Climate Change

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The era of procrastination, of half measures, of soothing and baffling expedients, of delays, is coming to its close. In its place we are entering a period of consequences.

Winston Churchill, 1936
Carbon dioxide (CO$_2$) and other greenhouse gases warm the earth surface; higher concentrations produce a warmer surface.

Human activities have increased the concentration of the major greenhouse gases since ~1750; rate of concentration increase is increasing.

Average global temperature has increased ~0.8°C since 1900. Warming since the 1950s very likely (>90% chance) due to human increases in GHG.

Evidence of change is increasingly evident throughout the Earth’s system.

Without drastic changes in current emissions trends, greenhouse gas concentrations will increase dramatically over the next century and beyond.
Blue line is 10-year running mean; Green bar is 2006 (provisional value)
Longer term trends
Atmosphere
(Absorbers are Gases -- CO₂, water vapor, and ozone -- and Clouds)

Thermal radiation from the atmosphere
Greenhouse effect

Thermal energy lost to space; must balance absorbed solar energy

Ground

Solar energy in
Annual Average CO2 Concentration
Mauna Loa, HI (Elevation: 12,000 ft.)

Year

Concentration (ppm)
Antarctic Ice Core Data

CO₂ Concentration, ppm

Year

Mauna Loa Data

CO₂ Growth rate 1000 to 1800 = ~ 0
GTonnes of CO2 produced from fossil fuel usage
CO2 Growth Rates (per year)

**Fossil fuel emissions:**
- 1980s: 19.8 GtCO₂/yr
- 1990s: 23.5 GtCO₂/yr
- 2000-2005: 26.4 GtCO₂/yr

**Land Use Change flux:**
- 1980s: 5.1 GtCO₂/yr
- 1990s: 5.9 GtCO₂/yr

**Atmospheric CO₂ growth rate:**
- 1960 – 2005: 1.4 ppm/yr
- 1995 – 2005: 1.9 ppm/yr

![Graph showing CO₂ growth rates](image)
Total CO₂ emissions since 1950 in billions of tons:

- U.S. 186.1
- European Union 127.8
- Russia 68.4
- China 57.6
- Japan 31.2
- Australia 7.6
- India 15.5
- Kazakhstan 10.1
- South Africa 8.5
- Canada 14.9
- Mexico 7.8
- Trinidad and Tobago
- United Arab Emirates
- Kuwait

© TIME magazine

Time, 9 April 2001
Global Climate Models
Understanding the past, predicting the future

- 4D model: Latitude, longitude, height, time
- Equations solved on grid with ~250 km resolution
- Topography averaged to horizontal resolution
- Captures large scale well, but not local scale
Simulated Temperature change (IPCC)

Attribution of current change
Projected Carbon Dioxide Emissions

Emissions

Atmospheric Concentration

Scenarios depend on population, economic projections, future choices for energy, governance/policy options in development.
Multi-model Averages and Assessed Ranges for Surface Warming

Scenarios

Projected warming

IPCC: Summary for Policy Makers, Figure 5
Updated 13 Feb 2007

Average of 21 climate models forced by Scenario A1B.

Robust drying of the subtropics, 20-35N&S.

Stippling is where the multimodel average change exceeds the standard deviation of the models.

Scenario A1B: Drier or Wetter
Climate changes due to human activity

<table>
<thead>
<tr>
<th>Phenomenon and direction of trend</th>
<th>Likelihood that trend occurred in the 20th century (pre-1980)</th>
<th>Likelihood of a human contribution to each trend in the last 50 years</th>
<th>Likelihood of future trends based on projections for 21st century using SRES scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warmer and fewer cold days and nights over most land areas</td>
<td>Very likely</td>
<td>More likely than not</td>
<td>Virtually certain</td>
</tr>
<tr>
<td>Warmer and more frequent hot days and nights over most land areas</td>
<td>Very likely</td>
<td>More likely than not</td>
<td>Virtually certain</td>
</tr>
<tr>
<td>Warm spells/heat waves. Frequency increases over most land areas</td>
<td>More likely than not</td>
<td>Virtually certain</td>
<td>Very likely</td>
</tr>
<tr>
<td>Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas</td>
<td>Less likely than not</td>
<td>Virtually certain</td>
<td>Very likely</td>
</tr>
<tr>
<td>Area affected by droughts increases</td>
<td>More likely than not</td>
<td>Virtually certain</td>
<td>Likely</td>
</tr>
<tr>
<td>Intense tropical cyclone activity increases</td>
<td>More likely than not</td>
<td>Virtually certain</td>
<td>Likely</td>
</tr>
<tr>
<td>Increased incidence of extreme high sea level (excludes tsunami)</td>
<td>Less likely than not</td>
<td>Virtually certain</td>
<td>Likely</td>
</tr>
</tbody>
</table>

Virtually certain > 99%  Very likely > 90%  Likely > 66%  More likely than not > 50%

IPCC 2006
Changes in extremes

- Distribution (Gaussian) changes in mean or changes in shape

**Gaussian Example**

- Change in mean
- Change in shape

**Probability DF**

- More intense events

**Cumulative DF**
Food availability and the developing world

800 M people are malnourished today
• 95% are in the tropics/subtropics

What food do they eat?

- Rice (26%)
- Wheat (17%)
- Sugar Cane (8%)
- Maize (6%)
- Nuts (5%)
- Casava (4%)
- Other (34%)

These are countries with a large population of the very poor who depend heavily on agriculture for both food and income.

Extreme precipitation events: the wet gets wetter

- Increase in extreme precipitation greater than increase in mean
- Warmer climates lead to more intense precipitation events, even when the total precipitation amount is reduced slightly (IPCC AR4)
- Extreme precipitation matters more than the mean for erosion and natural hazards

Leyte, Philippines Landslide, 17 Feb 2006 (U.S. Navy photo by Petty Officer 1st Class Michael D. Kennedy)

Drying in Northern & Southern Africa projected by more than 16 of 21 models: 10-15% of annual mean in S. Africa; 20-30% in N. Africa (regions that are marginal for agriculture today).

About 20% wetter in E. Africa

The models diverge for the Sahel: half the models show drying
A word of caution

- Projections based on global models with coarse resolution
- Regional features have large uncertainties
- We have techniques to guide us
  - Statistical downscaling
  - Regional models embedded in a GCM
- Little of this has research has been done for the developing world
  - Lack of data
  - Lack of support
- Following example for Pacific Northwest
Regional climate change

- Use nested, high-resolution modeling
- Limited number of centers for this type of research, but growing
Temperature trends

2020s 2050s 2090s

Change in Winter Temperature (degrees C)
Number of Summertime Days with Max Temp > 90°F at SeaTac

<table>
<thead>
<tr>
<th>Decade</th>
<th>Number of Days per Decade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990s</td>
<td>60</td>
</tr>
<tr>
<td>2020s</td>
<td>70</td>
</tr>
<tr>
<td>2050s</td>
<td>80</td>
</tr>
<tr>
<td>2090s</td>
<td>180</td>
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</table>
Large Drop in Snowpack in the Mountains

Annual Cycle of Water Equivalent Snow Depth at Stampede Pass

- 1990s
- 2020s
- 2050s
- 2090s
Streamflow Impacts

Higher winter streamflows
Earlier and lower peak runoff (mid/high basins)
Lower late spring streamflow
Lower, warmer summer streamflow

Projected streamflow changes in the Quinault and Yakima Rivers

Quinault River
- early 20th century
- late 20th century
- ~2050s to 2080s

Yakima River
- early 20th century
- late 20th century
- ~2050s to 2080s

+3.6 (~2050s) to +5.4°F (~2080s)
Salmon Impacted Across Full Life-Cycle

- Fish spawning in freshwater stream
- Eggs in stream gravel hatch in 1-3 months
- Alevins in stream gravel 1-5 months
- Fry emerge in spring or summer
- Juvenile fish in freshwater a few days to 4 years, depending on species and locality
- Smolt migration to ocean usually in spring or early summer
- Fish spend 1-4 years in ocean
- Timing of migration to spawning grounds depends on species and race

- Early peak flows
- Warm, low streamflow
- Floods

??
Impacts of climate change

- Increased temperatures
  - Reduced crop yields and reduced nutritional content in developing countries
  - Loss of water storage in mountain glaciers and snow – reduced river flow in amount and timing
  - Additional stress on wildlife species, particularly fish that are adapted to current water cycles
Impacts of climate change

- Changes in precipitation
  - Decreased precipitation in dryer areas
    - Reduced yields and abandonment of some areas
  - Uncertain impacts on monsoons – likely to be more variable
  - Increased flooding in equatorial rain areas and midlatitudes
  - Soil erosion and nutrient leaching

- Likely increase in strength of hurricanes/typhoons

Hurricane Katrina
Impacts of climate change

- Sea-level rise – minimum of .3 to .5 m by 2100
  - Could be more if ice sheets collapse
- Changes in pests and pathogens: unknown

Potential impact of sea-level rise on Bangladesh

<table>
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<th>Today</th>
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<tr>
<td>Total population: 112 Million</td>
</tr>
<tr>
<td>Total land area: 134,000 km²</td>
</tr>
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</table>

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<th>1.5 m - Impact</th>
</tr>
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<tr>
<td>Total population affected: 17 Million (15%)</td>
</tr>
<tr>
<td>Total land area affected: 22,000 km² (16%)</td>
</tr>
</tbody>
</table>
Solutions
Mitigation

Solving the Global Warming Problem

- We want to stabilize climate (no more climate change due to greenhouse gases)

- Therefore, we must stabilize CO2 at some relatively low concentration (2 x industrial level?)

- Therefore, we must stop emitting CO2 completely!

- But how do we get there?
Billions of Tons Carbon Emitted per Year

Historical Emissions

Historical emissions
1.6

Interim Goal

Billions of Tons Carbon Emitted per Year

Current path = “ramp”

Historical emissions

Stabilization Triangle

Interim Goal

Flat path →

1950
2000
2050
2100
1.6

Billions of Tons Carbon Emitted per Year

Current path = “ramp”

16 GtC/y

Eight “wedges”

Goal: In 50 years, same global emissions as today

Historical emissions

Flat path
Wedge strategies

Energy Efficiency & Conservation

Fuel Switching
CO₂ Capture & Storage

Stabilization Triangle

Renewable Fuels & Electricity
Forest and Soil Storage

Nuclear Fission

Carbon Mitigation Institute, Princeton University
Figure 1. U.S. Greenhouse Gas Emissions by Gas, 2007

Energy-Related Carbon Dioxide* 5,916.7 (81.2%)
High-GWP Gases 176.9 (2.4%)
Nitrous Oxide 383.9 (5.3%)
Other Carbon Dioxide 105.1 (1.4%)

2007 Total = 7,282.4

Source: EIA estimates.

Figure 12. U.S. Carbon Dioxide Emissions from Other Sources, 2007

Cement Manufacture 46.0
Natural Gas Production 27.4
Limestone Consumption 18.8
Other Industrial Sources 12.9

2007 Total = 105.1

Source: EIA estimates.
Climate change and energy policy: What needs to be done

- **Reduce**
  - Dependence on foreign oil
  - Greenhouse gas emissions

- **By promoting**
  - Conservation
  - Alternative energy technologies
  - Infrastructure development

- **Using a balance between**
  - Government regulation (CO2 emissions)
  - Market forces (cost of energy)
Can we afford this?

US 2008 budget = $2,900 Billion

Mandatory = $1788
Discretionary = $1114
DoD and War on Terror = 56% of Discretionary spending
U.S. Defense Spending Since 2001
(in current dollars)

Notes: Base budget figures are from OMB and include Department of Energy nuclear weapons activities and DOD-related spending by other agencies. Iraq-Afghanistan war budget figures are from CBO, "Analysis of the Growth in Funding for Operations in Iraq and Afghanistan," February 11, 2008.
Gibbons and Blair, 1991, Physics Today
Some comparisons

- 1% of Defense + War budget = $7 B
- Current Energy R&D = $4.5 B
- US global change research program = $2 B (about same as military spending per day)
- ALL science and space = $30 B
- Cumulative funding (1998-2007) by DOE on
  - Renewable energy = $4 B
  - Energy efficiency = $6 B
In closing ....

- Climate is changing and we are responsible
- Projected climate change will have many devastating effects, globally and regionally
- This is an ethical and moral issue – there will be losers (and a few winners)
- We can solve this problem by a combination of adaptation and mitigation
- We need to start NOW!
Do we have the will to change our lifestyle?
(and help save the planet at the same time)

Thanks for your attention!