Today I Learned About Uncertainty

"We're dealing with a very complex system. Many, many interacting components: the transmission of radiation through the atmosphere, wind, the coupling with the ocean, ocean circulation, the land surface, the whole biosphere, which interacts with all of that."
Professor Kerry Emanuel, MIT Dept. of Earth, Atmospheric and Planetary Science
TILclimate podcast: Today I Learned About Uncertainty

Beat the Uncertainty Game

Developed by the National Oceanic and Atmospheric Administration, the game "Beat the Uncertainty" models climate-resilient cities. In this simulation, you and your teammates are leaders of a coastal city. You are challenged to make decisions to make your city more resilient to rising sea levels.

Questions

As you choose which adaptation strategies to promote in your city:

- Are you planning for a worst-case or best-case scenario?
- How does uncertainty about the future factor into your decisions?

As you play the game:

- How are climate events similar to a roll of the dice?
- How does a run of particularly good luck or bad luck affect the game?

After you finish the game:

- In the game, each outcome is a known roll of the dice – an exact probability. In the real world, are these events predictable to that level?
- How should uncertainty affect decision-making?

A Brief Introduction to Sea Level Rise

As we burn fossil fuels like coal, oil, and natural gas and cut down forests, we release carbon dioxide (CO_2) into the atmosphere. This CO_2, along with other gases, acts like a blanket around Earth, trapping heat. Trapped heat warms our Earth, ocean, and air. In the ocean, this causes sea level rise through two mechanisms:

- Warmer water takes up more space because warmer water molecules move around more. This is called *thermal expansion*.
- Land ice, such as glaciers and the Greenland and Antarctic ice sheets, melts due to warmer air and sea temperatures. This meltwater adds to the volume of the ocean and raises sea levels.

Globally, sea levels have risen 8-9 inches since 1880[1]. The amount of sea level rise each coastal community has experienced varies due to geological processes and other effects.

1 Climate Change: Global Sea Level from Climate.gov
https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

Today I Learned About Uncertainty

> [Climate scientists] all make different assumptions about what's happening on scales that are too small for them to actually compute. [It] is a way of with uncertainty. So you have different groups making different assumptions about how to do this, running different models, and comparing them."
>
> *Professor Kerry Emanuel, MIT Dept. of Earth, Atmospheric and Planetary Science*
>
> *TILclimate podcast: Today I Learned About Uncertainty*

Representative Concentration Pathways

As we burn fossil fuels like coal, oil, and natural gas and cut down forests, we release carbon dioxide (CO_2) into the atmosphere. This CO_2, along with other gases, acts like a blanket around Earth, trapping heat. Trapped heat warms our Earth, ocean, and air. A warmer planet is causing dramatic changes to climate and weather patterns all over the world, including extreme weather and sea level rise. But what exactly will our future look like?

National and international scientific organizations use a series of *Representative Concentration Pathways* (RCPs) to model different possible futures. Each pathway is based on a different story about the future of heat-trapping gas emissions through 2100.

RCP8.5 is sometimes referred to as a 'business as usual' scenario, because its CO_2 emissions curve follows a similar path as the observed trend up from 2000-2020. However, RCP8.5 was never meant to be a likely scenario. (For example, it includes a 500% increase in the use of coal and almost no carbon-reducing policies.)[1] Similarly, RCP2.6 is also extremely unlikely, as it would require CO_2 emissions to have peaked in 2020 and begun to come down in 2021. RCP4.5 and RCP6.0, then, are the most likely scenarios. Both scenarios cover a wide range of possibilities, depending on emissions and the complexity of Earth's climate system.

On the next page, find a graph and chart that explain the four RCPs. Then come back to answer the questions.

RCP Questions

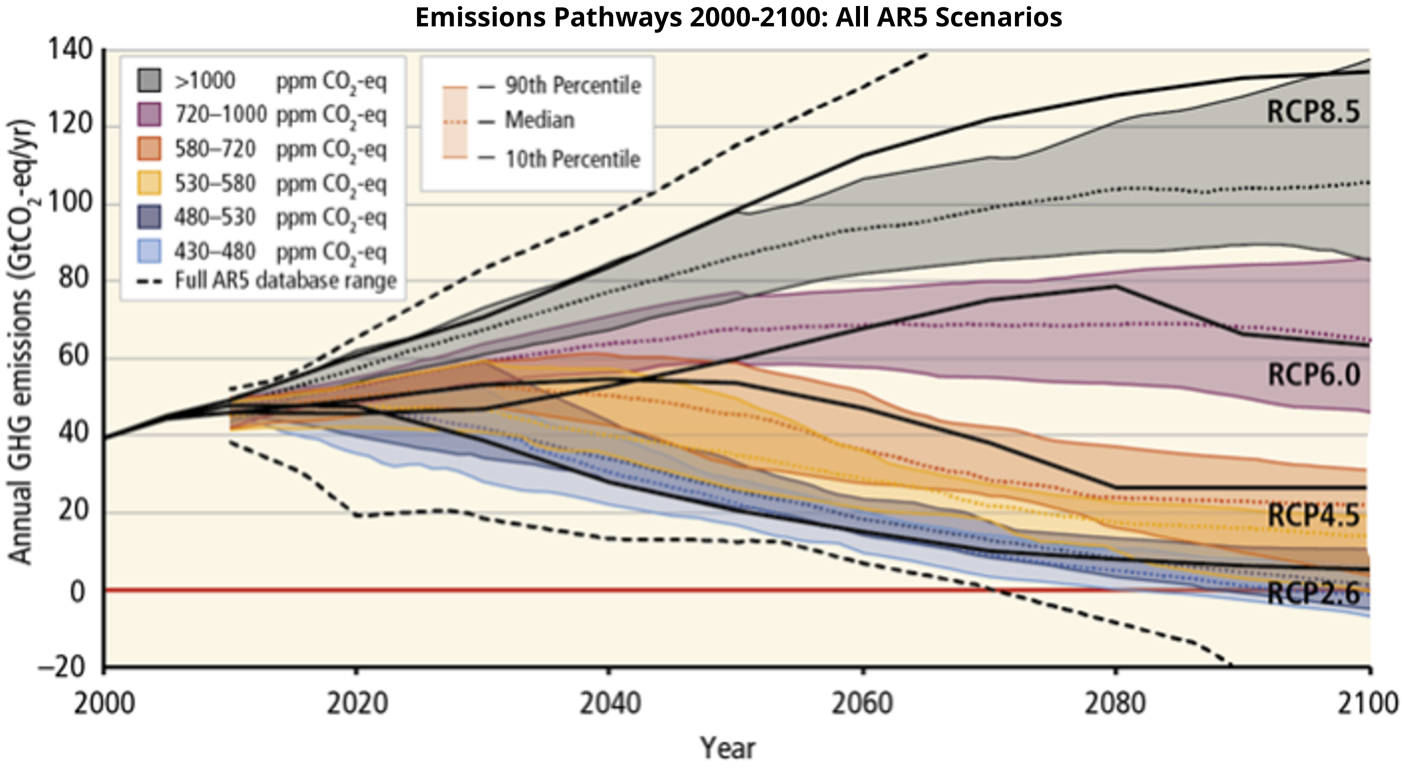
1. Describe the four RCPs in your own words.
2. What is the benefit of having scientists work within agreed-upon scenarios?
3. Why is it important to include RCP8.5 and RCP2.6, even if they are both extremely unlikely to occur? (Consider adaptation and other future planning needs.)
4. RCP4.5 is based on a CO_2 emissions peak in 2040. Research what commitments, plans, and actions your city, county, state, and/or country are undertaking to meet these goals. In the US, Transportation, Electricity, and Industry are the largest sources of emissions.[2]

1 "Climate change: Worst emissions scenario 'exceedingly unlikely'" BBC (Matt McGrath) January 29, 2020 https://www.bbc.com/news/science-environment-51281986
2 US EPA "Sources of Greenhouse Gas Emissions" https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

MIT ENVIRONMENTAL SOLUTIONS INITIATIVE

Today I Learned About Uncertainty

Representative Concentration Pathways



Title	CO_2-eq* Emissions Peak	2100 CO_2-eq Emissions Compared to 2010	CO_2-eq in Atmosphere by 2100 (in ppm**)
RCP2.6	2020	-118% to -78%	430-480
RCP4.5	2040	-134% to -21%	580-720
RCP6.0	2080	-7% to 72%	720-1000
RCP8.5	After 2100	74% to 178%	>1000

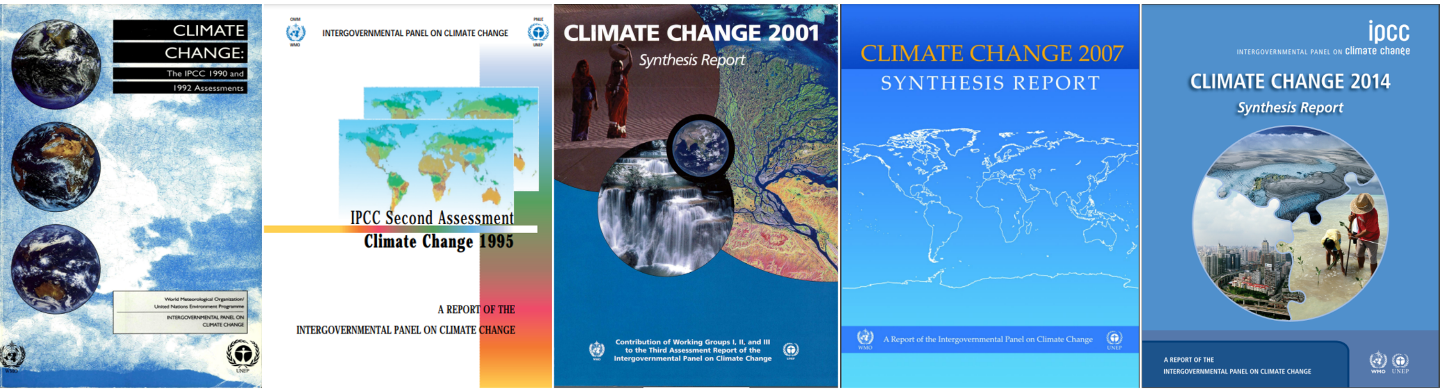
*CO_2-eq, also written CO_2e are *carbon dioxide equivalents*. To make comparison between different heat-trapping gases simpler, climate scientists convert other gases (such as methane (CH_4) or nitrous oxide (N_2O)) into their equivalent in CO_2. For more, read https://climate.mit.edu/explainers/greenhouse-gases

**ppm, or *parts per million* is a ratio, like a percent. 500ppm= 0.05%

Figure SPM11.a from the IPCC AR5 Summary for Policymakers https://www.ipcc.ch/report/ar5/syr/summary-for-policymakers/

Today I Learned About Uncertainty

“If we have a temperature increase of about 6 degrees Centigrade it may be catastrophic. The probability is not large, but it's not zero, and it's not tiny either. And so you have to think about that.”
Professor Kerry Emanuel, MIT Dept. of Earth, Atmospheric and Planetary Science
TILclimate podcast: Today I Learned About Uncertainty



The Intergovernmental Panel on Climate Change

Scientists from over 195 countries work together to assess the physical science of climate change, the effects of climate change, and strategies to slow or prevent climate change. Working groups then write *assessment reports* (AR) that are numbered in order. IPCC AR5 was released in 2013-2014. IPCC AR6 will be released over the course of 2021-2022. The first assessment report was released in 1990.

Real-life climate systems are made up of infinite tiny interactions. No current computer is powerful enough to model at that level, so all models must make assumptions and adaptations. When multiple groups of scientists model the same topic, their models can be compared to see how likely any one outcome might be.

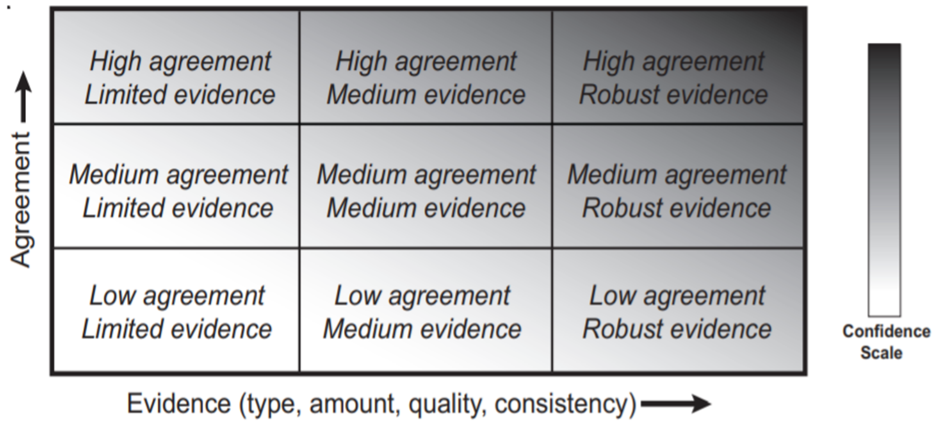
To make these comparisons consistent across all working groups and all assessment reports, the IPCC developed a set of guidelines for talking about the chances of certain outcomes and the confidence of scientists’ assessments.

On the next page, find the guidance that the IPCC gives scientists about *confidence* and *likelihood* when writing their assessments.

Images are the front covers of the IPCC Assessment Reports from 1990, 1995, 2001, 2007, and 2014. https://www.ipcc.ch/reports/

Today I Learned About Uncertainty

IPCC: Confidence and Likelihood



For *confidence*, scientists are asked to evaluate the amount, quality, and consistency of evidence for a statement from different studies and models. Then they compare this to the amount of agreement across studies and models.

Instead of assigning a specific probability to any one outcome, IPCC reports place statements within a range of probabilities on a scale from *virtually certain* to *exceptionally unlikely*.

By making these terms consistent across documents, IPCC reports can be compared across years as well as among working groups.

Likelihood	**Probability**
Virtually certain	99-100%
Extremely likely	95-100%
Very likely	90-100%
Likely	66-100%
More likely than not	50-100%
About as likely as not	33-66%
Unlikely	0-33%
Very unlikely	0-10%
Extremely unlikely	0-5%
Exceptionally unlikely	0-1%

Confidence and Likelihood Questions

1. What would it mean for a statement to have *high confidence* but be *extremely unlikely*?
2. What would it mean for a statement to have *low confidence* but be *very likely*?
3. Why is it important to have consistent guidelines across different assessment reports?

Graphics from “Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties” 2010
https://www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf

Today I Learned About Uncertainty

"Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems."
Intergovernmental Panel on Climate Change
Assessment Report 5: Climate Change 2014 Synthesis Report Summary for Policymakers

Summary for Policymakers

Each IPCC Assessment Report includes a Summary for Policymakers, which condenses the major findings from all three Working Groups. This document is written for government officials, policy organizations, and other decision-makers, instead of scientists.

You will read a one-page edited excerpt from the Summary for Policymakers (SPM.) As you read, pay close attention to terms reflecting confidence (from *very low* to *very high*) and likelihood (from *exceptionally unlikely* to *virtually certain*.) The language in these reports can be very dense. Do not worry if you do not understand every piece of it. Focus on the use of the confidence and likelihood language.

Questions

1. What kinds of statements do the writers qualify with confidence or likelihood markers?
2. In your own words, sum up three key messages from the excerpt, along with their confidence/likelihood.
3. Why do you think it is important to have consistent language for confidence and likelihood in a report like the IPCC?
4. What portions of the report did you find confusing? What information would you need to make sense of the pieces that were unclear?

Pair up with people who read different sections of the IPCC. Discuss:

1. Media that attempts to sow doubt about climate change often says that scientists don't really know what causes climate change, what is happening, and what will happen in the future. Based on the pieces you read, do you think this is accurate? Why or why not?
2. This document is written for policymakers, such as political leaders and non-governmental organizations. How does uncertainty make it more complicated to create policies in response to climate change? To what degree should uncertainty and risk be considered? Does the existence of uncertainty make a scientific matter any less real or important to act on? Explain your reasoning.

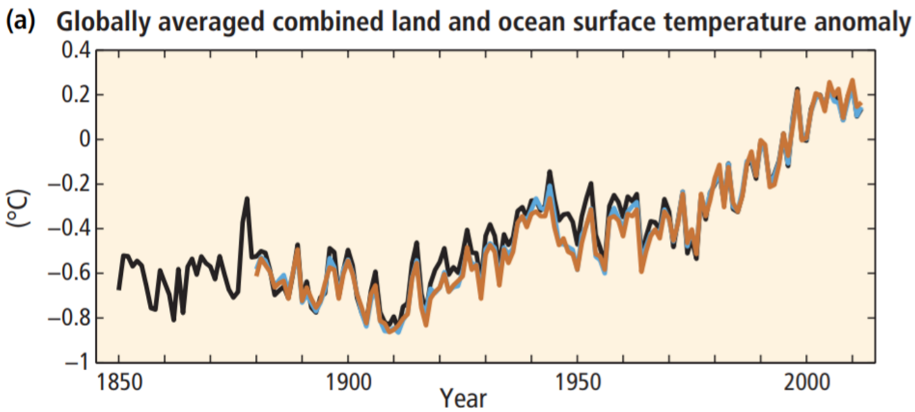
For the full Summary for Policymakers, visit https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf

Excerpts from IPCC AR5 Summary for Policymakers

SPM 1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

Figure SPM.1a

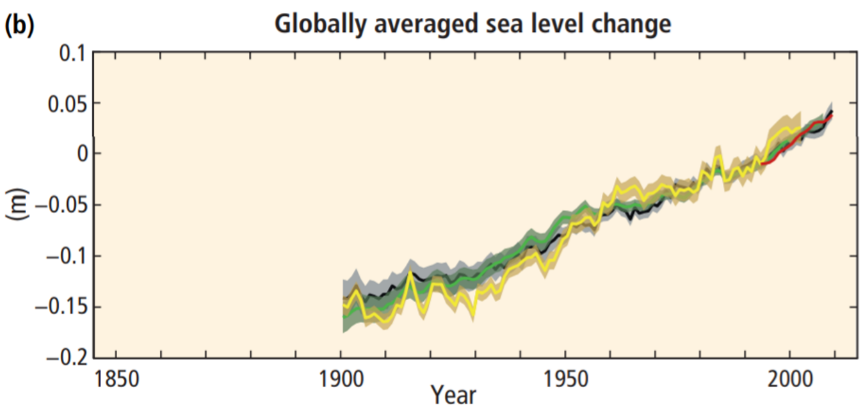


Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere, where such assessment is possible (medium confidence). The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C over the period 1880 to 2012, when multiple independently produced datasets exist.

Since the beginning of the industrial era, oceanic uptake of CO2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 (high confidence), corresponding to a 26% increase in acidity, measured as hydrogen ion concentration.

Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m. The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (high confidence).

Figure SPM.1b



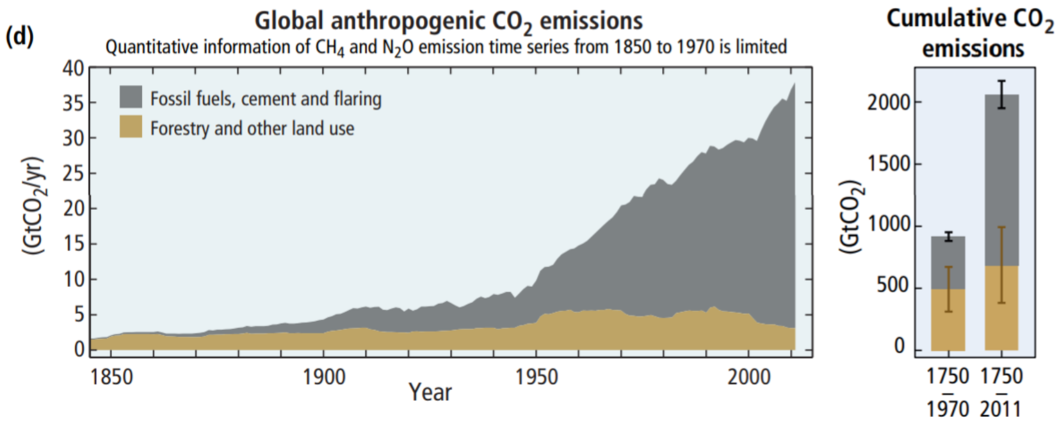
The full Summary for Policymakers, as well as all other reports from AR5, can be found at https://www.ipcc.ch/report/ar5/syr/

Excerpts from IPCC AR5 Summary for Policymakers

SPM 1.2 Causes of climate change

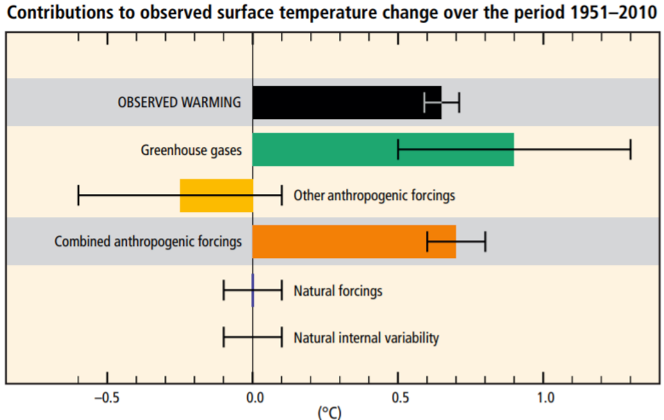
Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century.

Figure SPM.1d



Anthropogenic greenhouse gas (GHG) emissions since the pre-industrial era have driven large increases in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 $GtCO_2$. About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (high confidence.)

Figure SPM.3



The evidence for human influence on the climate system has grown since the IPCC Fourth Assessment Report (AR4). It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period

The full Summary for Policymakers, as well as all other reports from AR5, can be found at https://www.ipcc.ch/report/ar5/syr/

Excerpts from IPCC AR5 Summary for Policymakers

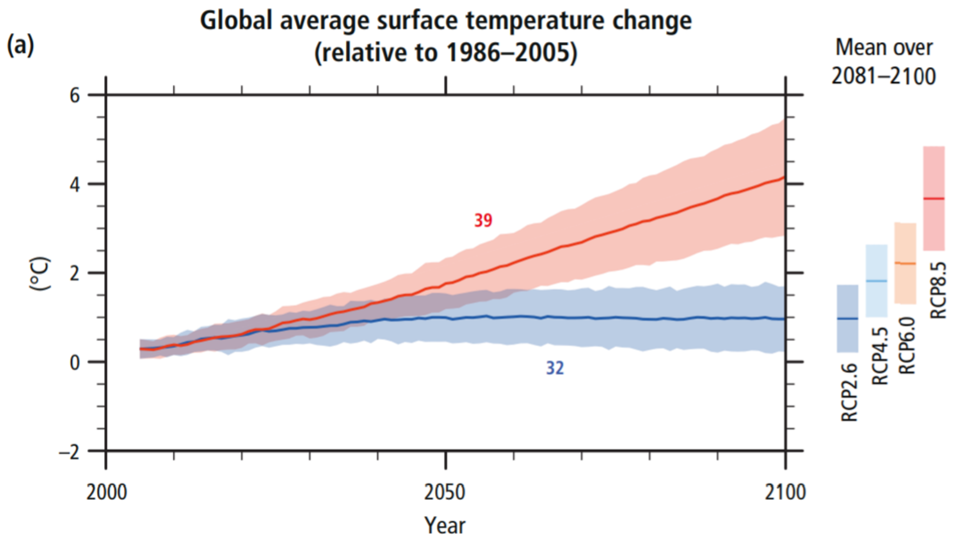
SPM 2.2 Projected changes in the climate system

Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise.

Future climate will depend on committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability. The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will likely be in the range 0.3°C to 0.7°C (medium confidence). By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario.

Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to likely exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (high confidence). Warming is likely to exceed 2°C for RCP6.0 and RCP8.5 (high confidence), more likely than not to exceed 2°C for RCP4.5 (medium confidence), but unlikely to exceed 2°C for RCP2.6 (medium confidence).

Figure SPM.6a



It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is very likely that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur.

The global ocean will continue to warm during the 21st century, with the strongest warming projected for the surface in tropical and Northern Hemisphere subtropical regions.

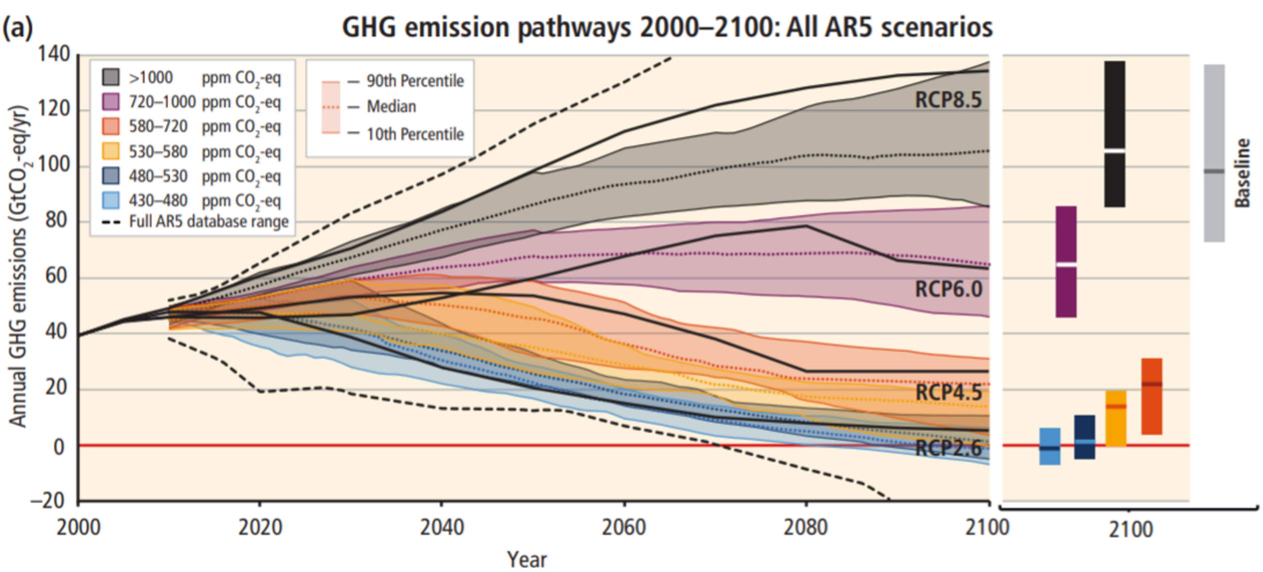
The full Summary for Policymakers, as well as all other reports from AR5, can be found at https://www.ipcc.ch/report/ar5/syr/

Excerpts from IPCC AR5 Summary for Policymakers

SPM 3.4 Characteristics of mitigation pathways

There are multiple mitigation pathways that are likely to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO2 and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales.

Figure SPM.11



Without additional efforts to reduce GHG emissions beyond those in place today, global emissions growth is expected to persist, driven by growth in global population and economic activities. Global mean surface temperature increases in 2100 in baseline scenarios—those without additional mitigation—range from 3.7°C to 4.8°C above the average for 1850–1900 for a median climate response. They range from 2.5°C to 7.8°C when including climate uncertainty (5th to 95th percentile range) (high confidence).

Emissions scenarios leading to CO_2-equivalent concentrations in 2100 of about 450 ppm or lower are likely to maintain warming below 2°C over the 21st century relative to pre-industrial levels. These scenarios are characterized by 40 to 70% global anthropogenic GHG emissions reductions by 2050 compared to 2010, and emissions levels near zero or below in 2100. Mitigation scenarios reaching concentration levels of about 500 ppm CO_2-eq by 2100 are more likely than not to limit temperature change to less than 2°C, unless they temporarily overshoot concentration levels of roughly 530 ppm CO_2-eq before 2100, in which case they are about as likely as not to achieve that goal. In these 500 ppm CO_2-eq scenarios, global 2050 emissions levels are 25 to 55% lower than in 2010.

The full Summary for Policymakers, as well as all other reports from AR5, can be found at https://www.ipcc.ch/report/ar5/syr/