Climate Change

• Review of Muller’s chapter on Climate Change from Physics for Future Presidents
• Will review data on temperature and carbon dioxide abundance.
• Discuss physics issues connected to the “greenhouse effect”
• Warning: “politically charged” and “exaggerated claims” are common!
• APS (American Physical Society) policy statement
  http://www.aps.org/policy/statements/07_1.cfm
• APS (American Physical Society) controversy on climate change (e.g. resignation of Hal Lewis, Ivar Giaever and other notable members)
The Data (but note *the suppressed zero on the y-axis*)

Figure 10.1. Earth average temperature 1850 to 2006
The trend

• There was a $2^0$ F increase in the average temperature since 1850 (data)

• *If this trend increases and is amplified* by increased use of fossil fuels such as coal, gasoline, which release carbon dioxide, there is the possibility of 6-10$^0$ F increase in the next 50 years

• This would have *disastrous consequences* (melting of the permafrost in Alaska, massive flooding of coastal regions, farm land in the continental US would become arid and so on).

• Release of carbon dioxide acidifies the oceans may have further dangerous consequences.
Some climate changes basics

• IPCC = Intergovernmental Panel on Climate Change
• The IPCC issues reports on the situation that represent the consensus of the world’s scientists
• The IPCC together with former US VP Al Gore received the 2007 Nobel Peace Prize in Oslo.
• The IPCC concludes that the probability that the temperature increase in the last 50 years was a natural phenomena is only 10%. The likelihood that it is anthropogenic is 90%.
Conclusion of the IPCC report in 2007

1 Here is the actual quote from the IPCC 2007 report: “The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is extremely unlikely that global climate change of the past fifty years can be explained without external forcing, and very likely that it is not due to known natural causes alone.” The IPCC defines *very likely* as 90% confidence. That is equivalent to saying that there is a 10% chance that none of the global warming is caused by humans. In other parts of the report, however, a similar statement is made with the word *most* added, implying that there is a 90% chance that humans are responsible for *most* of the warming. The IPCC report doesn’t explain the discrepancy in words. If we include the word *most*, then its conclusion implies that there is a 10% chance that *most* of the observed warming is due to something other than *humans*, such as solar variability or natural fluctuations in clouds.

It is interesting to note that the IPCC panel of scientists gives probabilities for its conclusions (this acknowledges the existence of experimental and physical uncertainties as well as climate fluctuations).
What the IPCC report says: the change in the last 50 years is anthropogenic. Early changes are probably natural.
The IPCC review process

Attempt to find scientific consensus and avoid bias
Some argue that previous studies are biased by funding or location of measurement points in urban “heat islands”. The Berkeley study group, an independent study headed by Muller et al. redid the analysis and checked the results.

Good agreement found (results announced in Oct 2011 and submitted to journals)
The data on a much longer time scale

R. Muller et al, measured temperature from oxygen isotopes in air bubbles in Greenland ice cores

Note the landmarks such as the beginning of human agriculture after the end of the last Ice age

Figure 10.2. Temperatures from 12,000 BC to the present, estimated from Greenland ice measurements of oxygen isotopes.
Some Cultural Artifacts of the “Little Ice Age” in Europe

Little Ice Age in Holland

Frozen Thames river in England

Frost fairs etc....
Large Scale Ice ages are cyclic (time scale ~80,000-90,000 years)

Typically, every 80,000-90,000 years followed by an “interglacial period” that lasts 10,000-20,000 years.

The idea of recurring ice ages can excite the imagination!
These indicators all **increase** in a warming world

These indicators all **decrease** in a warming world

Website of the US National Oceanic and Atmospheric Administration (NOAA): National Climatic Data Center
What is the composition of the Earth’s atmosphere?

The Earth’s atmosphere is 78% N₂ (nitrogen), 21% O₂ (oxygen), argon, and a few other gases.

What about CO₂?

CO₂, carbon dioxide, is only 0.038% of the atmosphere (i.e., has a concentration of 380 parts per million or ppm) but plays an important role in regulation of the temperature.

What are the “greenhouse gases”?

CO₂ (carbon dioxide), CH₄ (methane), N₂O (nitrous oxide) and “CFC’s”.

What is the major source of methane (worldwide)?

Ans: Cow flatulence
The Role of Carbon Dioxide in the atmosphere and Global warming

Plants take it in along with sunlight and water

Nobelist Melvin Calvin (Berkeley) who discovered how it works using Carbon-14
The Most Famous Data on Carbon Dioxide comes from the observatory at Mauna Loa (First done by Charles Keeling)

Increase of CO₂ at Mauna Loa since pre-industrial times

Why Hawaii?  Little Industry or population at Mauna Loa. Good mixing in the wind
The trend in Carbon Dioxide

It is very likely, according to the IPCC, that the increase in CO$_2$ is responsible for the global warming in the last 50 years.

Units on the y-axis are part per million (ppm).

This plot is sometimes shown with a suppressed zero (be careful).

“hockey stick plot’

Figure 10.3. Carbon dioxide in the atmosphere from 800 AD to the present in ppm (parts per million). The sudden 36% rise in the past 100 years is due primarily to the burning of fossil fuels and the clearing of rainforests.
On a longer time scale

Last time CO₂ levels were this high
was 20 million years ago
1. Higher carbon dioxide levels than we have now were last seen about
   A. 600 years ago
   B. 2,000 years ago
   C. 13,000 years ago
   D. 2 million years ago

(D) last time was about 20 (typo !) million years ago

Tripati et al, Science, Oct 8, 2009 issue
These long term changes are due to perturbations of the earth’s orbit by other planets (Venus, Jupiter a.k.a Milankovitch theory)

Suppressed zero and no scale on the y-axs!!

Certainly a poor and misleading way to present data although the conclusion is correct!
Physics review: Stefan-Boltzmann Law

For blackbody radiation

\[ j = \frac{P}{A} = \sigma T^4 \]

Sun is about 5800° K

\[ \sigma = \frac{2\pi^5 k^4}{15c^2h^3} = 5.670400 \times 10^{-8} \text{ J s}^{-1} \text{ m}^{-2} \text{ K}^{-4}, \]
Earth is in empty space (no conduction, no convection but reradiation of a black body)

2 The following optional calculation is for those who have taken other physics courses. $T_S = \text{Sun temperature}; T_E = \text{Earth temperature}; R_s = \text{Sun radius}; R_e = \text{Earth radius}; D = \text{Earth-Sun distance}; \sigma$ is the constant that comes into the $T^4$ law. Power radiated by Sun = $P_s = 4 \pi R_s^2 \sigma T_S^4$. Power absorbed by the Earth is $P_e = P_s (\pi R_e^2)/(4 \pi D^2)$. Power emitted by the Earth is $P_e = 4 \pi R_e^2 \sigma T_E^4$. Solving these equations gives $T_E = T_S \sqrt{R_s/(2D_s)}$. We know from looking at the size of the Sun that $R_s/D \approx 1/200$. So $T_E = T_S/20 = 6000/20 = 300 \text{ K}$.

Or about 80 F

This calculation assumes that all sunlight that strikes the earth is absorbed. This is not right, only about 60% of the IR is absorbed (and the remaining 40% is reflected).

This would give an average temperature of 26 F, well below freezing

How do we explain the difference?
“Green House effect” required for human life

Carbon dioxide can increase the size of the Greenhouse effect and lead to climate change

Water and Carbon Dioxide absorb and reemit the infrared radiation

Note: atmosphere is transparent to visible wavelengths but not to long wavelength IR.
But there are some complications (such as reflection from clouds and leakage).

Note that there is a feedback mechanism with clouds: more CO$_2$ leads to more water evaporation and more clouds, which reflect more sunlight and tend to cool the atmosphere.

Figure 10.5. The Greenhouse Effect showing leakage and clouds.
Connection between energy and carbon dioxide emissions
Energy use per person are high in the US but........

Figure 10.10. Energy use vs. income, per person, for various countries
This figure explains why the US senate rejected the Kyoto treaty by a large margin. Even if the US retains to its 1970 level of carbon emission, the increase will be more than compensated by the extra carbon emissions from India and China (“developing countries”).

Byrd-Hagel resolution passed by a 95-0 vote. The US should NOT ratify the Kyoto treaty unless timetable and limits are included for developing countries.
19. If the United States reduced CO\textsubscript{2} emissions to those suggested by the Kyoto treaty, and the developing nations continued to increase theirs at the current (allowed) rate, then global warming would be delayed by about
   A. 3 years
   B. 10 years
   C. 30 years
   D. 70 years

   A. Only about 3 years, since emissions are dominated by India and China

20. A key feature of the Kyoto treaty is that it
   A. required CO\textsubscript{2} reductions for China
   B. did not require reductions for Japan
   C. reduced CO\textsubscript{2} but ignored other greenhouse gases such as methane
   D. set up a method to trade carbon credits

   The Kyoto protocol set up such a system, and the countries that endorsed that treaty are now using these credits. The approach is called \textit{cap and trade}. A country is given a limit for the amount of CO\textsubscript{2} that it emits; that’s the cap. If they go under that limit, they get credits that they can trade; if they go over the limit, they are required to buy credits to cover the pollution.
More Review Questions

7. Carbon dioxide in the atmosphere has increased over the past 100 years by about
   A. 0.6%
   B. 6%
   C. 36%
   D. 96%

Sometimes this plot is shown with a suppressed zero.

C
2. The country that produces the most carbon dioxide each year is
   A. United States
   B. Russia
   C. China
   D. India
   C. China

3. The country that produces the most carbon dioxide per person every year is
   A. United States
   B. Russia
   C. China
   D. Saudi Arabia
   A. US

9. A “treaty” that was signed by the United States but not ratified by the Senate is:
   A. IPCC
   B. CIGS
   C. SEGS
   D. Kyoto
   D. Kyoto
Extreme Weather Events
Muller claims that Gore “cherry-picked” data on hurricanes. Note that monitoring has improved with addition of satellites so total number observed has increased.
Figure 10.7. Strong to violent tornadoes in the U.S.

Muller notes that improved monitoring via radar has lead to an increase in the total number of tornados
Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation

Special Report of the Intergovernmental Panel on Climate Change

Special report issued by the IPCC in 2012
It is very likely that there has been an overall decrease in the number of cold days and nights, and an overall increase in the number of warm days and nights, at the global scale, that is, for most land areas with sufficient data. It is likely that these changes have also occurred at the continental scale in North America, Europe, and Australia. There is medium confidence in a warming trend in daily temperature extremes in much of Asia. Confidence in observed trends in daily temperature extremes in Africa and South America generally varies from low to medium depending on the region. In many (but not all) regions over the globe with sufficient data, there is medium confidence that the length or number of warm spells or heat waves has increased. [3.3.1, Table 3-2]

There have been statistically significant trends in the number of heavy precipitation events in some regions. It is likely that more of these regions have experienced increases than decreases, although there are strong regional and subregional variations in these trends. [3.3.2]

There is low confidence in any observed long-term (i.e., 40 years or more) increases in tropical cyclone activity (i.e., intensity, frequency, duration), after accounting for past changes in observing capabilities. It is likely that there has been a poleward shift in the main Northern and Southern Hemisphere extratropical storm tracks. There is low confidence in observed trends in small spatial-scale phenomena such as tornadoes and hail because of data inhomogeneities and inadequacies in monitoring systems. [3.3.2, 3.3.3, 3.4.4, 3.4.5]

There is medium confidence that some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense, or shorter, for example, in central North America and northwestern Australia. [3.5.1]

3rd paragraph agrees with observations of Muller about hurricane and tornado data
There is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scales because the available instrumental records of floods at gauge stations are limited in space and time, and because of confounding effects of changes in land use and engineering. Furthermore, there is low agreement in this evidence, and thus overall low confidence at the global scale regarding even the sign of these changes. [3.5.2]

It is likely that there has been an increase in extreme coastal high water related to increases in mean sea level. [3.5.3]

There is evidence that some extremes have changed as a result of anthropogenic influences, including increases in atmospheric concentrations of greenhouse gases. It is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures at the global scale. There is medium confidence that anthropogenic influences have contributed to intensification of extreme precipitation at the global scale. It is likely that there has been an anthropogenic influence on increasing extreme coastal high water due to an increase in mean sea level. The uncertainties in the historical tropical cyclone records, the incomplete understanding of the physical mechanisms linking tropical cyclone metrics to climate change, and the degree of tropical cyclone variability provide only low confidence for the attribution of any detectable changes in tropical cyclone activity to anthropogenic influences. Attribution of single extreme events to anthropogenic climate change is challenging. [3.2.2, 3.3.1, 3.3.2, 3.4.4, 3.5.3, Table 3-1]
Models project substantial warming in temperature extremes by the end of the 21st century. It is virtually certain that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale. It is very likely that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas. Based on the A1B and A2 emissions scenarios, a 1-in-20 year hottest day is likely to become a 1-in-2 year event by the end of the 21st century in most regions, except in the high latitudes of the Northern Hemisphere, where it is likely to become a 1-in-5 year event (see Figure SPM.4A). Under the B1 scenario, a 1-in-20 year event would likely become a 1-in-5 year event (and a 1-in-10 year event in Northern Hemisphere high latitudes). The 1-in-20 year extreme daily maximum temperature (i.e., a value that was exceeded on average only once during the period 1981–2000) will likely increase by about 1°C to 3°C by the mid-21st century and by about 2°C to 5°C by the late 21st century, depending on the region and emissions scenario (based on the B1, A1B, and A2 scenarios). [3.3.1, 3.1.6, Table 3-3, Figure 3-5]

It is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe. This is particularly the case in the high latitudes and tropical regions, and in winter in the northern mid-latitudes. Heavy rainfalls associated with tropical cyclones are likely to increase with continued warming. There is medium confidence that, in some regions, increases in heavy precipitation will occur despite projected decreases in total precipitation in those regions. Based on a range of emissions scenarios (B1, A1B, A2), a 1-in-20 year annual maximum daily precipitation amount is likely to become a 1-in-5 to 1-in-15 year event by the end of the 21st century in many regions, and in most regions the higher emissions scenarios (A1B and A2) lead to a stronger projected decrease in return period. See Figure SPM.4B. [3.3.2, 3.4.4, Table 3-3, Figure 3-7]