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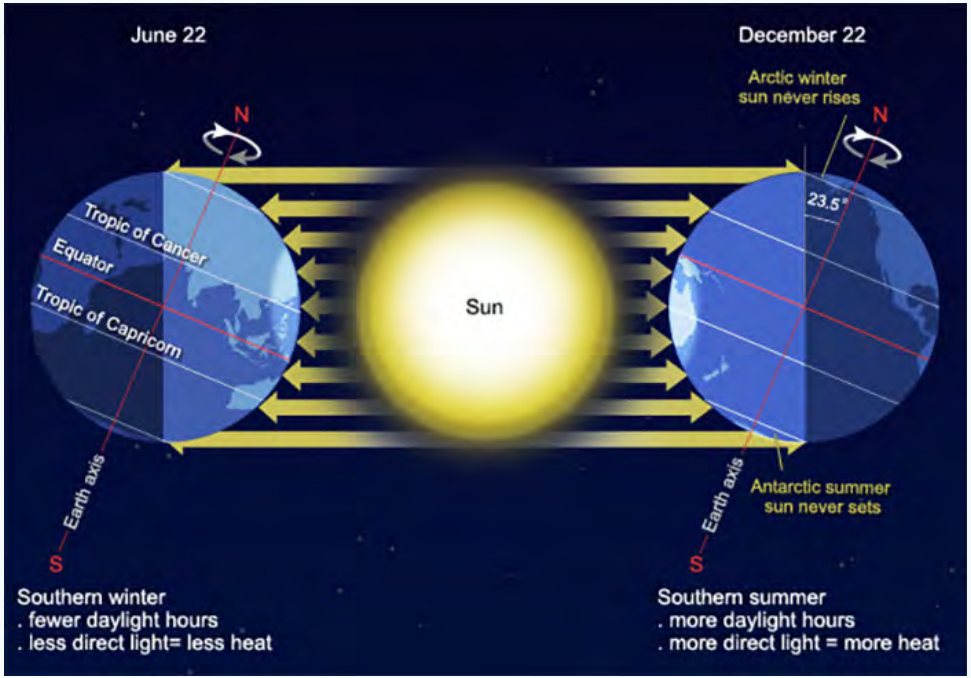
Climate Change

GEOG0005

Seasons

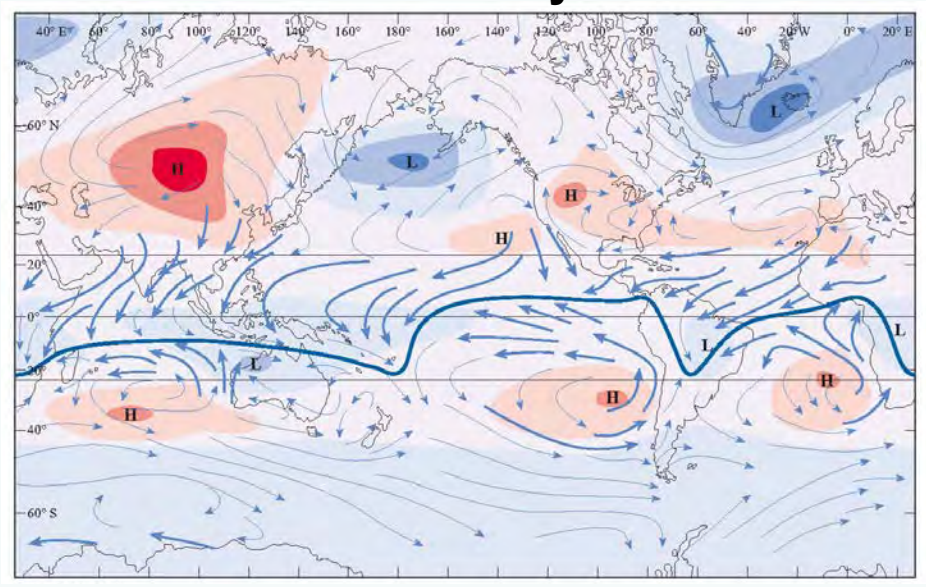
Seasons

- Earth is tilted at an angle of 23.5^{o} from its orbital plane
- Different parts of Earth receive the Sun's most direct rays
- When North Pole tilts toward the Sun, it is summer in the Northern Hemisphere.
- When South Pole tilts toward the Sun, it's winter in the Northern Hemisphere.

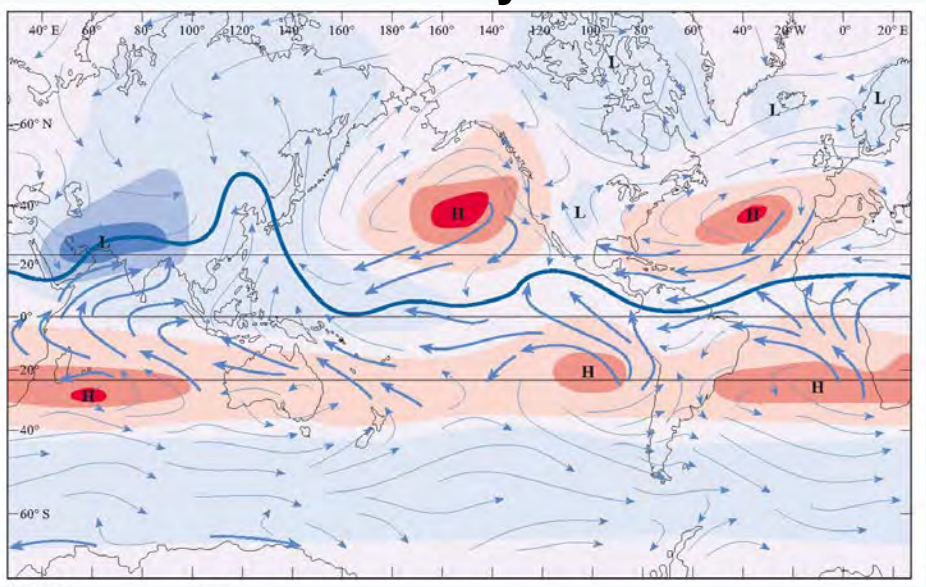


Seasonality of Surface Pressure and Winds

January



July



mean position of ITCZ

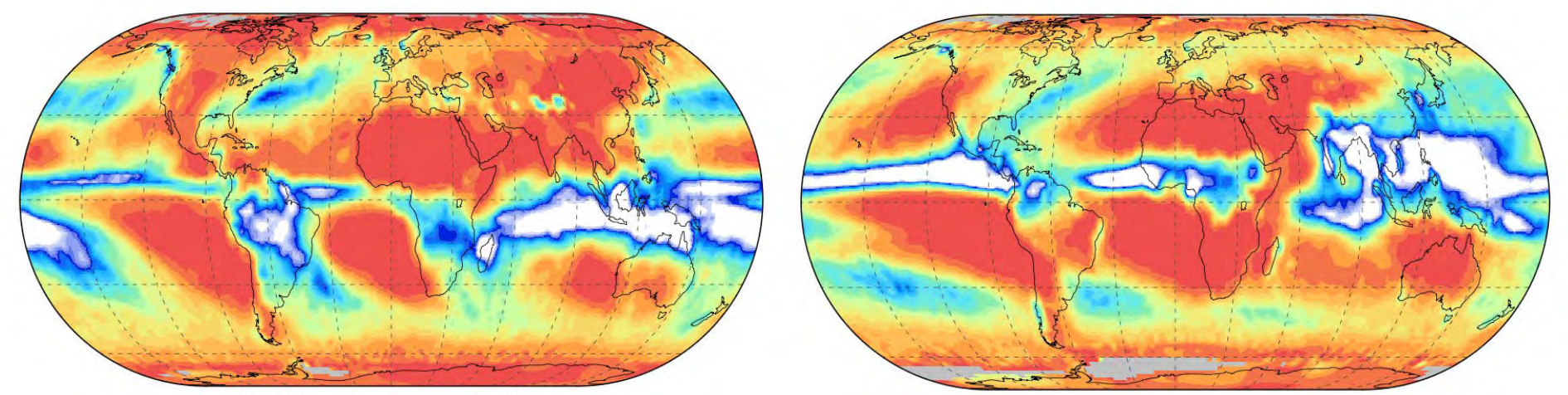
most frequent wind direction

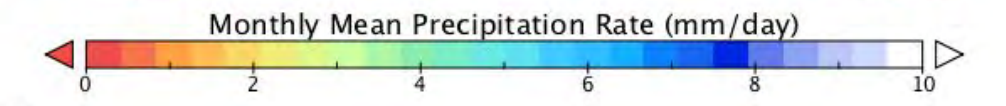
prevailing wind direction

Seasonality of Precipitation

January

July





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Climate Change

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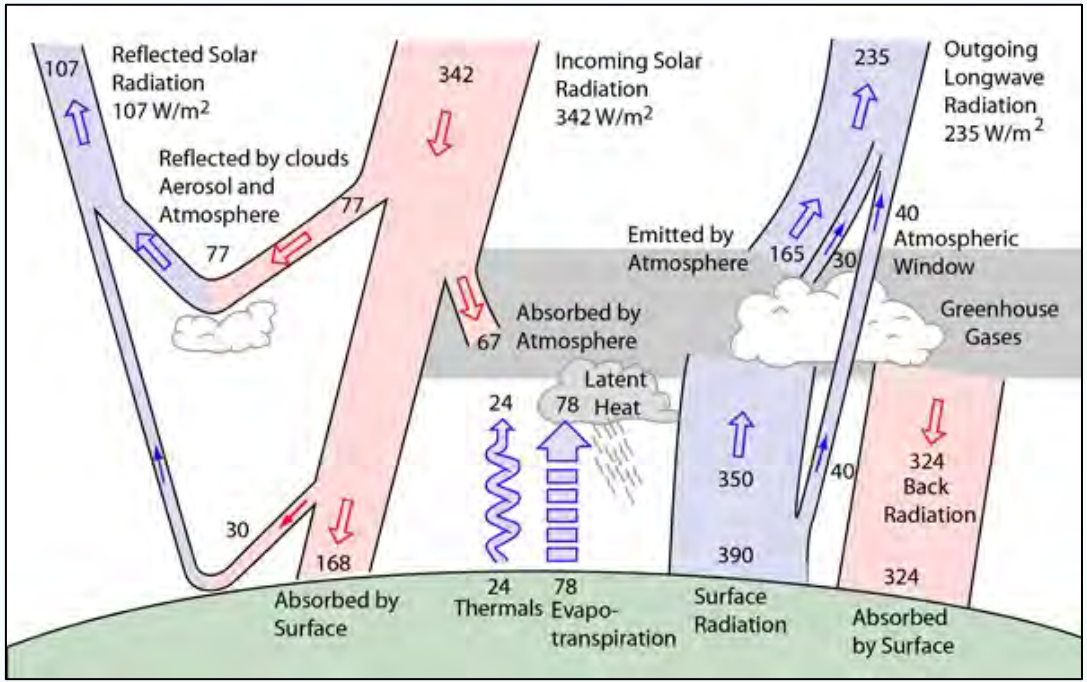
THEORY

- Radiative forcing
- Drivers of change
- Feedbacks

Energy Balance

- A system in equilibrium gains as much energy as it loses:
  - Energy in = Energy out

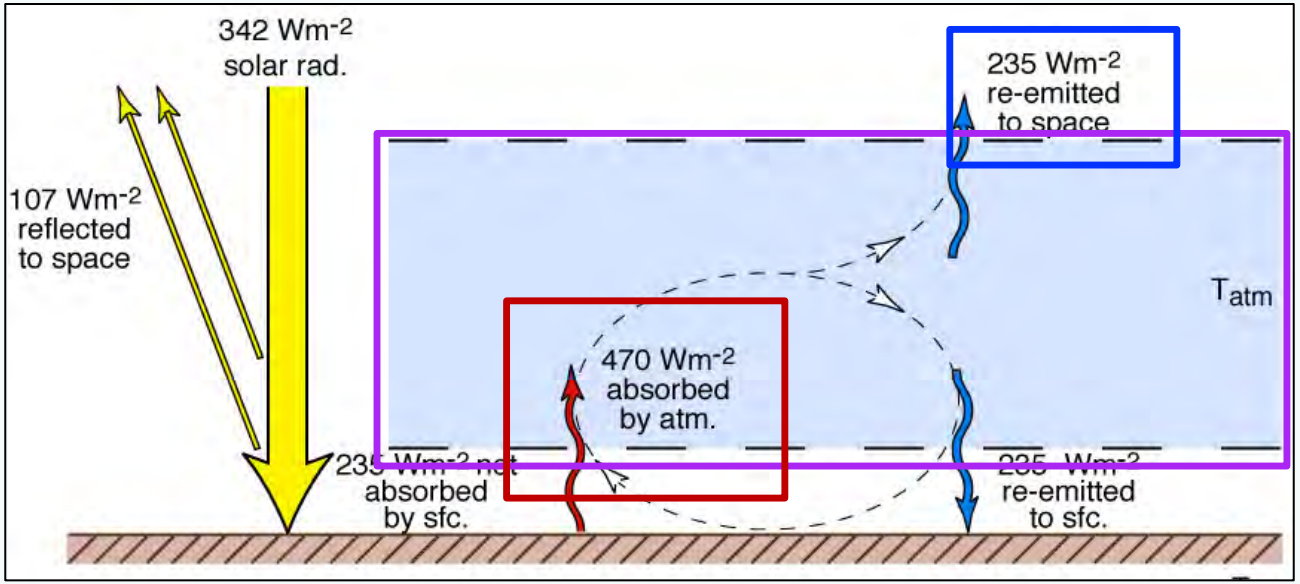
- Balance between incoming solar UV/visible (shortwave) radiation and outgoing infrared (longwave) radiation



Offsetting that Energy Balance

Earth's atmosphere is a grey body ($\varepsilon \sim 0.77$) due to GHGs

Add more GHGs, increase ε (emissivity) or amount of radiation absorbed by atmosphere



Atmospheric layer of GHGs

Amount absorbed by atmosphere **increases**

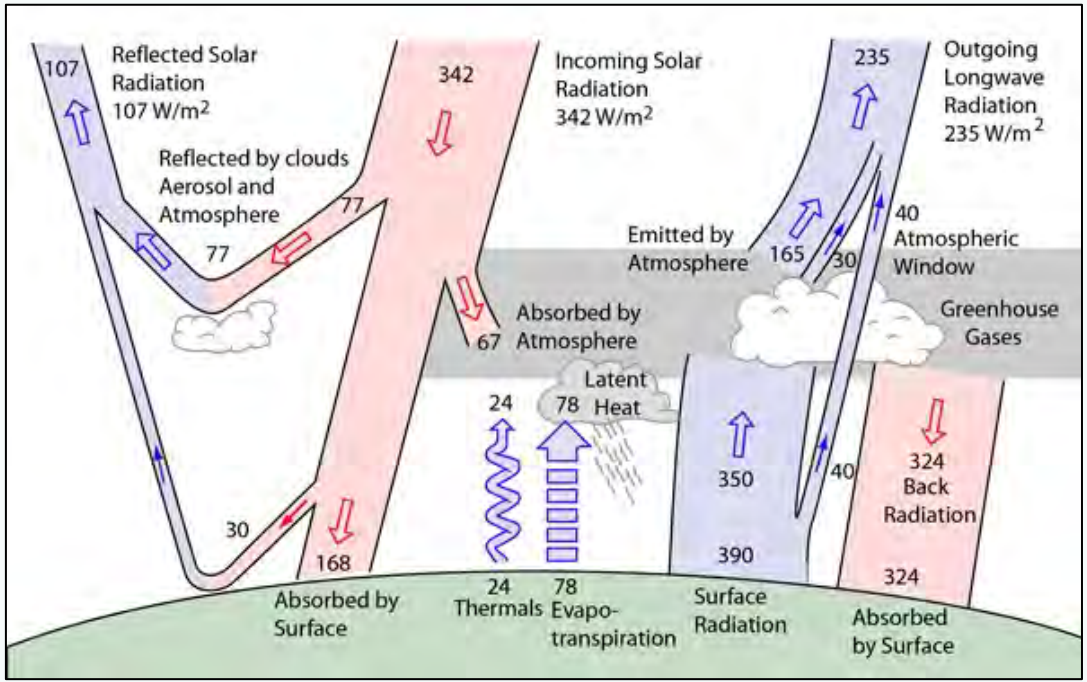
Amount re-emitted to space **decreases**

Offsetting Energy Balance

- System out of balance due to increase in GHGs:

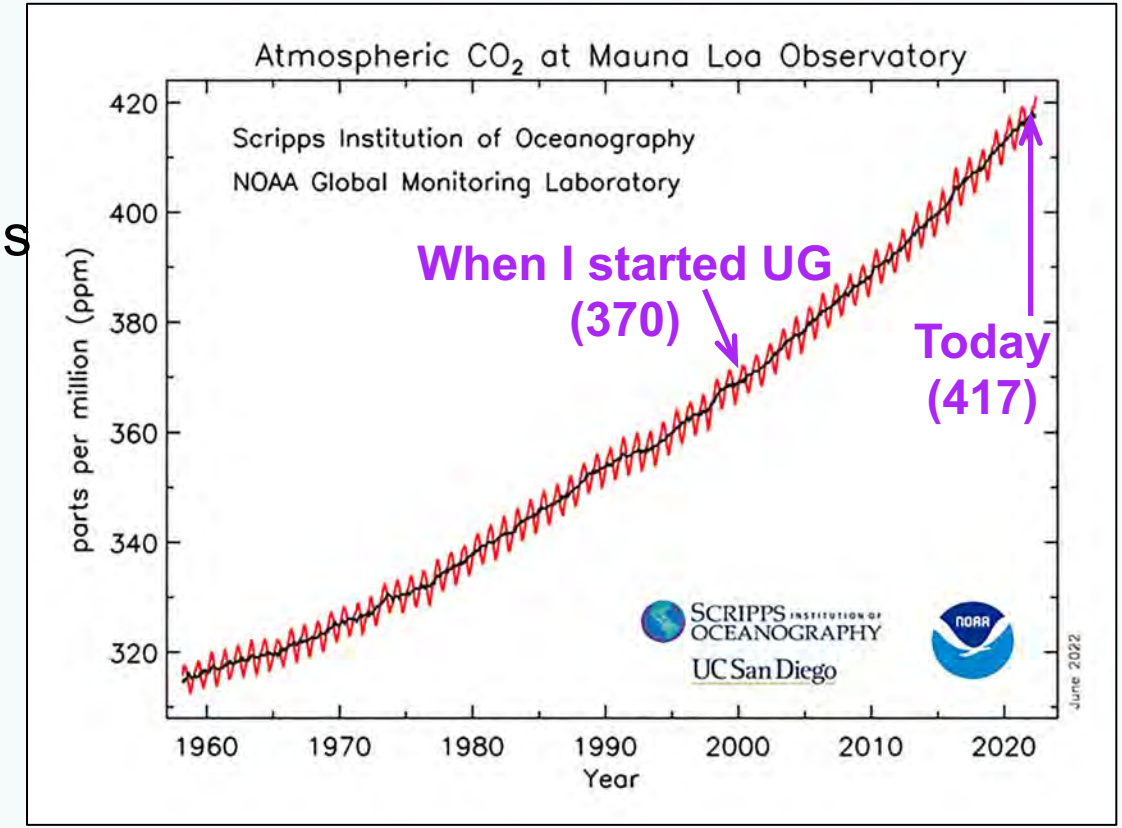
  Energy in > Energy out

- Reduces outgoing energy
- Leads to energy/heat gain by the atmosphere
- Earth responds by re-establishing balance



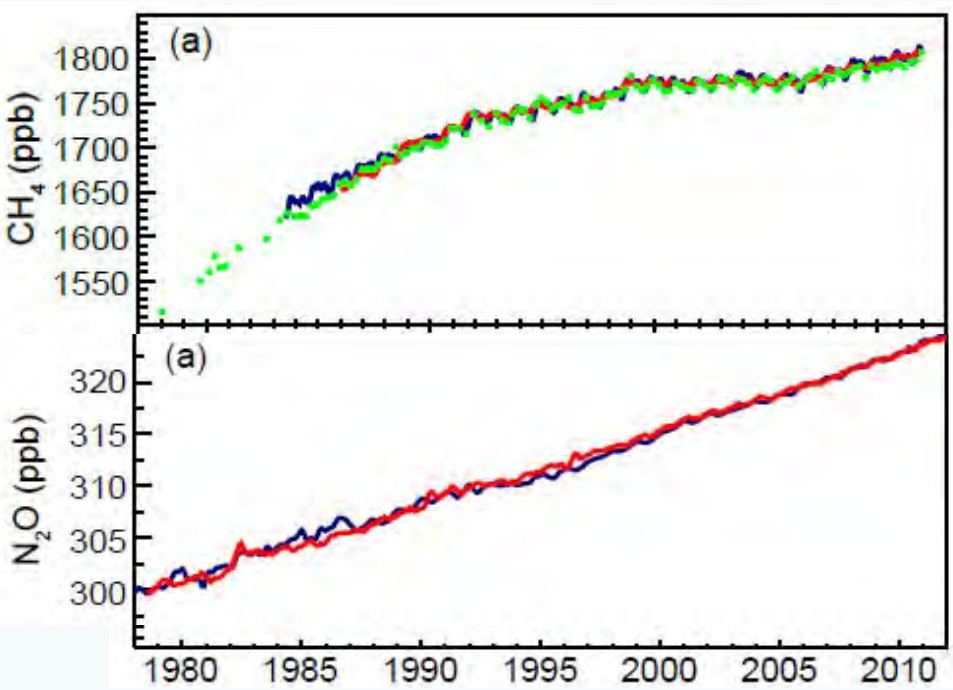
Increases in Carbon Dioxide (CO_2)

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

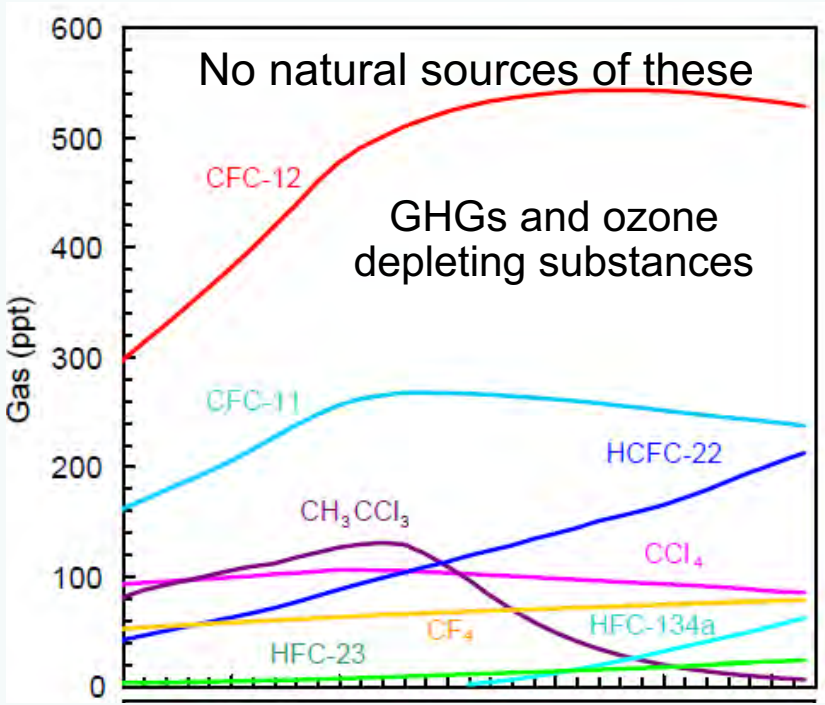


Increase in other Greenhouse Gases

Methane & Nitrous Oxide



Montreal Gases



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

Radiative Forcing

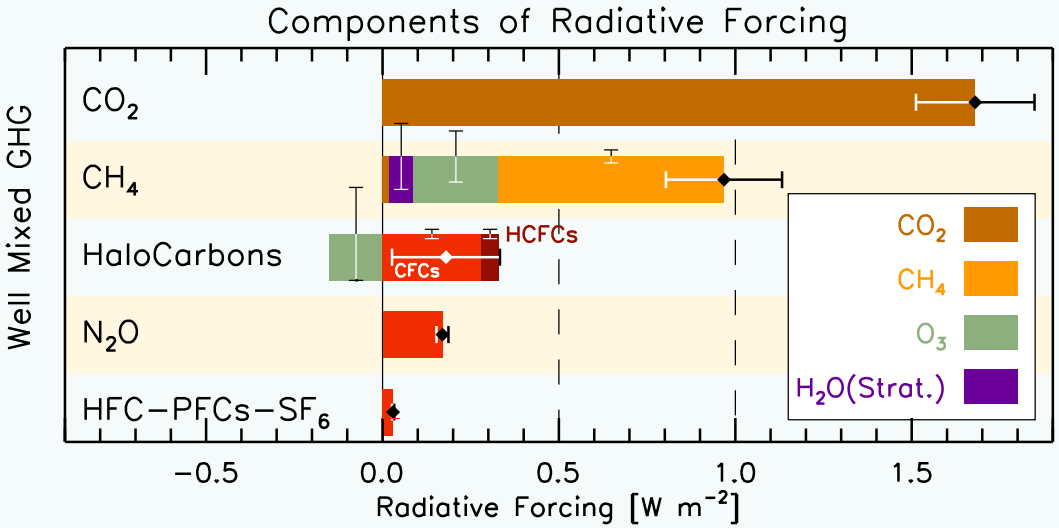
- The difference between incoming and outgoing radiation in W/m^2
  Incoming energy – Outgoing energy = Radiative forcing

  Quantifies energy imbalance:
  0=balanced; >0:warming; <0:cooling

- If Energy in > Energy out:
  → outgoing longwave radiation decreases → more heat trapped in atmosphere → positive radiative forcing → temperature of Earth's atmosphere increases (warming)

Radiative Forcing

Radiative forcing of individual greenhouse gases



CO_2: carbon dioxide

CH_4: methane

N_2O: nitrous oxide

CO_2 forcing: **1.7 W m^{-2}**

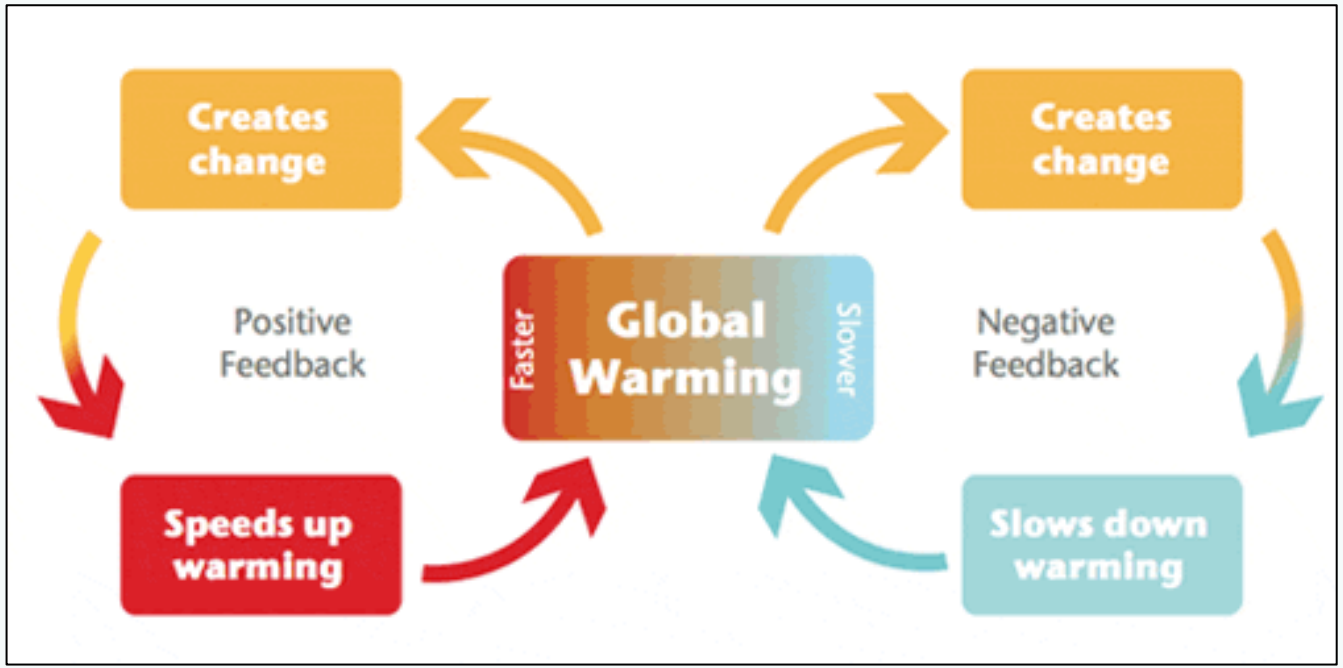
Sum of other GHGs: **1.3 W m^{-2}**

[IPCC report]

Depends on abundance and wavelength region and intensity of absorption

Climate Feedbacks

- An initial response (warming or cooling) is amplified or reduced
- **Positive** if amplifies and **negative** if reduces initial response



Four Main Feedbacks

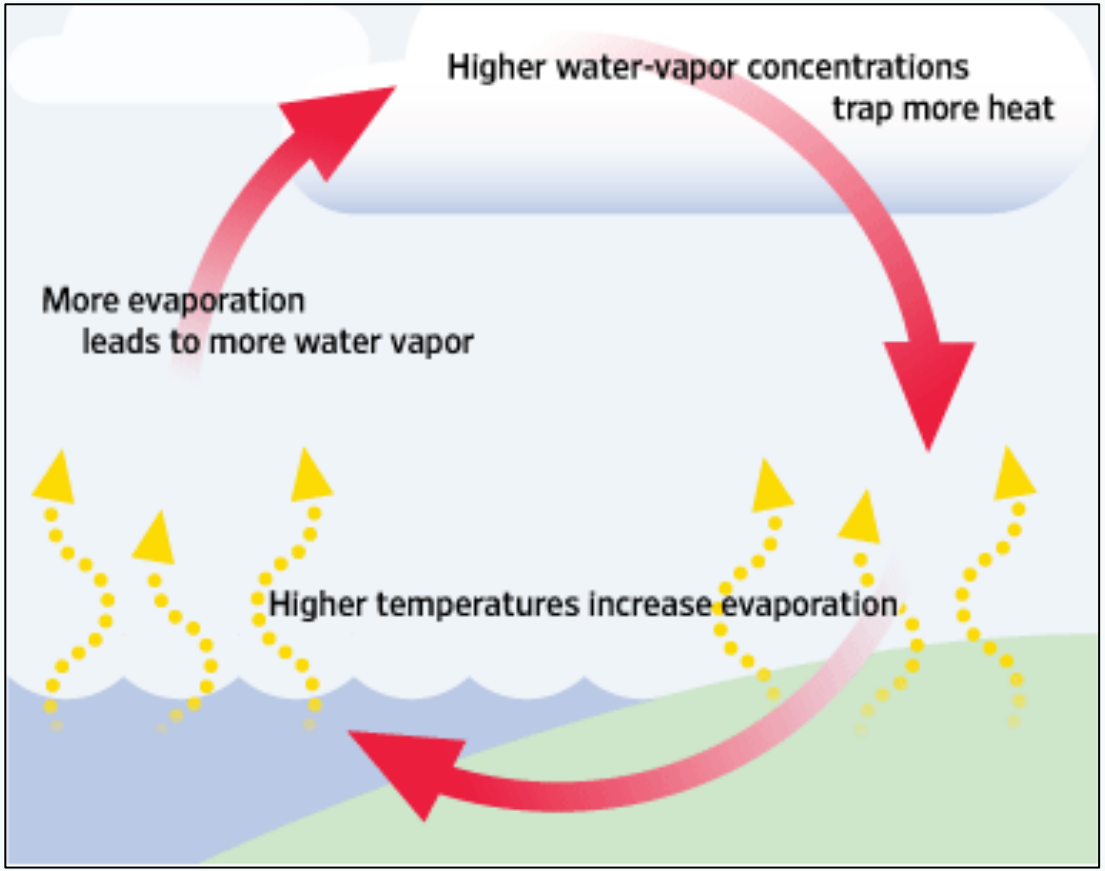
1. **Water Vapour**

2. **Ice-Albedo**

3. **Clouds**

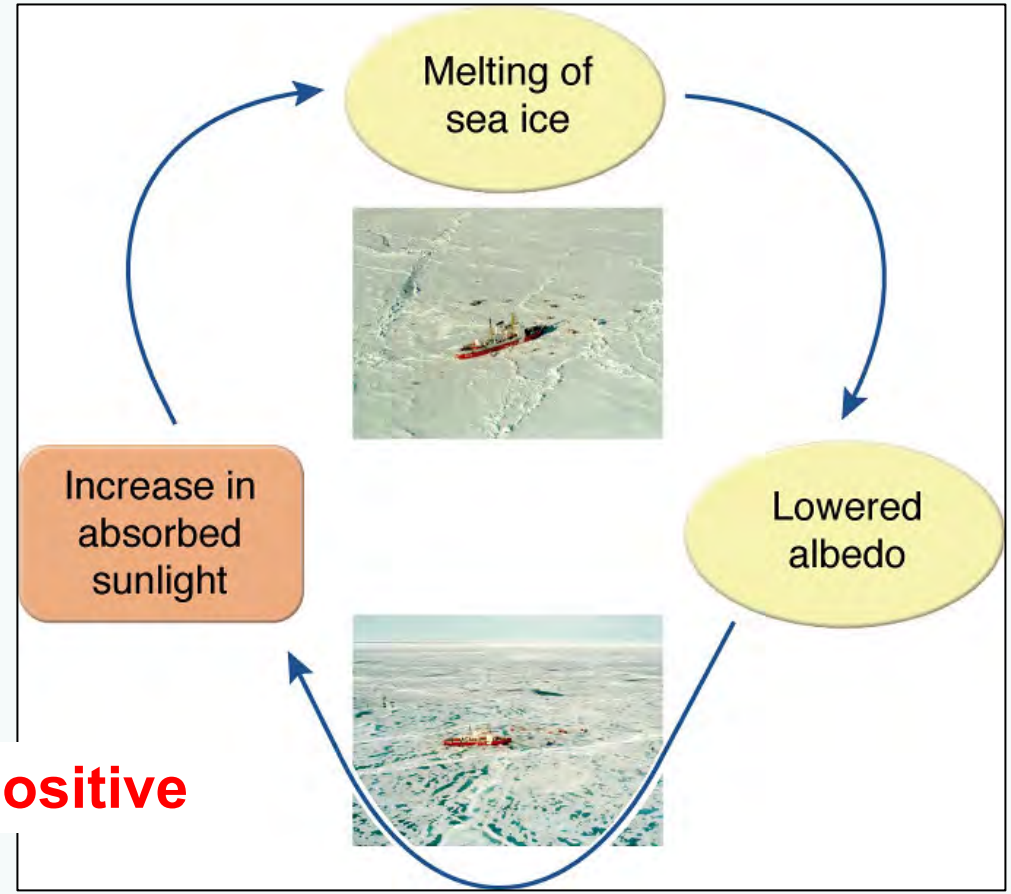
4. **Lapse Rate**

Water vapour feedback

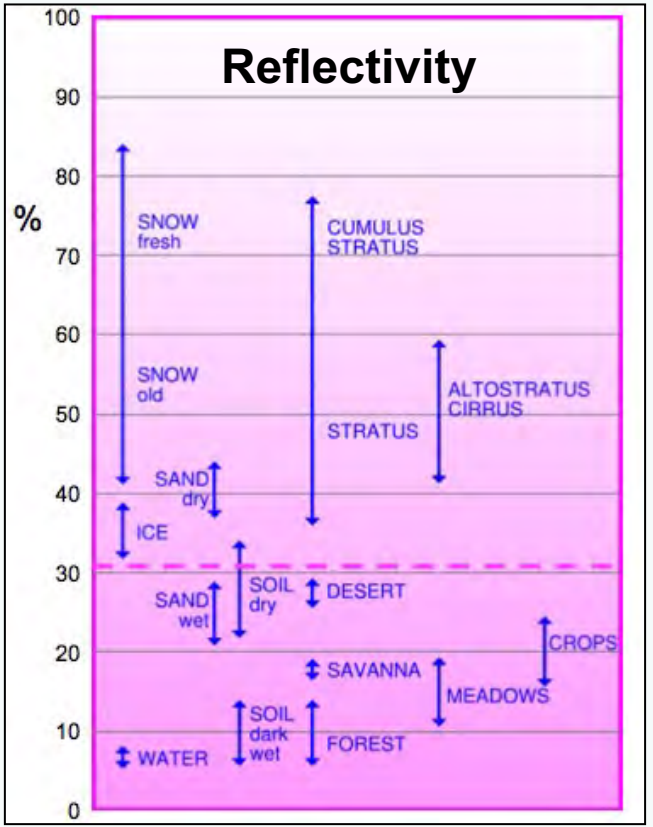


Positive

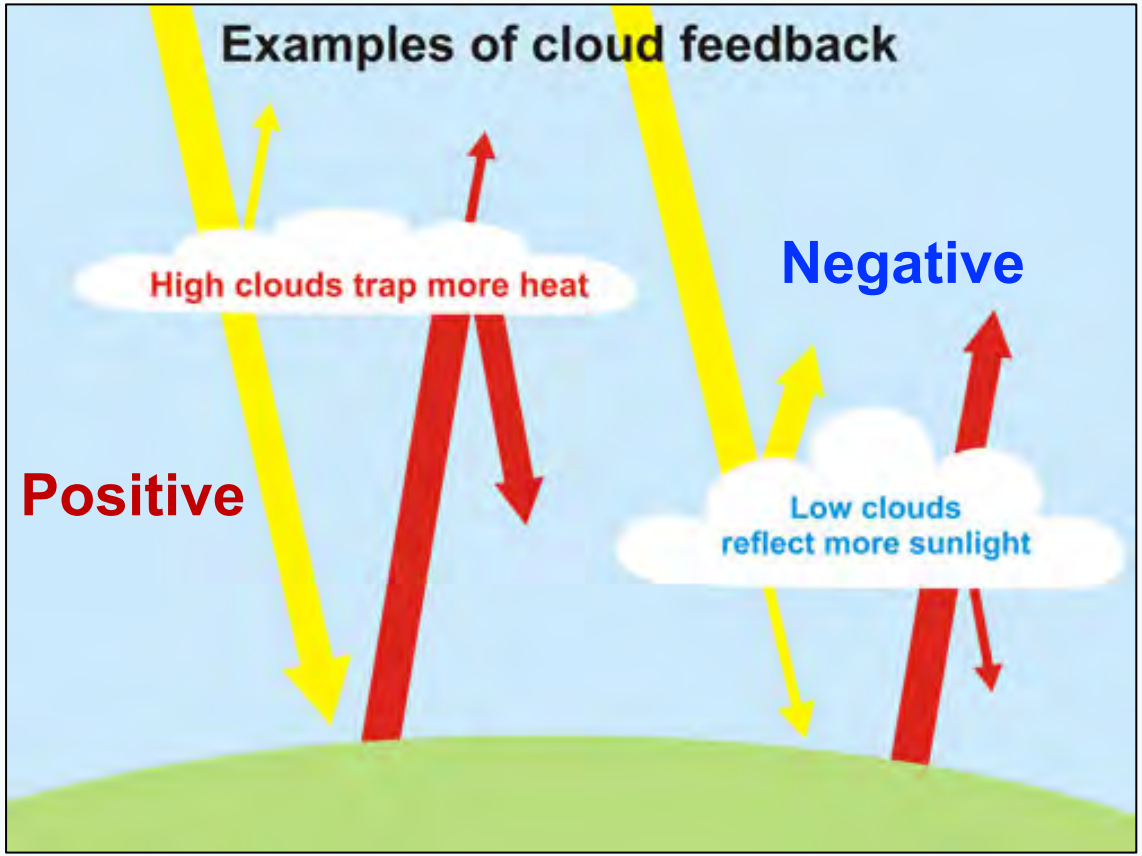
Ice-Albedo Feedback



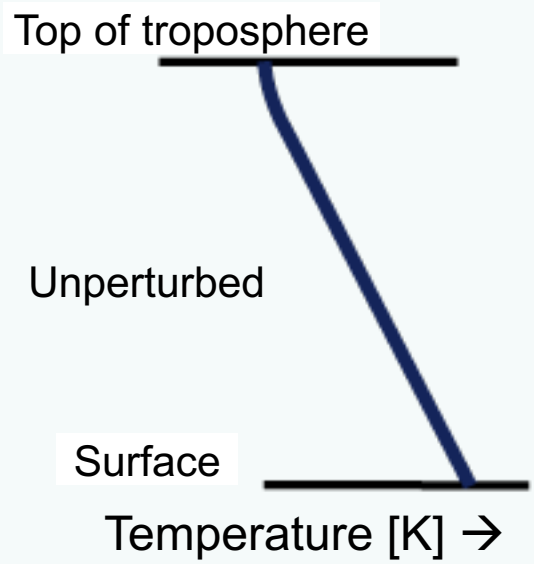
Positive



Cloud Feedback

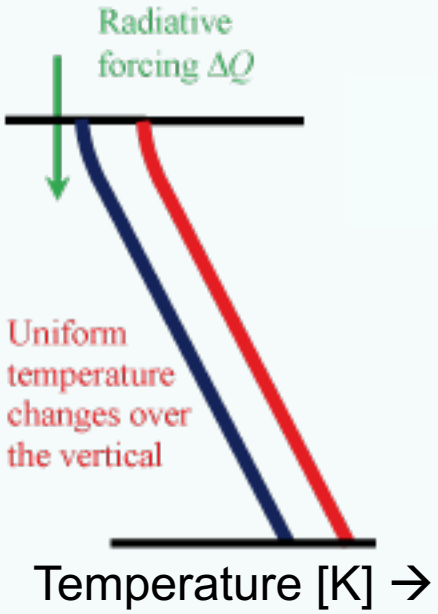


Lapse Rate Feedback



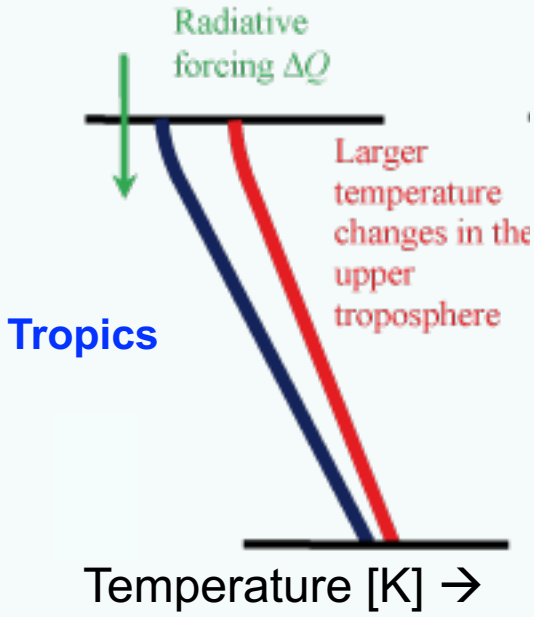
- **Lapse rate**: steepness of temperature gradient with altitude
- Gradient: Temperature difference between tropopause and surface
- Steeper gradient → greater greenhouse effect
- Steep gradient → outgoing radiation at colder temperature → greater greenhouse effect

Lapse Rate Feedback



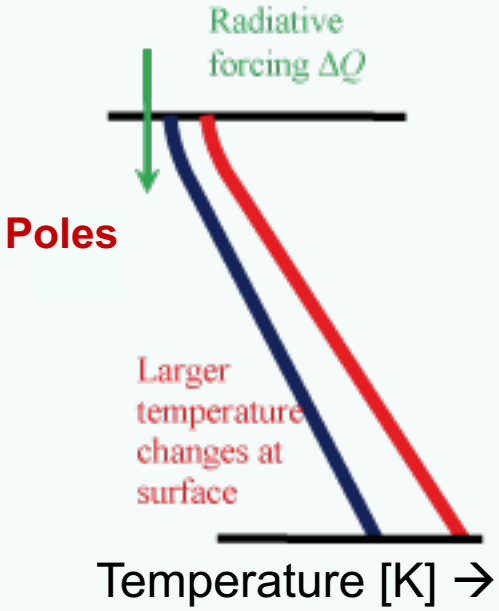
- Uniform change in temperature
- No change in gradient
- **No lapse rate feedback**

Lapse Rate Feedback



- Tropics experiences greatest warming at top of troposphere
- Gradient decreases (less steep)
- Greenhouse effect dampens
- **Negative feedback**

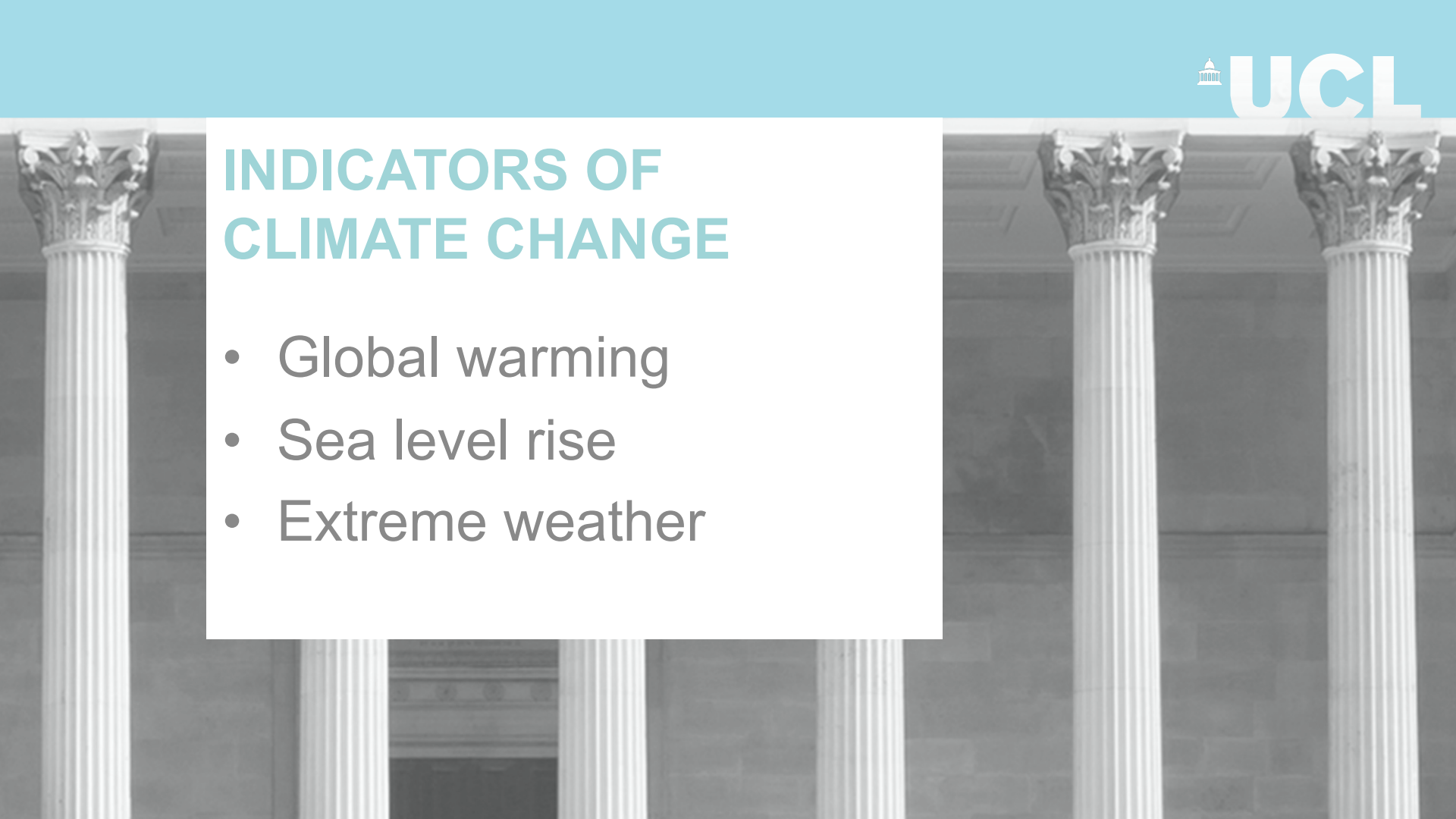
Lapse Rate Feedback



- Poles experience greatest warming at surface
- Gradient increases (more steep)
- Greenhouse effect increases
- **Positive feedback**

Four Main Feedbacks

1. **Water Vapour**
   Positive
2. **Ice-Albedo**
   Positive
3. **Clouds**
   Uncertain, but likely positive
4. **Lapse Rate**
   Negative in the tropics; positive at the poles

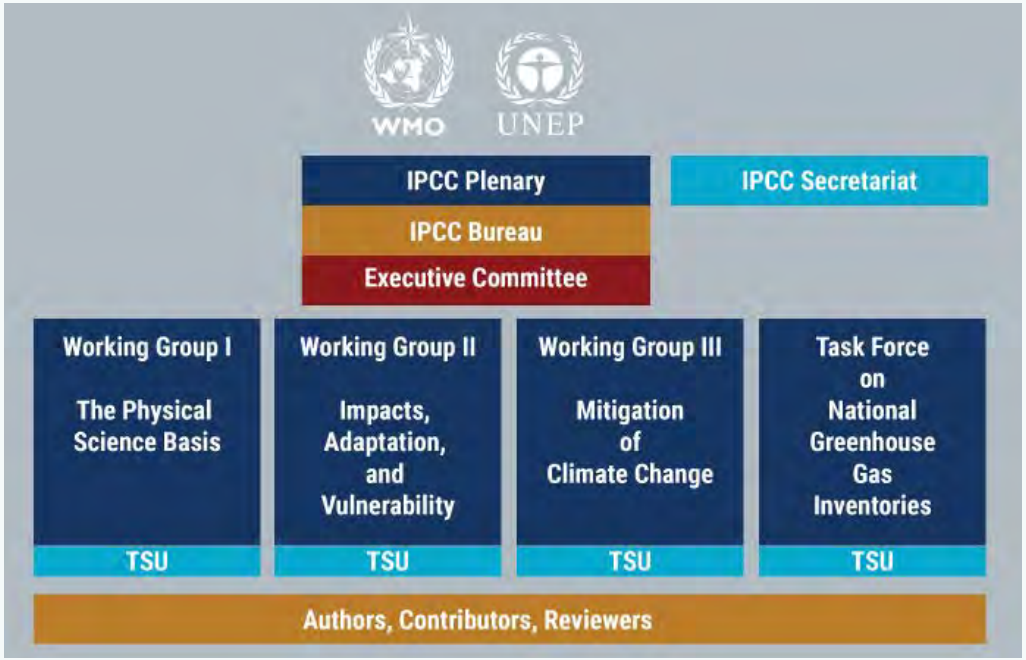


INDICATORS OF CLIMATE CHANGE

- Global warming
- Sea level rise
- Extreme weather

The Intergovernmental Panel on Climate Change (IPCC)

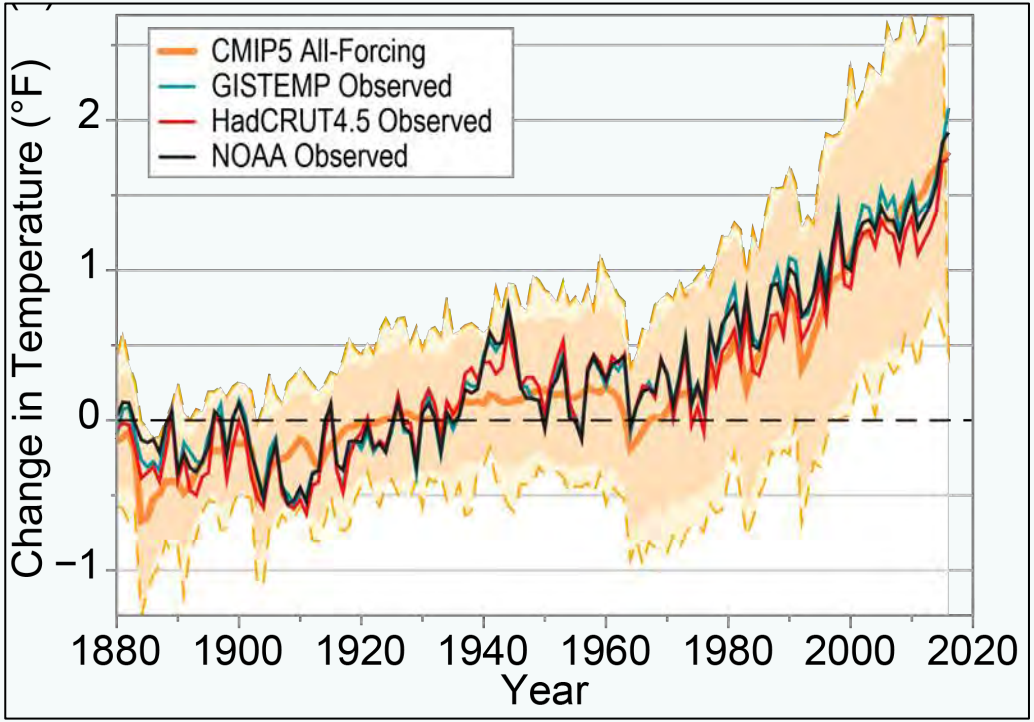
- Creates regular comprehensive reviews of state-of-knowledge of climate change
- Also co-ordinates climate model projections
- Next report (AR6): 2021/2022
- Reports written by experts (volunteers)
- Split into thematic groups
- Signed off by governments



TSU: technical support unit

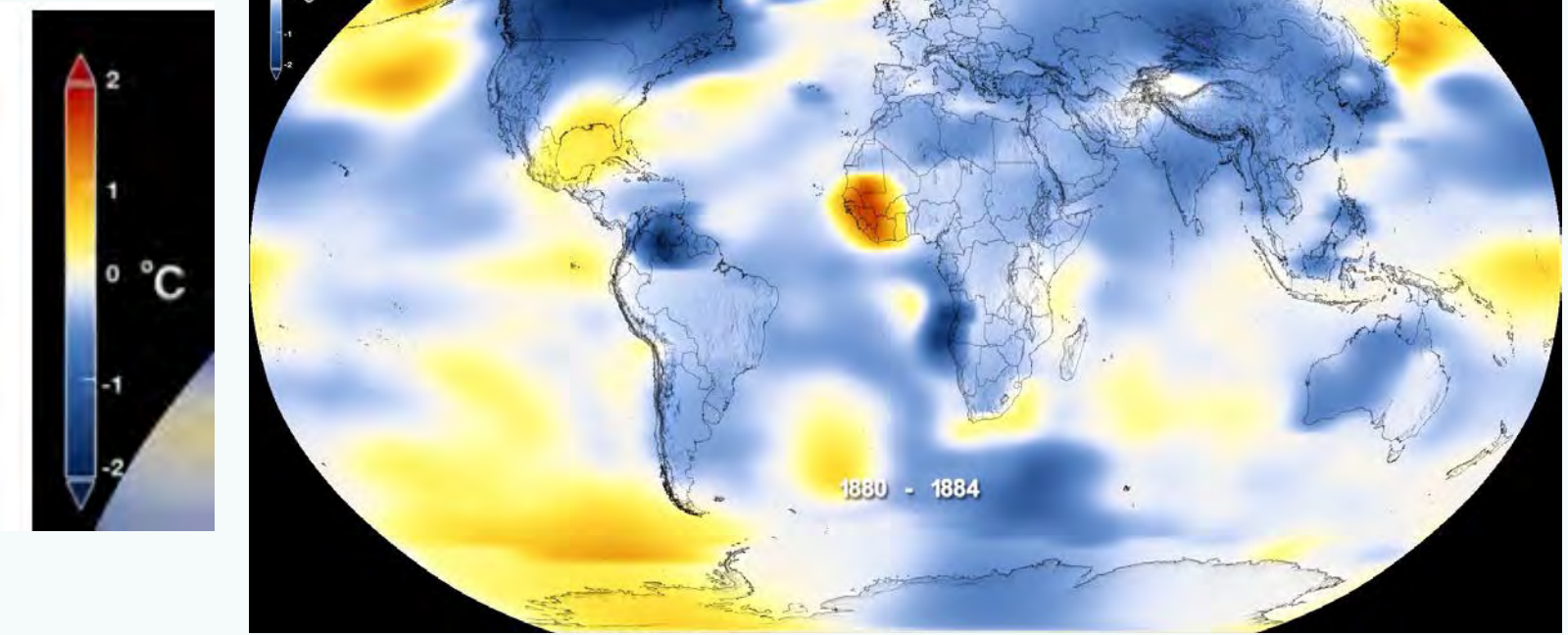
Global Warming (Time Perspective)

Change in global mean temperature

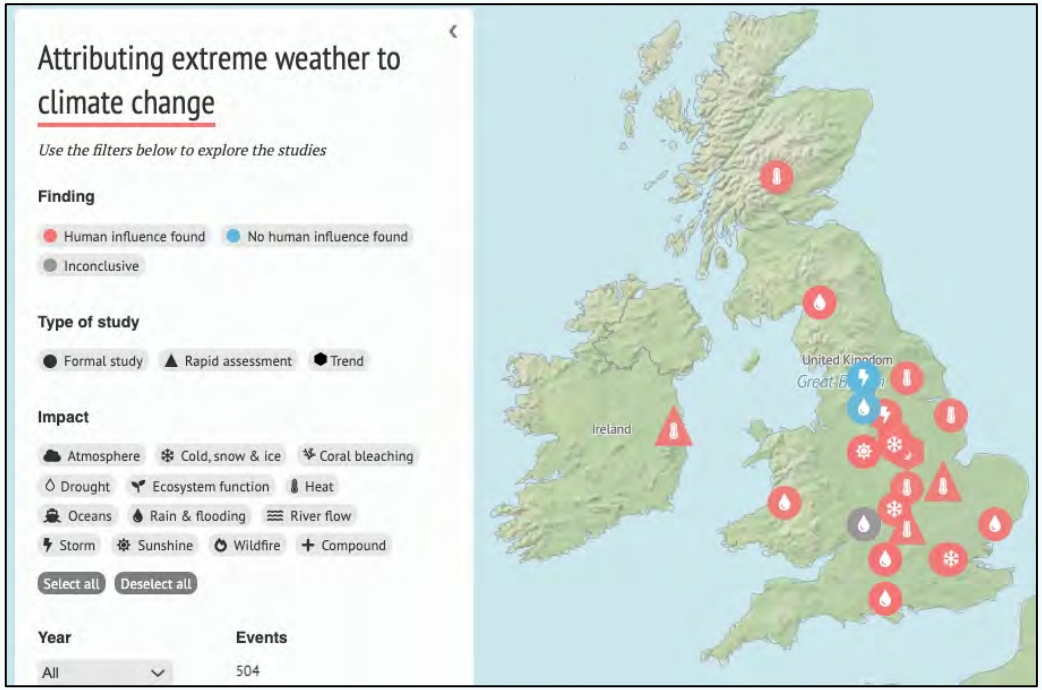


Spatial Variability

- Warming not uniform (Arctic vs Antarctic)
- Change in many locations already > 1.5ºC

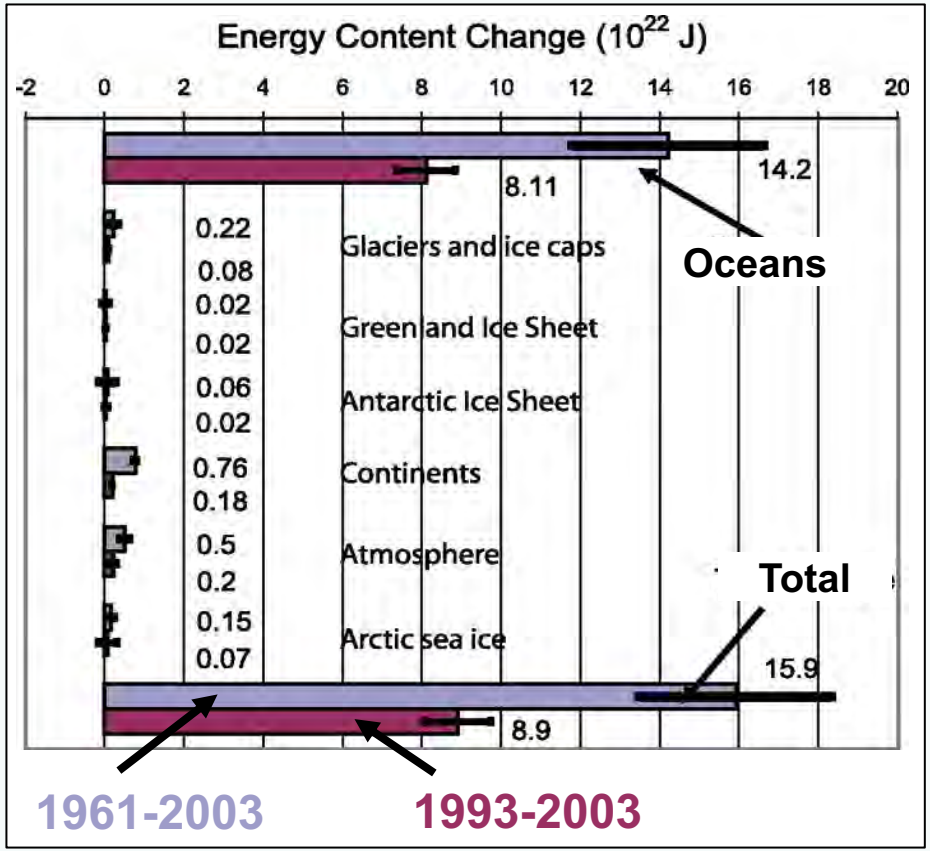


Extreme Weather



- Occurs naturally
- Climate change increases severity and frequency
- Interactive tool of global extreme weather events and links to climate change: https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world

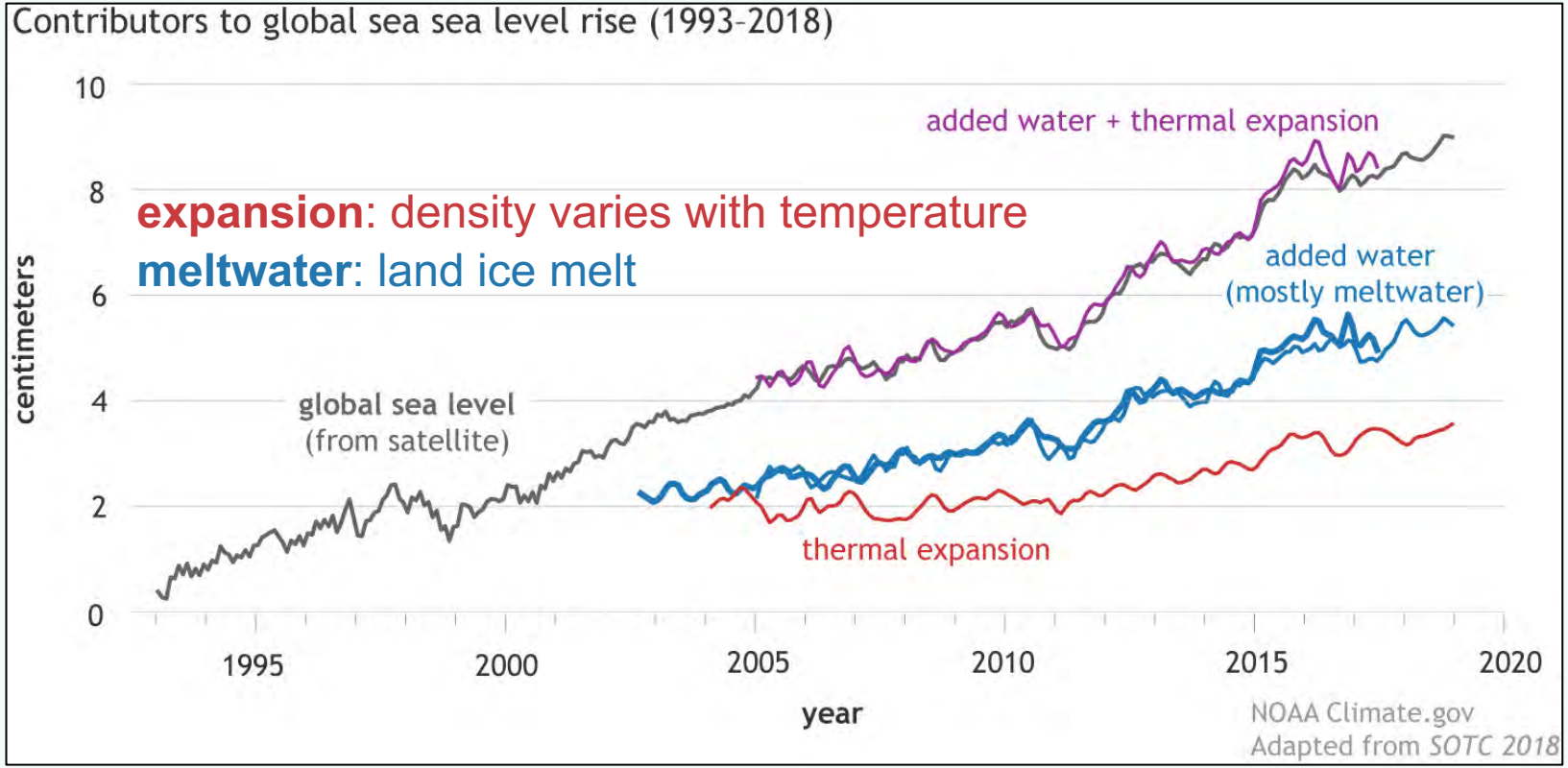
Global Heat Uptake



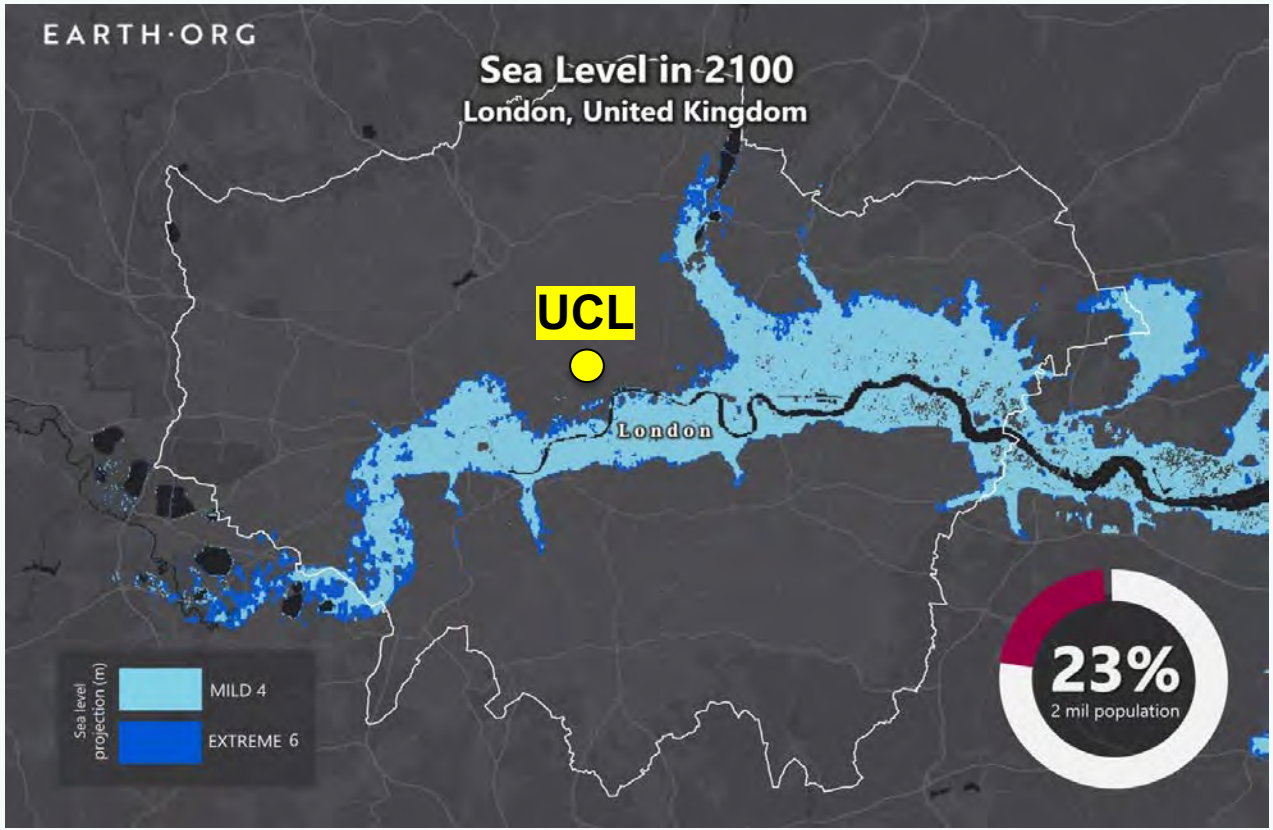
- Oceans absorb most additional heat energy
- Leads heat gain (in J or Joules)
- The amount of heat the planet can store (thermal inertia) controls the pace of change

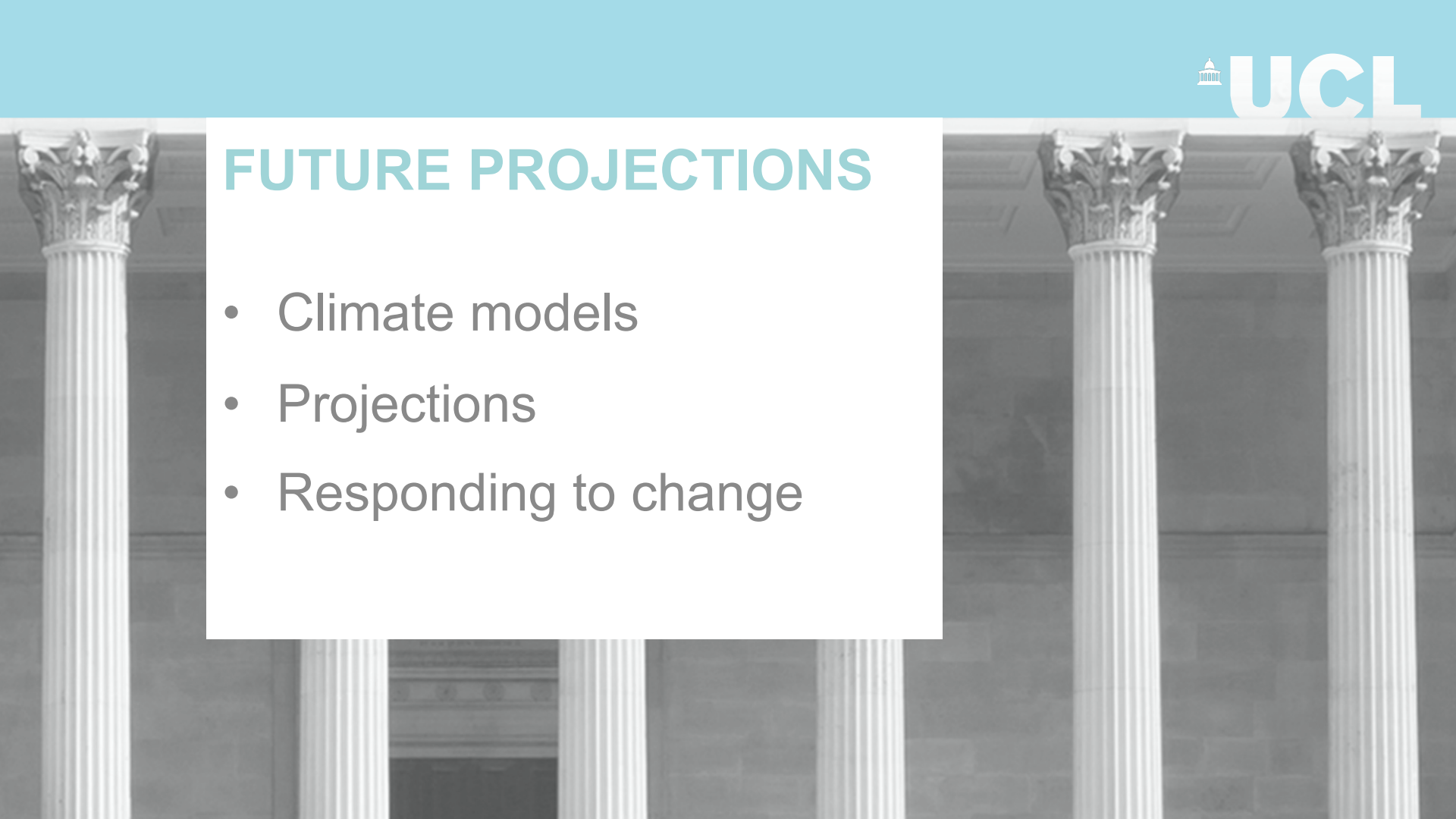
Sea Level Rise

Sea level change from expansion and meltwater



Sea Level Rise



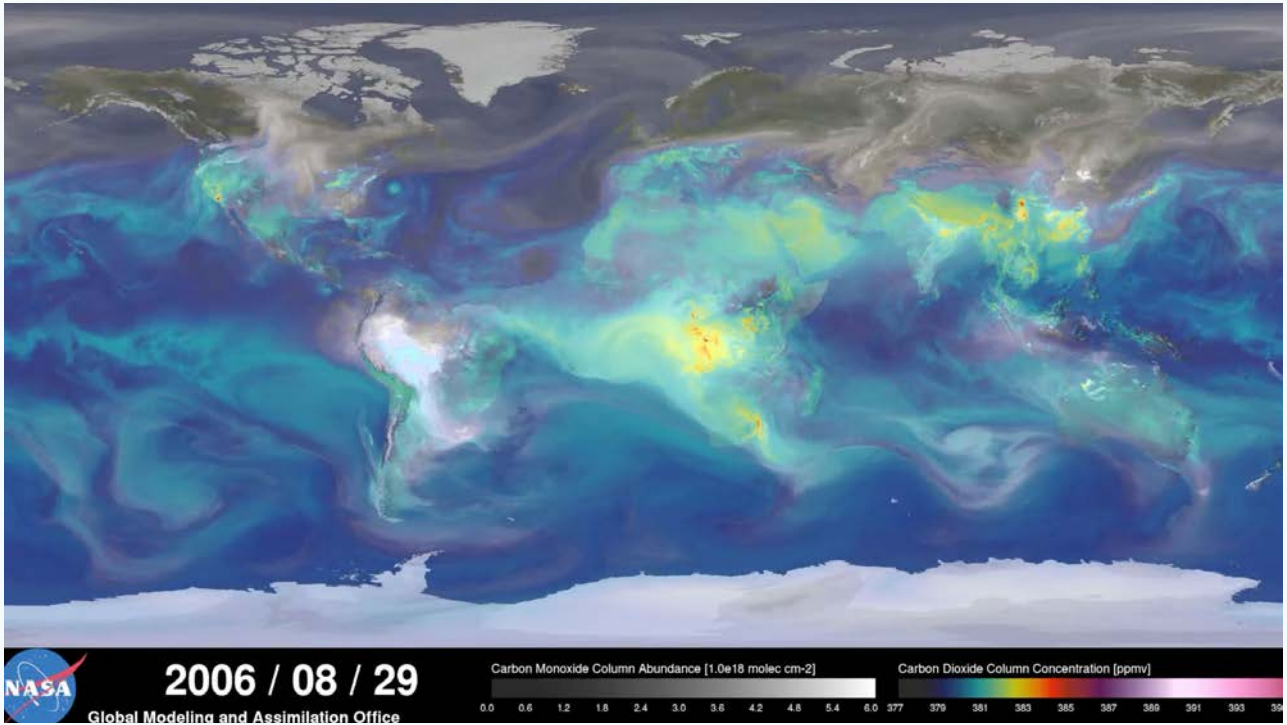


FUTURE PROJECTIONS

- Climate models
- Projections
- Responding to change

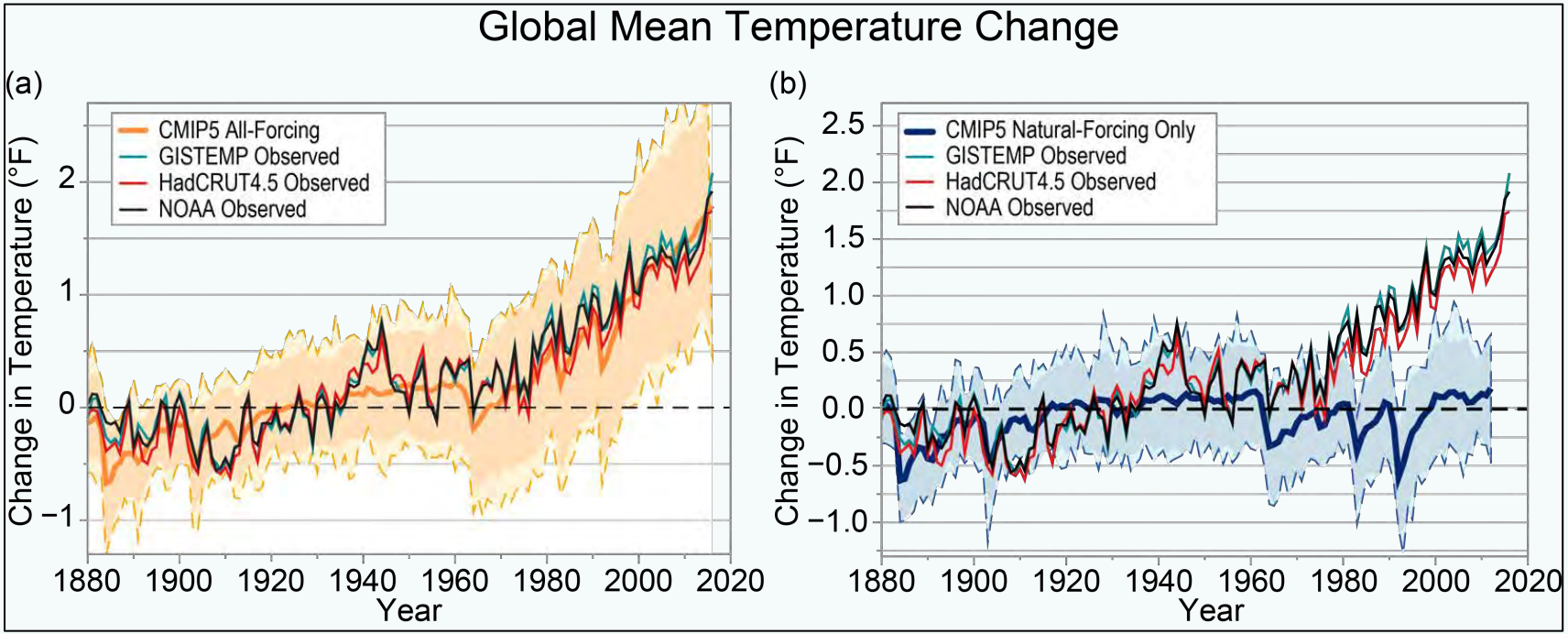
Climate Models

- Mathematical formulae and parameterizations for atmospheric processes
- Test scenarios (not always possible in real world)
- Computationally intensive



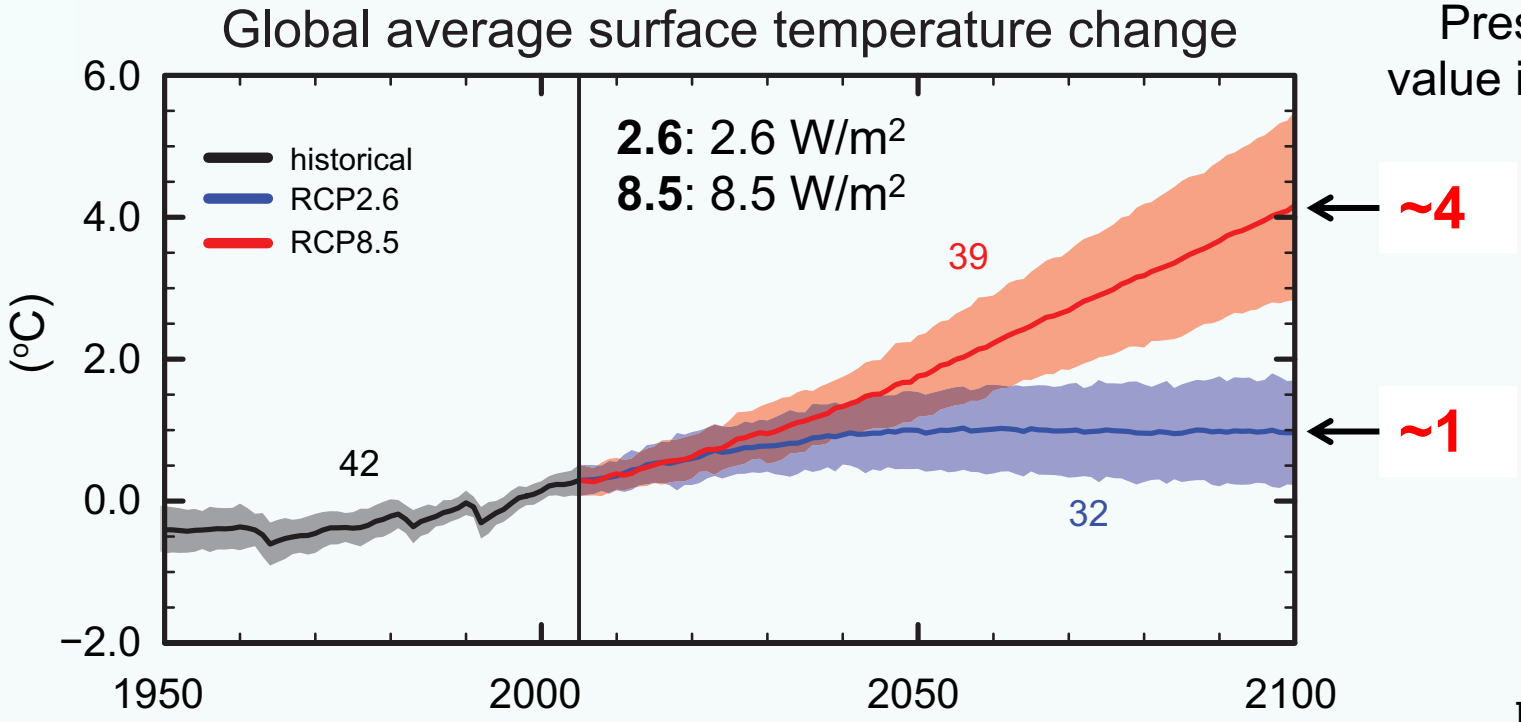
Climate Models

Tease out factors contributing to changes in climate variables like temperature



Climate Models

Predict likely future outcomes for potential future radiative forcings

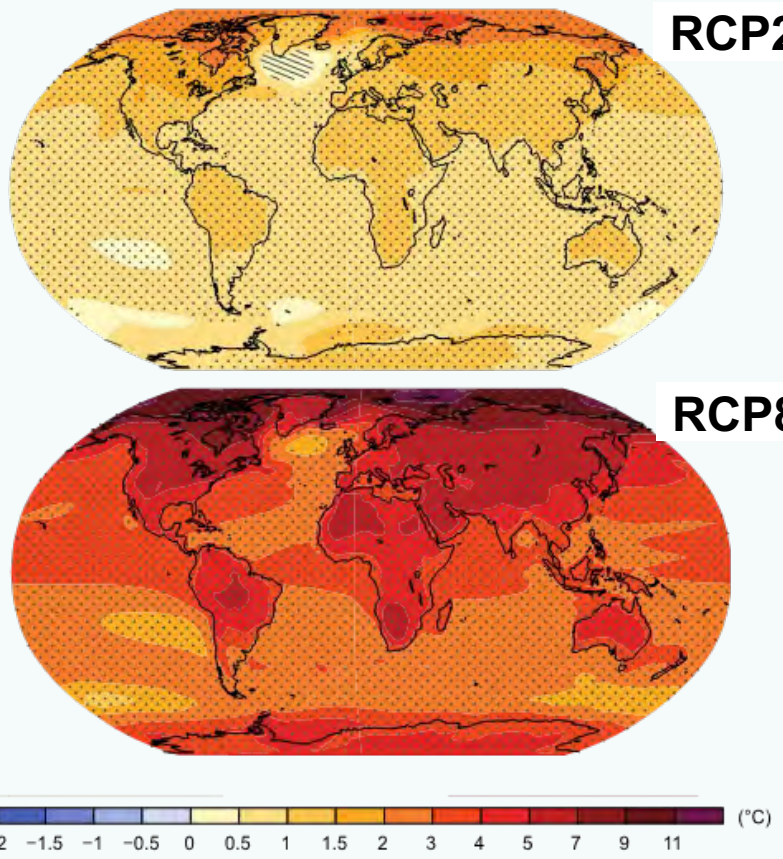


IPCC, AR5, SPM 7a

Spatial Pattern of Warming

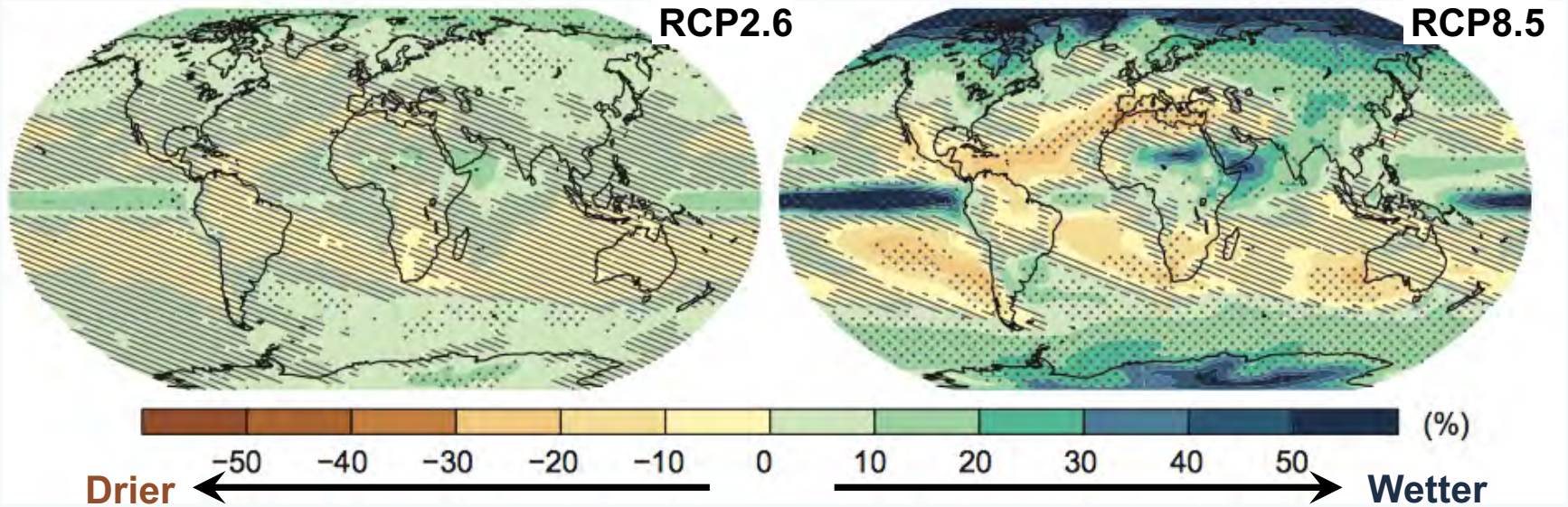
- Arctic and land warm fastest
- Minima in Southern Ocean and North Atlantic
- Nowhere is exempt from warming
- For climate scenarios, pattern is similar, magnitude varies

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



Rainfall / Precipitation

Change in average precipitation (2081-2100 minus 1986-2005)



- Stippling: change is large and robust (model agreement)
- Hatching: change is small and not as robust (fewer models agree)

Changes to other climate variables: https://ar5-syr.ipcc.ch/topic_futurechanges.php

Responding to climate change

Mitigate/Prevent

- Reduce radiative 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

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/]

Summary

- Climate changes (warms) due to increases 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
  - Increase incidence and severity of extreme weather
- Changes will continue and magnify:
  - Strong warming
  - Disrupted hydrological cycle
  - Mitigate and/or adapt?