Key Topic 2: Measuring and Monitoring a Changing Climate

6. Describe the history of international collaboration on climate change and analyze the successes and shortcomings.
7. Describe the various sources of scientific data which are used as evidence of climate change and explain how we know this data to be reliable.
8. Evaluate climate data and draw conclusions based on that data.
9. Explain the use of modelling in forecasting climate and the sources of uncertainty in climate projections.

Study Resources

Resource Title	Source	Located on
A Short History of International Climate Change Negotiations – from Rio to Glasgow	*Mark Maslin, University College London, 2021*	Pages 50-56
Climate Models	*US National Oceanic and Atmospheric Administration (NOAA), 2022*	Pages 57-59
Climate Change Projections	*Government of Canada, Canadian Centre for Climate Services, 2021*	Pages 60-61

Please Note: Hyperlinks found in text are not considered required reading; however, included video links are required to watch.

Study Resources begin on the next page 

A Short History of International Climate Change Negotiations – from Rio to Glasgow

25 January 2021

Despite decades of intense and continuous international negotiations on climate change, progress has been slow. Professor Mark Maslin reflects on the history of negotiations and why there is now hope that states will substantially cut down greenhouse gas emissions.

The last 30 years have been a period of intense and continuous international negotiation to deal with climate change. During the same 30 years, humanity has doubled the amount of anthropogenic carbon dioxide in the atmosphere.

In 1989 Margaret Thatcher, the Prime Minster of the UK, gave an address to the UN outlining the science of climate change, the threat it posed to all nations, and the actions needed to avert the crisis. She summed up by saying: “We should work through this great organisation and its agencies to secure world-wide agreements on ways to cope with the effects of climate change, the thinning of the ozone layer, and the loss of precious species” (Margaret Thatcher Foundation, 2020). This sentiment was echoed in similar speeches by George Bush Senior, President of the United States, including one in 1992 when he outlined his ‘Clear Skies’ and ‘Global Climate Change’ initiatives at the National Oceanic and Atmospheric Administration.

This was because by the end of the 1980s the threat of climate change had finally been recognized. This was due to the global temperature record ‘hockey stick’ upturn at the end of the 1980s (Maslin, 2021). This led to the rediscovery of the underpinning science of climate change that had been essentially carried out and settled by the mid-1960s (Weart, 2008). This was combined with our increased knowledge of how past climate was controlled by changes in atmospheric CO2 and significant improvements in supercomputer modelling of our climate system (Maslin, 2021). There was also the emergence of global environmental awareness in the late 1980s driven by a series of catastrophic local pollution events and the discovery of the ozone hole over Antarctica (Corfee-Morlot et al., 2007). By the beginning of the 1990s climate change had become a global issue - even if it was still a highly disputed one (Oreskes and Conway, 2012).

The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988 and produced its very first science report in 1990. Two years later, with support from leaders from all around the world, the UN held the Rio Earth Summit - officially called the United Nations Conference on Environment and Development (UNCED) - to help member states cooperate on sustainability and protecting the world’s environment. The Summit was a huge success and led to the *Rio Declaration on Environment and Development*, the local sustainability initiative called Agenda 21 and Forest Principles (Gupta, 2014). It also set up the *United Nations Convention to Combat Desertification*, the *Convention on Biological Diversity* and the *Framework Convention on Climate Change (UNFCCC)* that underlies the negotiations to limit global greenhouse gas

emissions. The Rio Earth Summit also laid the foundations for the Millennium Development Goals and the subsequent Sustainable Development Goals.
The United Nations Framework Convention on Climate Change (UNFCCC) officially came into force on 21 March 1994. As of March 2020, the UNFCCC has 196 parties. Enshrined within the UNFCCC are a number of principles including agreement by consensus of all parties and differential responsibilities (Gupta, 2014). The latter is because the UNFCCC acknowledges that different countries have emitted different amounts of greenhouse gases (GHGs) and therefore need to make greater or lesser efforts to reduce their emissions. For example, per capita emissions of CO2 in the USA are ten times greater than in India. The UNFCCC pays heed to the principle of contraction and convergence - the idea that every country must reduce its emissions and that all countries must converge on net zero emissions. The net zero emissions target emerged from the important IPCC 1.5˚C global warming report published in 2018 which clearly showed that to achieve 1.5˚C there had to be zero carbon emissions by about 2050 and then negative carbon emissions for the rest of the century (IPCC, 2018).

Kyoto 1997

Since the UNFCCC was set up, the nations of the world, 'the parties', have been meeting annually at the 'Conference of the Parties' (COP) to move negotiations forward. Only five years after the UNFCCC was created, at COP3 in December 1997, the first international agreement was drawn up, the Kyoto Protocol (Gupta, 2014). This stated the general principles for a worldwide treaty on cutting GHG emissions and, more specifically, that all developed nations would aim to cut their emissions by 5.2% relative to their 1990 levels by 2008-12. The Kyoto Protocol was ratified and signed in Bonn on 23 July 2001, making it a legal treaty. The USA, under the leadership of President Bush, withdrew from the climate negotiations in March 2001 and so did not sign the Kyoto Protocol at the Bonn meeting. With the USA producing about one-quarter of the world's carbon dioxide pollution at this time, this was a big blow for the treaty. Moreover, the targets set by the Kyoto Protocol were reduced during the Bonn meeting to make sure that Japan, Canada, and Australia would join. Australia finally made the Kyoto Protocol legally binding in December 2007.

In order to balance out the historic legacy of emissions by developed countries, the treaty did not include developing countries, but it was assumed that developing countries would join the post-2012 agreement. The Kyoto Protocol came into force in February 2005, after Russia ratified the treaty, thereby meeting the requirement that at least 55 countries representing more than 55 per cent of the global emissions were participating (Gupta, 2014).

Copenhagen 2009

There were huge expectations of COP15 (Copenhagen) in 2009 despite coming a year after the global financial crash. New quantitative commitments were expected to ensure a post-2012 agreement in order to move seamlessly on from the Kyoto Protocol. Barack Obama had just become President of the USA, raising hopes of a more positive approach. The EU had prepared an unconditional 20% reduction of emissions by 2020 on a 1990 baseline and a conditional target rising to 30% if other developed countries adopted binding targets. Most other developed

countries had something to offer. Norway was willing to reduce emissions by 40% and Japan by 25% from a 1990 baseline. Even the USA offered a 17% reduction on a 2005 baseline, which was an equivalent drop of 4% on a 1990 baseline. But the Copenhagen conference went horribly wrong. First the Danish government had completely underestimated the interest in the conference and provided a venue that was too small. So in the second week, when all the high-powered country ministers and their support arrived, there was not enough room, meaning that many NGOs were denied access to the negotiations. Second, it was clear that the negotiators were not ready for the arrival of the ministers and that there was no agreement. This led to the leaking of 'The Danish Text', subtitled 'The Copenhagen Agreement', and the proposed measures to keep average global temperature rise to 2°C above pre-industrial levels (Gupta, 2014). It started an argument between developed and developing nations as it was brand new text that had just appeared in the middle of the conference. Developing countries accused the developed countries of working behind closed doors and making an agreement that suited them without seeking consent from the developing nations (Byrne and Maslin, 2015). Lumumba Stanislaus Di-Aping, chairman of the G77, said, 'it's an incredibly imbalanced text intended to subvert, absolutely and completely, two years of negotiations. It does not recognize the proposals and the voice of developing countries' (Guardian, 2009).

The final blow to getting an agreement on binding targets came from the USA. Barack Obama, arriving only two days before the end of the conference, convened a meeting of the USA with the BASIC (Brazil, South Africa, India, and China) countries which excluded other UN nations, and created the Copenhagen Accord (Maslin, 2021). This recognized the scientific case for keeping temperature rises below 2°C, but did not contain a baseline for this target, nor commitments for reduced emissions that would be necessary to achieve it. Earlier proposals that would have aimed to limit temperature rises to 1.5°C and cut CO2 emissions by 80 per cent by 2050 were dropped. The agreement made was non-binding and countries had until January 2010 to provide their own voluntary targets. It was also made clear that any country that signed up to the Copenhagen Accord was also stepping out of the Kyoto Protocol. Hence the USA was able to move away from the binding targets of Kyoto Protocol, which should have been enforced until 2012, and a weak voluntary commitment approach was adopted. The Bolivian delegation summed up the way the Copenhagen Accord was reached - 'anti-democratic, anti-transparent and unacceptable' (Guardian, 2009). It was also not clear what legal status the Copenhagen Accord had as it was only 'noted' by the parties, not agreed, as only 122, subsequently rising to 139 countries, agreed to it (Bryne and Maslin, 2015).

Trust in the UNFCCC negotiations took another blow when in January 2014 it was revealed that the US Government negotiators had information during the conference obtained by eavesdropping on meetings of other conference delegations. Documents leaked by Edward Snowden showed how the US National Security Agency (NSA) had monitored communications between countries before and during the conference. The leaked documents show that the NSA provided US delegates with advance details of the Danish plan to 'rescue' the talks should they founder, and also about China's efforts before the conference to coordinate its position with that of India (Guardian, 2014).

Paris 2015

The failure of COP15 in Copenhagen and its voluntary commitments cast a long shadow over the successive COP meetings, compounded by the revelation by Wikileaks that US aid funding to Bolivia and Ecuador was reduced because of their opposition to the Copenhagen Accord Guardian (2010). It took over five years for the negotiations to recover from the mess created by Barack Obama and the USA negotiators. At COP16 in Cancun and COP17 in Durban the UNFCCC negotiations were slowly put back on track with the aim of getting legally binding targets. Significant progress was made in the REDD+ (Reduced Emissions from Deforestation and Forest Degradation), including safeguards for local people. It was, however, at COP18 in Doha in December 2012 that a second commitment period starting in January 2013 was agreed, to last eight years. This ensured that all Kyoto mechanisms and accounting rules remained intact for this period, and that parties could review their commitments with a view to increasing them. All this laid the foundations for the possibility of a future global climate agreement, which was agreed at COP21 in Paris in 2015.

The climate negotiations in Paris 2015 were a huge success primarily because the French hosts understood the grand game of international negotiation and used every trick in the book to get countries to work together to achieve an agreement signed by all (Lewis, 2015). The agreement states that the parties will hold temperatures to "well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels". Paris was a high-stakes game of geopolitical poker. Surprisingly, the least powerful countries did much better than expected. The climate talks were subject to a series of shifting alliances going beyond the usual income-rich northern countries and income-poor global south countries. Central to this was, firstly, the US-Chinese diplomacy as both agreed to limit emissions. Secondly, a new grouping of countries called the Climate Vulnerable Forum forced the 1.5°C target higher up the political agenda, so much so that it is mentioned in the key aims of the agreement (Lewis, 2015). Political support from the Paris Agreement allowed the IPCC to write the seminal 1.5˚C global warming report which was published in 2018. This report documented the significant increase in the impact between a 1.5˚C and 2.0˚C world (IPCC, 2018). It also documented how a 1.5˚C world could be achieved - which in essence shows that the world must have net zero carbon emissions by 2050 and then carbon must be taken out of the atmosphere for the rest of the century. The quicker the world gets to net zero the less carbon needs to be extracted from the atmosphere between 2050 and 2100 (Goodall, 2020). The Paris Agreement was just the start of the process because taking into account all the country pledges and assuming that they will be fulfilled then the world would still warm by about 3˚C (Maslin, 2019).

The role of global environmental social movements

There have been three main waves of environmental social movements. The first was in the late 1980s and early 1990s and provided global support for the Rio Summit. The second wave was in 2008 and 2009, focusing on the hope of a major climate deal at the Copenhagen climate conferences. In the UK it was very successful and lead to the Climate Change Act in 2008 (Bryne, 2019). As we know, Copenhagen ended in abject failure due to the lack of international leadership, sabotage by the US, lobbying by powerful climate change deniers and the global

worries about dealing with the 2008 global financial crash (Maslin, 2021). For almost 10 years the global environmental movement was held back due to the focus on the global economy. This all changed in 2018.

The third wave of the global environmental social movement started in 2018 (Figueres and Rivett-Carnac, 2020). In May 2018 Extinction Rebellion was set up in the UK and launched in October 2018 with over 100 academics calling for action on climate change. The aim of Extinction Rebellion is to use non-violent civil disobedience to compel governments around the world to avoid tipping points in the climate system and biodiversity loss to avoid both social and ecological collapse (Lewis and Maslin, 2018). In November 2018 and April 2019 they brought central London to a standstill, and Extinction Rebellion has now spread to at least 60 other cities around the world.

In August 2018, Greta Thunberg - at the age of 15 - started to spend her school days outside the Swedish Parliament holding a sign saying Skolstrejk för klimatet (School strike for climate) calling for stronger action on climate change. Soon other students all around the world started similar school strikes once a month on a Friday and they called the movement ‘Fridays for Future’ (Thunberg, 2019). It has been estimated that by the end of 2019 there were over 4500 strikes across over 150 countries, involving 4 million school children and this has rising further in 2020 (Fridays for Future, 2020).

In 2018 and 2019 three extremely influential IPCC reports were published. First, in 2018, was the Special Report on Global Warming of 1.5°C which documented what the world needed to do if global temperature rise was to be kept at only 1.5˚C (IPCC, 2018). It also showed the positive and negative interactions of climate change mitigation and the Sustainable Development Goals. The second was the special report on the land and how climate change would impact desertification, land management, food security, and the terrestrial ecosystems (IPCC, 2019a). The third was the IPCC Special Report on the Ocean and Cryosphere showing the impacts of climate change on the speed of melting of ice sheets, mountain glaciers and sea ice, and their implications of sea level rise and marine ecosystems (IPCC, 2019b).

This new social movement and the very latest science inspired many corporations to take a leading role (Hawken, 2018). Microsoft has set the agenda for the technology sector with the ambitious target to become carbon negative by 2030. By 2050 they want to remove all the carbon pollution from the atmosphere that they and their supply chain have emitted since the founding of the company in 1975. Sky has set the agenda for the media sector; as they are already carbon neutral they have pledged that they and their supply chain will go carbon negative by 2030. BP has also declared that it will be carbon neutral by 2050 by eliminating or offsetting over 415 million tons of carbon emissions. These companies form part of a group of over 850 global companies that have pledged to adopt Science Based Targets, meaning, in effect, that they will all have achieved net zero carbon emissions by 2050 (CDP, 2020).

Given all this pressure in 2019, governments all around the world started to declare that we are, in fact, in a climate emergency and action has to be taken. At the time of the publication of this article, over 1,400 local governments and over 35 countries have made climate emergency declarations. Despite the fact that in 2020 the whole world was focused on dealing with the Covid-19 pandemic, climate change remained a major issue (Jones and Maslin, 2020).

Glasgow 2021

This new wave of public global environmental concern meant there were great expectations for COP26 in Glasgow at the end of 2020, co-hosted by the UK and Italy. But due to the Covid-19 pandemic, the resultant lockdowns, and the major impact on both Italy and Britain, this pivotal meeting was postponed until November 2021. This meeting is critical because it is the third meeting of the parties to the 2015 Paris Agreement (CMA3) and is the first global stock-take outlined in the Paris Agreement. COP26 will review the progress made since 2015 and encourage greater commitments and pledges from countries to cut their greenhouse gas emissions. Importantly this will be the first COP meeting where 'net zero' carbon emissions targets will be the primary global ambition, and the discussion will be about how fast this can be achieved and which countries will lead (Hawken, 2018; Figueres and Rivett-Carnac, 2020; Mann, 2021).

Despite 2020 and 2021 being dominated by the Covid-19 pandemic, the geopolitical landscape around climate change has seismically shifted. First, in June 2019, the UK parliament amended the Climate Change Act (2008) to require the government to reduce the UK's net emissions of greenhouse gases by 100% relative to 1990 levels by 2050. Second, the European Commission is proposing that the EU reduces its GHG emissions by at least 55% by 2030 from 1990 levels, instead of the 40% cut agreed six years ago. This target would be written into EU law and made binding on all 27-member states. This is a major step towards the EU pledge of matching the UK ambition of reaching carbon neutrality by 2050. Third, in September 2020 China's President Xi Jinping announced via video-link to the UN General Assembly in New York that the country would aim to reach peak emissions before 2030, followed by a long-term target to become carbon neutral by 2060. China is the world's largest carbon emitter accountable for around 28% of global GHG emissions and up to now has not committed to a long-term emissions goal. Under the Paris Agreement, China had pledged to cut the carbon intensity of its economy by 60-65% against a 2005 baseline. This announcement came after long and detailed discussions between China and the EU concerning climate change.

COP26 marks the re-engagement with the USA, second largest emitter of around 15% of global GHG emissions. In 2017 the Paris Agreement had a major setback. President Trump declared he was taking the USA out of the Agreement, as he believed it was unfair and biased towards developing countries. In accordance with Article 28 of the Paris Agreement, a country cannot give notice of withdrawal from the Agreement before three years of its start date in the relevant country. So, the earliest possible effective withdrawal date by the United States was November 4, 2020—one day after the 2020 U.S. presidential election. President Biden has already re-joined the Paris Agreement and is a clear advocate of collective international action to deal with

climate change. He has appointed John Kerry as United States Special Presidential Envoy for Climate, which has been made a cabinet position.

The new President faces additional challenges because over the four years of the Trump presidency nearly 100 environmental rules and regulations have been rescinded or are in the process of being removed. These included rolling back the Obama administration's fuel efficiency and emissions standards for vehicles, reductions in their coal emissions standards for coal-fired power plants, and weakening the efficient lighting regulation, meaning less efficient light bulbs can still be purchased after 2020. President Biden is already undoing many of these changes through executive orders.

For example President Trump also gave the executive orders to approve two controversial oil pipelines, Keystone XL and Dakota Access. In 2018, plans were announced to allow drilling in nearly all US waters, creating a huge expansion of offshore oil and gas leases. In 2019, the Trump administration completed plans for opening the entire coastal plain of the Arctic National Wildlife Refuge to drilling. All of these are in the process of being rescinded.

For the first time in over a decade there is now hope that the nations of the world can cut greenhouse gas emissions significantly and start the journey to a cleaner, greener, safer, healthier and more sustainable world.

Conclusion

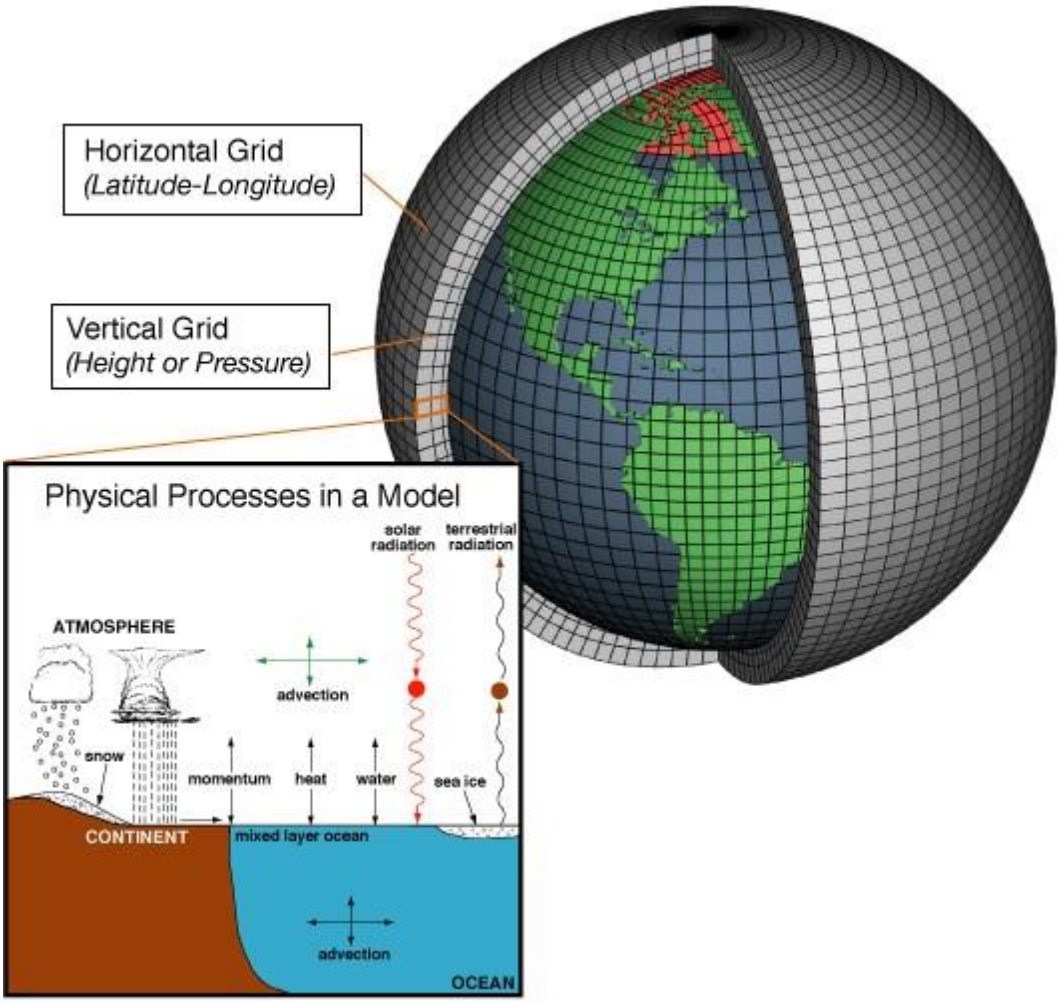
In the last 30 years the amount of human-emitted carbon dioxide has doubled. This represents a collective failure of the world’s leaders to focus on this issue. As a consequence, the ambition of the climate change negotiations has increased. The Kyoto Protocol aimed for developed countries to cut emissions by 5.2% relative to their 1990 levels, while the Glasgow COP26 will aim to get all countries to agree to be net carbon zero as early as possible in this century. No one is underestimating how difficult but important it is to get a deal in Glasgow.

Climate Models

How We Use Models

Models help us to work through complicated problems and understand complex systems. They also allow us to test theories and solutions. From models as simple as toy cars and kitchens to complex representations such as flight simulators and virtual globes, we use models throughout our lives to explore and understand how things work.

Climate Models, and How They Work



This image shows the concept used in climate models. Each of the thousands of 3-dimensional grid cells can be represented by mathematical equations that describe the materials in it and the way energy moves through it. The advanced equations are based on the fundamental laws of physics, fluid motion, and chemistry. To "run" a model, scientists specify the climate forcing (for instance, setting variables to represent the amount of greenhouse gases in the atmosphere) and have powerful computers solve the equations in each cell. Results from each grid cell are passed to neighboring cells, and the equations are solved again. Repeating the process through many time steps represents the passage of time. Image

source: NOAA (http://celebrating200years.noaa.gov/breakthroughs/climate_model/modeling_schematic.html).

Climate models are based on well-documented physical processes to simulate the transfer of energy and materials through the climate system. Climate models, also known as general circulation models or GCMs, use mathematical equations to characterize how energy and matter interact in different parts of the ocean, atmosphere, land. Building and running a climate model is complex process of identifying and quantifying Earth system processes, representing them with mathematical equations, setting variables to represent initial conditions and subsequent changes in climate forcing, and repeatedly solving the equations using powerful supercomputers. Check out The Very, Very Simple Climate Model » (https://scied.ucar.edu/simple-climate-model)

Climate Model Resolution

Climate models separate Earth's surface into a three-dimensional grid of cells. The results of processes modeled in each cell are passed to neighboring cells to model the exchange of matter and energy over time. Grid cell size defines the resolution of the model: the smaller the size of the grid cells, the higher the level of detail in the model. More detailed models have more grid cells, so they need more computing power.

Climate models also include the element of time, called a time step. Time steps can be in minutes, hours, days, or years. Like grid cell size, the smaller the time step, the more detailed the results will be. However, this higher temporal resolution requires additional computing power.

How are Climate Models Tested?

Once a climate model is set up, it can be tested via a process known as “hind-casting.” This process runs the model from the present time backwards into the past. The model results are then compared with observed climate and weather conditions to see how well they match. This testing allows scientists to check the accuracy of the models and, if needed, revise its equations. Science teams around the world test and compare their model outputs to observations and results from other models.

Using Scenarios to Predict Future Climate

Once a climate model can perform well in hind-casting tests, its results for simulating future climate are also assumed to be valid. To project climate into the future, the climate forcing is set to change according to a possible future scenario. Scenarios are possible stories about how quickly human population will grow, how land will be used, how economies will evolve, and the atmospheric conditions (and therefore, climate forcing) that would result for each storyline.

In 2000, the Intergovernmental Panel on Climate Change (IPCC) issued its Special Report on Emissions Scenarios (SRES)

(http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0), describing four scenario families to describe a range of possible future conditions. Referred to by letter-number combinations such as A1, A2, B1, and B2, each scenario was based on a complex relationship between the socioeconomic forces driving greenhouse gas and aerosol emissions and the levels to which those emissions would climb during the 21st century. The SRES scenarios have been in use for more than a decade, so many climate model results describe their inputs using the letter-number combinations.

In 2013, climate scientists agreed upon a new set of scenarios that focused on the level of greenhouse gases in the atmosphere in 2100. Collectively, these scenarios are known as Representative Concentration Pathways or RCPs. Each RCP indicates the amount of climate forcing, expressed in Watts per square meter, that would result from greenhouse gases in the atmosphere in 2100. The rate and trajectory of the forcing is the pathway. Like their predecessors, these values are used in setting up climate models.

Learn more about RCPs » (http://www.skepticalscience.com/rcp.php?t=1)

Results of Current Climate Models

Around the world, different teams of scientists have built and run models to project future climate conditions under various scenarios for the next century. So the groups can make a fair comparison of their results, they run the same experiment. Because each climate model is slightly different, the results show a range of projections. Though yearly values projected for temperature and precipitation differ among the models, the trend and magnitude of change is fairly consistent.

Global climate model results from groups around the world project that global temperature will continue to increase. They also show that human decisions and behavior we choose today will determine how dramatically climate will change in the future.

How are Climate Models Different from Weather Prediction Models?

Unlike weather forecasts, which describe a detailed picture of the expected daily sequence of conditions starting from the present, climate models are probabilistic, indicating areas with higher chances to be warmer or cooler and wetter or drier than usual. Climate models are based on global patterns in the ocean and atmosphere, and records of the types of weather that occurred under similar patterns in the past.

Climate Change Projections

How computer models help us understand climate

The most powerful computers on Earth are used to run climate models. Scientists use these models to understand how Earth's climate works and to make predictions about how it might change in the future.

Climate models have successfully helped reconstruct climates of the distant and recent past, answering important questions, such as "what caused the last ice age?". The proven ability of climate models to describe Earth's past and present climates gives us confidence that they can simulate the planet's future climate, too.

There are many research centres and thousands of climate scientists creating and fine-tuning computerized climate models worldwide. For example, the Met Office Hadley Centre for Climate Science and Services in England is one of the world's leading climate research institutions. It has over 200 staff dedicated to climate research and uses clusters of supercomputers to create some of the most effective climate models in the world. Here in Canada, the federal Canadian Centre for Climate Modelling and Analysis (CCCma) has been creating excellent climate models since the early 1980s.

Climate scientists at institutions like the Hadley Centre and the CCCma combine scientific research and advanced computing to predict what the climate will look like in the decades to come.

General Circulation Models

The first computer models describing global warming were created in the 1960s. They calculated changes in the temperature of the planet by modelling the balance between the energy coming in from the sun and the energy escaping Earth's atmosphere back into space. The scientific community has been improving on these first models for over 50 years now.

Modern climate models are called "General Circulation Models" or "Earth Systems Models." They address much more than the sun-Earth energy balance. Working from the foundations of physics and chemistry, they take thousands of factors into account to model the entire climate system, including solar radiation, greenhouse gas emissions, volcanic eruptions, cloud formation, ocean currents, chemical reactions in the atmosphere, land use changes, and much more.[1]

New climate models are constantly improving our understanding of the climate system and our improving understanding of the climate system is improving the models. The overall conclusions of the models have not changed—human greenhouse gas emissions are driving global warming.[2]

How do we know climate models work?

Models allow scientists to test their understanding of how the climate works and how it might change in the future. But do the models do a good job of simulating the real world?

Climate models are extensively tested by “hindcasting”, which means modelling the climate of the past.

Climate models are considered successful only if they can recreate to a high degree the averages, extremes, and seasonal patterns that match up with observed climate.

There is one major difference between predicting climate and predicting weather. A weather forecast attempts to create very precise hour-by-hour predictions on a very small scale. Climate models, on the other hand, effectively combine many simulations of possible weather to produce the accumulated story of what average and extreme conditions might happen. In other words, the goal of a climate model is to project changes in climates over years, decades and longer, whereas weather predictions are interested in what is expected to happen in the coming days.

Climate models do create simulations of day-to-day weather over many years, but in no way are they meant to be used to state what the weather is expected to be in the future, on any particular day or sequence of days. Instead, these daily simulations are interpreted statistically, resulting in statements about the probability of particular weather conditions being observed in the future. They do not produce weather forecasts; they produce climate projections. And importantly, scientists keep track of how well models perform as the years pass. Since 1990, for example, the observed rate of global warming is well within the original range projected by climate models.

Why do we use so many climate models?

Canada is one of dozens of countries that has independently produced its own climate models. International organizations help coordinate all of these modelling experiments and gather them into an “ensemble”, or collection of many different models.

Why do this? Although each model is carefully designed to be consistent and plausible, working with an ensemble of many models lets us look at a range of future projections instead of just one. Working with ensembles lets us do a better job of taking natural climate variability into account, helps eliminate the effects of modelling uncertainty, and means that our conclusions are not biased by the weaknesses or strengths of any one model on its own.

Comparing the results of many different models makes one thing very clear: all climate models clearly indicate that temperatures will continue to rise as greenhouse gas emissions accumulate in the atmosphere.