Module 1 The science of climate change

THE WEATHER & THE CLIMATE

Have you ever wondered why it can rain one minute and be sunny the next, but why it is always drier in central Australia than it is on the coast?

The reason is simple: while the weather can change quickly, with big variations over a day, the climate changes over much longer timeframes. Rainfall patterns do not simply change overnight.

Changes in the weather are generally well-understood and despite what many people think meteorologists are pretty good at predicting what the weather will be the following day.

The climate is a different matter. The Earth's climate system is affected by the interactions of different subsystems such as the atmosphere, the hydrosphere (the oceans and rivers) and the biosphere (including the forests, the plants and the soil). Although individual interactions between, for example, the forests and the atmosphere are well understood, the way all these different subsystems interact is very complex and much harder to understand.

In the past, scientists have had great difficulty understanding and predicting changes in the climate. More recently, reliable evidence has emerged of how these subsystems have interacted to produce past climatic changes.

Using complex climate models that have been improved with sophisticated computer programs, scientists have been able to simulate the weather and the climate and to predict the changes that could follow from human-induced changes that may occur.

A **model** is a set of mathematical equations that represent interactions between various components of a complex system. Models can never capture all of the complexity of a system like the climate or the economy, so there is always some uncertainty remaining.

Climate models simulate the interactions between the different subsystems. For example, they can predict, to a degree, the impact on the climate if huge tracts of the Earth's forests are destroyed.

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GREENHOUSE EFFECT

The Earth's atmosphere is like a big blanket that surrounds the globe keeping humans warm. If it was suddenly stripped off the Earth's average temperature would plummet and everything would freeze.

Like a blanket that could be made from a mix of cotton and wool, the Earth's atmosphere is made from a mixture of gases. The main gases are nitrogen, oxygen and argon. However, there also trace gases such as carbon dioxide, water vapour, methane, ozone and nitrous oxide. These are called the greenhouse gases because they create a warm environment for the Earth.

The greenhouse effect occurs because the Sun's shortwave radiation passes through the atmosphere and warms the Earth's surface. This warm surface then radiates long wave infra-red radiation back into space. However, the greenhouse gases absorb some of the infrared radiation and re-radiate back to the atmosphere and the ground.

This makes the temperature of the atmosphere and the Earth higher than it would be without the presence of the greenhouse gases – see **Figure 1**.

The process is similar to how a greenhouse traps warmth and why the term **greenhouse effect** has become part of everyday language. Any change to the volume of greenhouse gases therefore changes the temperature on Earth. It is a bit like putting an extra blanket on your bed – it traps more of your body heat under the covers. As the earth slowly warms, the whole climate system is affected.

Some greenhouse gases such as carbon dioxide are constantly added to and removed from the atmosphere by natural processes. However, the recent increase in their concentration and the addition of new gases due to human actions is the driving force of changes in climate that the world is now experiencing.

Figure 1 The Greenhouse Effect

Department of the Environment, Water, Heritage and the Arts, http://www.greenhouse.gov.au/science/faq/question1.html, © Commonwealth of Australia, reproduced by permission.

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HUMAN ACTIVITIES & THE ENHANCED GREENHOUSE EFFECT

Since the middle of the 19th century and the Industrial Revolution, when major changes occurred in agriculture, manufacturing and transportation – including the replacement of organic fuels like wood with fossil fuels like coal – the concentration of greenhouse gases (with the exception of water vapour) has been increasing. For example, the concentration of **carbon dioxide (CO_2)** in the atmosphere has been increasing rapidly since the Industrial Revolution as we have burnt more fossil fuels – see **Table 1**.

To check whether this might simply be a coincidence, scientists have examined the long term geological record to see whether the increase in CO_2 over the last two centuries is normal or unusual. Ice cores taken from Antarctica and the Arctic indicate that, since pre-industrial times, the concentrations of CO_2 have risen at a rate that has no precedent in the geological record. There are no known natural processes that would create such a large increase in CO_2, so scientists conclude that human activities are the main cause of the increase in CO_2 in the atmosphere.

In addition to burning fossil fuels, clearing of forests and the release of industrial gases such as refrigerants have also contributed to the enhanced greenhouse effect.

Another of the main greenhouse gases is **methane (CH_4)**, which is 25 times as effective a greenhouse gas as CO_2 on a mass for mass basis. This means that although methane is less abundant than CO_2, its presence has a major impact on heat absorption in the atmosphere. In other words, although most of the blanket surrounding the Earth is made of CO_2, the part made of methane is a bit like pure wool, it keeps you very warm.

Table 1 Sources, concentrations and contributions of greenhouse gases

	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)	Chlorofluoro carbons (CFCs)	Tropospheric ozone (O_3)	Water vapour (O_2)
Pre industrial concentrations (parts per billion)	280,000	790	288	0	10	Not known
Present concentrations (parts per billion)	355,000	1720	310	0.28-0.48	20-40	3000-6000
Relative contribution to human-induced greenhouse effect	60%	15%	5%	12%	8%	Not known

Source: Skinner, BSkinner, B., Porter, S. and Botkin, D. 1999, *The Blue Planet: an introduction to earth system science*, Wiley and Sons, New York.

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Methane is generated by the bacterial decay of dead plant and animal material (including in waste landfills), by livestock farming (due to fermentation processes in the gut of ruminants such as cattle), rice cultivation, and by leakage from fossil fuel production processes such as coal mining and natural gas distribution.

The analysis of ice cores indicates that changes in methane concentrations in the atmosphere over time coincide with rises in the human population. This suggests that human activities associated with urbanisation, industry and agriculture are all significant factors in methane production, and hence climate change.

In addition to these two major greenhouse gases, other trace gases that are important include **nitrous oxide (N_2O)**, **ozone (O_3)** and **water vapour**, as well as a range of synthetic gases with chlorine and/or fluorine in their molecular structures. These are known as **chlorofluorocarbons (CFCs)**. Similar patterns of change since the industrial revolution are also evident with these gases, which can be attributed to various human activities.

The issue of ozone depletion is an entirely different process to the greenhouse effect. The two are commonly confused, but they are, simply, two destructive processes occurring in the atmosphere in response to human activities.

The Ozone Layer

Ultraviolet radiation is a part of the solar radiation spectrum. It causes sun-burn and is deadly to living organisms, including humans. Ozone can absorb the most lethal type of ultraviolet rays and is therefore crucial to life on Earth. Since 1980, the ozone in the atmosphere has been depleted by around four per cent per decade largely because of pollutants emitted from human manufacture, such as chlorofluorocarbons (CFCs).

Although the two are commonly confused, ozone depletion is different from the enhanced greenhouse effect. While some materials with a greenhouse impact also have an effect on the ozone layer (for example, CFCs), they are two quite distinct environmental problems that affect the atmosphere.

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ARE HUMAN ACTIVITIES REALLY THE CAUSE OF GLOBAL WARMING?

Climate is generally unpredictable and changes over time. This is called 'natural variability' and is caused by:

- the complex, chaotic behaviour of the many subsystems like the atmosphere and the oceans that make up the climate;
- the natural oscillation, or swinging, between warm and cool periods over years, decades or centuries, such as the El Nino effect;
- variations in solar activity such as sun spots; and
- random volcanic eruptions, which can put soot into the atmosphere and cause cooling.

The study of ice cores, coral and tree rings has helped scientists understand how the climate has varied over the past. This has been helped by the use of climate models. By understanding natural climate variability, we can use the models to compare trends in climate in the post industrial period with past climates.

Scientists have discovered that the rate of global warming and climate change is far beyond what can be explained by natural variability. Based on the work of around 2,500 scientists, the United Nations Intergovernmental Panel on Climate Change (IPCC, see **Module 4**) has concluded that there is a 90 per cent certainty that humans are the cause of climate change.

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STUDENT ACTIVITIES

Comprehension Questions

- What is the greenhouse effect? What is the enhanced greenhouse effect?
- What are the main greenhouse gases? Describe the role of one greenhouse gas.
- How do we know that global warming is caused by human activities?
- What human activities contribute to climate change?
- Explain in your own words 'ozone depletion'.

Analysis Question

- Should we wait until predictions of climate change are more accurate before taking action to control or prepare for climate change and its impacts?

Exercise 1

The Earth's climate system is complex and can be difficult to understand. Each of the following questions addresses a different aspect. Research and answer one of the questions.

What is the difference between the climate and the weather?

What are the gases that comprise the Earth's atmosphere? What percentage of the Earth's atmosphere does each gas represent?

Find out about the Earth's carbon cycle. Explain in your own words how carbon is transferred between the different subsystems.

Notes for Teachers

This could work well as a group exercise. Split the class into three groups and ask each group to use the internet (for example, the **Department of Climate Change website**) and other available resources in the school library to answer one of the questions.

Once all the groups have finished their research, the students discuss their findings with the rest of the class.