THE GREENHOUSE EFFECT AND CLIMATE CHANGE

INTRODUCTION

Good afternoon.

The purpose of today's presentation is to address some of the questions raised about the changing climate and the science involved in studying it.

I propose to talk for about 45 minutes, and then to have a 15-minute question and answer session, during which time any issues of interest to you not covered earlier may be raised.

In the course of a short talk, one can only skim the surface of such a broad topic, and I propose to focus on just a couple of key areas:

… The role of greenhouse gases.

… Recent global climate trends

… Recent Australian climate trends

… How climate models work

… Causes of recent climate change

… The Intergovernmental Panel on Climate Change

… Projecting the future climate

… Australia's possible future climate

… Asking the question: Is the science settled?

… Robust findings

… Key uncertainties

… Communicating the science to policy makers

… The way forward

… Any Questions?

THE ROLE OF GREENHOUSE GASES

Greenhouse gases are gases in the atmosphere that trap the sun's heat in much the same manner as does a greenhouse.

The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone.

Life on Earth depends on the presence of greenhouse gases in the atmosphere to insulate our planet's surface against the chill of space; without them the Earth's average climate would be about 33°C cooler.

The atmosphere is largely transparent to the Sun's energy, most of which arrives in the form of light.

At the Earth's surface, this energy is partly reflected out to space, and partly absorbed and re-radiated as heat.

The greenhouse gases in the atmosphere can both absorb and re-radiate much of the outgoing heat energy.

The atmospheric concentrations of some greenhouse gases are being affected directly by human activities namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and synthetic gases, such as chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs).

Water vapour is also a major greenhouse gas, but its concentration in the atmosphere is not influenced directly by human activities.

Since the industrial revolution around 1750, human activities have added significant quantities of greenhouse gases into the atmosphere.

CO_2 levels are rising mainly because of the burning of fossil fuels and deforestation.

The global mean CO_2 level is now more than 400 parts per million.

This concentration represents a 50 per cent increase from pre-industrial levels; it is likely to be at the highest concentration in at least 2 million years.

Methane and nitrous oxide concentrations, mostly from agriculture, have also substantially increased since 1750.

The additional greenhouse gases are contributing to global warming and to associated climatic changes.

The global average concentration of water vapour quickly rises in response to an increase in global temperature, due to the increased water-holding capacity of a warmer atmosphere.

Because water vapour is a greenhouse gas, the original warming is amplified.

This amplification is known as a positive feedback.

Half of the CO2 released to the atmosphere is absorbed by natural CO2 sinks, on the land and in the ocean, helping to mitigate emissions from human activities.

One consequence of the additional CO2 in the oceans is an increase in acidification.

RECENT GLOBAL CLIMATE TRENDS

For many decades, palaeoclimatologists have examined how the Earth's temperature changed over the centuries in the distant past.

From this work emerged a view of the past climate based on limited data from tree rings, historical documents, ice cores, sediments and other proxy data sources.

Today, many more palaeoclimate records are available from around the world, providing a much-improved view of past changes in the Earth's temperature.

The Earth’s temperature has fluctuated naturally over hundreds of millions of years.

These past changes can help us understand the relationship between temperature, greenhouse gases and other climate drivers today.

Some of the clearest changes in temperature and atmospheric composition are recorded in ice cores over nearly 1 million years.

The Earth has experienced cycles of ice ages separated by warm interglacial periods approximately every 100,000 years.

These are primarily driven by regular “wobbles” in the Earth’s orbit, which affects the amount of solar radiation reaching the Earth.

During the onset of interglacial periods, the warming takes about 5000 years to complete.

Significant warming begins in the Antarctic and several hundred years later the warming causes the carbon dioxide (CO2) increase, mainly through ocean processes.

The Northern Hemisphere deglaciation follows the CO2 increase.

Therefore, increases in CO2 contribute an amplification (positive feedback) throughout most of the warming.

The ice sheets also cause a feedback (as they disappear, reflection of the sun’s energy by them diminishes).

The observed temperature changes and rates of change during glacial-interglacial periods cannot be simulated without the observed changes in CO2 or ice extent.

The past 11, 000 years (the Holocene) is marked by much smaller global temperature changes, typically up to 1-1.5 °C.

Greenhouse gas concentrations were relatively stable until the large and rapid increases that began about 200 years ago as a result of anthropogenic emissions.

The concentration of CO2 is now higher than for at least the past 800,000 years.

Although each proxy temperature record is different, they all indicate similar patterns of temperature variability over the last 500 to 2000 years.

The terms Medieval Warm Period and Little Ice Age describe two past climate epochs in Europe and neighbouring regions.

The Little Ice Age was a period of cooling that occurred after the Medieval Warm Period.

Thus, during the past millennia there have been lengthy periods of somewhat warmer and cooler conditions.

Most striking is the fact that each proxy record reveals a steep increase in the rate or spatial extent of warming since the mid-19th to early 20th centuries.

Records indicate the temperatures of the most recent decades are the warmest in the entire record.

RECENT AUSTRALIAN CLIMATE TRENDS

Australia's average air temperature has warmed by just over 1℃ over the past century.

Oceans around Australia have also warmed by around 1℃ over the same period.

Australia's warming trend has led to an increase in the frequency of extreme heat events.

For example, very high monthly maximum temperatures that used to occur around 2% of the time now happen about 12% of the time.

Most regions have seen an increase in the most extreme fire weather days, and fire seasons have lengthened.

Rainfall in the winter half of the year has been steadily decreasing in Western Australia's southwest for many years and has decreased since the 1990s in southeast Australia.

In contrast, rainfall has increased in parts of northern Australia since the 1970s.

The observed long-term reduction in rainfall across southern Australia has led to reductions in streamflow there but has increased in many parts of northern Australia.

A warmer atmosphere can hold more moisture, and this is an important driver of the observed increase in the intensity of short-duration rainfall, sometimes linked to flash flooding.

Historically, significant weather and climate events are often the result of the combined influence of several extreme factors at once.

Higher temperatures during periods of below-average rainfall, for instance, can exacerbate drought conditions.

Temperature, dryness and wind come together to create dangerous bushfire conditions.

The warming in Australia's oceans has contributed to longer and more frequent marine heatwaves – defined as periods when sea surface temperatures are much warmer than average.

The world's oceans are a crucial moderator of the climate, taking up more than 90% of the extra heat in the system – most of it is absorbed by the Southern Ocean.

Sea levels continue to rise through the combined effects of warming oceans and melting ice from land-based glaciers and ice sheets and has risen by more than 20cm over the past 150 years, but the rate varies from place to place.

About 25% of the CO_2 emitted by human activity diffuses into the oceans, making them more acidic in the process.

We have also seen bleaching events in parts of the Great Barrier Reef, linked to marine heatwave events.

HOW CLIMATE MODELS WORK

Future climate changes over the 21st century cannot be simply extrapolated from past climate.

Non-linear processes must be considered, along with a range of plausible future greenhouse gas and aerosol concentration pathways.

The best tools for projecting climate change are global climate models.

These are mathematical representations of the climate system run on powerful computers.

Their fundamentals are based on the laws of physics, including conservation of mass, energy and momentum.

Global climate models are closely related to models used for daily weather prediction.

Global climate models represent the atmosphere and ocean on three-dimensional grids, with a typical atmospheric resolution of 200 km or less, with 20 to 50 and even more levels in the vertical.

Models explicitly represent large-scale synoptic features of the atmosphere, such as the progression of high- and low-pressure systems, and large-scale oceanic currents and overturning.

Although spatial resolution has improved over time, grid scales of global models limit representation of some important regional and local scale features and processes.

Many important physical processes occur at finer spatial scales.

Examples include radiation and precipitation processes, cloud formation and atmospheric and oceanic turbulence.

The impacts of such processes are included in ‘parameterisations’, whereby their effects are expressed in approximate form on the coarser model grid.

Parameterisations are typically the result of intensive theoretical and observational study, and essentially represent ‘sub-models’ within the climate model itself.

These can be important for the local distribution of rainfall for example.

To try to include such features, techniques for downscaling can be applied, whereby regions of higher resolution are "embedded" within a global model, or where statistical relationships between local scale climate and broad scale climate features are exploited.

Climate models have undergone continuous development for the last three decades, and now incorporate interactions between the atmosphere, oceans, sea ice and land surface.

Confidence in models comes from their basis in fundamental physical principles, and from their ability to represent important features of the current and past climate.

Global climate models have shown a substantial and robust warming signal resulting from increasing greenhouse gas concentrations over several generations of model development.

However, uncertainties arise, particularly in the details and timing of changes.

These come from uncertainties in parameterisations, and therefore confidence in projections is greater in some variables (e.g. temperature) than others (e.g. precipitation).

These uncertainties are partly reflected in the ranges presented for projections.

A broad suite of climate variables has been reported on for these projections.

While most models perform reasonably well, there is no single “best” model or subset of models, and climate projections differ between models.

Model evaluation determines how well climate models represent historical climate and forms an integral part of the confidence building exercise for climate change projections.

Confidence in a climate projection is a measure of how plausible the projected range of change is for a given emission scenario.

Confidence comes from multiple lines of evidence including physical theory, past climate changes and climate model simulations.

CAUSES OF RECENT CLIMATE CHANGES

In climate science, ‘attribution’ describes accounting for the causes of observed changes in the climate system.

Researchers typically use a combination of climate modelling, instrumental observations, studies of feedback processes and sometimes palaeoclimate reconstructions to investigate cause and effect.

Climate models can characterise both natural climate variability and changes to the climate system that are driven by factors such as increases in greenhouse gases, variations in solar radiation and emissions of volcanic aerosols.

Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions.

Evidence of human influence on the climate system has strengthened over the past decades.

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes.

THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.

It provides the world with an objective, scientific view of climate change, its natural, political and economic impacts and risks, and possible response options.

The IPCC is the leading international body for the assessment of climate change, and a source of scientific information and technical guidance.

The IPCC's main activities are:

… The preparation of comprehensive Assessment Reports on climate change;

… Practical guidance to assist Parties to the international climate change treaties prepare national greenhouse gas inventories; and,

… Special Reports on various topics.

The IPCC does not undertake new research but synthesises published and peer-reviewed literature to develop a comprehensive assessment of scientific understanding, which is published in IPCC Assessment Reports.

The most recent IPCC Assessment Report concluded that human influence has been the dominant cause of the observed warming since the mid-20th century.

The IPCC noted that global mean temperature has risen by around 1 °C over the past 150 years, and at a greater rate of more than 0.1 °C per decade more recently.

It found that increasing greenhouse gases were likely to have been responsible for most of that warming, but with contributions from other anthropogenic impacts, including the cooling effect of aerosols.

The IPCC also concluded that it is very likely that anthropogenic influences, particularly greenhouse gases and stratospheric ozone depletion, has led to:

… A detectable observed pattern of tropospheric warming and a corresponding cooling in the lower stratosphere.

… A substantial contribution to increases in global upper ocean heat content.

… Observed increases in atmospheric moisture content in the atmosphere

… Global-scale changes in precipitation patterns over land

… Intensification of heavy precipitation over land regions

… Changes in surface and sub-surface ocean salinity

… Observed changes in the frequency and intensity of temperature extremes

… Arctic sea ice loss, the retreat of glaciers, and to the increased surface mass loss of the Greenland ice sheet

… The global mean sea level rise since the 1970s.

However, the IPCC is confident that whilst changes in total solar irradiance have not contributed to the recent increase in global mean surface temperature, it also considered that the 11-year cycle of solar variability influences decadal climate fluctuations in some regions.

PROJECTING THE FUTURE CLIMATE

Global climate models allow scientists to answer questions about our climate.

Scenarios of future greenhouse gas and aerosol emissions are used to drive the climate models.

These scenarios are derived to encompass the uncertainty around future anthropogenic emissions including consideration of unknowns in population and economic growth, technological developments and transfer, and political and social change.

The non-linear and chaotic nature of the climate system creates some natural limits to the predictability of climate, such as decreasing skill in weather predictions beyond a few days.

Future climate cannot simply be extrapolated from past climate, and further may depend sensitively on the evolution of future greenhouse gas concentration.

Multi-decadal projections are also affected by the chaotic climate system or natural climate variability.

There is a substantial international climate science and modelling community.

Around the world, many groups have created global climate models and all of them vary to a lesser or greater degree from each other.

This is mainly due to the justifiably different ways some physical processes are mathematically represented in these models.

Global modelling groups perform simulations using the same emissions scenarios and make their results available for further analysis and evaluation.

The Earth's future climate will depend on whether the world manages to slow or even reduce greenhouse gas emissions, but warming is likely to continue.

With greenhouse gas emissions continuing to increase, we expect the warming trend of the past century to accelerate throughout this century.

We also expect changes to rainfall patterns and to the frequency of extreme weather events like cyclones and droughts.

The Earth's future climate will depend on whether the world manages reduce greenhouse gas emissions.

Since greenhouse gases have a long lifetime in the atmosphere, any change in emissions will have a delayed effect on atmospheric concentrations, so these concentrations are expected to continue to increase, leading to further warming and climate change for many decades.

Different emissions scenarios have been developed, based on different assumptions about future demographic change, economic development and technological advances.

The concentration paths are similar up to about 2030, and then diverge markedly.

AUSTRALIA'S POSSIBLE FUTURE CLIMATE

Well-established scientific theory and climate model studies both show that recent warming would largely not have occurred without the increase in greenhouse gas concentrations.

In addition, the current increase in temperatures accords with projections made nearly 30 years ago.

Warming is projected to continue as the effect of past emissions continue, and more greenhouse gases are emitted.

Australia is projected to experience increases in sea and air temperatures, with more hot days and marine heatwaves, and fewer cool extremes.

It takes time for the climate system to warm in response to increases in greenhouse gases, and the historical emissions over the past century have locked in some warming over the next two decades, regardless of any changes we might make to global emissions in that period.

Specifically:

Average temperatures across Australia are projected to rise by 0.6 to 1.5°C by 2030, compared with the climate of 1990, noting that Australia warmed by 0.6°C between 1910 and 1990.

By 2070, warming is projected to be 1.0 to 2.5°C for low greenhouse gas emissions, and 2.2 to 5.0°C for a high emissions scenario.

Australians will experience this warming through an increase in the number of hot days and warm nights and a decrease in cool days and cold nights.

Climate models show that there may be less rainfall in southern areas of Australia during winter and in southern and eastern areas during spring.

Wet years are likely to become less frequent and dry years and droughts more frequent.

Climate models suggest that rainfall near the equator will increase globally, but it’s not clear how rainfall may change in northern Australia.

Australia will also experience climate-related changes to extreme weather events.

In most areas of the country, intense rainfall events will become more extreme.

Fire-weather risk is also likely to increase, and fire seasons will be longer.

And although it is likely that there will be fewer tropical cyclones in the Australian region, the proportion of intense cyclones may increase.

By the mid-21st century, higher ongoing emissions of greenhouse gases will lead to even greater warming and associated impacts.

However, reducing emissions will lead to less warming and fewer associated impacts.

IS THE SCIENCE SETTLED?

A distinction needs to be made between science that is robust and science that is relatively uncertain.

Science is rarely, if ever, 'settled'.

The nature of the scientific method – whereby hypotheses are routinely questioned, tested, refined and retested – is such that understanding is improved over time.

The peer-review process is central to this by minimising the chance of low-quality science being published – and eventually self-corrects any that does.

Better questions to consider are 'Is the science robust?' and 'What are the reasons for uncertainties, and can they be reduced?'

ROBUST FINDINGS

In climate change science, the robust findings include:

Clear evidence for global warming and sea level rise over the past century.

Due to the uptake of anthropogenic CO_2, ocean acidity has increased.

Most of the global average warming over the past 50 years is extremely likely due to anthropogenic greenhouse gas increases.

Continued global greenhouse gas emissions will lead to further climate change.

Anthropogenic warming and sea level rise would continue for centuries even if greenhouse gas emissions were to be reduced sufficiently for atmospheric concentrations to stabilise.

Increased frequencies and intensities of some extreme weather events are very likely.

Systems and sectors at greatest risk are ecosystems, low-lying coasts, water resources in some regions, tropical agriculture, and health in areas with low adaptive capacity.

Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt.

Many impacts can be reduced, delayed or avoided by mitigation (net emission reductions).

Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower greenhouse gas stabilisation levels.

KEY UNCERTAINTIES

Some of the key uncertainties include:

Observed climate data coverage remains limited in some regions.

Analysing and monitoring changes in extreme events is more difficult than for climatic averages because longer data sets with finer spatial and temporal resolutions are required

Effects of climate changes on human and some natural systems are difficult to detect due to adaptation and non-climatic influences

Difficulties remain in reliably attributing observed temperature changes to natural or human causes at smaller than continental scales

Models differ in their estimates of the strength of different feedbacks in the climate system, particularly cloud feedbacks, oceanic heat uptake and carbon cycle feedbacks

Confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. rainfall), and it is higher for broad-scale and long-term changes

Direct and indirect impacts of aerosol (fine atmospheric particles) on the magnitude of the temperature response, on clouds and on rainfall remain uncertain.

Future changes in the Greenland and Antarctic ice sheet mass are a major source of uncertainty that could increase sea level rise projections

Impact assessment is hampered by uncertainties surrounding regional projections of climate change, particularly rainfall

Understanding of low-probability/high-impact events and the cumulative impacts of sequences of smaller events is generally limited.

Barriers, limits and costs of adaptation are not fully understood

Estimates of mitigation costs and potentials depend on uncertain assumptions about future socio-economic growth, technological change and consumption patterns.

COMMUNICATING THE SCIENCE TO POLICY MAKERS

A former Director of the Australian Bureau of Meteorology, Dr Geoff Love, has observed a disconnection between the way scientists and policy makers think.

As a result, much is lost in translation.

Dr Love notes:

Scientists are trained to be sceptical – but in a different way to lawyers … for whom one counter-fact destroys an argument … A non-scientist will see a piece of data that is at odds with the most likely conclusion as disproving a theory … The scientist says there is probably more going on here, let's look at the long run of data and construct probability statements.

By this means, we scientists can better communicate to policy makers our level of confidence in what might, or might not, happen.

THE WAY FORWARD

There is ample, well-supported evidence to provide a basis for action through:

… mitigation of greenhouse gas emissions; and,

… for adaptation to reduce our vulnerability.

It is true that we need to quantify the cost to the community of implementing any policy position that might be adopted.

However, in so doing, attention needs also to be directed to the cost of failing to act in full consideration of the best advice that our understanding of the science offers us.

That advice is clear.

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ANY QUESTIONS?