists a number of technologies which produce negative emissions of greenhouse gases. Most widely analysed are those which remove carbon dioxide from the atmosphere, either to geologic formations such as bio-energy with carbon capture and storage and carbon dioxide air capture, or to the soil as in the case with biochar. It has been pointed out by the IPCC, that many long-term climate scenario models require large scale manmade negative emissions in order to avoid serious climate change.

Related effects



MOPITT 2000 global carbon monoxide.

Carbon monoxide has an indirect radiative effect by elevating concentrations of methane and tropospheric ozone through scavenging of atmospheric constituents (e.g., the hydroxyl radical, **OH**) that would otherwise destroy them. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to carbon dioxide. Carbon monoxide has an atmospheric lifetime of only a few months and as a consequence is spatially more variable than longer-lived gases.

Another potentially important indirect effect comes from methane, which in addition to its direct radiative impact also contributes to ozone formation. Shindell *et al.* (2005)

argue that the contribution to climate change from methane is at least double previous estimates as a result of this effect.

Chapter- 8

Ozone Depletion

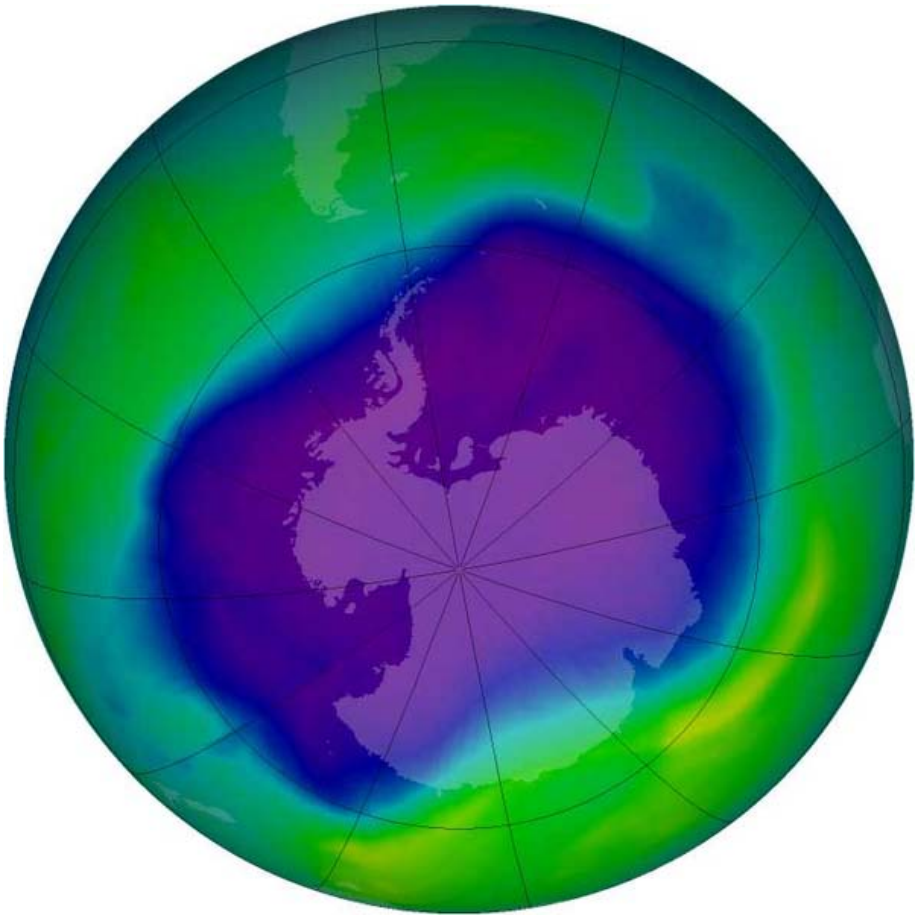


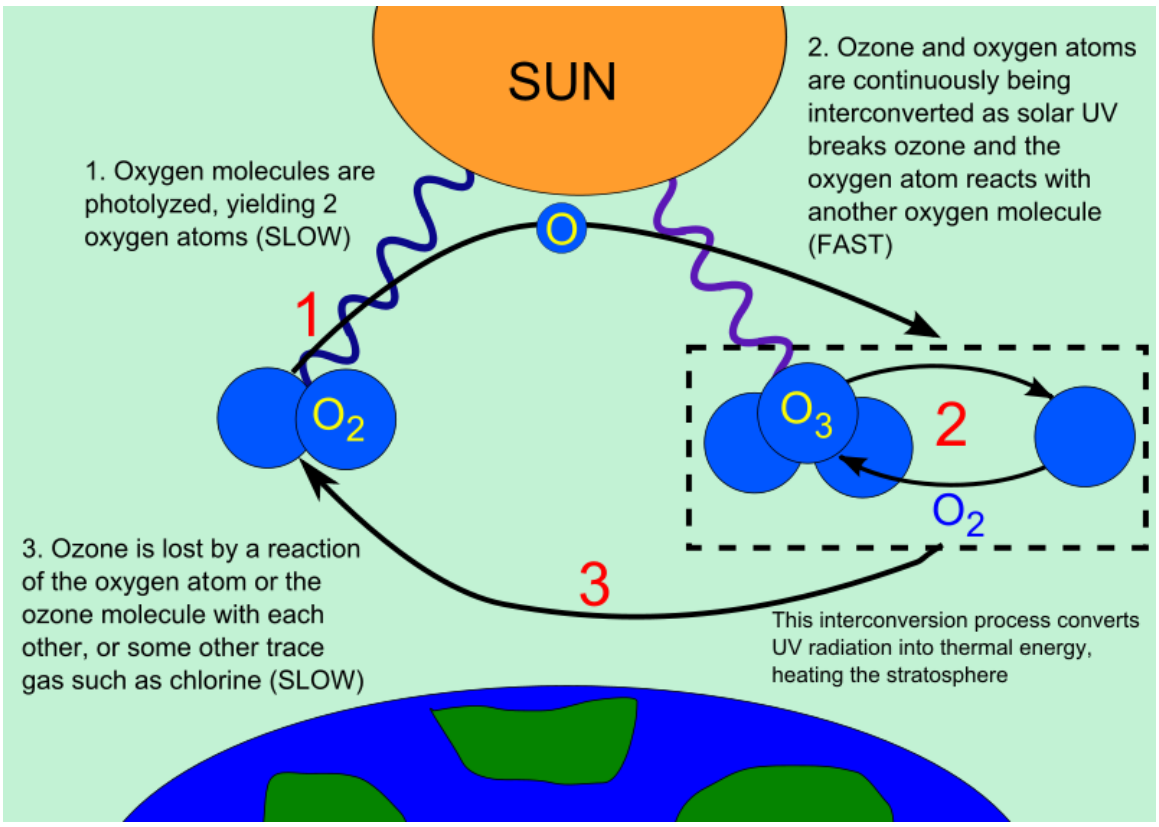
Image of the largest Antarctic ozone hole ever recorded (September 2006).

Ozone depletion describes two distinct, but related observations: a slow, steady decline of about 4% per decade in the total volume of ozone in Earth's stratosphere (the ozone layer) since the late 1970s, and a much larger, but seasonal, decrease in stratospheric ozone over Earth's polar regions during the same period. The latter phenomenon is commonly referred to as the **ozone hole**. In addition to this well-known stratospheric ozone depletion, there are also tropospheric ozone depletion events, which occur near the surface in polar regions during spring.

The detailed mechanism by which the polar ozone holes form is different from that for the mid-latitude thinning, but the most important process in both trends is catalytic destruction of ozone by atomic chlorine and bromine. The main source of these halogen atoms in the stratosphere is photodissociation of chlorofluorocarbon (CFC) compounds, commonly called freons, and of bromofluorocarbon compounds known as halons. These compounds are transported into the stratosphere after being emitted at the surface. Both ozone depletion mechanisms strengthened as emissions of CFCs and halons increased.

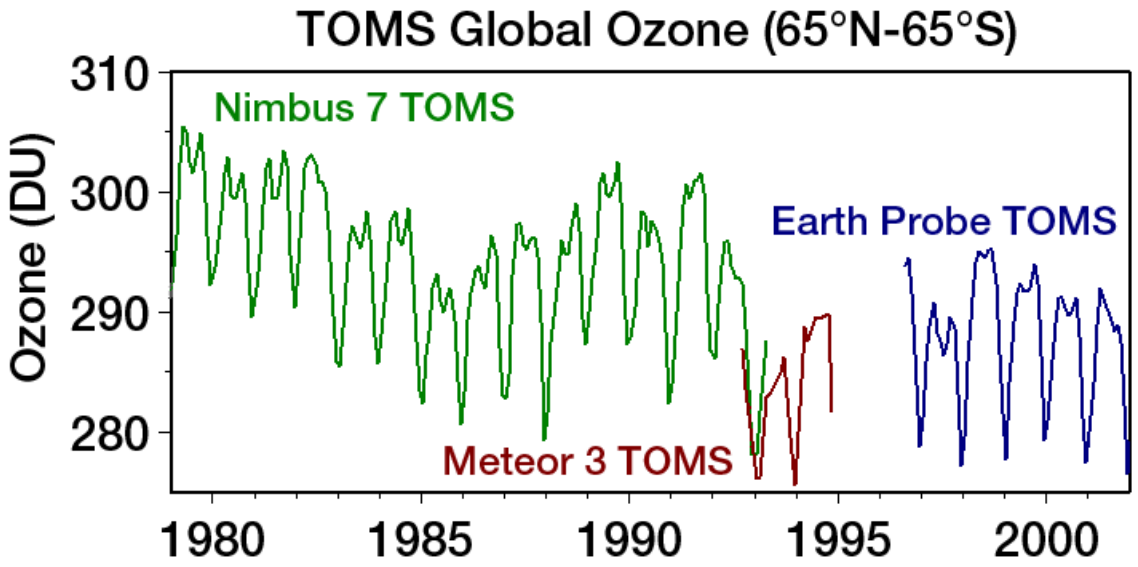
CFCs and other contributory substances are commonly referred to as **ozone-depleting substances** (**ODS**). Since the ozone layer prevents most harmful UVB wavelengths (280–315 nm) of ultraviolet light (UV light) from passing through the Earth's atmosphere, observed and projected decreases in ozone have generated worldwide concern leading to adoption of the Montreal Protocol that bans the production of CFCs and halons as well as related ozone depleting chemicals such as carbon tetrachloride and trichloroethane. It is suspected that a variety of biological consequences such as increases in skin cancer, cataracts, damage to plants, and reduction of plankton populations in the ocean's photic zone may result from the increased UV exposure due to ozone depletion.

Ozone cycle overview

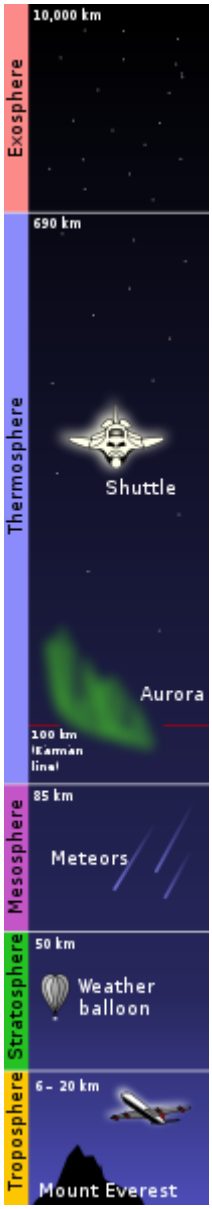


The ozone cycle

Three forms (or allotropes) of oxygen are involved in the ozone-oxygen cycle: oxygen atoms (O or atomic oxygen), oxygen gas (O_2 or diatomic oxygen), and ozone gas (O_3 or triatomic oxygen). Ozone is formed in the stratosphere when oxygen molecules photodissociate after absorbing an ultraviolet photon whose wavelength is shorter than 240 nm. This produces two oxygen atoms. The atomic oxygen then combines with O_2 to create O_3. Ozone molecules absorb UV light between 310 and 200 nm, following which ozone splits into a molecule of O_2 and an oxygen atom. The oxygen atom then joins up with an oxygen molecule to regenerate ozone. This is a continuing process which terminates when an oxygen atom "recombines" with an ozone molecule to make two O_2 molecules: $O + O_3 \rightarrow 2\ O_2$



Global monthly average total ozone amount.



Layers of the atmosphere (not to scale)

The overall amount of ozone in the stratosphere is determined by a balance between photochemical production and recombination.

Ozone can be destroyed by a number of free radical catalysts, the most important of which are the hydroxyl radical (OH·), the nitric oxide radical (NO·), atomic chlorine (Cl·) and bromine (Br·). All of these have both natural and manmade sources; at the present time, most of the OH· and NO· in the stratosphere is of natural origin, but human activity has dramatically increased the levels of chlorine and bromine. These elements are found in certain stable organic compounds, especially chlorofluorocarbons (CFCs), which may find their way to the stratosphere without being destroyed in the troposphere due to their low reactivity. Once in the stratosphere, the Cl and Br atoms are liberated from the parent

compounds by the action of ultraviolet light, e.g. ('h' is Planck's constant, 'ν' is frequency of electromagnetic radiation)

$CFCl_3 + h\nu \rightarrow CFCl_2 + Cl$

The Cl and Br atoms can then destroy ozone molecules through a variety of catalytic cycles. In the simplest example of such a cycle, a chlorine atom reacts with an ozone molecule, taking an oxygen atom with it (forming ClO) and leaving a normal oxygen molecule. The chlorine monoxide (i.e., the ClO) can react with a second molecule of ozone (i.e., O_3) to yield another chlorine atom and two molecules of oxygen. The chemical shorthand for these gas-phase reactions is:

$Cl + O_3 \rightarrow ClO + O_2$

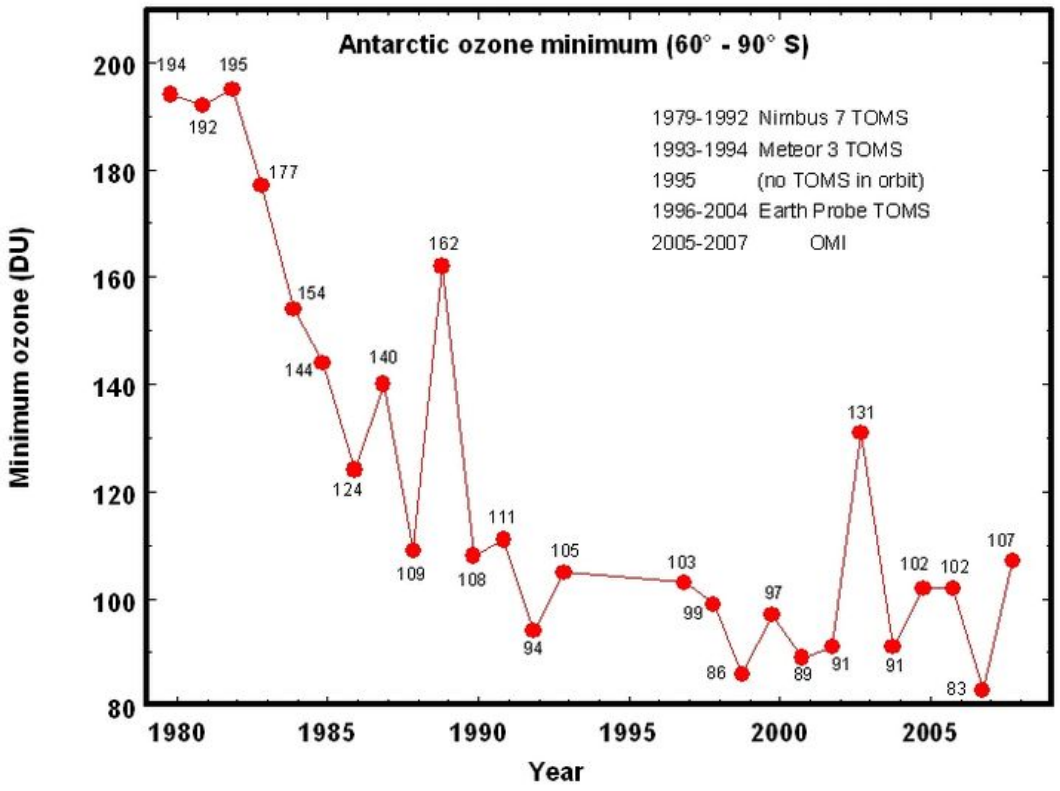
$ClO + O_3 \rightarrow Cl + 2\ O_2$

The overall effect is a decrease in the amount of ozone. More complicated mechanisms have been discovered that lead to ozone destruction in the lower stratosphere as well.

A single chlorine atom would keep on destroying ozone (thus a catalyst) for up to two years (the time scale for transport back down to the troposphere) were it not for reactions that remove them from this cycle by forming reservoir species such as hydrogen chloride (HCl) and chlorine nitrate ($ClONO_2$). On a per atom basis, bromine is even more efficient than chlorine at destroying ozone, but there is much less bromine in the atmosphere at present. As a result, both chlorine and bromine contribute significantly to the overall ozone depletion. Laboratory studies have shown that fluorine and iodine atoms participate in analogous catalytic cycles. However, in the Earth's stratosphere, fluorine atoms react rapidly with water and methane to form strongly bound HF, while organic molecules which contain iodine react so rapidly in the lower atmosphere that they do not reach the stratosphere in significant quantities. Furthermore, a single chlorine atom is able to react with 100,000 ozone molecules. This fact plus the amount of chlorine released into the atmosphere by chlorofluorocarbons (CFCs) yearly demonstrates how dangerous CFCs are to the environment.

Observations on ozone layer depletion

The most pronounced decrease in ozone has been in the lower stratosphere. However, the ozone hole is most usually measured not in terms of ozone concentrations at these levels (which are typically of a few parts per million) but by reduction in the total *column ozone*, above a point on the Earth's surface, which is normally expressed in Dobson units, abbreviated as "DU". Marked decreases in column ozone in the Antarctic spring and early summer compared to the early 1970s and before have been observed using instruments such as the Total Ozone Mapping Spectrometer (TOMS).



Lowest value of ozone measured by TOMS each year in the ozone hole.

Reductions of up to 70% in the ozone column observed in the austral (southern hemispheric) spring over Antarctica and first reported in 1985 (Farman et al. 1985) are continuing. Through the 1990s, total column ozone in September and October have continued to be 40–50% lower than pre-ozone-hole values. In the Arctic the amount lost is more variable year-to-year than in the Antarctic. The greatest declines, up to 30%, are in the winter and spring, when the stratosphere is colder.

Reactions that take place on polar stratospheric clouds (PSCs) play an important role in enhancing ozone depletion. PSCs form more readily in the extreme cold of Antarctic stratosphere. This is why ozone holes first formed, and are deeper, over Antarctica. Early models failed to take PSCs into account and predicted a gradual global depletion, which is why the sudden Antarctic ozone hole was such a surprise to many scientists.

In middle latitudes it is preferable to speak of ozone depletion rather than holes. Declines are about 3% below pre-1980 values for 35–60°N and about 6% for 35–60°S. In the tropics, there are no significant trends.

Ozone depletion also explains much of the observed reduction in stratospheric and upper tropospheric temperatures. The source of the warmth of the stratosphere is the absorption

of UV radiation by ozone, hence reduced ozone leads to cooling. Some stratospheric cooling is also predicted from increases in greenhouse gases such as CO_2; however the ozone-induced cooling appears to be dominant.

Predictions of ozone levels remain difficult. The World Meteorological Organization Global Ozone Research and Monitoring Project—Report No. 44 comes out strongly in favor for the Montreal Protocol, but notes that a UNEP 1994 Assessment overestimated ozone loss for the 1994–1997 period.

Chemicals in the atmosphere

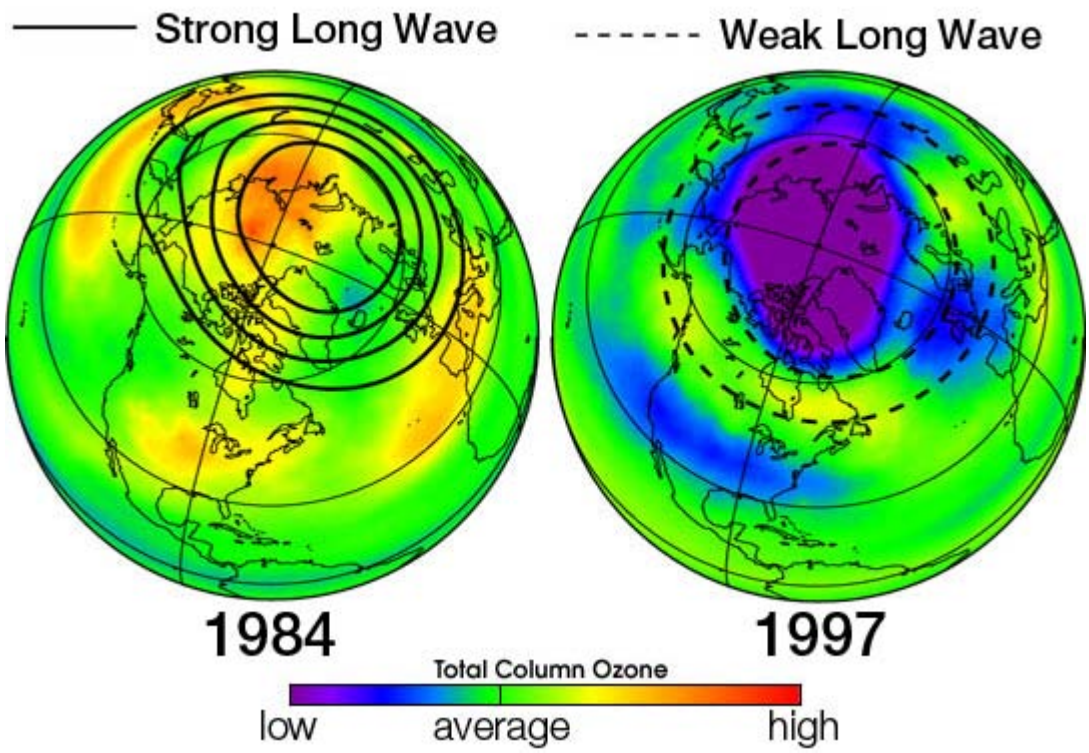
CFCs in the atmosphere

Chlorofluorocarbons (CFCs) were invented by Thomas Midgley, Jr. in the 1920s. They were used in air conditioning/cooling units, as aerosol spray propellants prior to the 1980s, and in the cleaning processes of delicate electronic equipment. They also occur as by-products of some chemical processes. No significant natural sources have ever been identified for these compounds — their presence in the atmosphere is due almost entirely to human manufacture. As mentioned in the *ozone cycle overview* above, when such ozone-depleting chemicals reach the stratosphere, they are dissociated by ultraviolet light to release chlorine atoms. The chlorine atoms act as a catalyst, and each can break down tens of thousands of ozone molecules before being removed from the stratosphere. Given the longevity of CFC molecules, recovery times are measured in decades. It is calculated that a CFC molecule takes an average of 15 years to go from the ground level up to the upper atmosphere, and it can stay there for about a century, destroying up to one hundred thousand ozone molecules during that time.

Verification of observations

Scientists have been increasingly able to attribute the observed ozone depletion to the increase of man-made (anthropogenic) halogen compounds from CFCs by the use of complex chemistry transport models and their validation against observational data (e.g. SLIMCAT, CLaMS). These models work by combining satellite measurements of chemical concentrations and meteorological fields with chemical reaction rate constants obtained in lab experiments. They are able to identify not only the key chemical reactions but also the transport processes which bring CFC photolysis products into contact with ozone.

The ozone hole and its causes



Ozone hole in North America during 1984 (abnormally warm reducing ozone depletion) and 1997 (abnormally cold resulting in increased seasonal depletion).

The Antarctic ozone hole is an area of the Antarctic stratosphere in which the recent ozone levels have dropped to as low as 33% of their pre-1975 values. The ozone hole occurs during the Antarctic spring, from September to early December, as strong westerly winds start to circulate around the continent and create an atmospheric container. Within this polar vortex, over 50% of the lower stratospheric ozone is destroyed during the Antarctic spring.

As explained above, the primary cause of ozone depletion is the presence of chlorine-containing source gases (primarily CFCs and related halocarbons). In the presence of UV light, these gases dissociate, releasing chlorine atoms, which then go on to catalyze ozone destruction. The Cl-catalyzed ozone depletion can take place in the gas phase, but it is dramatically enhanced in the presence of polar stratospheric clouds (PSCs).

These polar stratospheric clouds(PSC) form during winter, in the extreme cold. Polar winters are dark, consisting of 3 months without solar radiation (sunlight). The lack of sunlight contributes to a decrease in temperature and the polar vortex traps and chills air. Temperatures hover around or below -80 °C. These low temperatures form cloud particles. There are three types of PSC clouds; nitric acid trihydrate clouds, slowly cooling water-ice clouds, and rapid cooling water-ice(nacerous) clouds; that provide surfaces for chemical reactions that lead to ozone destruction.

The photochemical processes involved are complex but well understood. The key observation is that, ordinarily, most of the chlorine in the stratosphere resides in stable "reservoir" compounds, primarily hydrochloric acid (HCl) and chlorine nitrate ($ClONO_2$). During the Antarctic winter and spring, however, reactions on the surface of the polar stratospheric cloud particles convert these "reservoir" compounds into reactive free radicals (Cl and ClO). The clouds can also remove NO_2 from the atmosphere by converting it to nitric acid, which prevents the newly formed ClO from being converted back into $ClONO_2$.

The role of sunlight in ozone depletion is the reason why the Antarctic ozone depletion is greatest during spring. During winter, even though PSCs are at their most abundant, there is no light over the pole to drive the chemical reactions. During the spring, however, the sun comes out, providing energy to drive photochemical reactions, and melt the polar stratospheric clouds, releasing the trapped compounds. Warming temperatures near the end of spring break up the vortex around mid-December. As warm, ozone-rich air flows in from lower latitudes, the PSCs are destroyed, the ozone depletion process shuts down, and the ozone hole closes.

Most of the ozone that is destroyed is in the lower stratosphere, in contrast to the much smaller ozone depletion through homogeneous gas phase reactions, which occurs primarily in the upper stratosphere.

Interest in ozone layer depletion

While the effect of the Antarctic ozone hole in decreasing the global ozone is relatively small, estimated at about 4% per decade, the hole has generated a great deal of interest because:

- The decrease in the ozone layer was predicted in the early 1980s to be roughly 7% over a 60 year period.
- The sudden recognition in 1985 that there was a substantial "hole" was widely reported in the press. The especially rapid ozone depletion in Antarctica had previously been dismissed as a measurement error.
- Many were worried that ozone holes might start to appear over other areas of the globe but to date the only other large-scale depletion is a smaller ozone "dimple" observed during the Arctic spring over the North Pole. Ozone at middle latitudes has declined, but by a much smaller extent (about 4–5% decrease).
- If the conditions became more severe (cooler stratospheric temperatures, more stratospheric clouds, more active chlorine), then global ozone may decrease at a much greater pace. Standard global warming theory predicts that the stratosphere will cool.
- When the Antarctic ozone hole breaks up, the ozone-depleted air drifts out into nearby areas. Decreases in the ozone level of up to 10% have been reported in New Zealand in the month following the break-up of the Antarctic ozone hole.

Consequences of ozone layer depletion

Since the ozone layer absorbs UVB ultraviolet light from the Sun, ozone layer depletion is expected to increase surface UVB levels, which could lead to damage, including increases in skin cancer. This was the reason for the Montreal Protocol. Although decreases in stratospheric ozone are well-tied to CFCs and there are good theoretical reasons to believe that decreases in ozone will lead to increases in surface UVB, there is no direct observational evidence linking ozone depletion to higher incidence of skin cancer in human beings. This is partly because UVA, which has also been implicated in some forms of skin cancer, is not absorbed by ozone, and it is nearly impossible to control statistics for lifestyle changes in the populace.

Increased UV

Ozone, while a minority constituent in the Earth's atmosphere, is responsible for most of the absorption of UVB radiation. The amount of UVB radiation that penetrates through the ozone layer decreases exponentially with the slant-path thickness/density of the layer. Correspondingly, a decrease in atmospheric ozone is expected to give rise to significantly increased levels of UVB near the surface.

Increases in surface UVB due to the ozone hole can be partially inferred by radiative transfer model calculations, but cannot be calculated from direct measurements because of the lack of reliable historical (pre-ozone-hole) surface UV data, although more recent surface UV observation measurement programmes exist (e.g. at Lauder, New Zealand).

Because it is this same UV radiation that creates ozone in the ozone layer from O_2 (regular oxygen) in the first place, a reduction in stratospheric ozone would actually tend to increase photochemical production of ozone at lower levels (in the troposphere), although the overall observed trends in total column ozone still show a decrease, largely because ozone produced lower down has a naturally shorter photochemical lifetime, so it is destroyed before the concentrations could reach a level which would compensate for the ozone reduction higher up.

Biological effects

The main public concern regarding the ozone hole has been the effects of increased surface UV and microwave radiation on human health. So far, ozone depletion in most locations has been typically a few percent and, as noted above, no direct evidence of health damage is available in most latitudes. Were the high levels of depletion seen in the ozone hole ever to be common across the globe, the effects could be substantially more dramatic. As the ozone hole over Antarctica has in some instances grown so large as to reach southern parts of Australia, New Zealand, Chile, Argentina, and South Africa, environmentalists have been concerned that the increase in surface UV could be significant.

Effects on humans

UVB (the higher energy UV radiation absorbed by ozone) is generally accepted to be a contributory factor to skin cancer. In addition, increased surface UV leads to increased tropospheric ozone, which is a health risk to humans.

1. **Basal and Squamous Cell Carcinomas** — The most common forms of skin cancer in humans, basal and squamous cell carcinomas, have been strongly linked to UVB exposure. The mechanism by which UVB induces these cancers is well understood—absorption of UVB radiation causes the pyrimidine bases in the DNA molecule to form dimers, resulting in transcription errors when the DNA replicates. These cancers are relatively mild and rarely fatal, although the treatment of squamous cell carcinoma sometimes requires extensive reconstructive surgery. By combining epidemiological data with results of animal studies, scientists have estimated that a one percent decrease in stratospheric ozone would increase the incidence of these cancers by 2%.

2. **Malignant Melanoma** — Another form of skin cancer, malignant melanoma, is much less common but far more dangerous, being lethal in about 15–20% of the cases diagnosed. The relationship between malignant melanoma and ultraviolet exposure is not yet well understood, but it appears that both UVB and UVA are involved. Experiments on fish suggest that 90 to 95% of malignant melanomas may be due to UVA and visible radiation whereas experiments on opossums suggest a larger role for UVB. Because of this uncertainty, it is difficult to estimate the impact of ozone depletion on melanoma incidence. One study showed that a 10% increase in UVB radiation was associated with a 19% increase in melanomas for men and 16% for women. A study of people in Punta Arenas, at the southern tip of Chile, showed a 56% increase in melanoma and a 46% increase in nonmelanoma skin cancer over a period of seven years, along with decreased ozone and increased UVB levels.

3. **Cortical Cataracts** — Studies are suggestive of an association between ocular cortical cataracts and UV-B exposure, using crude approximations of exposure and various cataract assessment techniques. A detailed assessment of ocular exposure to UV-B was carried out in a study on Chesapeake Bay Watermen, where increases in average annual ocular exposure were associated with increasing risk of cortical opacity. In this highly exposed group of predominantly white males, the evidence linking cortical opacities to sunlight exposure was the strongest to date. However, subsequent data from a population-based study in Beaver Dam, WI suggested the risk may be confined to men. In the Beaver Dam study, the exposures among women were lower than exposures among men, and no association was seen. Moreover, there were no data linking sunlight exposure to risk of cataract in African Americans, although other eye diseases have different prevalences among the different racial groups, and cortical opacity appears to be higher in African Americans compared with whites.

4. **Increased Tropospheric Ozone** — Increased surface UV leads to increased tropospheric ozone. Ground-level ozone is generally recognized to be a health risk, as ozone is toxic due to its strong oxidant properties. At this time, ozone at ground level is produced mainly by the action of UV radiation on combustion gases from vehicle exhausts.

Effects on non-human animals

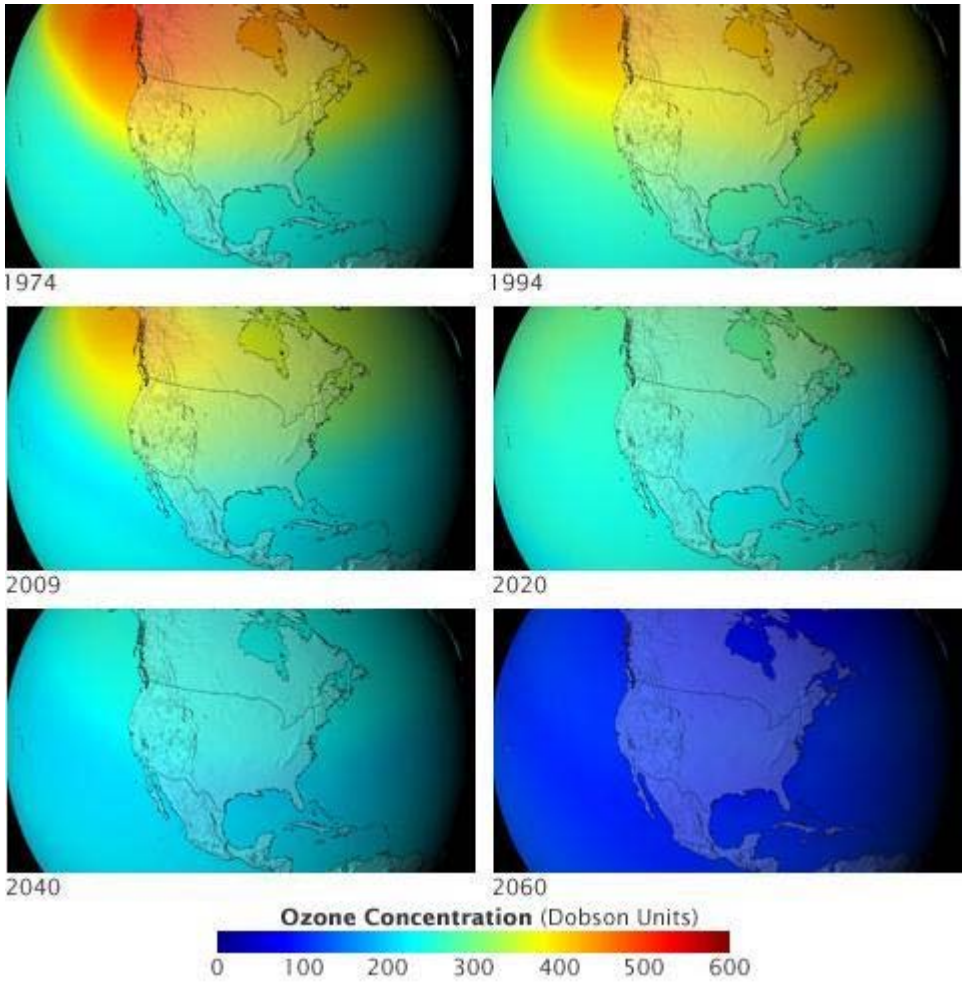
A November 2010 report by scientists at the Institute of Zoology in London found that whales off the coast of California have shown a sharp rise in sun damage, and these scientists "fear that the thinning ozone layer is to blame"

The study photographed and took skin biopsies from over 150 whales in the Gulf of California and found "widespread evidence of epidermal damage commonly associated with acute and severe sunburn," having cells which form when the DNA is damaged by UV radiation. The findings suggest "rising UV levels as a result of ozone depletion are to blame for the observed skin damage, in the same way that human skin cancer rates have been on the increase in recent decades."

Effects on crops

An increase of UV radiation would be expected to affect crops. A number of economically important species of plants, such as rice, depend on cyanobacteria residing on their roots for the retention of nitrogen. Cyanobacteria are sensitive to UV light and they would be affected by its increase.

Public policy



NASA projections of stratospheric ozone concentrations if chlorofluorocarbons had not been banned.

The full extent of the damage that CFCs have caused to the ozone layer is not known and will not be known for decades; however, marked decreases in column ozone have already been observed (as explained before).

After a 1976 report by the United States National Academy of Sciences concluded that credible scientific evidence supported the ozone depletion hypothesis a few countries, including the United States, Canada, Sweden, Denmark, and Norway, moved to eliminate the use of CFCs in aerosol spray cans. At the time this was widely regarded as a first step towards a more comprehensive regulation policy, but progress in this direction slowed in subsequent years, due to a combination of political factors (continued resistance from the halocarbon industry and a general change in attitude towards environmental regulation during the first two years of the Reagan administration) and scientific developments (subsequent National Academy assessments which indicated that the first estimates of the magnitude of ozone depletion had been overly large). The United States banned the use of CFCs in aerosol cans in 1978. The European Community rejected proposals to ban CFCs in aerosol sprays, and in the U.S., CFCs continued to be used as refrigerants and

for cleaning circuit boards. Worldwide CFC production fell sharply after the U.S. aerosol ban, but by 1986 had returned nearly to its 1976 level. In 1993, DuPont shut down its CFC facility.

The U.S. Government's attitude began to change again in 1983, when William Ruckelshaus replaced Anne M. Burford as Administrator of the United States Environmental Protection Agency. Under Ruckelshaus and his successor, Lee Thomas, the EPA pushed for an international approach to halocarbon regulations. In 1985 20 nations, including most of the major CFC producers, signed the Vienna Convention for the Protection of the Ozone Layer which established a framework for negotiating international regulations on ozone-depleting substances. That same year, the discovery of the Antarctic ozone hole was announced, causing a revival in public attention to the issue. In 1987, representatives from 43 nations signed the Montreal Protocol. Meanwhile, the halocarbon industry shifted its position and started supporting a protocol to limit CFC production. The reasons for this were in part explained by "Dr. Mostafa Tolba, former head of the UN Environment Programme, who was quoted in the 30 June 1990 edition of The New Scientist, '...the chemical industry supported the Montreal Protocol in 1987 because it set up a worldwide schedule for phasing out CFCs, which [were] no longer protected by patents. This provided companies with an equal opportunity to market new, more profitable compounds.'"

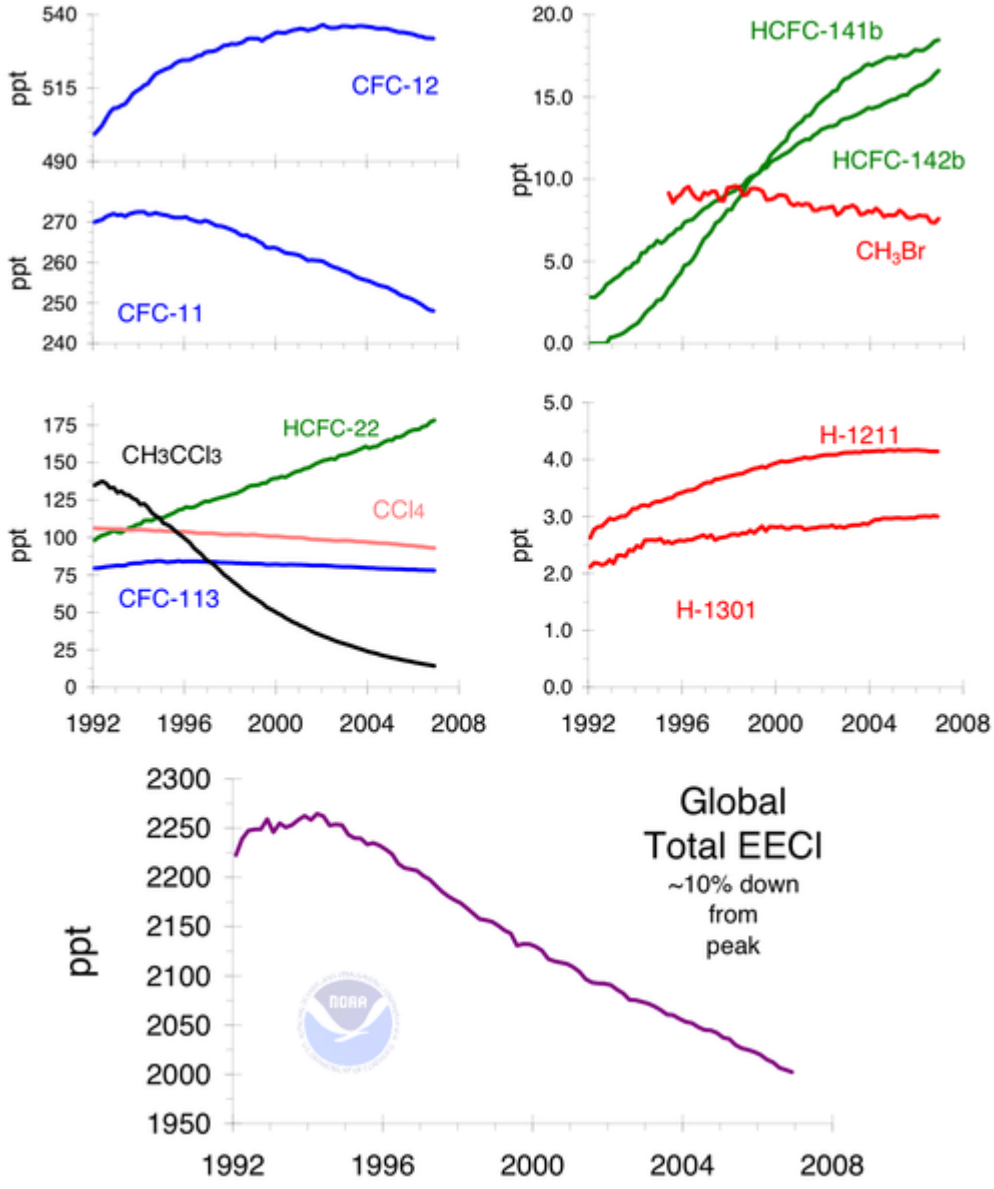
At Montreal, the participants agreed to freeze production of CFCs at 1986 levels and to reduce production by 50% by 1999. After a series of scientific expeditions to the Antarctic produced convincing evidence that the ozone hole was indeed caused by chlorine and bromine from manmade organohalogens, the Montreal Protocol was strengthened at a 1990 meeting in London. The participants agreed to phase out CFCs and halons entirely (aside from a very small amount marked for certain "essential" uses, such as asthma inhalers) by 2000 in non-Article 5 countries and by 2010 in Article 5 (less developed) signatories At a 1992 meeting in Copenhagen, the phase out date was moved up to 1996.. At the same meeting, methyl bromide (MeBr), a fumigant used primarily in agricultural production, was added to the list of controlled substances. It should be noted that for all substances controlled under the Protocol, phaseout schedules were delayed for less developed ('Article 5(1)') countries, and phaseout in these countries was supported by transfers of expertise, technology, and money from non-Article 5(1) Parties to the Protocol. Additionally, exemptions from the agreed schedules could be applied for under the Essential Use Exemption (EUE) process for substances other than methyl bromide and under the Critical Use Exemption (CUE) process for methyl bromide.

To some extent, CFCs have been replaced by the less damaging hydro-chloro-fluoro-carbons (HCFCs), although concerns remain regarding HCFCs also. In some applications, hydro-fluoro-carbons (HFCs) have been used to replace CFCs. HFCs, which contain no chlorine or bromine, do not contribute at all to ozone depletion although they are potent greenhouse gases. The best known of these compounds is probably HFC-134a (R-134a), which in the United States has largely replaced CFC-12 (R-12) in automobile air conditioners. In laboratory analytics (a former "essential" use) the ozone depleting substances can be replaced with various other solvents.

Ozone Diplomacy, by Richard Benedick (Harvard University Press, 1991) gives a detailed account of the negotiation process that led to the Montreal Protocol. Pielke and Betsill provide an extensive review of early U.S. government responses to the emerging science of ozone depletion by CFCs.

More recently, policy experts have advocated for efforts to link ozone protection efforts to climate protection efforts. Many ODS are also greenhouse gasses, some significantly more powerful agents of radiative forcing than carbon dioxide over the short and medium term. Policy decisions in one arena affect the costs and effectiveness of environmental improvements in the other.

Prospects of ozone depletion



Ozone-depleting gas trends.

Since the adoption and strengthening of the Montreal Protocol has led to reductions in the emissions of CFCs, atmospheric concentrations of the most significant compounds have been declining. These substances are being gradually removed from the atmosphere—since peaking in 1994, the Effective Equivalent Chlorine (EECl) level in the atmosphere had dropped about 10% by 2008. It is estimated that by 2015, the Antarctic ozone hole will have reduced by 1 million km² out of 25 (Newman *et al.*, 2004); complete recovery of the Antarctic ozone layer is not expected to occur until the year 2050 or later. Work has suggested that a detectable (and statistically significant) recovery will not occur until around 2024, with ozone levels recovering to 1980 levels by around 2068. The decrease in ozone-depleting chemicals has also been significantly affected by a decrease in bromine-containing chemicals. The data suggest that substantial natural sources exist for atmospheric methyl bromide (CH_3Br). The phase-out of CFCs means that nitrous oxide (N_2O), which is not covered by the Montreal Protocol, has become the most highly emitted ozone depleting substance and is expected to remain so throughout the 21st century.

When the 2004 ozone hole ended in November 2004, daily minimum stratospheric temperatures in the Antarctic lower stratosphere increased to levels that are too warm for the formation of polar stratospheric clouds (PSCs) about 2 to 3 weeks earlier than in most recent years.

The Arctic winter of 2005 was extremely cold in the stratosphere; PSCs were abundant over many high-latitude areas until dissipated by a big warming event, which started in the upper stratosphere during February and spread throughout the Arctic stratosphere in March. The size of the Arctic area of anomalously low total ozone in 2004-2005 was larger than in any year since 1997. The predominance of anomalously low total ozone values in the Arctic region in the winter of 2004-2005 is attributed to the very low stratospheric temperatures and meteorological conditions favorable for ozone destruction along with the continued presence of ozone destroying chemicals in the stratosphere.

A 2005 IPCC summary of ozone issues concluded that observations and model calculations suggest that the global average amount of ozone depletion has now approximately stabilized. Although considerable variability in ozone is expected from year to year, including in polar regions where depletion is largest, the ozone layer is expected to begin to recover in coming decades due to declining ozone-depleting substance concentrations, assuming full compliance with the Montreal Protocol.

Temperatures during the Arctic winter of 2006 stayed fairly close to the long-term average until late January, with minimum readings frequently cold enough to produce PSCs. During the last week of January, however, a major warming event sent temperatures well above normal — much too warm to support PSCs. By the time temperatures dropped back to near normal in March, the seasonal norm was well above the PSC threshold. Preliminary satellite instrument-generated ozone maps show seasonal

ozone buildup slightly below the long-term means for the Northern Hemisphere as a whole, although some high ozone events have occurred. During March 2006, the Arctic stratosphere poleward of 60° North Latitude was free of anomalously low ozone areas except during the three-day period from 17 March to 19 when the total ozone cover fell below 300 DU over part of the North Atlantic region from Greenland to Scandinavia.

The area where total column ozone is less than 220 DU (the accepted definition of the boundary of the ozone hole) was relatively small until around 20 August 2006. Since then the ozone hole area increased rapidly, peaking at 29 million km² 24 September. In October 2006, NASA reported that the year's ozone hole set a new area record with a daily average of 26 million km² between 7 September and 13 October 2006; total ozone thicknesses fell as low as 85 DU on 8 October. The two factors combined, 2006 sees the worst level of depletion in recorded ozone history. The depletion is attributed to the temperatures above the Antarctic reaching the lowest recording since comprehensive records began in 1979.

On October 2008 the Ecuadorian Space Agency published a report called HIPERION, a study of the last 28 years data from 10 satellites and dozens of ground instruments around the world among them their own, and found that the UV radiation reaching equatorial latitudes was far greater than expected, climbing in some very populated cities up to 24 UVI, the WHO UV Index standard considers 11 as an extreme index and a great risk to health. The report concluded that the ozone depletion around mid latitudes on the planet is already endangering large populations in this areas. Later, the CONIDA, the Peruvian Space Agency, made its own study, which found almost the same facts as the Ecuadorian study.

The Antarctic ozone hole is expected to continue for decades. Ozone concentrations in the lower stratosphere over Antarctica will increase by 5%–10% by 2020 and return to pre-1980 levels by about 2060–2075, 10–25 years later than predicted in earlier assessments. This is because of revised estimates of atmospheric concentrations of Ozone Depleting Substances — and a larger predicted future usage in developing countries. Another factor which may aggravate ozone depletion is the draw-down of nitrogen oxides from above the stratosphere due to changing wind patterns.

History of the research

The basic physical and chemical processes that lead to the formation of an ozone layer in the Earth's stratosphere were discovered by Sydney Chapman in 1930. These are discussed in Ozone-oxygen cycle — briefly, short-wavelength UV radiation splits an oxygen (O_2) molecule into two oxygen (O) atoms, which then combine with other oxygen molecules to form ozone. Ozone is removed when an oxygen atom and an ozone molecule "recombine" to form two oxygen molecules, i.e. $O + O_3 \rightarrow 2O_2$. In the 1950s, David Bates and Marcel Nicolet presented evidence that various free radicals, in particular hydroxyl (OH) and nitric oxide (NO), could catalyze this recombination reaction, reducing the overall amount of ozone. These free radicals were known to be present in the stratosphere, and so were regarded as part of the natural balance – it was

estimated that in their absence, the ozone layer would be about twice as thick as it currently is.

In 1970 Prof. Paul Crutzen pointed out that emissions of *nitrous* oxide (N_2O), a stable, long-lived gas produced by soil bacteria, from the Earth's surface could affect the amount of *nitric* oxide (NO) in the stratosphere. Crutzen showed that nitrous oxide lives long enough to reach the stratosphere, where it is converted into NO. Crutzen then noted that increasing use of fertilizers might have led to an increase in nitrous oxide emissions over the natural background, which would in turn result in an increase in the amount of NO in the stratosphere. Thus human activity could have an impact on the stratospheric ozone layer. In the following year, Crutzen and (independently) Harold Johnston suggested that NO emissions from supersonic aircraft, which fly in the lower stratosphere, could also deplete the ozone layer.

The Rowland-Molina hypothesis

In 1974 Frank Sherwood Rowland, Chemistry Professor at the University of California at Irvine, and his postdoctoral associate Mario J. Molina suggested that long-lived organic halogen compounds, such as CFCs, might behave in a similar fashion as Crutzen had proposed for nitrous oxide. James Lovelock (most popularly known as the creator of the Gaia hypothesis) had recently discovered, during a cruise in the South Atlantic in 1971, that almost all of the CFC compounds manufactured since their invention in 1930 were still present in the atmosphere. Molina and Rowland concluded that, like N_2O, the CFCs would reach the stratosphere where they would be dissociated by UV light, releasing Cl atoms. (A year earlier, Richard Stolarski and Ralph Cicerone at the University of Michigan had shown that Cl is even more efficient than NO at catalyzing the destruction of ozone. Similar conclusions were reached by Michael McElroy and Steven Wofsy at Harvard University. Neither group, however, had realized that CFCs were a potentially large source of stratospheric chlorine — instead, they had been investigating the possible effects of HCl emissions from the Space Shuttle, which are very much smaller.)

The Rowland-Molina hypothesis was strongly disputed by representatives of the aerosol and halocarbon industries. The Chair of the Board of DuPont was quoted as saying that ozone depletion theory is "a science fiction tale...a load of rubbish...utter nonsense". Robert Abplanalp, the President of Precision Valve Corporation (and inventor of the first practical aerosol spray can valve), wrote to the Chancellor of UC Irvine to complain about Rowland's public statements (Roan, p 56.) Nevertheless, within three years most of the basic assumptions made by Rowland and Molina were confirmed by laboratory measurements and by direct observation in the stratosphere. The concentrations of the source gases (CFCs and related compounds) and the chlorine reservoir species (HCl and $ClONO_2$) were measured throughout the stratosphere, and demonstrated that CFCs were indeed the major source of stratospheric chlorine, and that nearly all of the CFCs emitted would eventually reach the stratosphere. Even more convincing was the measurement, by James G. Anderson and collaborators, of chlorine monoxide (ClO) in the stratosphere. ClO is produced by the reaction of Cl with ozone — its observation thus demonstrated that Cl radicals not only were present in the stratosphere but also were actually involved

in destroying ozone. McElroy and Wofsy extended the work of Rowland and Molina by showing that bromine atoms were even more effective catalysts for ozone loss than chlorine atoms and argued that the brominated organic compounds known as halons, widely used in fire extinguishers, were a potentially large source of stratospheric bromine. In 1976 the United States National Academy of Sciences released a report which concluded that the ozone depletion hypothesis was strongly supported by the scientific evidence. Scientists calculated that if CFC production continued to increase at the going rate of 10% per year until 1990 and then remain steady, CFCs would cause a global ozone loss of 5 to 7% by 1995, and a 30 to 50% loss by 2050. In response the United States, Canada and Norway banned the use of CFCs in aerosol spray cans in 1978. However, subsequent research, summarized by the National Academy in reports issued between 1979 and 1984, appeared to show that the earlier estimates of global ozone loss had been too large.

Crutzen, Molina, and Rowland were awarded the 1995 Nobel Prize in Chemistry for their work on stratospheric ozone.

The ozone hole

The discovery of the Antarctic "ozone hole" by British Antarctic Survey scientists Farman, Gardiner and Shanklin (announced in a paper in *Nature* in May 1985) came as a shock to the scientific community, because the observed decline in polar ozone was far larger than anyone had anticipated. Satellite measurements showing massive depletion of ozone around the south pole were becoming available at the same time. However, these were initially rejected as unreasonable by data quality control algorithms (they were filtered out as errors since the values were unexpectedly low); the ozone hole was detected only in satellite data when the raw data was reprocessed following evidence of ozone depletion in *in situ* observations. When the software was rerun without the flags, the ozone hole was seen as far back as 1976.

Susan Solomon, an atmospheric chemist at the National Oceanic and Atmospheric Administration (NOAA), proposed that chemical reactions on polar stratospheric clouds (PSCs) in the cold Antarctic stratosphere caused a massive, though localized and seasonal, increase in the amount of chlorine present in active, ozone-destroying forms. The polar stratospheric clouds in Antarctica are only formed when there are very low temperatures, as low as -80 degrees C, and early spring conditions. In such conditions the ice crystals of the cloud provide a suitable surface for conversion of unreactive chlorine compounds into reactive chlorine compounds which can deplete ozone easily.

Moreover the polar vortex formed over Antarctica is very tight and the reaction which occurs on the surface of the cloud crystals is far different from when it occurs in atmosphere. These conditions have led to ozone hole formation in Antarctica. This hypothesis was decisively confirmed, first by laboratory measurements and subsequently by direct measurements, from the ground and from high-altitude airplanes, of very high concentrations of chlorine monoxide (ClO) in the Antarctic stratosphere.

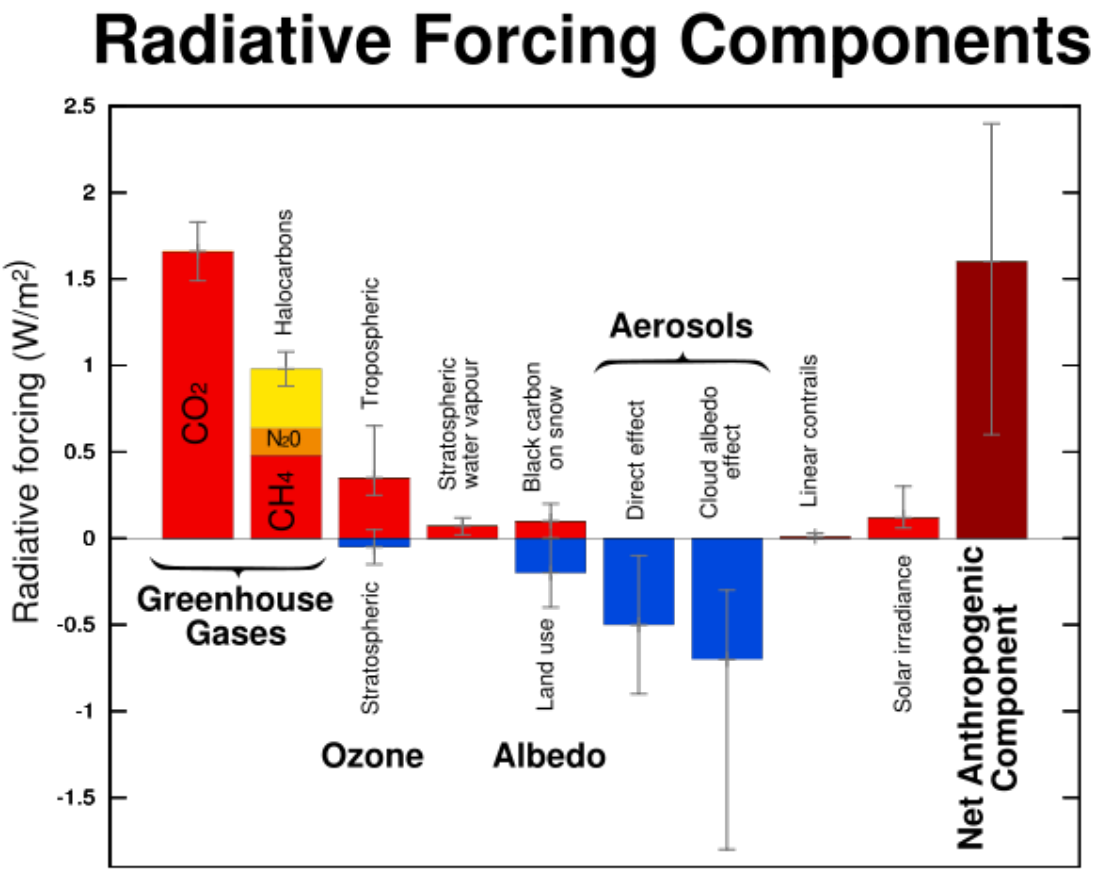
Alternative hypotheses, which had attributed the ozone hole to variations in solar UV radiation or to changes in atmospheric circulation patterns, were also tested and shown to be untenable.

Meanwhile, analysis of ozone measurements from the worldwide network of ground-based Dobson spectrophotometers led an international panel to conclude that the ozone layer was in fact being depleted, at all latitudes outside of the tropics. These trends were confirmed by satellite measurements. As a consequence, the major halocarbon producing nations agreed to phase out production of CFCs, halons, and related compounds, a process that was completed in 1996.

Since 1981 the United Nations Environment Programme has sponsored a series of reports on scientific assessment of ozone depletion, based on satellite measurements. The 2007 report showed that the hole in the ozone layer was recovering and the smallest it had been for about a decade. The 2010 report found that "Over the past decade, global ozone and ozone in the Arctic and Antarctic regions is no longer decreasing but is not yet increasing... the ozone layer outside the Polar regions is projected to recover to its pre-1980 levels some time before the middle of this century... In contrast, the springtime ozone hole over the Antarctic is expected to recover much later."

Ozone depletion and global warming

There are five areas of linkage between ozone depletion and global warming:



Radiative forcing from various greenhouse gases and other sources.

- The same CO_2 radiative forcing that produces global warming is expected to cool the stratosphere. This cooling, in turn, is expected to produce a relative *increase* in ozone (O_3) depletion in polar area and the frequency of ozone holes.
- Conversely, ozone depletion represents a radiative forcing of the climate system. There are two opposing effects: Reduced ozone causes the stratosphere to absorb less solar radiation, thus cooling the stratosphere while warming the troposphere; the resulting colder stratosphere emits less long-wave radiation downward, thus cooling the troposphere. Overall, the cooling dominates; the IPCC concludes that "*observed stratospheric O_3 losses over the past two decades have caused a negative forcing of the surface-troposphere system*" of about −0.15 ± 0.10 watts per square meter (W/m²).
- One of the strongest predictions of the greenhouse effect is that the stratosphere will cool. Although this cooling has been observed, it is not trivial to separate the effects of changes in the concentration of greenhouse gases and ozone depletion since both will lead to cooling. However, this can be done by numerical stratospheric modeling. Results from the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory show that above 20 km (12.4 miles), the greenhouse gases dominate the cooling.

- As noted under 'Public Policy', ozone depleting chemicals are also often greenhouse gases. The increases in concentrations of these chemicals have produced 0.34 ± 0.03 W/m² of radiative forcing, corresponding to about 14% of the total radiative forcing from increases in the concentrations of well-mixed greenhouse gases.
- The long term modeling of the process, its measurement, study, design of theories and testing take decades to document, gain wide acceptance, and ultimately become the dominant paradigm. Several theories about the destruction of ozone were hypothesized in the 1980s, published in the late 1990s, and are currently being proven. Dr Drew Schindell, and Dr Paul Newman, NASA Goddard, proposed a theory in the late 1990s, using a SGI Origin 2000 supercomputer, that modeled ozone destruction, accounted for 78% of the ozone destroyed. Further refinement of that model accounted for 89% of the ozone destroyed, but pushed back the estimated recovery of the ozone hole from 75 years to 150 years. (An important part of that model is the lack of stratospheric flight due to depletion of fossil fuels.)

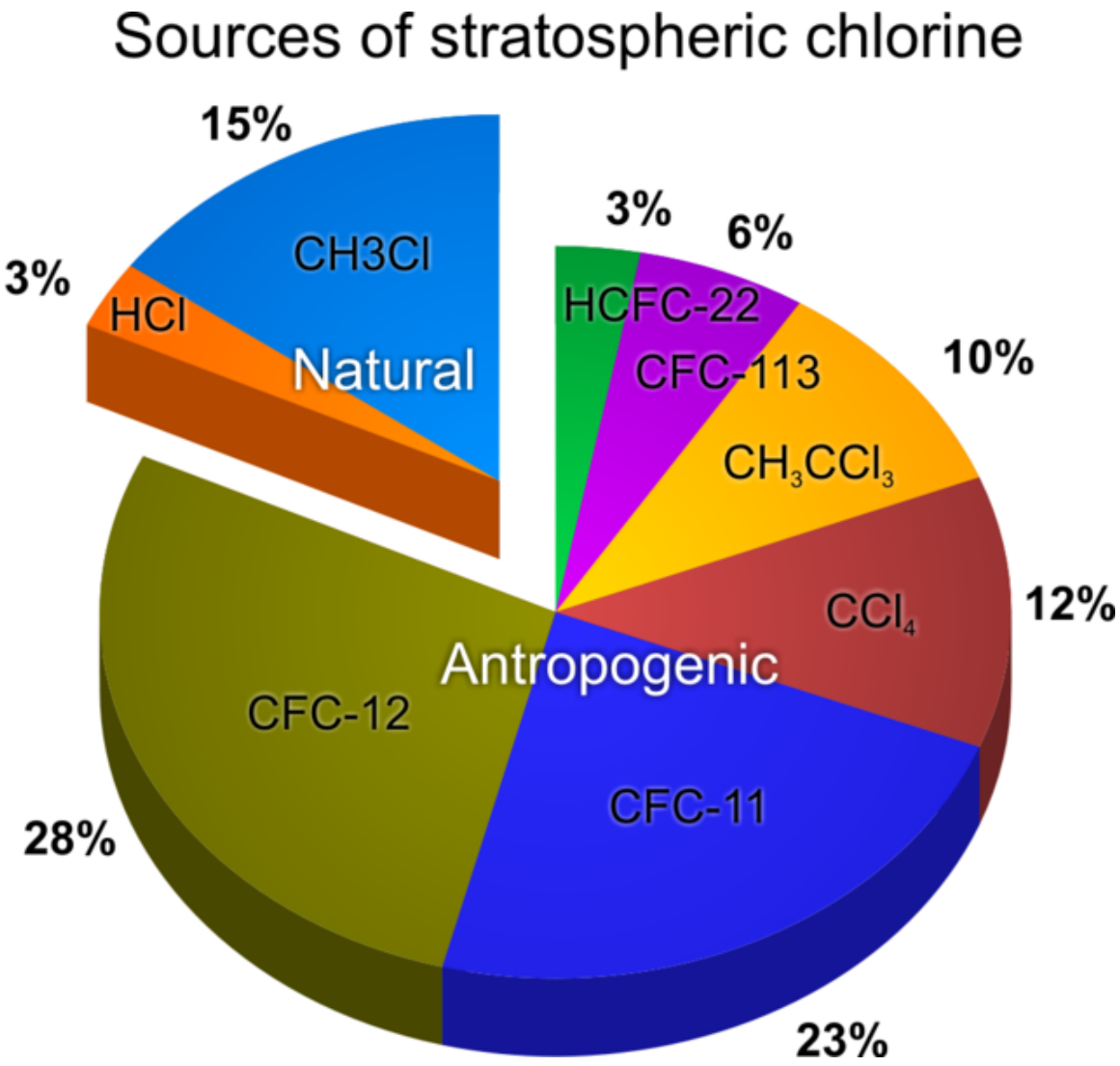
Misconceptions about ozone depletion

A few of the more common misunderstandings about ozone depletion are addressed briefly here; more detailed discussions can be found in the ozone-depletion FAQ.

CFCs are "too heavy" to reach the stratosphere

It is commonly believed that CFC molecules are heavier than air (nitrogen or oxygen), so that the CFC molecules cannot reach the stratosphere in significant amount. But atmospheric gases are not sorted by weight; the forces of wind can fully mix the gases in the atmosphere. Despite the fact that CFCs are heavier than air and with a long lifetime, they are evenly distributed throughout the turbosphere and reach the upper atmosphere.

Man-made chlorine is insignificant compared to natural sources



Another misconception is that "it is generally accepted that natural sources of tropospheric chlorine are four to five times larger than man-made one". While strictly true, *tropospheric* chlorine is irrelevant; it is *stratospheric* chlorine that affects ozone depletion. Chlorine from ocean spray is soluble and thus is washed by rainfall before it reaches the stratosphere. CFCs, in contrast, are insoluble and long-lived, allowing them to reach the stratosphere. In the lower atmosphere, there is much more chlorine from CFCs and related haloalkanes than there is in HCl from salt spray, and in the stratosphere halocarbons are dominant . Only methyl chloride which is one of these halocarbons has a mainly natural source , and it is responsible for about 20 percent of the chlorine in the stratosphere; the remaining 80% comes from man made sources.

Very violent volcanic eruptions can inject HCl into the stratosphere, but researchers have shown that the contribution is not significant compared to that from CFCs. A similar erroneous assertion is that soluble halogen compounds from the volcanic plume of Mount Erebus on Ross Island, Antarctica are a major contributor to the Antarctic ozone hole.

An ozone hole was first observed in 1956

G.M.B. Dobson (Exploring the Atmosphere, 2nd Edition, Oxford, 1968) mentioned that when springtime ozone levels over Halley Bay were first measured in 1956, he was surprised to find that they were ~320 DU, about 150 DU below spring levels, ~450 DU, in the Arctic. These, however, were at this time the known normal climatological values because no other Antarctic ozone data were available. What Dobson describes is essentially the *baseline* from which the ozone hole is measured: actual ozone hole values are in the 150–100 DU range.

The discrepancy between the Arctic and Antarctic noted by Dobson was primarily a matter of timing: during the Arctic spring ozone levels rose smoothly, peaking in April, whereas in the Antarctic they stayed approximately constant during early spring, rising abruptly in November when the polar vortex broke down.

The behavior seen in the Antarctic ozone hole is completely different. Instead of staying constant, early springtime ozone levels suddenly drop from their already low winter values, by as much as 50%, and normal values are not reached again until December.

The ozone hole should be above the sources of CFCs

Some people thought that the ozone hole should be above the sources of CFCs. However, CFCs are well mixed in the troposphere and the stratosphere. The reason for occurrence of the ozone hole above Antarctica is not because there are more CFCs concentrated but because the low temperatures help form polar stratospheric clouds. In fact, there are findings of significant and localized "ozone holes" above other parts of the earth.

The "ozone hole" is a hole in the ozone layer

There is a common misconception that “ozone hole” is really a hole in the ozone layer.When the "ozone hole" occurs, the ozone in the lower stratosphere is destroyed. The upper stratosphere is less affected, so that the amount of ozone over the continent decreases by 50 percent or even more. The ozone hole does not disappear through the layer; on the other hand, it is not a uniform 'thinning' of the ozone layer. It is a "hole" which is a depression, not in the sense of "a hole in the windshield."

ODS requirements in the Marine industry

IMO has amended MARPOL Annex VI Regulation 12 regarding ozone depleting substances.

As from 1 July 2010 all vessels where MARPOL Annex VI is applicable should have a list of equipment using ozone depleting substances. The list should include name of ODS, type and location of equipment, quantity in kg and date. All changes since that date should be recorded in a ODS Record book on board recording all intended or unintended releases to the atmosphere. Further more new ODS supply or landing to shore facilities

should be recorded as well. More info and how to draft a record book and an example of ODS list can be found in ANCO Maritime Activities Ltd web site.

World Ozone Day

In 1994, the United Nations General Assembly voted to designate the 16th of September as "World Ozone Day", to commemorate the signing of the Montreal Protocol on that date in 1987.