CLIMATE CHANGE PT. I: THE PROBLEM

LESSON OBJECTIVES

01

Define climate change and its effects

02

Analyze economic impacts of climate change

03

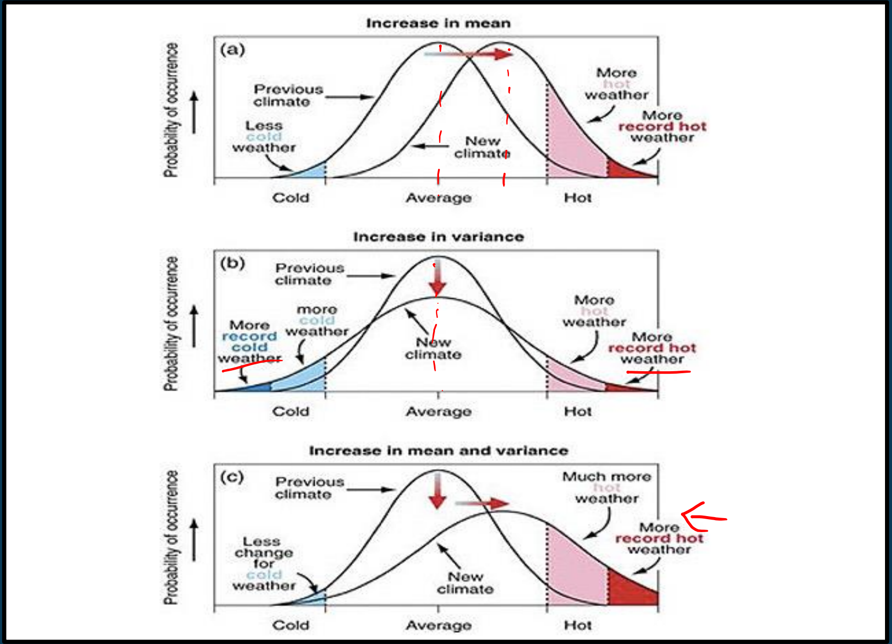
Analyze strategies to reduce climate change impacts

01

CLIMATE CHANGE AND ITS EFFECTS

WHAT IS CLIMATE CHANGE?

WHAT IS CLIMATE CHANGE?



<u>Climate change</u>

A significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years.

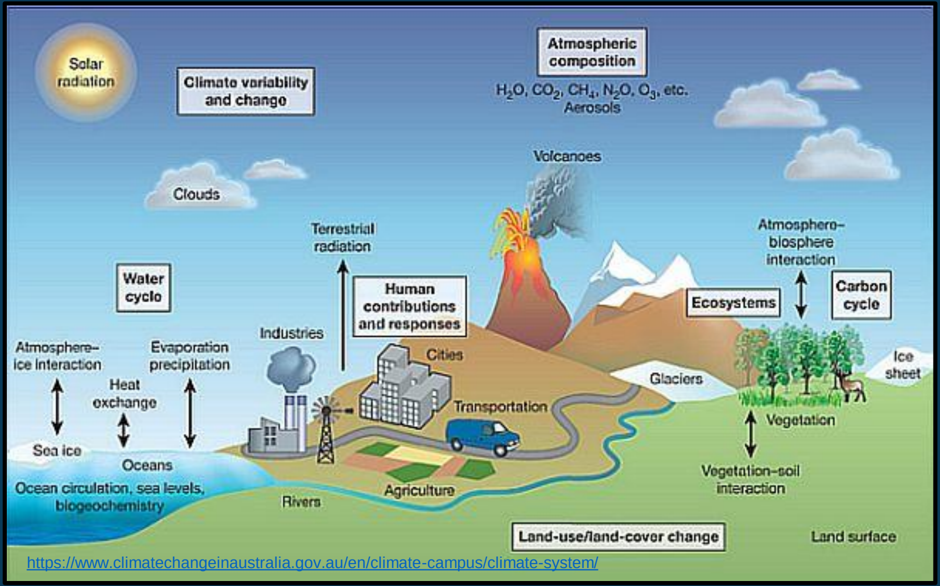
This can come from:

- Change in average weather conditions
- Change in the variance of weather conditions (i.e., more or fewer extreme weather events)
- A combination

WHAT CAUSES CLIMATE CHANGE?

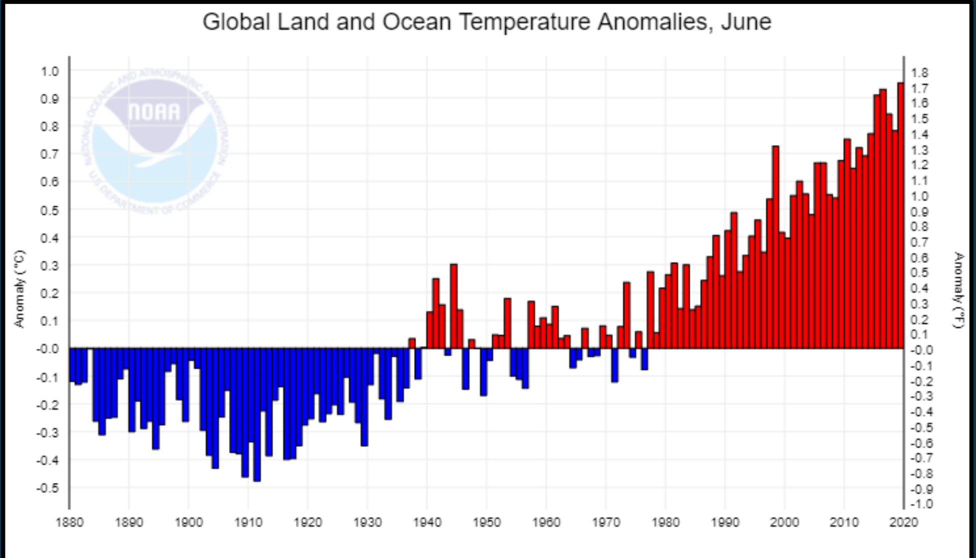
Climate change can be caused by a variety of factors that include:

- Oceanic processes
- Variations in solar radiation received by Earth
- Plate tectonics and volcanic eruptions
- Human-induced alterations of the natural world



https://www.climatechangeinaustralia.gov.au/en/climate-campus/climate-system/

WHAT IS GLOBAL WARMING?



Source: www.ncdc.noaa.gov

Global warming refers to the recent and ongoing rise in global average temperature near Earth's surface.

IPCC 2014 Report

"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."

http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

Average temperature has risen by 1.4°F in last 100 years

Projected to rise another 2 to 11.5°F over the next 100 years.

WHAT DOES THE FUTURE HOLD?

EARTH'S WARMING TREND

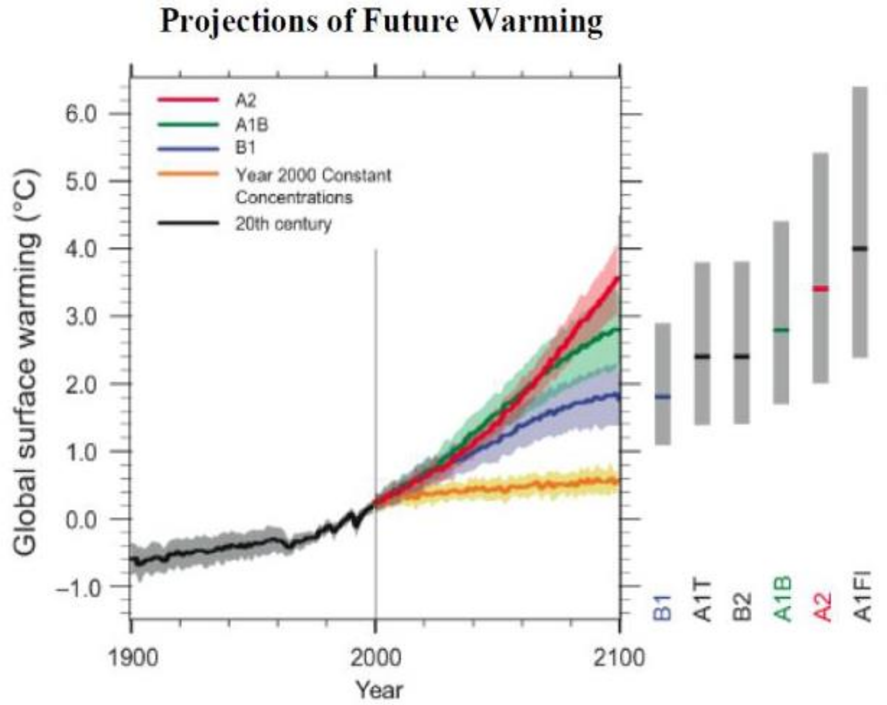


Figure 3. The orange line represents warming if atmospheric concentration were held constant at year 2000 levels. The others are projections of various scenarios:
A2 – population grows continuously, fragmented regional economies
A1B - rapid economic growth, population peaks mid century, rapid use of new efficient technology
B1 – population peaks mid century, rapid shift toward service and information economy, clean and efficient technologies
The gray bars on the right, represent the likely temperature ranges for these 3 scenarios plus 3 others run by IPCC.

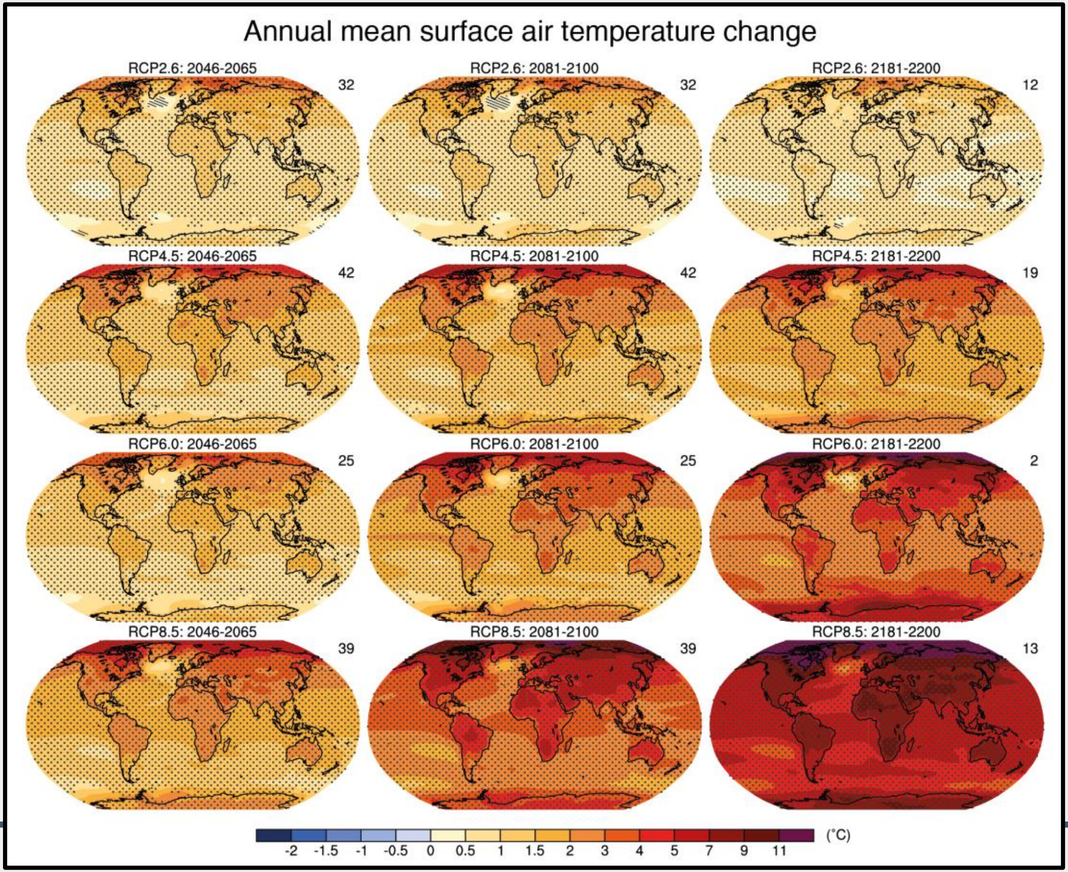
EARTH'S WARMING TREND

Very low emissions

Medium emissions

Medium-high emissions

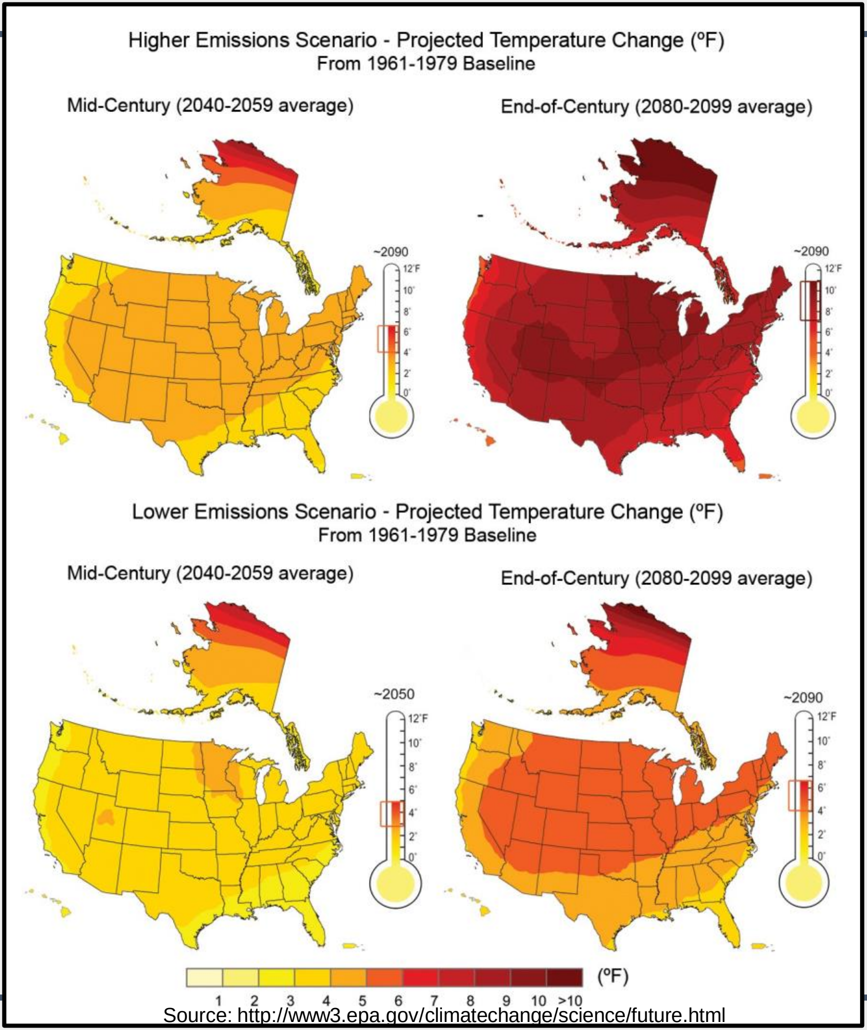
Very high emissions

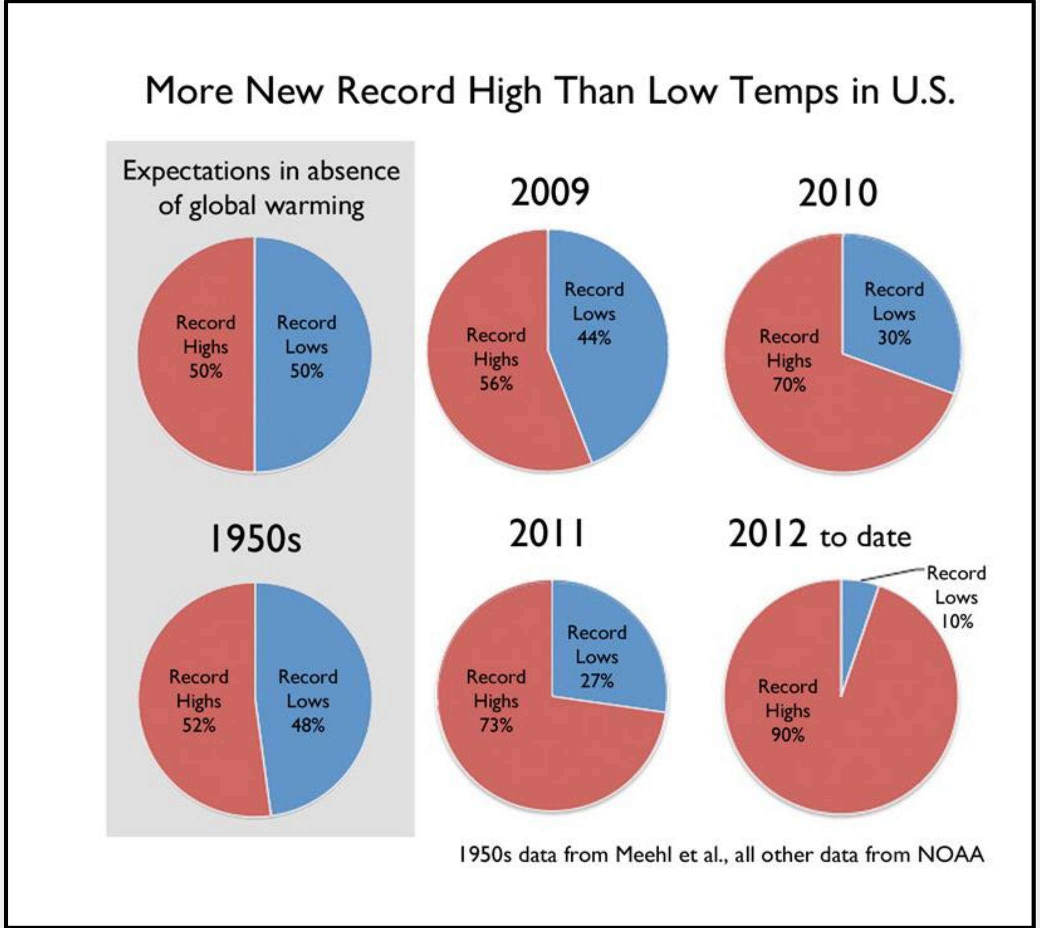


EARTH'S WARMING TREND

Higher emissions scenario →

Lower emissions scenario →

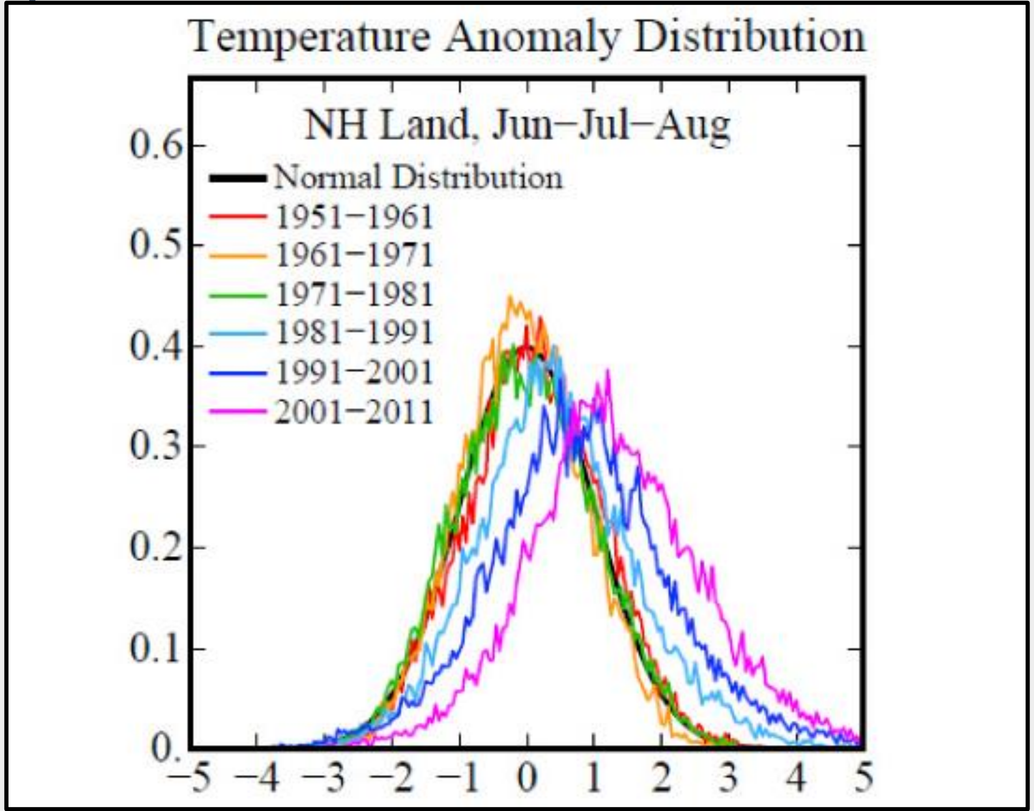




EARTH'S WARMING TREND

Average annual temperatures are expected to increase, but what about the distribution within a year?

What is happening to the extremes?

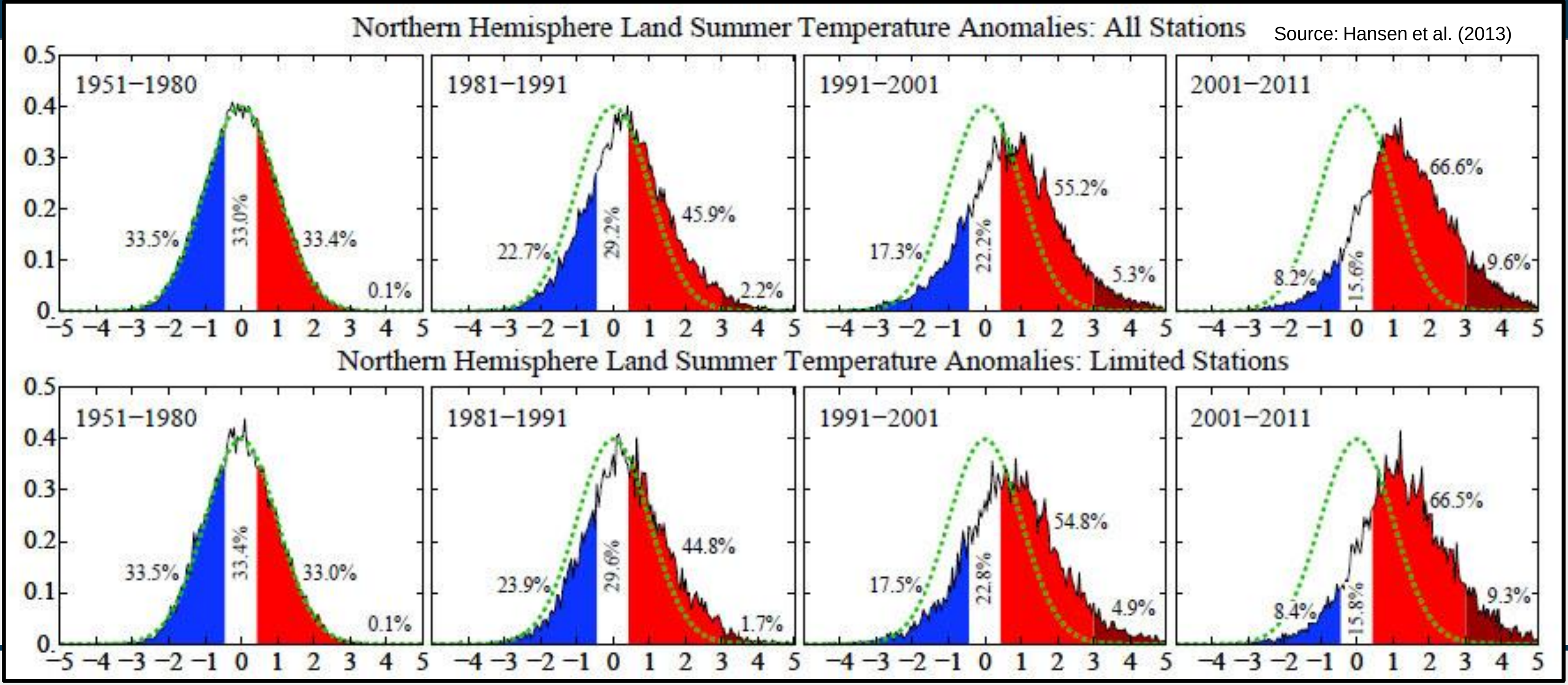


EARTH'S WARMING TREND

Frequency of summer temperature anomalies (how often they deviated from the historical normal of 1951-1980) over the summer months in the northern hemisphere.

Summer 2019 was the hottest ever recorded.
19 of 20 warmest years occurred in the 21st century

EARTH'S WARMING TREND



Source: Hansen et al. (2013)

WHAT ARE THE EFFECTS OF CLIMATE CHANGE?

EFFECTS OF CLIMATE CHANGE

Small changes in the average temperature of the planet can translate to large and potentially dangerous shifts in climate and weather

- More floods, droughts, or intense rain
- More frequent and severe heat waves

Intergovernmental Panel on Climate Change (IPCC)

> "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."

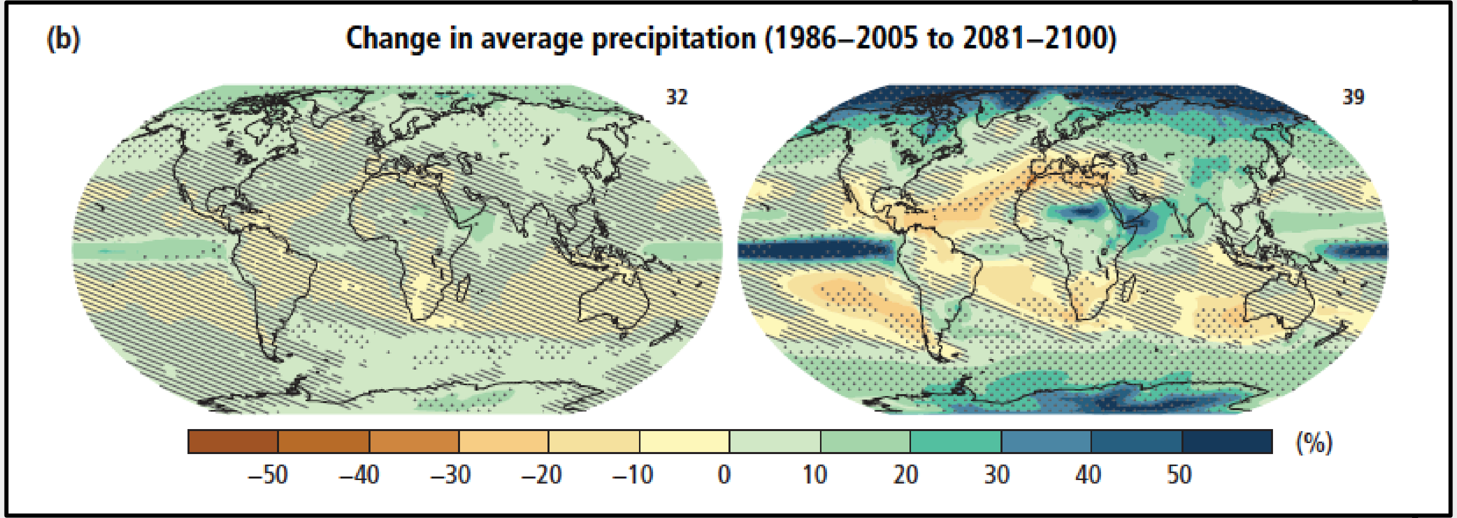
EFFECTS OF CLIMATE CHANGE

A Few Outcomes:

- Changes in temperature
- Changes in precipitation
- Changes to oceans
- Changes in extreme weather
- Biodiversity loss

REGIONAL PRECIPITATION VARIATION

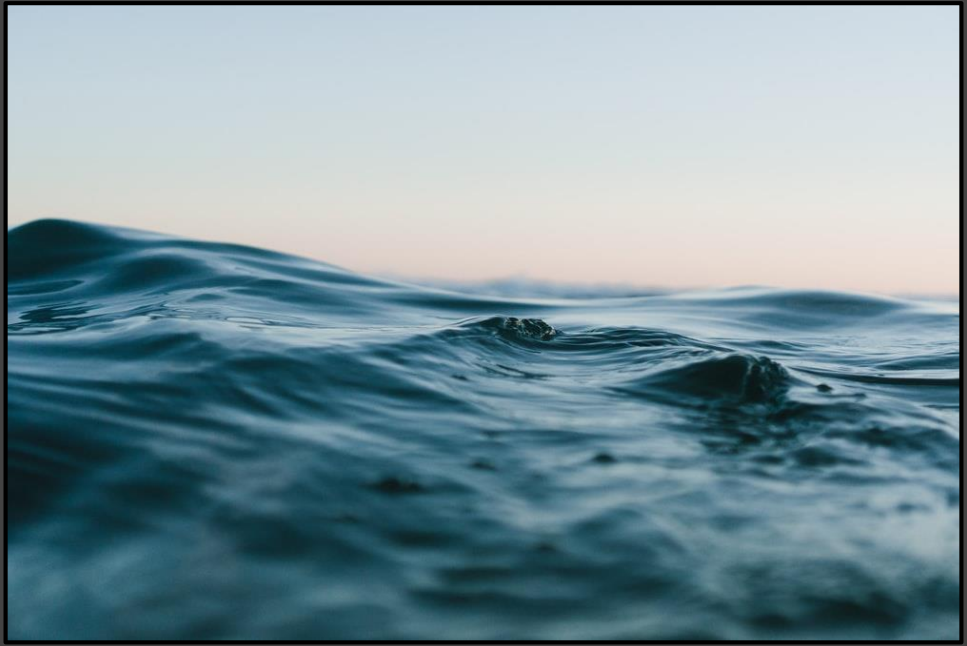
Effect is not the same everywhere
some places drier, some wetter



Low emissions scenario

High emissions scenario

OCEANS AND CLIMATE CHANGE

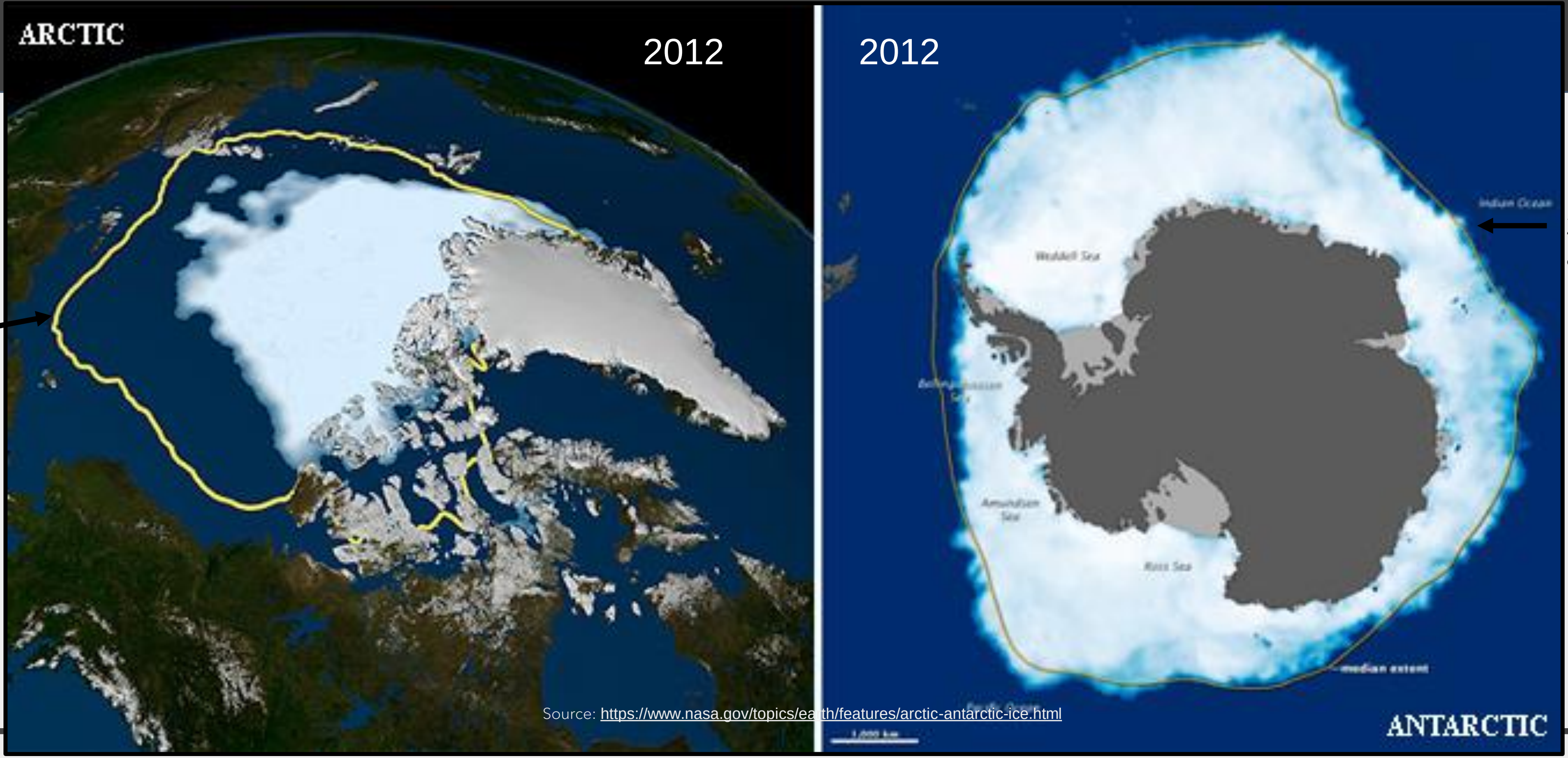


Climate change has several effects on climates:

- Oceans warming
- Ice caps melting
- Sea levels rising
- Oceans becoming more acidic

OCEANS: ICE CAPS

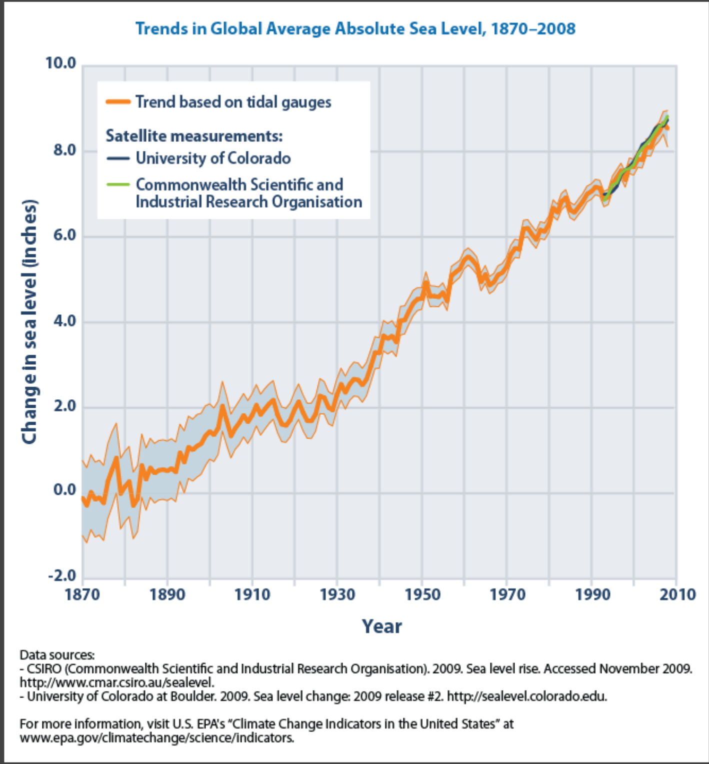
1979-
2010
average



1979-
2001
average

Source: https://www.nasa.gov/topics/earth/features/arctic-antarctic-ice.html

OCEANS: SEA-LEVELS



IPCC 2013:

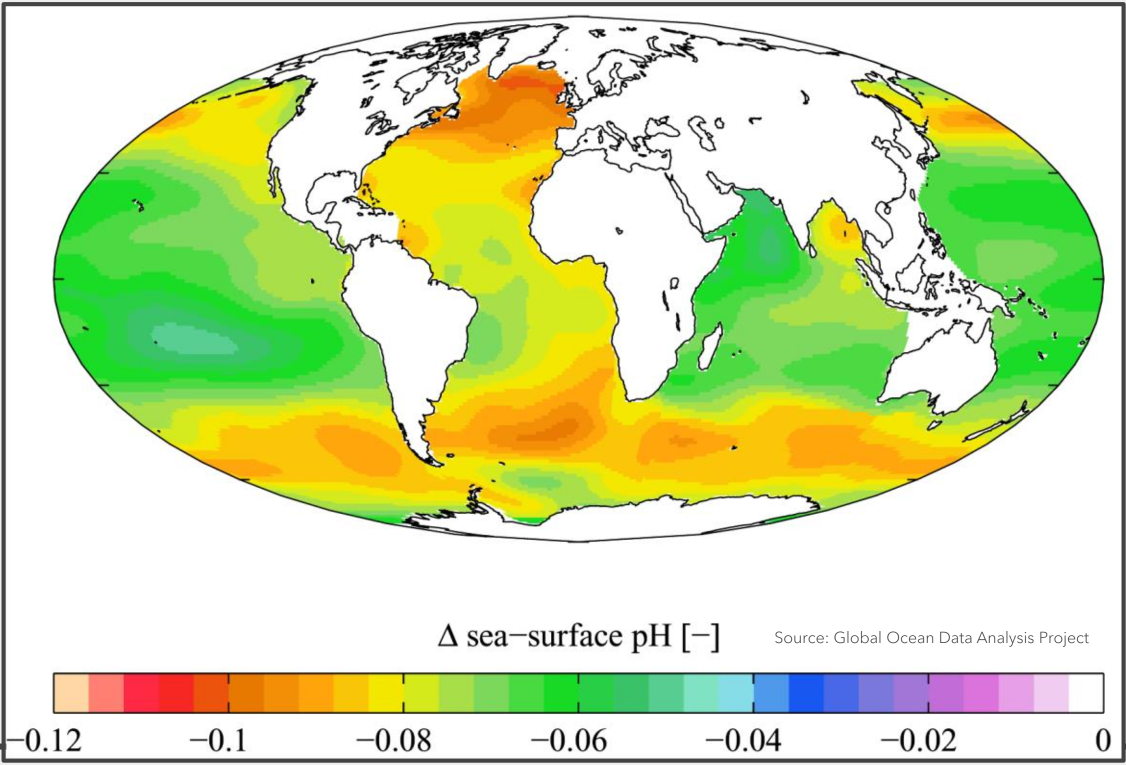
The panel found it "extremely likely" that humans were responsible for "more than half of the observed increase in global average surface temperature from 1951 to 2010.....There is high confidence that this has warmed the ocean, melted snow and ice, raised global mean sea level, and changed some climate extremes in the second half of the 20th century."

The panel also said the evidence is now "unequivocal" for the phenomenon of global sea level rise, which it expects to increase by about 1 to 3 feet by 2100, depending on actions taken to reduce greenhouse gas emissions between now and the end of the century.

OCEANS: SEA-LEVELS

OCEANS: ACIDIFICATION

Estimated change in sea water pH from 1700s to 1990 due to anthropogenic climate change



Source: Global Ocean Data Analysis Project

OCEANS: ACIDIFICATION

Since the beginning of the Industrial Revolution, the pH of surface ocean waters has fallen by 0.1 pH units.

- The pH scale is logarithmic, so this change represents ~30% increase in acidity.

Projected CO_2 levels suggest surface waters of the ocean could be ~150% more acidic by the end of the century

- A pH level that the oceans haven't experienced for more than 20 million years.

Potential impacts (NOAA):

- Ocean acidification is expected to impact ocean species to varying degrees.
- Photosynthetic algae and seagrasses may benefit from higher CO_2 conditions in the ocean
- Calcifying species, including oysters, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton, will have a negative effect.
- When shelled organisms are at risk, the entire food web may also be at risk.

EXTREME WEATHER EVENTS

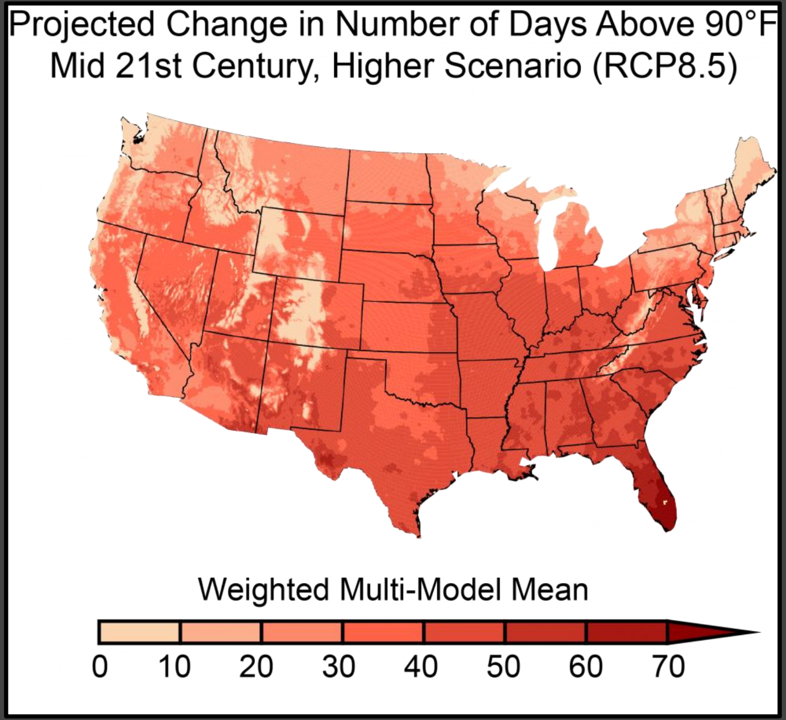
Changes in extremes:

- More floods, droughts, or intense rain
- More frequent and severe heat waves
- Storm intensity *might* increase

EXTREME WEATHER: HEAT WAVES

Heat waves are expected to increase in frequency, duration, and intensity.

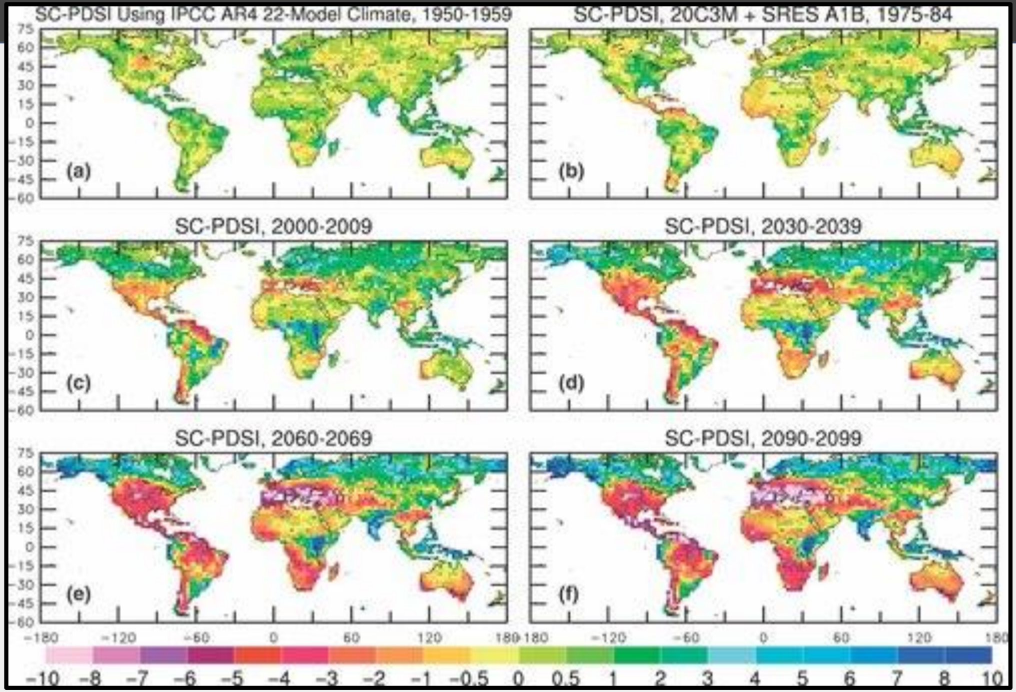
Example:
Projected change in the number of days per year with max temperature above 90˚F from 1976-2005 to 2036-2065



SOURCE: CICS-NC and NOAA NCEI by Russel Vose, available in Climate Science Special Report.

EXTREME WEATHER: DROUGHTS

Estimated drought index measured using the Palmer Drought Severity Index (PDSI)



Source: Dai (2012): https://onlinelibrary.wiley.com/doi/abs/10.1002/wcc.81

BIODIVERSITY

Habitats are shifting

- Quick adapting species may benefit as niches expand
- Slow adaptation and/or highly specialized species at most risk

An estimated ~8% of species are at risk of extinction due to climate change.

Caused by the factors discussed above.

FEEDBACK LOOPS

Some effects of climate change are associated with *positive feedback loops* where the effects of climate change can accelerate climate change.

<u>Examples:</u>

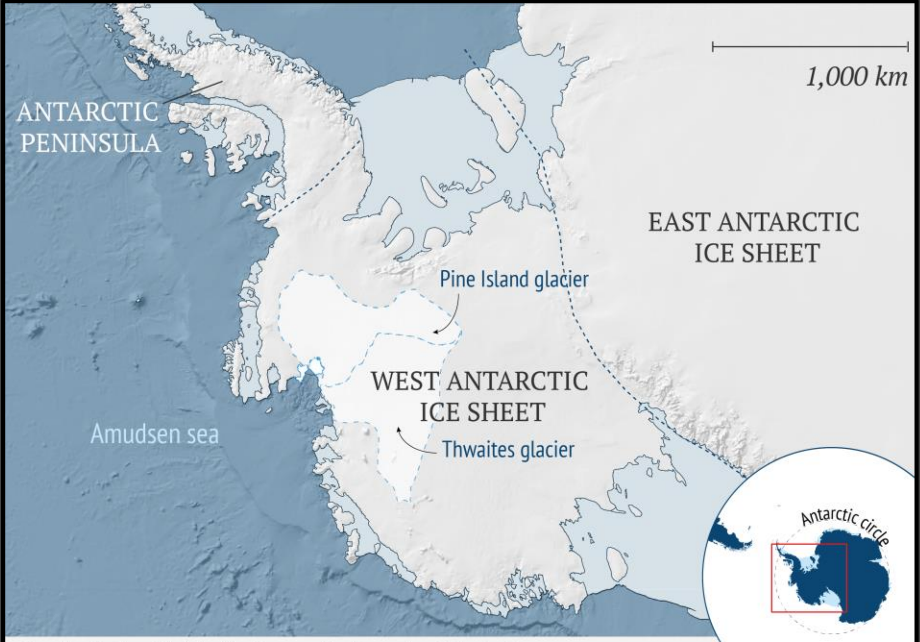
Ice-Albedo feedback loop

- Temperatures rise, ice melts, more sunlight is absorbed, repeat…

Wetland-Methane feedback loop

- Methane released, increased GHG concentration, temperatures rise, bacterial respiration increases, repeat…

TIPPING POINTS



Graphic: Carbon Brief. Credit: Quantarctica/Norwegian Polar Institute.

Select effects of climate change have been called *climate tipping points*

These are large, irreversible effects of climate change.

While there is low probability of occurrence, impacts are expected to be large.

<u>Examples:</u>

- Loss of the Amazon rainforest
- Collapse of the West Antarctic ice sheet

02

ECONOMIC IMPACTS OF CLIMATE CHANGE

WHAT ARE THE ECONOMIC IMPACTS OF CLIMATE CHANGE?

ECONOMIC IMPACTS OF CLIMATE CHANGE

We've seen what climate change looks like and some of its effects. So, what are the *economic* impacts?

A Few Impacts:

- Agriculture/food
- Human health
- Transportation infrastructure
- Energy Use & Supply
- Water Resources
- Societal Impacts

AGRICULTURE/FOOD

Many crops show positive responses to elevated carbon dioxide and low levels of warming, but higher levels of warming often negatively affect growth and yields.

Extreme weather events such as heavy downpours and droughts are likely to reduce crop yields

Weeds, diseases, and insect pests benefit from warming

Forage quality in pastures and rangelands generally declines with increasing carbon dioxide concentration

Increased heat, disease, and weather extremes are likely to reduce livestock productivity.

HUMAN HEALTH

Increases in the risk of illness and death related to extreme heat

Warming is likely to make it more challenging to meet air quality standards necessary to protect public health.

Extreme weather events cause physical and mental health problems.

Some diseases transmitted by food, water, and insects are likely to increase.

Rising temperature and carbon dioxide concentration increase pollen production

Certain groups, including children, the elderly, and the poor, are most vulnerable to a range of climate-related health effects.

TRANSPORTATION INFRASTRUCTURE

Sea-level rise and storm surge will increase the risk o f major coastal impacts, including both temporary and permanent flooding of airports, roads, rail lines, and tunnels.

The increase in extreme heat will limit some transportation operations and cause pavement and track damage. Decreased extreme cold will provide some benefits such as reduced snow and ice removal costs.

Increased intensity of strong hurricanes would lead to more evacuations, infrastructure damage and failure, and transportation interruptions.

Arctic warming will continue to reduce sea ice, lengthening the ocean transport season, but also resulting in greater coastal erosion due to waves.

ENERGY USE & SUPPLY

Warming will be accompanied by decreases in demand for heating energy and increases in demand for cooling energy. The latter will result in significant increases in electricity use and higher peak demand in most regions.

Energy production is likely to be constrained by rising temperatures and limited water supplies in many regions.

Energy production and delivery systems are exposed to sea-level rise and extreme weather events in vulnerable regions.

Climate change is likely to affect some renewable energy sources across the nation, such as hydropower production in regions subject to changing patterns of precipitation or snowmelt

WATER RESOURCES

Climate change has already altered, and will continue to alter, the water cycle, affecting where, when, and how much water is available for all uses.

Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change, and rainfall becomes more concentrated into heavy events (with longer, hotter dry periods in between).

Precipitation and runoff are likely to increase in the Northeast and Midwest in winter and spring, and decrease in the West, especially the Southwest, in spring and summer.

Surface water quality and groundwater quantity will be affected by a changing climate.

Climate change will place additional burdens on already stressed water systems.

The past century is no longer a reasonable guide to the future for water management.

SOCIETAL IMPACTS

Population shifts and development choices are making more Americans vulnerable to the expected impacts of climate change.

Vulnerability is greater for those who have few resources and few choices.

City residents and city infrastructure have unique vulnerabilities to climate change.

Climate change affects communities through changes in climate-sensitive resources that occur both locally and at great distances.

Insurance is one of the industries particularly vulnerable to increasing extreme weather events such as severe storms, but it can also help society manage the risks.

The United States is connected to a world that is unevenly vulnerable to climate change and thus will be affected by impacts in other parts of the world.

ATTENDANCE QUESTION

Briefly think about the following question and, in a few sentences, sketch out your thoughts.

How can we think about climate change using what we have learned in this class?

- Think about BCA, dynamic efficiency, sustainability, etc.

ATTENDANCE QUESTION

Briefly think about the following question and, in a few sentences, sketch out your thoughts.

How can we think about climate change using what we have learned in this class?
- Think about BCA, dynamic efficiency, sustainability, etc.

BCA: Can we quantify the benefits and costs and compare for different climate policies
Dynamic efficiency: We should be considering our use of the climate as we would any other renewable resource. We need to ensure we equate MNB across periods and not over extract.
Sustainability: If we "extract" climate we need to invest the gains in other forms of capital.
Policy: If there are externalities associated with climate, we need to implement regulation to ensure the true costs and benefits are internalized.

HOW DO WE QUANTIFY THESE IMPACTS?

So we’ve seen some of the economic impacts from climate change.

How can we quantify and monetize these impact?

Like we would with a BCA!

SOCIAL COST OF CARBON (SCC)

To analyze our use of the climate from an economic perspective, we need to quantify and monetize the impacts.

To do this, economists use the **social cost of carbon**.

Social cost of carbon:
Measure of the economic impact from emitting one ton of CO_2 into the atmosphere

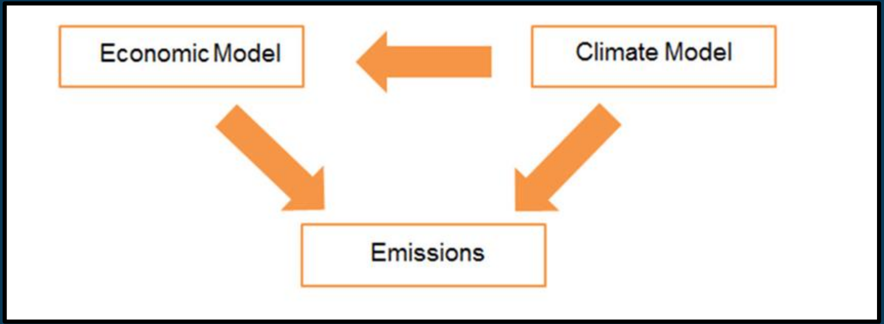
Does this sound like something we've used in the past?
Marginal damages!

SOCIAL COST OF CARBON (SCC)

To estimate the SCC, economists typically use one of two approaches:

1. Integrated Assessment Models (IAMs)
2. Econometric Models

INTEGRATED ASSESSMENT MODELS (IAMS)



Integrated assessment models
Integrate economic growth models with climate models to project economic outcomes

Many different IAMs have been constructed.
Often they vary in their focus.

Benefits of IAMs:
- Flexibility
- Scope

Problems with IAMs:
- Assumptions
- Lack of empirically-based damage function
- Can be hard to solve

ECONOMETRIC MODELS

Econometric models use data on historical impacts to predict future impacts.

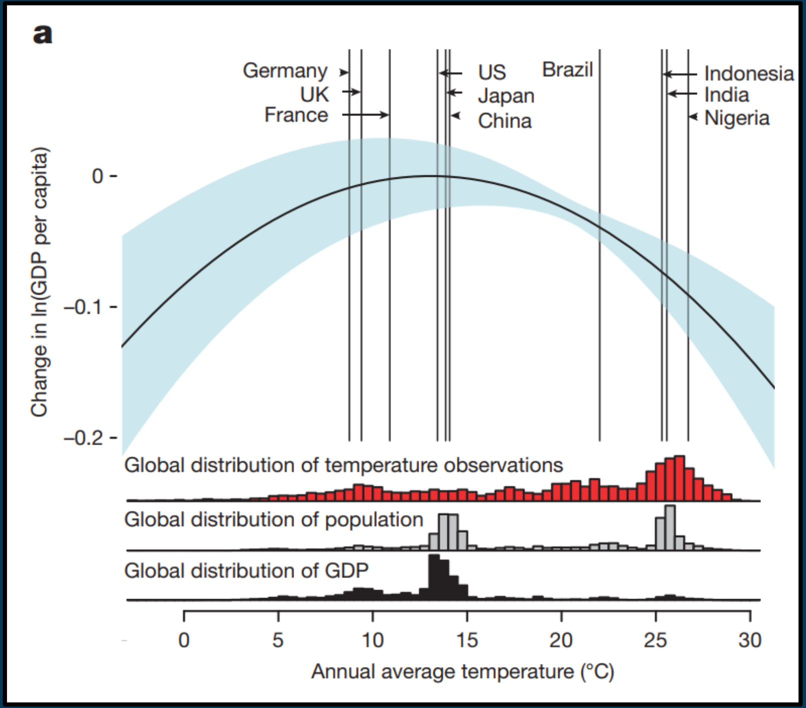
Primarily focus on microeconomic impacts but have recently been used to study macroeconomic impacts.

Benefits of econometric models:

- Empirically-based estimates
- Can provide information about changes in the past (eg. adaptation)

Problems of econometric models:

- Future may not look like the past
- Only capture use values
- Lack of mechanism for macro-models



Source: Burke et al. (2015)

SOCIAL COST OF CARBON (SCC)

To estimate the SCC, economists typically use one of two approaches:

1. Integrated Assessment Models (IAMs)
2. Econometric Models

In 2009 an inter-agency working group was formed in the US to get a number for the SCC.

- Used 3 IAMs
- Estimated a SCC of ~$50 for 2020
- Was disbanded in 2017.

Table 1: Social Cost of CO_2 (in 2017 dollars per metric ton of CO_2) [1]

Year of Emission	Average estimate at 5% discount rate	Average estimate at 3% discount rate—IWG's Central Estimate	Average estimate at 2.5% discount rate	High Impact Estimate (95th percentile estimate at 3% discount rate)
2020	$14	**$50**	$74	$148
2025	$17	**$55**	$82	$166
2030	$19	**$60**	$88	$182
2035	$22	**$66**	$94	$202
2040	$25	**$72**	$101	$220
2045	$28	**$77**	$107	$236
2050	$31	**$83**	$114	$254

Source: https://costofcarbon.org/faq/what-is-the-scc

PROBLEMS WITH QUANTIFYING IMPACTS

There are a few problems that arise when quantifying the impacts of climate change:

1. What discount rate
2. Uncertainties/risk

Discount rate we've looked at in the past.
Climate change is a problem with a long time-horizon
Small changes in discount rate can have a **large** impact

So what about uncertainties and risks

WEITZMAN'S FAT-TAIL RISK

Table 2 Probabilities of exceeding $T = 5°C$ and $T = 10°C$ for given G = ppm of CO_2e

G:	**400**	**500**	**600**	**700**	**800**	**900**
Median T	1.5°	2.5°	3.3°	4.0°	4.5°	5.1°
$Prob_P[T \geq 5°C]$	1.5%	6.5%	15%	25%	38%	52%
$Prob_N[T \geq 5°C]$	10^{-6}	2.0%	14%	29%	42%	51%
$Prob_P[T \geq 10°C]$	0.20%	0.83%	1.9%	3.2%	4.8%	6.6%
$Prob_N[T \geq 10°C]$	10^{-30}	10^{-10}	10^{-5}	0.1%	0.64%	2.1%

Table 3 Multiplicative-quadratic damages $M(T)$ (as fraction of output)

T	**2°C**	**4°C**	**6°C**	**8°C**	**10°C**	**12°C**
$M(T)$	1%	4%	8%	13%	19%	26%

Source: Weitzman (2015)

WHAT CAN WE DO?

We’ve discussed the impacts of climate change
We’ve discussed how to measure, quantify, and monetize those impacts.

So what can we do?

The three prongs of climate policy:

1. Mitigation
2. Adaptation
3. Climate engineering

MITIGATION

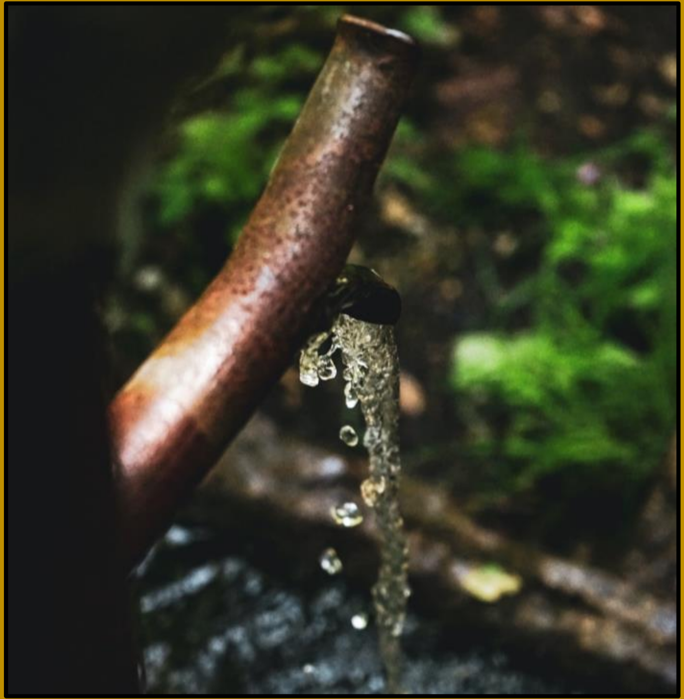
Mitigation

Efforts to reduce emissions or concentrations of greenhouse gases (GHGs) in the atmosphere

Deals with the source of climate change

- Reduce emission of GHGs
- Aid the planet's ability to absorb GHGs

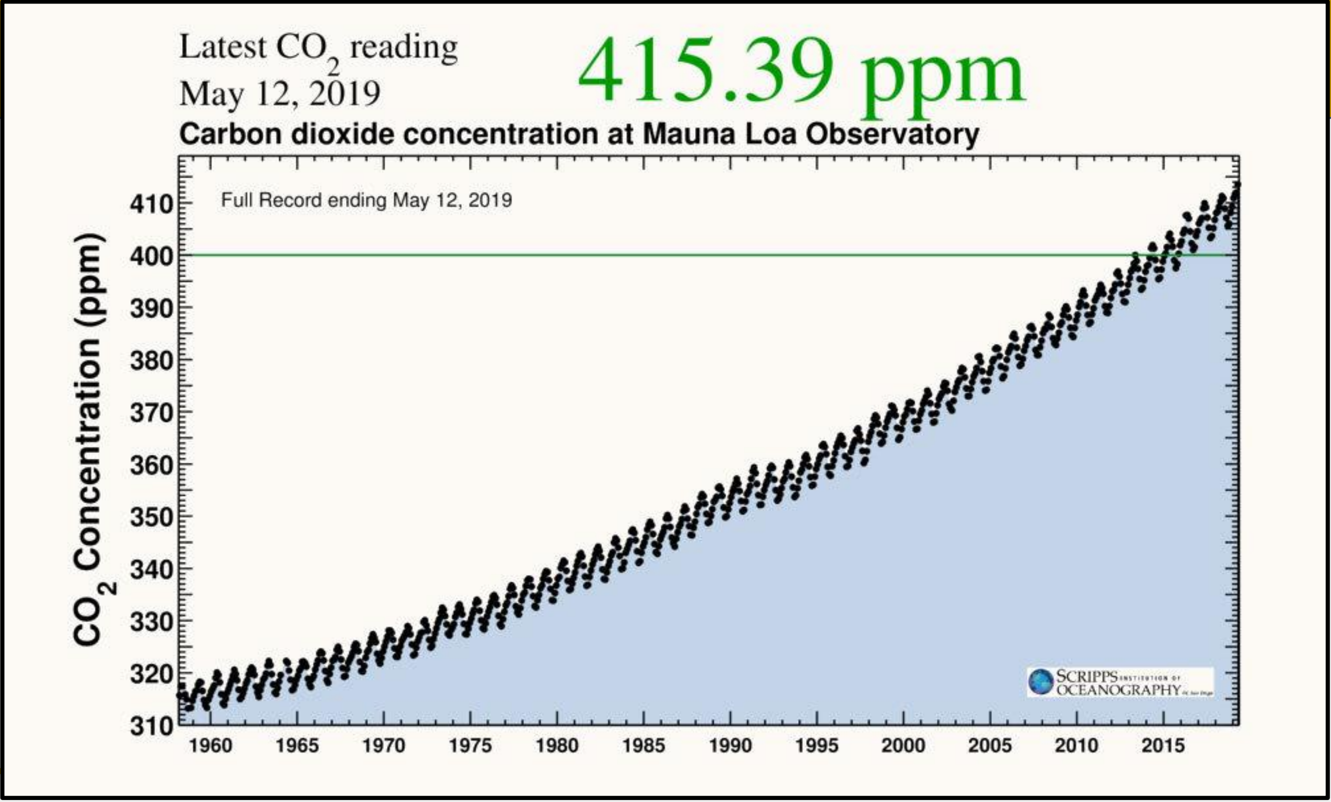
What are the sources of GHGs and how can we reduce them?



CURRENT GHG CONCENTRATION LEVELS

CO_2 concentrations have been steadily climbing since the industrial revolution.

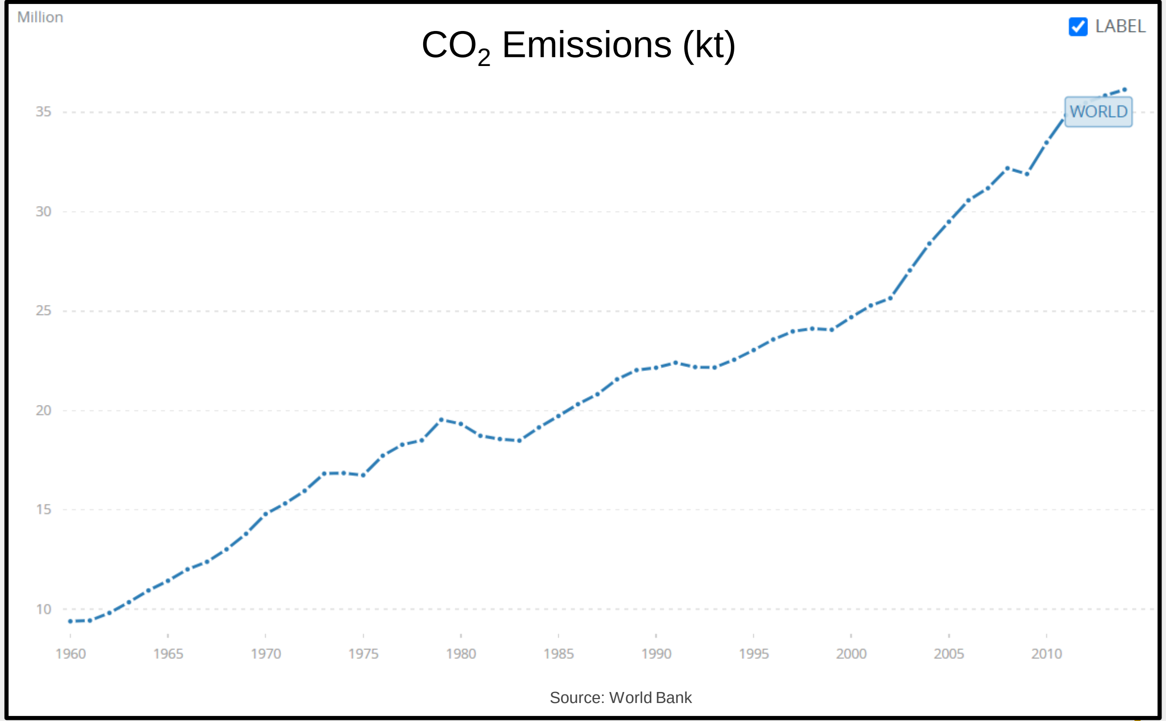
Many scientists warn we should strive to stay under 500ppm.



EMISSIONS OVER TIME

Not only are concentrations rising, emission rates are too!

Think of the climate like a bath tub. Not only is it filling, but we are opening the faucet wider.



REGIONAL EMISSIONS

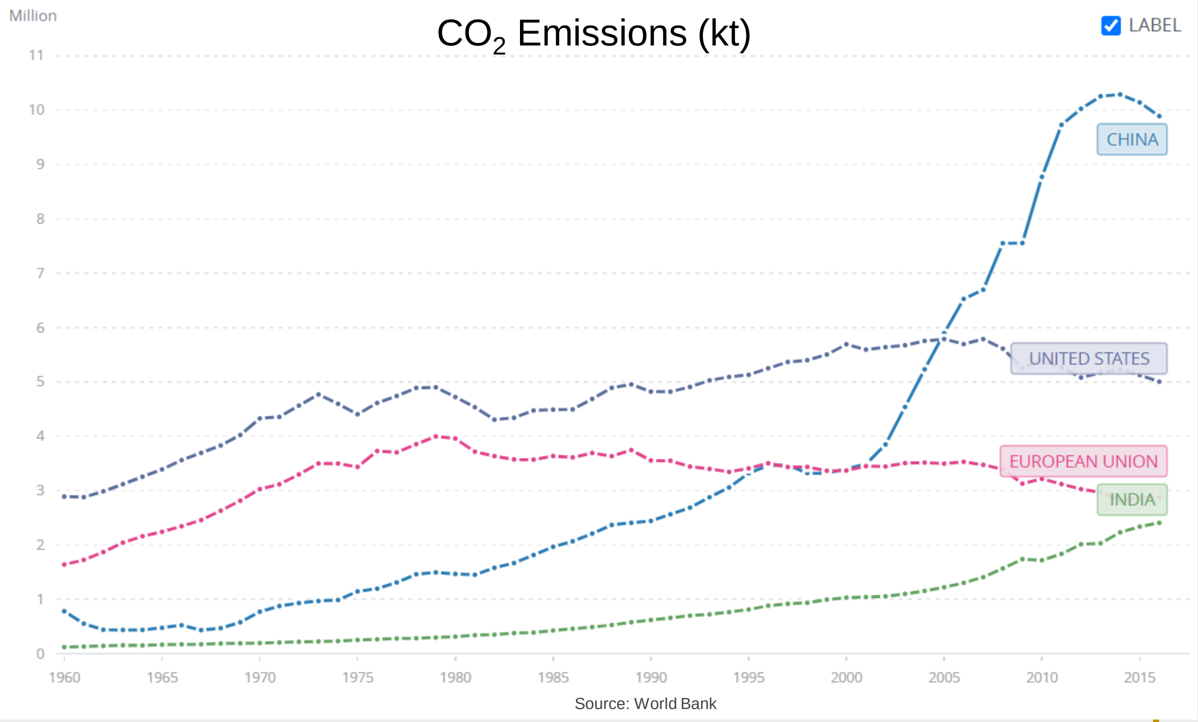
The growth (and level) of emissions is not the same everywhere!

General trends in recent years:

- Emissions *starting* to decline in developed countries (eg. USA and EU)
- Emissions growing in developing countries (eg. China and India)

On a per capita basis US is still one of the largest emitter.

This may remind you of the Environmental Kuznets Curve!



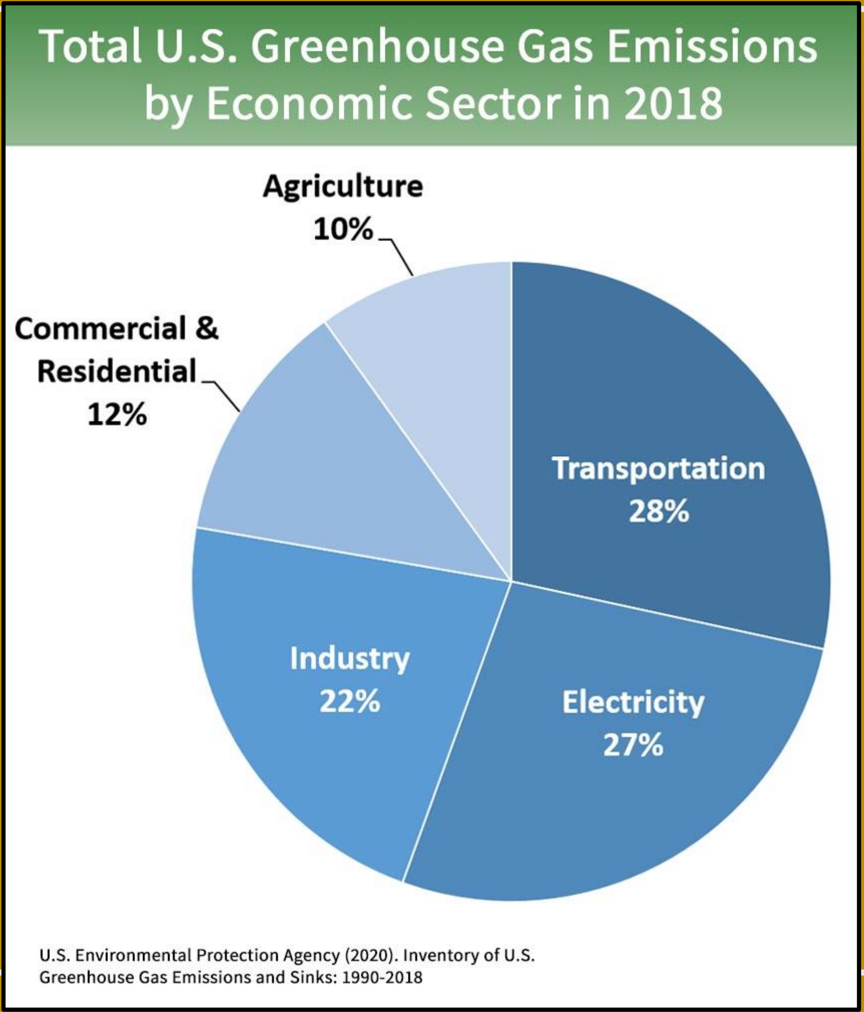
SOURCES OF EMISSIONS

The quantity of emissions varies considerably by source.

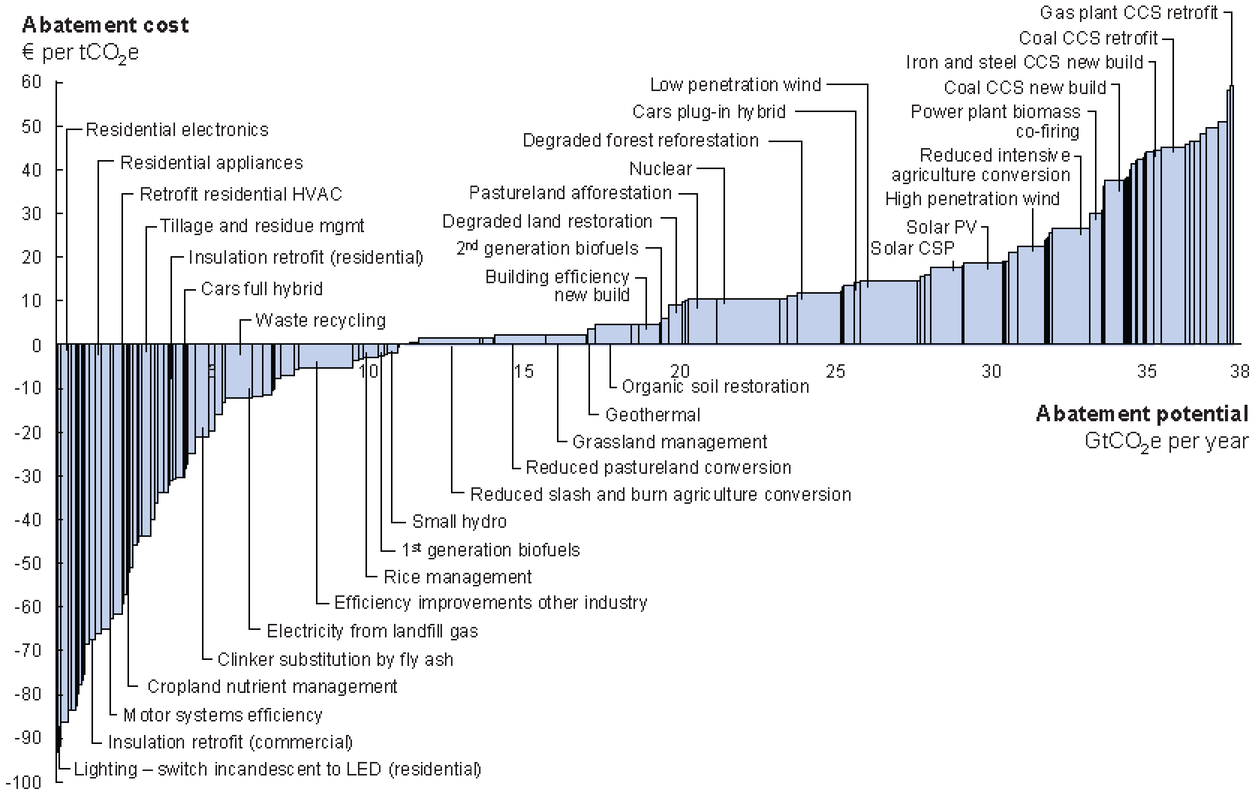
Transportation and electricity are the source of the majority of emissions.

Where emissions come from is important to understanding the costs of reducing emissions.

For example, the recent increased use of natural gas (a cleaner fuel than coal) has decreased emissions from the energy sector.



COSTS OF REDUCING EMISSIONS



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

RENEWABLE ENERGY

As we saw, transportation and energy sectors are the source of a majority of emissions.

This is, at least in part, why there has been a push for decarbonizing these sectors

<u>Transportation</u>

- Electric vehicles
- Biofuels
- Hydrogen cell technology

<u>Energy</u>

- Hydropower
- Nuclear power
- Wind and solar

COSTS OF REDUCING EMISSIONS

Can reduce emissions through three methods:

- Reduce output
- Substitute inputs
- Increase efficiency

Low cost reductions are going to be heavily dependent on substitutability and technological progress.

Some industries are hard/impossible to decarbonize

Eg. Airlines and steel manufacturing

What does economic theory say we should do?

Efficient decarbonization would suggest we should not reduce emissions from each industry equally if the costs of mitigation are heterogeneous!

ALTERNATIVES TO MITIGATION

PROBLEM

Mitigation is often seen as slow and costly.

What else could we do?

SOLUTION?

One option is to adapt!

Think of it as investing to change the marginal damages function

ADAPTATION

Adaptation:
Increasing resilience to climate change

By investing in adaptation rather than mitigation, we are *reducing* the impacts of climate change, rather than reducing climate change itself

A few options for adaptation:

- Migrate from coastlines
- Build sea-walls
- Increasing supply chain resilience
- Air conditioning

CLIMATE ENGINEERING

Climate engineering
Deliberate intervention or manipulation of the climate

Also called **geoengineering**

There are two broad forms:
1. Solar geoengineering
2. Carbon removal and storage

SOLAR GEOENGINEERING

Solar geoengineering
Intentional reflection of incoming solar radiation

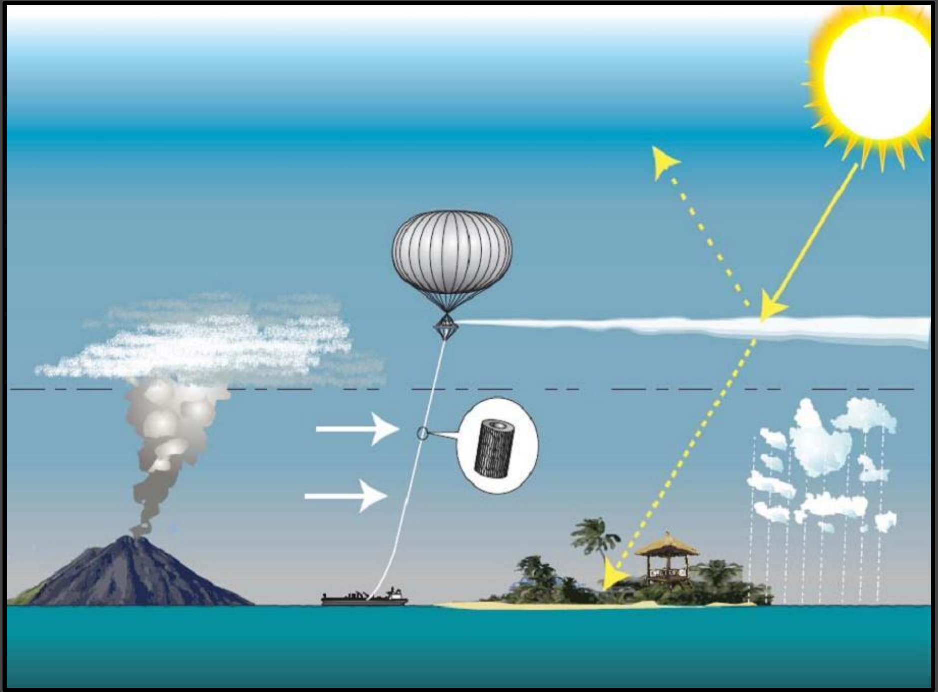
Also called **solar radiation management**

Few different proposed methods:

- Aerosol injection
- Marine cloud brightening
- Space mirrors
- Increasing albedo of crops and buildings

Methods vary in their cost, feasibility, and effectiveness.

Solar geoengineering is quick, inexpensive, and imperfect.



SOLAR GEOENGINEERING

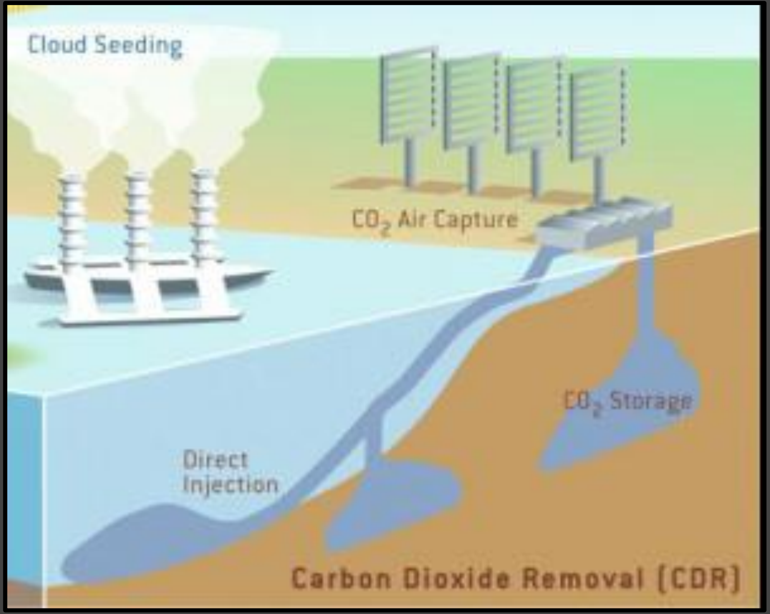
There remain large uncertainties around the method.

Have looked at the effect of volcanos.

- Mt. Pinatubo associated with a short-term decline of ~0.5°C

Recent push for field testing to learn more.

CARBON DIOXIDE REMOVAL AND STORAGE



Carbon dioxide removal and storage
Extraction of CO_2 from the atmosphere to be stored or converted

Extract CO_2 deals directly with the source of climate change.

Could allow us to continue to emit and then remove using this technology.

Can be stored (usually underground)

Also efforts to convert to other forms such as energy

ADAPTATION AND CLIMATE ENGINEERING

Mitigation is no the only way to deal with the impacts of climate change.

General sentiment among economists is that an efficient approach to climate change will use a combination of not just mitigation, but also adaptation and climate engineering.

NEXT TIME...

We've introduced the climate change problem
We've analyzed its effects
We've quantified and monetized the impacts
We've discussed methods to deal with it

Next time, we will cover:
How can we design efficient climate policy?
What climate policy is actually used?
What are some of the problems that arise around climate policy?

LESSON OBJECTIVES

01

Define climate change and its effects

02

Analyze economic impacts of climate change

03

Analyze strategies to reduce climate change impacts