Global Warming

GEOG/ENST 3331 – Lecture 21

Ahrens: Chapter 16; Turco: Chapter 12

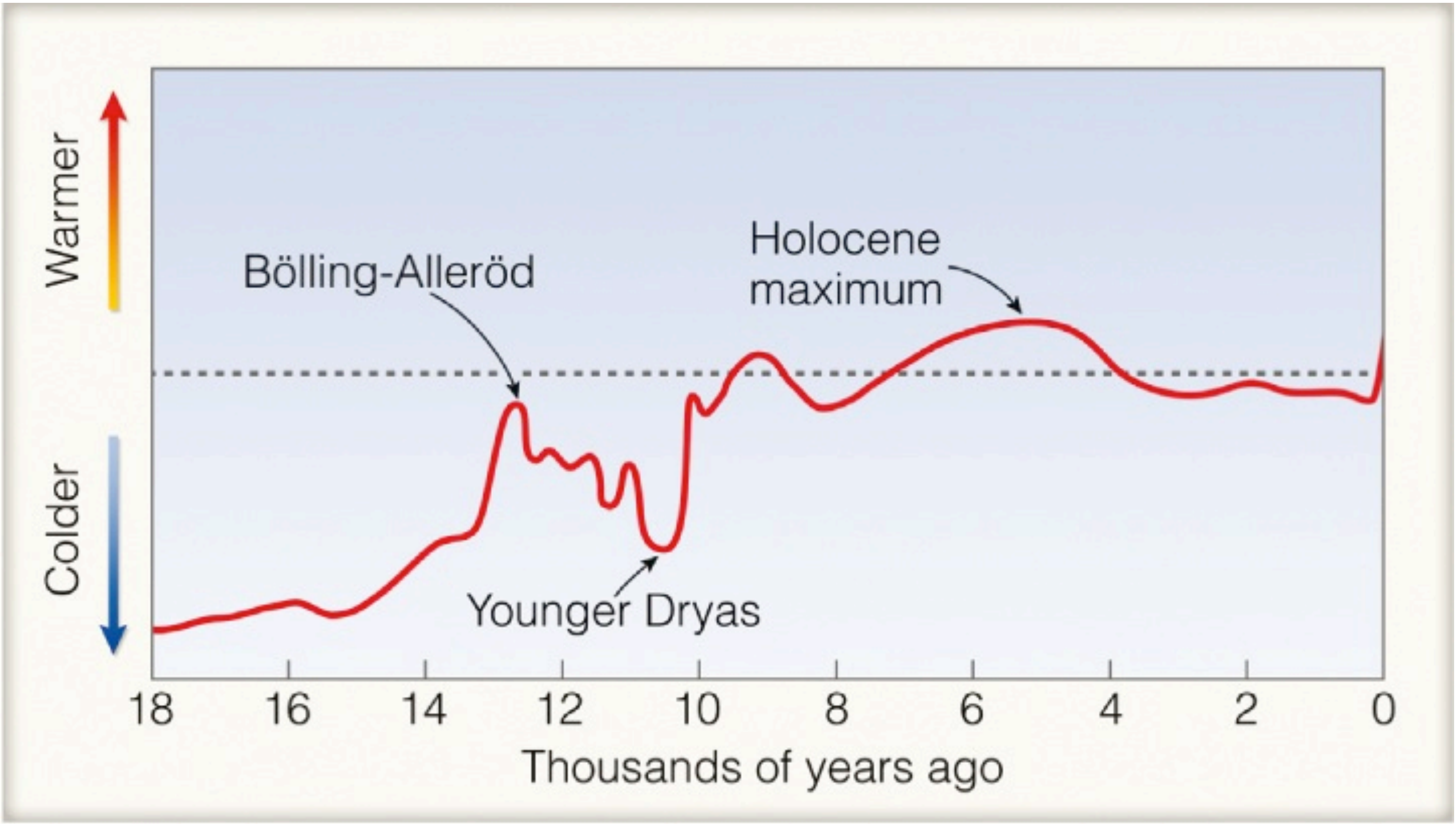
Previous lecture

- Radiation budget review
- Driving factors
  - Albedo
  - Solar forcing
  - Greenhouse gases
- Feedbacks
- The “climate machine”

Last glacial maximum

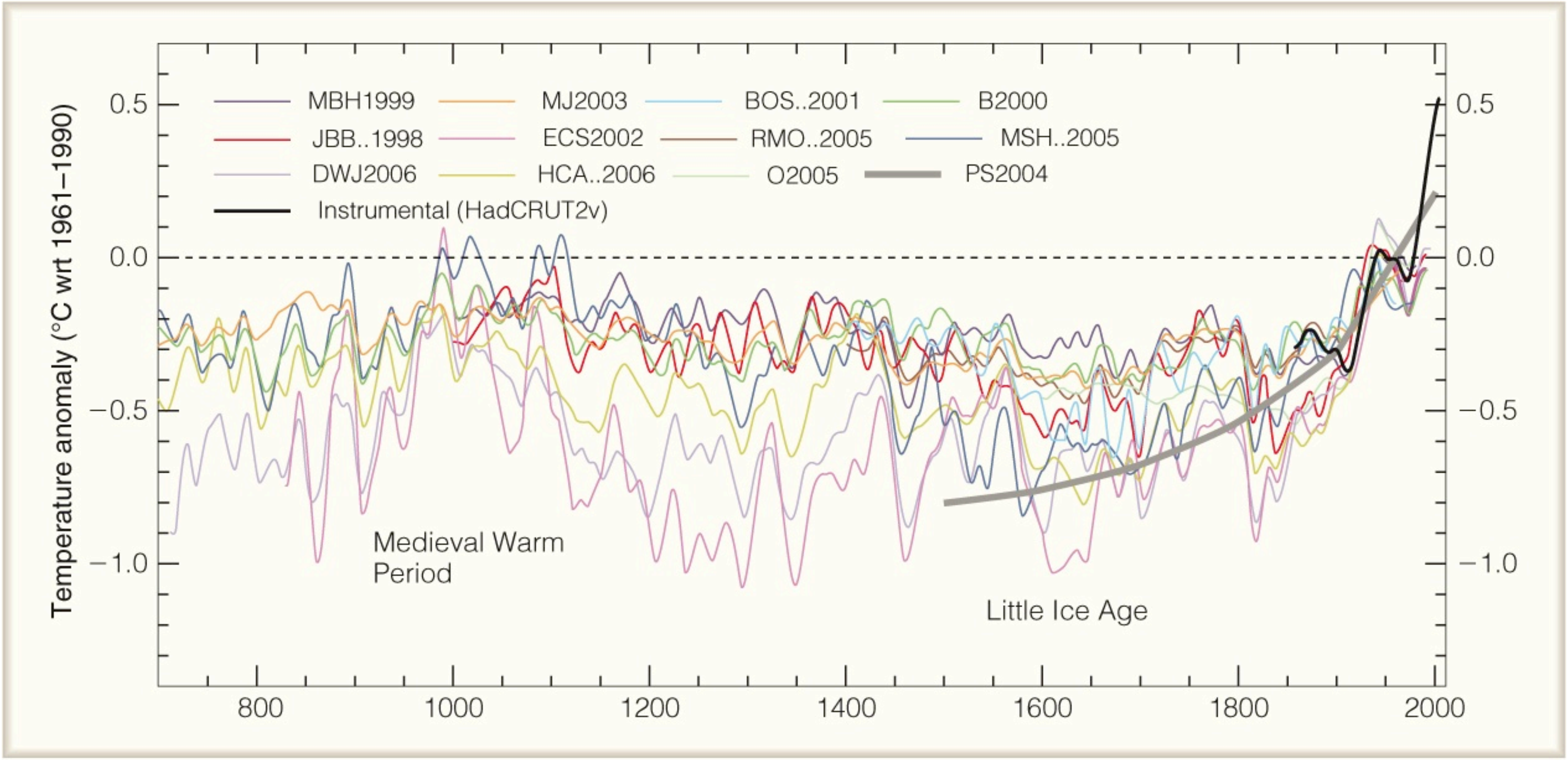
- Ice sheets 3 500 – 4 000 m thick
- Sea level 120 m lower than today
- Globally averaged temperature was probably 5-8° C colder than today
  - Regional temperature differences varied by distance to ice sheets

Recent interglacial



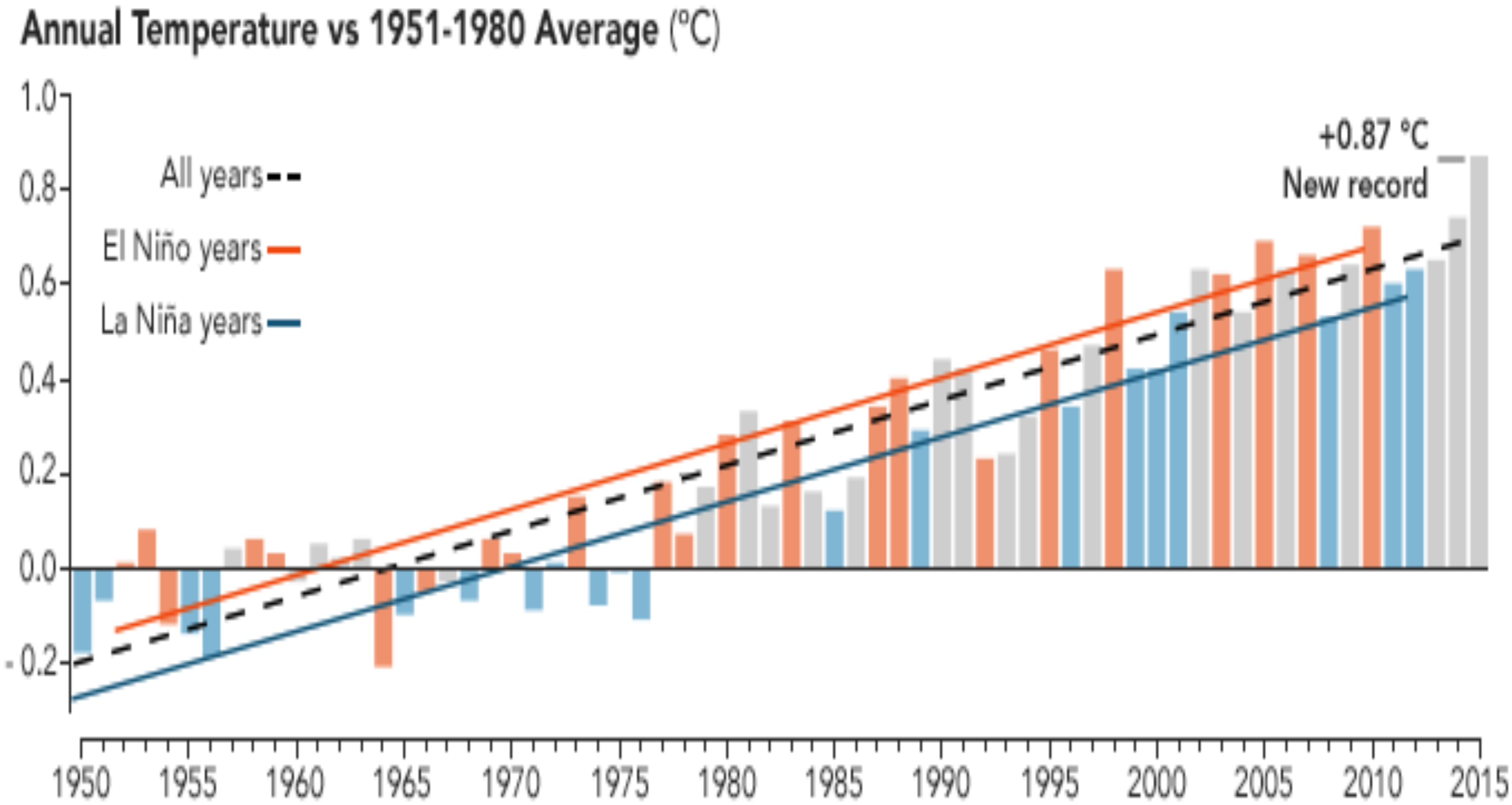
Ahrens: Fig. 16.5

Last 1300 years

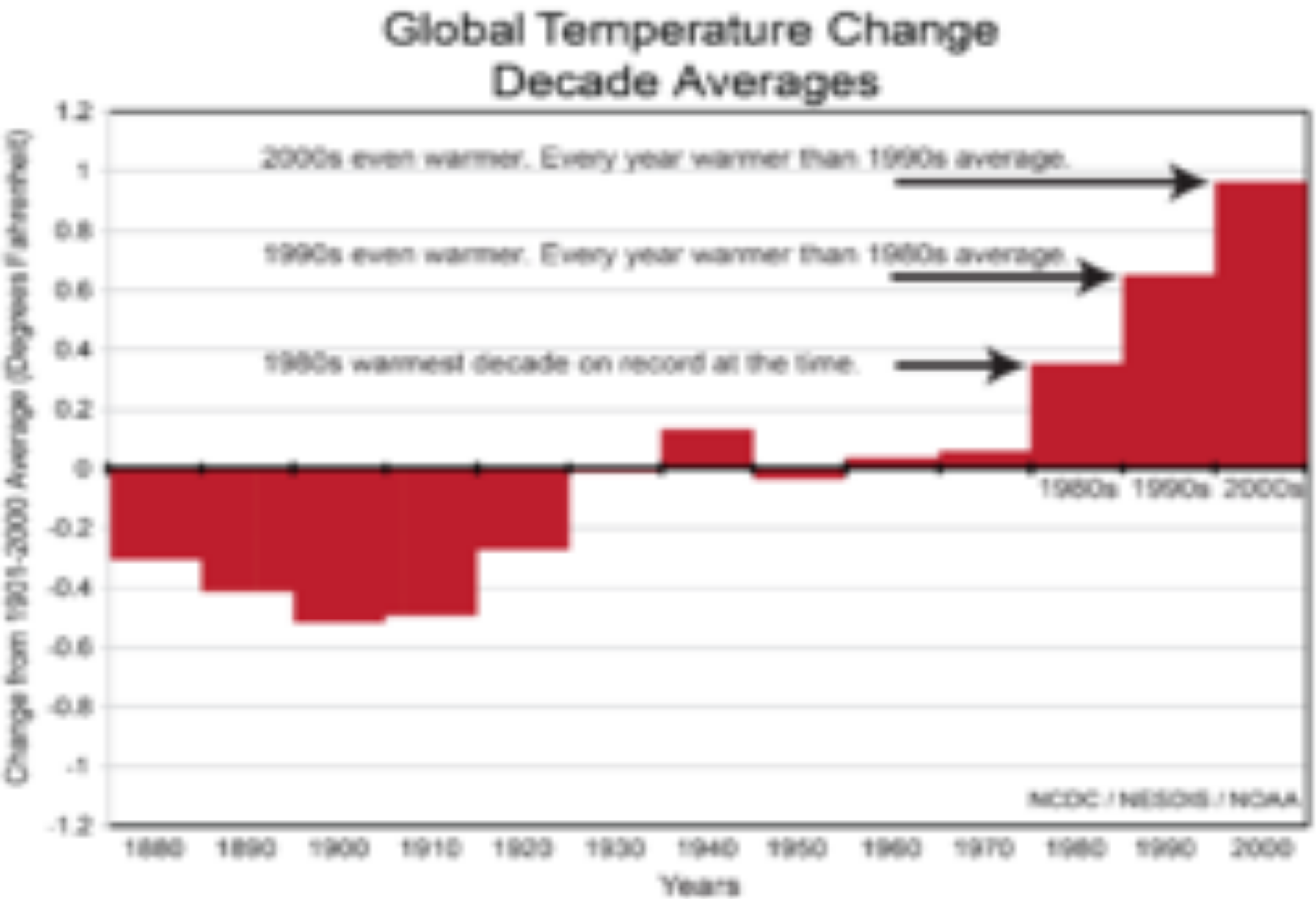


Zero line is 1961-1990 average global temperature
Ahrens: Figure 16.6

Instrumental temperature record 1950-2015



Zero line is 1951-1980 average global temperature


Global Temperature Change
Decade Averages
2000s even warmer. Every year warmer than 1990s average.
1990s even warmer. Every year warmer than 1980s average.
1980s warmest decade on record at the time.
1980s 1990s 2000s
Change from 1901-2000 Average (Degrees Fahrenheit)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
Years
NCDC / NESDIS / NOAA

Radiative Forcing

- A change in the driving factors that forces a change in the radiative balance
  - Solar strength
  - Albedo
  - Greenhouse gases

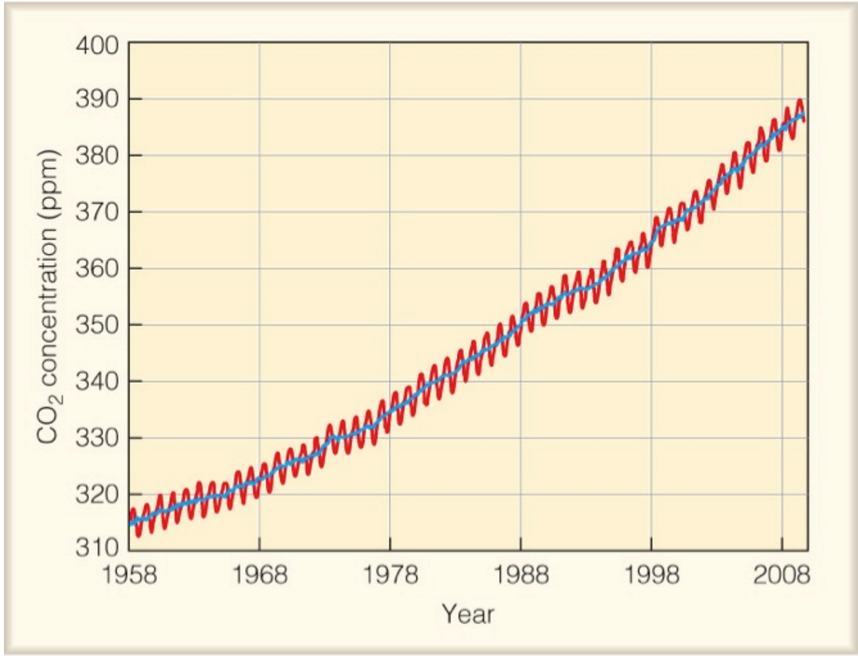
IPCC

- Intergovernmental Panel on Climate Change
- Founded by United Nations in 1988
- Purpose: to provide periodic assessments of the current status of knowledge about climate change

- Does not conduct research
- Operates by consensus
  - More likely to understate risks

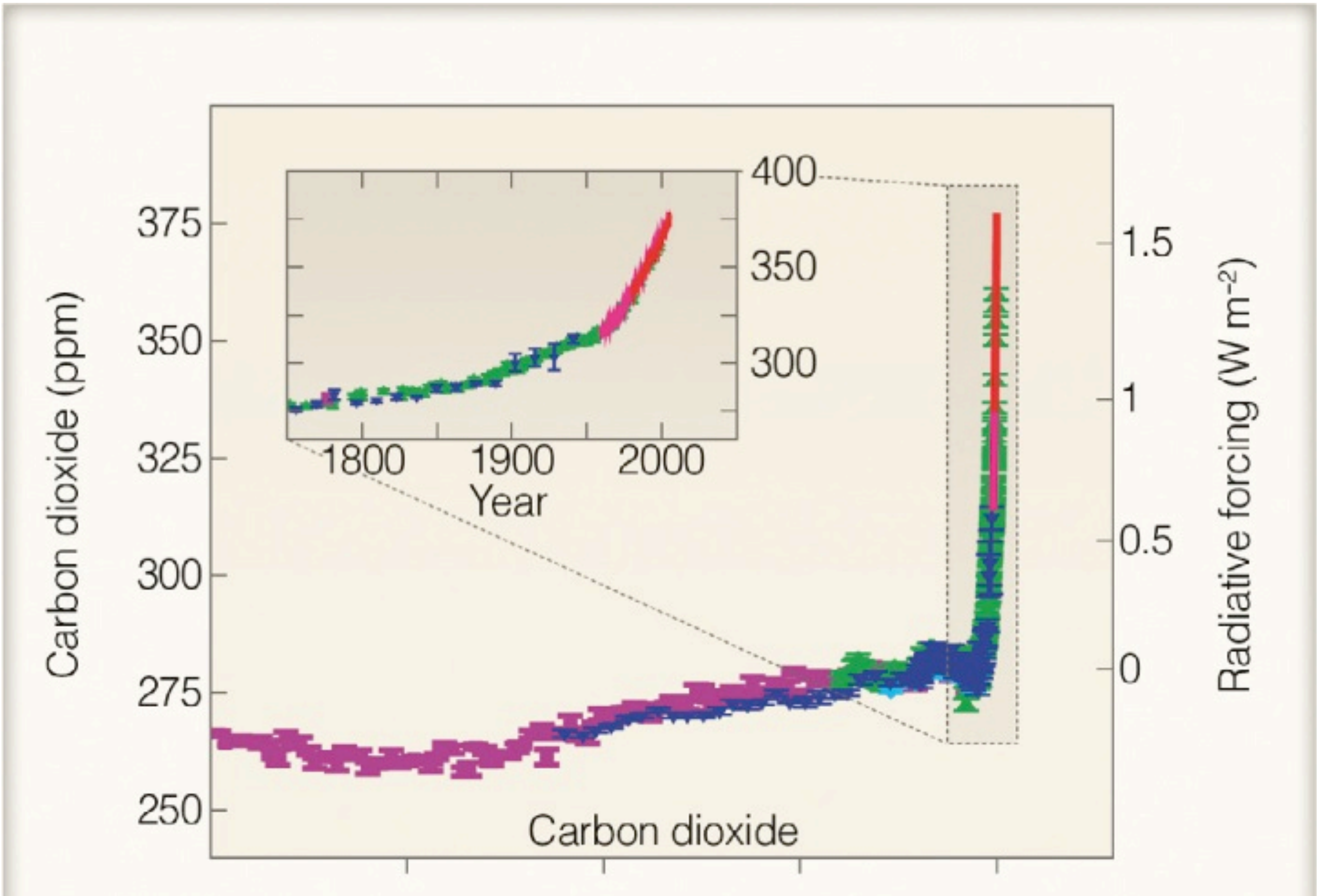
Carbon Dioxide (CO_2)

- Prior to 1800s, varied between 180-300 ppmv.
- Current concentration is about 404 ppmv.
- Emissions:
  - Fossil fuels, 6 GtC/yr
  - Deforestation, 2 GtC/yr
- CO_2 doubling (560 ppmv) will occur around 2050
- Indefinite lifetime



CO_2 concentration, 1958-2008
Ahrens: Fig. 1.5

Historical CO_2



10000 years before 2005

Ahrens: Fig. 16.17

Carbon sinks

- Ocean
  - Dissolution increases as atmospheric concentration increases
- Terrestrial biosphere
  - Photosynthesis on land is limited by CO_2 availability
  - Increased CO_2 fertilizes growth
- Net effect
  - Roughly 50% of new carbon persists in the atmosphere
  - Reservoir is increasing by roughly 4 GtC per year

Methane (CH_4)

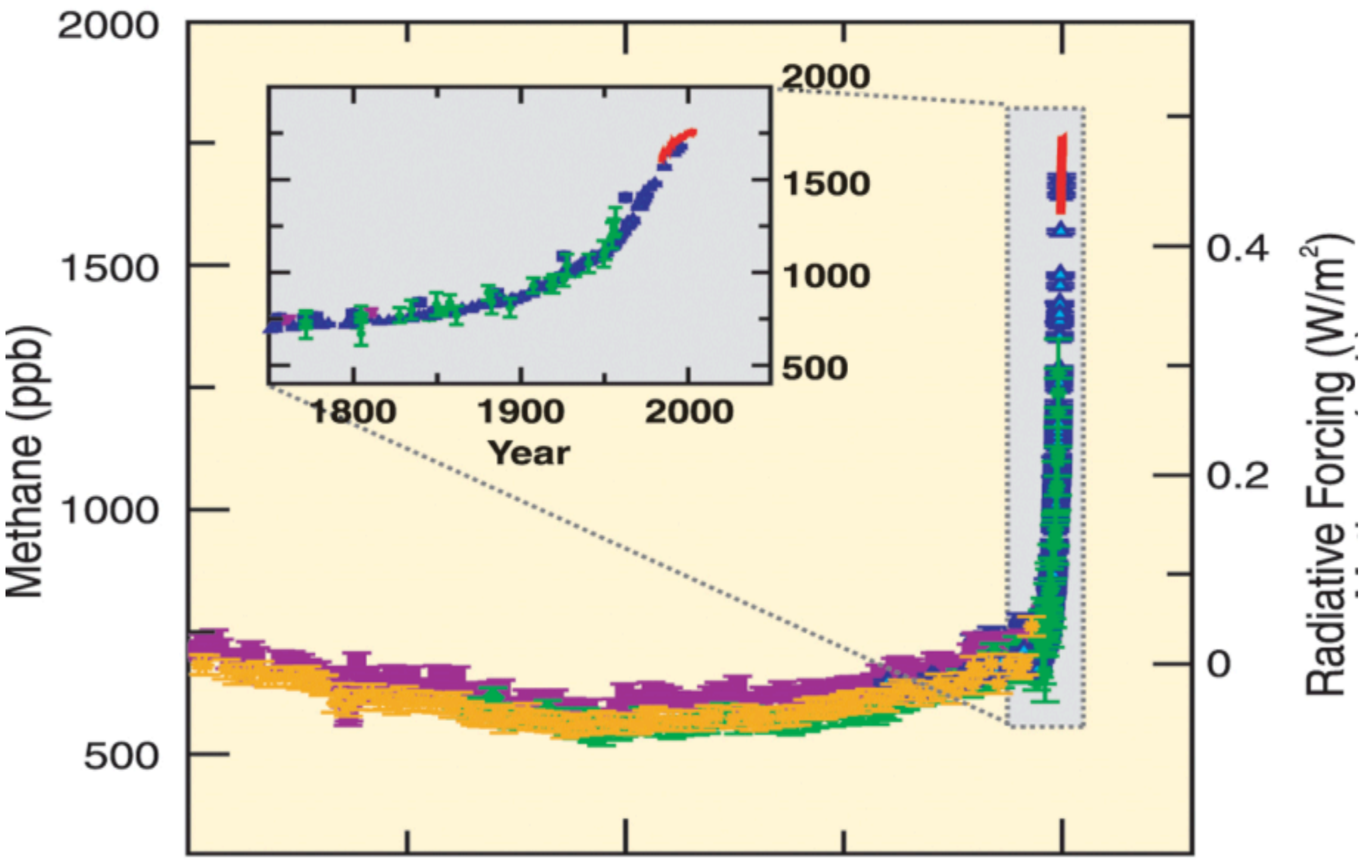
1.78 ppmv

Strength:

26 times CO_2 per molecule

Lifetime:

8-12 years



10000 years
Ahrens: Fig. 16.17

Methane sources and sink

- Natural
  - Wetlands, termites, oceans, chemical reactions
- Anthropogenic
  - Ruminant livestock, gas/oil production, coal mining, landfills and sewage, biomass burning
- Wetlands are single biggest source, but anthropogenic sources are 60% of total

- Sink:
  - Converted by atmospheric OH into CO_2 and H_2O

Nitrous Oxide (N_2O)

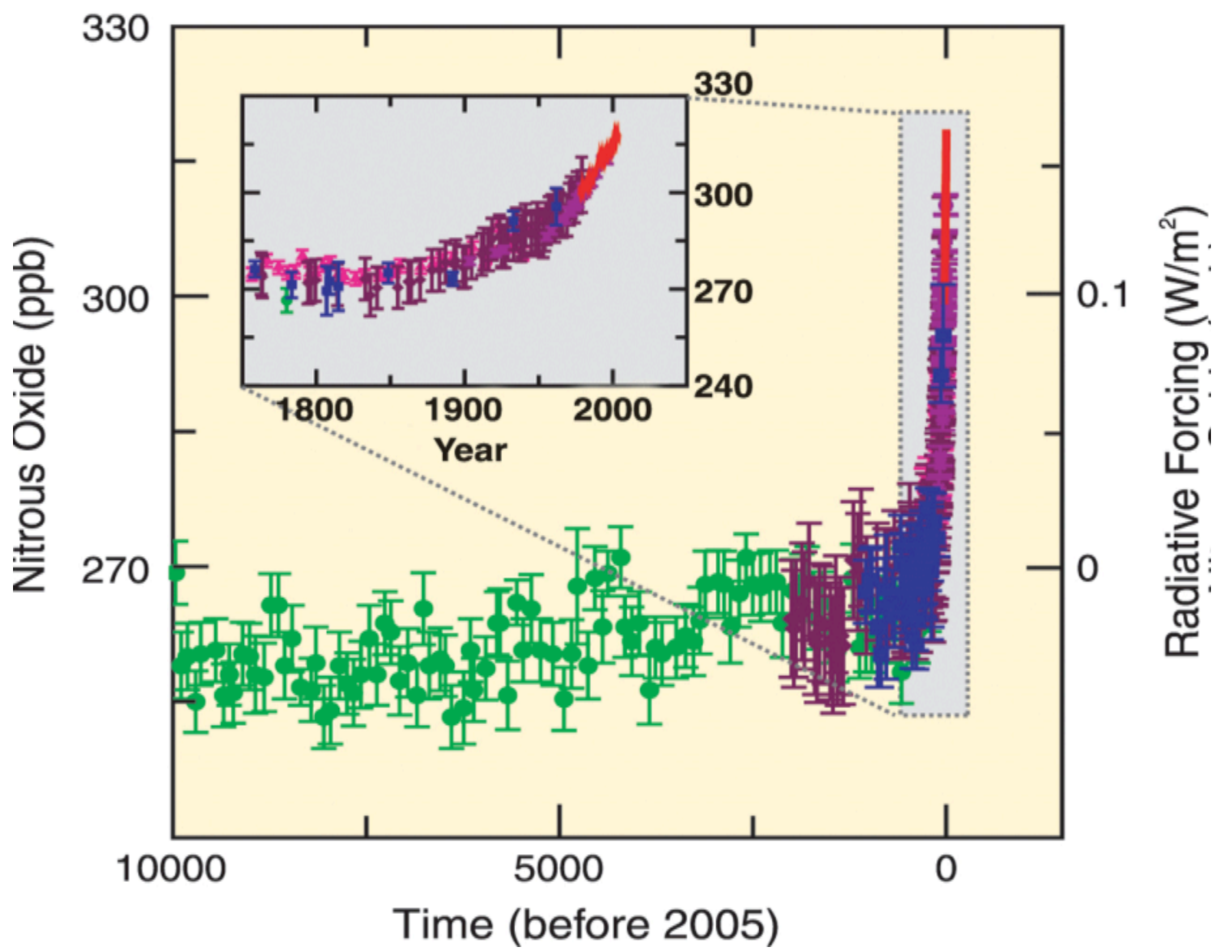
319 ppbv

Strength:

206 times CO_2 per molecule

Lifetime:

120 years



Ahrens: Fig. 16.17

Nitrous Oxide sources and sink

- Natural
  - Lightning, fires, decomposition, oceans
- Anthropogenic
  - Nitrogen fertilizers, fossil fuel and biomass combustion
- Sink:
  - Converted by UV radiation in stratosphere to N_2 and NO_x

Halocarbons (CFCs, HCFCs, HFCs)

- Used in refrigeration and air conditioning
- Atmospheric lifespan generally under 100 years
  - some in the thousands of years
- Per molecule, several thousand times as strong as CO_2

- Rapid increase 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)

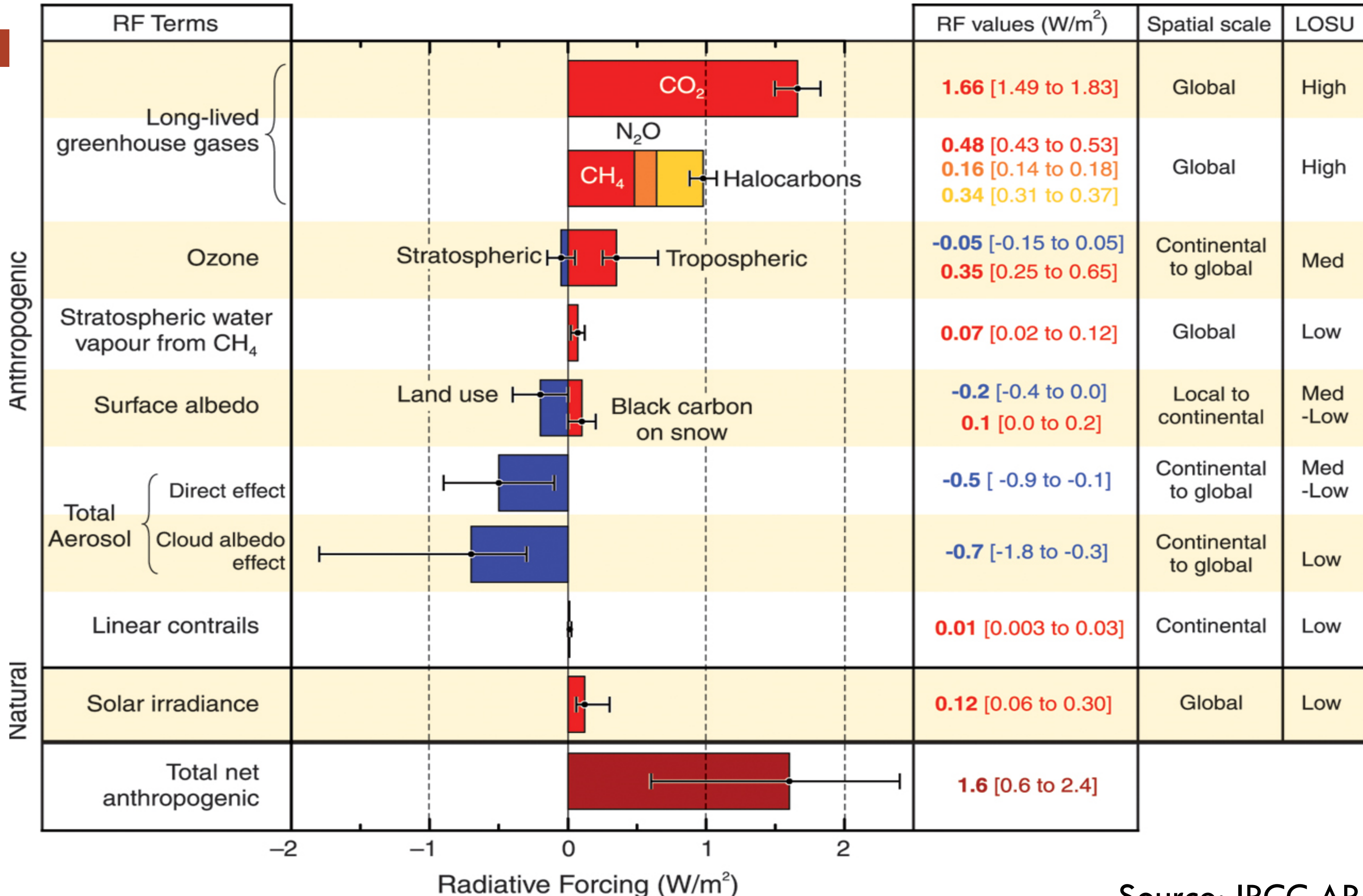
- Doubled in the NH; in many cities it is up by 5-10 times preindustrial levels.
- Very short lifespan (hours)
- Ozone precursors:
  - NO and NO_2
  - VOCs

- Main sources:
  - Burning biomass and fossil fuels

Stratospheric ozone (also O_3)

- Decreasing trend due to CFCs and HCFCs
- Contributes to observed cooling in the stratosphere

Radiative Forcing

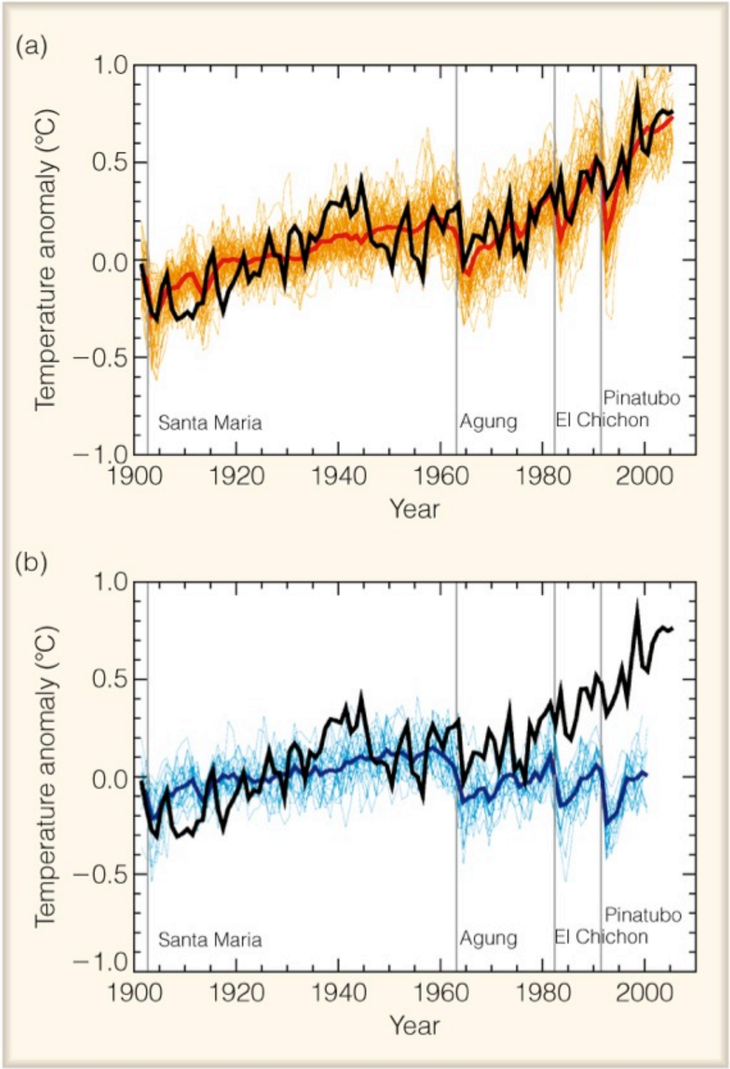


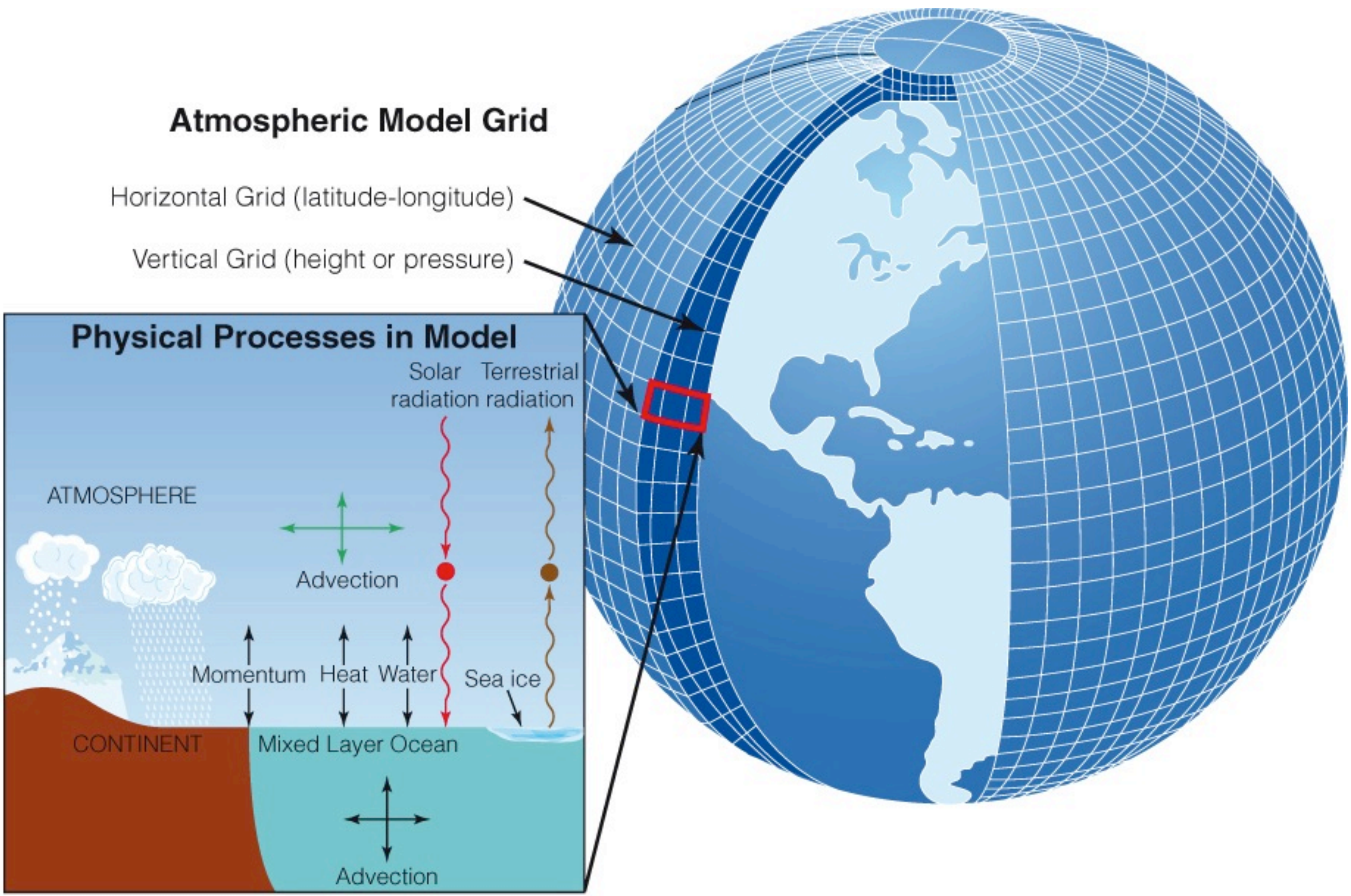
Source: IPCC AR4

Modelling climatic change

- Climate model simulations driven by:
  - Solar forcing
  - Volcanic forcing
  - With (top) and without (bottom) anthropogenic forcing

Ahrens: Fig. 16.19





Ahrens: Ch. 16 Fig. 4

Equilibrium response

- Decades after a change in forcing, climate will approach a new equilibrium
- Equivalent 2×CO_2
  - Combination of all GHGs
  - Will be reached by 2050
  - Global mean surface temperature increase of 2-4.5°C

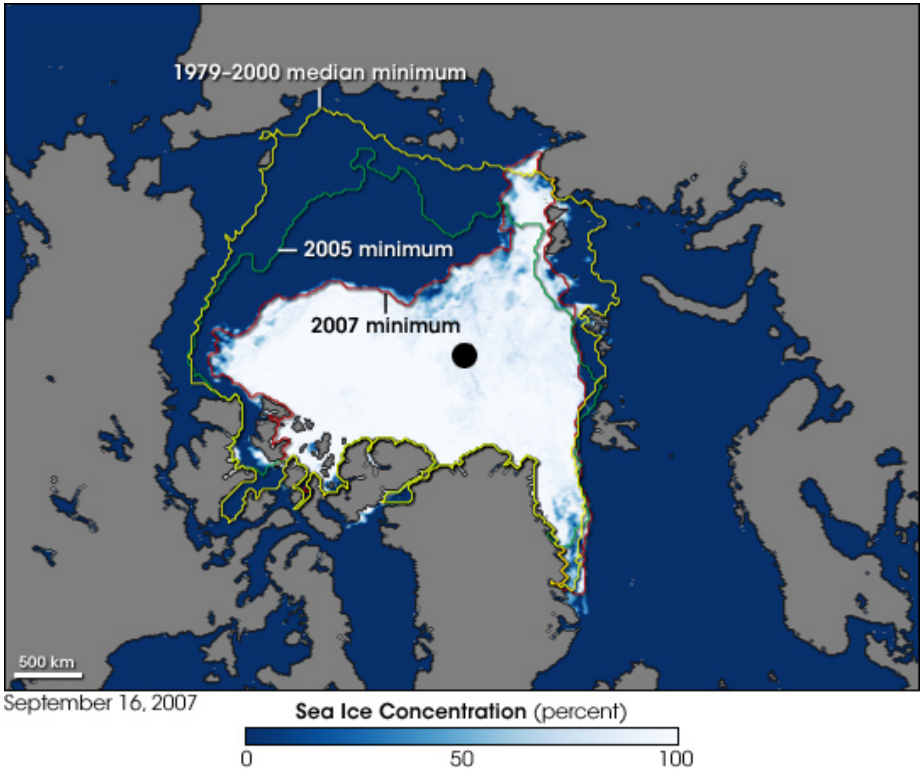
Equilibrium response: High confidence

- Global mean surface temperature increase of 2-4.5°C.
- Greater warming at high latitudes
- Greater warming at high latitudes in winter
- Greater warming of continents than oceans
- More intense hydrological cycle
- Cooler stratosphere

Greater warming at high latitudes

- Reduced ice and snow cover
  - Feedback is much stronger locally than globally

- Greater warming in winter:
  - In the winter, sea ice insulates air from warmer water
  - Thinner ice means less insulation
  - Therefore the surface air temperatures become higher



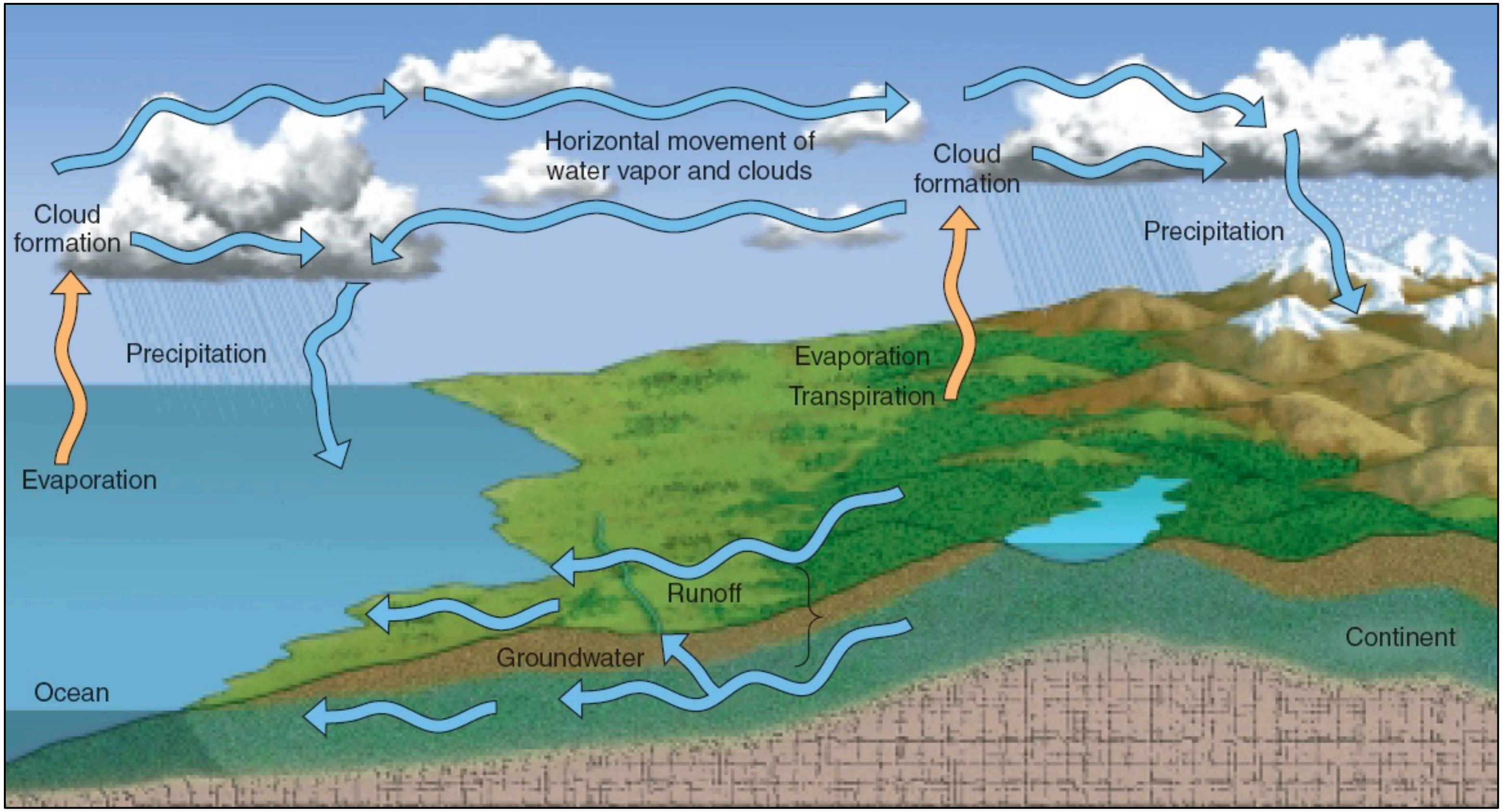
Source: NASA

Greater warming of continents

- Higher temperatures mean increased evapotranspiration
  - Surface cooling through absorption of latent heat
- Over land, evapotranspiration is limited
  - Actual evapotranspiration less than potential because of limited water supply
- Over sea, evaporation occurs at the potential rate
  - Water supply is unlimited

More intense hydrologic cycle

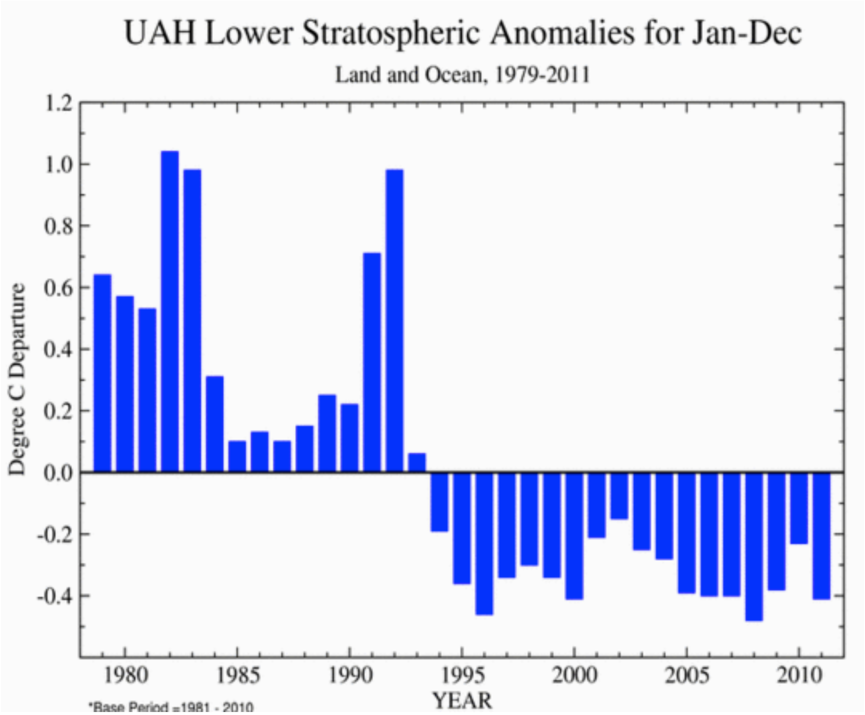
- Higher temperatures mean increased evapotranspiration
- Increased evapotranspiration means increased precipitation
- More rain (but not everywhere), and more frequent heavy rains



A&B: Figure 5-1

Cooler stratosphere

- Radiation balance in stratosphere is distinct
  - Heating through O_3 absorption of UV radiation
  - Cooling through CO_2 emission of IR radiation
- Increased CO_2 means increased cooling
  - As does stratospheric ozone depletion



Source: NOAA

Equilibrium response: Also likely

- 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

Storms

- Summer thunderstorms
  - High confidence in becoming more intense and frequent
  - Higher temperatures and higher humidity
- Midlatitude cyclones
  - May get weaker
  - Reduced meridional temperature gradient
- Tropical cyclones
  - May be fewer but more powerful storms
  - Some predictions of greater numbers in North Atlantic

Rise in sea level

- Melting ice sheets
  - Greenland, Antarctica, high altitudes
- Thermal expansion

- Likely 25-100 cm by 2100
  - Could be more
  - *Will* be more, eventually

Impact on natural systems

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

Impacts on human systems

- Agricultural losses, especially in tropics
  - Heat-sensitive crops
  - Valuable coastal land lost to sea level rise
  - Droughts and floods
- Lots of population centres near the ocean
- Melting permafrost at high latitudes

Impacts on humans

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

Mitigation

- Need to reduce GHG emissions from a large number of sources
- 1992: United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janiero
- 1997: Kyoto Protocol
  - Ratified by 182 countries

Kyoto Protocol (1997)

- CO_2, CH_4, N_2O, HFC, PFCs, SF_6
- Annex I countries have individual targets for reductions in 2008-2012 compared to 1990
- Understanding that additional protocols will include all parties

Details

- Cost sharing: countries initially set their own targets
- Funding mechanisms: no current targets for LDCs
- Non-compliance: no penalties
- Policy instruments:
  - Emissions trading between Annex I countries
  - Joint implementation with LDCs
- Largely countries are on their own to meet targets domestically

Canada

- 2002: Ratified the treaty
- Never taken any meaningful steps
- Harper government withdrew Canada from Kyoto in 2011 at Durban (COP 17)
- Will fail to meet targets in 2020

- US: never ratified, but bigger reductions than Canada

Kyoto Protocol Targets

Member	Target (1990 – 2008-2012)
EU-15, Bulgaria, Czech Republic, Estonia, Latvia, Liechtenstein, Lithuania, Monaco, Romania, Slovakia, Slovenia, Switzerland	-8%
USA	-7%
Canada, Hungary, Japan, Poland	-6%
Croatia	-5%
New Zealand, Russia, Ukraine	0
Norway	+1%
Australia	+8%
Iceland	+10%

Overall commitment among these countries amounts to -5.6% of 1990 baseline.

Annual Conferences of the Parties (COPs) since Kyoto

COP 15 – Copenhagen (2009)

- No binding agreement or binding targets
- "Meaningful agreement" on 2°C as a maximum warming

COP 17 – Durban (2011)

- Future treaty to be signed in 2015, implemented in 2020
- Kyoto objectives to continue until 2020

COP 18 – Doha (2012)

- Wealthy countries may be liable for damages if climate change is not mitigated

COP 21 Paris (2015)

Where do we go from here?

- Follow-ups to Kyoto haven't been inspiring
  - Kyoto was never expected to do enough on its own
- Smaller international groups and actors
- Action by individual people is important but insufficient
- Change is required
  - Reduce energy demand
  - Switch to non-fossil energy sources

Next lecture

- Global Engineering