Global Climatic Change

GEOG/ENST 2331 – Lecture 22

Ahrens: Chapter 16

Global Climatic Change

- Review: Radiation balance
- Enhanced greenhouse effect
  - human-induced change
- Climate feedbacks

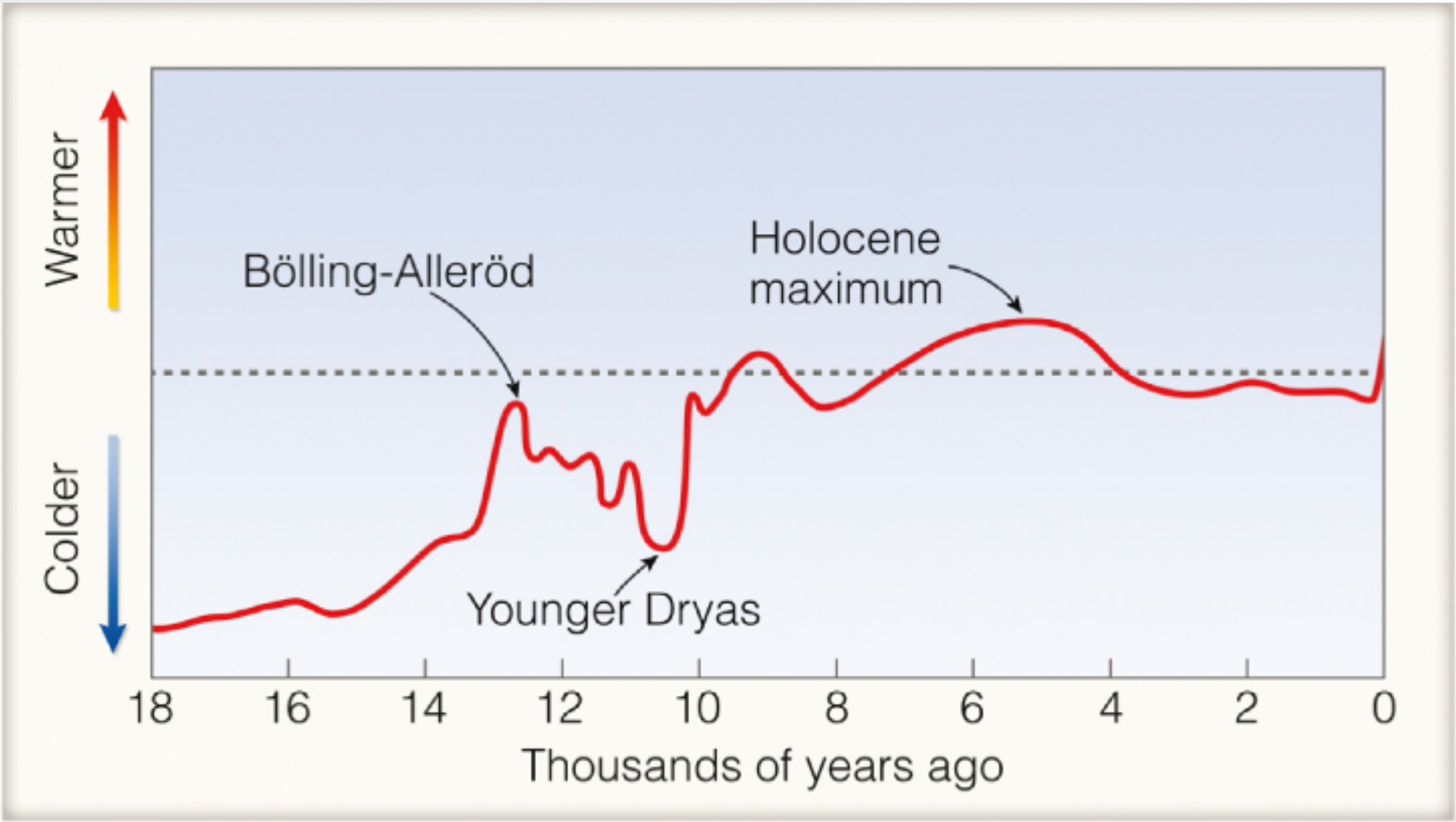
Climatic change

- Climate
  - Long-term description of weather patterns
  - “Expectations”
  - Mean, variability, extremes, frequency
- Climatic change
  - A change in these statistical values
  - Climate change, such as warming, may vary differentially across the globe

Climate and weather

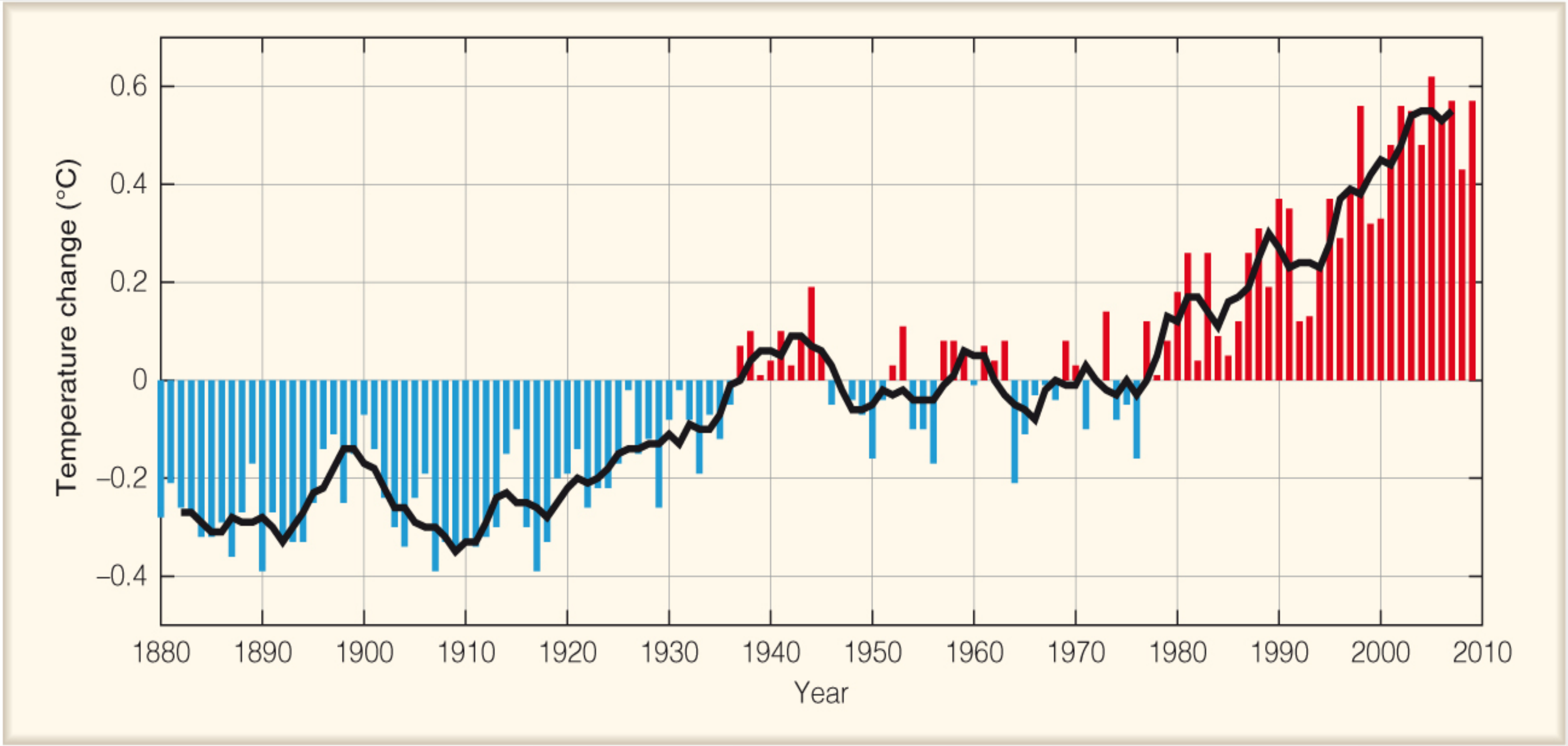
- Weather changes happen all the time
  - These are regular features of a complex system
- Local climate changes can occur as a result of changes to local conditions
  - Albedo, landforms, water bodies
- Global climate changes require changes in the global energy balance

Climate change history



Ahrens: Fig. 16.5

Recent global warming



Zero line is 1951-1980
Ahrens: Fig. 16.7

Thermodynamics

- First Law of Thermodynamics
  - Energy cannot be created or destroyed
  - $E_{in} = E_{out} + \Delta E_{stored}$
  - At equilibrium, $\Delta E_{stored} = 0$ and $E_{in} = E_{out}$
- Note that T is a function of E_{stored}

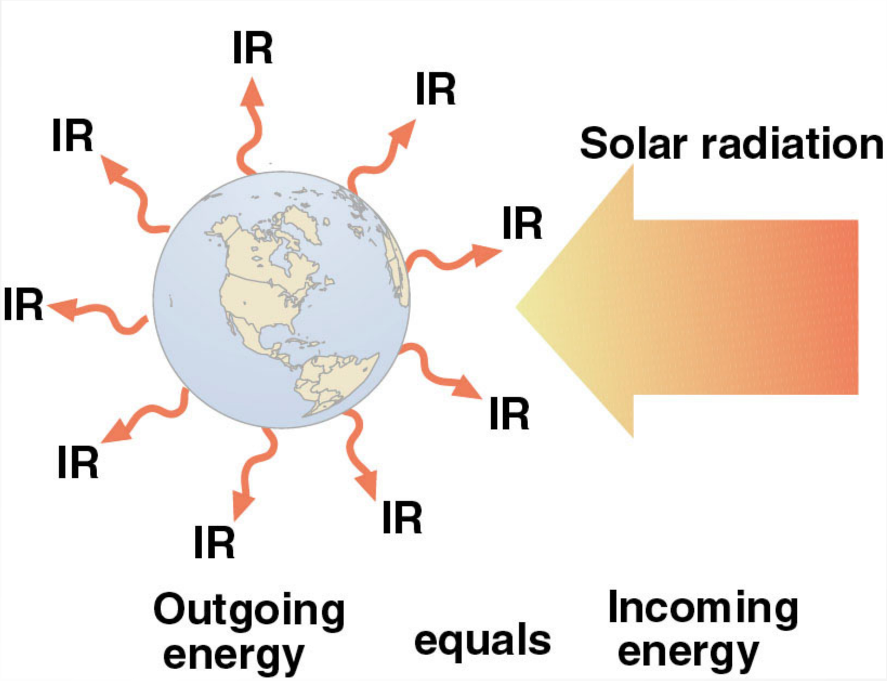
Thermodynamics

- Stefan-Boltzmann Law
  - All matter emits radiation proportional to the fourth power of its temperature
  - E_{out} is proportional to T^4
- For the Earth:
  - E_{in} is radiation coming from the sun
  - E_{out} is radiation emitted by Earth

Thermodynamics

- So:
  - At *equilibrium*, Earth's temperature must be $E_{out} = E_{in}$
  - If E_{out} is less than E_{in} there will be an increase in E_{stored}
  - This will cause T to increase until the fluxes are equal again
  - **If the amount of radiation emitted by the Earth is less than what it receives from the Sun, there will be a global warming**

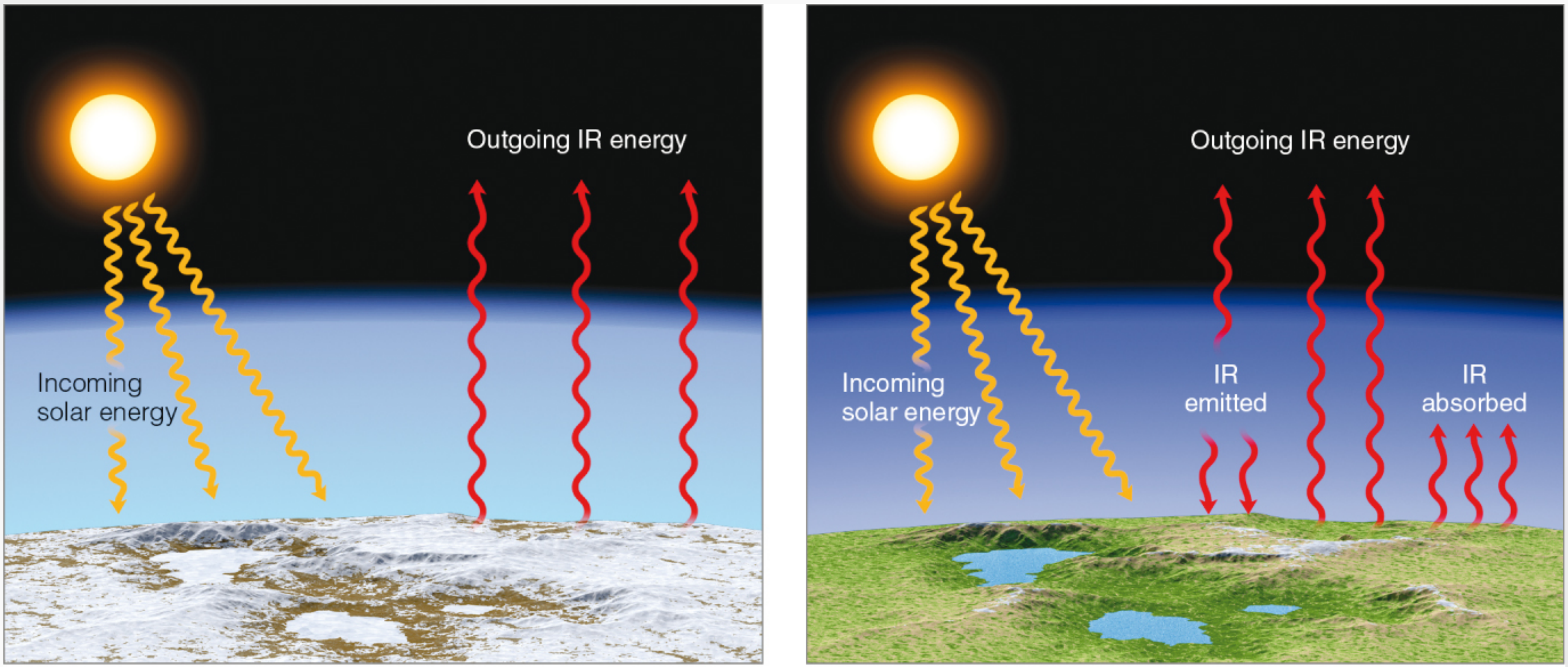
Earth's Energy Balance



- We calculated the effective radiative temperature of Earth:

  255 K (-18°C)

The Greenhouse Effect



255 K | 288 K

Ahrens, Fig. 2.12

What can change the global energy balance?

- Incoming energy
  - Solar strength
  - Aerosols (e.g. volcanoes)
- Outgoing energy
  - Greenhouse gases
  - Change in land use

Greenhouse effect

Natural

- H_2O
- CO_2
- CH_4
- N_2O
- O_3

Enhanced

- CO_2
- CH_4
- N_2O
- O_3
- Halocarbons (CFCs)
- SF_6
- Perfluorocarbons (PFCs)

Carbon Dioxide

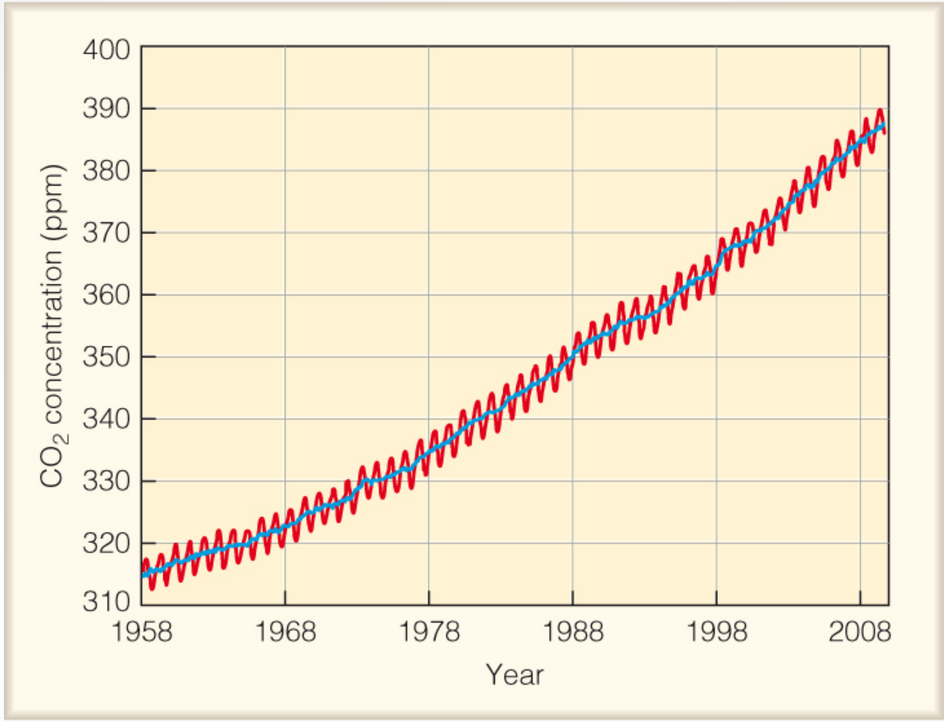
Preindustrial concentration was 280 ppmv

Current concentration is about 400 ppmv

Emissions:

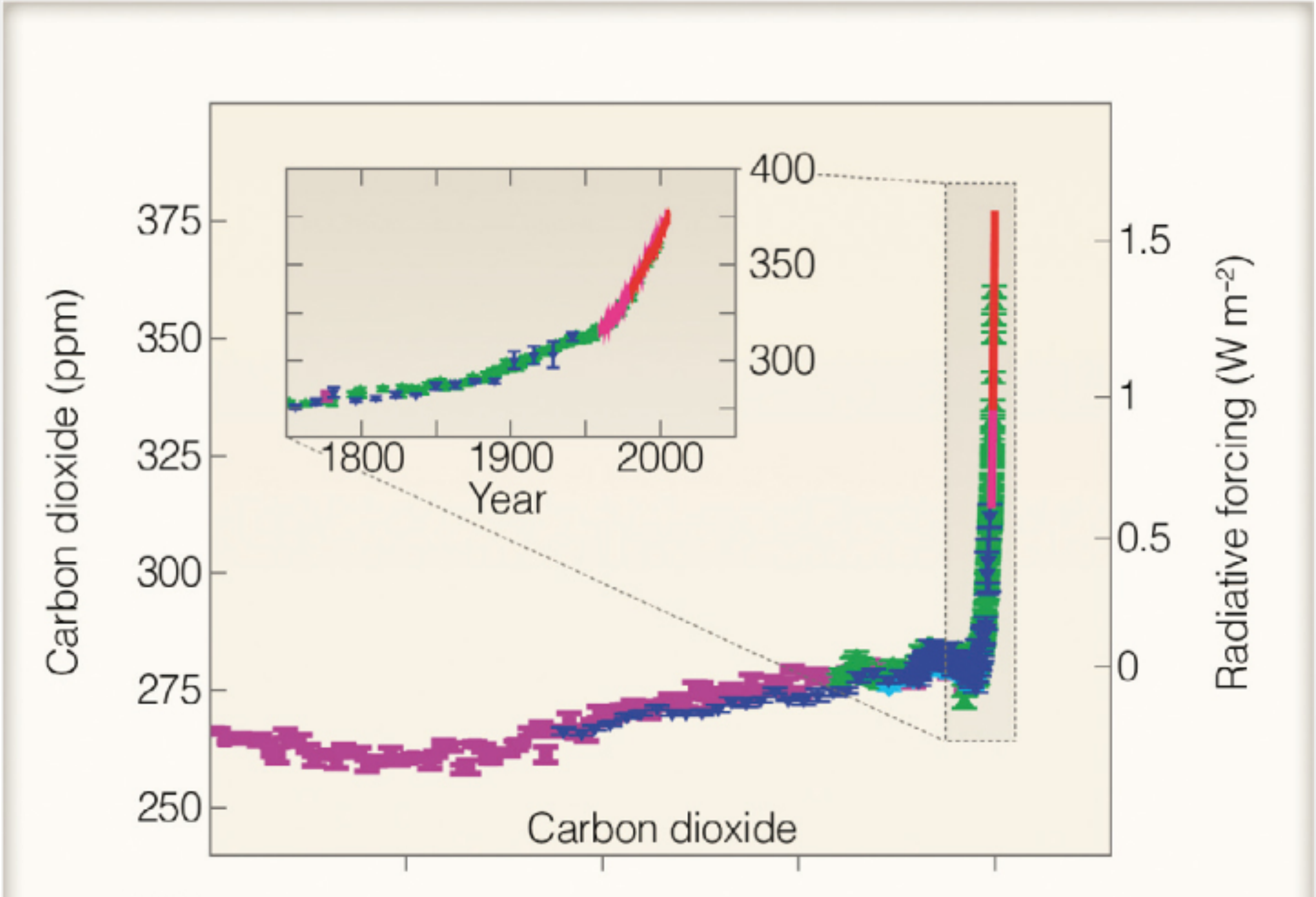
- Fossil fuels, 9 GtC/year
- Deforestation, 2 GtC/year

CO_2 doubling will occur around 2050 (560 ppmv)



Ahrens: Fig. 1.5

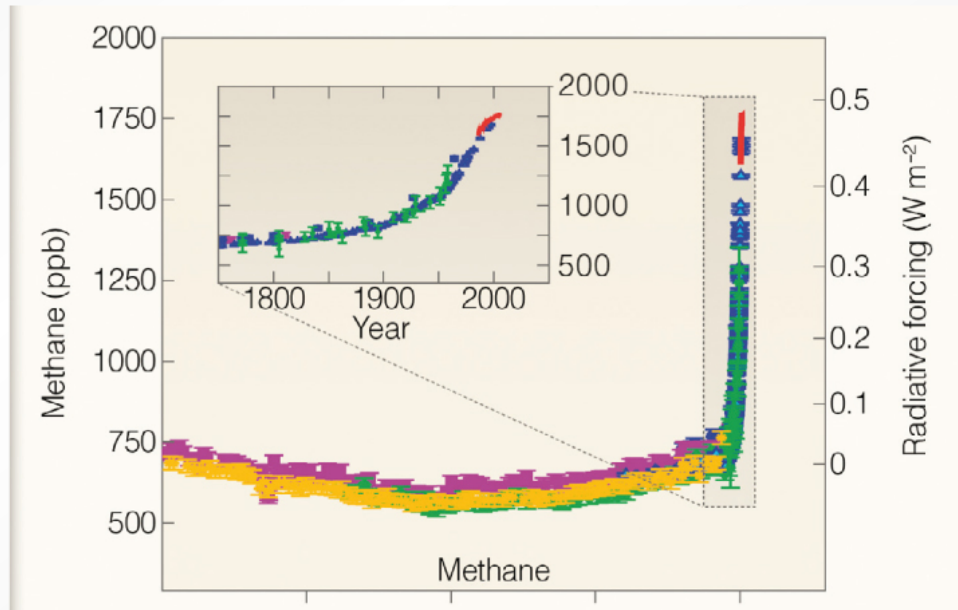
Historical Carbon Dioxide



10000 years from the present

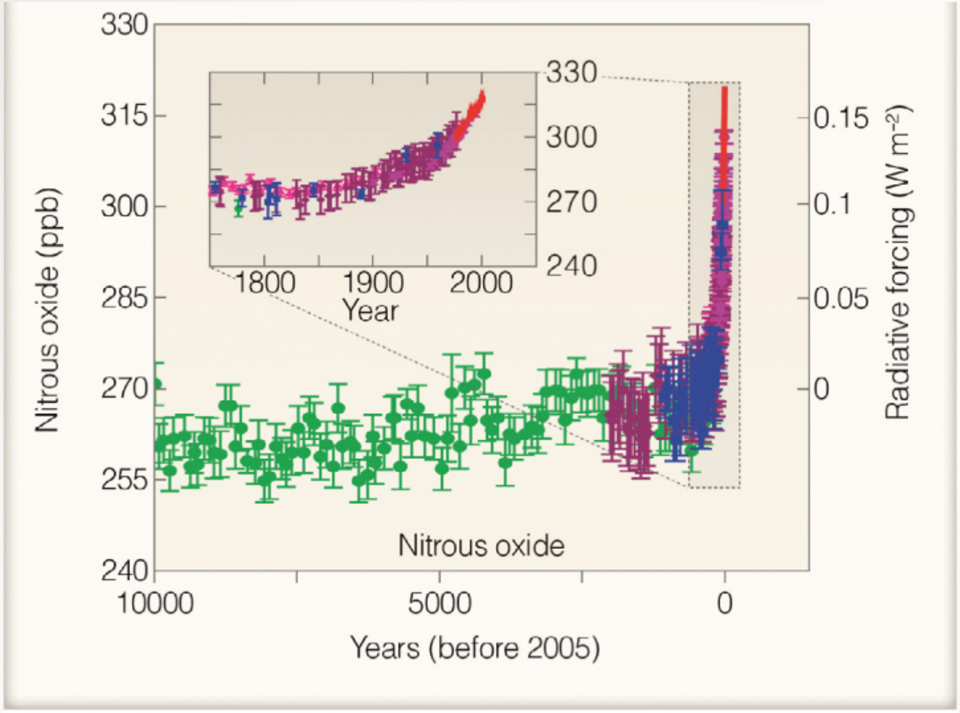
Methane: CH_4

Preindustrial	**0.7 ppmv**
Current	1.78 ppmv
Atmospheric Lifetime	8-12 years
Anthropogenic Emissions	Livestock (cattle) Natural Gas Leaks Oil and Coal Extraction Landfills Biomass Burning Sewage Treatment Rice Paddies
Strength vs. CO_2	26 times



10000 years before present

Nitrous Oxide: N_2O



Preindustrial	0.275 ppmv
Current	0.32 ppmv
Atmospheric Lifetime	120 years
Anthropogenic Emissions	Fertilizers Fossil Fuels Deforestation
Strength vs. CO_2	206 times

Ahrens: Fig. 16.27

Halocarbons: CFCs, HCFCs, HFCs

- Used in refrigeration and air conditioning
- Per molecule, often several thousand times as strong as CO_2

- Rapid increase in concentration since 1960s
- CFCs deplete stratospheric ozone; replaced by HCFCs and HFCs

Other anthropogenic gases

- Sulphur Hexafluoride (SF_6)
  - Electrical insulator for power distribution
  - Lifetime: 3 200 years
  - Strength: 36 000 times as strong as CO_2

- Perfluorocarbons (PFCs)
  - Solvents, refrigerants
  - Lifetime: thousands of years
  - Strength: thousands of times as strong as CO_2

Tropospheric ozone: O_3

- Doubled in the NH; in many cities it is up by 5-10 times preindustrial levels.
- Very short lifespan (hours)
- Ozone precursors:
  - NO and NO_2
  - Hydrocarbons
  - CO
- Main sources:
  - Burning biomass and fossil fuels

Stratospheric ozone: also O_3

- Decreasing trend due to CFCs, HCFCs, and others
- **Loss contributes to global *cooling* in the stratosphere**

Other contributors to global climatic change

- Aerosols
  - Tiny particles suspended in the air
  - Reflect sunlight and increase cloud reflectivity

  - Tropospheric air pollution (SO_x, NO_x)
  - Volcanoes

Other contributors to global climatic change

- Land cover change
  - Urban heat islands
  - Deforestation increases surface albedo

- Solar variation
  - Observed changes have been small
  - Long-term cycles not well-understood

Feedbacks

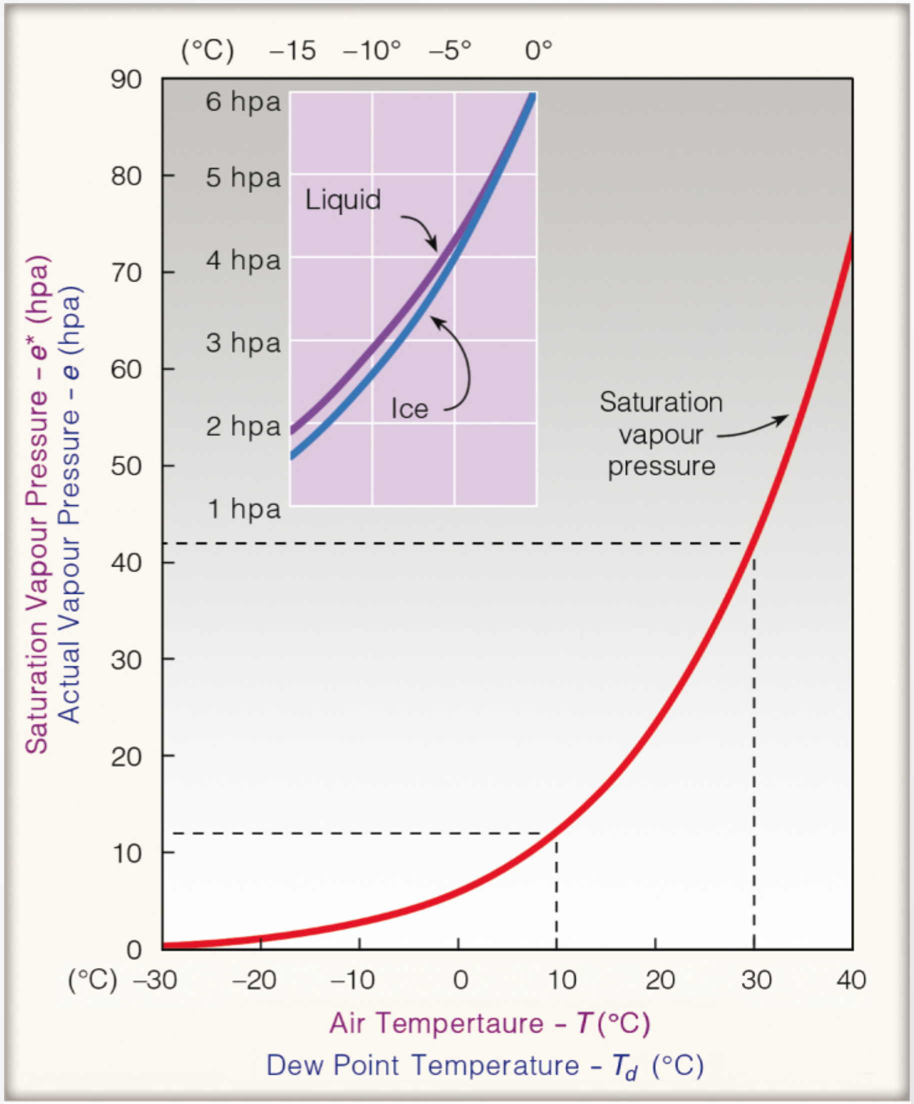
- A response to an change that acts to amplify or diminish the initial change
- E.g. sound system amplifier, thermostat

- A climate feedback responds to a change in climate by causing *less or further change*
  - Positive feedback: more change
  - Negative feedback: less change

Water vapour

- Saturation vapour pressure depends on temperature
- Higher temperatures lead directly to increased water vapour

- Water vapour is a greenhouse gas
- Positive feedback



Ice and snow

- Ice and snow are very reflective
- Sensitive to changes in temperature
- Also a positive feedback

Ahrens: Fig. 2.13

Clouds

- Reflect shortwave (solar) radiation
  - Cover 50% of surface, albedo of 50%
- Absorb longwave (terrestrial) radiation
- Emit radiation to space and back down to the surface

- Changes in the extent of clouds affects all three

Forcing from Doubling CO_2

- Pre-industrial CO_2: 280 ppmv
- *Actual* doubling of CO_2: 560 ppmv
  - Likely around 2050

- However, other greenhouse gases are increasing as well
- *Equivalent* $2 \times CO_2$ when the combined *radiative forcing* is equal to that of 560 ppmv of CO_2

Climate sensitivity

- The globally averaged equilibrium change in temperature in response to a given radiative forcing
  - Decades after a change in forcing, climate will approach a new equilibrium
- The predicted climate sensitivity to $2\times CO_2$ is between 1.5 and 4.5°C
- To date,

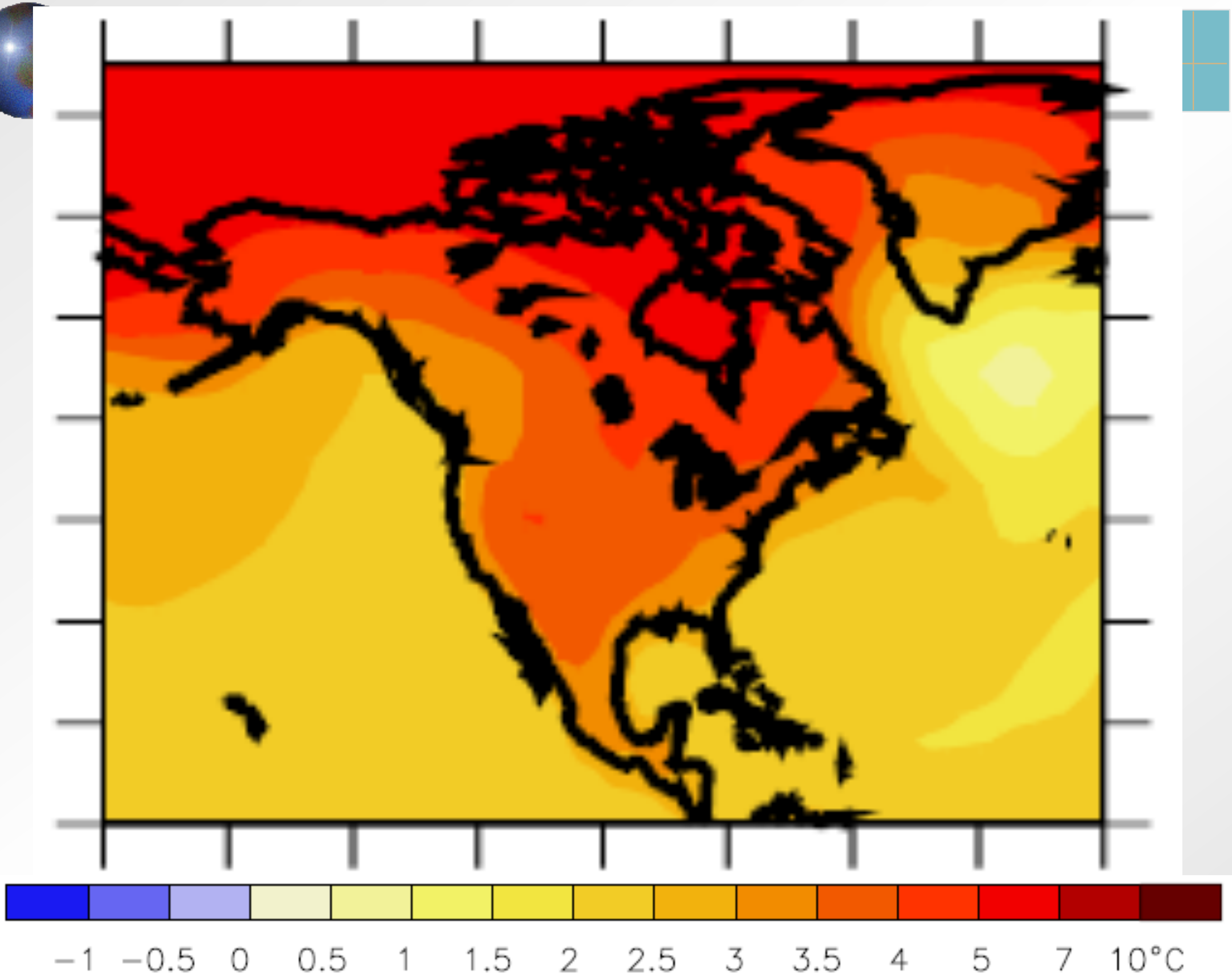
Continentality

- With warmer temperatures, rate of evaporation will increase
  - Evaporation causes latent cooling
  - Increase in evaporation will be larger over open water
- Continents will warm more than the average
  - And oceans will warm less
  - Mid-continents with dry soil will warm the most

Latitude

1. Greater warming is occurring at higher latitudes due to the ice albedo feedback

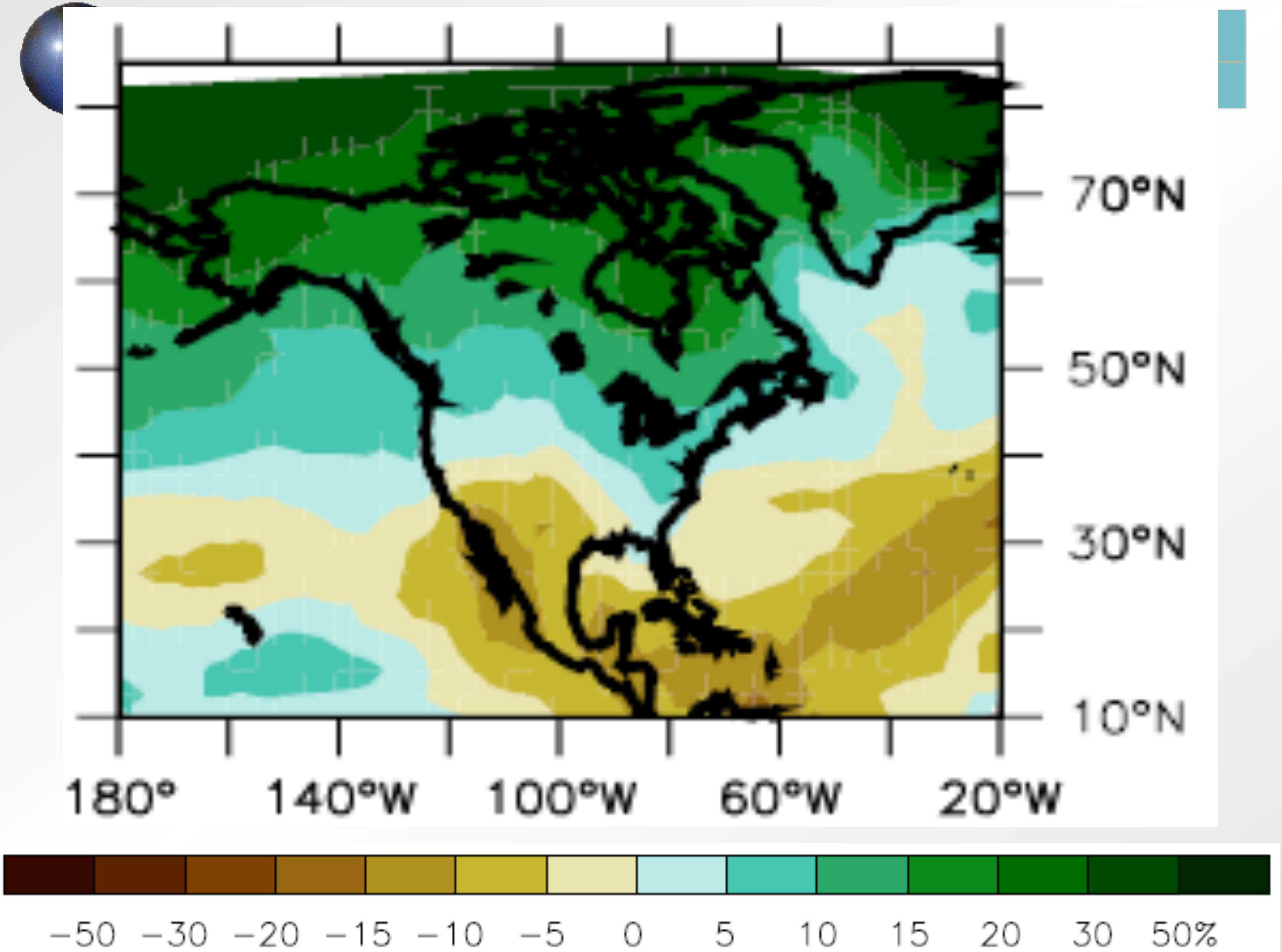
2. In the winter, sea ice insulates cold air from warmer water
   - Thinner ice means less insulation
   - Even greater polar amplification in winter


−1 −0.5 0 0.5 1 1.5 2 2.5 3 3.5 4 5 7 10°C

Hydrological cycle

- More intense overall
  - Increased evapotranspiration, precipitation

- Likely (but less certain):
  - Drier soils at mid-continents in summer
  - Midlatitude precipitation belts will shift poleward
  - Increased variability of precipitation
    - More droughts and floods
  - Stronger monsoons in Asia and West Africa


70°N
50°N
30°N
10°N
180°
140°W
100°W
60°W
20°W
−50 −30 −20 −15 −10 −5 0 5 10 15 20 30 50%

Storms

- Summer thunderstorms
  - High confidence in becoming more intense and frequent
- Midlatitude cyclones
  - May get weaker
- Tropical cyclones (hurricanes)
  - Opposing factors at work
  - Could become less frequent but more intense

Rise in sea level

- Melting ice sheets
  - Greenland
  - Antarctica
  - Mountains
- Thermal expansion

Rise in sea level

- IPCC expects 30-100 cm by 2100
  - **Probably a low estimate**
  - Much more on the way; sea level rise is slow

- Inundation
- Infiltration
- Storm damage

ENSO

- Average climatic conditions could become more El Niño-like
- El Niño events could become stronger or more frequent, increasing climatic variability.

Impacts on natural systems

- Loss of habitat
- Species extinctions
- Ecosystem reorganization
- Forest diebacks
  - Increased fire frequency

Impacts on built systems

- Agricultural losses, especially in tropics
  - Heat-sensitive crops
  - Valuable coastal land lost to sea level
  - Droughts and floods
- Population centres affected by sea level rise
- Melting permafrost at high latitudes
  - Buildings, road, railways, pipelines

Impacts on humans

- Water supply
  - Moisture deficits more common
  - Timing of rainfall can cause stress
  - Saline intrusion along coastlines
- Infectious diseases
  - Disease vectors will shift poleward
  - E.g. Malaria mosquito
- Heat stress

Conference of the Parties (COP) Paris, France COP 21

Final exam

- Saturday, December 12
  - 1 pm – 4 pm
  - Gymnasium W and Y
- Cumulative for all lecture material
- Same format as the midterm
  - 80 multiple choice
  - 8 short answer

Atmospheric circulations

- Thermal winds
  - Land/lake breeze
  - Mountain/valley breeze
  - Monsoon
- Global circulation
  - Three cell model
  - Jet Streams
  - Planetary Waves
- ENSO

Moving air

- Air masses
  - Source regions and classification
  - Modifying air masses
- Fronts
  - Warm, cold, stationary, occluded, dryline
  - Changes in temperature, humidity, wind direction, pressure and cloud cover

Midlatitude cyclones

- Polar front theory
  - Life cycle and dissipation
- Upper air divergence
  - Baroclinic instability
  - Jet streaks
  - Vorticity

Thunderstorms

- Ordinary storms
- Multicell storms
- Supercell storms

- Lightning and thunder
- Hail
- Tornadoes

Hurricanes (Tropical Cyclones)

- Climatology
- Dynamics
- Lifespan

- Hazards
  - High winds
  - Storm surge
  - Heavy rains
- Forecasting

- Polar lows

Climate Classification

- The Köppen system
- Based on vegetation
- 5 types, plus ‘Highland’

Global climatic change

- Causes
  - Review of the radiation balance
  - Anthropogenic greenhouse gases
  - Radiative forcing
  - Feedbacks

- Results
  - Climate sensitivity
  - Distribution of changes in temperature and precipitation
  - Sea level rise

That's all, and

DO WELL!