Anthropogenic Changes and the Atmosphere

The Atmosphere and Greenhouse Gases

- Review: Composition of Earth's Atmosphere (see Lecture 14)
  - Nitrogen (N2): 78.08%
  - Oxygen (O2): 20.95%
  - Argon (Ar): 0.93%
  - Carbon Dioxide (CO2): 380ppm (353ppm in 1990)
  - Neon (Ne): 18ppm
  - Helium (He): 5ppm
  - Methane (CH4): 2ppm
  - Krypton (Kr): 1ppm
  - Water vapor (H2O): variable
- Review: Greenhouse Effect (see Lecture 14)
  - Earth's equilibrium temperature is -18C/0F. The equilibrium T is the temperature the Earth has at the surface when insolation (received solar radiation) is in equilibrium with energy that is lost to space.
  - Due to the presence of greenhouse gases (presently mainly CO2 and water vapor), the actual surface T is 33C 59F higher: 15C/59F.
- Greenhouse Gases
  - H2O (most important greenhouse gas; huge variations due primarily to natural causes, i.e. climate and weather)
  - CO2: amount of CO2 in atmosphere has increased by 32% from 280ppm in 1800 to 370ppm in 2000
    * Causes for change: Natural: temporarily also from volcanic activity, but the contribution in historical times has been insignificant
    * Human: burning of biological mass and fossil fuels (80%)
    * Human: removal of rainforest (though the contribution of this is relatively small) (17.3%)
    * Human: cement production (smaller yet) (2.7%)

    NB: almost all of the current increase in CO2 is anthropogenic.
  - CH4: has increased 150% from 0.7ppm in 1750 to 2ppm in 2000; more effective greenhouse gas than CO2 but less relevant due to slower current increase. This problem will become more prominent as the population increase requires more farming.

    - Causes for change: Natural: wetlands (72%)
    - Natural: termites (12.5%)
    - Natural: ocean (6%)
    - Natural: other (9.5%)
    - Natural: recent global warming also releases methane in the tundra that has been "locked" in frozen ground (positive climate feedback)
    - Natural: potential release of large amounts of gas hydrates from submarine icy lenses could happen, if current warming persists (at which point this actually happens is currently unknown)
    - Natural: a natural gas seep off-shore Santa Barbara releases significant amounts though most may be dissolved in water, unless it is transported very quickly to the sea surface
    - Human: coal mining, natural gas, petroleum industry (27%)
    - Human: rice paddies (16%)
    - Human: cattle farming (enteric fermentation, animal wastes)(29%)
    - Human: waste disposal sites (sewage, landfill, biomass burning) (28%)

    NB: anthropogenic release is currently estimated to be 2.5 times larger than natural release.
  - N2O:
    - Causes for change: Human: agriculture (chemical fertilizer)
    - Human: car and truck engines
  - O3: protects from UV radiation in stratosphere but is a greenhouse gas and a pollutant in the troposphere
    - Causes for change: Natural: changes in solar activity (in stratosphere)
    - Human: cars and industry (troposphere)
  - CFCs: exclusively of human origin, does not occur naturally; greenhouse gas and destroyer of protecting stratospheric ozone layer; long lived; a single CFC molecule is therefore capable of destroying large amounts of ozone molecules
    - Sources: air conditioning and refrigerators
    - foam insulations
    - until recently: propellant in aerosol spray cans
    - most countries have banned CFCs and other ozone killers but some developing countries still produce CFCs

Greenhouse Gases and Their Relevance

There is almost 200 times more CO2 in the atmosphere than CH4, yet the warming by CH4 is relatively important because its ability to trap heat is 20 times stronger. According to the textbook, the contribution of each greenhouse gas to warming is:

Table 1: Relative Contribution to warming

Gas	relative contribution	ability to trap heat
CO2	60%	1
CH4	16%	21
CFCs	11%	12,000
tropospheric O3	8%	2000
N2O	5%	310

The Industrial Age and CO2

- CO2 measured from trapped bubbles in ice cores for times prior to 1958 and direct measurements in atmosphere since then
- industrial revolution at the end of 1700s started a steady increase in CO2
- increase from 280ppm in 1800 to 370ppm in 2000; the increase has accelerated within last 50 years
- current CO2 level is the highest in last 650,000 years
- U.S. major contributor (25% of world's CO2 production!)
- China and India catching up rapidly

Global Increase in Temperature

- The link between atmospheric CO2 increase and temperature increase is difficult to assess since global temperature depends on many factors, not just the atmospheric content of greenhouse gases. global temperature rose 1.0C within last 140 yrs

  Possible Reasons:

  - millennial warming (¡0.02C)
  - solar warming (0.2C)
  - industrial revolution (¿0.8C)
  - volcanism (insignificant)
- greatest increases in 1910-1945 and since 1976

- Abbott speculates that the first increase is due to increased sun activity (but sunspot maximum was actually in 1950s to 1960s) and lack of volcanism
- temperatures decreased between 1940 and 1970; the minimum in 60ies-70ies coincides with drop in solar activity
- second increase is most likely due to injection of greenhouse gases
- global average temperature rose by 0.4C between 1970 and 1990

Global Warming and the Oceans - Effects on The Carbon Cycle

- Carbon reservoirs on Earth are coupled (see APPENDIX C; lecture 15)
- changes in atmospheric CO2 therefore affect other reservoirs, such as oceans
- human CO2 production has actually risen faster than content in atmosphere -¿ some CO2 had to have gone somewhere else
- evidence points toward oceans
- some argue that increase in CO2 in oceans could be beneficial to increase photosynthesis and plankton production
- current estimates are that atmosphere stores about 46% of human produced CO2, oceans take up 29%, northern hemisphere forest regrowth 7% and other parts in the biosphere 18%
- and experiment off Hawaii therefore looks at the possibility of CO2 sequestration into the deep ocean
- however, recent findings indicate that oceans instead become more acidic
- profound negative impact for coral growth and shell producing life forms

Global Warming and Sea Level Rise

Rising temperatures lead to thermal expansion of the water in the oceans and melting of glaciers and ice sheets. Both results in a rise in sea level.

- In last 100 years, global sea level has risen by 15cm
- Estimated contributions to sea level rise: thermal expansion: 30%
- melting of glaciers: 20%
- melting of Greenland ice sheet: 20%

- melting of Antarctic ice sheet: unknown but likely large
- various model predictions range from 2-5C warming and a 40 - 200cm rise in sea level in next 100 years
- this is of the same order as the typical tidal reach and sea surface elevation due to low pressure in a hurricane
- consequences: flooding of coastal areas; landward migration of estuaries; displacement of millions of people

The Kyoto Protocol

- established in 1997
- realization that, in order to stabilize CO2 at 450 ppm, emission would have to fall below 1990 level
- industrial countries have to reduce to 5.2% below 1990 level by 2012
- 96 countries ratified, incl. E.U. and Japan which make up 37.4% of production in industrial countries
- need countries responsible of ¿ 50% to ratify
- U.S. (25% of total CO2 and 36.4% of production in industrial countries) bailed out; major argument against ratification: "this would hurt national economy"
- Russia (17.4%) and Poland (3%) initially pledged to ratify the protocol, which would account for 57.8% of production
- jeopardized when Russia bailed out in 2003, but ratified when it joined in October 2004
- European Union and Brazil proposed phasing out fossil fuel burning; Europe has increased the use of alternative energy (e.g. wind), while Brazil has a strong biodiesel program
- the Kyoto protocol is opposed by:
  - fossil fuel industry
  - oil-producing countries
  - major fossil fuel users (U.S., China)
- new threat: developing countries are catching up (e.g. China, India) though some was accounted for in Kyoto Protocol
- check out news clip

Table 2: A Table from the most recent "State of the World" (2006) issued by the World Watch Institute

Country	Carbon Emission (Mio tons)	per person) (tons)	Emission per GDP,PPP (tons per $Mio)	increase 1990-2004 (%)
China	1,021	0.8	158	+67%
India	301	0.3	99	+88%
Europe	955	2.5	94	+6%
Japan	338	2.7	95	+23%
United States	1,616	5.5	147	+19%

The Ozone Hole

- Ozone: solar radiation converts O2 to O3. Protective layer in 10-50km altitude
- lack in stratospheric ozone lets carginogenic UV radiation reach the Earth's surface, causing skin cancer, cataracts, impaired immune system, reduced crop yields
- stratospheric ozone attacked by human-made CFC and other halogen componds
- ozone "holes": sharp decrease in thickness of protective ozone layer in stratosphere
- process most effective at low temperatures and in presence of sunlight
- ozone holes therefore near poles; seasonal changes
- ozone destruction most severe in early spring
- decline first noticed in 1980s
- ozone hole caused by human action alone; no natural process known to destroy ozone layer
- chlorofluorocarbons (CFCs) attack and destroy ozone molecules in stratosphere
- sunlight breaks down CFCs; Cl recombines with one of the oxygen atoms of O3
- CFCs have very long lifetime so can destroy ozone over a long time
- it has been conjectured that the ozone hole will likely increase before the ozone layer recovers, despite recent efforts to reduce CFC input

- Montreal Protocol established in 1987: CFC phased out by 1996 by 140 countries, incl. U.S.
- unlike Kyoto, Montreal was ratified by many because the (sole) human cause of CFC production was more obvious
- effects from CFC reduction not expected to be effective before 2025
- in 2006, the Antarctic ozone hole was the largest ever
- another problem: other halocarbons - like hydrochloro-flourocarbons (HCFC) replaced CFCs. These are less destructive to the ozone layer but are nevertheless greenhouse gases. These will be phased out by 2030. HFCs (hydroflourocarbons) are also greenhouse gases but their lifetime in the atmosphere is significantly shorter than CFCs and HCFCs.

NB: the ozone hole does not contribute to global warming/global warming and the ozone hole are two phenomena that are not related. Ozone absorbs in the infrared (IR) part of the spectrum, but much more so in the ultraviolet (UV) part. The ozone hole lets more UV light to Earth's surface which does not directly warm the planet.

Fossil Fuels and Pollution

- Consumption of Energy in the U.S., 1997

Table 3: Consumption of Energy in the U.S., 1997

Energy Resource	Fraction 1997	Fraction 2002
Petroleum	41%	41%
Natural Gas	24%	22%
Coal	22%	24%
Nuclear	7%	9%
Hydroelectric	5%	3%
others	1%	1%

- Primary Pollutants from Burning of Fossil Fuels
  - NB: the greenhouse gas CO2 is not considered a pollutant and is therefore not included in this table!
  - NB: Ozone near the surface is actually a pollutant. Surface ozone is the major constituent of smog and is most severe on sunny days when sunlight interacts with nitrous oxides from car engines to form ozone. Ozone is unhealtyh and causes crop damage and corrodes material.

Table 4: Primary Pollutants from Burning of Fossil Fuels

Pollutant	Fraction
Carbon Monoxide	49.1%
Sulfur Oxides	16.4%
Nitrogen Oxides	14.8%
Volatile Organics	13.6%
Particulates	6.0%

- Sources of the Primary Pollutants

  Given the fact that the burning of fossil fuels causes global warming and pollutes the atmosphere, and given the fact that some fossil fuels will be used up within a century, it seems clear that we need to cut back our dependency on fossil fuels. Nevertheless the World Summit on Sustainable Development in Johannesburg/South Africa in the summer of 2002 displayed the great dilemma. The European Union and Brazil proposed the adoption of specific numerical targets for the phasing out of fossil fuels and the increase in usage of renewable energy worldwide. This was strongly opposed by the fossil fuel industry, the governments of most oil producing countries and major fossil fuel consumers, including the U.S. and China.

Table 5: Sources of the Primary Pollutants

Process	Fraction
Transportation	46.2%
Stationary Source Fuel Combustion	27.3%
Industrial Processes	15.0%
Miscellaneous	9.0%
Solid Waste Disposal	2.5%

- Acid Rain

  - burning of coal, especially low-grade coal that contains large amounts of Pyrite (FeS2) produces SO2
  - SO2 mixes with rain in air to form sulfuric acid the main constituent of acid rain; much more aggressive than carbonic acid
  - some nitrogen oxides (NOx) mix with rain to form nitric acid, also a contributer to acid rain
  - Acid rain is responsible for massive fish kills in freshwater lake (e.g. Scandinavia, Canada, northeastern U.S.)

- Survey of 1000 lakes and thousands of km of streams showed that 75% of lakes and 50% of streams were acidified
- in U.S. the pH value is lowest along the coal mining and burning areas in the Eastern U.S. (sulfuric acid), and in Southern California, where traffic related acid fog is found (nitric acid)
- acid rain is responsible for massive tree kills, especially conifers
- mountain forests damaged, particularly at higher elevations
- $1 billion of damage each year to buildings and monuments
- Relationship between acid rain and coal burning firmly established as damage is most severe downwind from coal burning power plants
- About 50% of Canada's fallout has source in U.S.
- Clean Air Act: passed by U.S. congress in 1991. Legislature requires power plants to reduce annual SO_2 production by 10Mio tons and annual NO_2 production by 2 Mio tons by 2000.
- Deregulation of U.S. railroad system lowered transport costs to make transport of higher grade western U.S. coal to eastern U.S. more attractive.

Summary

There are basically four problems with a fossil fuel-based society like ours:

- hydrocarbons, such as oil, are non-renewable and resources are probably exhausted within a few decades but 100 years at most; natural gas will last a little longer; so will coal (300 years)
- burning fossil fuels pollutes the environment (gas burns "cleaner" but still pollutes)
- burning fossil fuels accelerates the greenhouse effect
- burning coal causes acid rain

Action is Needed NOW - Some Suggestions

- temporary transition to "cleaner burning" natural gas instead of oil and coal is ok as short-term solution, but only as that
- nuclear power "clean" but poses waste disposal, accident and public security problems
- "traditional" alternative energy (incl. hydroelectric power, geothermal, solar, wind, biomass burning) each have disadvantages, the most serious being that they cannot replace the massive amount of energy produced by fossil fuels

- "modern" alternate energy (incl. fuel cells, hydrogen-based society, fusion) is in its infancy; some of which may never be realized
- more efficient use of energy: more fuel-efficient cars; technically feasible but repeatedly discouraged by oil-industry, especially in U.S.; replace incandescent light bulbs with flourescent tubes; more energy-efficient household appliances; turn computer off instead of putting it in sleep mode
- societal changes/conservation

Related Web Sites

- Intergovernmental Panel on Climate Change
- Real Climate
- Stephen Schneider at Stanford
- Worldwatch Institute

Recommended Reading

Not required to pass the tests, but for the interested souls:

- "Earth's Climate, Past and Future" by William F. Ruddiman, 2000. W.H. Freeman and Company, ISBN: 0-7167-3741-8
- "State of the World" by The Worldwatch Institute, W.W. Norton and Company. Topics change from year to year but the 2004 book (ISBN: 0-393-32539-3) was on consumerism and globalization, waste/recycling of resources, catch-up of developing countries, water productivity and increasing shortage. Earlier books were on energy resources, greenhouse effect, Kyoto Protocol and the spread of and fight against diseases.
- check out Worldwatch Institute web site
- "Earthshock" by Andrew Robinson, 1993, Thames and Hudson, ISBN: 0-500-27738-9
- "Global Warming" by John Houghton, 1999, Cambridge Univ. Press, ISBN: 0-521-62932-2