Physics 105  Fall 2011
Physics for Decision Makers:
The Global Energy Crisis

Lecture  Climate Change continued

How did Dan Lathrop do?

1. Great
2. OK
3. Not so good
Assignments

- Nov 15: Each group will submit a one page Market Analysis with references.
- Read the article and two opinions on the Keystone XL Pipeline in the course documents section - (item 13)
  - Write a very short description (a couple of sentences) of what the article and opinions were about.
  - Due Nov. 22.

Is it really possible to change the climate?

- The atmosphere is an exponential with a scale height of about 8km (pressure drops by \(1/e\) every 8km)
- At 4600m (15,000') pressure is 0.58 atm
  - 8 psi vs 14.7 at sea level
- Total height equivalent to 10m of water
- Radius of earth 6,400 km \(\Rightarrow\) atmosphere 1/3000
Eyjafjallajökull

- Will it help global warming?

Mount Pinatubo, Philippines June 1991

- In the twentieth century, this (1991) eruption was second in size only to an eruption in Katmai, Alaska, in 1912. Ten times larger than the eruption of Mount St. Helens in 1980.
Climate Change and Volcanos

- Mt. Pinatubo injected 20 million tons of sulfur dioxide (6 Tg S) into the stratosphere!
- The sulfur dioxide was observed around the globe in the equatorial regions.

Global air temperature before and after Mt. Pinatubo

no New Zealand Coleraine wine was none made in either 1992 or 1993 as sunlight was obscured by smoke and ash from the eruption of Mt. Pinatubo on the Philippines.
Anthropogenic Change

- Anthropogenic effects, processes, objects, or materials are those that are derived from human activities rather than natural causes.
- Anthropogenic sources include industry, agriculture, mining, transportation, construction, habitations and deforestation.

Nuclear Winter

- A major nuclear holocaust could darken the skies for years.
- The smoke resulting would be largely opaque to solar radiation but transparent to infra-red, thus cooling by blocking sunlight but not causing warming from enhancing the greenhouse effect.
- Forest fires resulting from non-urban targets could increase aerosol production further.
- Dust from near-surface explosions against hardened targets also contributes; each Mt-equivalent of explosion could release up to 5 million tons of dust, but most would quickly fall out; high altitude dust is estimated at 0.1-1 million tons per Mt-equivalent of explosion.
One Study of Nuclear Winter

- A global average surface cooling of −7°C to −8°C persists for years, and after a decade the cooling is still −4°C.
- Considering that the global average cooling at the depth of the last ice age 18,000 yr ago was about −5°C, this would be a climate change unprecedented in speed and amplitude in the history of the human race.
- The temperature changes are largest over land ... Cooling of more than −20°C occurs over large areas of North America and of more than −30°C over much of Eurasia, including all agricultural regions.
- The Extinction of the dinosaurs...
- However this is a short term effect...

“I think we won”
**Atmospheric CO\(_2\)**

- The mass of the Earth atmosphere is \(6 \times 10^{18}\) kg, \(3 \times 10^{15}\) tons (3,000,000 Gigatons.)
- CO\(_2\) concentration is 388 ppm
- The world adds 26.7 billion tons of CO\(_2\) \(\rightarrow \)6 ppm CO\(_2\) per year
- In 1999, 2.25 Gt of CO\(_2\) were produced in the U.S. as a result of electric energy generation. This is an output rate of 0.6 kg (1.3 pounds) per kWh.
- The US produces 6Gt CO\(_2\) per year – 1.8 GtC (Gigatons Carbon)/yr
  - (C weighs 12 amu, O\(_2\) is 32 so CO\(_2\) is 44)
- A gallon of gasoline, which weighs about 6.3 pounds produces 20 pounds of carbon dioxide (CO\(_2\)) when burned. However, most of the weight of the CO\(_2\) doesn't come from the gasoline itself, but the oxygen in the air.

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**World Atmospheric Carbon Production (GtC)**

(Note 1 Gt of Carbon = 3.67 Gt of CO\(_2\))

![Graph showing world atmospheric carbon production over time](chart.png)

- **Total**
- **Petroleum**
- **Coal**
- **Natural gas**
- **Cement production**
- **Gas Flaring**

32 Gigatons CO\(_2\)

US Production
1997 Indonesian Peat Fires

Between 13% and 40% of the average carbon emissions caused by the burning of fossil fuels around the world in a single year

Trees get most of their mass from:

1. The soil
2. Air
3. Water
4. All of the above
5. Soil & water
6. Air & water
Where does a tree come from?
- Soil?
- Air?
- Tree circumference: 100 cm
- Tree Type: Hardwood
- Amount of carbon stored: 322 kg
- Amount of carbon dioxide $\text{CO}_2$: 1,182 kg

$(1 \, \text{kg of dried tree}) \times (0.45 \, \text{kg of C/1 kg of dried tree}) \times (44 \, \text{amu of CO}_2/12 \, \text{AMU of C}) = 1.65 \, \text{kg of CO}_2$

Sea Level is rising

From historical records (e.g. Roman fish ponds) - little change for previous 2000 yrs.

Water expands when heated; Melting of ice
In my lifetime I expect the sea to rise:

1. 0 cm
2. 2 cm
3. 10 cm
4. 20 cm
5. 50 cm
6. 100 cm
7. 200 cm
8. 500 cm

IPCC Sea level Rise

*By 2050 – predictions range from 20-50cm (8-20 inches)*

* Excludes ice sliding into the ocean

Elevations of Land Close to Sea Level
Elevations are above spring high tide during new and full moons, and approximately the inland boundary of tidal wetlands. This map is a general graphical representation of elevations in the area depicted, not designed to estimate the precise elevations at specific locations. Due to the use of a variety of data sources, actual elevations at specific locations may be 50 cm above or below the elevation shown for Washington, but 150 cm for Maryland and Virginia.

Source: J.G. Titus and J. Wang, 2005. “Maps of Lands Close to Sea Level along the Mid-Atlantic Coast”. US Environmental Protection Agency
Northern Hemisphere Snow cover

Positive Feedback

- As polar ice pack declines, the albedo gets smaller
  - $\text{Albedo}_{\text{snow}} = 0.5 \text{--} 0.9$
  - $\text{Albedo}_{\text{water}} = 0.08$

More solar energy is absorbed
Less ice coverage
Lower albedo
Polar Ice Pack is shrinking

Annual Sea Ice Minimum

million square km


2007

previous record

Polar Ice pack is shrinking

September 16, 2007

Concentration de la mer en glace (%)

8 50 100

2007 minimum

2005 minimum

2006-2000 median minimum
Sea Ice This Year – 2nd lowest
WASHINGTON, DC (May 14, 2008) – Today the U.S. Fish and Wildlife Service (FWS) issued its decision to list the polar bear as “threatened” under the Endangered Species Act. The decision comes only under court order and more than three years after the FWS was first petitioned to protect polar bears.
Surface Melt on Greenland

Melt descending into a moulin, a vertical shaft carrying water to ice sheet base.

Source: Roger Braithwaite, University of Manchester (UK)
Greenland Mass Loss – From Gravity Satellite

Movement: -162 +/- 22 km$^2$/yr
Sea Level Rise: ~0.4 +/- 0.1 mm/yr

Velicogna and Wahr, 2005

Greenland Ice Mass Anomaly
Negative feedback

- Increased CO₂ stimulates more plant growth
- More plants remove CO₂ from atmosphere

Negative feedback tends to suppress effects
Positive feedback enhances effects
What do we know?

- CO$_2$ has been rising dramatically since humans started using fossil fuels, to levels not seen in hundreds of thousands of years.

- CO$_2$ is a greenhouse gas

- Historical records show warm periods are correlated with high levels of CO$_2$

- The same is true with methane (CH$_4$)

The BIG questions

- Will added CO$_2$ in the atmosphere cause increased temperatures?

- Is the Earth’s temperature rising?

- If so, is it due to man, or to natural variations?

- Are observed changes (such as ice pack shrinkage) due to man?

- Will increased temperatures be bad for the planet/humans?
Is the Earth Warming?

The hottest years are the recent ones
September 2011

How do scientists decide what’s right?

- **Peer Reviewed Articles**
  - aka refereed articles

- **How does it work**
  - Scientist writes an article for a journal
  - Journal editors send it out for anonymous review (usually 2 people)

  - a) The paper should be published in PRL as it is. . . . . ( )
  - b) The paper should be published in PRL after minor revisions are made, without further review. . . . . ( )
  - c) The paper, with revisions and further review, might be publishable in PRL. . . . . ( )
  - d) The paper with extensive revisions, and further review could possibly be published in PRL. . . . . ( )
  - e) The paper should not be published in PRL. . . . . ( )
The main activity of the IPCC is to provide in regular intervals Assessment Reports of the state of knowledge on climate change. The latest one is "Climate Change 2007", the Fourth IPCC Assessment Report.

They, along with Al Gore, won the 2007 Nobel Peace Prize for this report!

The IPCC was established to provide the decision-makers and others interested in climate change with an objective source of information about climate change. The IPCC does not conduct any research nor does it monitor climate related data or parameters.

Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation.

IPCC reports should be neutral with respect to policy, although they need to deal objectively with policy relevant scientific, technical and socio-economic factors. They should be of high scientific and technical standards, and aim to reflect a range of views, expertise and wide geographical coverage.
Where uncertainty in specific outcomes is assessed then the following likelihood ranges are used
- virtually certain >99%;
- extremely likely >95%;
- very likely >90%;
- likely >66%;
- more likely than not > 50%;
- about as likely as not 33% to 66%;
- unlikely <33%; very
- unlikely <10%;
- extremely unlikely <5%;
- exceptionally unlikely <1%.

IPCC Fourth Assessment Report

Radiative Forcing Components

Characterize effects in terms of radiative forcing (W/m²) - as if the Sun were brighter
### Phenomena and Direction of Impact

<table>
<thead>
<tr>
<th>Likelihood of higher handara climate change for 21st century using SRES scenarios</th>
<th>Examples of major projected impacts by sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over most land areas, warmer and longer cold days, shorter, warmer, and more frequent cold days and nights</td>
<td>Agriculture, forestry and fisheries (Arts. 4, 5, 7, 9)</td>
</tr>
<tr>
<td></td>
<td>Water resources (Arts. 2, 4)</td>
</tr>
<tr>
<td></td>
<td>Human health (Arts. 5, 6, 9)</td>
</tr>
<tr>
<td></td>
<td>Industry, settlement and society (Arts. 7, 9)</td>
</tr>
</tbody>
</table>

- **Increased yields in many areas; decreased yields in some areas.**
- **Increased frequency of heatwaves.**
- **Increased frequency of extreme weather events.**

### Africa

- **By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change.**
- **By 2050, in some countries, yields from rain-fed agriculture could be reduced by up to 50% if agriculture production, including access to food, in many African countries is projected to be severely compromised.**
- **Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10% of Gross Domestic Product (GDP).**
- **By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (TS).**

### Asia

- **By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease.**
- **Coastal areas, especially heavily populated megadeltas region in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the river.**
- **Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanisation, industrialisation and economic development.**
- **Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle.**

### Australia and New Zealand

- **By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics.**
- **By 2050, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions.**
- **By 2050, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire.**
- **By 2050, warming coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increase in the severity of storms and coastal flooding.**

### Europe

- **Climate change is expected to magnify regional differences in Europe’s natural resources and assets.**
- **Negative impacts will include increased risk of inland flash floods and more frequent coastal flooding and increased erosion (due to storminess and sea level rise).**
- **Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extreme species losses (in some areas up to 60% under high emissions scenarios by 2080).**
- **In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and reduce water availability, hydropower potential, summer tourism and, in general, crop productivity.**
- **Climate change is also projected to increase the health risks due to heat waves and the frequency of wildfires.**
### Latin America
- By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation.
- There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America.
- Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase (TS; medium confidence).
- Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.

### North America
- Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources.
- In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5 to 20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilised water resources.
- Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts.

### Polar Regions
- The main projected biophysical effects are reductions in thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators.
- For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed.
- Detrimental impacts would include those on infrastructure and traditional indigenous ways of life.
- In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered.

### Small Islands
- Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities.
- Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources.
- By mid-century, climate change is expected to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods.
- With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands.

### IPCC Fourth Assessment Report

#### Equilibrium global mean temperature increase above preindustrial

![Temperature Increase Diagram](image)

- **I**: 0-2°C
- **II**: 2-4°C
- **III**: 4-6°C
- **IV**: 6-8°C
- **V**: 8-10°C
- **VI**: 10-12°C

<table>
<thead>
<tr>
<th>GHG concentration stabilization level (ppm CO₂ eq)</th>
<th>Temperature increase (°C)</th>
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<tbody>
<tr>
<td>300</td>
<td>0</td>
</tr>
<tr>
<td>400</td>
<td>2</td>
</tr>
<tr>
<td>500</td>
<td>4</td>
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<td>600</td>
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<td>700</td>
<td>8</td>
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<td>800</td>
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<tr>
<td>900</td>
<td>12</td>
</tr>
<tr>
<td>1000</td>
<td>14</td>
</tr>
</tbody>
</table>
Based on multiple models that all exclude ice sheet flow due to a lack of basis in published literature, it is estimated that sea level rise will be: in a low scenario 18 to 38 cm (7 to 15 inches) in a high scenario 26 to 59 cm (10 to 23 inches)

It is very likely that there will be an increase in frequency of warm spells, heat waves and events of heavy rainfall. It is likely that there will be an increase in areas affected by droughts, intensity of tropical cyclones (which include hurricanes and typhoons) and the occurrence of extreme high tides. “Sea ice is projected to shrink in both the Arctic and Antarctic ... In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century.”
Special Report on Emissions Scenarios

SRM Scenarios

Atmosphere-Ocean General Circulation Model projections of surface warming
Summary for Policymakers

"Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the timescales required for removal of this gas from the atmosphere."

IPCC Errors

- **Projected date of melting of Himalayan glaciers; use of 2035 in place of 2350**
- **Main article: Criticism of the IPCC AR4**
- A paragraph in the 2007 Working Group II report (“Impacts, Adaptation and Vulnerability”), chapter 10 included a projection that Himalayan glaciers could disappear by 2035
- This projection was not included in the final summary for policymakers. The IPCC has since acknowledged that the date is incorrect, while reaffirming that the conclusion in the final summary was robust.
Other possible impacts

- Disruption of thermohaline ocean cycles
  - Younger Dryas - about 12,000 years ago, sudden (10 years) 5-10°C drop in temperature in Europe
  - Thought to be due to draining of Lake Agassiz

- Thawing permafrost
  - Could release 100s of Gt of carbon

Target Atmospheric CO₂: Where Should Humanity Aim?

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Abstract: Paleoclimate data show that climate sensitivity is ~3°C for doubled CO₂, including only fast feedback processes. Equilibrium sensitivity, including slower surface albedo feedbacks, is ~6°C for doubled CO₂ for the range of climate states between glacial conditions and ice-free Antarctica. Decreasing CO₂ was the main cause of a cooling trend that began 50 million years ago, the planet being nearly ice-free until CO₂ fell to 450 ± 100 ppm; barring prompt policy changes, it at a critical level will be passed, in the opposite direction, within decades. If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO₂ will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that. The largest uncertainty in the target arises from possible changes of non-CO₂ forcings. An initial 350 ppm CO₂ target may be achievable by phasing out coal use except where CO₂ is captured and adopting agricultural and forestry practices that sequester carbon. If the present overshoot of this target CO₂ is not brief, there is a possibility of seeding irreversible catastrophic effects.

Keywords: Climate change, climate sensitivity, global warming.