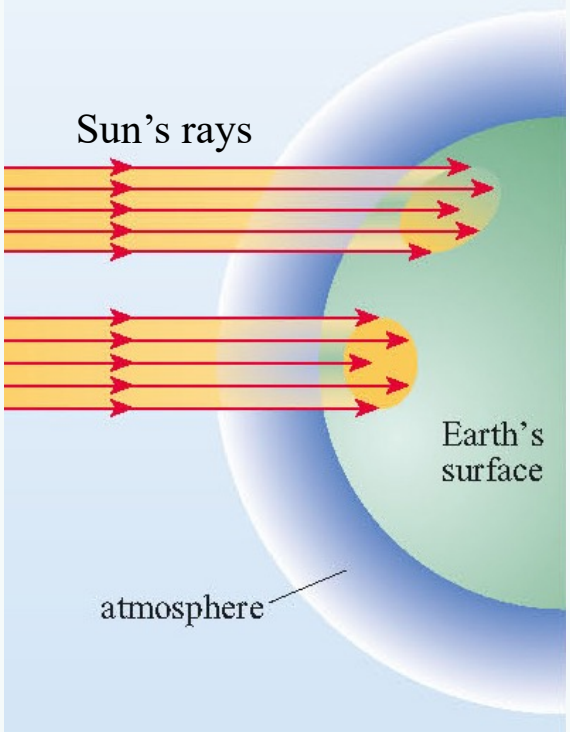
DEPARTMENT OF GEOGRAPHY

Climate

GEOG0005

Equator gets more sun radiation than the Poles



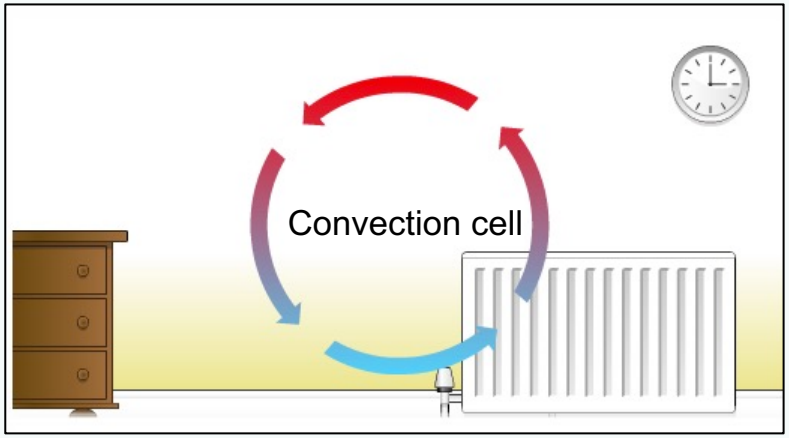
Less

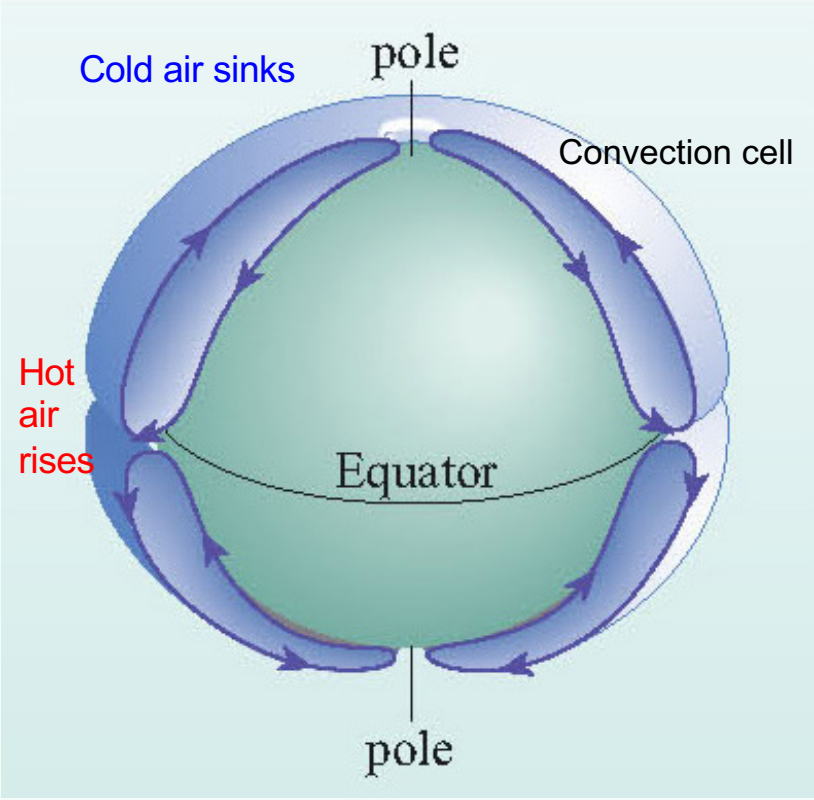
More

Energy Transfer

Redistribution of Heat

- Convection plays role
- Not as simple as Hadley's 1735 suggestion that convection cell extends from Equator to the Poles

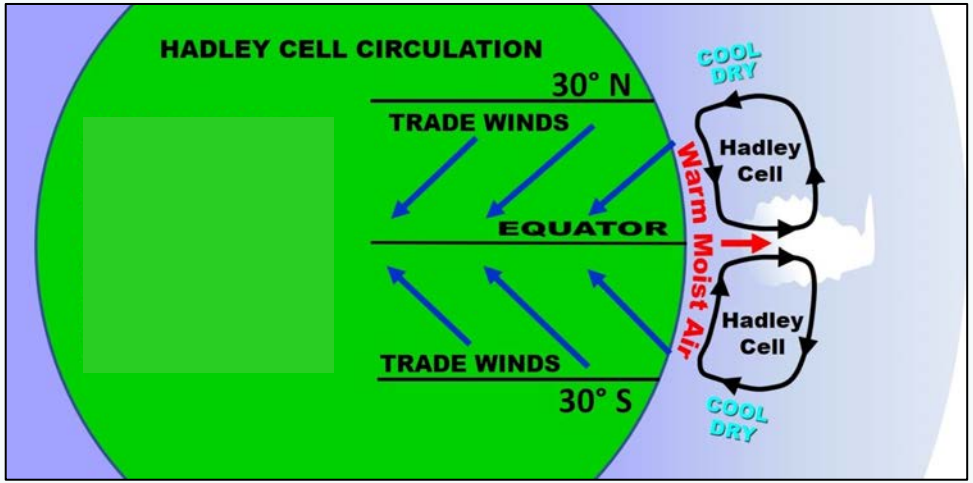




Does not account for the **Coriolis effect**

Tropical Hadley Cells

- Sun heats Equator
- Hot air rises
- Air masses move toward Poles
- Air masses diverge from north-south path due to Coriolis effect
- Cool dry air sinks at about 30^{o} latitude (deserts)
- Still named Hadley cell



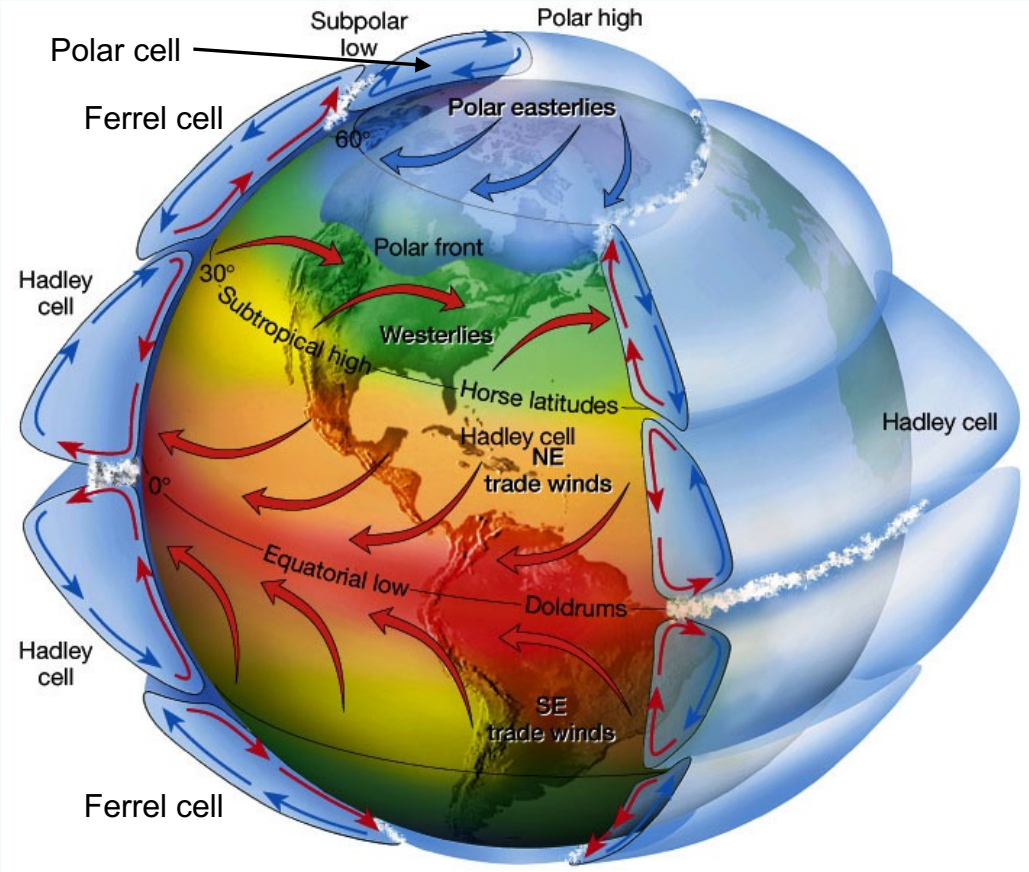
Convection cells and Surface Winds

Convection Cells:

- moist, warm air rises, forms clouds
- cold, dry air subsides (warms)

Surface Winds:

- subsiding branch of cell reaches surface, forms surface winds that diverge due to Coriolis effect
- poleward and equatorward winds meet, air forced upward, maintains convective cells



Annual mean surface temperature

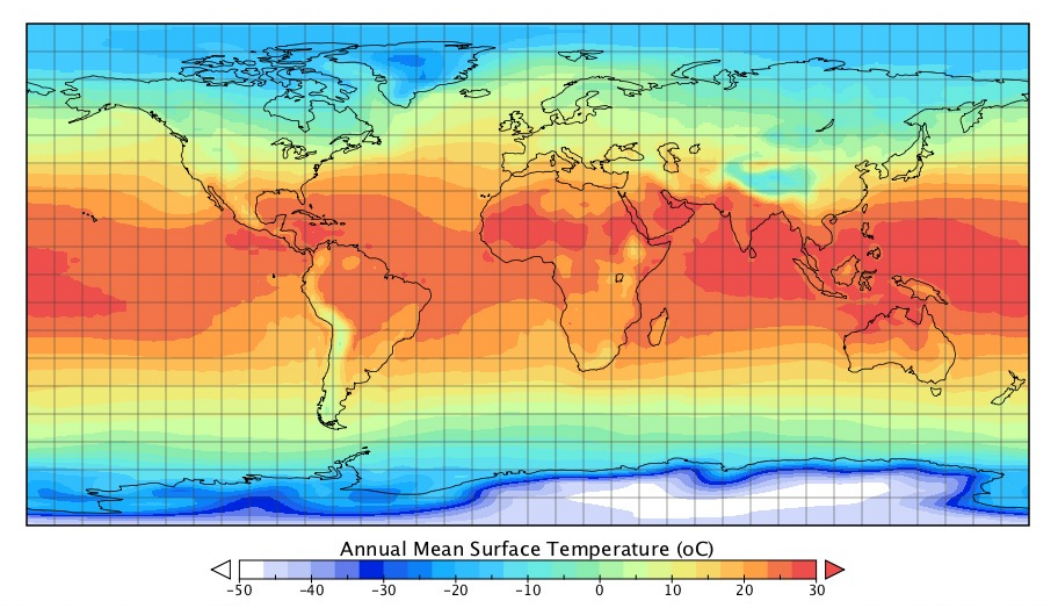
Warmest at the Equator

Coldest at the Poles

Antarctic colder than Arctic (isolated - less land mass to redistribute head)

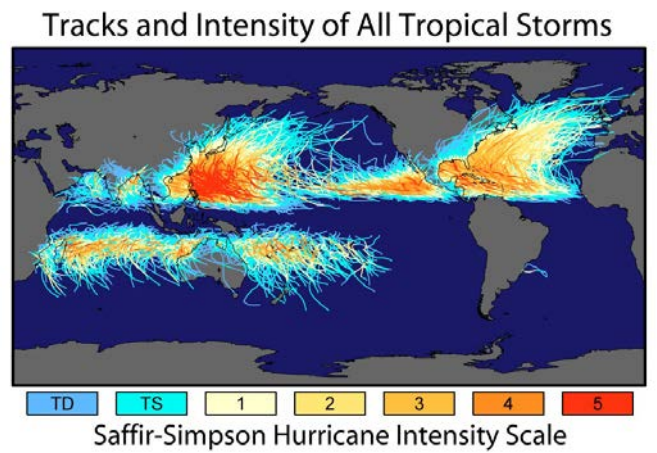
Colder at elevation

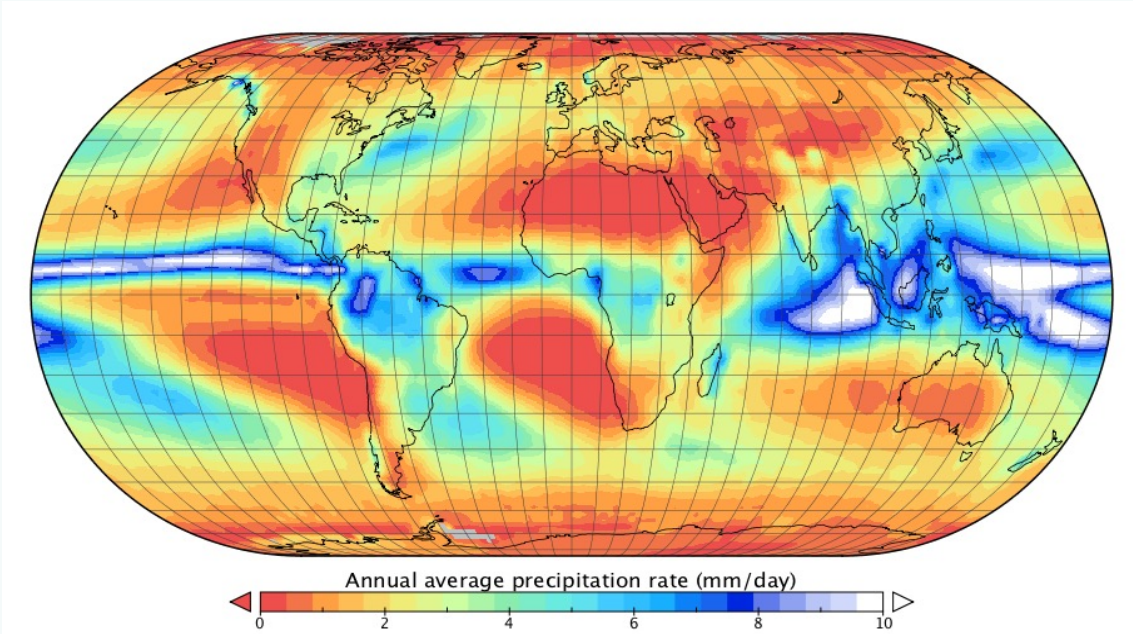
Canada colder than Europe



Annual mean rainfall/precipitation

- Most rain in Intertropical Convergence Zone (ITCZ) (convective uplift)
- Little rain at edge of tropics ~30^{o}N (subsidence)
- More rain over Equatorial oceans (storm tracks)



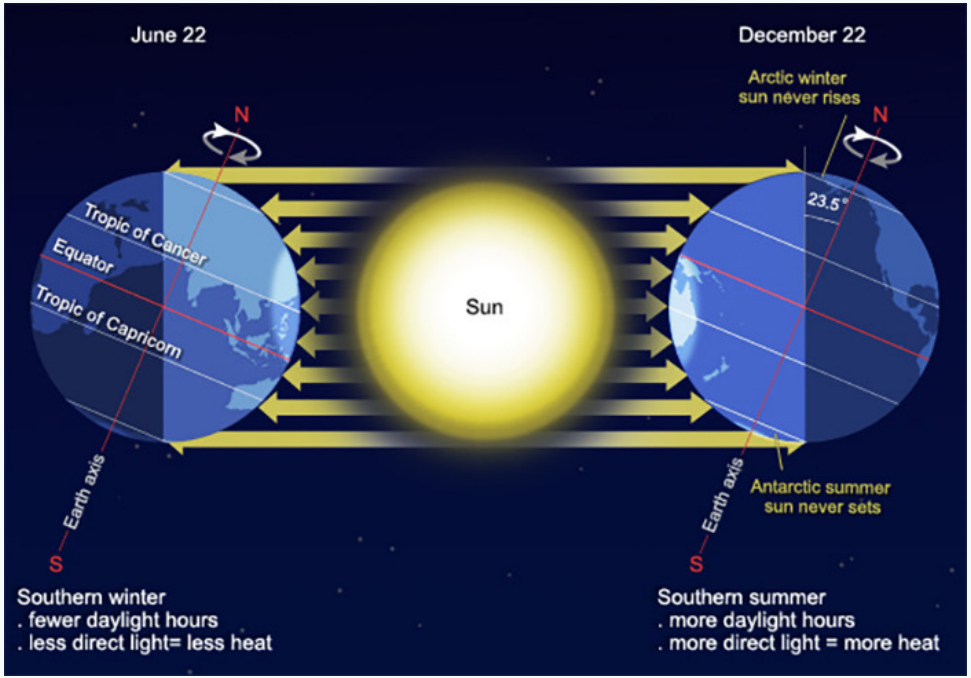


Circulation patterns not always stable

- Seasonal variability
- Interannual variability:
  - North Atlantic Oscillation
  - El Nino-Southern Oscillation
  - Extreme weather
- Longer timescale variability of 1000s of years (not the focus of this module)

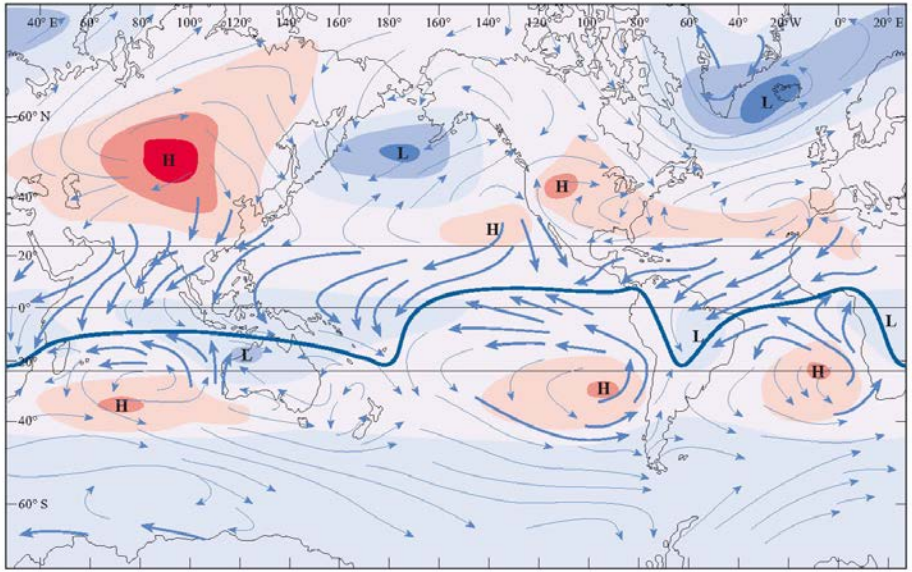
Seasons

- 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.

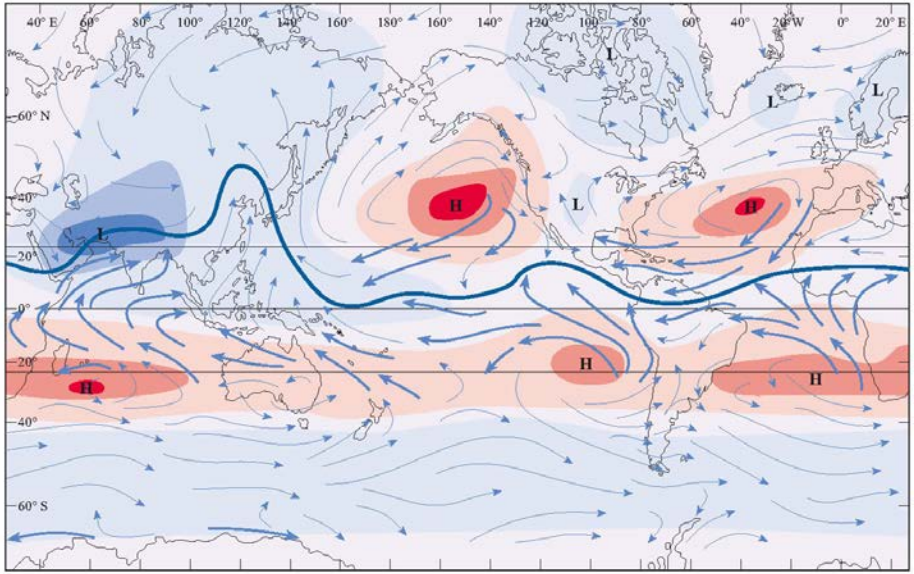


Seasonality of Surface Pressure and Winds

January



July

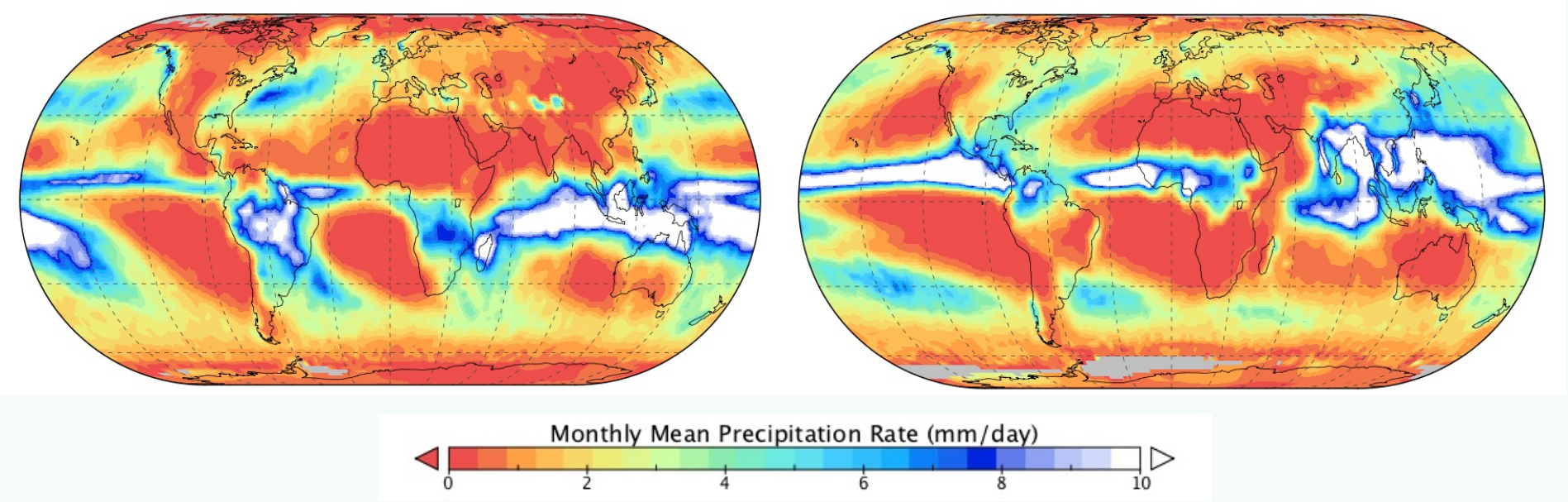


mean position of ITCZ ← most frequent wind direction ← prevailing wind direction

Seasonality of Precipitation

January

July



DEPARTMENT OF GEOGRAPHY

Climate Change

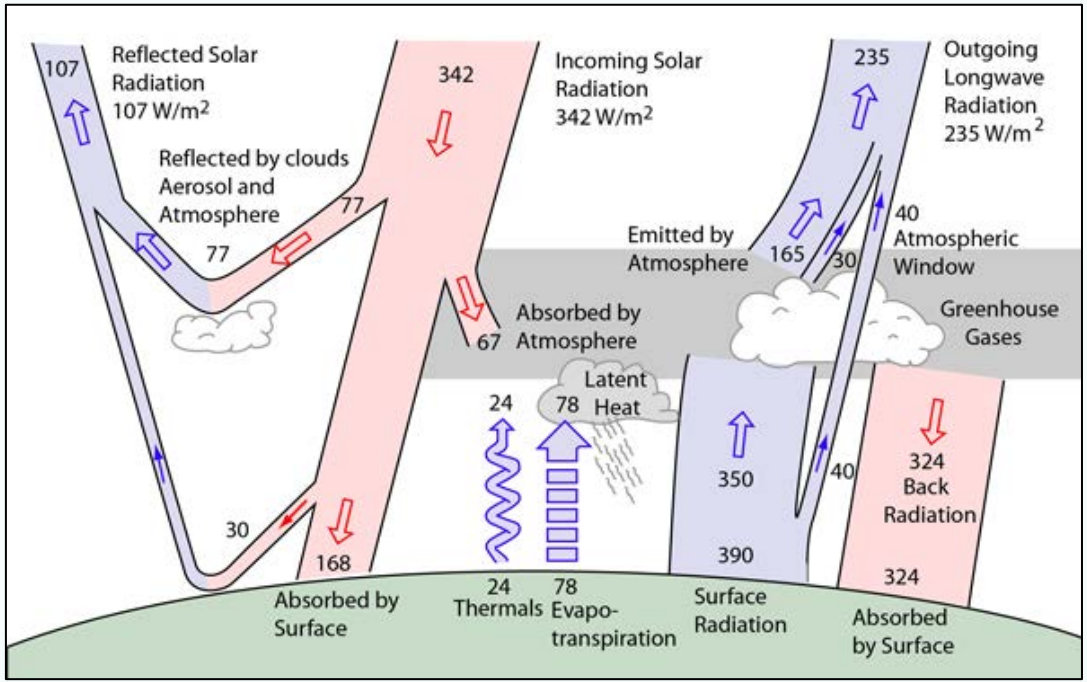
GEOG0005

THEORY

- Radiative balance
- Drivers of change
- Feedbacks

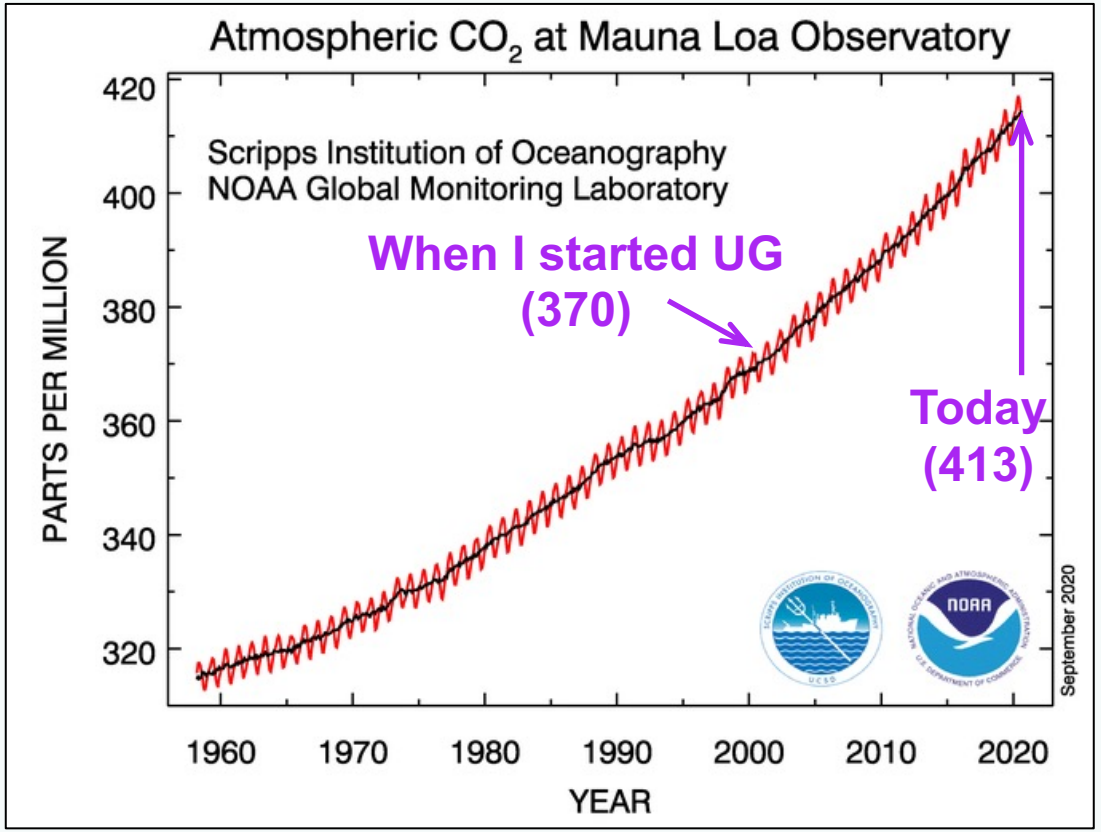
Energy Balance

- 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
- Leads to energy/heat gain
- Earth responds to re-establish balance



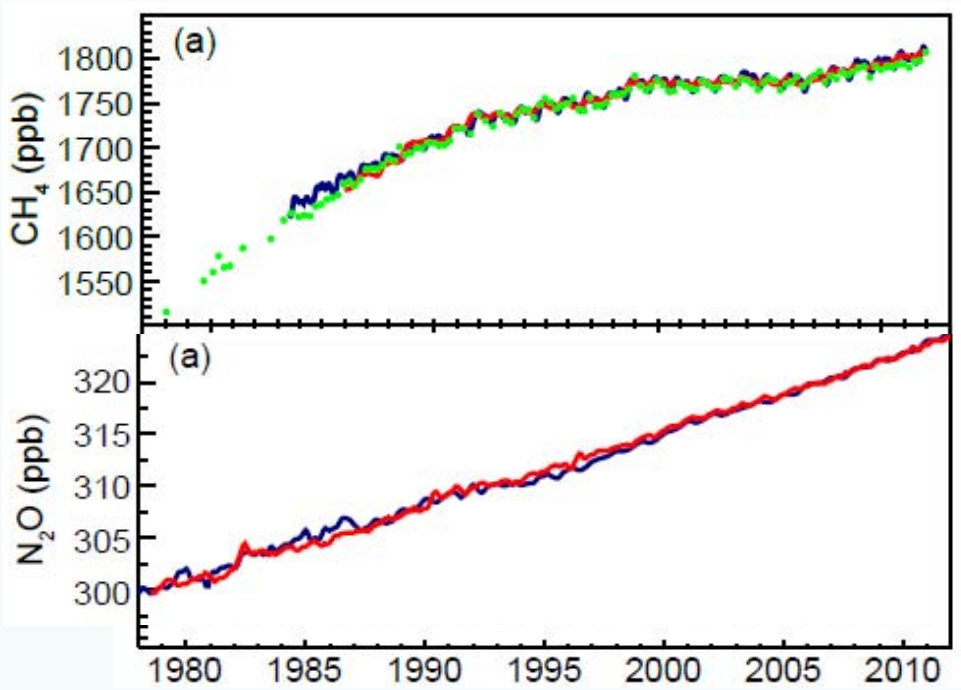
Increases in Carbon Dioxide (CO_2)

- 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”

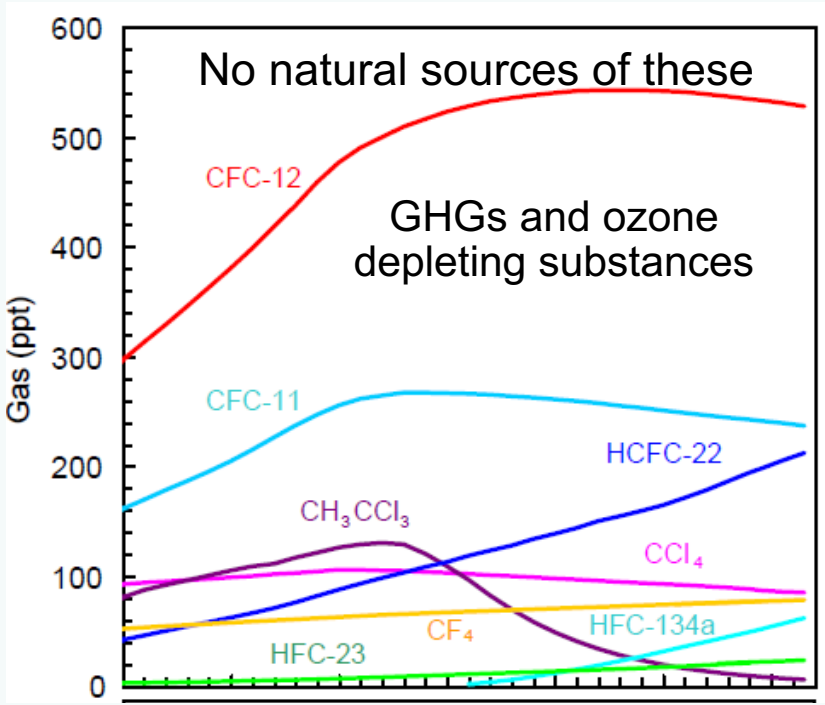


Increase in other Greenhouse Gases

Methane & Nitrous Oxide



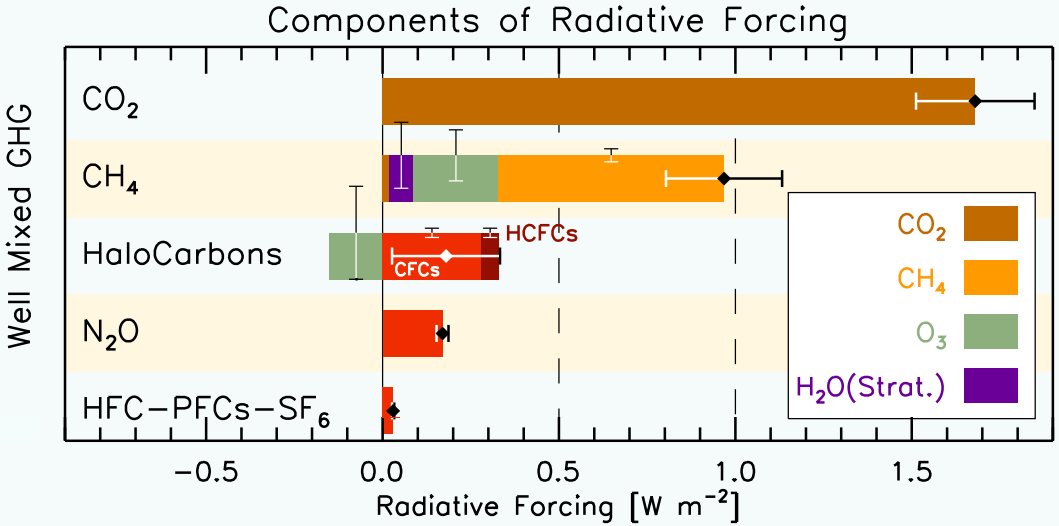
Montreal Gases



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

Radiative Forcing

- Measure of the impact of changes in greenhouse gas concentrations on top-of-atmosphere irradiance (in W/m^2)
- Energy in > Energy out → outgoing longwave radiation decreases → positive radiative forcing → planet warms



CO_2: carbon dioxide

CH_4: methane

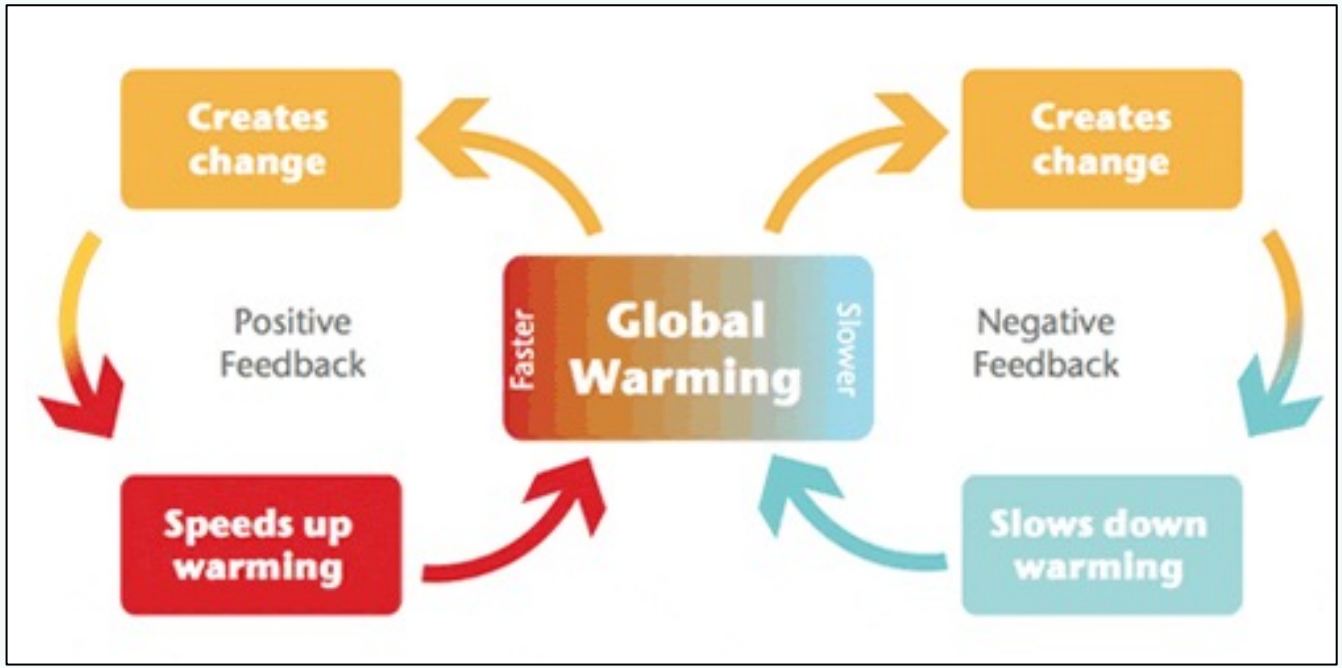
N_2O: nitrous oxide

CO_2 forcing: 1.7 W m^{-2}

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

Feedbacks

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



Four Main Feedbacks

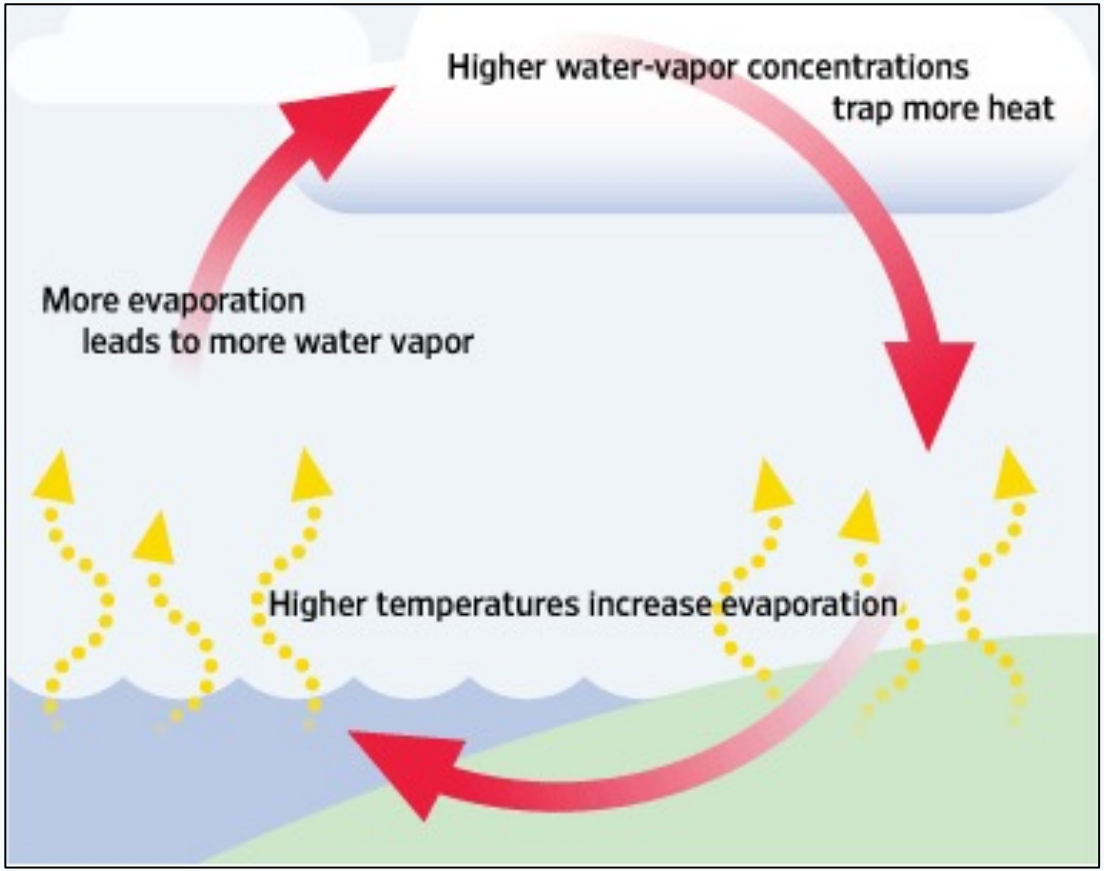
1. **Water Vapour**

2. **Ice-Albedo**

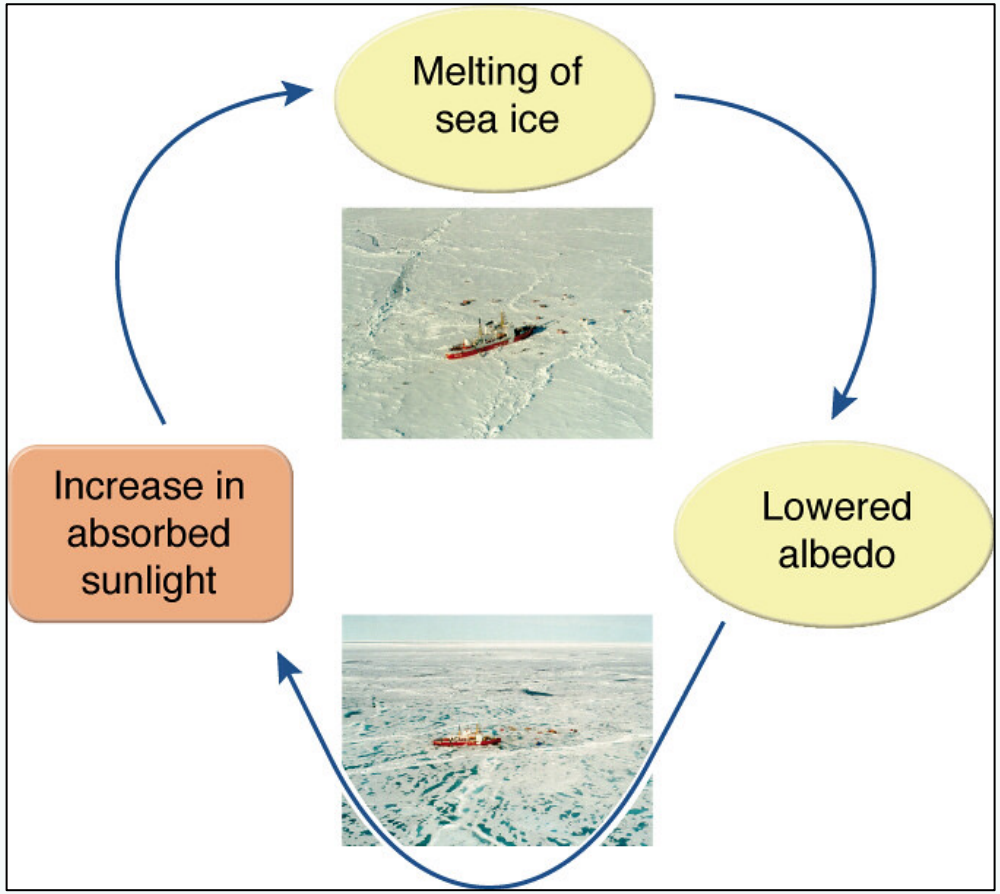
3. **Clouds**

4. **Lapse Rate**

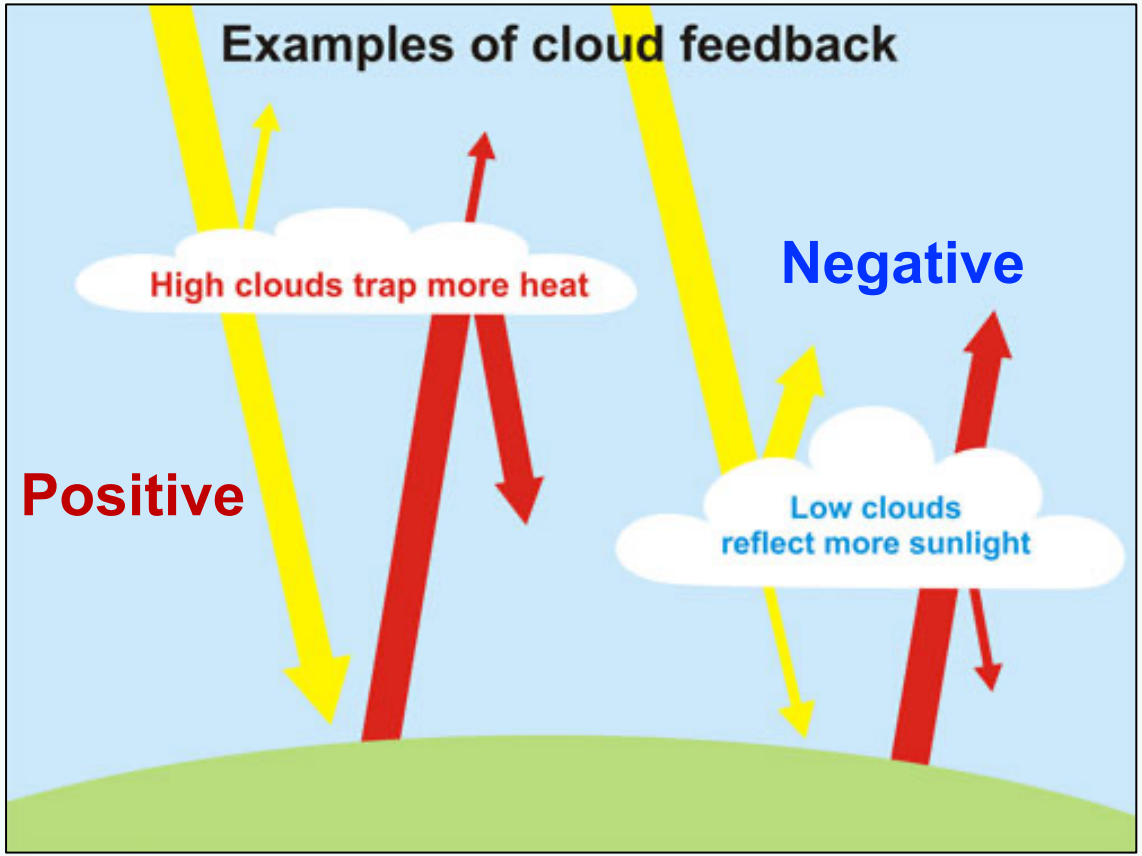
Water vapour feedback



Ice-Albedo Feedback

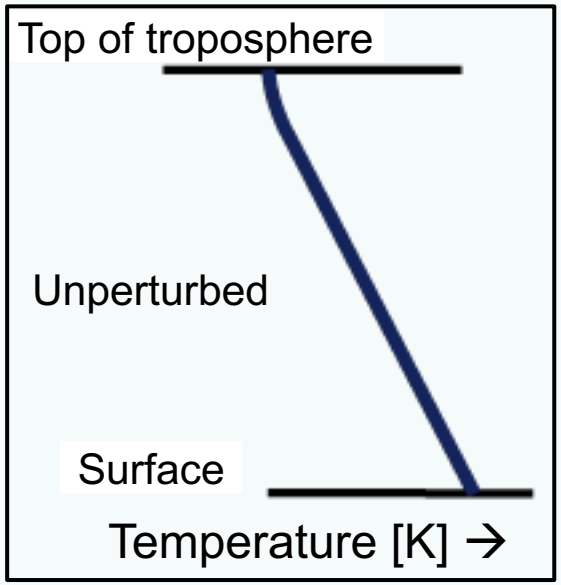


Cloud Feedback



Lapse Rate Feedback

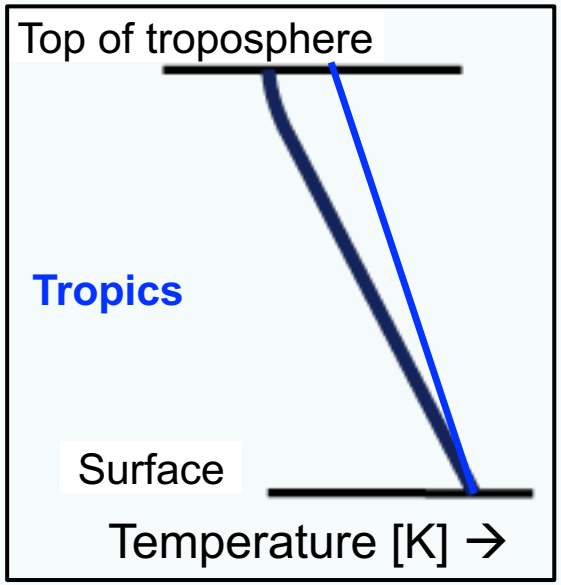
Lapse rate:
steepness of temperature gradient with altitude



- Steeper the gradient (lapse rate), the greater the greenhouse effect
- **Tropics**: warming greatest at top of troposphere → gradient becomes less steep → greenhouse effect dampens. **Negative**
- **Poles**: warming greatest at surface → gradient becomes more steep → greenhouse effect increases. **Positive**

Lapse Rate Feedback

Lapse rate:
steepness of temperature gradient with altitude



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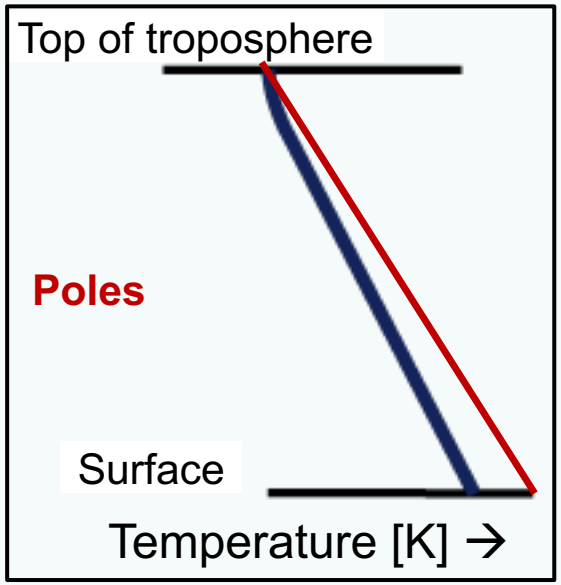

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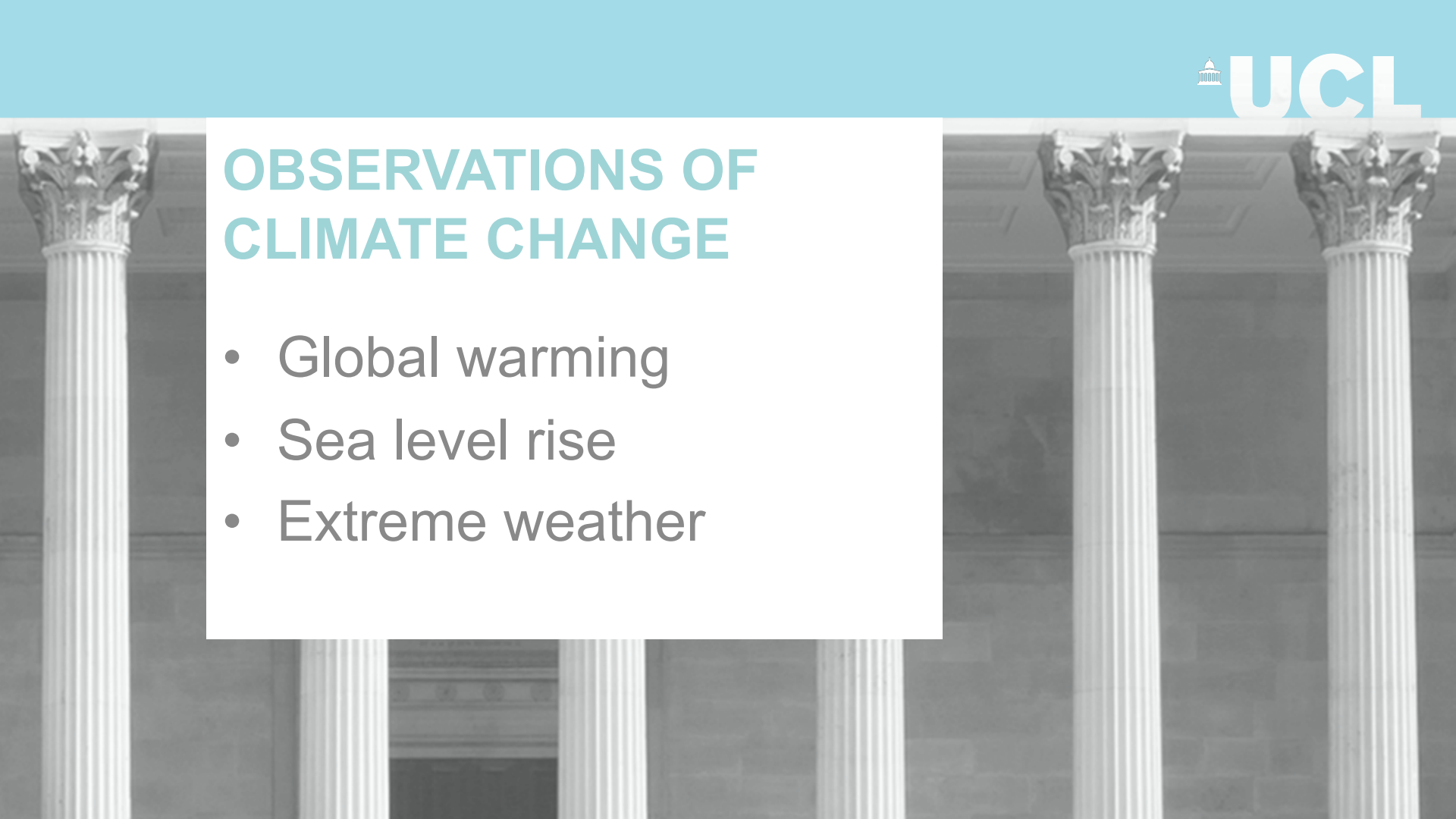
Four Main Feedbacks

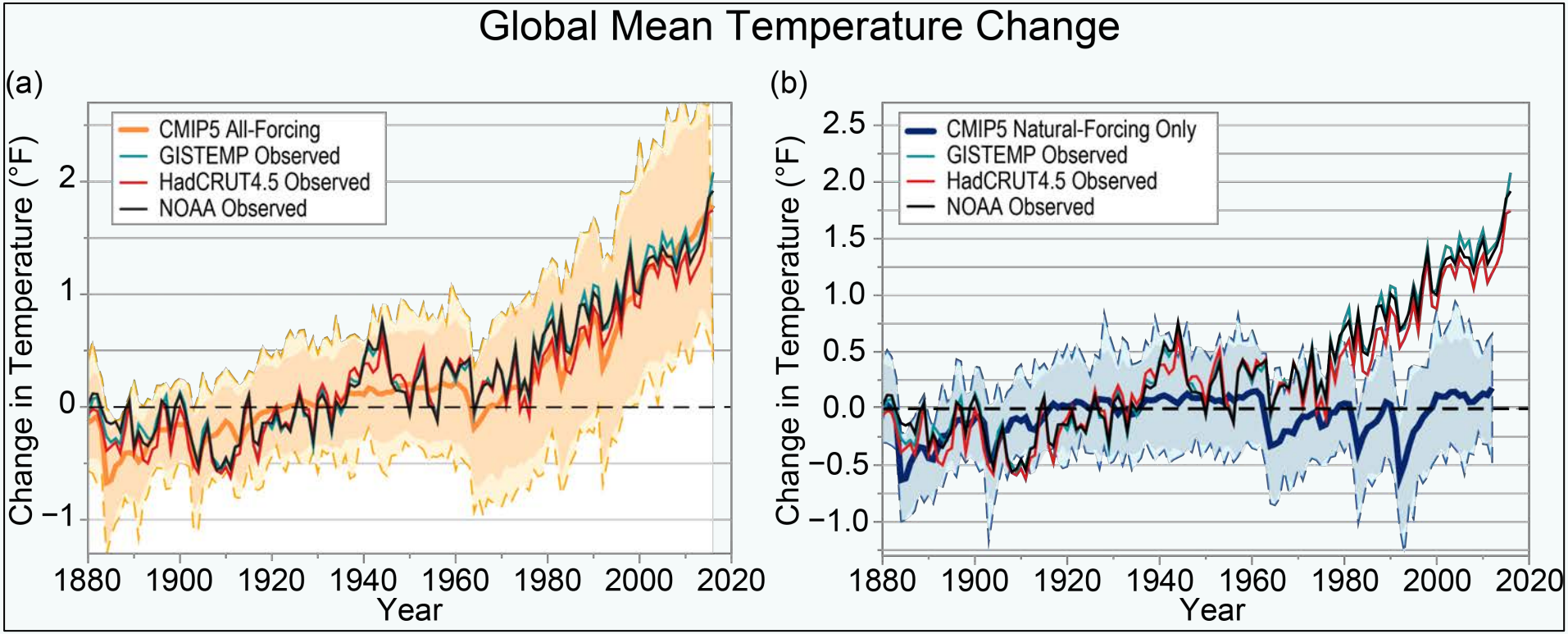
1. **Water Vapour**
   Positive
2. **Ice-Albedo**
   Positive
3. **Clouds**
   Uncertain, but likely positive
4. **Lapse Rate**
   Negative in the tropics; positive at the poles



OBSERVATIONS OF CLIMATE CHANGE

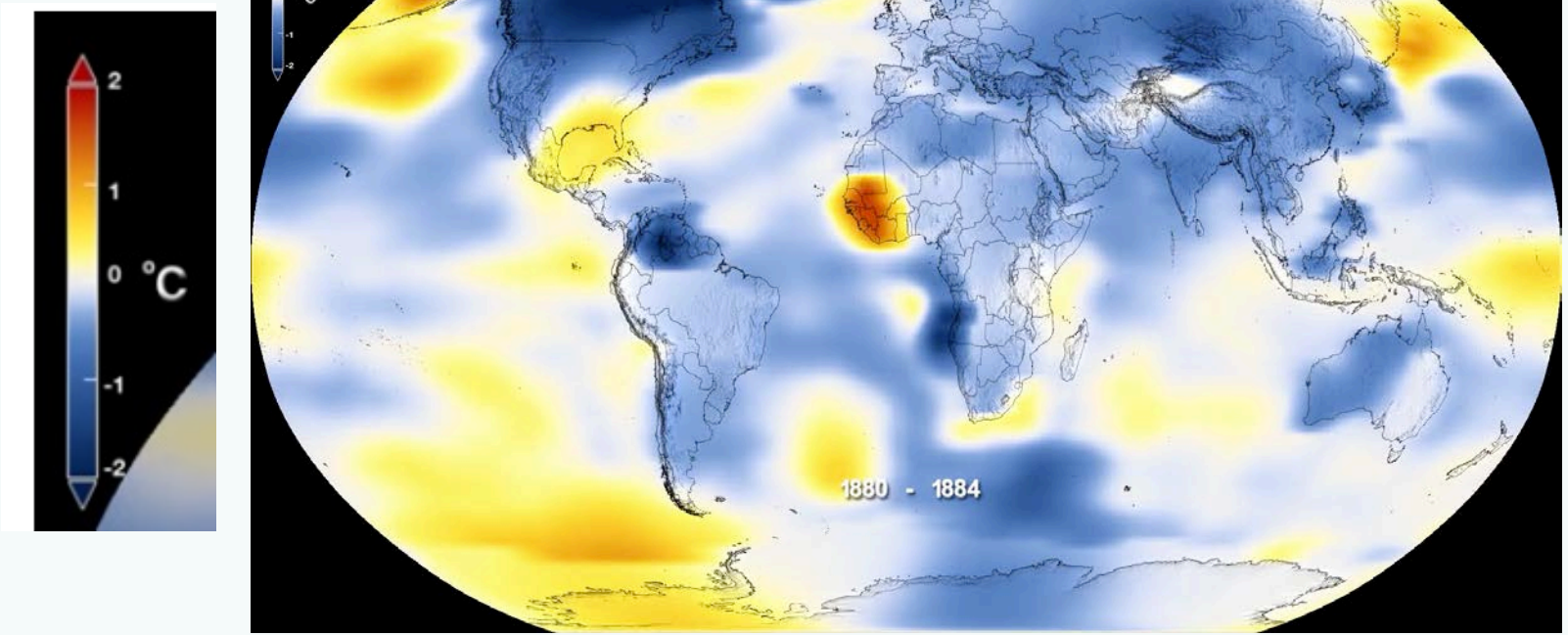
- Global warming
- Sea level rise
- Extreme weather

Global Warming (Time Perspective)

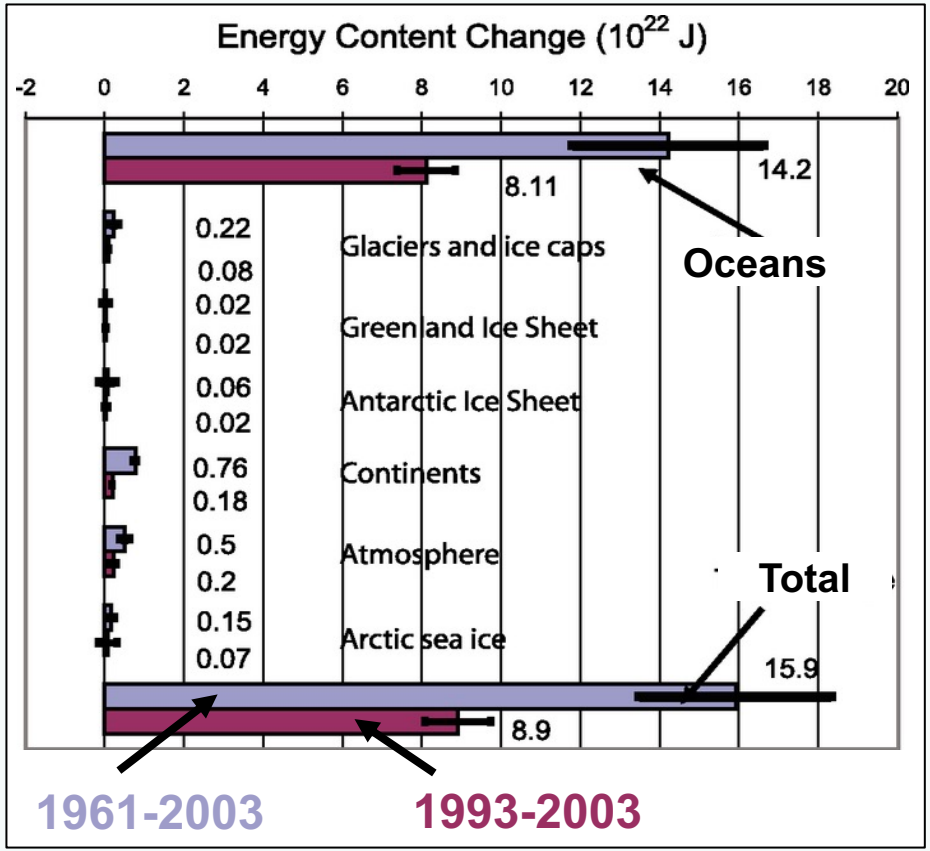


Spatial Variability

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



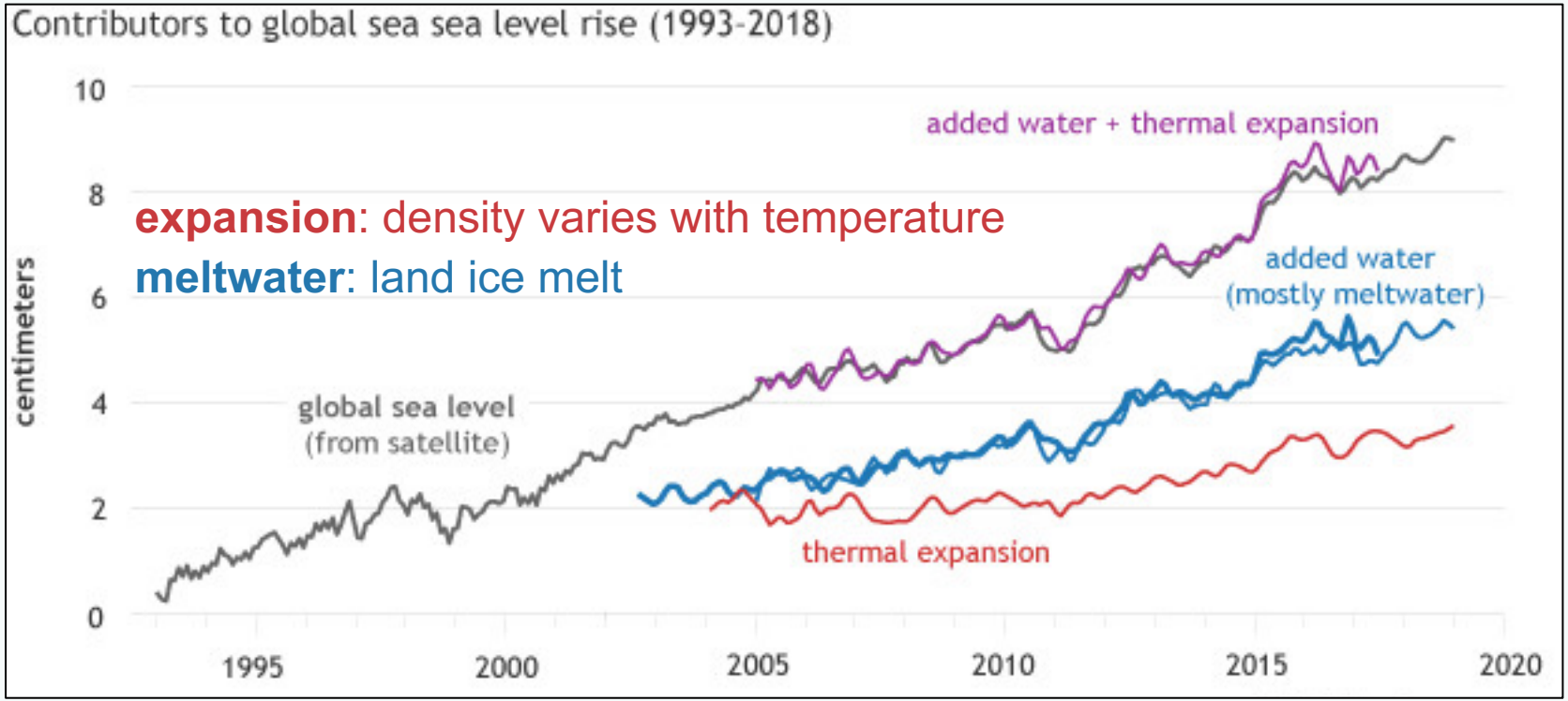
Global Heat Uptake



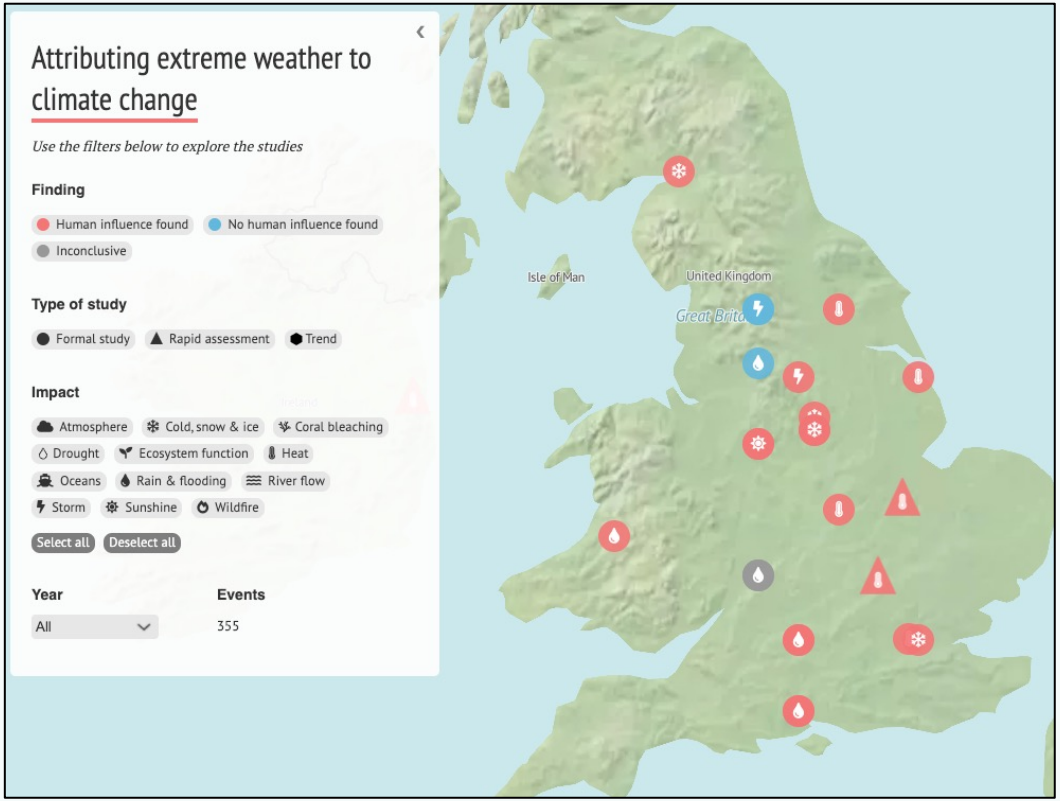
- Oceans absorbing majority of additional heat energy
- Radiative forcing is an energy flow (J s^{-1} m^{-2})
- We expect a gain in heat (in J)
- The amount of heat the planet can store (thermal inertia) controls the pace of change

Sea Level Rise

Sea level changes can come from 2 sources:



Extreme Weather



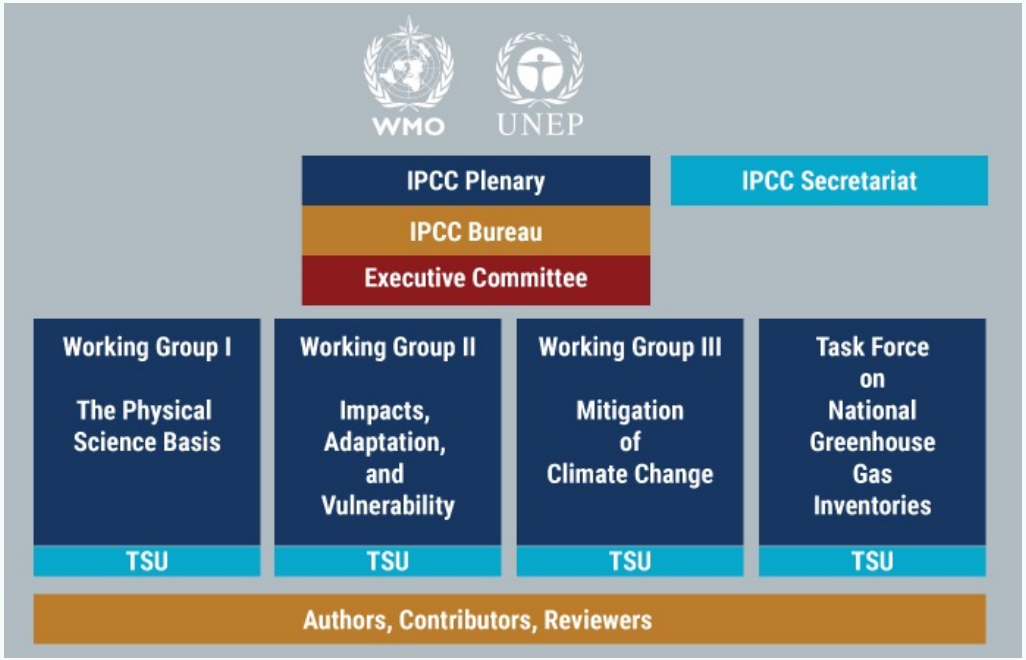
- Extreme weather and related events increase in severity and frequency
- Many attributed to climate change
- Interactive tool to explore documented extreme weather events and link to climate change: https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world

FUTURE PROJECTIONS

- Climate models
- IPCC
- Responses

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

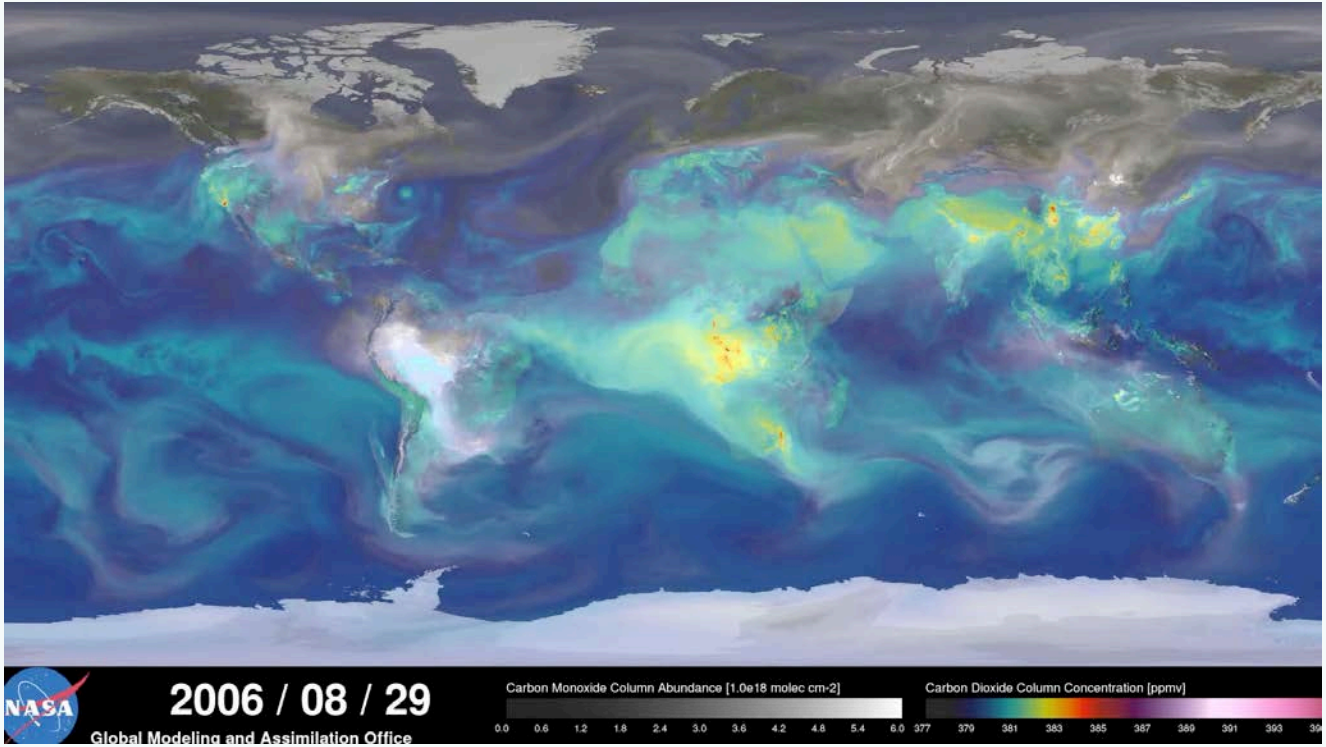


TSU: technical support unit

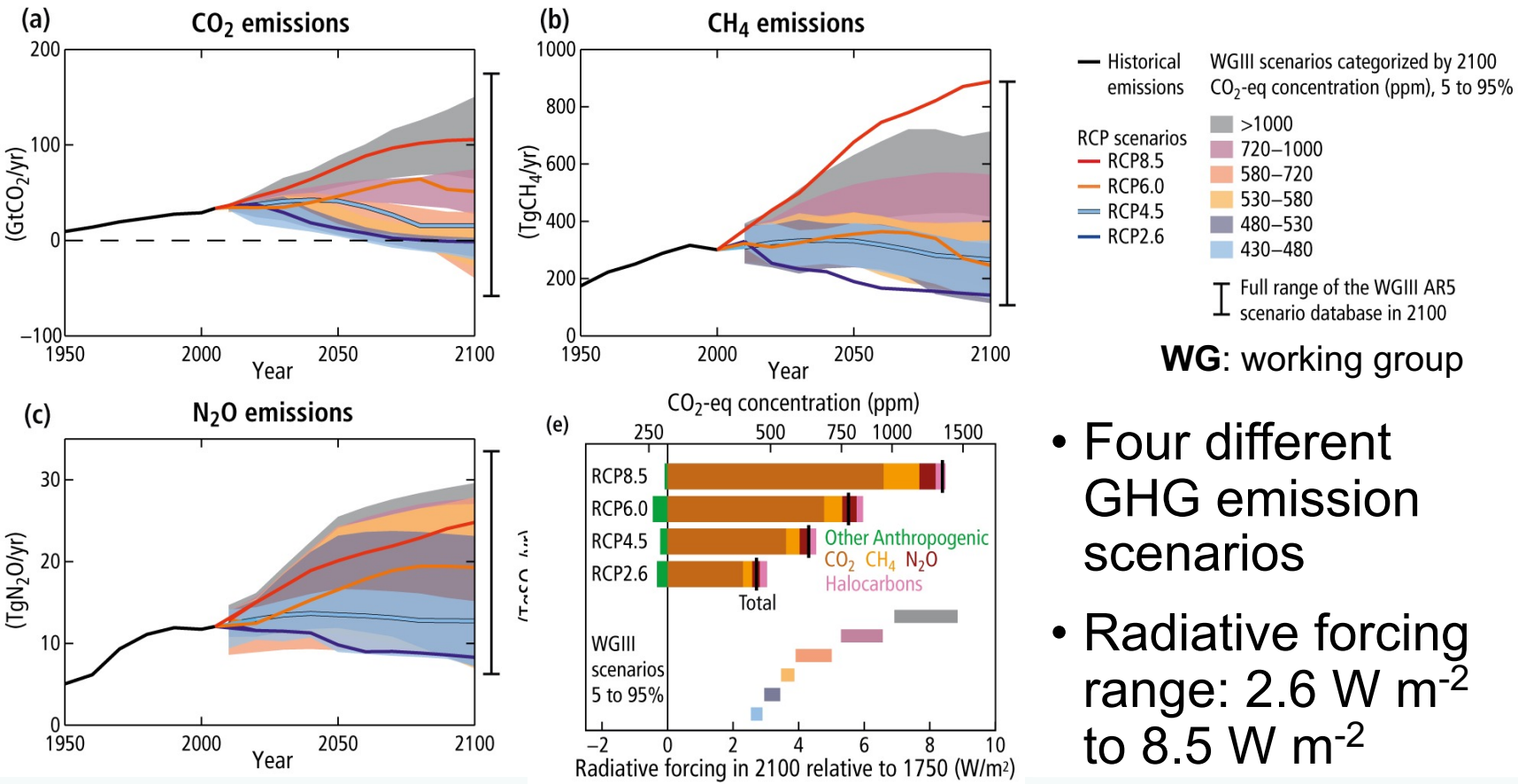
Climate Models

- 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



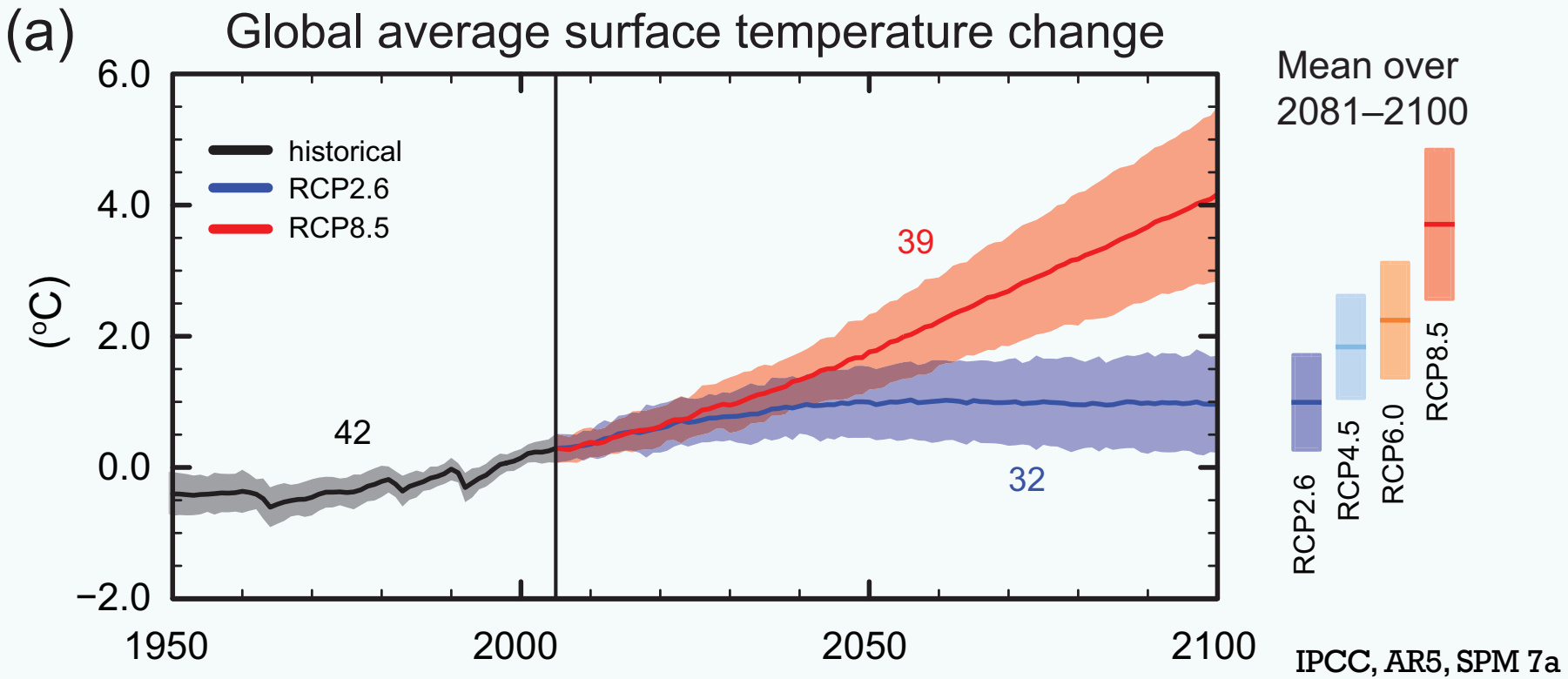
Scenarios



WG: working group

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

Future Temperatures

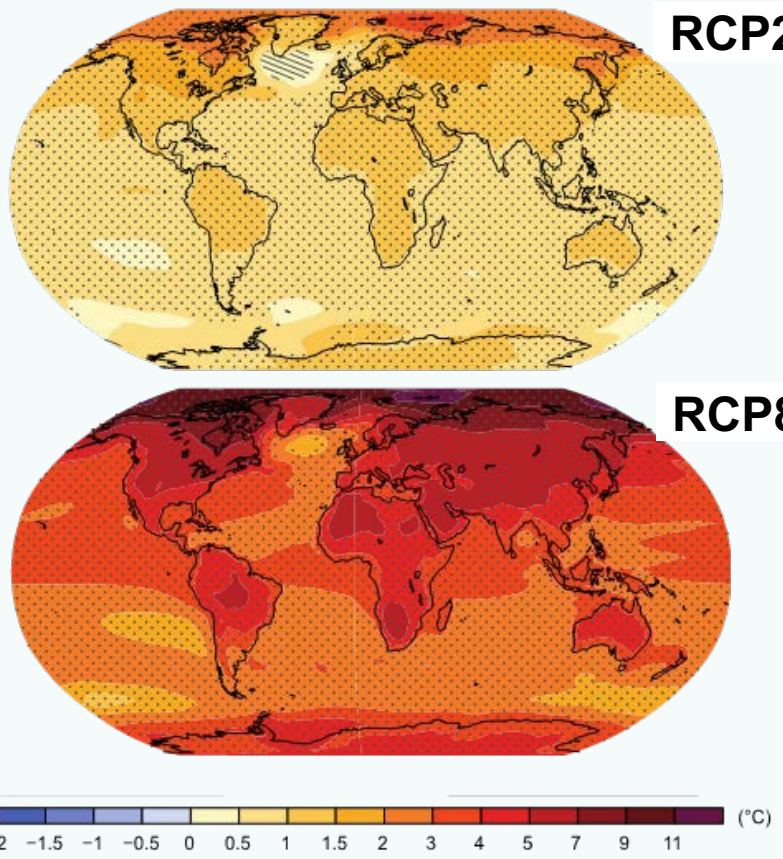


IPCC, AR5, SPM 7a

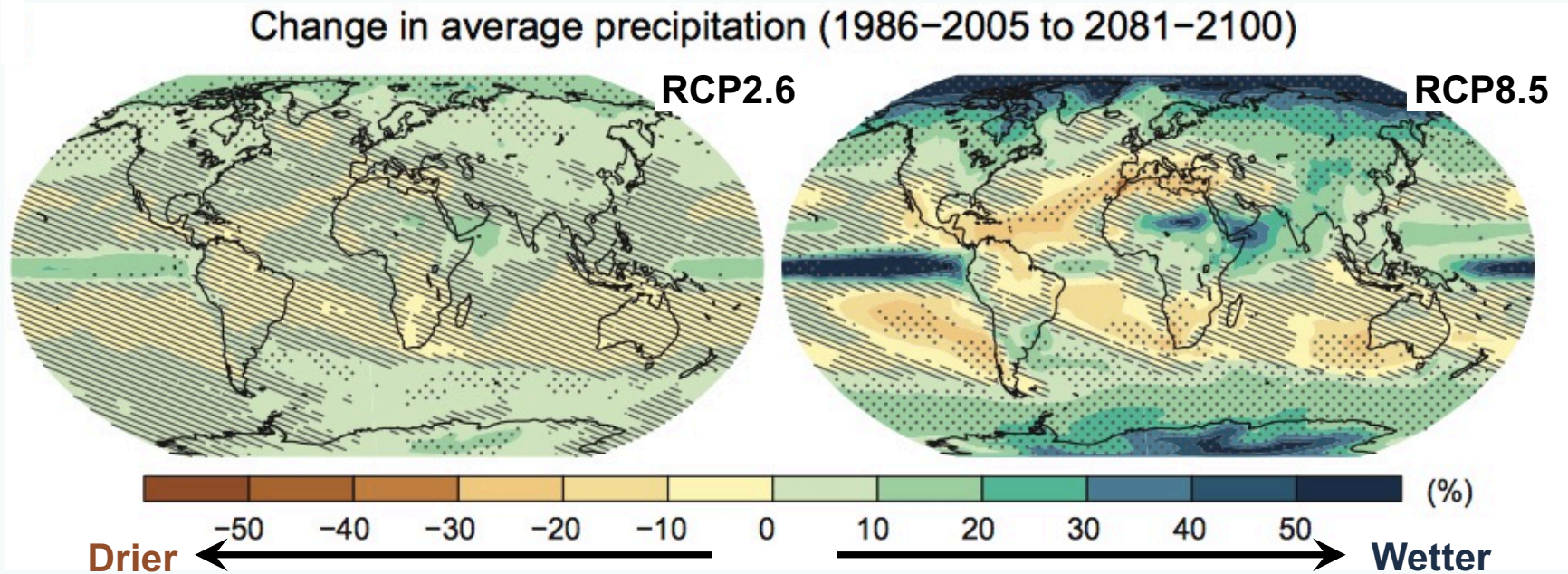
Spatial Pattern of Warming

- 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)

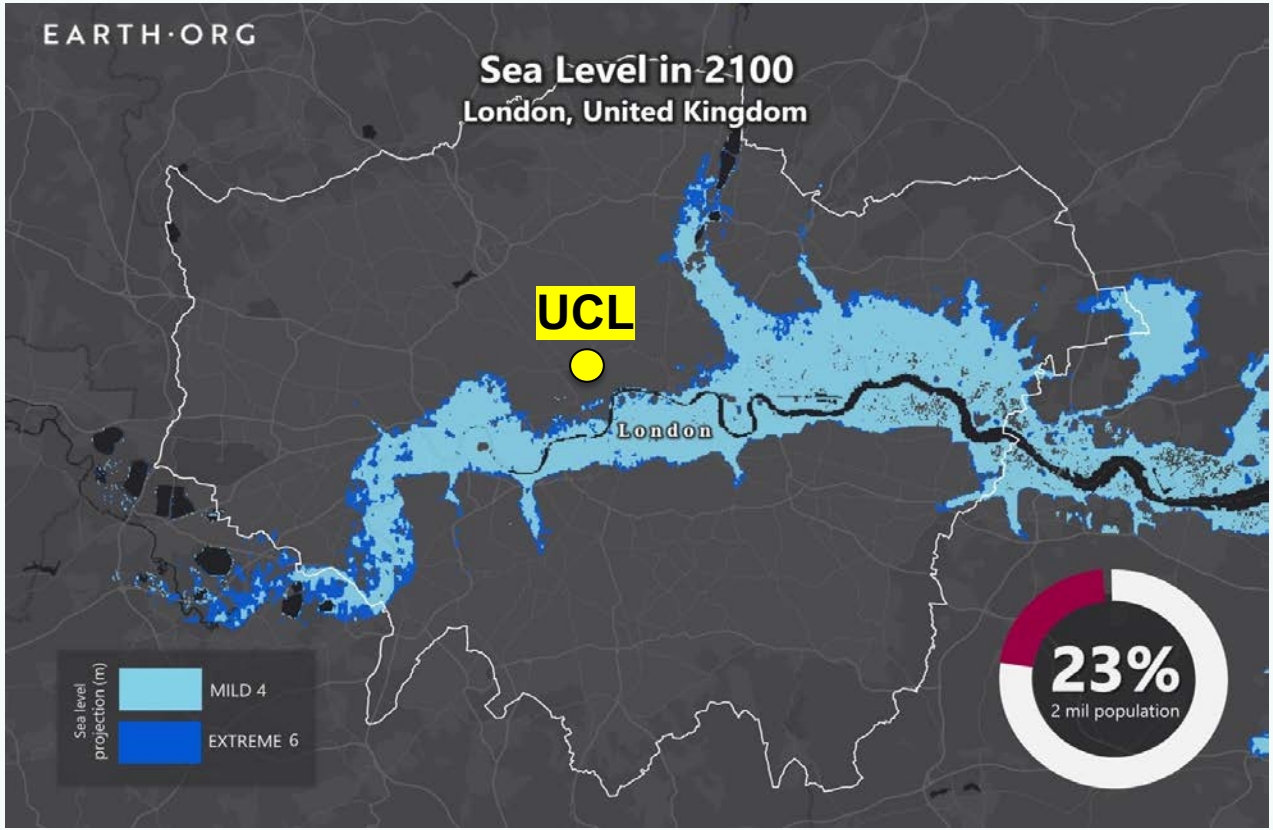


Rainfall / Precipitation



- 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)

Sea Level Rise



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

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/]

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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?