# Prediction and impacts of climate change

# UNIT-3

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| **Prediction and impacts of climate change** | Factors that control emissions |
| | Emissions scenarios |
| | Physical impacts |
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# Factors that control emissions

# Green house gas Emissions

- The emissions of other greenhouse gases also generally scale with the amount of consumption
- Total emissions by a society are basically set by that society's GDP
- Strong evidence of the link between GDP and emissions can be seen during recessions
- During a recession in late 2009, for example, the *New York Times* reported that Global carbon emissions are expected to post their biggest drop in more than 40 years this year as the global recession froze economic activity and slashed energy use around the world
- GDP -product of two factors- population and affluence
- Emissions must also scale with population

# Green house gas Emissions

- Third factor to convert a level of total consumption, expressed in dollars, to greenhouse-gas emissions
- This third term relates how much greenhouse gas is emitted for every dollar of consumption; it is known as the *greenhouse-gas intensity*
- Putting these all together, we can now relate emissions to the factors that control it in a simple equation:

$$I = PAT$$

Here $I$ is equal to the total emissions of greenhouse gases into the atmosphere (these emissions then cause climate impacts, which is why emissions are represented by the letter $I$);

$P$ is the population,

$A$ stands for affluence

$T$ stands for greenhouse-gas intensity.

Affluence $A$ is GDP per person – the average amount of goods and services each person consumes – so the product of $P$ and $A$ is the GDP. IPAT Relation or Kaya Identity

- The greenhouse-gas-intensity term $T$ can be further broken down into two terms:

$$T = \text{EI} \times \text{CI}$$

EI stands for *energy intensity* – the number of joules of energy it takes to generate 1 dollar of goods and services .

CI, which is the amount of greenhouse gas emitted per joule of energy generated

- *Energy Intensity*: determined by two factors

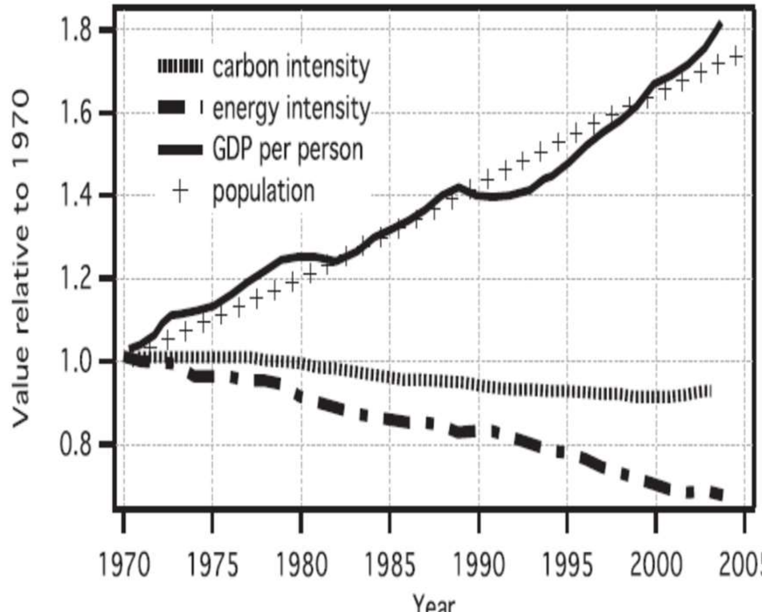
  -- First is the mix of economic activities in the society. For example, e energy for a steel mill to produce 1 dollar's worth of steel than for a university to produce 1 dollar's worth of teaching.

  --The second factor in determining the energy intensity of an economy is the efficiency with which the economy uses energy. For any economic activity, there are usually several technologies to accomplish it. Example standard incandescent light bulb (the kind with the filament), the compact fluorescent light bulb, and the newly developed light-emitting diode or LED light bulb.

- *Carbon intensity:* This term reflects the mix of technologies that a society uses to generate energy, including fossil fuels as well as technologies that do not emit carbon dioxide
  - Natural gas - lowest carbon intensity
  - Oil – higher carbon intensity
  - Coal – highest carbon intensity
  - hydroelectric, nuclear, wind, or solar energy sources - no emission of $CO_2$
- IPAT Units – units of $CO_2$ emitted

# Population

- 1804 - global population reached 1 billion
- 1927 - global population reached 2 billion
- 1960 - global population reached 3 billion
- 1999 – 6 billion
- 2011 – 7 billion
- Figure shows that the population has increased by 80% over the past few decades
- World population is increasing by roughly 200,000 people per day, a population growth rate of approximately 1% per year.
- Most of this growth is occurring in the developing world, where fertility rates remain high.



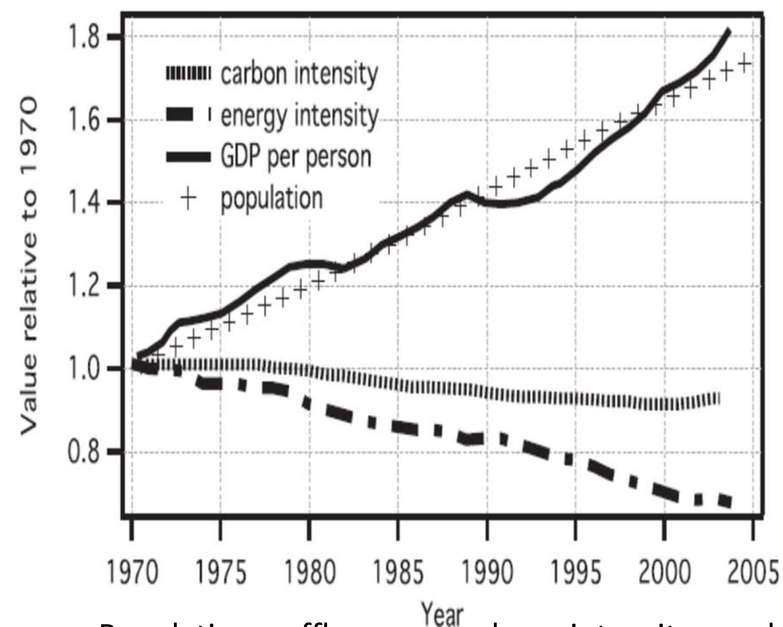

Population, affluence, carbon intensity, and energy intensity for the entire world, relative to values in 1970

# Affluence

- Affluence, measured as GDP per person, increased by 80% over the past few decades of the 20th century
- Discrete political events in the affluence data, such as the 1989 collapse of the Soviet Union and the associated political upheaval in Eastern Europe, as well as various recessions
- In the past decade, the remarkable economic growth of China (with affluence growing at 10% per year or so) and other large developing countries has played a key role in driving global growth

# Technology

- The energy intensity term, has decreased over the past century as our society has developed more efficient ways to use energy
- Each new generation of a particular piece of equipment uses slightly less energy than the previous version
- Over the past century, the fraction of the world economy based on energy-intensive heavy industry and manufacturing has declined, while the fraction based on services has increased.
- the amount of carbon dioxide released per joule of energy generated has decreased slightly over the past few decades as the world shifted from coal to cleaner natural gas.
- Recently, however, as the world begins to run out of cheap oil and gas, the decline has been arrested as the world switches back to coal.
- Increases in population (*P*) and affluence (*A*) have tended increase emissions, while a decrease in greenhouse-gas intensity (*T*) has tended to decrease emissions
- The rate of increase in population and affluence has been much greater than the rate of decrease of greenhouse-gas intensity, so the net change in emissions between 1970 and 2005 was an increase of 75%.




Population, affluence, carbon intensity, and energy intensity for the entire world, relative to values in 1970

# How these factors will change over the 21st century

# Population

- The factors that control population are not completely understood, however. For example, it has recently been discovered that average family size has started increasing in the richest countries, which was unexpected
- World population will peak in the second half of the 21st century at between 9 and 10 billion people.
- However, given our uncertain knowledge about population growth, it is certainly possible that the actual population trajectory could deviate significantly from this.

# Affluence

- Factors such as the level of education in the population, rule of law, free trade, and access to technology are key factors in determining how fast affluence grows
- In general, economic growth rates are highest for countries making a transition out of poverty and into the group of rich countries of the world
- For example, economic growth was fastest in the United States in the late 19th century, in Japan after World War II, and in China today. Growth rates are lower for large, advanced societies
- Based on these factors, expert predictions are that affluence will increase over the 21st century at 2–3% per year for developing countries and 1–2% per year for industrialized countries

# Technology

- Energy intensity has at times decreased as fast as 2% per year, but the periods of fastest decreases occurred during periods of rapid shift in economic mix or as responses to energy price shocks
- Over the 20th century, the average decrease was 1% per year for the entire world. Prospects for future progress are likely of a similar magnitude.
- Continued reductions in carbon intensity are possible through the expanded use of natural gas to replace oil and coal and by shifting new energy supplies to noncarbon sources.
- However, current energy-market conditions are not supporting this shift, as the recent shift toward coal shows.

# Emissions scenarios

# Emissions scenarios

- It is so difficult to make a single accurate prediction of the factors that control emissions, the community of experts has avoided making a single prediction for the 21st century
- Set of alternative but equally plausible *emissions scenarios* has been created
- Each emissions scenario is an internally consistent vision of one way the world might evolve in the future, and the full set of emissions scenarios is designed to span a range of alternative future evolutions of the world
- The scenarios are not referred to as predictions but are instead described as projections.
- Although this may seem to be an insignificant word change, it is extremely important to keep this distinction in mind when you think about the emissions scenarios
- The most well-known set of scenarios comes from the IPCC
- As part of its assessment process in the late 1990s, the IPCC constructed four main emissions scenarios, each based on a different storyline of how the world might evolve over the 21st century. These four families have the extremely unimaginative names A1, A2, B1, and B2.

# Summary of scenario families

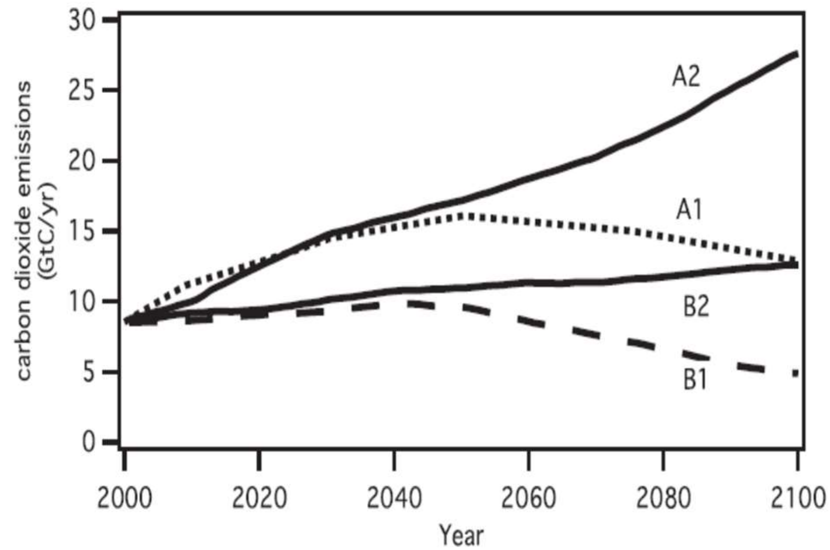
- A1: This storyline describes a future world of rapid economic growth, where both the rich and poor experience gains in wealth, leading to a reduction in the wealth gap between rich and poor and a decrease in poverty. Because of the wealth gains of the poor, population growth diminishes, and global population peaks in mid-century and declines thereafter. There is also a rapid introduction of new and more efficient technologies.
- A2: This storyline also describes a world of high economic growth, but the growth is unevenly distributed. Consistent with the poverty of this scenario, the global birthrate remains high, resulting in a population that continuously increases throughout the $21^{st}$ century. Because of the uneven economic growth, technological development is slower than in other storylines, with deployment of new technologies occurring mainly in the richer parts of the world.
- B1: This storyline describes a world where economic growth is evenly distributed. Economic growth is slower than in the A1 scenario because of an emphasis on sustainable growth and environmental protection. This storyline has the same global population that peaks in mid-century and declines thereafter as in the A1 storyline. The world economy shifts toward a service and information economy, with associated reductions in energy intensity, and the introduction of clean and resource-efficient technologies.
- B2: This storyline describes a world where economic growth is unevenly distributed –. Population increases continuously, although at a rate slower than the A2 scenario, and with less rapid and more diverse technological change than in the A1 and B1 storylines. Sustainability and environmental protection are the focus at local and regional levels.

# Summary of scenario families

- To summarize, the “A” storylines (A1, A2) describe worlds with high rates of economic growth. The “B” storylines (B1, B2) describe worlds where economic growth is slower but the Earth’s resources are managed in a more sustainable way
- The “1” storylines (A1, B1) are worlds in which poverty is reduced and there is an overall convergence between the rich and poor, whereas the “2” storylines (A2, B2) are worlds in which the current split between rich and poor remains
- These storylines are internally consistent, so that the assumptions for population, affluence, and technology all fit together
- For example, because people have fewer children as they get richer, the scenarios in which the world’s poor become richer (A1, B1) feature slower population growth than the scenarios in which poverty is rampant (A2, B2).
- The emissions scenarios described by the IPCC all assume that the world makes no explicit effort to address climate change by reducing emissions

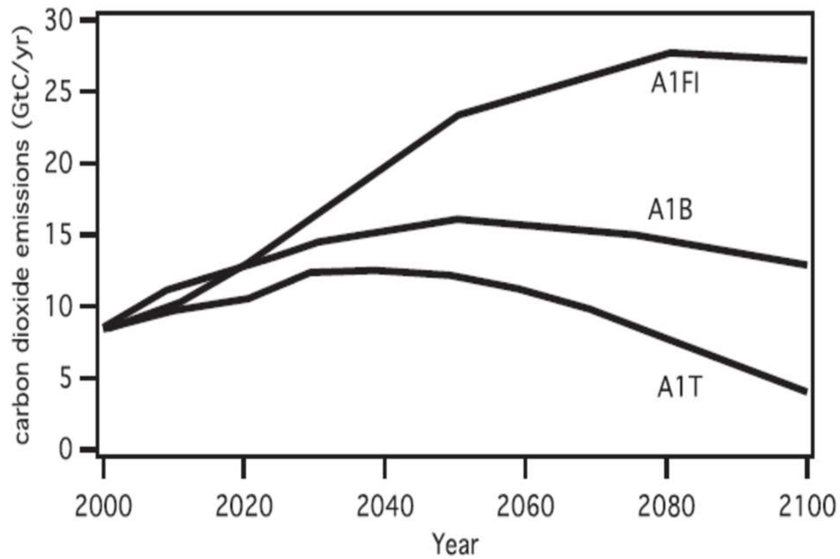
# Summary of scenario families

- The B1 scenario has the lowest emissions because there is moderate population growth and strong technological development directed toward development and deployment of alternative energy sources that emit little or no carbon dioxide.
- This scenario predicts that emissions peak in the middle of the 21st century and decline thereafter, reaching 5 GtC/yr or so in 2100, which is approximately half of what humans are now emitting.
- On the other end of the spectrum is the A2 scenario. That scenario's high population growth, high economic growth directed primarily toward the rich, and slower technological development produces high emissions throughout the century.
- By the year 2100, emissions for the A2 scenario reach 30 GtC/yr, which is roughly three times what humans are emitting today.



# Summary of scenario families

- The A1 family contains two additional scenarios, designated A1T and A1FI, which utilize exactly the same assumptions for population and affluence but sharply different assumptions about technology.
- The A1T scenario (the letter *T* stands for technology) assumes a shift toward energy sources that do not emit carbon dioxide over the next few decades.
- The A1FI scenario (the acronym FI stands for fossil intensive) assumes a shift to coal.
- In 2100, the A1FI scenario predicts emissions close to 30 GtC/yr, whereas the A1T scenario predicts emissions close to 5 GtC/yr.
- The spread between these two scenarios is the same as the spread in emissions between the four scenario families
- A1B - a balance between fossil fuels and new technology
- This emphasizes the importance of technology in controlling emissions. It is possible to get an enormous range of emissions simply by changing the assumptions about technology development and implementation.

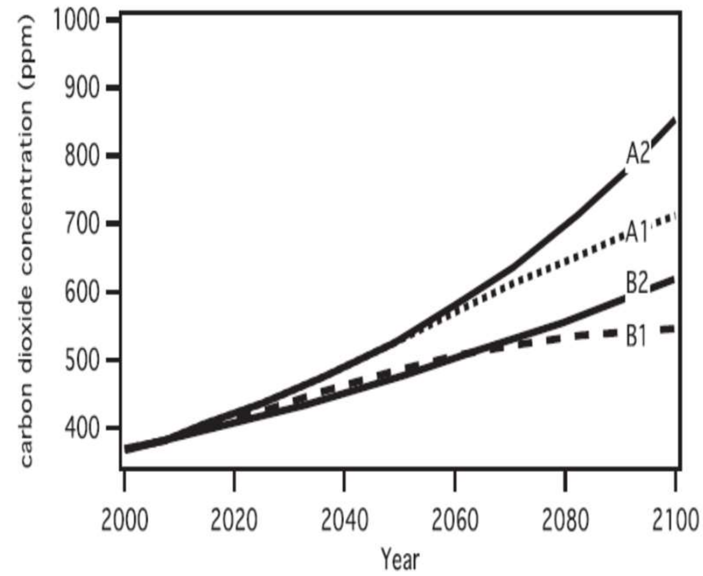



Emissions of carbon dioxide for the three scenarios in the A1 storyline. The emissions are in GtC/yr

# Predictions of future atmospheric composition

Conversion of atmospheric concentrations to greenhouse gases

- This is done by feeding the emissions scenarios into a carbon-cycle model
- The carbon-cycle model calculates how much of the carbon dioxide emitted to the atmosphere is absorbed by the ocean and land reservoirs
- The remainder stays in the atmosphere and increases atmospheric carbon dioxide
- From an abundance of carbon dioxide of 390 ppm in 2010, the IPCC's scenarios project that atmospheric carbon dioxide abundances will be between 550 and 900 ppm in 2100
- The lower limit, 550 ppm, from the B1 scenario, represents roughly twice the pre-industrial atmospheric abundance of carbon dioxide.
- The upper limit, 900 ppm, from the A2 scenario, represents more than a tripling of pre-industrial carbon dioxide abundances.



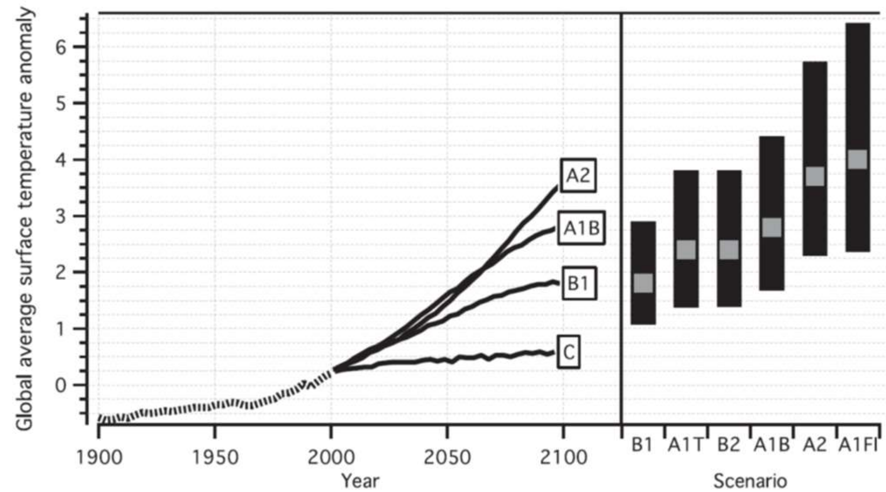

Atmospheric abundances of carbon dioxide (in ppm) for the four emissions families (adapted from Albritton et al., 2001, Fig. 18).

# Predictions of future atmospheric composition

- Other greenhouse gases (e.g., methane) and non-greenhouse gases (e.g., aerosols, land-use changes) that are also forcing the climate
- The same methods used to develop carbon dioxide scenarios are used to develop scenarios for all of these other things that can alter our climate
- Calculations suggest that, by the end of the 21st century, total radiative forcing would be 4–8 $W/m^2$ above pre-industrial levels
- This is a huge amount of radiative forcing – comparable to the largest variations over the past 500 million years
- Such radiative forcings have changed the Earth from an ice-age planet into one that is completely ice free
- And carbon dioxide is responsible for 80% of the radiative forcing, which is why it is the single most important factor in future climate change

# Predictions of future climate

- Model simulations suggest that by the end of the 21st century, the Earth will be 1.8–3.6 ◦C warmer than the late 20th century
- Predicted surface temperature will continue to increase by 0.4 ◦C over the next several decades
- Temperatures keep rising even after greenhousegases stabilize - enormous heat capacity of water, the Earth is not presently in thermal equilibrium and must continue to warm to reestablish energy balance
- Warming is essentially unavoidable - committed warming
- Much of the warming over the 21st century could still be avoided if we take prompt action
- Figure shows that the difference in projected temperature in 2100 between the low-end (B1) and high-end (A2) scenarios is approximately a factor of 2
- Also shows that, for a single emissions scenario, there is a similar factor of 2 difference between the highest temperature predicted by the group of models and the lowest temperature.



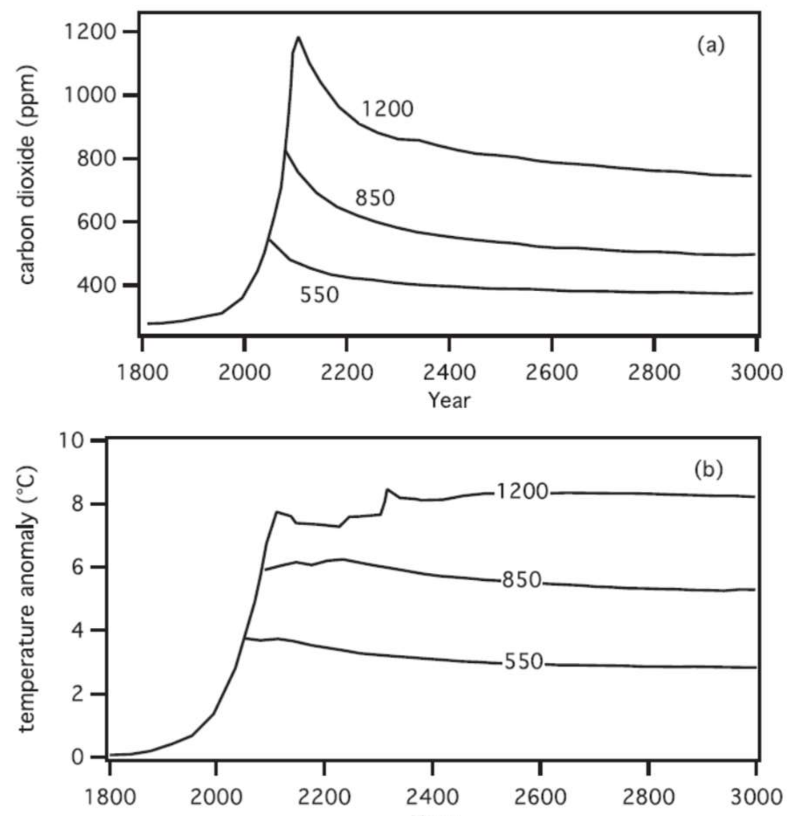
# Predictions of future climate

- The uncertainty in predicted temperature in 2100 is approximately evenly split between uncertainty in emissions and uncertainty in the physics of climate
- If the Sun does become either brighter or dimmer, then that could have an important impact on the evolution of the climate. Unfortunately, we have essentially no ability to predict what the Sun will do, so this remains another uncertainty in out predictions of climate.
- In the same vein, a large volcanic eruption could also significantly alter the climate
- However, such a perturbation would last only a few years, so it is unlikely that a volcano could radically alter the long-term trajectory of the climate

Go, change the world

# Climate change beyond 2100

- Long residence time of carbon dioxide in our atmosphere is shown in Figure a), which shows atmospheric carbon dioxide over the next 1,000 years for emissions scenarios where atmospheric carbon dioxide increases until it reaches 550, 850, and 1,200 ppm, at which point emissions from human activity decline instantly to zero
- Even by Year 3000, eight to nine centuries after carbon dioxide emissions ceased, atmospheric carbon dioxide in all scenarios remains well above pre-industrial values (280 ppm). This is simply a reflection of how long it takes for an addition to atmospheric carbon dioxide to be removed from the atmosphere.
- The temperatures associated with each carbon dioxide time series are shown in Figure b. Even after emissions cease, the temperatures do not decline significantly over the next 1,000 years.
- This is a consequence of three factors. First, carbon dioxide remains elevated throughout the millennium, so it continues to heat the planet even after emissions stop. Second, the ocean's large heat capacity. Third, the slow feedbacks, such as the loss of the big ice sheets, will act to oppose any cooling.




(a) Amount of carbon dioxide in the atmosphere as a function of time, for the next 1,000 years. Carbon dioxide emissions rise at 2% per year until it hits a peak abundance (550, 850, and 1,200 ppm); then emissions are decreased instantly to zero. (b) The temperature time series corresponding to each carbon dioxide time series

# Impacts of Climate Change

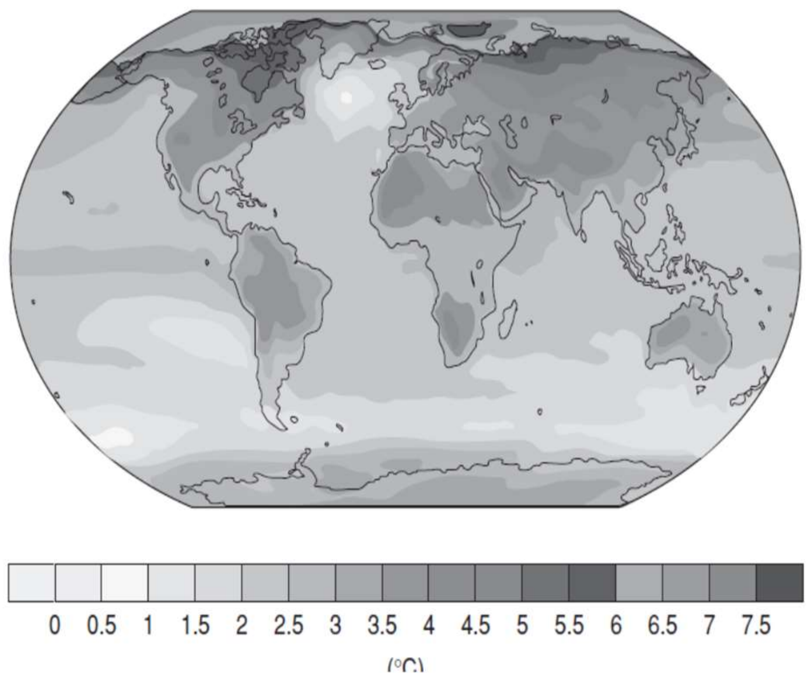
# Why should you care about climate change?

Predictions of warming of a few degrees Celsius over the next century should be taken seriously. This is a huge amount of warming; for comparison, the last ice age was only 5–8 ◦C colder than the temperature today

**Temperature**

- Continents warm more than oceans because of the larger heat capacity of the oceans. As a result, warming in northern North America and Eurasia is projected to be more than 40% greater than the global average warming.

- High latitudes will warm more than the tropics. This is primarily due to the ice–albedo feedback: The warming causes loss of ice, and the loss of ice exposes dark ocean, which absorbs more sunlight and leads to further warming. The models also predict more warming in the Arctic than in the Antarctic. These changes are all continuations of trends that have been observed over the past century.
- In 2050, warming in the high-emissions scenario is 2–3 ◦C while warming in the low-emissions scenario is 1–2 ◦C.

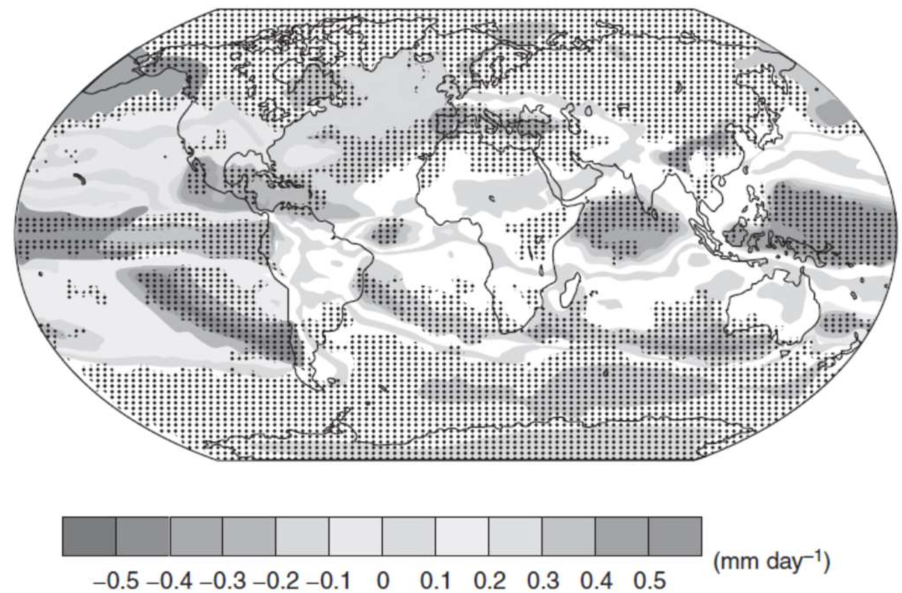


# Temperature

- It is highly likely that the temperature is going up every decade and that the general distribution of the warming will be in accord with these model predictions
- In 2090, however, the warming for the high-emissions scenario is 4–5 ◦C, which is roughly twice the warming in the low-emissions scenario of 2–3 ◦C. Thus, we do still have significant control of warming in the second half of the 21st century

# Precipitation

- As greenhouse gases increase, $E_{in}$ for the surface increases because of increased infrared radiation from the atmosphere falling on the surface. This leads to an increase in evaporation from the oceans, and because precipitation must balance evaporation, this means that precipitation also increases.
- Total global precipitation that increases by a few percent for every degree Celsius of global average warming
- Total rainfall is expected to increase, the increase will not be distributed evenly. We expect precipitation to increase in the high latitudes and decrease in most subtropical land regions as well as some parts of the tropics.
- Predictions of changes in annual average precipitation from a set of climate models are shown in Figure




Change in annual mean precipitation over the 21st century as predicted by climate models driven by a mid-range emissions scenario (A1B). Stippled regions are where at least 80% of models agree on the sign of the mean change (data obtained from Meehl et al., 2007, Fig. 10.12).

# Precipitation

- Continuing a trend of the 20th century, it is likely that more of the rainfall will come in the heaviest downpours
- During a heavy downpour, the soil saturates before the end of the rain event, and the remaining rain therefore runs off
- Heavy runoff can lead to a number of negative consequences, such as increased erosion and a higher risk of flooding
- Predictions of future precipitation patterns are quite uncertain
- Precipitating clouds can be small (sometimes only a few kilometers across), and climate model grids are too coarse to simulate such small entities.
- As a result, precipitation must be parameterized in climate models
- Model predictions based on parameterized aspects of the atmosphere should be considered to be more uncertain than those that the climate model explicitly resolves.

# Sea-level rise and ocean acidification

- The 2007 IPCC report predicted increases in sea level of several tens of centimeters over the next century
- However, this estimate excluded rapid changes in the world's big ice sheets on Greenland and Antarctica, so it should be considered a lower limit
- More recent work suggests that we can expect at least 1m of sea-level rise this century unless emissions are significantly reduced
- The oceans absorb more and more carbon dioxide, the oceans will become more acidic
- At present, the ocean is now more acidic than it has been for more than 20 million years

# Impacts of climate changes

- Humans are directly sensitive to rising temperatures, particularly extreme heat events, as evidenced by the tens of thousands of people who perished during the European heat wave in the summer of 2003
- Warmer temperatures also affect other things we care about, such as agriculture
- Even under the most favorable emissions scenario (B1), yields of our most important crops are expected to decline by roughly one third or 33% over the next century
- Although some regions may see benefits to agriculture, the research that's been done on this suggests that the beneficial effects of increased carbon dioxide are overwhelmed by the negative effects of these other changes, particularly if the warming is severe
- Many systems managed for human use, such as agriculture, commercial forests, rangelands, and fisheries, will be affected by climate change
- a significant fraction of plant and animal species may be at increased risk of extinction if global average temperatures increase by a few degrees Celsius
- Changes in precipitation, combined with increasing temperature, are expected to lead to changes in the availability of fresh water

# Impacts of climate changes

- Overall, the negative impacts of climate change on systems and activities reliant on fresh water are generally expected to be significant
- Rising seas will also bring impacts that are strongly negative because a significant fraction of the world's population lives within a few feet of sea level
- Moreover, some of the world's most productive farmland is located in river deltas and other regions that are particularly sensitive to sea-level rise
- The acidification of the ocean is another important impact. Organisms often build shells or skeletons out of calcium carbonate, and their ability to do this will be strongly affected by increases in acidity
- Human health to be negatively impacted by climate change
- Warming temperatures also increase disease risk as a result of expansions in ranges of animals that transmit the diseases (e.g., mosquitoes), shortening of the diseases' incubation periods, lack of very cold temperatures that can kill the transmitters, and disruption and relocation of large human populations

# Impacts of climate changes

- A particularly important factor in determining the severity of the impacts will be the rate of climate change
- Ecosystems have adapted to large climate change in the past, such as the warming from the previous ice age.
- However, the warming predicted for the next century will be as much as 50 times faster.

## Abrupt climate changes

- Changes in temperature, precipitation, and sea level – are all certain. These changes *will* be happening; the only question is the magnitude and distribution of the changes
- We will add enough greenhouse gas that the climate system would undergo a large and rapid shift to an entirely new climate state
- During the Paleocene-Eocene thermal maximum (PETM) approximately 55 million years ago, there was a rapid release of greenhouse gases and a subsequent warming of 5–9 $^\circ$C in just a few thousand years
- Climate models do not predict the occurrence of an abrupt climate change, and most experts view the probability to be low, but not zero
- If an abrupt change did occur, though, it would be an unprecedented catastrophe. Such low-risk, high consequence events pose significant challenges to our society
- Once the abrupt change takes place, it will be very difficult, if not impossible, to reverse.

# Abrupt climate changes

- Abrupt climate changes are a serious problem for several reasons, and they can have far-reaching and often detrimental consequences for the environment, ecosystems, and human societies. Here are some of the key reasons why abrupt climate changes are a cause for concern:

1. **Speed and Magnitude**: Unlike gradual climate change, which occurs over longer periods, abrupt climate changes happen relatively quickly and can be of significant magnitude. This rapid change can overwhelm the ability of natural and human systems to adapt, leading to more severe and immediate impacts.
2. **Disruption of Ecosystems**: Abrupt climate changes can disrupt ecosystems and ecological relationships, as many species may struggle to adapt to rapidly changing conditions. This can lead to population declines, extinctions, and shifts in the distribution of species, impacting biodiversity.
3. **Food and Water Security**: Abrupt climate changes can affect crop yields, disrupt growing seasons, and lead to water shortages. This has serious implications for food and water security, potentially leading to food scarcity, price increases, and conflicts over resources.

# Abrupt climate changes

1. **Extreme Weather Events**: Abrupt climate changes can lead to an increase in extreme weather events, such as hurricanes, droughts, floods, and heatwaves. These events can have devastating consequences for communities, causing damage to infrastructure, loss of life, and economic disruption.
2. **Sea-Level Rise**: Rapid melting of ice sheets and glaciers, which can be triggered by abrupt climate changes, contributes to sea-level rise. This, in turn, threatens coastal communities, infrastructure, and ecosystems, increasing the risk of coastal flooding and erosion.
3. **Economic Impact**: Abrupt climate changes can lead to economic instability due to the disruption of industries like agriculture, tourism, and insurance. Governments and businesses may face increased costs related to disaster response and recovery.
4. **Social Disruption**: Climate-related disasters can lead to the displacement of people from their homes and communities. This can result in social and political instability, as well as conflicts related to resource scarcity and migration.
5. **Feedback Loops**: Abrupt climate changes can trigger positive feedback loops, where one change amplifies another. For example, the release of methane from thawing permafrost can accelerate warming, creating a self-reinforcing cycle of climate change.
6. **Health Impacts**: Abrupt climate changes can affect human health directly through extreme heat events, the spread of disease vectors, and reduced air and water quality. Indirectly, they can impact mental health and well-being due to increased stress and displacement.

# Abrupt climate changes

1. **Loss of Critical Ecosystem Services**: Ecosystems provide essential services like pollination, water purification, and carbon sequestration. Abrupt changes can disrupt these services, affecting agriculture, water quality, and climate regulation.
2. **Long-Term Implications**: Abrupt climate changes can have long-lasting impacts that persist for centuries or even millennia. These changes can alter the Earth's climate and ecosystems in ways that are difficult to reverse.

# THANK YOU