Climate change: drivers, impacts, scenarios

Climate macroeconomics & finance course 2022/23 - Lecture 2

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In the last lecture

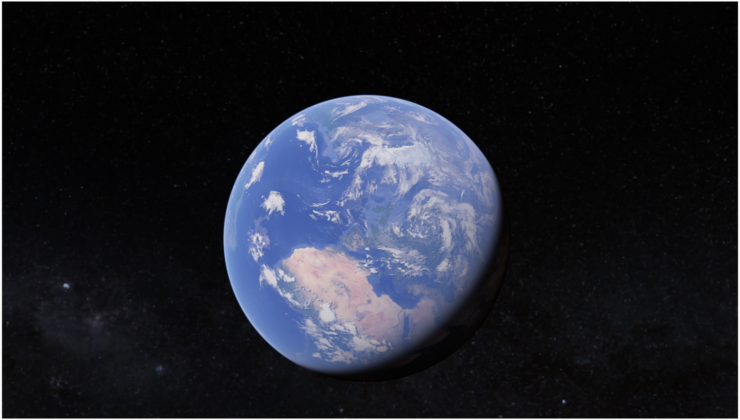
- Introduction to the course
  - Any logistic pending questions?
  - Group-work topic choice closes on 25 Sept
  - Problem-set submission by 27 Sept
- General overview of the problem
  - Climate change threats to human societies → Decarbonisation
  - A rapid low-carbon transition might come with costs
  - How do we design/implement a rapid and smooth low-carbon transition?
- Let's start from the beginning:
  - What's the problem we're facing exactly?

Outline of today's lecture

- Earth's climate system 101
  - Atmosphere, energy balance, forcing, feedbacks, tipping points, etc.
- Climate changes
  - Long-term climate dynamics
  - Observed climate changes in recent decades
  - Is this us? Yes.
- Climate futures
  - Common scenarios: SSPs, RCPs
  - Climate risks and adaptation
- Climate impacts on human societies
  - Impact channels and outcomes
  - Methods to assess economic impacts
  - $\rightarrow$ Looking for a damage function (lecture 5)

Earth's climate system

Where we are



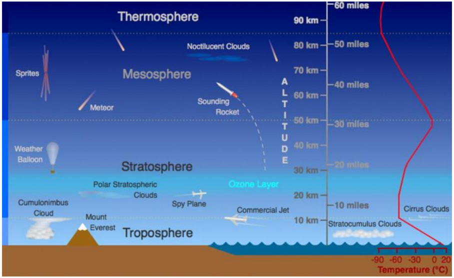
Small rock orbiting around a star. Source: Google Earth

- No human control over Earth dynamics
- Planet entirely dependent on incoming solar energy

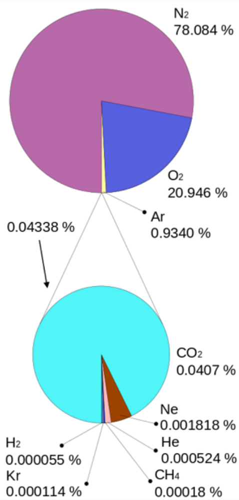
Earth's climate system

- Global system with five interacting component:
  - Atmosphere (gaseous envelope surrounding the Earth)
  - Hydrosphere (oceans, seas, rivers, lakes, etc.)
  - Cryosphere (glaciers, ice sheets, permafrost, etc.)
  - Lithosphere (upper layer of solid Earth, continental/oceanic)
  - Biosphere (ecosystems and living organisms)
- Climate system dynamic flows
  - Earth's energy balance
  - Circulation of air and water
  - Biogeochemical cycles (e.g. carbon cycle)

- Nitrogen (N_2), oxigen (O_2), argon (Ar) + 'trace gases' + water vapour + clouds + aerosols



Atmospheric layers. Source: UCAR



Composition of Earth's atmosphere by volume (dry air). Source: Wikimedia

Greenhouse gases (GHGs)

- GHGs absorb infrared thermal radiation (from Earth to space) and warm the atmosphere
    - Greenhouse effect (without GHGs average temp. 30°C lower..)
- The main GHGs we will look at, heavily produced by humans:
    - Carbon dioxide (CO2)
    - Methane (CH4)
    - Nitrous oxide (N2O)
- Other GHGs:
    - Water vapour (H20; not directly affected by human activity)
    - Ozone (O3; benefits to humans)
    - Synthetic F-gases (CFCs, HCFCs, HFCs, SF6, etc.; some of which ozone-depleting)

Note: measurement

- Reminder on unit prefixes
  - Kilo (k): 10^3
  - Mega (M): 10^6
  - Giga (G): 10^9
  - Tera (T): 10^{12}
  - Peta (P): 10^{15}
- Often used measures in climate research:
  - Tonne: 1 million (10^6) grams
  - 1 gigatonne (Gt) = 1 petagram (Pg)
- CO2$\neq$Carbon (C):
  - CO2: one atom of carbon, two atoms of oxigen
  - Conversion factor: 3.664 (1Gt C$\rightarrow$ 3.664 Gt CO2)

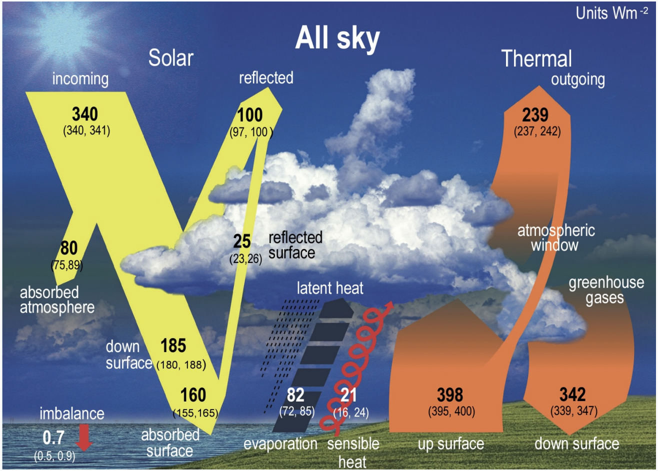
The carbon cycle

- Carbon ($_6C$)
  - Backbone of all life on Earth
  - Constant amount of carbon on the planet
- Reservoirs (sinks)
  - In atmosphere, oceans, vegetation, soil, fossil fuels, rocks, etc.
- Exchanges between reservoirs, e.g.
  - Atmosphere-vegetation via photosynthesis/respiration (video)
  - Atmosphere-surface ocean exchange (atmospheric CO2 $\rightarrow$ carbonic acid)
  - Surface-deep ocean exchange

Glacial ice on Earth

- 99% in ice sheets (continental glaciers)
  - Mass greater than 50,000 km2, covering terrain
  - Only Antarctica and Greenland; more before
- Ice shelves
  - Large floating platform of ice attached to ice sheet or glacier
  - Antarctica, Greenland, Northern Canada, Russian Arctic
- Sea ice
  - Floating frozen seawater, covers 7% of planet
  - Mainly in the Arctic and Antarctic ice packs
- Glaciers
  - Smaller masses in mountainous regions
  - Largest reservoir of planet's freshwater (69%)

Earth's energy balance



Global mean energy budget of the Earth. Source: IPCC 2021 WGI, Ch. 7

In a stable climate: Incoming energy ≈ outgoing energy

Radiative forcing

- Radiative forcing concept (F)
  - Change in net radiative flux at the top of atmosphere (troposphere) due to some external climate driver
  - Unit of measure: watt/m2
- IPCC concept: Effective Radiative Forcing (ERF)
  - Includes climate system adjustments (directly related to forcing agent; e.g. change in cloud cover)
  - Excludes surface temperature response (see feedbacks later)
- Planck response
  - Earth will restore positive/negative balance by warming/cooling: $\Delta T_P = -\frac{\Delta F}{\alpha_P}$
  - AR6: $\alpha_P = -3.22 Wm^{-2\circ} C^{-1}$ (high confidence)
  - $\rightarrow$ A forcing of $1 Wm^{-2}$ increases equilibrium T_P by $\approx 0.31^\circ C$

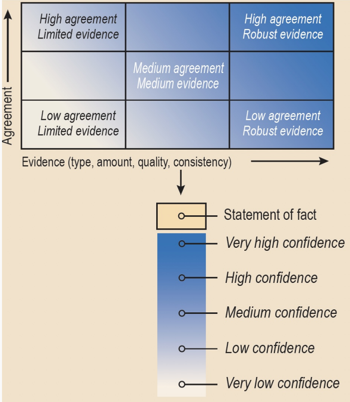
Additional climate feedbacks

- Climate feedbacks driven by ΔT:
  - Climate–carbon cycle feedback (e.g. change in CO2 ocean-atmosphere exchange)
  - Cloud feedback: ΔT affects cloud cover, which affects albedo (% of incoming radiation reflected back to space)
  - Ice-albedo feedback: ΔT reduces ice cover, which reduces albedo, further increasing T

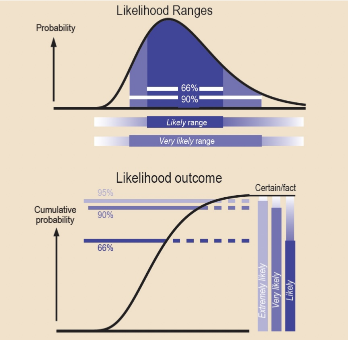
Feedback Parameter α_x ($W\ m^{-2}\ °C^{-1}$)	CMIP5 GCMs	CMIP6 ESMs	AR6 Assessed Ranges			
	Mean and 5–95% Interval	Mean and 5–95% Interval	Central Estimate	*Very likely* Interval	*Likely* Interval	Level of Confidence
Planck	−3.20 [−3.3 to −3.1]	−3.22 [−3.3 to −3.1]	**−3.22**	−3.4 to −3.0	−3.3 to −3.1	*high*
WV+LR	1.24 [1.08 to 1.35]	1.25 [1.14 to 1.45]	**1.30**	1.1 to 1.5	1.2 to 1.4	*high*
Surface albedo	0.41 [0.25 to 0.56]	0.39 [0.26 to 0.53]	**0.35**	0.10 to 0.60	0.25 to 0.45	*medium*
Clouds	0.41 [−0.09 to 1.1]	0.49 [−0.08 to 1.1]	**0.42**	−0.10 to 0.94	0.12 to 0.72	*high*
Biogeophysical and non-CO_2 biogeochemical	Not evaluated	Not evaluated	**−0.01**	−0.27 to 0.25	−0.16 to 0.14	*low*
Residual of kernel estimates	0.06 [−0.17 to 0.29]	0.05 [−0.18 to 0.28]				
Net (i.e., relevant for ECS)	−1.08 [−1.61 to −0.68]	−1.03 [−1.54 to −0.62]	**−1.16**	−1.81 to −0.51	−1.54 to −0.78	*medium*
Long-term ice-sheet feedbacks (millennial scale)				>0.0		*high*

Synthesis assessment of climate feedbacks. Source: IPCC 2021 WGI, Ch. 7

Note: uncertainty in IPCC assessment



The IPCC AR6 approach for characterizing understanding and uncertainty in assessment findings. Source: IPCC 2021 WGI, Ch.1



Likelihood	**Outcome 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%

Forcing drivers

- Forcings $\neq$ Internal variability
  - E.g. North Atlantic Oscillation, El Niño–Southern Oscillation (ENSO), etc.
- Forcings are 'external'
  - Solar variations (e.g. 11-year solar cycles)
  - Orbital forcing (Milankovitch cycles)
  - Aerosols from volcanic activity (e.g. 1815 Tambora eruption)
  - Long term: position of continents (affects ocean circulation)
  - Changing atmospheric composition (GHGs, aerosols)
  - Land-use change
- Natural vs anthropogenic drivers
  - Focus on anthropogenic GHG emissions: what's the temperature response we should expect?

GHG lifetime and radiative efficiency

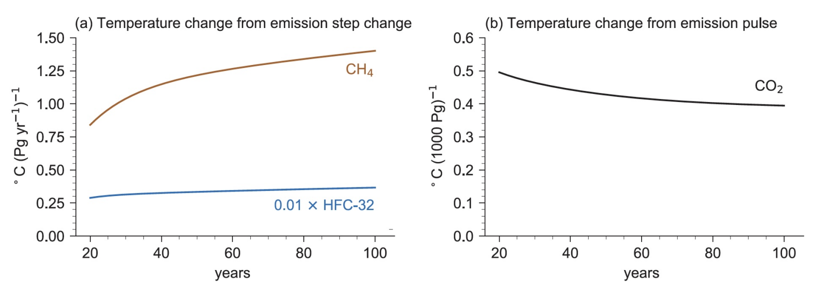
- Different lifetimes across GHGs
  - CO2 has no specific lifetime, as it moves among carbon sinks
  - Some of it absorbed by oceans within years..
  - .. but 20-35% lingers for millennia
- Different radiative efficiency
  - Radiative efficiency: change in ERFs per unit change in concentration

Species	Lifetime (Years)	Radiative Efficiency (W m^{-2} ppb^{-1})
CO_2	Multiple	$1.33 \pm 0.16 \times 10^{-5}$
CH_4-fossil	11.8 ± 1.8	$5.7 \pm 1.4 \times 10^{-4}$
CH_4-non fossil	11.8 ± 1.8	$5.7 \pm 1.4 \times 10^{-4}$
N_2O	109 ± 10	$2.8 \pm 1.1 \times 10^{-3}$
HFC-32	5.4 ± 1.1	$1.1 \pm 0.2 \times 10^{-1}$
HFC-134a	14.0 ± 2.8	$1.67 \pm 0.32 \times 10^{-1}$
CFC-11	52.0 ± 10.4	$2.91 \pm 0.65 \times 10^{-1}$
PFC-14	50,000	$9.89 \pm 0.19 \times 10^{-2}$

GHG lifetime and radiative efficiency. Source: IPCC 2021 WGI, Ch. 7

Warming/temperature response to GHGs

- Temperature response
  - T response to CO2 impulse: rapid and stable → TCRE concept



Temperature responses for emission step (left: CH4, HFC-32) or pulse (right: CO2).
Source: IPCC 2021 WGI, Ch. 7

Comparing GHGs

- How do we compare GHGs with different lifetime and radiative efficiency?
  - → Global warming potential (GWP) or Global temperature change potential (GTP)
- CO2e (CO2 equivalent): GHGs weighted by their GWP/GTP
  - GWP-100 most common metric
  - E.g. 1 ton of CH4-fossil = 29.8 tons of CO_2e

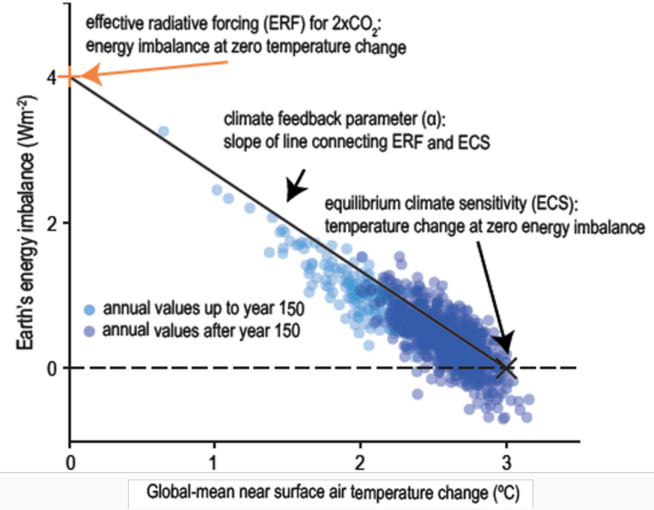
Species	Lifetime (Years)	Radiative Efficiency ($W\ m^{-2}\ ppb^{-1}$)	GWP-20	GWP-100	GWP-500	GTP-50	GTP-100	CGTP-50 (years)	CGTP-100 (years)
CO_2	Multiple	$1.33 \pm 0.16 \times 10^{-5}$	1.	1.000	1.000	1.000	1.000		
CH_4-fossil	11.8 ± 1.8	$5.7 \pm 1.4 \times 10^{-4}$	82.5 ± 25.8	29.8 ± 11	10.0 ± 3.8	13.2 ± 6.1	7.5 ± 2.9	2823 ± 1060	3531 ± 1385
CH_4-non fossil	11.8 ± 1.8	$5.7 \pm 1.4 \times 10^{-4}$	79.7 ± 25.8	27.0 ± 11	7.2 ± 3.8	10.4 ± 6.1	4.7 ± 2.9	2675 ± 1057	3228 ± 1364
N_2O	109 ± 10	$2.8 \pm 1.1 \times 10^{-3}$	273 ± 118	273 ± 130	130 ± 64	290 ± 140	233 ± 110		
HFC-32	5.4 ± 1.1	$1.1 \pm 0.2 \times 10^{-1}$	2693 ± 842	771 ± 292	220 ± 87	181 ± 83	142 ± 51	78,175 ± 29,402	92,888 ± 36,534
HFC-134a	14.0 ± 2.8	$1.67 \pm 0.32 \times 10^{-1}$	4144 ± 1160	1526 ± 577	436 ± 173	733 ± 410	306 ± 119	146,670 ± 53,318	181,408 ± 71,365
CFC-11	52.0 ± 10.4	$2.91 \pm 0.65 \times 10^{-1}$	8321 ± 2419	6226 ± 2297	2093 ± 865	6351 ± 2342	3536 ± 1511		
PFC-14	50,000	$9.89 \pm 0.19 \times 10^{-2}$	5301 ± 1395	7380 ± 2430	10,587 ± 3692	7660 ± 2464	9055 ± 3128		

Emission metrics. Source: IPCC 2021 WGI, Ch. 7

Equilibrium Climate Sensitivity (ECS)

- Equilibrium climate sensitivity (ECS) concept:
  - Long-term increase in temperatures caused by a doubling of CO2 concentration w.r.t. pre-industrial levels
  - Equilibrium: T is no longer moving to balance the energy imbalance (centuries/millenia timescales; excludes ice sheet feedbacks)
- 'Process-based' assessment:
  - Find ERF associated to doubling of CO2 concentration: $\Delta F_{2xCO2} = 3.93 \pm 0.47 Wm^{-2}$
  - Divide by net feedback parameter $\alpha = -1.16$
  - $\rightarrow \Delta T = -\frac{\Delta F}{\alpha} \approx 3.38^{\circ} C$
- Additional assessment methods available
  - Instrumental recors, paleoclimate, etc.
  - $\rightarrow$ AR6 best estimate of ECS: $3^{\circ} C$, likely range between $2.5^{\circ} C$ and $4^{\circ} C$

Relation between ERF, ECS and α

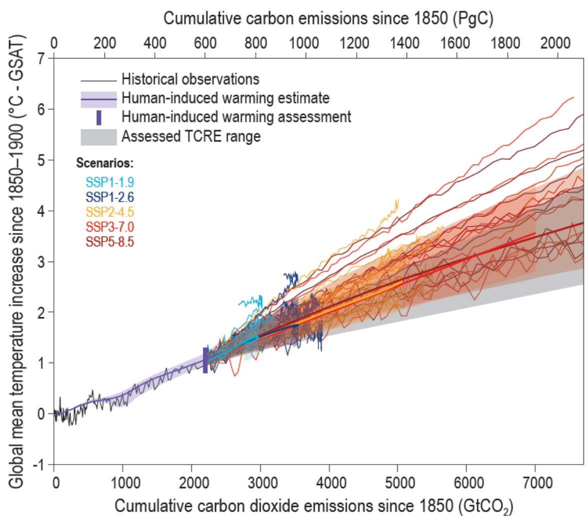


Stylised representation of relation between ERF, ECS and climate feedback parameter.
Source: IPCC 2021 WGI, Ch. 7

Transient climate response to cumulative CO2 emis. (TCRE)

- Not to be confused with transient climate response (TCR),
  - TCR: ΔT in scenario where CO2 increases 1%/yr from pre-industrial level to 2xCO2 concentration time (year 70)
  - AR6: TCR best estimate: $1.8°C$; likely range: $1.4 - 2.2°C$
- Transient climate response to cumulative CO2 emis. (TCRE)
  - ΔT per unit of cumulative CO2 emissions since the pre-industrial period, usually 1000 GtC (or PgC)
  - Roughly independent of time and concentration levels
  - Allows us to calculate 'carbon budgets' (see next lecture)
  - TCRE likely range: $1.0 - 2.3°C$ per 1000 GtC
- Near-linear relationship
  - Temperature reaction to CO2 concentration increase $\Delta T/\Delta M$: concave increasing function of time
  - Increase in CO2 concentration per unit of cum. emissions $\Delta M/\Delta S$: convex decreasing function of time
  - $\rightarrow$ Roughly compensate each other after short initial period

Temperature and cumulative emissions

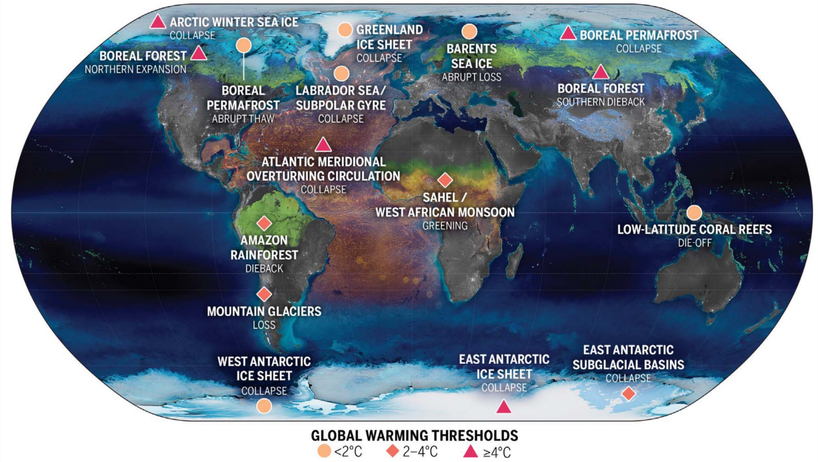


Cumulative CO2 emissions and GSAT. Source: IPCC 2021 WGI, Ch. 7

Tipping points

- Tipping points:
  - "Critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system" (Lenton et al. 2008)
  - Destabilising feedbacks prevails on stabilising ones, leading to a (temporary) run-away situation (new attraction basin)
  - Often irreversible; not necessarily abrupt; tipping cascades
  - Tipping elements: component of the Earth system, at least subcontinental in scale, susceptible to a tipping point
- Interesting for later:
  - *Social* tipping points (see Otto et al. 2020)

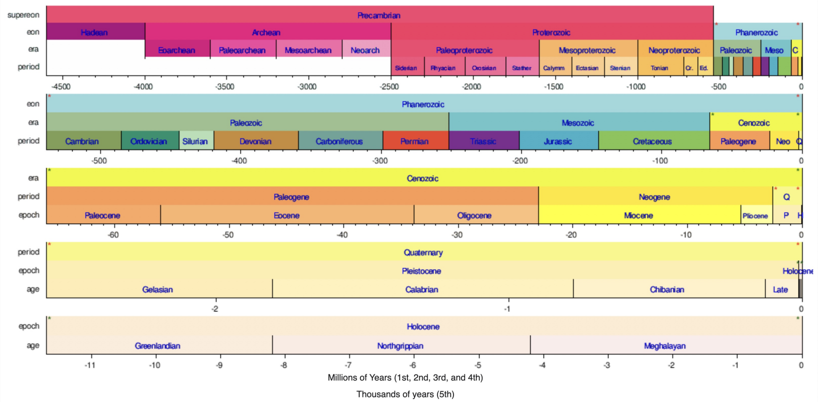
Earth's tipping elements



Climate tipping elements. Source: Armstrong McKay et al. (2022)

Climate changes

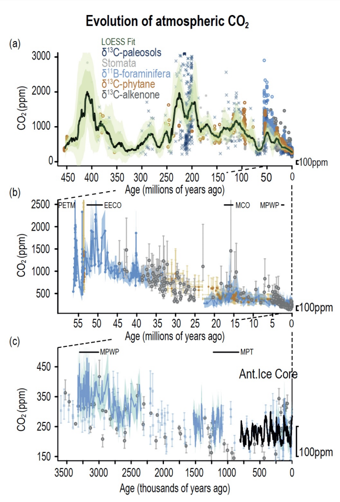
Earth's history



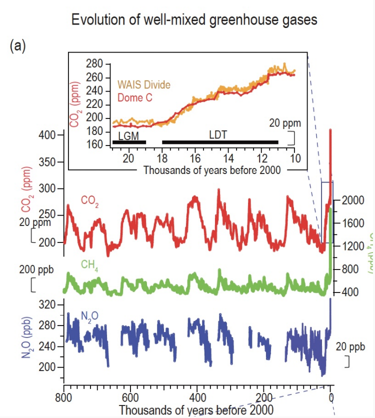
Geological timescales (Figure source)

- Quaternary period: 2.58ma with Arctic cap (ongoing ice age!)
- Holocene epoch: 11700ya with end of last glacial period
- Moving to the Anthropocene?

Long-term GHG concentration

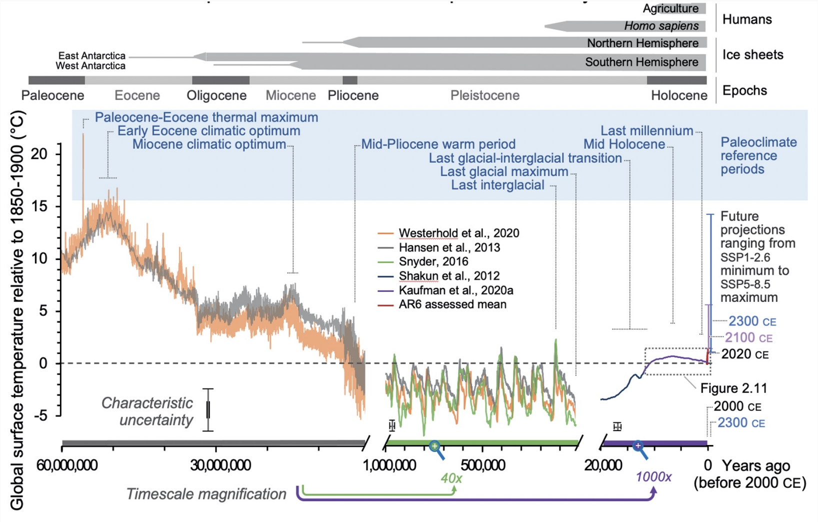


Atmospheric CO2 concentrations from continental rock, marine sediment and ice core records. Source: IPCC 2021 WGI, Ch. 2



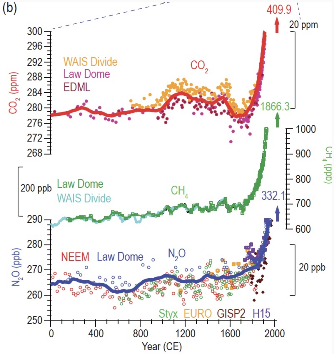
Atmospheric well-mixed greenhouse gas (WMGHG) concentrations from ice cores. Source: IPCC 2021 WGI, Ch. 2

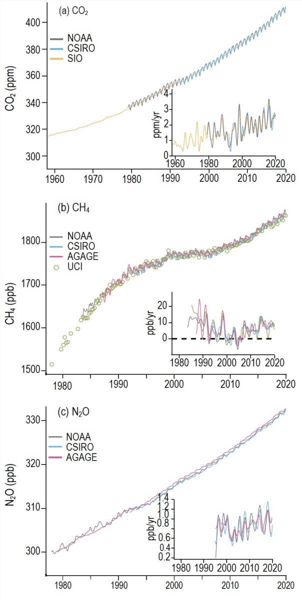
Long-term temperature dynamics



Global mean surface temperature rel. to 1850–1900. Source: IPCC WGI Ch.2 (2021)

More recent evolution of GHG concentration





Above: Atmospheric WMGHG concentrations ice cores.
On the right: Atmospheric WMGHG concentrations from direct observation.
Source: IPCC 2021 WGI, Ch. 2
See also: Keeling curve

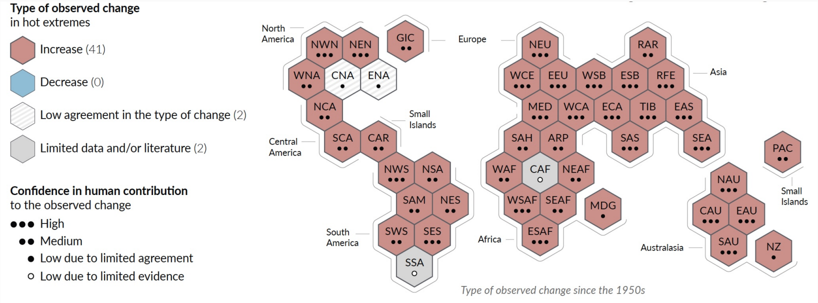
Temperature trends of the Cenozoic era (66Ma-now)

- Last 50Myr:
  - After PETM: long-term cooling (tectonics, oceans, feedbacks)
  - Development of Antarctic Ice Sheet (AIS) 35–30 Ma
  - Northern Hemisphere ice-sheets by 3 Ma
  - Mid-Pliocene Warm Period (3.3-3.0Ma): CO2 conc. $\approx$ today
- Last million years
  - Glacial-interglacial fluctuations (orbital forcing + carbon cycle)
  - Last Interglacial period (129-116 ka)
  - Last Glacial Maximum: most recent glaciation
- Holocene interglacial period (last 12ka)
  - Warming up to Mid-Holocene (6.5–5.5ka) then cooling
  - Overall stable and favourable $\rightarrow$ human civilization
- Last millennium
  - Natural changes (e.g. Medieval 'little ice age')
  - From 1850 $\rightarrow$ warming driven by anthropogenic GHGs

Observed changes in the climate system

- Increase in GHG atmospheric concentration
    - CO_2: 410ppm (pre-industrial: ≈ 277). Updates from NASA
    - CH_4: 1866ppb (pre-industrial: ≈ 770)
    - N20: 332ppb (pre-industrial: ≈ 270)
- Increase in temperature
    - GSAT in 2011-20: 1.09°C higher than 1850–1900 (land: 1.59°C; ocean: 0.88°C)
- Changes in climate system (IPCC AR6 WGI)
    - Warming and acidification of oceans
    - Sea level rise of 0.20m between 1901 and 2018
    - More (less) frequent/intense hot (cold) extremes
    - Increase in average precipitation since 1950s
    - Increase in frequency/intensity of heavy precipitation event
    - Increases in agricultural/ecological droughts in some regions
    - Retreat of glaciers; decrease in Arctic sea ice area
    - Ecosystems change (e.g. loss of coral reefs)

An example: hot extremes

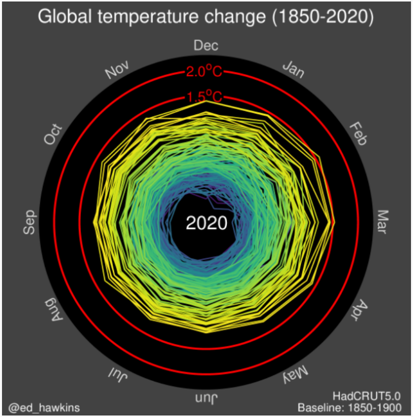


Synthesis of assessment of observed change in hot extremes. Source: IPCC 2021 WGI, SPM

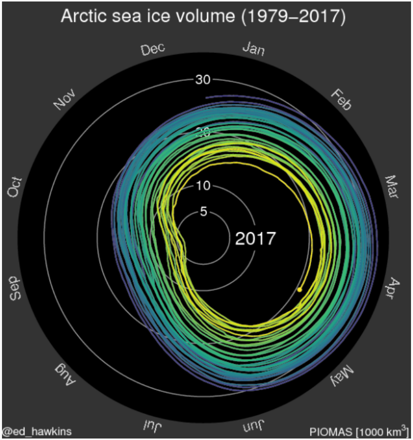
Ice coverage dynamics

Check out the NASA Ice Viewer

Climate spirals visualization

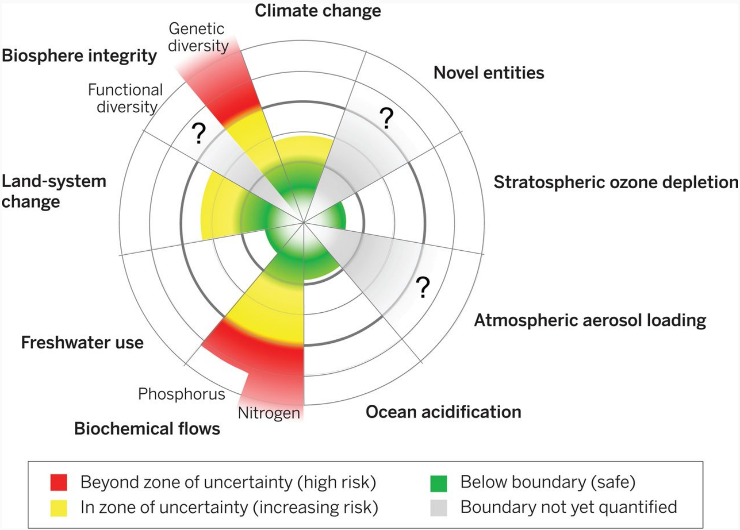


Source: Climate Lab Book



Source: Climate Lab Book

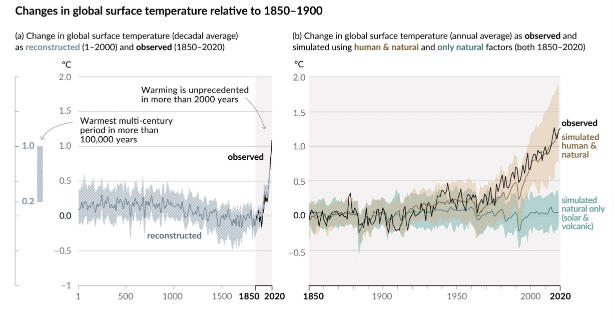
Wider Earth system changes



Assessment of planetary boundaries. Source: Steffen et al. (2015)

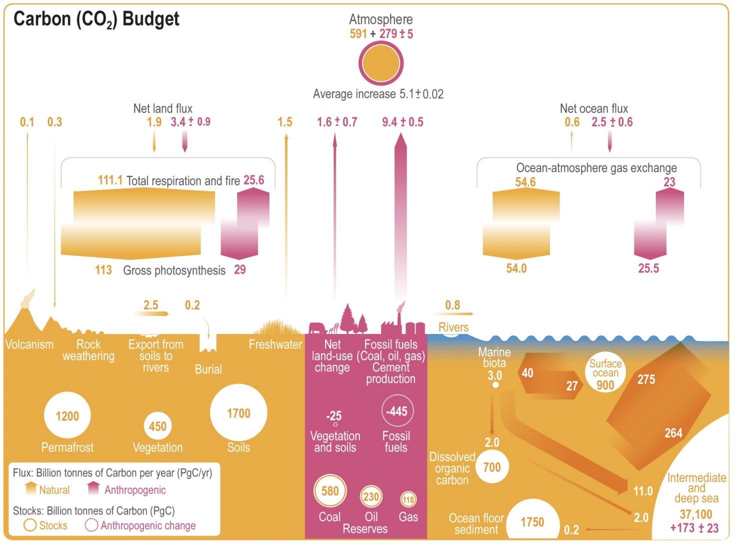
Are these changes driven by humans?

- IPCC AR6 WGI:
  - Increases in GHG concentrations since around 1750 unequivocally caused by human activities
  - Human-caused GSAT increase: 1.07°C (likely range 0.8-1.3°C)
  - Human influence likely to extremely likely the main driver of other climate system changes



History of GSAT change and causes of recent warming. Source: IPCC 2021 WGI, SPM

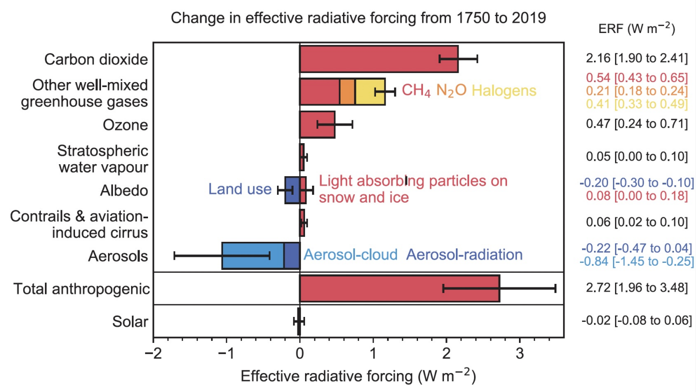
Human intervention on the carbon cycle



Global carbon (CO2) budget (2010–2019). Source: IPCC 2021, Ch.5

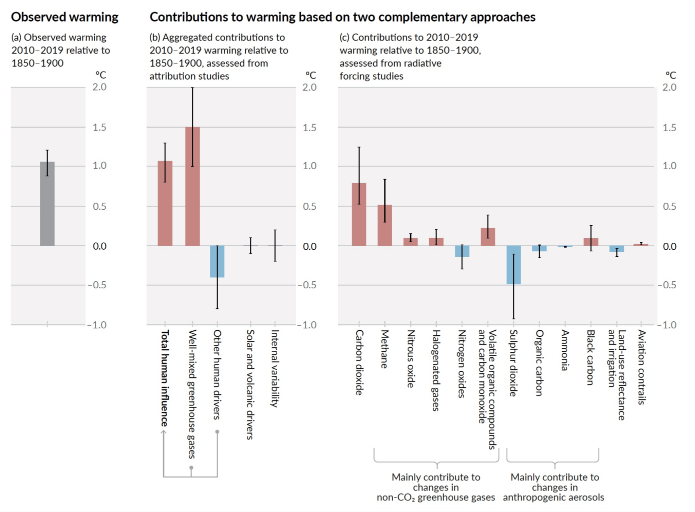
Change and drivers of ERF 1750-2019

- Increased GHG concentrations are driving Earth's energy imbalances



Change in effective radiative forcing (ERF) from 1750 to 2019 by contributing forcing agents. Source: IPCC 2021 WGI, Ch. 7

Contribution to observed warming



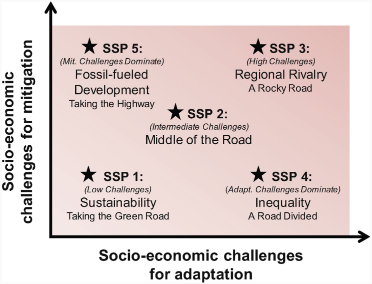
Assessed contributions to observed warming in 2010–2019 relative to 1850–1900.
Source: IPCC 2021 WGI, SPM

Climate futures

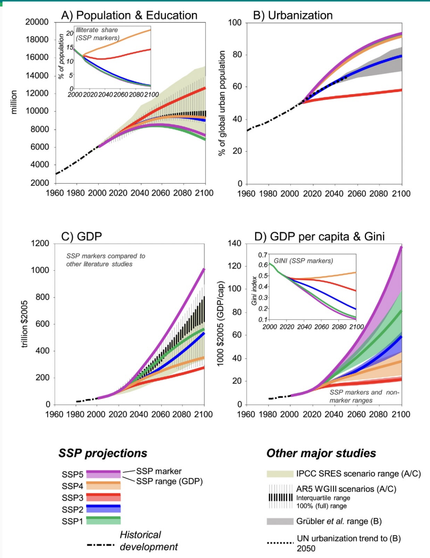
Climate scenarios

- Scenarios:
  - Internally consistent descriptions of how the future may develop
  - Not predictions but ‘what-if’ investigations
- AR5 Representative Concentration Pathways (RCPs)
  - Based on radiative forcing in 2100
  - RCP2.6 ; RCP4.5; RCP6.0; RCP8.5
- Shared Socio-economic Pathways (SSPs)
  - Plausible future socio-economic trends (pop, GDP, etc)
  - Do not account for climate effects
  - No new climate policy assumed
  - Develop SSP energy/emission scenarios using IAMs
- AR6 SSP scenarios
  - Combine SSP narratives with radiative forcing in 2100
  - Include climate mitigation assumption

Shared Socio-economic Pathways (SSPs)

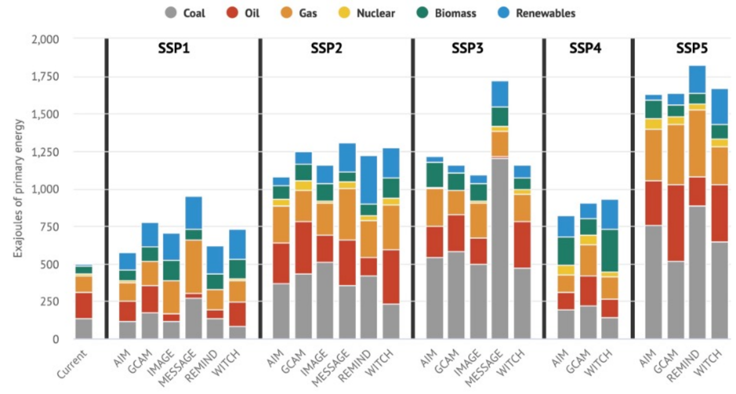


The five SSP narratives. Source: O'Neill et al. (2017)



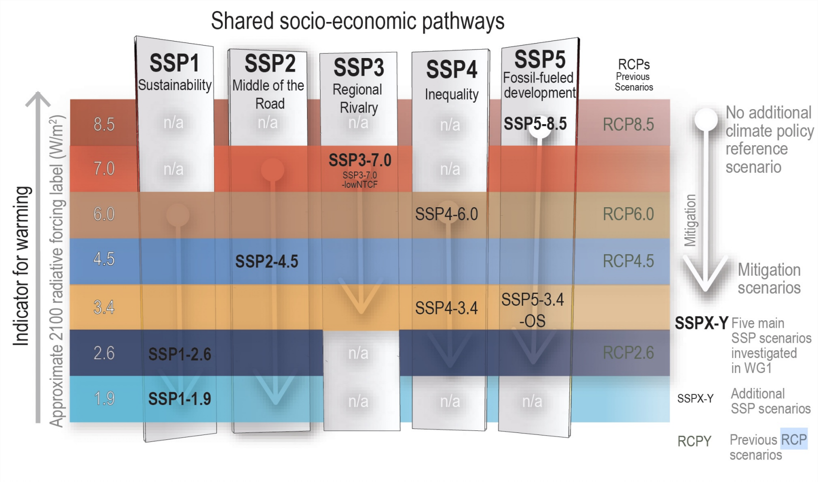
Development of key variables in SSPs. Source: Rihai et al. (2017)

SSP energy implications



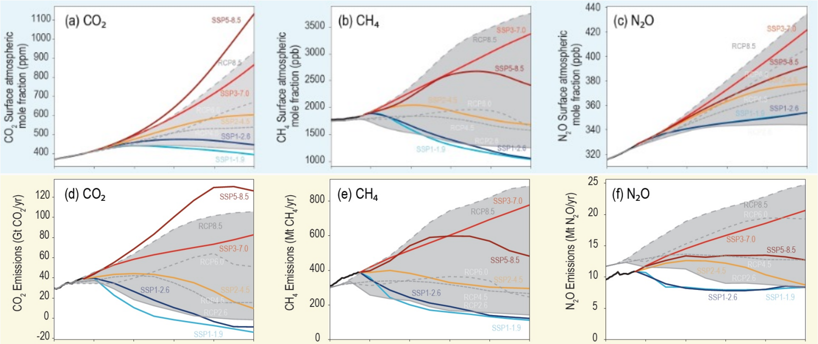
Primary energy in 2100 by model for SSP baseline scenarios. Source: Carbon Brief (2018)

SSP-RCP storylines in IPCC AR6



SSP-RCP storylines in IPCC AR6. Source: IPCC AR6 WGI, Ch.1

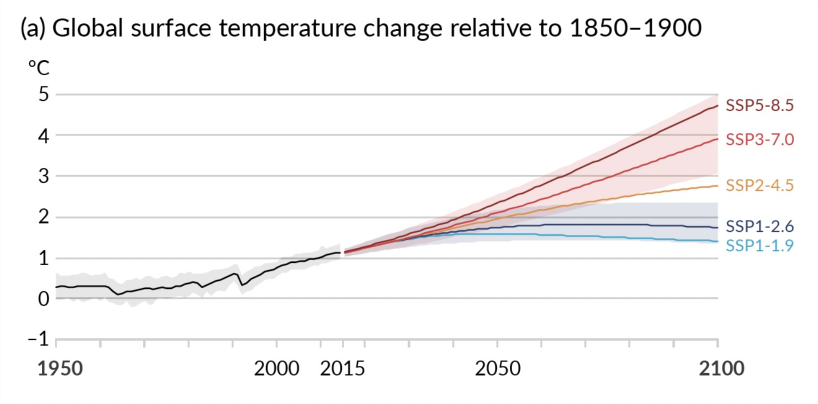
SSP emission and concentration pathways



GHG concentration and emission pathways in AR6 SSP scenarios (with comparison to RCPs). Source: IPCC AR6 WGI, Ch.1

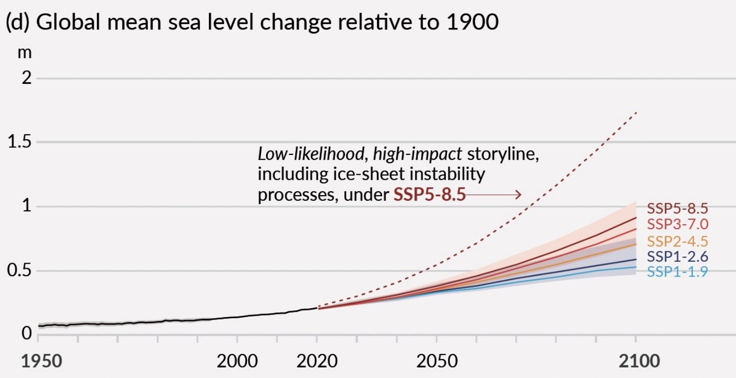
- More on transition pathways later on..

Temperature pathways



Temperature pathways by SSP. Source: IPCC AR6 WGI, SPM

Sea level rise pathways



Sea level pathways by SSP. Source: IPCC AR6 WGI, SPM

- But slower trend, already partially locked in
- SSP1-2.6 up to 3m in 2300; SSP5-8.5 up to 7m..
- East-Antarctica ice-sheet melting: 60m SLR

Climate socio-economic impacts

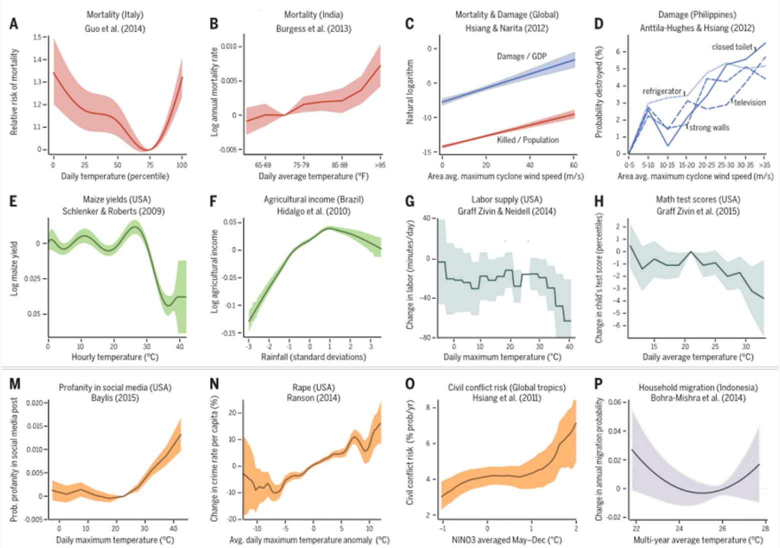
Climate economic impacts

- Biophysical impacts → Socio-economic impacts
- Market vs non-market impacts
  - Market: impacts on variables that have a clear monetary value (e.g. expenditure, GDP, assets)
  - Non-market: impacts on variables without a monetary values (e.g. mortality, amenities, ecosystems) → Valuation techniques needed!
- Different interlinked lines of research
  - Bottom-up estimation of impact channels
  - Aggregation into economic impacts, with/without feedbacks
  - Top-down econometric estimates (temperature effect on GDP/growth)
  - Aggregate damage functions (to be used in IAMs)

Main impact channels

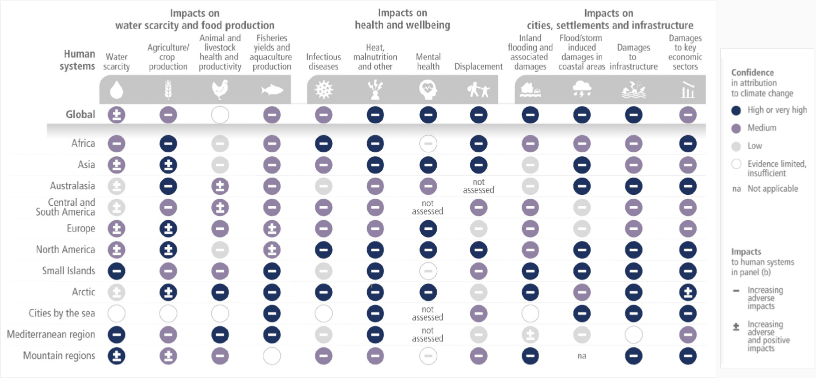
- Human health
  - Impacts of temperature and extreme events on mortality
  - Impacts on morbidity (e.g. humidity $\rightarrow$ diseases)
- Agricultural productivity
  - Temperature and rainfall can decrease crop yields
  - SLR $\rightarrow$ saltwater intrusion
- Labour supply and productivity
  - High temperatures $\rightarrow$ Decrease in work hours/intensity/quality
- Human security
  - Climate-driven violence and conflicts
  - Climate-driven migration
- Damages to physical assets
  - Household living assets, firm production assets, infrastructure
- Change in energy demand patterns
  - e.g. heat $\rightarrow$ power consumption for AC

Some empirical evidence



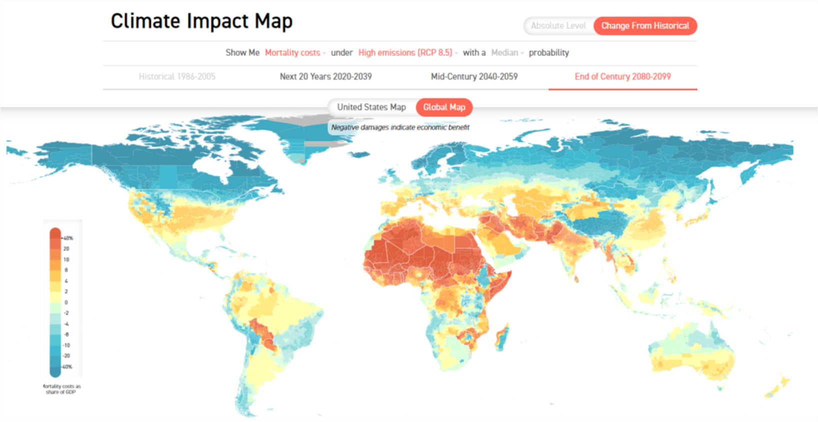
Climate socio-economic impacts. Source: Carleton and Hsiang (2016)

Observed impacts on human societies



Observed impacts of climate change on human systems. Source: IPCC AR6 WGII, SPM (2022)

Spatially-disaggregated evidence



Check out the material provided by the Climate Impact Lab

Non-market valuation

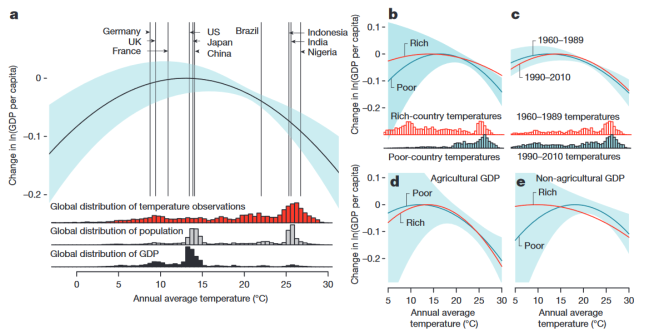
- Revealed preferences
  - Study actual economic behaviour
  - Hedonic pricing (e.g. impact of park proximity on real estate value?)
  - Travel-cost method (e.g. how much do people spend to visit the Yosemite park?)
- Revealed preferences
  - Ask preferences directly to individuals
  - Willingness-to-pay (WTP) vs willingness-to-accept (WTA)
- Value of statistical life
  - Willingness to pay to avoid one statistical life (1 out of larger sample)
- Use of byophysical-economic models
  - e.g. what is the economic impact of a crop failure?

Aggregation of economic impacts

- Enumeration
  - Add estimated damages from sectors
  - However, no consideration of feedback effects between impacts
- Final impacts
  - Include multiple sectoral damages into a model (e.g. CGE)
  - Allows to capture interaction/propagation of effects
- Alternative approach:
  - Jump the direct impact stage, use top-down econometrics to study the direct link between climate and economic variables
  - Usually exclude non-market damages and extreme events

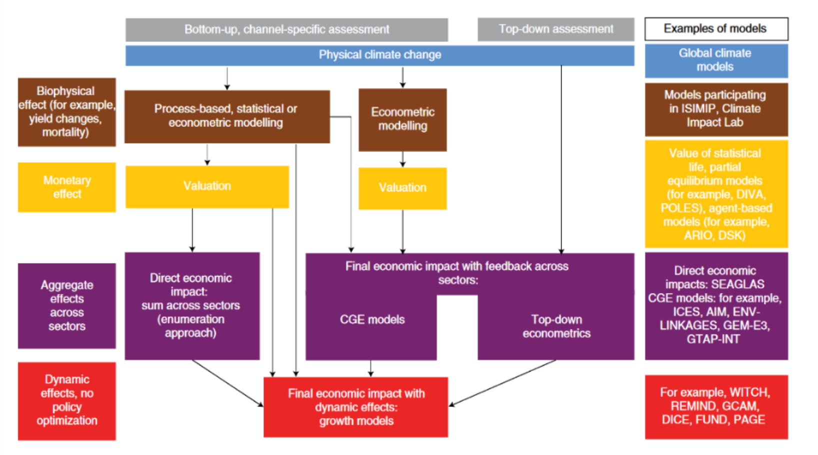
Temperature-income relationship

- Expanding evidence across countries and spatial granularity with comparable results: non-linear impacts of temperature



Non-linear impact of temperature on economic growth. Source: Burke et al. (2015)

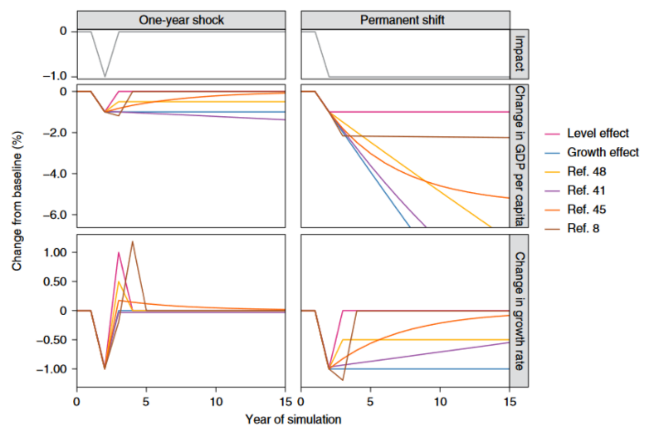
Overview of climate economic impact assessment methods



Taxonomy of approaches to capture economic impacts of climate change. Source: Piontek et al. (2022)

Level vs growth effects

- How persistent are climate economic impacts?



Climate impacts on percapita GDP and GDP growth (ref.8: Kalkuhl & Wenz (2020); ref.41: Kahn et al (2021); ref.45: Deryugina & Hsiang (2017); ref.48: Kikstra et al. (2021). Source: Piontek et al. (2022)

Aggregate damage functions

- Climate economic impacts, however estimated, can the be used to shape damage functions
  - Aggregate relations between temperature and output
  - Used in IAMs to derive optimal trajectories via cost-benefit analysis
  - Heated debate on their shape and derivation
  - Very important $\rightarrow$ Social cost of carbon estimates
  - Do we even have to use them at all?
- We will discuss damage functions more in detail in Lecture 5

Climate risks and adaptation

Climate risks

- Climate risk:
  - The potential for adverse consequences for human/ ecological systems (on lives, livelihoods, health, economic/social/ cultural assets, ecosystems, etc.)
  - Cascading and compounding risks
- Climate-related risks can arise from
  - Potential impacts of climate change
  - Human responses to climate change
- Risk $\neq$ impact
  - Impact: the consequences of *realised* risks on natural and human systems. Can be adverse or beneficial.

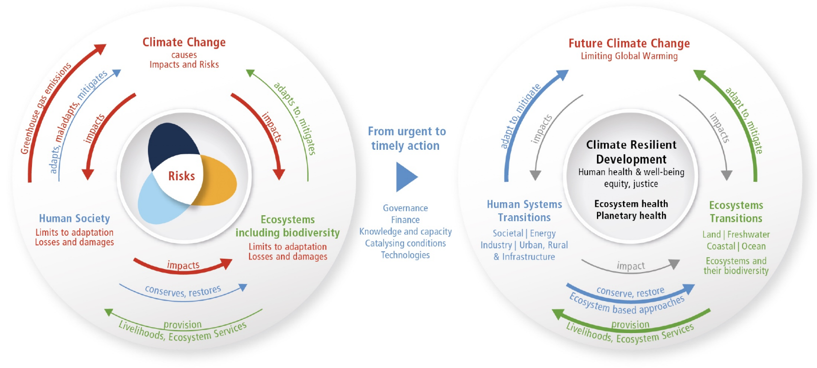
Climate risk components

- Hazards
  - Potential occurrence of physical event/trend that may cause damages
- Exposure
  - Presence of people, ecosystems, infrastructure etc. in settings that could be adversely affected
- Vulnerability
  - The propensity or predisposition to be adversely affected. It includes sensitivity to harm and capacity to cope/adapt.

IPCC climate risk framing. Source: IPCC AR6 WGII, Ch.1 (2022)

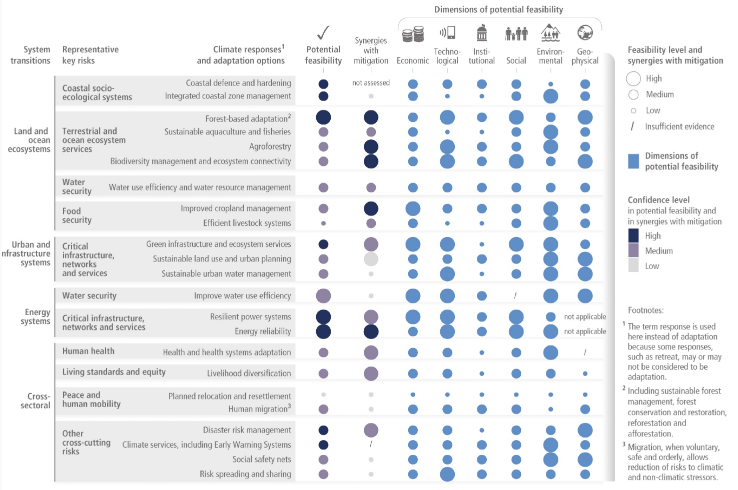
Adaptation and climate-resilient development

- Societies can adapt to climate change, and shape themselves to be resilient and able to transform



From climate risks to climate-resilient development. Source: IPCC AR6 WGII, SPM (2022)

Adaptation options



Feasibility of adaptation options and synergy with mitigation. Source: IPCC AR6 WGII, SPM (2022)

Conclusions

Conclusions

- Climate is being modified by humans at an unprecedented pace
  - Several lines of evidence confirming this
- What will happen in the future?
  - 1. We don't know 2. Depends on us
  - Study the future via scenarios
  - Worst-case scenario (SSP5-8.5) $\rightarrow$ large-scale climate change
- Is this worrying?
  - Yes. Multiple channels negatively affecting human societies
  - Focus on economic impacts
- Next lecture:
  - What can we do about it? $\rightarrow$ Mitigation