Climate Change

Greenhouse Warming Prediction

Major information sources:
Climate Change: IPCC Synthesis Reports at http://www.ipcc.ch/
Vital Climate Graphics, at http://www.grida.no/climate/vital/
Climate Change Impacts on US, at http://www.gcrio.org/NationalAssessment/
Energy Predictions

2% growth per year, or doubling in 35 years (shortcut: 70%/=doubling)
Fossil fuel contribution >80% globally

Sources:
Energy Information Administration (EIA);
International Energy Agency (IEA)

(Quadrillion (1E15) Btu)
1 quad = 1E15 British thermal units = 2.9E11 kWh
What is the evidence, causes and consequences of changes in Earth’s climate since the pre-industrial era?

- Has Earth’s climate changed since the pre-industrial era at the regional and/or global scale? If so, what part, if any, of the observed changes can be attributed to human influence and what part, if any, can be attributed to natural phenomena? What is the basis for that attribution?

- What is known about the environmental, social, and economic consequences of climate changes since the pre-industrial era with an emphasis on the last 50 years?

IPCC III, 2001
Integrated Framework of Climate Change

Schematic and simplified representation of integrated assessment framework for considering anthropogenic climate change. Yellow arrows show cycle of cause and effect among four quadrants in figure, while blue arrow indicates societal response to climate change impacts.
The Climate System
Direction of air flow and ascent and descent of air masses in convective (or Hadley) cells determine Earth’s climatic zones and biomes.
Global Ocean circulation: Ocean Conveyer
Greenhouse Effect

Solar radiation passes through the clear atmosphere.
Incoming solar radiation: 343 Watt per m²

Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules. The direct effect is the warming of the earth’s surface and the troposphere.

Solar energy is absorbed by the earth’s surface and warms it...
Incoming solar energy: 343 Watt per m²
... and is converted into heat causing the emission of longwave (infrared) radiation back to the atmosphere.

Net incoming solar radiation: 240 Watt per m²
Outgoing solar radiation: 103 Watt per m²
Net outgoing Infrared radiation: 240 Watt per m²

Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.
Main Greenhouse Gases

<table>
<thead>
<tr>
<th>Greenhouse gases</th>
<th>Chemical formula</th>
<th>Pre-industrial concentration</th>
<th>Concentration in 1994</th>
<th>Atmospheric lifetime (years)***</th>
<th>Anthropogenic sources</th>
<th>Global warming potential (GWP)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon-dioxide</td>
<td>CO₂</td>
<td>278 000 ppbv</td>
<td>358 000 ppbv</td>
<td>Variable</td>
<td>Fossil fuel combustion Land use conversion Cement production</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>700 ppbv</td>
<td>1721 ppbv</td>
<td>12.2 +/- 3</td>
<td>Fossil fuels Rice paddies Waste dumps Livestock</td>
<td>21 **</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>N₂O</td>
<td>275 ppbv</td>
<td>311 ppbv</td>
<td>120</td>
<td>Fertilizer industrial processes combustion</td>
<td>310</td>
</tr>
<tr>
<td>CFC-12</td>
<td>CCl₂F₂</td>
<td>0</td>
<td>0.503 ppbv</td>
<td>102</td>
<td>Liquid coolants. Foams</td>
<td>6200-7100 ****</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>CHClF₂</td>
<td>0</td>
<td>0.105 ppbv</td>
<td>12.1</td>
<td>Liquid coolants</td>
<td>1300-1400 ****</td>
</tr>
<tr>
<td>Perfluoromethane</td>
<td>CF₄</td>
<td>0</td>
<td>0.070 ppbv</td>
<td>50 000</td>
<td>Production of aluminium</td>
<td>6 500</td>
</tr>
<tr>
<td>Sulphur hexa-fluoride</td>
<td>SF₆</td>
<td>0</td>
<td>0.032 ppbv</td>
<td>3 200</td>
<td>Dielectric fluid</td>
<td>23 900</td>
</tr>
</tbody>
</table>

Global Warming Potential (GWP)
- used to compare the abilities of different greenhouse gases to trap heat in the atmosphere (heat-absorbing ability and decay rate)
- provides a construct for converting emissions of various gases into a common measure (relative to CO₂)
Radiative Forcing: Cooling and Heating

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W m⁻²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
<td>CO₂: 1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>N₂O: 0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>CH₄: 0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Halocarbons: 0.34 [0.31 to 0.37]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Ozone</td>
<td>Stratospheric: -0.05 [-0.15 to 0.05]</td>
<td>Continental</td>
<td>Med</td>
</tr>
<tr>
<td></td>
<td>Tropospheric: 0.35 [0.25 to 0.65]</td>
<td>Global to global</td>
<td>Med</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>Stratospheric water vapour from CH₄</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Surface albedo</td>
<td>Land use: 0.07 [0.02 to 0.12]</td>
<td>Continental</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Black carbon on snow: -0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med - Low</td>
</tr>
<tr>
<td></td>
<td>0.1 [0.0 to 0.2]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Aerosol</td>
<td>Direct effect: -0.5 [-0.9 to -0.1]</td>
<td>Continental to global</td>
<td>Med - Low</td>
</tr>
<tr>
<td></td>
<td>Cloud albedo effect: -0.7 [-1.8 to -0.3]</td>
<td>Continental to global</td>
<td>Low</td>
</tr>
<tr>
<td>Linear contrails</td>
<td>0.01 [0.003 to 0.03]</td>
<td>Continental</td>
<td>Low</td>
</tr>
<tr>
<td>Natural</td>
<td>Solar irradiance: 0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Total net anthropogenic: 1.5 [0.6 to 2.4]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LOSU is level of scientific understanding
IPCC IV, 2007 SFPM
Seasonal Landcover and Arctic Sea Ice
PHOTO CREDIT: NASA/Goddard Space Flight Center Scientific Visualization Studio.
Ice: Earth’s Thermometer
Ice House World: Pleistocene Glaciation

Pleistocene: 1.6 Ma – 10 ka
Wisconsin/Würm glaciation peaks ~18000 years ago
Vostok Ice and Modern Records

http://www.koshland-science-museum.org/exhibitgcc/index.jsp
Atmospheric Concentrations: Human Influence?

Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colors for different studies) and atmospheric samples (red lines). Corresponding radiative forcings are shown on right hand axes of large panels.
Primary determinants of carbon dioxide (CO₂) emission is amount of carbon in fuel. Gasoline carbon content per gallon is 2,421 grams.

To calculate the CO₂ emissions from a gallon of fuel, carbon emissions are multiplied by the ratio of the molecular weight of CO₂ (m.w. 44) to the molecular weight of carbon (m.w.12): 44/12. (oxidation factor (oxidized C) is 0.99)

CO₂ emissions from a gallon of gasoline = 2,421 grams x 0.99 x (44/12) = 8,788 grams/gallon = 8.8 kg/gallon = 19.4 pounds/gallon

<table>
<thead>
<tr>
<th>FUEL</th>
<th>INPUT amount</th>
<th>INPUT units</th>
<th>OUTPUT in Pounds CO2</th>
<th>OUTPUT in kg CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>1.00</td>
<td>gallons</td>
<td>=</td>
<td>19.37</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>barrels</td>
<td>=</td>
<td>813.54</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>Million BTU</td>
<td>=</td>
<td>154.91</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>Gigajoule</td>
<td>=</td>
<td>146.83</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>1.00</td>
<td>1000 cubic feet</td>
<td>=</td>
<td>120.59</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>cubic meters</td>
<td>=</td>
<td>4.24</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>million Btu</td>
<td>=</td>
<td>116.37</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>Gigajoules</td>
<td>=</td>
<td>110.30</td>
</tr>
<tr>
<td>Coal-electric</td>
<td>1.00</td>
<td>million Btu</td>
<td>=</td>
<td>207.91</td>
</tr>
<tr>
<td>utility</td>
<td>1.00</td>
<td>Gigajoules</td>
<td>=</td>
<td>197.07</td>
</tr>
</tbody>
</table>

http://www.rprogress.org/energyfootprint/
Changes in Temperature, Sea Level and NH Snow Cover

Changes are relative to corresponding averages for period 1961-1990. Smoothed curves represent decadal averaged values; circles show yearly values. Shaded areas are uncertainty intervals.

IPCC IV, 2007
2004 Global temperature anomalies

Places on Earth where average surface temperatures were warmer (yellows and reds), cooler (blues), or same as (white) climatological average (1951-1980). Areas most above average: Alaska (upper right), Antarctic Peninsula (bottom), and Central Asia (right of center), particularly region just east of the Caspian Sea.

Average global temperature anomaly. Upward trend since late 1800s is clear, and so is more rapid increase in temperatures since ~1980. Solid red line is five-year running average.

http://earthobservatory.nasa.gov
Components of climate system and interactions among them, including human component. All components have to be modeled as a coupled system that includes oceans, atmosphere, land, cryosphere and biosphere.

GCM, or General Circulation Model.

Comparison between Models and Observation

Comparison between modeled and observations of temperature rise since the year 1860

(a) Natural forcing only
(b) Anthropogenic forcing only
(c) Natural + Anthropogenic forcing

IPCC III, 2001
Climate Model (NCAR)

Short-term Climate Change from NCAR Global Circulation Model (2002)
Approach:
Pose and examine several major questions

Humans are "very likely" heating up the planet.
1990: "The size of this warming is broadly consistent with prediction of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase **could be largely due to** this **natural variability**" 

1995: "the balance of evidence suggests a **discernible human influence** on the climate"

2001: "most of the observed warming over the last 50 years is **likely** to have been **due** to the increase in greenhouse gas concentrations"

2007: "Most of the observed increase in globally averaged temperatures since the mid-20th century is **very likely due** to the observed increase in **anthropogenic** greenhouse gas concentrations."
Confidence Levels

The following terms are used to indicate the assessed likelihood, using expert judgment, of an outcome or a result:

- **Virtually certain** > 99% probability of occurrence
- **Extremely likely** > 95%
- **Very likely** > 90%
- **Likely** > 66%
- **More likely than not** > 50%
- **Unlikely** < 33%
- **Very unlikely** < 10%
- **Extremely unlikely** < 5%

IPCC 2007, Summary for Policymakers:

*Humans are "very likely" heating up the planet.*
Global Temperature Change

Scenarios:
What are they? Why use them?

• neither predictions nor forecasts
• alternative images of how the future might unfold
• A tool to analyze how driving forces may influence future emission outcomes and to assess associated uncertainties

IPCC Special Report on Emission Scenarios
Projections for the 21st Century

(a) CO₂ emissions

(b) CO₂ concentrations

(c) SO₂ emissions

(d) Temperature change

(e) Sea level rise
21st C Warming Prediction by IPCC IV (2007)

Constant 2000 – 0.6 °C
B1 – low scenario (1.8 °C)
A1B – medium scenario (2.8 °C)
A1F1 – high scenario (4.0 °C)
IPCC 4 (2007) – Key Findings

- It is very likely that human activities are causing global warming.
- Probable temperature rise by the end of the century will be between 1.8 and 4°C (3.2-7.2°F), with best estimate around 3°C.
- Possible temperature rise by the end of the century ranges between 1.1 and 6.4°C (2-11.5°F).
- Sea levels are likely to rise by 28-43cm (LOW ESTIMATE !)
- Arctic summer sea ice is likely to disappear in second half of century.
- It is very likely that parts of the world will see an increase in the number of heat waves.
- Climate change is likely to lead to increased intensity of tropical storms.
On aerosols (new to IPCC iv)
Anthropogenic contributions to aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect, with a total direct radiative forcing of $-0.5 \ [-0.9 \text{ to } -0.1] \text{ W m}^{-2}$ and an indirect cloud albedo forcing of $-0.7 \ [-1.8 \text{ to } -0.3] \text{ W m}^{-2}$. These forcings are now better understood than at the time of the [2001 report] due to improved in situ, satellite and ground-based measurements and more comprehensive modelling, but remain the dominant uncertainty in radiative forcing. Aerosols also influence cloud lifetime and precipitation.

On “hockey stick” debate
"Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years." and “Average Northern Hemisphere temperatures during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1,300 years. Some recent studies indicate greater variability in Northern Hemisphere temperatures than suggested in the [2001 report], particularly finding that cooler periods existed in the 12 to 14th, 17th, and 19th centuries.”
After CO$_2$ emissions are reduced and atmospheric concentrations stabilize, surface air temperature continues to rise slowly for a century or more. Thermal expansion of ocean continues long after CO$_2$ emissions are reduced, and melting of ice sheets continues to contribute to sea-level rise for many centuries. (Illustration for stabilization at level between 450 and 1,000 ppm.)
Climate Change Impacts

Impacts on...

- Health
  - Weather-related mortality
  - Infectious diseases
  - Air-quality respiratory illnesses

- Agriculture
  - Crop yields
  - Irrigation demands

- Forest
  - Forest composition
  - Geographic range of forest
  - Forest health and productivity

- Water resources
  - Water supply
  - Water quality
  - Competition for water

- Coastal areas
  - Erosion of beaches
  - Inundation of coastal lands
  - Additional costs to protect coastal communities

- Species and natural areas
  - Loss of habitat and species
  - Cryosphere: diminishing glaciers

Source: United States environmental protection agency (EPA)
Global Temperature Change Predictions

IPCC, http://www.grida.no/climate/
Thinning of Arctic Sea Ice and Ice Sheets

Ice Melting and sea-level rise:
- glaciers and ice caps: 0.5m
- Greenland ice sheet: 7m
- Antarctic ice sheet: 70m

Note: comparison of sea ice draft data acquired on submarine surveys between 1959 and 1979 with data from 1988-1997 indicates that mean ice draft at the end of the melt season has decreased by 1.0 m from 5.1 m to 4.1 m. Value is down by 40%.

Sea Level Rise

Recent Sea Level Rise
23 Annual Tide Gauge Records
- Three Year Average
- Satellite Altimetry

Post-Glacial Sea Level Rise

Sea level rise scenarios for 2100
Solid lines represent various scenarios including changes in aerosols beyond 1990. Dashed lines show the scenarios with constant 1990 aerosol.
Sea level rise: examples

Potential impact of sea level rise: Nile Delta

Population: 3,800,000
Cropland (Km²): 1,800

Potential impact of sea level rise on Bangladesh

Today
Total population: 112 Million
Total land area: 134,000 km²

1.5 m - Impact
Total population affected: 17 Million (15%)
Total land area affected: 22,000 km² (18%)

Sources: Otto Simonetti, UNEP/GRID Geneva; Prof. G. Sestini, Florence; Remote Sensing Centre, Carpo; DIERCKE, Weltwirtschaftsdaten.
Sea-level Rise

Make floodmaps:
http://flood.firetree.net/

Table 1. Total Surface Area Inundated and Population at Risk at Global and Regional Scales

<table>
<thead>
<tr>
<th>Sea Level Rise, m</th>
<th>Inundated Area, × 1000 km²</th>
<th>Population Affected, millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1054.99</td>
<td>107.94</td>
</tr>
<tr>
<td>2</td>
<td>1312.97</td>
<td>175.10</td>
</tr>
<tr>
<td>3</td>
<td>1538.58</td>
<td>233.99</td>
</tr>
<tr>
<td>4</td>
<td>1775.24</td>
<td>308.08</td>
</tr>
<tr>
<td>5</td>
<td>2004.37</td>
<td>376.26</td>
</tr>
<tr>
<td>6</td>
<td>2193.30</td>
<td>431.44</td>
</tr>
<tr>
<td>Southeastern United States (B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>62.28</td>
<td>2,639,650</td>
</tr>
<tr>
<td>2</td>
<td>104.51</td>
<td>5,492,852</td>
</tr>
<tr>
<td>3</td>
<td>137.35</td>
<td>8,706,661</td>
</tr>
<tr>
<td>4</td>
<td>164.76</td>
<td>13,217,481</td>
</tr>
<tr>
<td>5</td>
<td>190.62</td>
<td>17,086,124</td>
</tr>
<tr>
<td>6</td>
<td>210.40</td>
<td>19,271,168</td>
</tr>
</tbody>
</table>

Eos, Vol. 88, No. 9, 27 February 2007
Hurricane Katrina
(August 05)

Cat 5, to 4 at landfall
3-4m storm surge
Cost of Extreme Weather

Economic losses from catastrophic weather events have risen globally 10-fold (inflation-adjusted) from 1950s to 1990s.

Projected Precipitation and Water Usage

Changes in precipitation for 2090–2099, relative to 1980–1999. A1B scenario for December to February (left) and June to August (right).

Population growth and projected excess water usage in 2025

Maya Civilization (3-10\textsuperscript{th} C)

- Yucatan Peninsula (Meso-America)
- Rapid decline in 10\textsuperscript{th} C
- Likely related to drought from shifting Intertropical Convergence Zone (ITCZ), which is a belt of high precipitation.
## Health and Climate Change

<table>
<thead>
<tr>
<th>Disease</th>
<th>Vector</th>
<th>Population at risk (million)</th>
<th>Number of people currently infected or new cases per year</th>
<th>Present distribution</th>
<th>Likelihood of altered distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaria</td>
<td>Mosquito</td>
<td>2,400²</td>
<td>300-500 million</td>
<td>Tropics and Subtropics</td>
<td>Highly likely</td>
</tr>
<tr>
<td>Schistosomiasis</td>
<td>Water snail</td>
<td>600</td>
<td>200 million</td>
<td>Tropics and Subtropics</td>
<td>Very likely</td>
</tr>
<tr>
<td>Lymphatic Filariasis</td>
<td>Mosquito</td>
<td>1,094³</td>
<td>117 million</td>
<td>Tropics and Subtropics</td>
<td>Likely</td>
</tr>
<tr>
<td>African Trypanosomiasis (Sleeping sickness)</td>
<td>Tsetse fly</td>
<td>55⁴</td>
<td>250,000 to 300,000 cases per year</td>
<td>Tropical Africa</td>
<td>Unknown</td>
</tr>
<tr>
<td>Dracunculiasis (Guinea worm)</td>
<td>Crustacean (Copepod)</td>
<td>100⁵</td>
<td>100,000 per year</td>
<td>South Asia, Arabian Peninsula, Central-West Africa</td>
<td>Unknown</td>
</tr>
<tr>
<td>Leishmaniasis</td>
<td>Phlebotomine sand fly</td>
<td>350</td>
<td>12 million infected, 500,000 new cases per year⁶</td>
<td>Asia, Southern Europe, Africa, Americas</td>
<td>Unknown</td>
</tr>
<tr>
<td>Onchocerciasis (River blindness)</td>
<td>Black fly</td>
<td>123</td>
<td>17.5 million</td>
<td>Africa, Latin America</td>
<td>Unknown</td>
</tr>
<tr>
<td>American Trypanosomiasis (Chagas disease)</td>
<td>Triatome bug</td>
<td>100⁷</td>
<td>18 million</td>
<td>Central and South America</td>
<td>Unknown</td>
</tr>
<tr>
<td>Dengue</td>
<td>Mosquito</td>
<td>1,800</td>
<td>10-30 million per year</td>
<td>All Tropical countries</td>
<td>Unknown</td>
</tr>
<tr>
<td>Yellow Fever</td>
<td>Mosquito</td>
<td>450</td>
<td>more than 5,000 cases per year</td>
<td>Tropical South America, Africa</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

1. Top three entries are population-prorated projections, based on 1989 estimates.
5. Ranque, personal communication.
6. Annual incidence of visceral leishmaniasis; annual incidence of cutaneous leishmaniasis is 1-1.5 million cases/yr (PAHO, 1994).

Source: Climate change 1995, impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.
Malaria and Temperature Rise (~1°C)

Infectious parasitic disease transmitted to humans via bite of mosquito. Chills and fever for several hours and occurring every three or four days. If not treated, spleen and liver become enlarged, anemia develops, and jaundice appears. Death may occur from general debility, anemia, or clogging of vessels of cerebral tissues by affected red blood cells.

http://www.cdc.gov/

Martens et al., 1995, Environmental Health Perspectives.
Dengue Fever and Temperature Rise

Sudden onset of fever, severe headache, myalgias and arthralgias, leukopenia, thrombocytopenia and hemorrhagic manifestations

Occasionally produces shock and hemorrhage, leading to death

Globally, there are an estimated 50 to 100 million cases of dengue fever (DF) and several hundred thousand cases of dengue hemorrhagic fever (DHF) per year

Average case fatality rate of DHF is about 5%

http://www.cdc.gov/
Health: Temperature and Heat Predictions

Both models project substantial increases in the July heat index (which combines heat and humidity) over the 21st Century. These maps show the projected increase in average daily July heat index relative to the present. The largest increases are in the southeastern states, where the Canadian model projects increases of more than 25°F. For example, a July day in Atlanta that now reaches a heat index of 105°F would reach a heat index of 115°F in the Hadley model, and 130°F in the Canadian model.

Heat Related Deaths - Chicago, July 1995

This graph tracks maximum temperature (Tmax), heat index (HI), and heat-related deaths in Chicago each day from July 11 to 23, 1995. The gray line shows maximum daily temperature, the blue line shows the heat index, and the bars indicate number of deaths for the day.

Average Summer Mortality Rates
Attributed to hot weather episodes
Examples from the Northeast

Amplified by urban heat island effect, number of days over 90°F is projected to increase this century until, some cities could experience nearly an entire summer of above 90°F daytime heat.

Union Concerned Scientists, 2006
http://www.climatechoices.org/ne/pix_ne/nereport.gif
Policy: Kyoto Protocol (1997; ratified in 2004)
Started on 2/16/2005

Industrialized countries reduce emissions of greenhouse gases by 5.2% compared to 1990 (compared to expected 2010 emissions levels, this is a ~30% cut).
National targets range from 8% reductions for the European Union to 7% for the US, 6% for Japan, 0% for Russia, and permitted increases of 8% for Australia and 10% for Iceland.
There are three ways to reduce energy-related carbon emissions: **reducing demand for energy, adopting more energy-efficient equipment, and switching to less carbon-intensive or non-carbon fuels.**
Emissions trading allows countries to sell extra amounts to other countries.
Kyoto’s 1990 Levels and 2002 Greenhouse Gas Emissions


Time to Check Emissions
Many countries have approved the Kyoto Protocol, which is intended to reduce global emissions of heat-trapping gases. Only industrial nations that have signed the agreement must reduce their emissions. The United States and Australia are among those that have not approved the accord.

RATIFIED KYOTO ACCORD

- INDUSTRIALIZED (Emissions must be reduced to below 1990 levels during the 2008-12 period)
- DEVELOPING (Voluntary commitment to develop ways to limit growth of emissions)

COUNTRIES BOUND BY KYOTO TARGETS IN BOLD

- United States
- China
- Russia
- India
- Japan
- Germany
- Brazil
- Canada
- Britain
- Italy
- France
- South Korea
- Australia
- Ukraine
- Mexico
- Indonesia
- Iran
- South Africa
- Spain
- Poland
- Saudi Arabia
- Argentina
- Pakistan
- Thailand
- Venezuela
- Netherlands
- North Korea
- Uzbekistan
- Egypt
- Malaysia

PER CAPITA EMISSIONS TONS OF CARBON EQUIVALENT

- United States: 6.5
- China: 1.1
- Russia: 3.6
- India: 0.5
- Japan: 2.9
- Germany: 3.4
- Brazil: 1.4
- Canada: 6.4
- Britain: 2.9
- Italy: 2.6
- France: 2.5
- South Korea: 3.1
- Australia: 7.3
- Ukraine: 2.9
- Mexico: 1.4
- Indonesia: 0.7
- Iran: 1.9
- South Africa: 2.6
- Spain: 2.7
- Poland: 2.6
- Saudi Arabia: 4.3
- Argentina: 2.2
- Pakistan: 0.6
- Thailand: 1.2
- Venezuela: 2.7
- Netherlands: 3.6
- North Korea: 2.6
- Uzbekistan: 2.0
- Egypt: 0.8
- Malaysia: 2.0

Emissions figures include carbon dioxide, methane, nitrous oxide and three fluorinated greenhouse gases, resulting from land use change and deforestation. If included, the amounts would probably rise significantly for Brazil, Indonesia, and Malaysia.

Source: Climate Analysis Indicators Tool from the World Resources Institute

→ Redo: Climate treaty at Copenhagen (December, 2009)
Climate Change Impacts on the United States: Consequences of Climate Variability and Change

The objectives of the National Assessment:

- to synthesize, evaluate and report on what we presently know about the potential consequences of climate variability and change for the United States in the 21st century
- to identify key climatic vulnerabilities of particular regions and sectors
  - in context of other changes in nation’s environment, resources, and economy
- to identify highest priority uncertainties about which we must know more to understand climate impacts, vulnerabilities and our ability to adapt

Overview

Humanity’s influence on the global climate will grow in the coming century. Increasingly, there will be significant climate-related changes that will affect each one of us.

We must begin now to consider our responses, as the actions taken today will affect the quality of life for us and future generations.

http://www.usgcrp.gov/usgcrp/Library/nationalassessment/overview.htm
Agriculture and Forest Sectors

**KEY ISSUES**

- Crop Yield Changes and Associated Economic Consequences
- Changing Water Demands for Irrigation
- Surface Water Quality
- Increasing Pesticide Use
- Climate Variability

**KEY ISSUES**

- Effects on Forest Productivity
- Natural Disturbances such as Fire and Drought
- Biodiversity Changes
- Socioeconomic Impacts
Water, Coastal Areas and Marine Resources

**KEY ISSUES**

- Competition for Water Supplies
- Surface Water Quantity and Quality
- Groundwater Quantity and Quality
- Floods, Droughts, and Extreme Precipitation Events
- Ecosystem Vulnerabilities

**KEY ISSUES**

- Shoreline Erosion and Human Communities
- Threats to Estuarine Health
- Coastal Wetland Survival
- Coral Reef Die-offs
- Stresses on Marine Fisheries
Health Sector

KEY ISSUES

- Temperature-related Illnesses and Deaths
- Health Effects Related to Extreme Weather Events
- Air Pollution-related Health Effects
- Water- and Food-borne Diseases
- Insect-, Tick- and Rodent-borne Diseases
Regional Impacts

NORTHEAST

KEY ISSUES

- Increase in Weather Extremes
- Stresses on Estuaries, Bays, and Wetlands
- Multiple Stresses on Urban Areas
- Recreation Shifts
- Human Health
- Species Changes

SOUTHEAST

KEY ISSUES

- Weather-related Stresses on Human Populations
- Agricultural Crop Yields and Economic Impacts
- Forest Productivity Shifts
- Water Quality Stresses
- Threats to Coastal Areas

MIDWEST

KEY ISSUES

- Reduction in Lake and River Levels
- Health and Quality of Life in Urban Areas
- Agricultural Shifts
- Changes in Semi-natural and Natural Ecosystems

GREAT Plains

KEY ISSUES

- Alteration in Timing and Amount of Water
- Changes in Climate Extremes
- Invasive Species Effects on Economy and Ecology
- Stress on Human Communities
- Conservation of Soil Organic Matter
PACIFIC NORTHWEST

KEY ISSUES

- Changes in Timing of Freshwater Resources
- Added Stresses on Salmon
- CO₂ and Summer Drought Effects on Forests
- Sea-level Rise Impacts on Coastal Erosion

WEST

KEY ISSUES

- Changes in Water Resources
- Changes in Natural Ecosystems
- Effects on Agriculture and Ranching
- Shifts in Tourism and Recreation

ALASKA

KEY ISSUES

- Permafrost Thawing and Sea Ice Melting
- Increased Risk of Fire and Insect Damage to Forests
- Sensitivity of Fisheries and Marine Ecosystems
- Increased Stresses on Subsistence Livelihoods

ISLANDS IN THE CARIBBEAN AND THE PACIFIC

KEY ISSUES

- Freshwater Resources
- Public Health and Safety
- Ecosystems and Biodiversity
- Sea-level Variability
US Regional effects (Midwest and Michigan)

Projected changes in Michigan

A 5-10°F rise in winter and a 7-13°F rise in summer temperatures by the end of the century is projected.

Although average annual precipitation may not change much, an overall drier climate is expected because rainfall cannot compensate for the increase in evaporation resulting from greater temperatures. Thus Michigan may see drier soils and more droughts. Seasonally, winter precipitation is expected to increase by 5-25% while summer precipitation is expected to remain the same.

Extreme heat will be more common, and the frequency of heavy rainstorms will increase and could be 50-100% higher than today.

The growing season could be 8-10 weeks longer.

Declines in ice cover on the Great Lakes and inland lakes have been recorded over the past 100-150 years and are expected to continue.
Radiative Forcing: Cooling and Heating

Losu is level of scientific understanding
IPCC IV, 2007 SFPM

Toward geo-engineering?
Role of Human Innovation and Technology: GeoEngineering

**Albedo modification** (reflect solar radiation)

- SO2 particles: create reflective sulfate particles, like volcanoes do naturally
- artificial deflectors in space (mirrors)

**CO₂ removal**

- source removal (power plants); today
- Reforestation; today
- Ocean iron fertilization (OIF). Algal blooms, with 25% sinking to ocean floor upon dying
- Accelerated weathering; calcite formed after reacting with CO₂ (as weathering bicarbobates); lower ocean acidity

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Relative costs and risks of various geoengineering schemes. (2008, courtesy of Kurt House, Harvard University)
Carbon dioxide (CO$_2$) capture and storage (CCS)

Available technology captures about 85–95% of CO$_2$ processed in a capture plant.

A power plant equipped with a CCS system (with access to geological or ocean storage) would need roughly 10–40% more energy than a plant of equivalent output without CCS, of which most is for capture and compression.

For secure storage, net result is that a power plant with CCS could reduce CO$_2$ emissions to the atmosphere by approximately 80–90% compared to plant without CCS.
Methods for storing CO2 in deep underground geological formations

Overview of Geological Storage Options
1. Depleted oil and gas reservoirs
2. Use of CO2 in enhanced oil and gas recovery
3. Deep saline formations — (a) offshore (b) onshore
4. Use of CO2 in enhanced coal bed methane recovery

Methods of ocean storage
Areas in sedimentary basins where suitable saline formation, oil or gas fields, or coal beds may be found.

Compared with today’s distribution of large stationary CO$_2$ sources
Coda

• Debate on climate change is over. Magnitude of its effects is today’s GLOBAL issue.

• Immediate need for action on inevitable consequences of climate change to limit future impacts and make adjustment strategies (sustainability).

• Change our living expectation models ... and greater energy efficiency and transitioning to non-fossil fuel energy sources through developing and globally sharing of knowledge.

• Support technologies to limit and even reverse change.