DEPARTMENT OF GEOGRAPHY

UCL

Climate Change

Earth geog0005

Outline

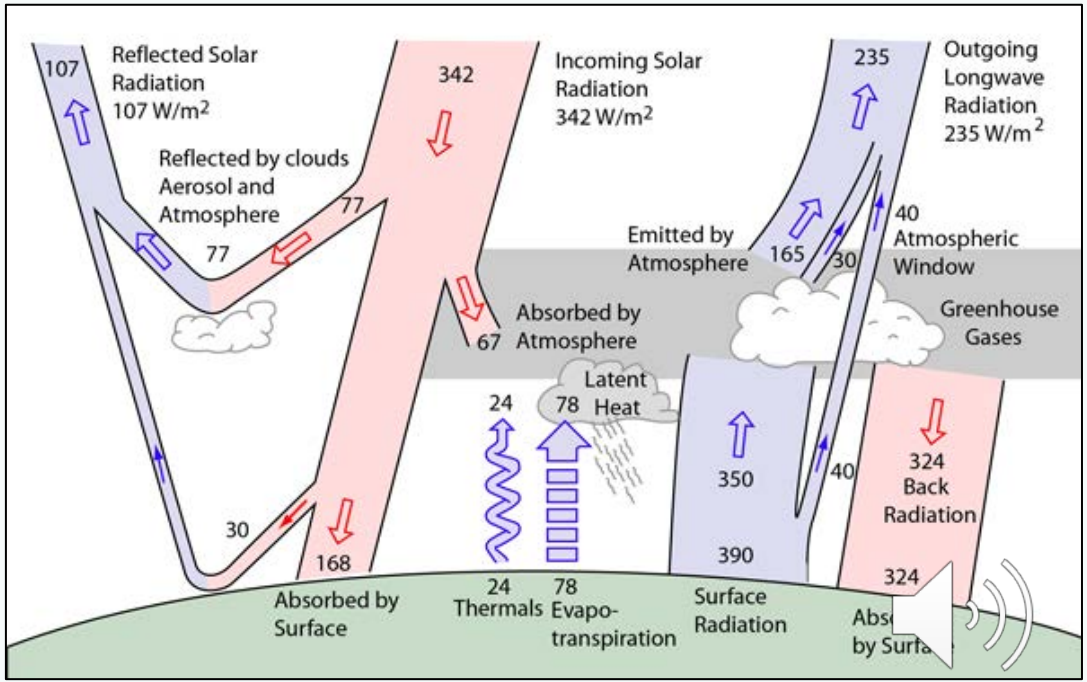
- **Theory**
  - Radiative balance
  - Drivers (radiative forcing)
  - Response (black-body and feedbacks)
- **Observations of change**
  - Increasing temperatures
  - Sea level rise
  - Extreme weather
- **Future climate**
  - Climate models
  - IPCC projections
  - Responses

THEORY

- Radiative balance
- Drivers of change
- Blackbody response and feedbacks

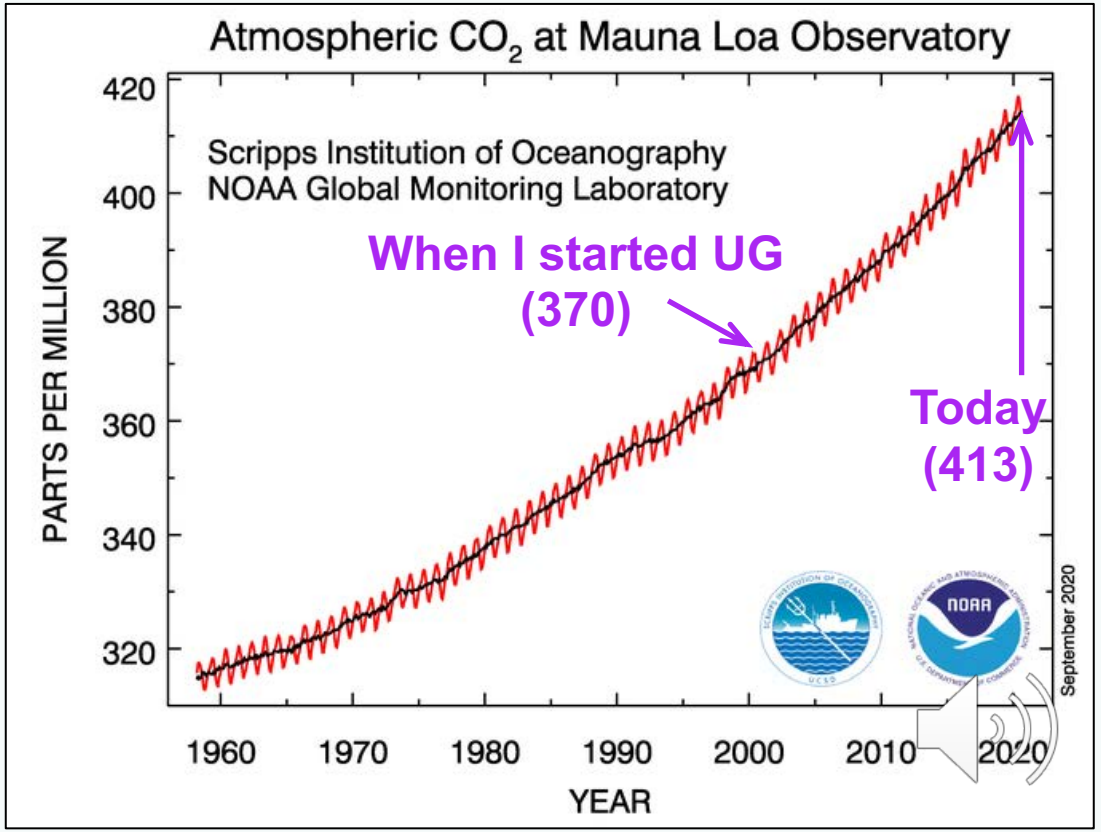
Energy Balance

- A system in equilibrium gains as much energy as it loses:
  - Energy in = Energy out
- Incoming solar (shortwave) balanced by outgoing infrared (longwave)
- Increase greenhouse gases reduces outgoing energy
  - Net energy/heat gain
- Earth responds to re-establish balance



Increases in Carbon Dioxide (CO_2)

- Anthropogenic CO_2 from combustion of fossil fuels
- Measured since 1950s in Hawaii
- CO_2 is long-lived, so well-mixed
- Steady increase
- Seasonal cycle due to northern hemisphere vegetation “breathing”



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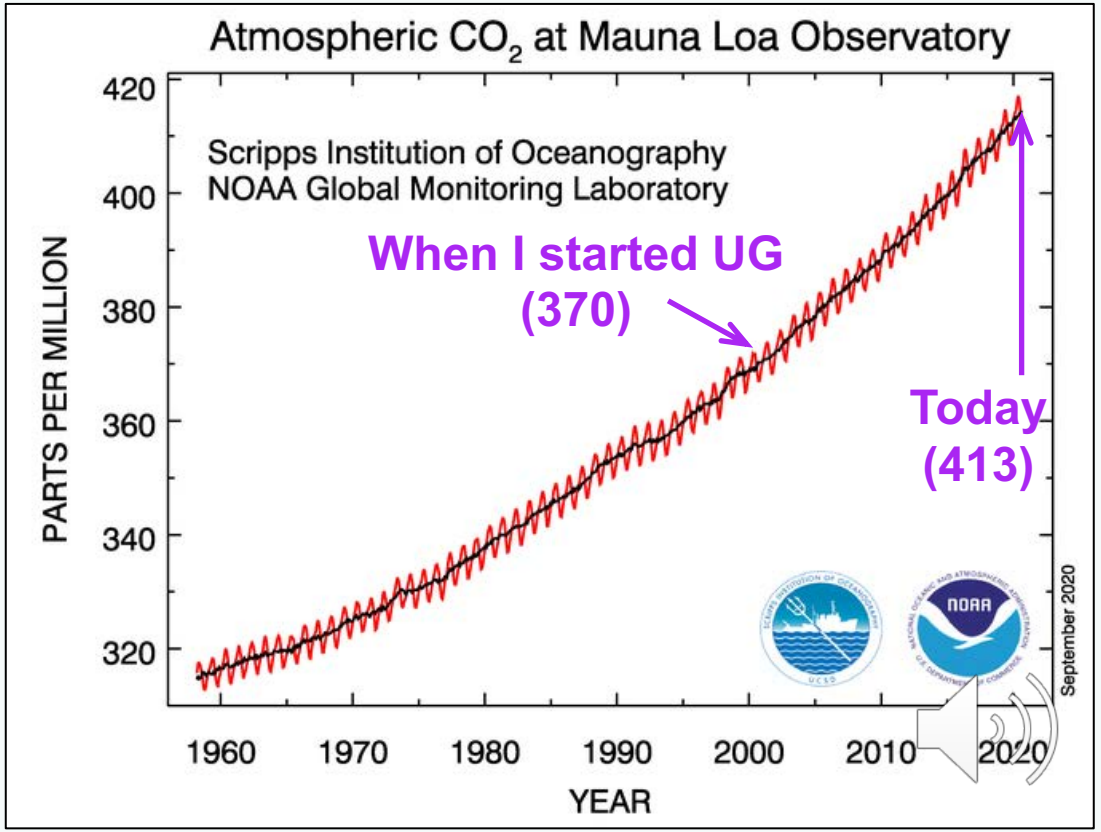
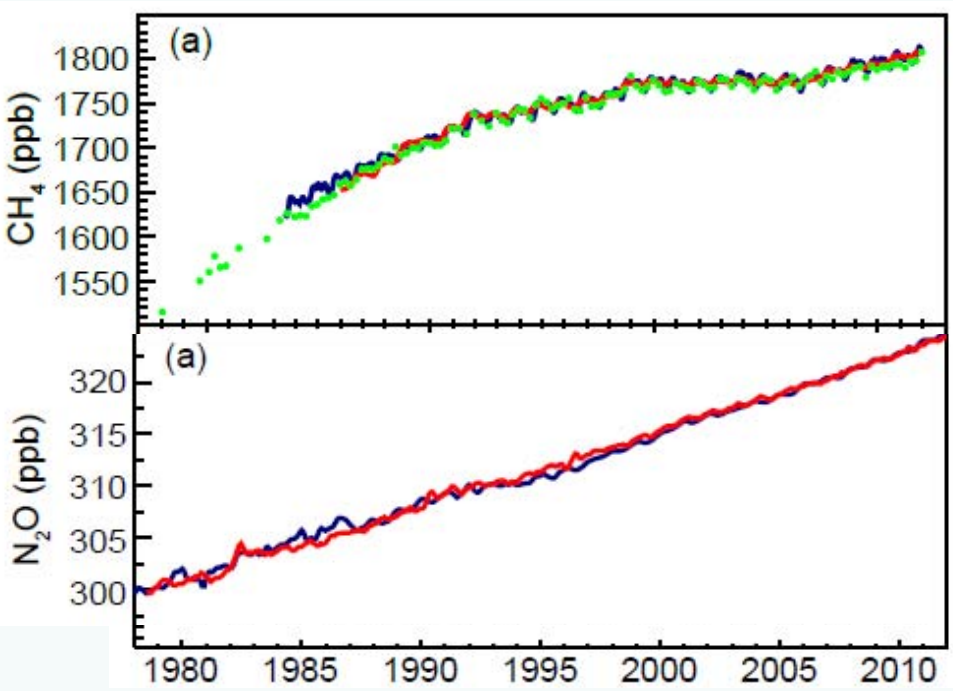
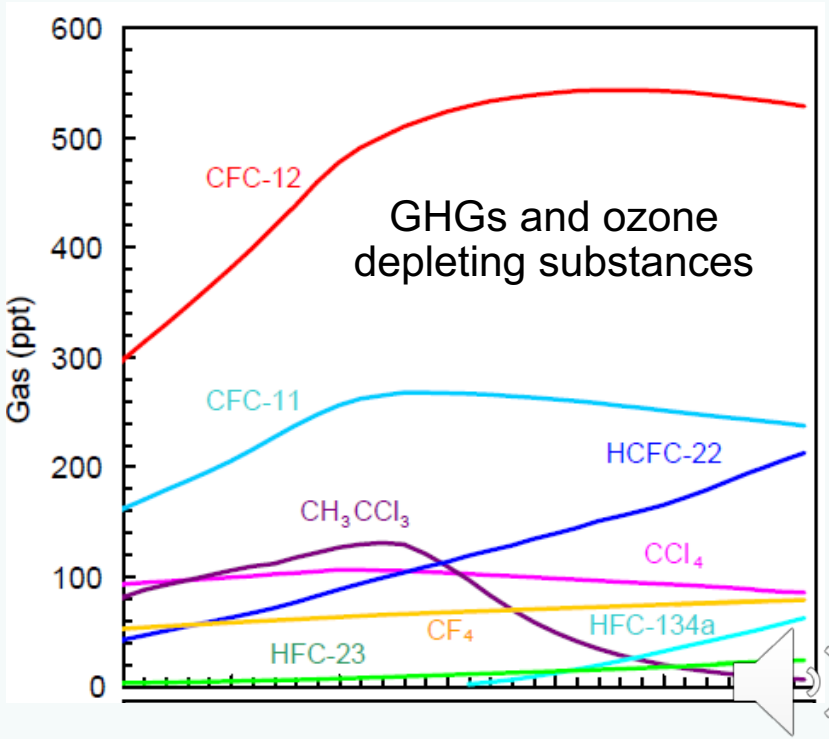


Other Greenhouse Gases

Methane & Nitrous Oxide

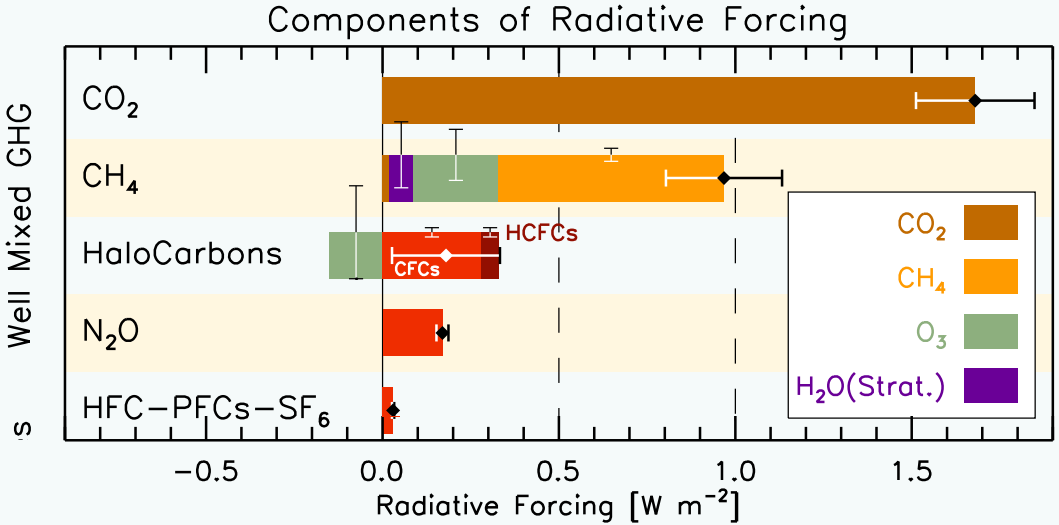


Montreal Gases



Carbon dioxide most abundant, but not most potent (global warming potential)

Radiative Forcing



CO_2: carbon dioxide

CH_4: methane

N_2O: nitrous oxide

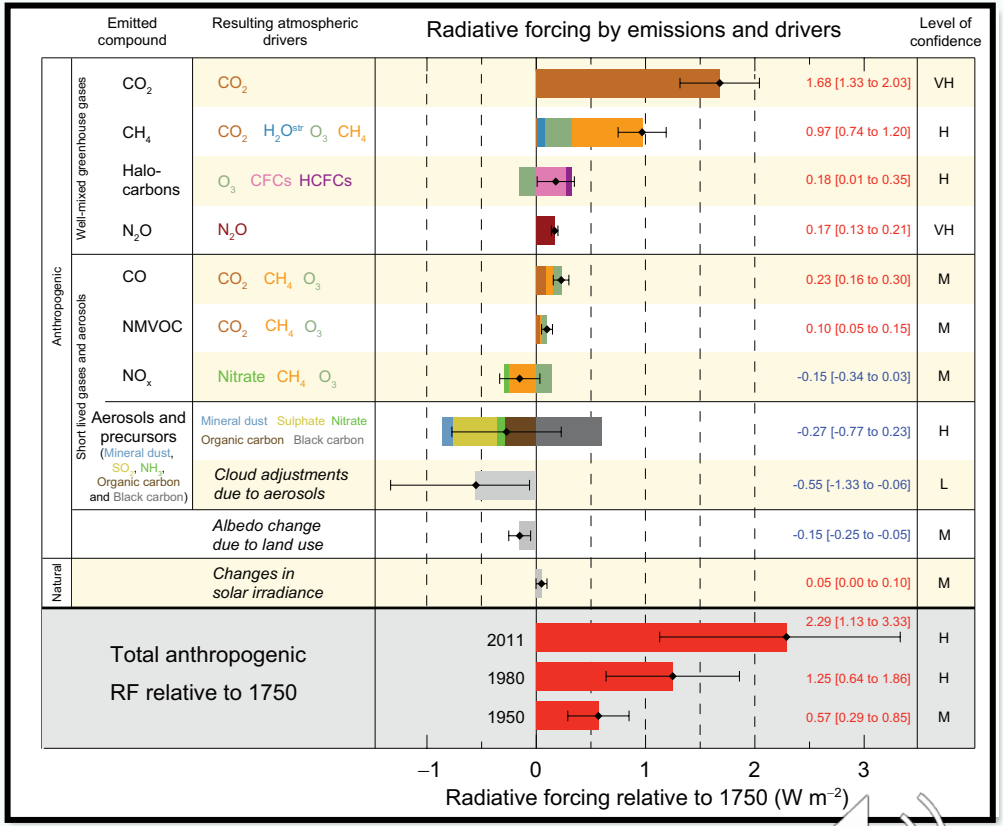
CO_2 forcing: 1.7 W m^{-2}

Sum of other GHGs: 1.3 W m^{-2}

- Radiative forcing: measure of the impact of changes in greenhouse gas concentrations on top-of-atmosphere energy balance
- If Energy in > Energy out → decrease in outgoing longwave radiation positive radiative forcing → planet warms

Other Forcings

- GHG not the only climate forcer
- Changes in Earth's albedo
- Aerosols (short-lived particles suspended in air)
  - Direct impact on sunlight
  - Indirect effects by altering cloud microphysics
- Also natural forcings: solar variability, volcanoes



Total: +2.34 W m^{-2} (range: 1.1-3.4 W m^{-2})

1750: pre-industrial baseline

Response to Energy Gain

- The Earth's atmosphere is gaining energy
  - All components: +2.3 W m^{-2} or 2.3 J s^{-1} m^{-2}
  - CO_2 only: +1.7 W m^{-2} or 1.7 J s^{-1} m^{-2}
- So it warms up (temperature increases)
- Warmer things radiate more energy:

$$I \propto \sigma T^4$$

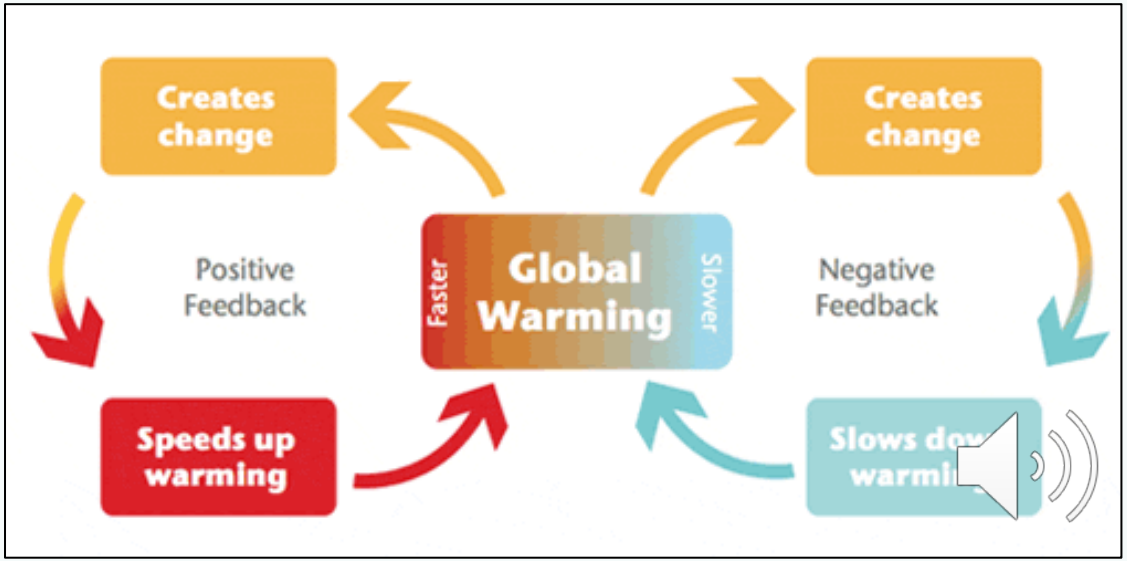
(Stefan-Boltzmann equation; $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4})

- This warming is called the Blackbody response
- If it warms up enough, it will restore the energy balance

Feedbacks

- An initial response (warming or cooling) can be amplified or reduced by climate interactions
- Positive if amplifies and negative if reduces initial response

- Feedback roughly doubles the initial response
- Many varied feedbacks
- Feedbacks are not necessarily linear



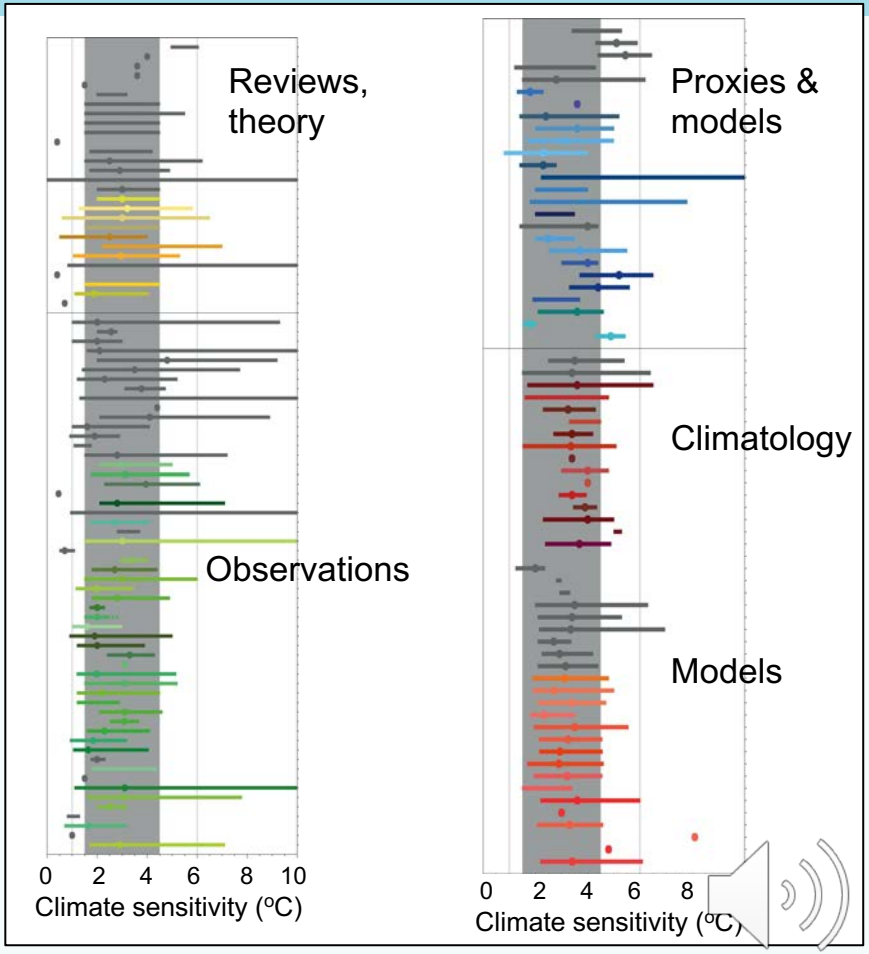
Main Feedbacks

1. **Water Vapor**
   Warmer air holds more water vapor → water vapor is a GHG. **Positive**
2. **Lapse Rate** (rate at which temperature decreases with altitude)
   Temperature change near top-of-atmosphere stronger than at surface → decrease lapse rate → dampen greenhouse effect. **Negative**
3. **Ice-Albedo**
   White, reflective ice replaced by dark land/sea → decrease Earth's albedo → increase absorption of solar radiation. **Positive**
4. **Clouds**
   Change is complex (type, altitude, location). **Probably net positive**

Climate Sensitivity

Equilibrium change in global mean temperature due to doubling of atmospheric concentrations of CO_2:

- 1.5 - 4.5°C
- > 1°C due to enhanced greenhouse effect alone
- Feedbacks also contribute
- Range due to feedback uncertainties



Snapshot from https://www.nature.com/articles/ngeo3017

Task: GHG persistence

The table below of greenhouse gases and the time it takes for these to be removed from the atmosphere (also called lifetime) are scrambled. Match these up correctly using Table 4.1 of this document: https://www.ipcc.ch/site/assets/uploads/2018/03/TAR-04.pdf

Greenhouse gas	Lifetime
1. CO_2	A. > 1000 years
2. Ozone	B. 114 years
3. SF_6	C. 10 years
4. N_2O	D. 5-200 years
5. CH_4	E. 1 month

This shows that even if we turn off all anthropogenic greenhouse gas sources today, their effects on climate persist for 100s of years.

Task: Climate Feedbacks

Select whether these statements are True or False.

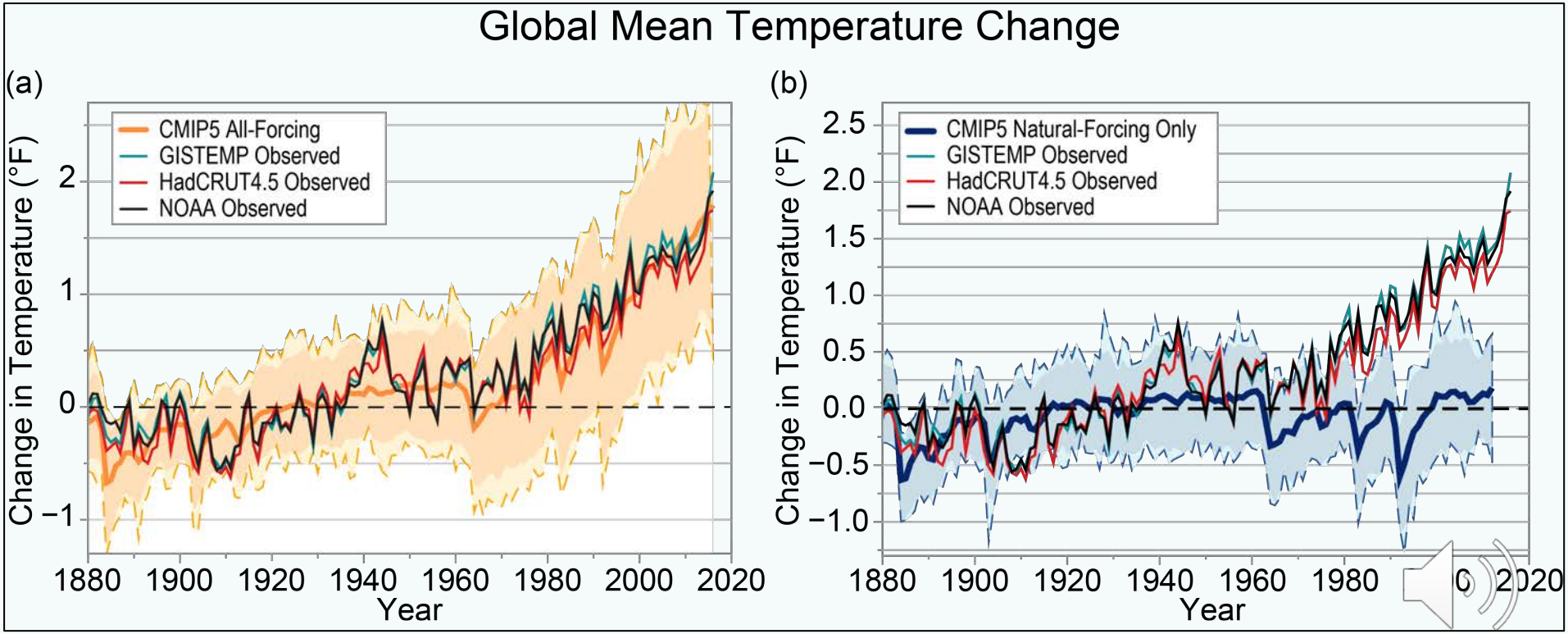
1. The change in land cover from dense forest to desert in response to warmer and drier conditions is an example of a negative feedback. True or False?

2. The increase in low-lying cloud cover during the day in response to warming is an example of positive feedback. True or False?

OBSERVATIONS OF CLIMATE CHANGE

- Global warming
- Sea level rise
- Extreme weather

Global Warming (Time Perspective)

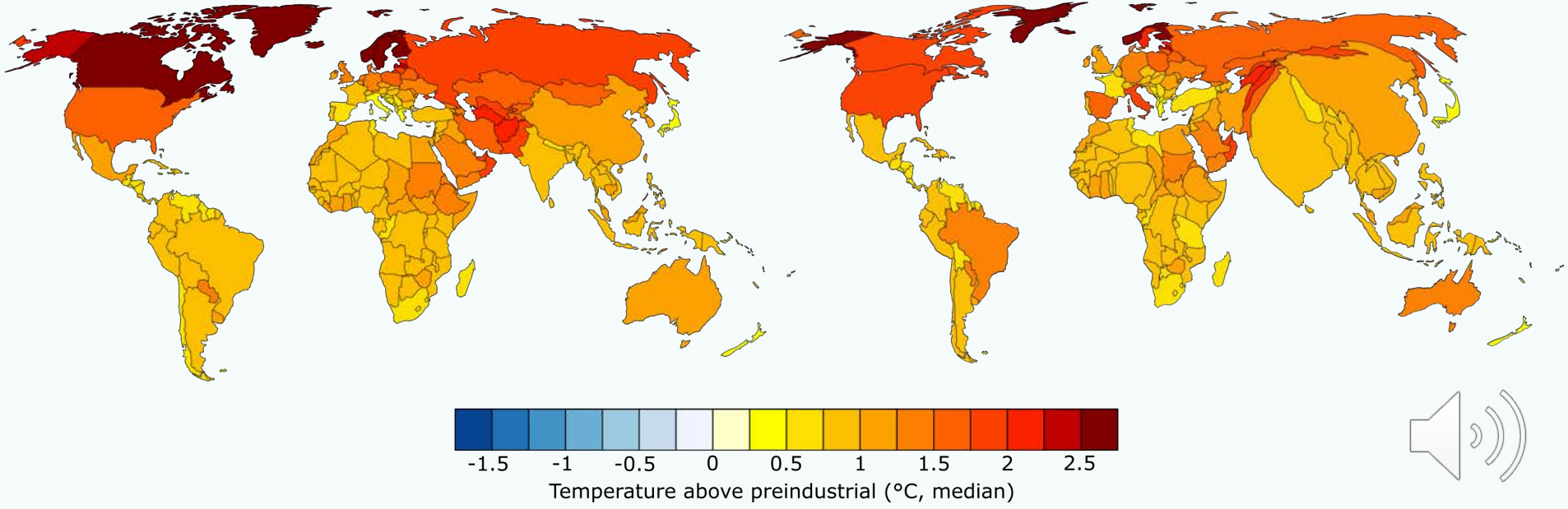


Global Warming (Spatial Perspective)

Different views of national changes in temperature by area and by population

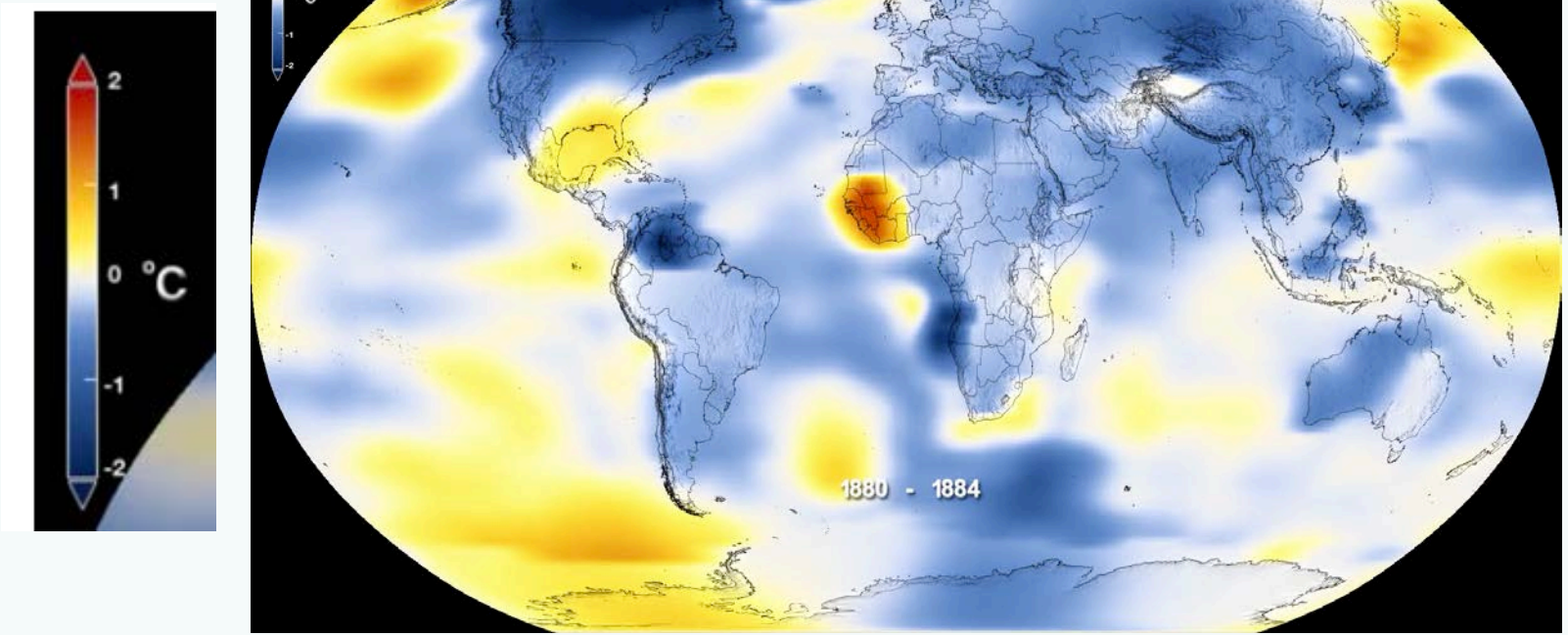
Area-weighted

Exposure Weighted

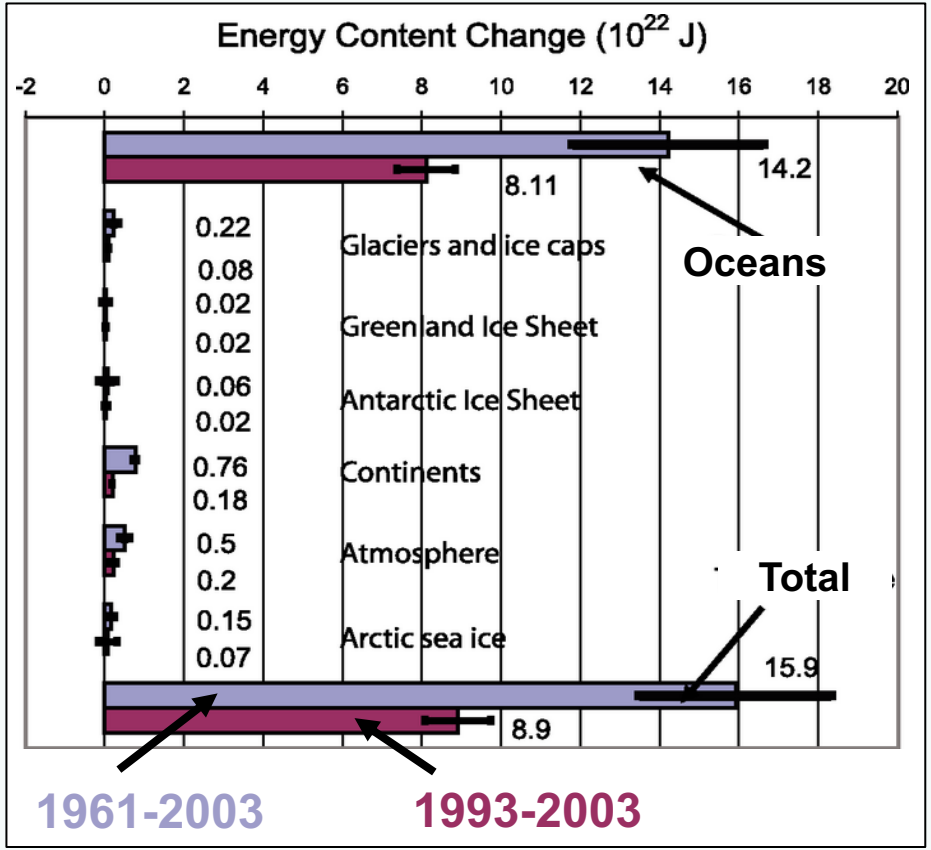


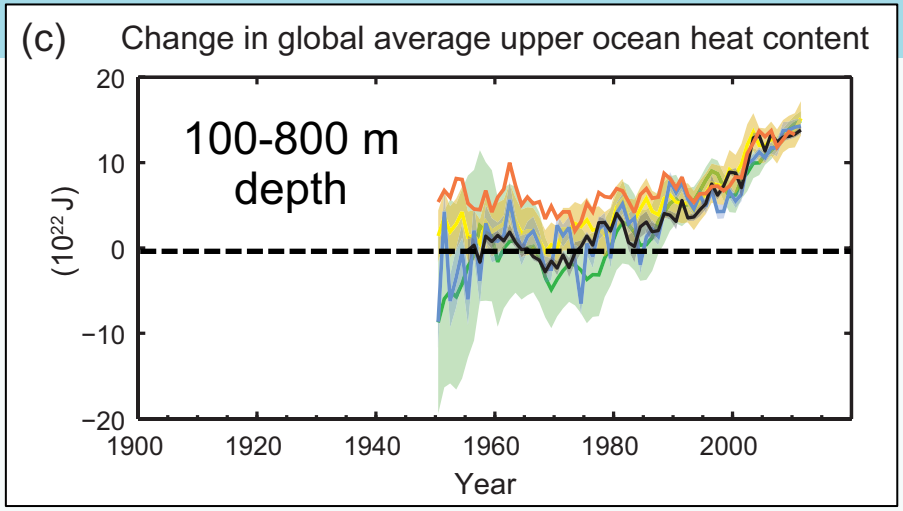
Spatial Variability

- Warming not uniform (Arctic vs Antarctic)
- Change in many locations already > 1.5ºC
- Multiyear mean dampens interannual variability



Global Heat Uptake

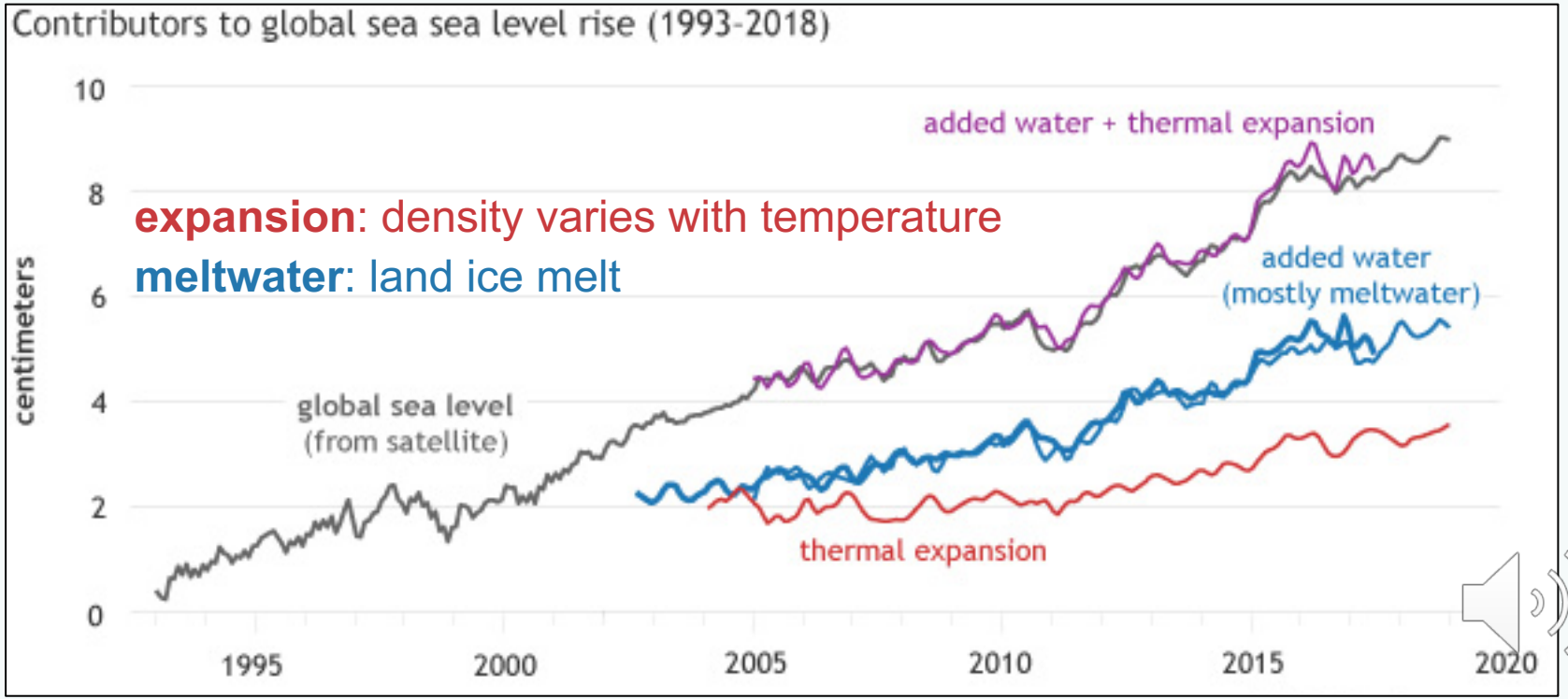




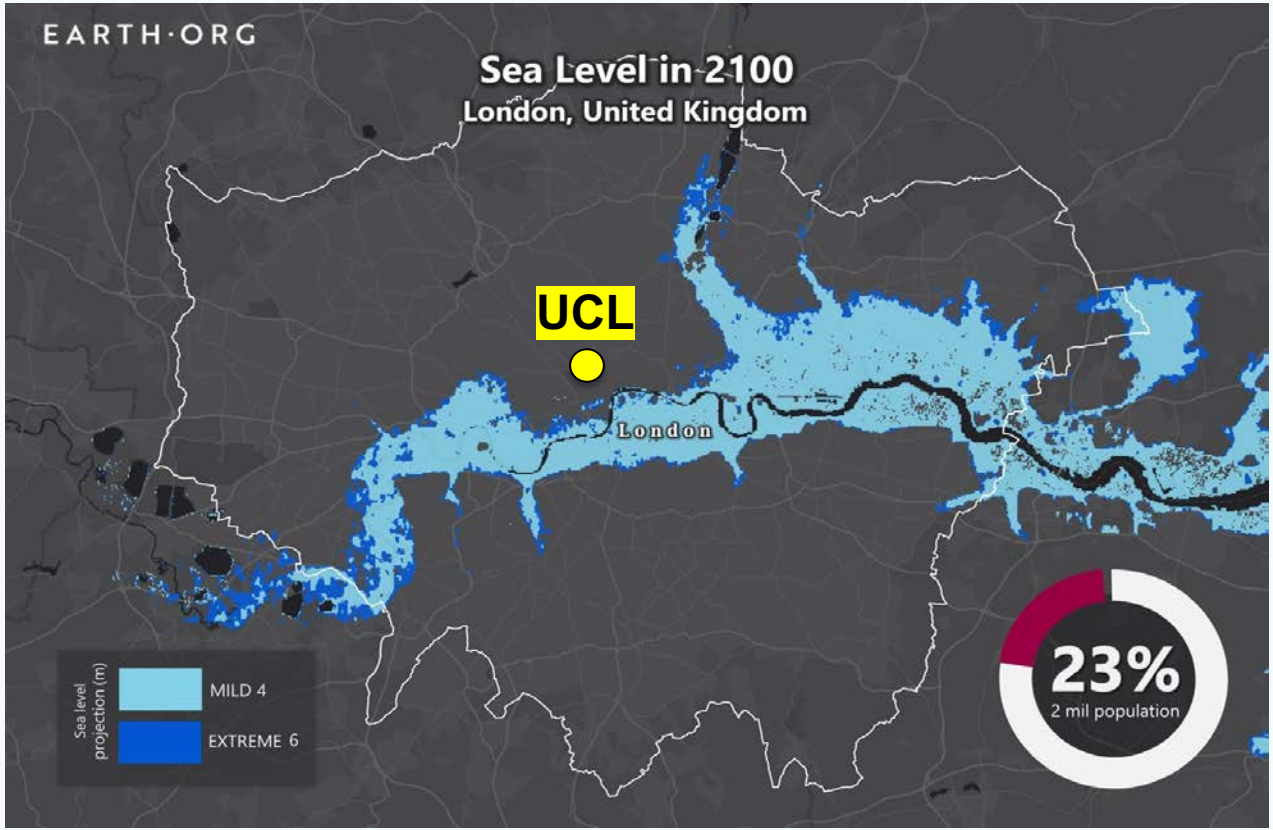
- Radiative forcing is an energy flow (J s^{-1} m^{-2})
- We expect a gain in heat (in J)
- The amount of heat the planet can store (thermal inertia) controls the pace of chang
- Ocean absorbs most heat

Sea Level Rise

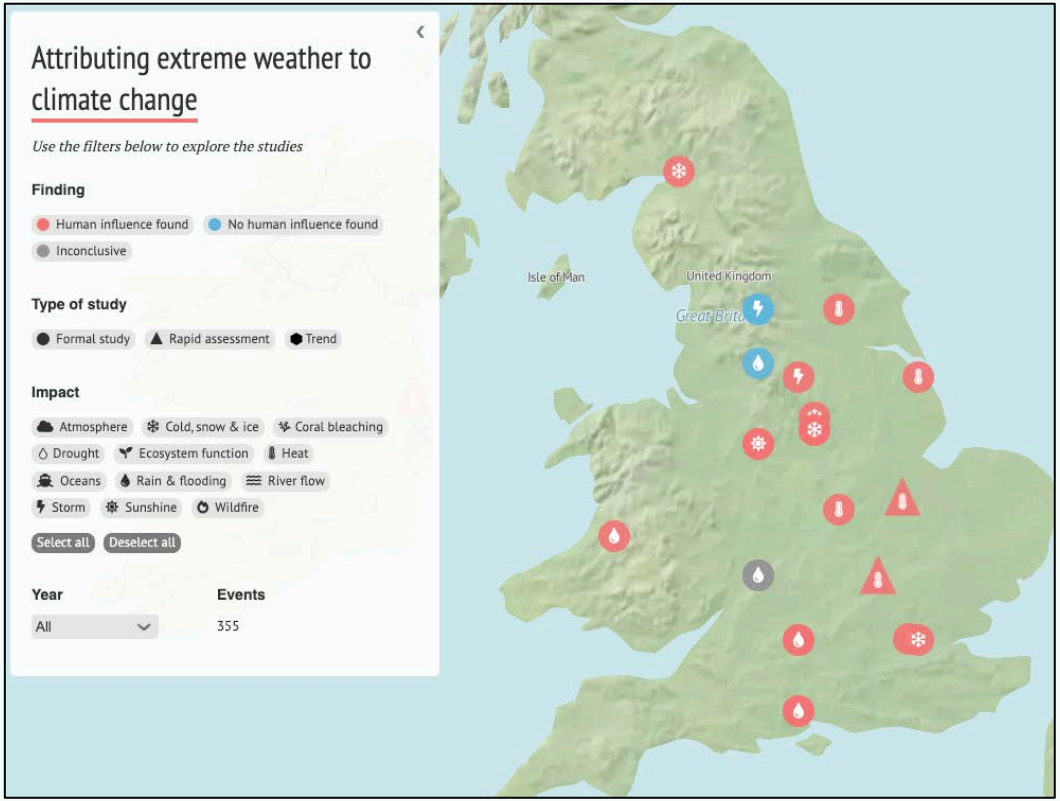
Sea level changes can come from 2 sources:



Sea Level Rise



Extreme Weather



- Extreme weather and related events increase in severity and frequency
- Many attributed to climate change
- Interactive tool to explore documented extreme weather events and link to climate change: https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world

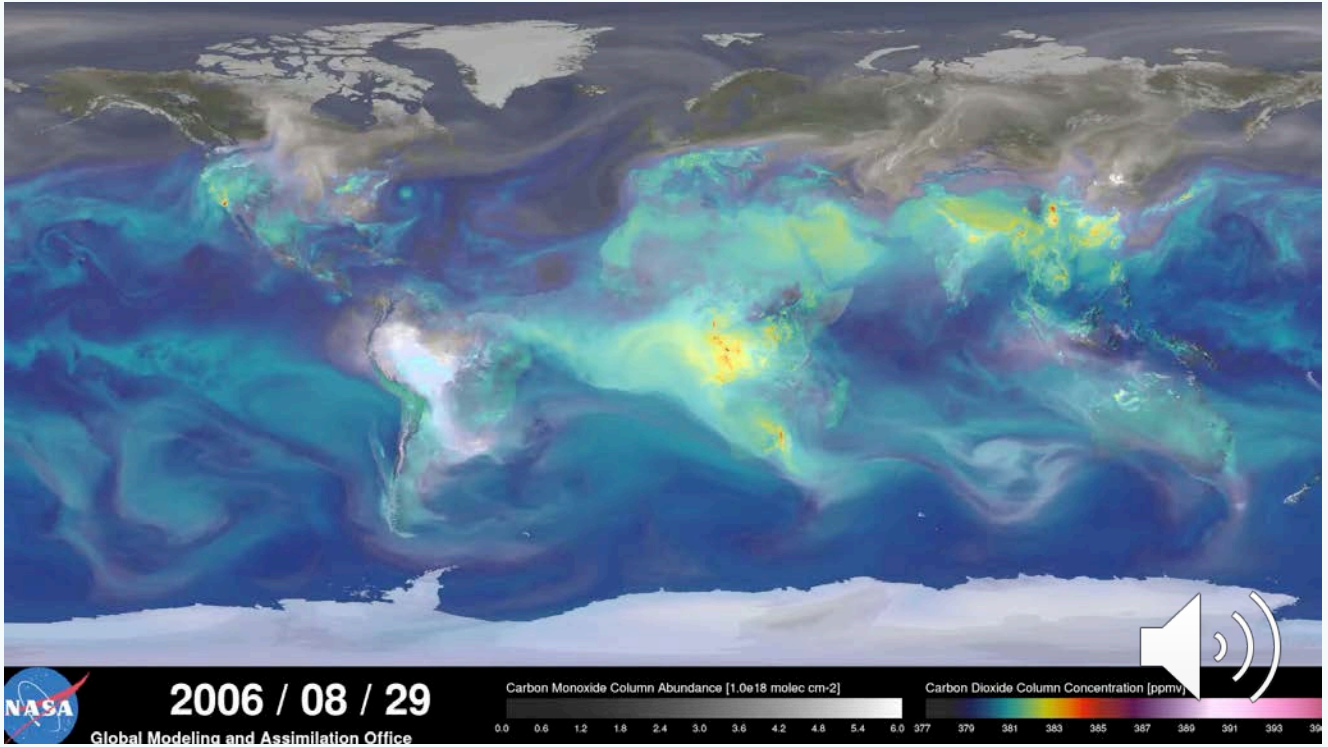
FUTURE PROJECTIONS

- Climate models
- IPCC
- Responses

Climate Models

- Solve fluid flow equations on a 3D latitude-longitude grid

- Test scenarios (not always possible in real world)
- Tease out different contributing factors
- Needs a lot of computer resources to run



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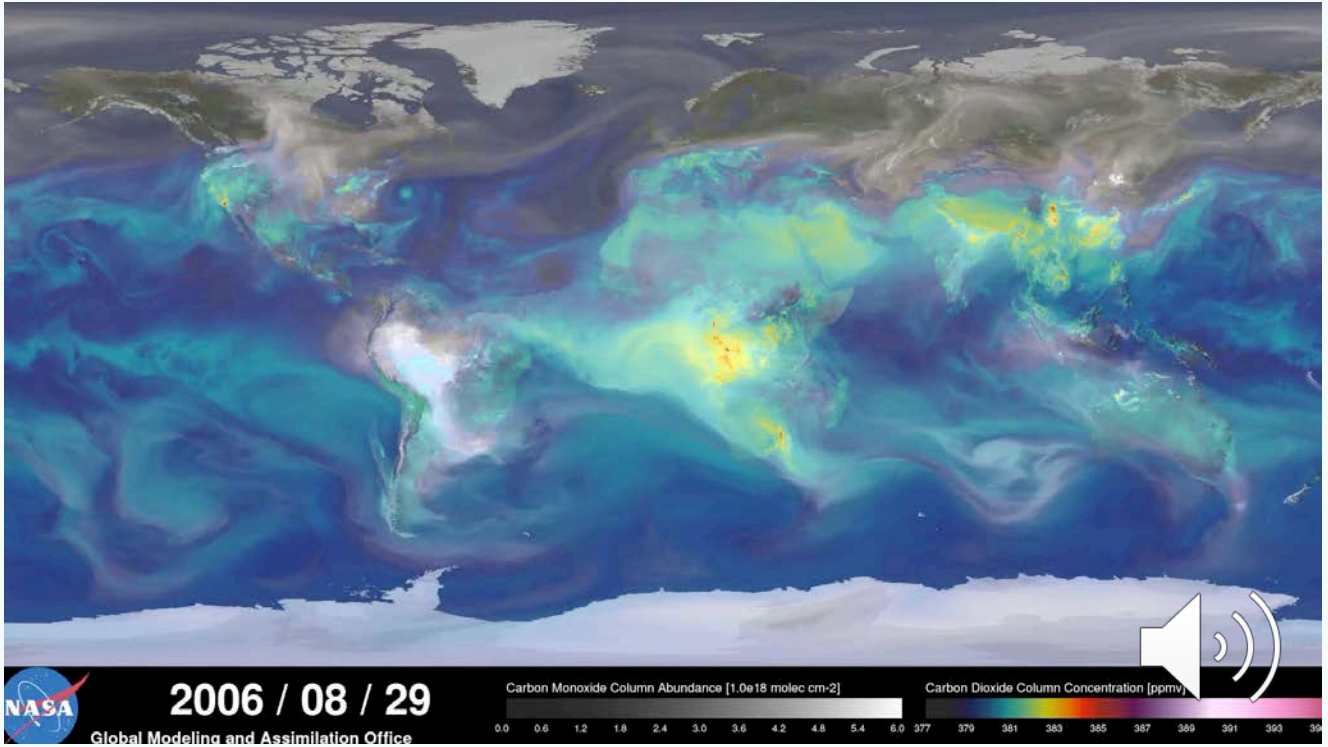
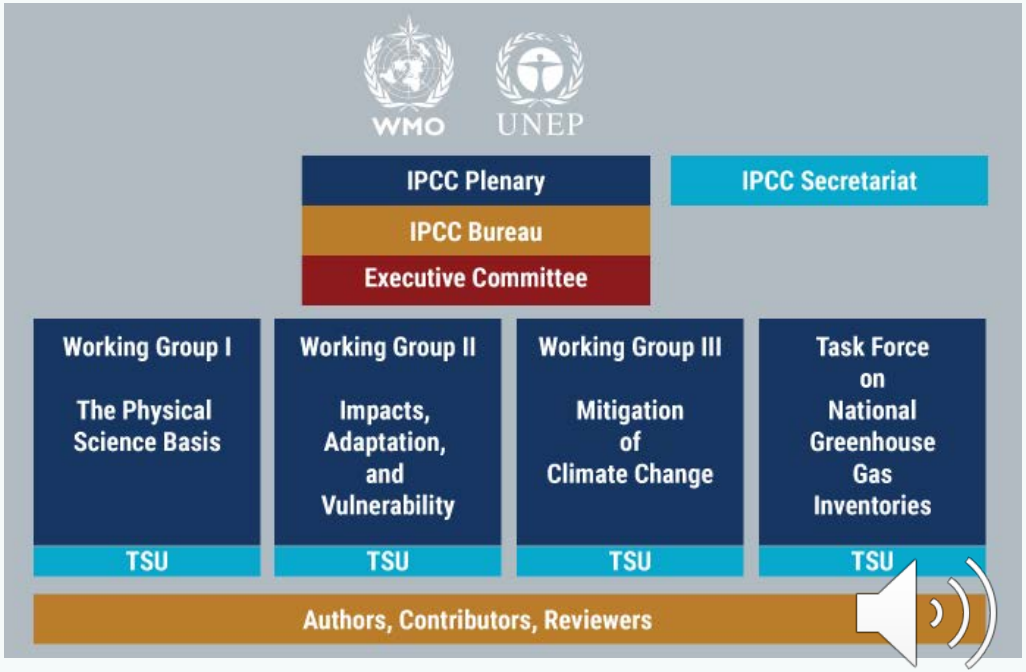


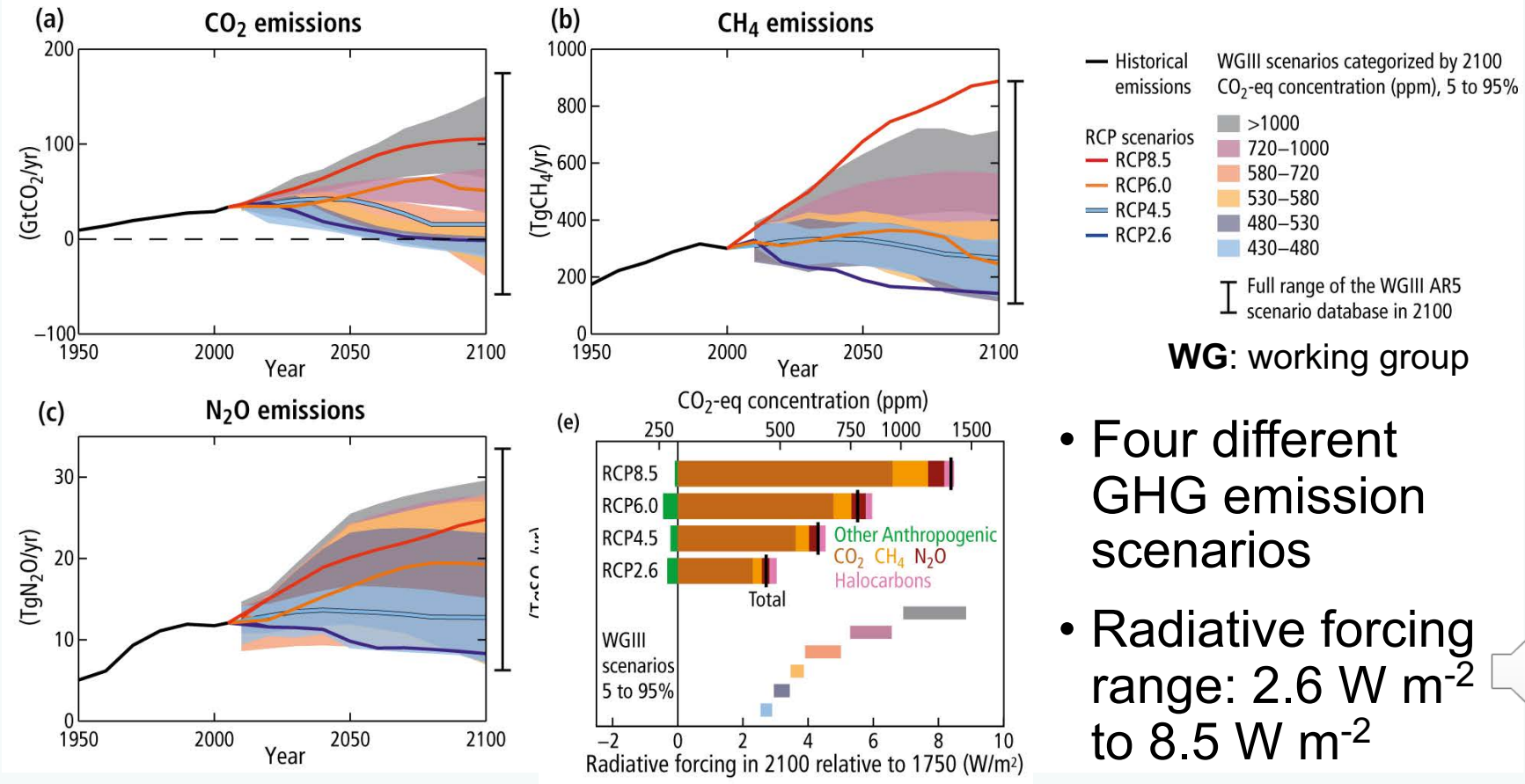
The Intergovernmental Panel on Climate Change (IPCC)

- Creates regular comprehensive reviews of state-of-knowledge of climate change
- Next report (AR6): 2021
- Reports written by large cohort experts (volunteers)
- Split into thematic working groups
- Signed off by governments
- Co-ordinates a series of climate model projections (ensemble of models)



TSU: technical support unit

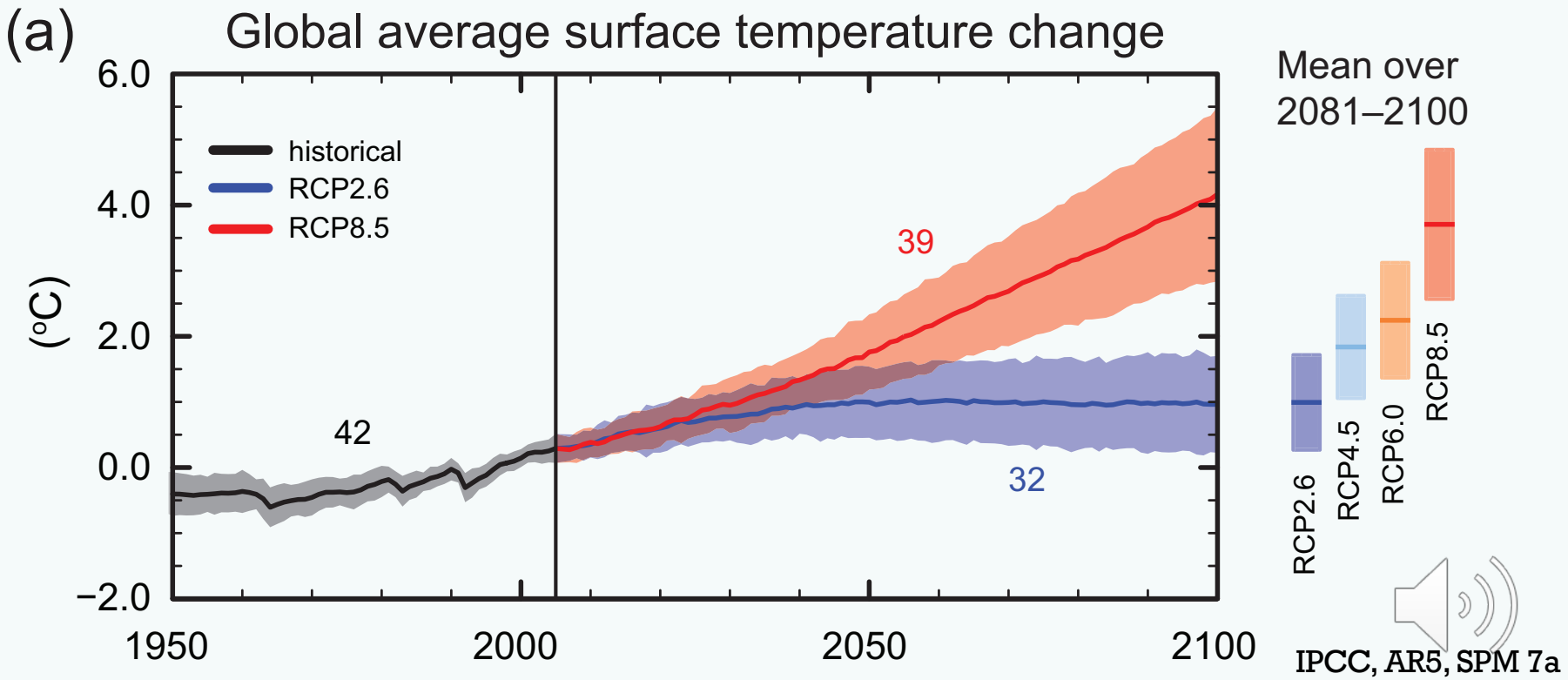
Scenarios



WG: working group

- Four different GHG emission scenarios
- Radiative forcing range: 2.6 W m^{-2} to 8.5 W m^{-2}

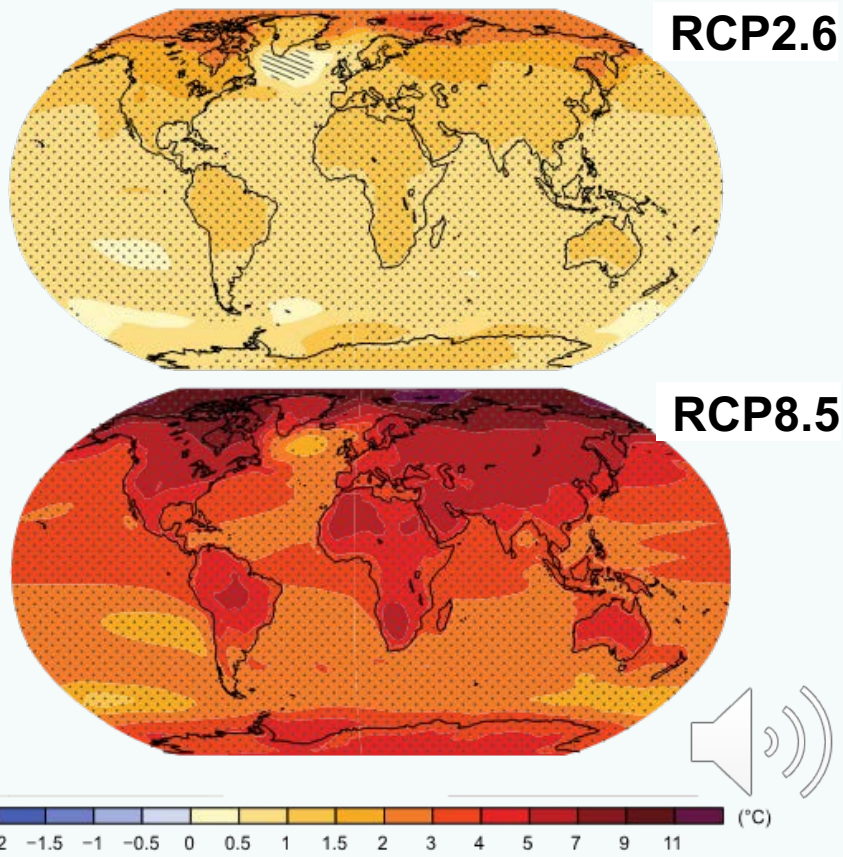
Future Temperatures



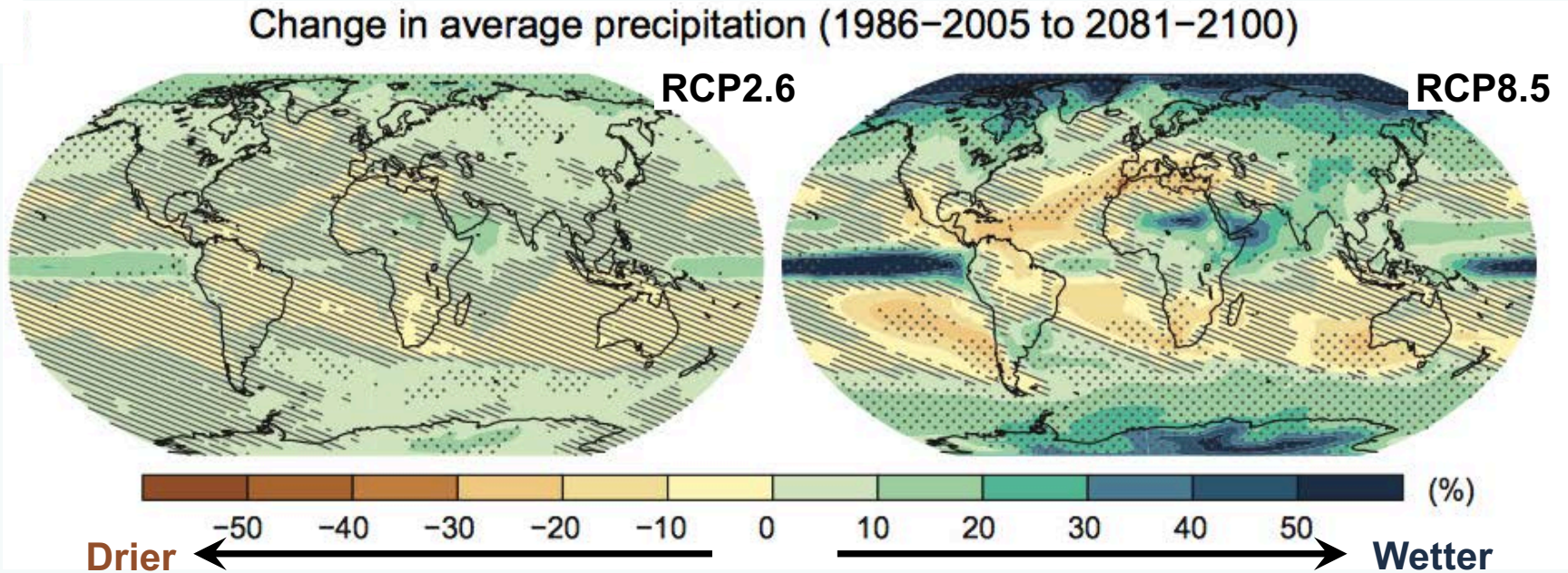
Spatial Pattern of Warming

- Arctic and land warm fastest
- Minima in Southern Ocean and North Atlantic
- Nowhere is exempt from warming
- For climate scenarios, pattern is similar, magnitude varies

Change in average surface temperature
(2081-2100 minus 1986-2005)



Rainfall / Precipitation



- Stippling: change is large (> 2 standard deviations of interannual variability) and robust (model agreement)
- Hatching: change is small (< 1 standard deviation of interannual variability) and not as robust (fewer models agree)

Responding to climate change

Mitigate/Prevent

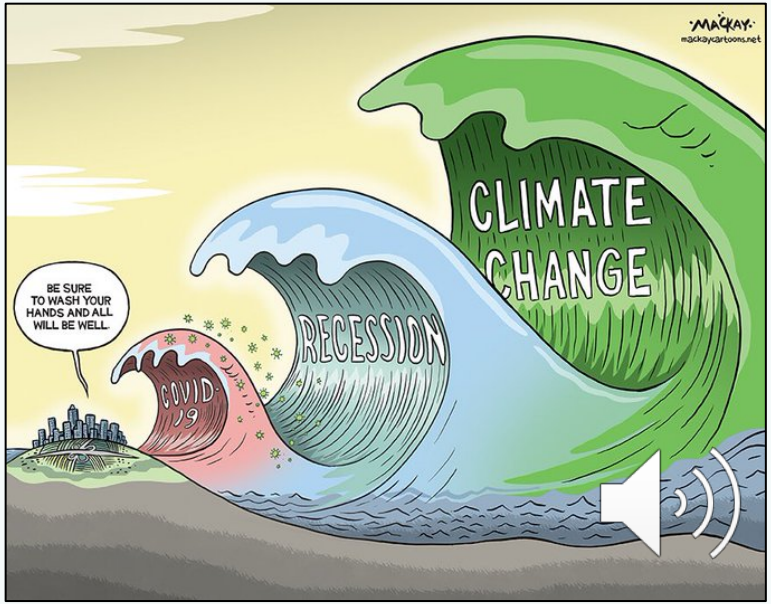
- Act to reduce the total amount of forcing
- Reduce GHG emissions
  - Clean technology
  - No deforestation
  - Increased energy efficiency
  - Reduced energy demand
- Geoengineering
  - Intentionally alter climate to mask the GHG forcing
  - Unintended consequences

Adapt

- Understand/predict changes
  - Some are inevitable or already occurring (extreme weather, sea level rise)
- Build resilience
  - Infrastructure
  - Bureaucratic systems
  - Agricultural shifts
- Many countries not equipped to adapt

Summary

- Climate changes (warms) due to increase in greenhouse gases:
  - Alters energy budget of Earth (radiative forcing)
  - Energy gain leads to warming
  - Warming amplified by positive feedbacks
- Observe changes in climate:
  - Warming of surface temperatures
  - Sea level rise from increased heat content
  - Increase in incidence and severity of extreme weather
- Changes will continue and magnify:
  - Strong warming
  - Disrupted hydrological cycle
  - Options are mitigation and adaptation (are both viable/achievable?)



Task: Who's to Blame?

Global cumulative CO_2-equivalent (CO_2e) greenhouse gas emissions from 1965 to 2017 total 1,354,388 $MtCO_2e$ (Mt = mega or million tonnes).

Combined, what is the percent contribution of the 10 companies on the right to this total?

A. 100%
B. 2.6%
C. 26%
D. Negligible
E. Not enough information given.

Top 10 greenhouse gas emitting companies
(values are cumulative for 1965-2017)

Company	Country	All Emissions, $MtCO_2e$
Saudi Aramco	Saudi Arabia	59,262
Chevron	U.S.	43,345
Gazprom	Russia	43,230
Exxon Mobil	U.S.	41,904
National Iranian Oil Co.	Iran	35,658
BP	UK	34,015
Royal Dutch Shell	Netherlands	31,948
Coal India	India	23,124
Pemex	Mexico	22,645
Petroleus de Venezuela	Venezuela	15,745

[Adapted from https://www.visualcapitalist.com/companies-carbon-emissions/]