An introduction to climate change

Geoffrey Swan

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Geoff Swan
Physics Discipline, School of Engineering
Edith Cowan University, Joondalup, WA 6027, Australia

Abstract Summary
A lecture presentation has been developed that introduces physics students to the science of climate change and its impact in society. Student feedback indicates a high level of satisfaction with the presentation.

Keywords: climate, model, energy, physics, environment, education

I. INTRODUCTION
The science and politics of climate change has been prominent in the media and the public consciousness for over a decade. Former US vice president Al Gore’s film [1] in 2006 significantly raised public concern about the affects of human activity on the Earth’s climate. With the release of the fourth assessment report of the IPCC (Intergovernmental Panel on Climate Change) [2] in 2007, public acceptance of anthropogenic climate change and pressure for action were high. Two reports [3,4] investigating an expansion in the Australian nuclear industry had been completed, and both major parties went into the 2007 Australian federal election with proposals to increase the cost of fossil fuels through a cap and trade scheme or carbon tax. How to respond to climate change had become a big issue in Australia.

A climate change lecture presentation, that requires only high school level physics and mathematics, was developed to expose various student cohorts to the science of climate change, results, predictions, modeling and other aspects relating to climate change in our society. Since 2007, variations of this presentation have been given to high school students as part of several visits to ECU (Edith Cowan University) and to ECU undergraduate students in scp1132 Introduction to Physics from 2007 to 2011, and scp1134 Foundations of Physics from 2012.

II. THE CLIMATE CHANGE PRESENTATION
A. Climate Change Science and Results
The presentation begins by briefly outlining the science of climate change and gives results and predictions from the physical science basis of the fourth assessment report of the IPCC (Intergovernmental Panel on Climate Change) [1]. A logical order is followed in which evidence in the form of scientific data is first presented to establish whether climate change has been occurring at all and if human activity is changing the planet on a global scale before looking at the more complicated assertion that human activity is causing climate change and making predictions for the future.

Fig. 1 shows that over the last 150 years or so the global average surface temperature has been increasing and the global average sea level rising. So the evidence shows that climate change is occurring, and looking at data over the last 50 years the rate of climate change is increasing. Nothing is said at this stage about the causes or whether these upward trends will continue. While snow cover for the Northern Hemisphere is also shown in the figure, the focus is on the change in surface temperature as the driver of other events.

Figure 1. Observed changes (relative to 1961-1990) in (a) global average surface temperature; (b) global average sea level rise and (c) Northern Hemisphere snow cover for March-April. [2]

Fig. 2 shows the atmospheric concentrations of carbon dioxide over the last 10,000 years, which have been fairly stable until recent times. The insert graph shows the that concentrations since 1750 have been increasing. This roughly corresponds with the start of the industrial revolution and the
burning of fossil fuels, which release carbon dioxide into the atmosphere, to drive machines. In particular, there has been a dramatic increase of atmospheric concentrations of carbon dioxide over the last 50 years which correlates well with the dramatic increase of industrialisation worldwide which in turn relies on the burning of fossil fuels. Hence it is easily established that human activity is significantly affecting the earth’s atmosphere on a global scale.

The greenhouse effect, where the earth's atmosphere is less transparent to outgoing infrared radiation emitted from the Earth's surface than the incoming visible radiation from the sun, keeps the Earth's surface warmer than it would otherwise be. Carbon dioxide's role as a significant greenhouse gas completes the key link between the human activity of burning fossil fuels and increasing global average surface temperature. Hence the case for anthropogenic climate change is established.

However, to make quantitative assessments of the impact of various drivers on climate change requires extensive use of models. Fig. 3 shows the estimated radiative forcing components for various anthropogenic (human) drivers affecting global temperature with uncertainties. In particular, it is noted that carbon dioxide released into the atmosphere due to human activity has the biggest impact on the energy balance at the Earth’s surface.

Fig. 4 shows how different climate models, that all fit historical data can give quite divergent predictions. This is further complicated with different possible scenarios for human activity in the future. While climate modeling is extremely complicated the IPCC predicted that a warming of 0.2°C per decade for the next two decades is very likely.

B. Global mean temperature model

An energy balance model to determine a global average surface temperature of the Earth is derived using high school level physics and mathematics [5]. Energy balance occurs when the rate at which energy is absorbed by the surface equals the rate at which energy is released. This equilibrium will occur at a specific temperature, T, which is the global average surface temperature.

The input power at which the earth’s surface absorbs the sun’s radiation, $P_{in}$, is given by (1).

$$ P_{in} = S \times \pi r^2 \times (1 - \alpha) $$

(1)
In this equation, the Solar constant, \( S \), is the incoming radiation intensity from the sun at the top of the atmosphere. Multiplying the solar constant by the cross sectional area of the Earth, where \( r \) is the radius of the Earth, gives the total power of the incoming solar radiation at the top of the Earth’s atmosphere. However, some of this radiation is reflected by the atmosphere and planet surface straight back into space, and hence a general variable known as Earth’s albedo, \( \alpha \), must also be included.

The output power at which the Earth’s surface emits radiation out to space, \( P_{out} \), is adapted from the Stefan’s Law [6] and given by (2).

\[
P_{out} = \varepsilon \times \sigma \times T^4 \times 4\pi r^2
\]  
\( (2) \)

In this equation, \( T \) is global average surface temperature of the Earth, \( r \) is the radius of the Earth, and \( \sigma \) is Stefan’s constant taken as \( 5.67 \times 10^{-8} \text{Js}^{-1}\text{m}^{-2}\text{K}^{-4} \). However, the Earth is not a black body with an emissivity of 1, and not all the radiation emitted from the Earth’s surface makes it through the atmosphere and into space. Therefore a general variable known as the Earth’s transparency, \( \varepsilon \), is included to account for these affects.

An expression for the global average surface temperature of the Earth is found by equating the input power to the output power. Energy balance is achieved at this steady state solution for temperature (3).

\[
P_{in} = P_{out}
\]
\[
S \times \pi r^2 \times (1 - \alpha) = \varepsilon \times \sigma \times T^4 \times 4\pi r^2
\]
so \( T = \frac{\sqrt[4]{\frac{S \times (1 - \alpha)}{4 \times \varepsilon \times \sigma}}}{}
\]  
\( (3) \)

Taking values [5] for the solar constant, Earth’s transparency and Earth’s albedo of 1370 Js^{-1}m^{-2}, 0.6 and 0.3 respectively, a surface temperature of about 17°C is obtained in (4). This is within a few degrees of observed values shown in Fig. 1.

\[
T = \frac{\sqrt[4]{1370 \times (1 - 0.3)}}{4 \times 0.6 \times 5.67 \times 10^{-8}} = 290K = 17°C
\]  
\( (4) \)

The Earth’s climate system is extremely complicated with a multitude of parameters affecting climate that are not mentioned in this article. However, the Earth’s transparency and the Earth’s albedo are designed to be catch all variables that replace all these parameters. This allows for a simple model which is particularly powerful when used to illustrate how small changes in transparency and albedo can affect surface temperature and produce climate change.

C. Affect of Earth’s transparency and Earth’s albedo on global average surface temperature

Having this model allows students to see how small changes in the solar constant, Earth’s transparency and Earth’s albedo can affect surface temperature. Fig. 5 shows the significant temperature changes for relatively small changes to the Earth’s transparency. In this model, the connection between increasing emissions of CO2 and other greenhouse gases (which reduce the Earth’s transparency) and quantifiable global warming is strong and fairly obvious.

Anthropogenic causes of global warming are not so directly observed when looking at the temperature changes associated with changing the Earth’s albedo as shown in Fig. 6. However, it is clear that changing albedo will change surface temperatures. The difference between the albedo of ice and snow (\( \alpha \sim 0.9 \)) and the ocean (\( \alpha \sim 0.1 \)) is large [5] and can lead to significant positive feedback loops during either periods of global cooling, which led to the ice ages, and global warming, which is believed to be the current situation.

Fig. 7 shows an example of a positive feedback where global warming acts to melt ice and snow, which in turn reduces the Earth’s albedo, which causes more global warming. This particular example has recently featured in the local media [7] in the rather alarming context of “tipping points” where the “Earth may be approaching its points of no return”. This is in stark contrast to any comfortable notions of the Earth with its numerous negative feedback loops always able to mitigate against the actions of humans and maintain the status quo.
D. Science and society

Other aspects of climate change, including regional predictions for Australia, are discussed. In addition, various climate change treaties, carbon taxes, renewable and nuclear alternatives, and the politics that pervade the climate change debate are presented. Negative publicity following the discovery of a small number of inaccuracies after the release of the IPCC fourth assessment report in 2007, and a global shift in priorities following the global financial crisis in 2009 are also discussed as affecting human action on climate change. The impact of scientists and science literacy on the debate at various levels in our society is addressed.

III. STUDENT FEEDBACK AND CONCLUSIONS

Students enrolled in scp1132 Introduction to Physics in semester 2, 2011, were given a one page anonymous survey to complete at the end of the presentation. These 24 students came from a variety of courses from the fields of science, education, aviation and engineering.

Overall, students were overwhelmingly satisfied with the presentation, found the energy balance model easy to understand, and believed that global warming (and hence climate change) was occurring. Most of these students thought that human activity was the main cause of climate change with the rest neutral. Although students found that the presentation increased their awareness of factors affecting climate change, the presentation did not change their beliefs or the strength of their beliefs in anyway. Students were split on whether they felt powerless to reduce the impact or amount of climate change. Most students believed that the presentation was a good application of physics concepts already covered in the heat and motion modules.

The climate change presentation not only shows application of high school level physics and mathematics to a real and current global issue, but also provides a wonderful opportunity, albeit superficially within the context of this physics unit, to enrich and broaden the educational context and extend students towards a more holistic “whole of problem” approach that is necessary when solving real problems. Scientists also need to develop knowledge and skills to communicate on different levels and be able to interact within a wider world perspective.

Future plans include introducing a computer activity for students to gain experience in modeling climate change and simultaneously gain useful generic skills in using Microsoft excel. This presentation will also be updated with the expected release (in stages) of the fifth assessment report of the IPCC in 2013 and 2014.

REFERENCES


