Chapter 15: Global Warming, Part I

I don't like the term "global warming" because it emphasizes on temperature, which is not very important. What matters is water resources, growing season, sea level, invasive species, local extinctions, spread of disease, etc. Who cares about temperature?

Example: If the average annual temperature in Laramie were 2°F warmer than average, would we even notice? Unlikely. We would, and do, notice drought! What happens when the river and our wells run dry?

- How do we identify Holocene climate change?
- What changes can we identify?

What is the Holocene?

- Time since last glacial retreat
- Approximately the last 10,000 years
- Why study this period?
  - T increase in last 10,000 years to now is…
  - Same as T increase from now to end of 21^{st} C

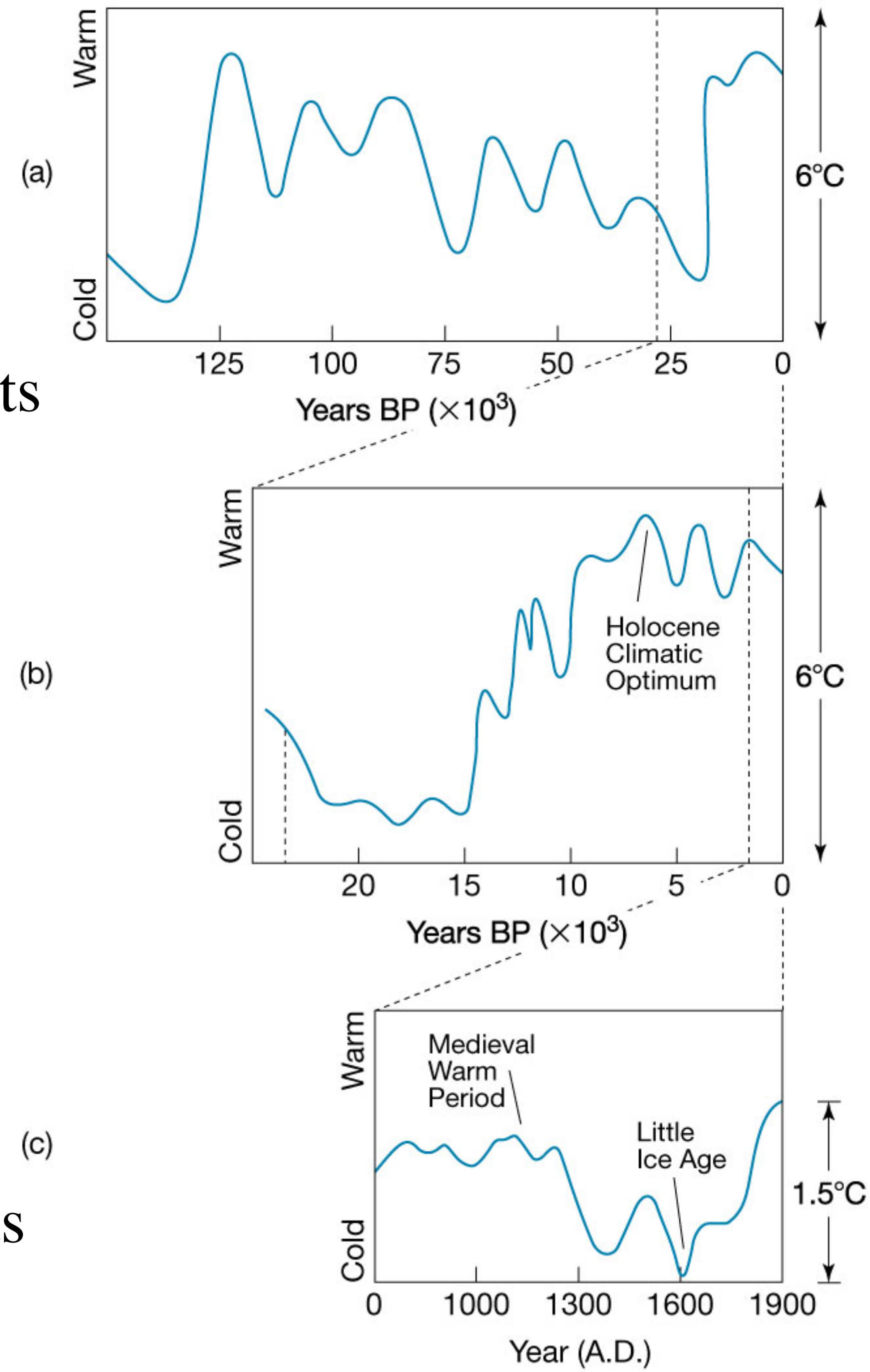
Holocene climate

Fig. 15.1

a) Deep sea sediments

b) pollen, glaciers

c) Historical records



Argentiere glacier, French Alps

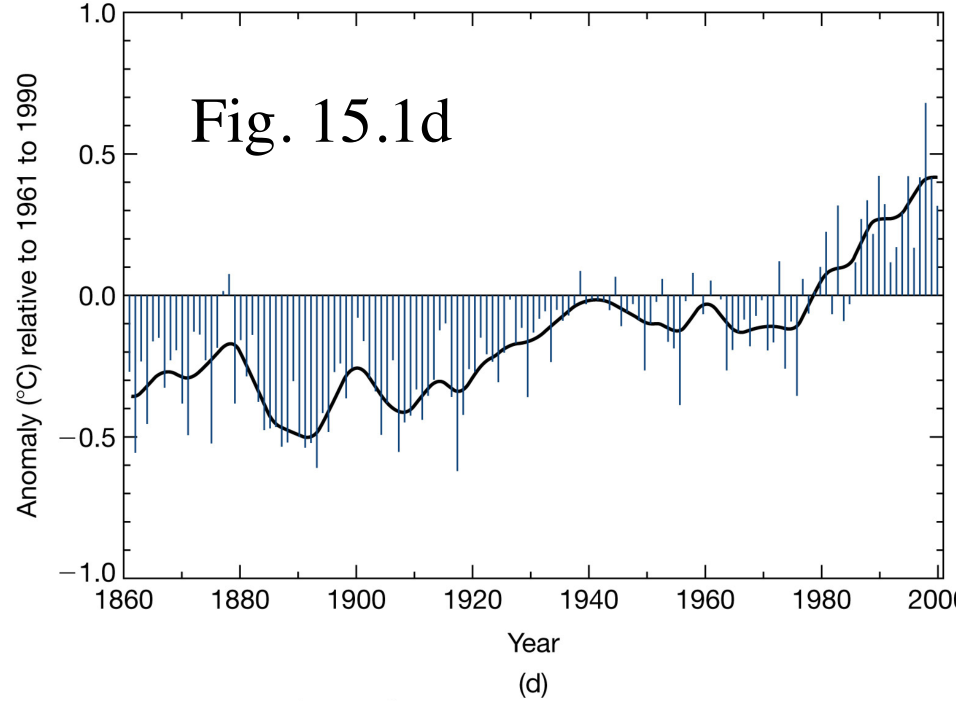
1850

1966

(a)

(b)

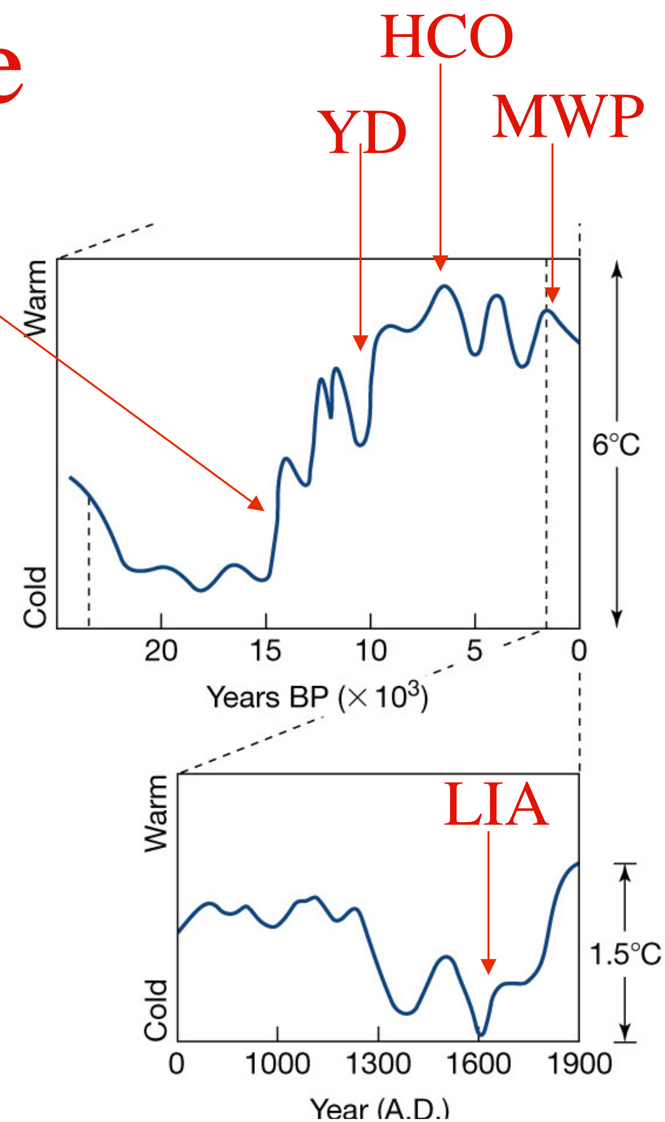
Sources of climate data



- Actual records
- Palynology
  - From pollen, reconstruct plant assemblages
  - Compare to present distribution of assemblages
- Dendrochronology
  - Width of tree ring indicates amount of annual growth
  - Related to T during growing season, water

Holocene

- Holocene warming 14,000 y ago
- Younger Dryas (10,500-8500 y)
- Holocene Climatic Optimum (3,000-6,000 y ago)
- Medieval Warm Period (1100-1300 AD)
- Little Ice Age (1550-1850 AD)



Holocene Climatic Optimum (3,000-6,000 y)

- Time of max. Holocene T, 1-2 C warmer than today
- Sahara was fertile, Nile R 3x water volume
- Great ancient civilizations

Medieval Warm Period (1100-1300 AD)

- Viking settlements in Greenland, Iceland
- Snowline 370 m higher in Rockies
- Vineyards in England
- Wheat grown in Norway

•*Hvalsey church, in southwest Greenland, is the best-preserved artifact of Norse Greenlanders, who mysteriously*

disappeared in the 15th century.

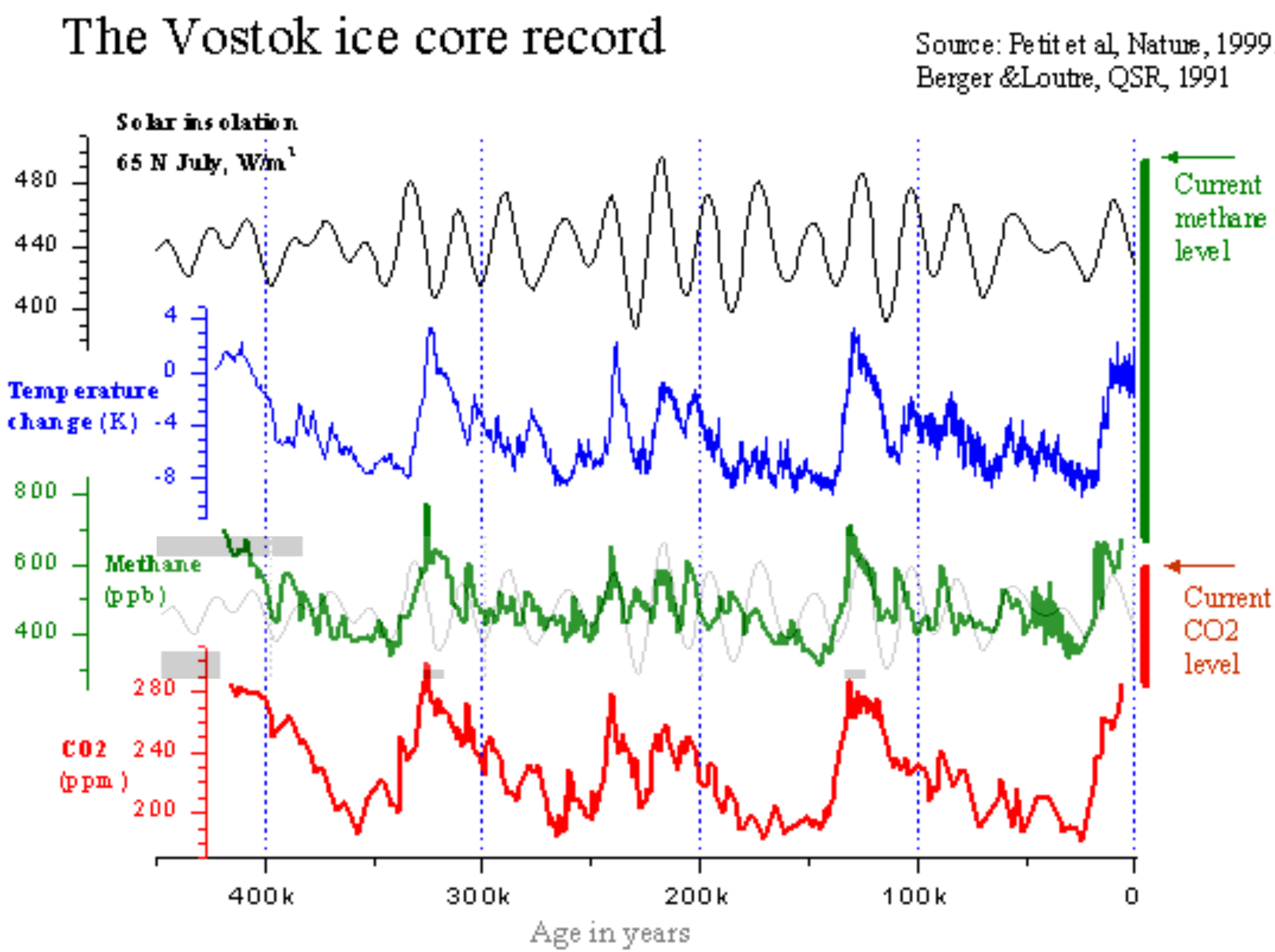
http://www.atmo.arizona.edu/students/courselinks/fall04/atmo336/lectures/sec5/holocene.html

Little Ice Age (1550-1850 AD)

- N Hemisphere T 1 C less than today
- Settlements in SW USA abandoned
- Glaciers re-advanced, covered houses in Swiss Alps
- Canals in Holland froze 3 months straight
- Agricultural productivity dropped

The cold winters of the little Ice Age were recorded in Dutch and Flemish paintings such as *Hunters in the Snow* by Pieter Bruegel (c. 1525-69)

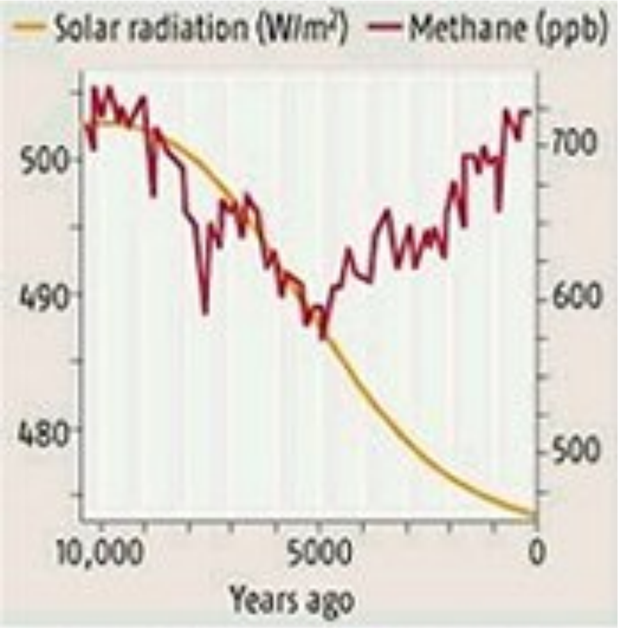
Aqueduct repair in the Swiss Alps; these structures get destroyed as glaciers advance…

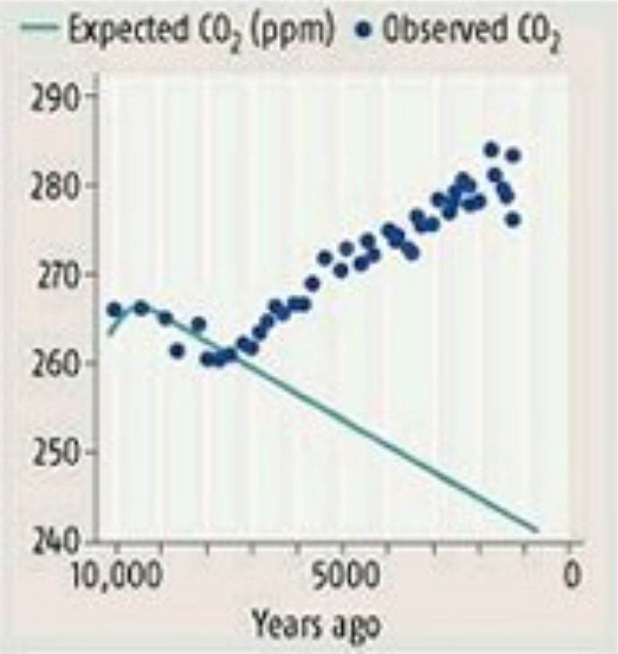


A close link between global temperatures, greenhouse gasses, and global ice volume

Have humans averted an ice age?

- Widespread land clearing starting 8000 years ago in Europe to support agriculture
- Domestication of rice and rice agriculture in Asia produce large amounts of methane (livestock as well)
- CONTROVERSIAL! (But interesting…)





Lessons from the Holocene

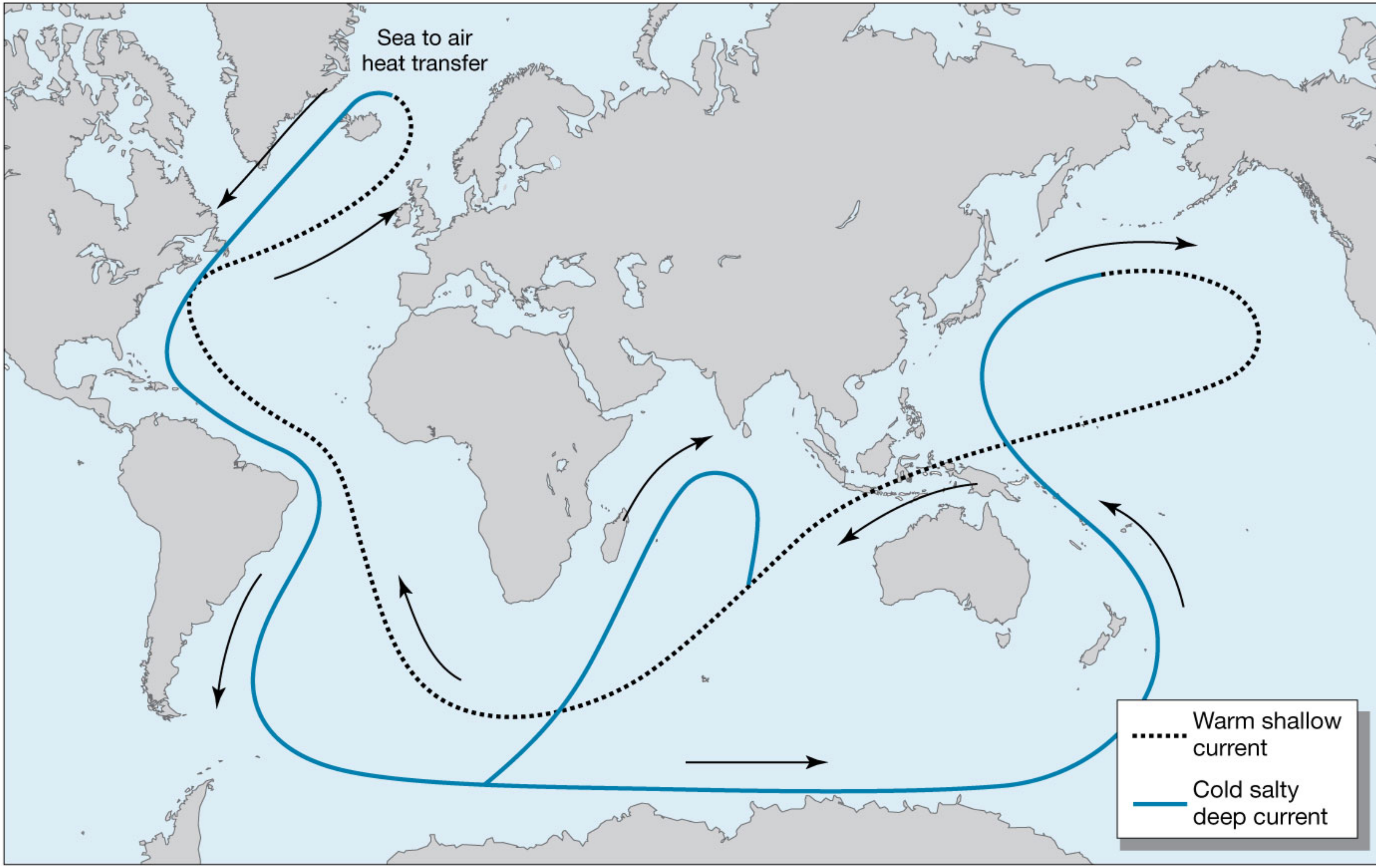
- Small changes in global T can have significant consequences, especially on regional scales
- Natural variations have occurred in the past, over approximately 200 year periods

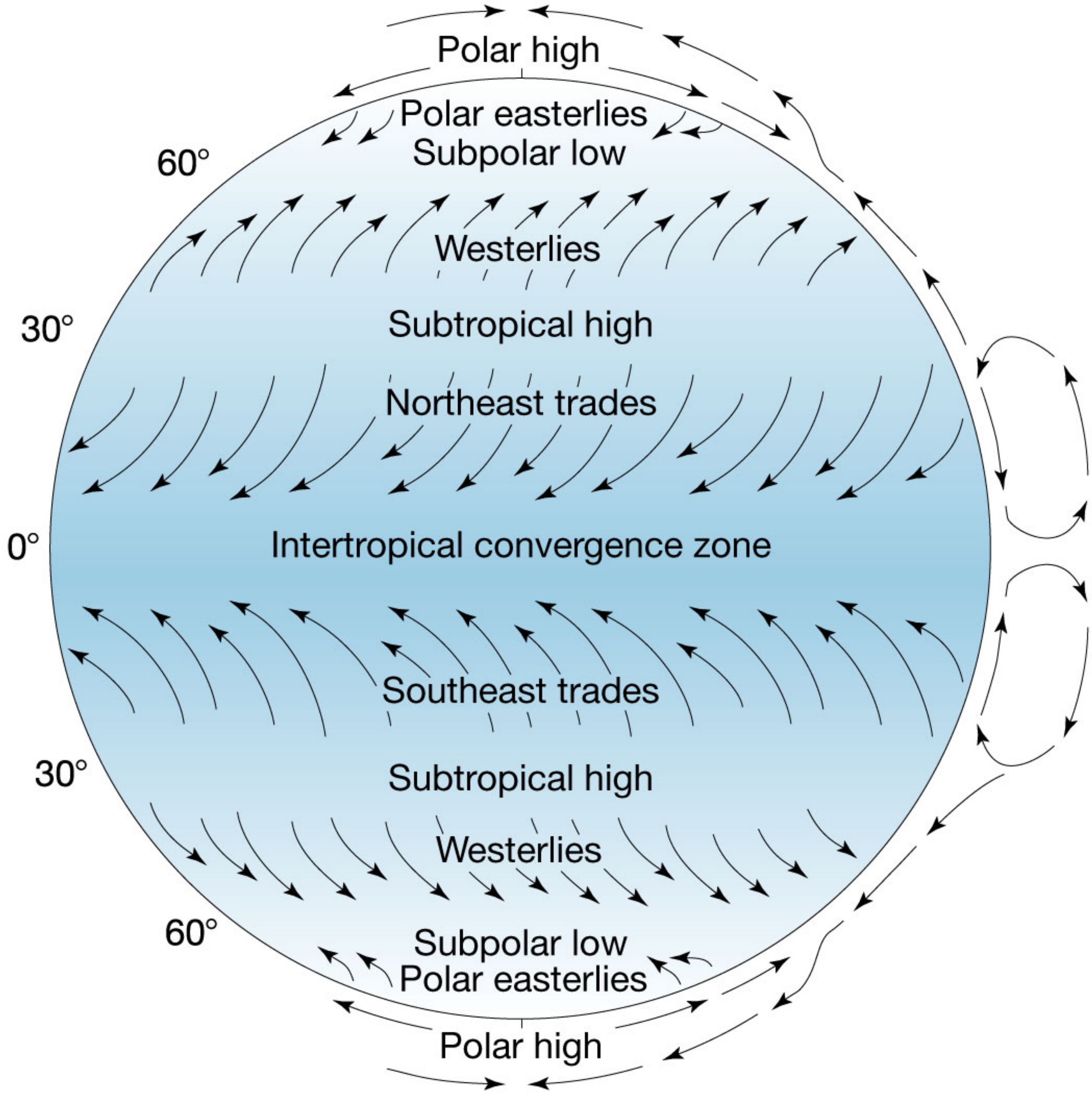
Causes of climate variability

1. Changes in ocean circulation
2. Volcanism
3. Orbital factors
4. Variations in solar output
5. Changes in sea ice

1. Changes in ocean circulation

Fig. 5-12





Polar high
Polar easterlies
Subpolar low
60°
Westerlies
30°
Subtropical high
Northeast trades
0°
Intertropical convergence zone
Southeast trades
30°
Subtropical high
Westerlies
60°
Subpolar low
Polar easterlies
Polar high

Younger Dryas (10,500-8500 y)

- Global T dropped 2 C in 50 y
- Attributed to a lessening/cease of NADW formation
- When circulation restarted, T rose 3 C, 7 C in N Europe

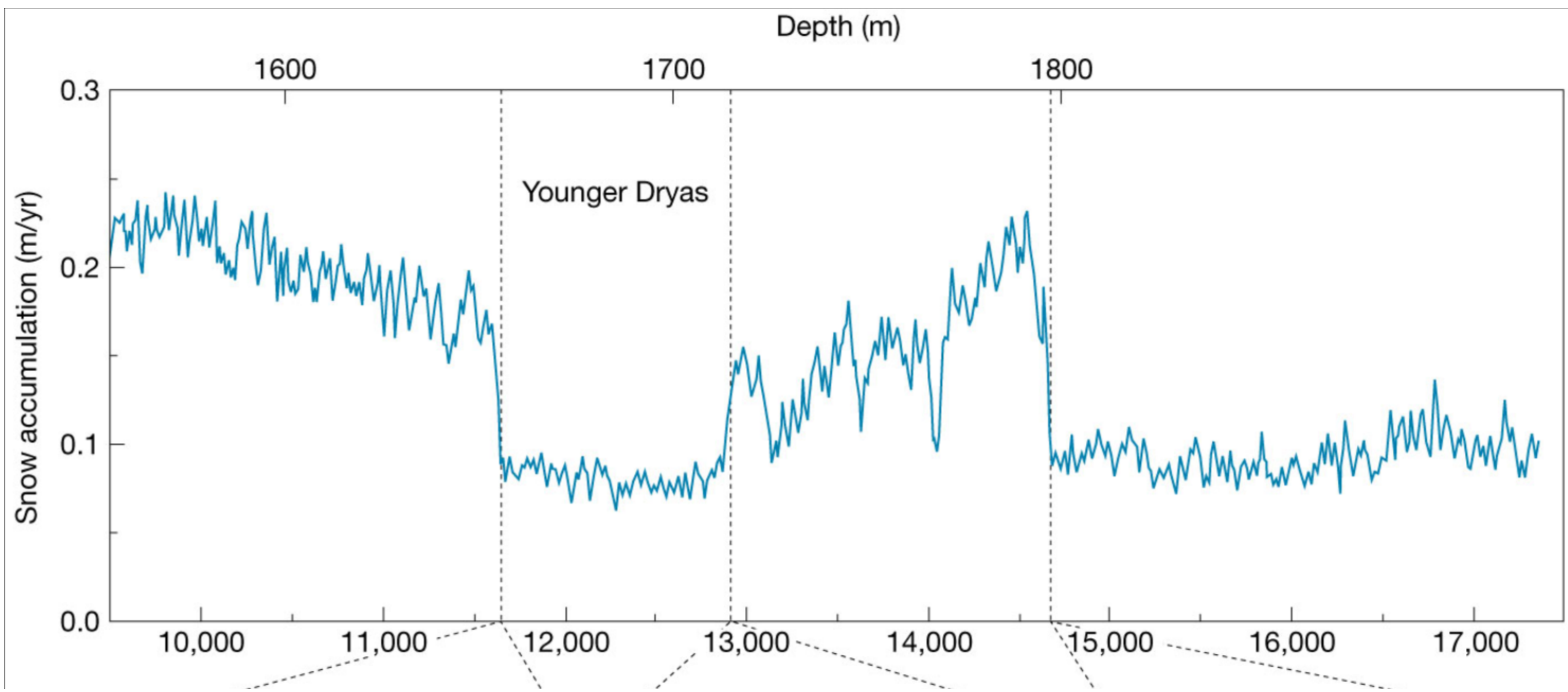
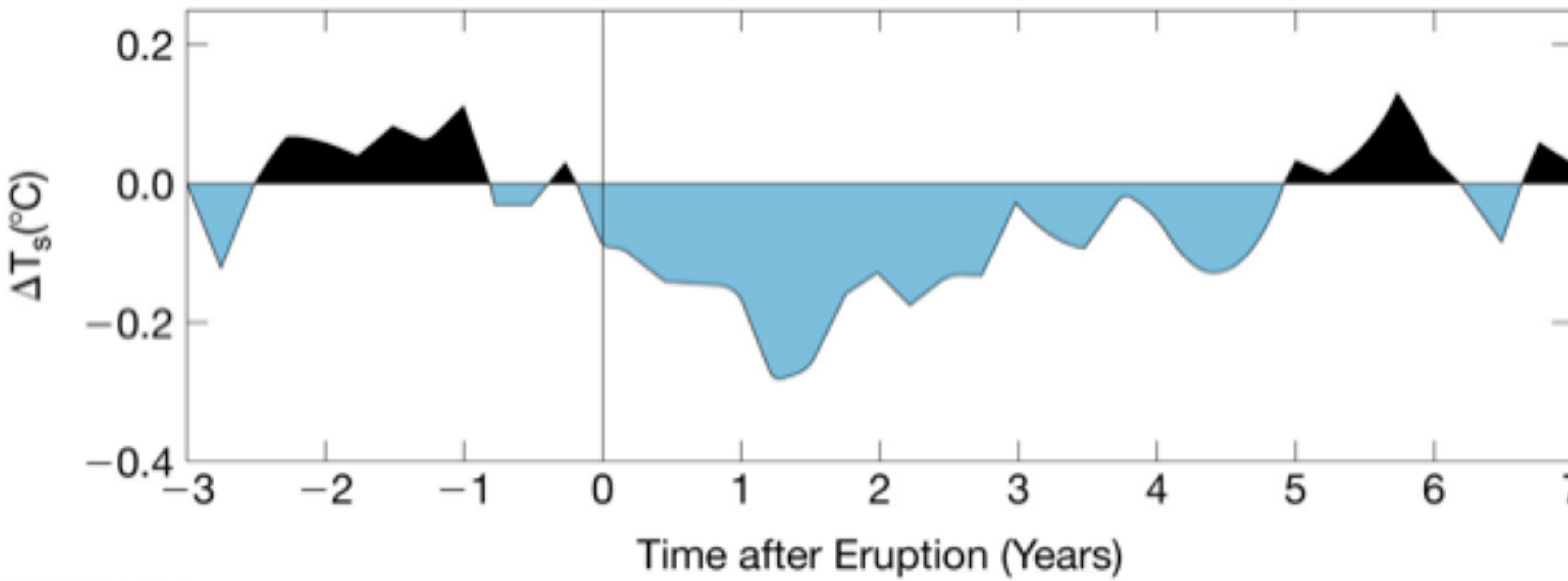


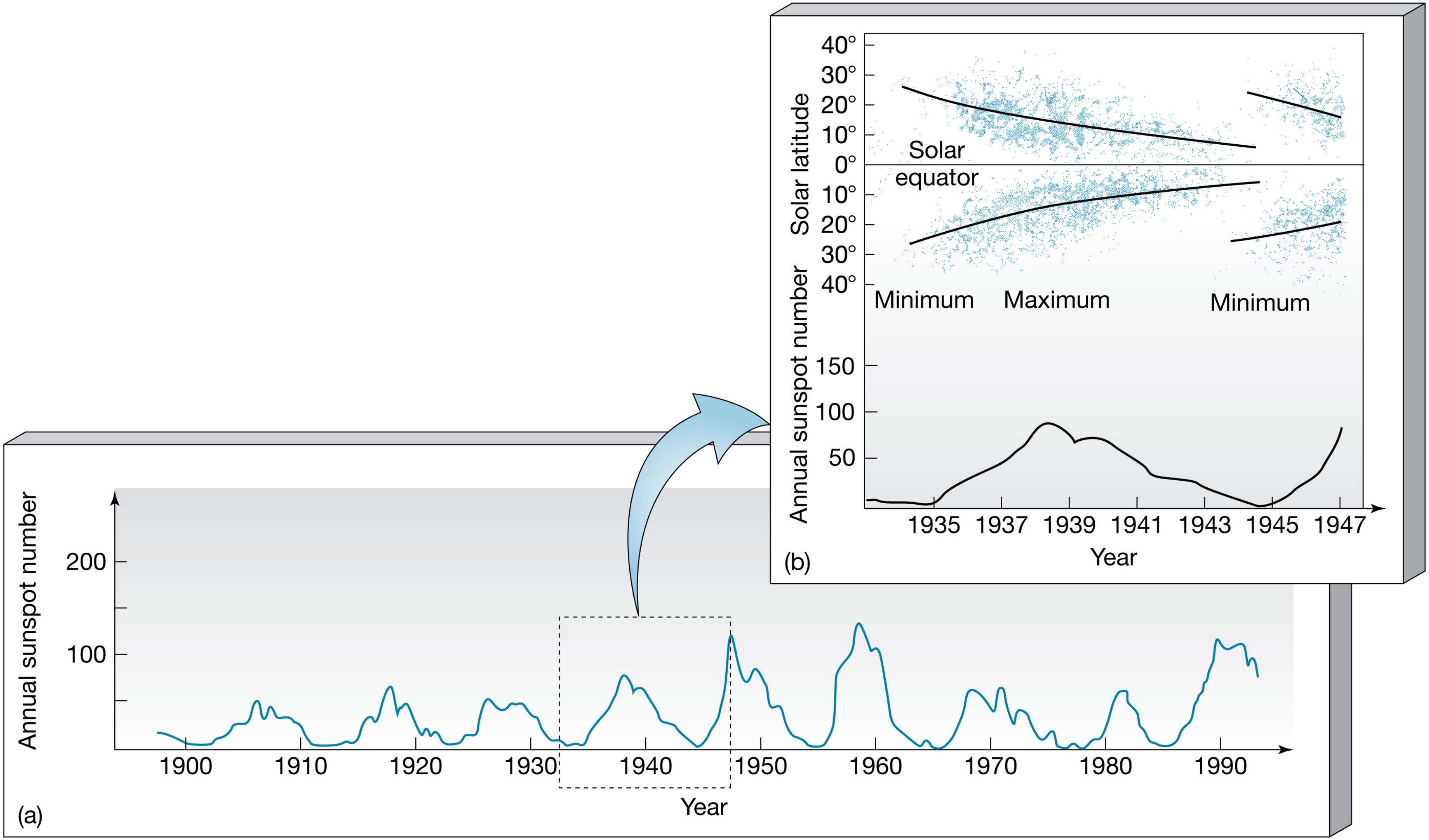
Fig. 15-2

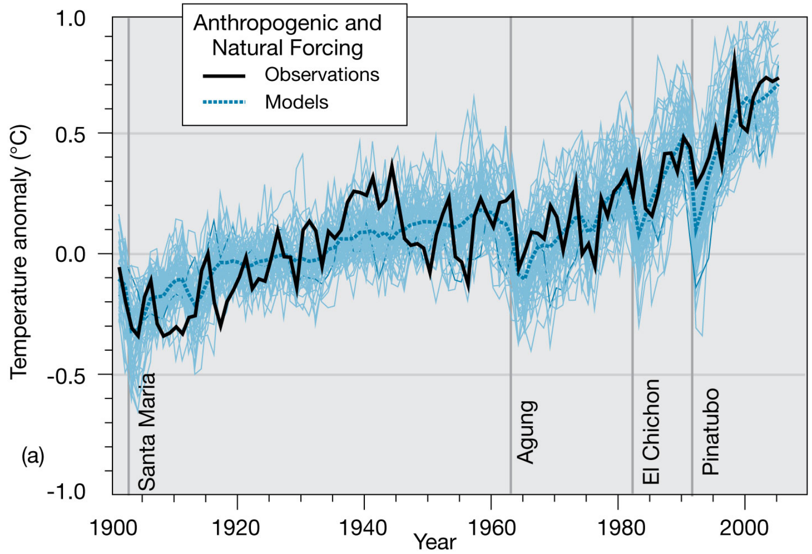
2. Volcanism



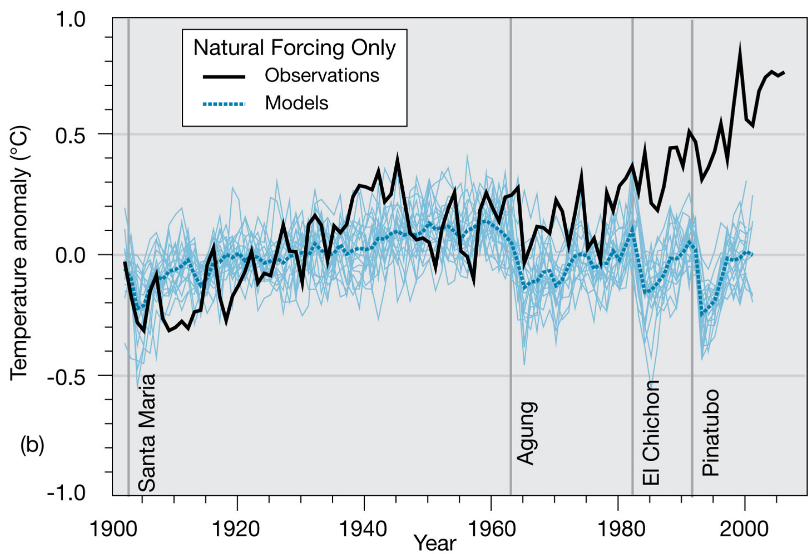
4. Variations in solar output-sunspots

Fig. 15-7





Anthropogenic and Natural Forcing
Observations
Models
1.0
0.5
0.0
-0.5
-1.0
Temperature anomaly (°C)
(a)
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year



Natural Forcing Only
Observations
Models
1.0
0.5
0.0
-0.5
-1.0
Temperature anomaly (°C)
(b)
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year

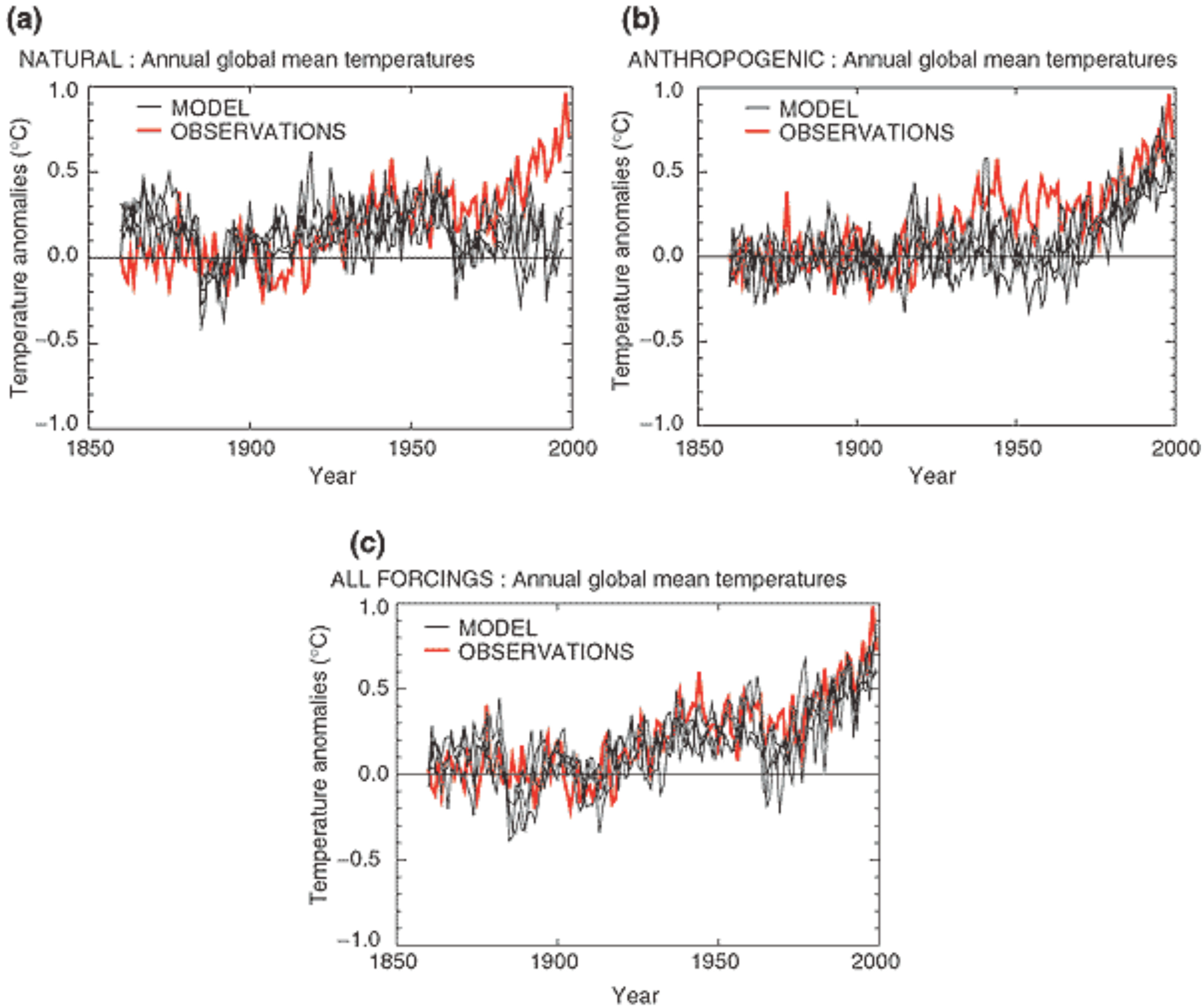

(a)
NATURAL : Annual global mean temperatures
MODEL
OBSERVATIONS
Temperature anomalies (°C)
Year
(b)
ANTHROPOGENIC : Annual global mean temperatures
MODEL
OBSERVATIONS
Temperature anomalies (°C)
Year
(c)
ALL FORCINGS : Annual global mean temperatures
MODEL
OBSERVATIONS
Temperature anomalies (°C)
Year

TABLE 15-1 Fossil-Fuel Reservoir Sizes and Burning Rates

Reservoir	Size,* Gton(C)	Burning rate, Gton(C)/yr	Projected lifetime** (yrs)
Coal	3800	2.8	1360
Oil	680	3.3	200
Natural gas	570	1.5	380
Cement production		0.3	
Total	5050	7.9	

*Reservoirs have been converted from gtoe (gigatons of oil equivalent) to Gton(C). The following conversion factors were applied: Coal: 1gtoe = 1.12 Gton(C); oil: 1 gtoe = 0.83 Gton(C); gas: 1 gtoe = 0.65 Gton(C).

**Projected lifetime = reservoir size ÷ burning rate.

Sources: Reservoir sizes from Table 9 of H.-H. Rogner, *Annual Review of Energy and the Environment* 22, November 1997, pp. 217–262, doi:10.1146/annurev.energy.22.1.217.; 2004 burning rates from U.S. Carbon Dioxide Information Analysis Center (CDIAC) website, http://cdiac.ornl.gov/trends/emis/tre_glob.htm.

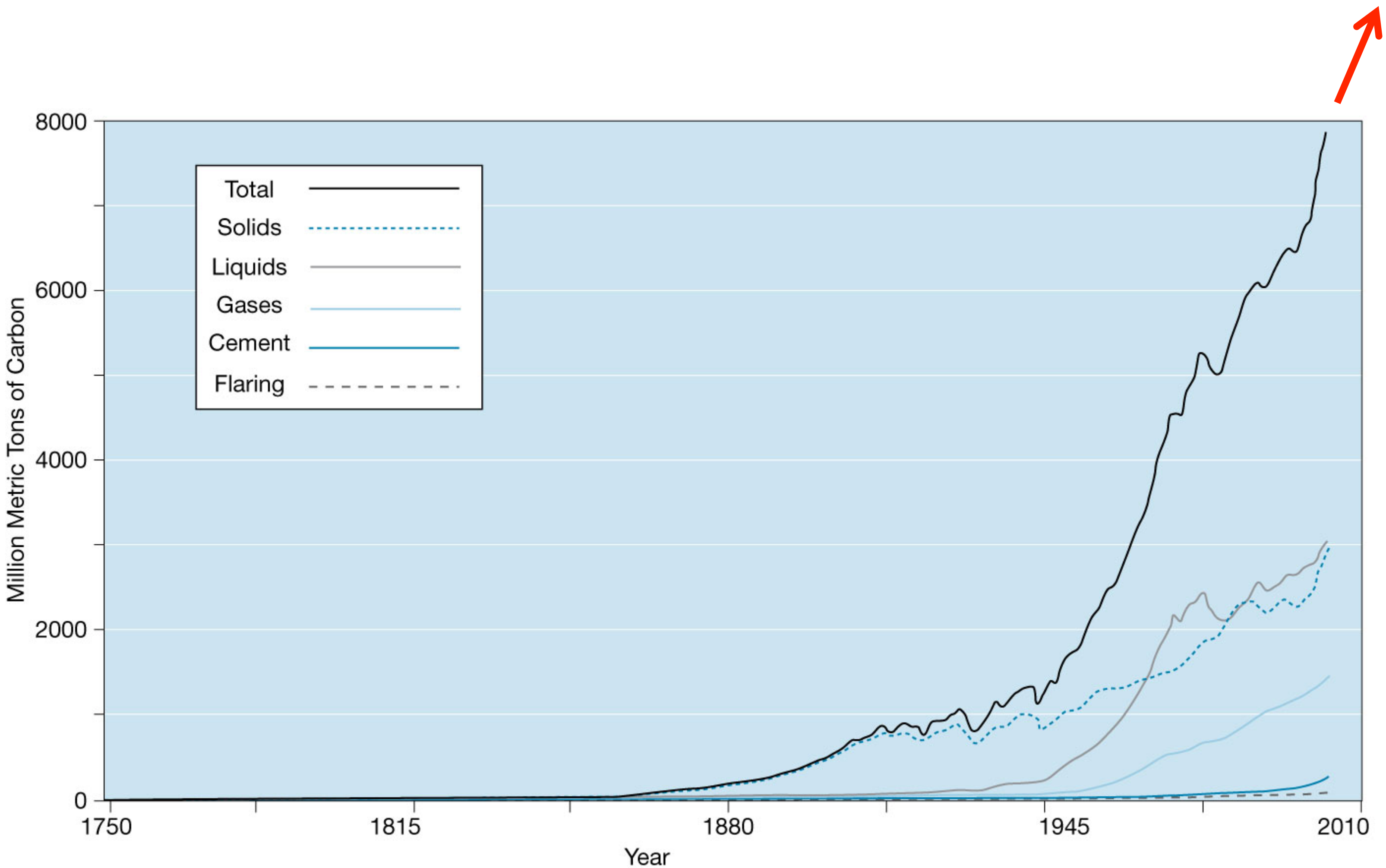
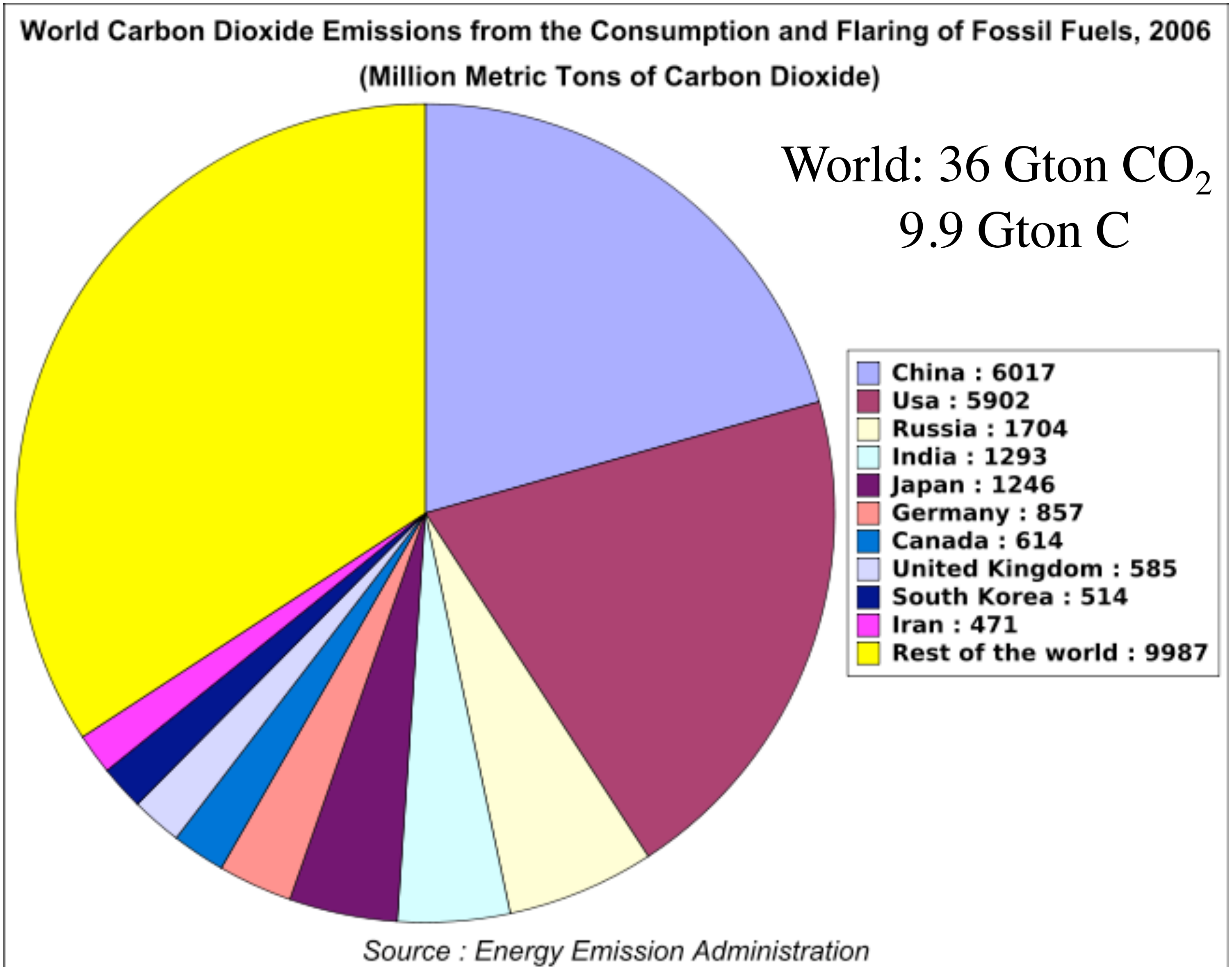

8000
6000
4000
2000
0
Million Metric Tons of Carbon
Total
Solids
Liquids
Gases
Cement
Flaring
1750
1815
1880
1945
2010
Year

TABLE 15-2 Fossil-Fuel Consumption by Geographic Region

Region	Consumption rate, Gton(C)/yr	
North America	1.8	1.9+
Central and South America	0.4	
Western Europe	0.9	
Eastern Europe (incl. Russia)	0.8	
Middle East	0.4	
Africa	0.3	
Oceania (Australia and Japan)	0.4	
China and Vietnam	1.4	2.3

Source: 2004 burning rates from U.S. Carbon Dioxide Information Analysis Center (CDIAC) website, http://cdiac.ornl.gov/trends/emis/tre_glob.htm.

Where does the United States stand?

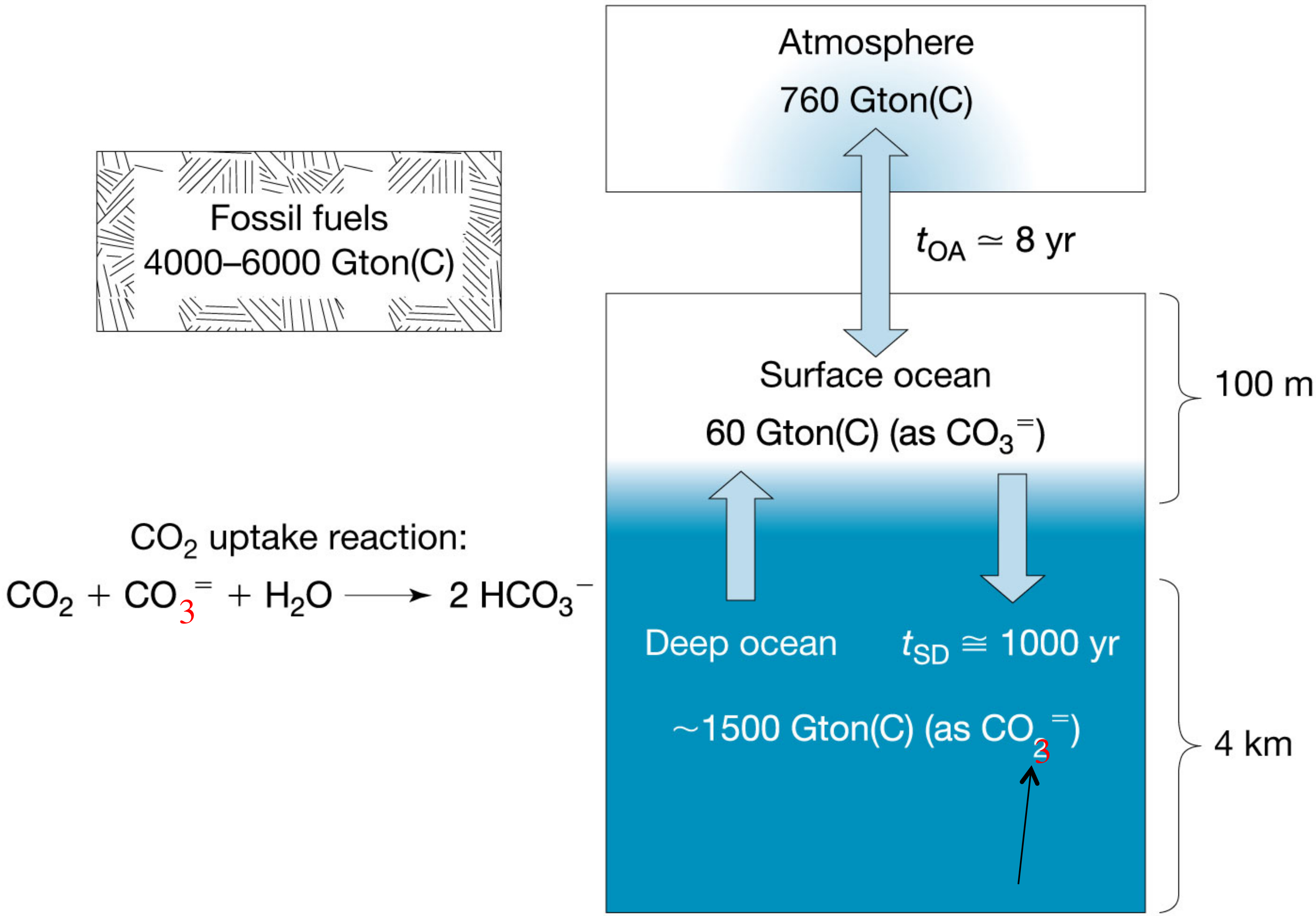


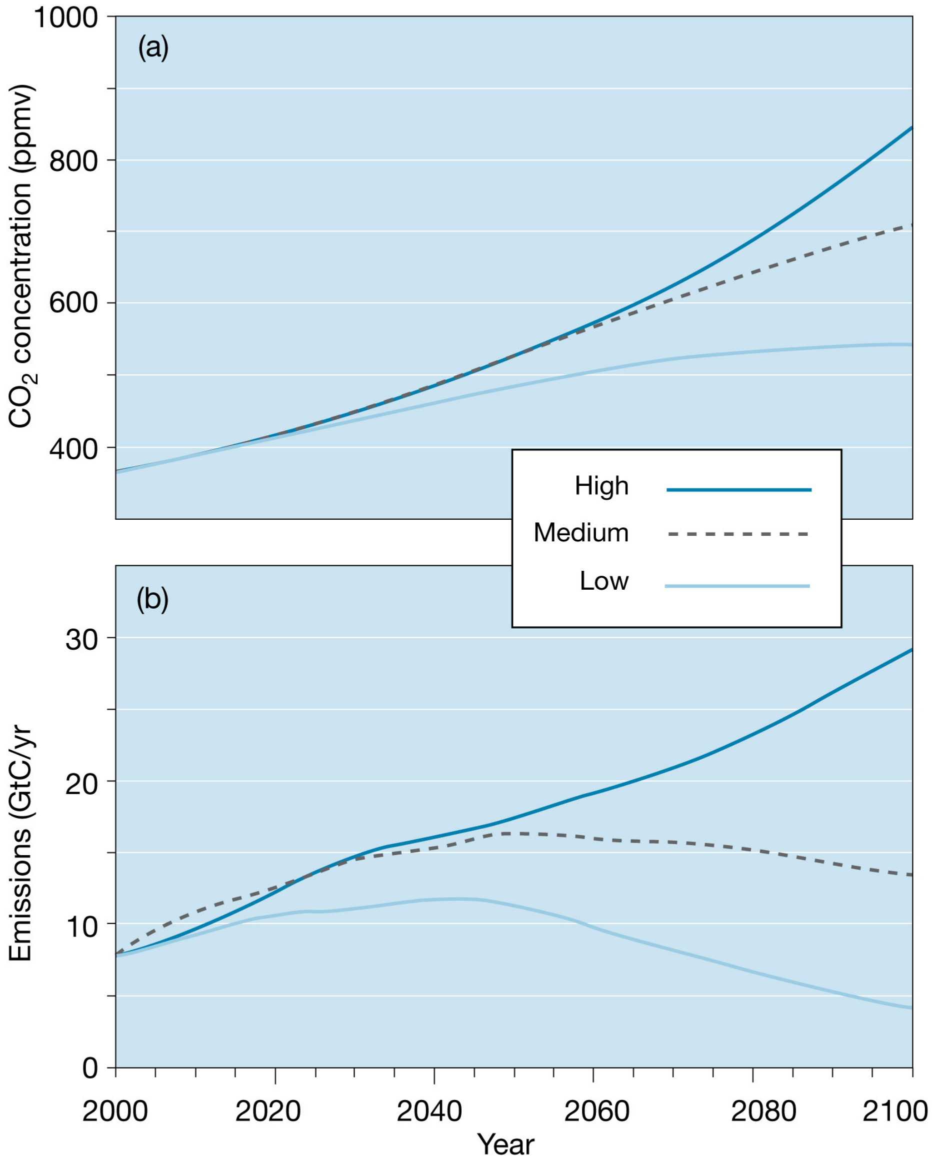
US:

- About 1.7 Gton annual emissions in 2006 (probably grew to 1.8 or so by 2008, and then fell 2.8% in 2008 because of that little economic crisis … 1.9 Gton now)
- China now emits more than the U.S. (about 2.2 Gton)
- U.S. per capita emissions are well over 5 tons per person per year, China's are about 1.5 tons per person per year.

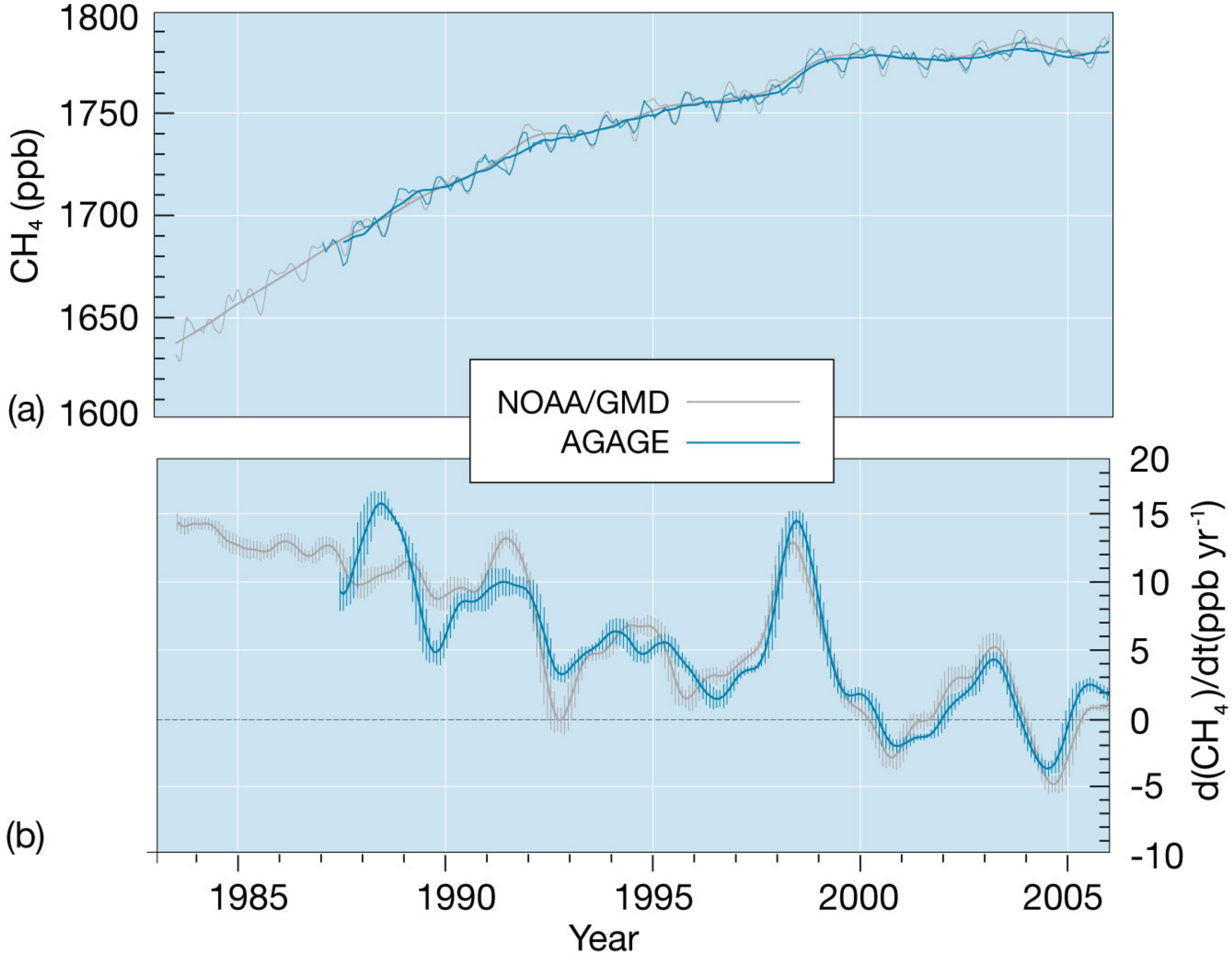
Where does Wyoming stand?

- **~420 million metric tons coal exported**
- **~90 million metric tons produced in-state (power exported)(i.e., emissions)**
- **90 million metric tons for 0.5 million people is 180 tons per person. 1.3 tons per person global average, 5.2 tons per person is US average!**
- **Only about 70% of total coal mass is carbon:**
- **390 MMT/8000 MMT = 0.0613, or 4.8% of global emissions and 490 MMT/1800 MMT = 0.22, or 22% of U.S. emissions!**

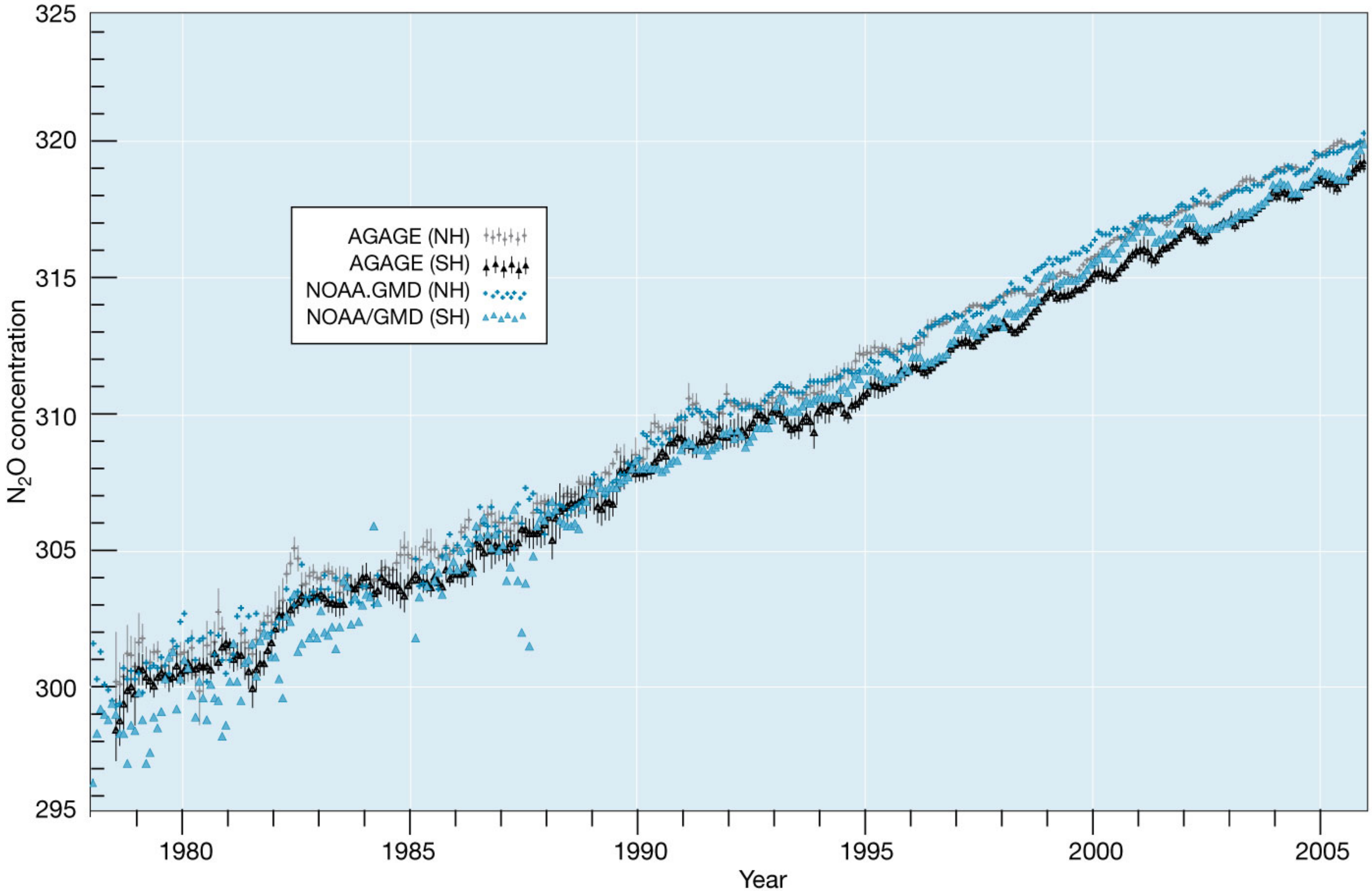

Fossil fuels
4000–6000 Gton(C)
Atmosphere
760 Gton(C)
$t_{OA} \simeq 8$ yr
Surface ocean
60 Gton(C) (as $CO_3^{=}$)
100 m
CO_2 uptake reaction:
$CO_2 + CO_3^{=} + H_2O \longrightarrow 2\ HCO_3^{-}$
Deep ocean
$t_{SD} \cong 1000$ yr
~1500 Gton(C) (as $CO_3^{=}$)
4 km

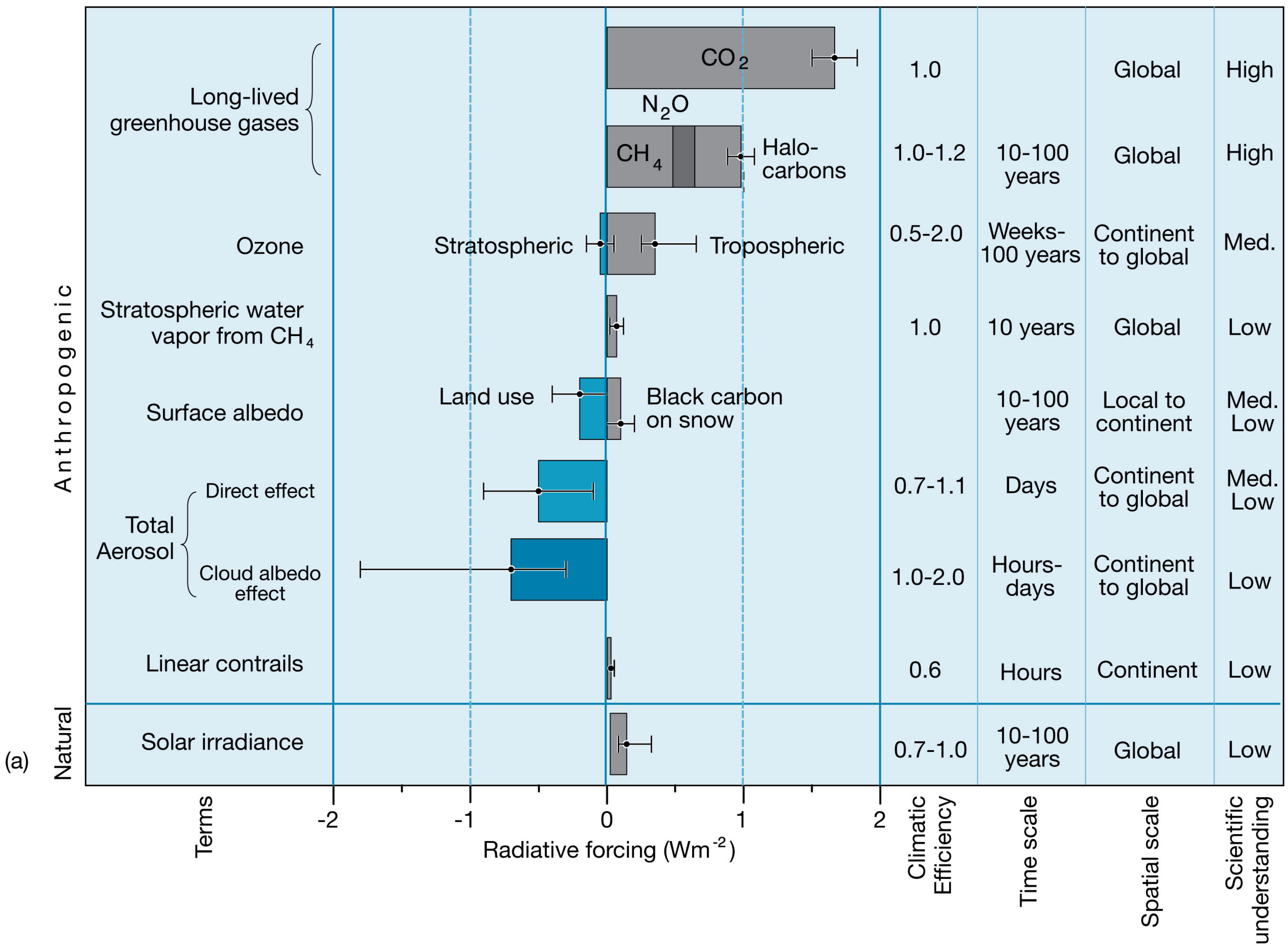


(a)
1000
800
600
400
CO2 concentration (ppmv)
High
Medium
Low
(b)
30
20
10
0
Emissions (GtC/yr)
2000
2020
2040
2060
2080
2100
Year

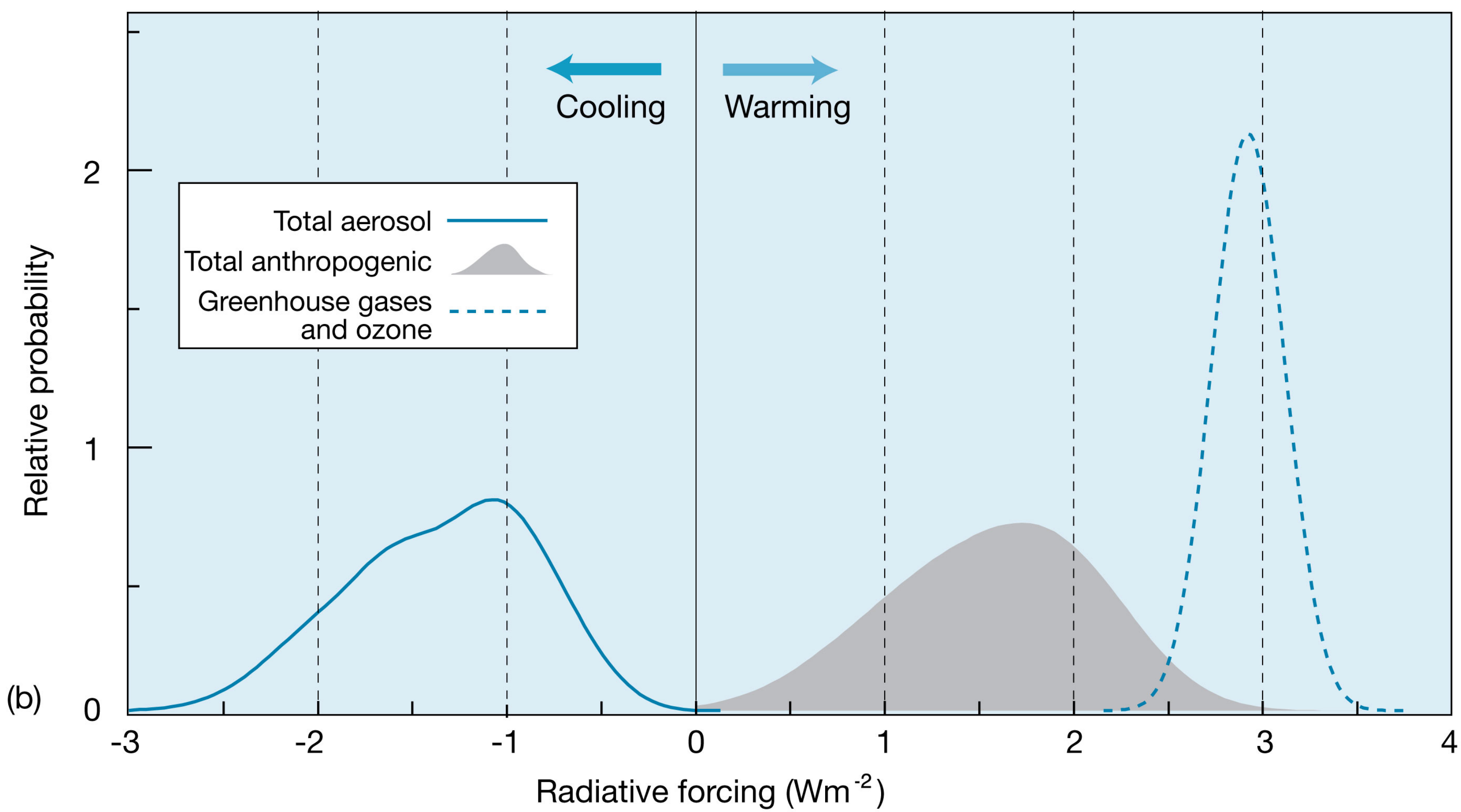


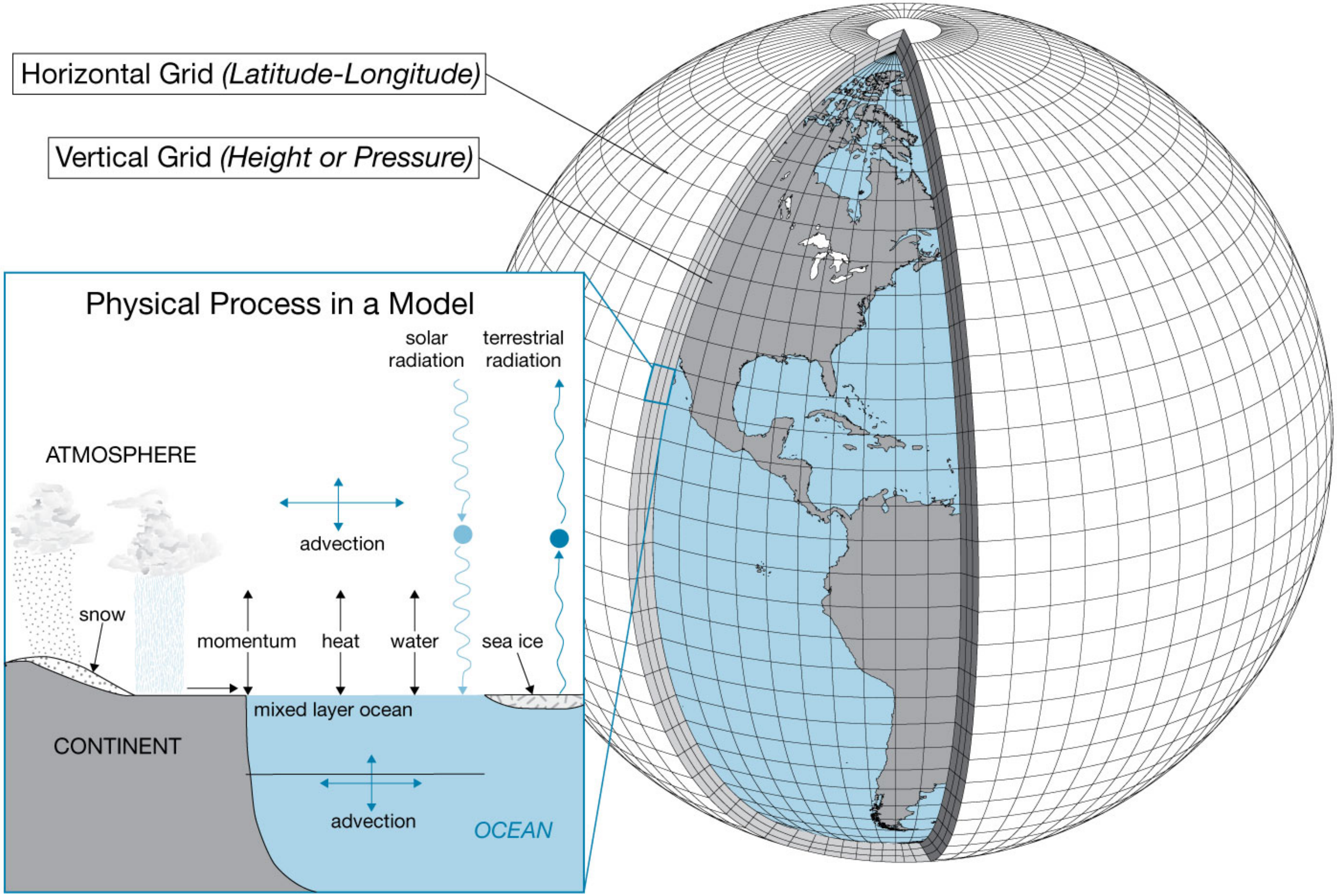
1800
1750
1700
1650
1600
CH4 (ppb)
(a)
NOAA/GMD
AGAGE
20
15
10
5
0
-5
-10
d(CH4)/dt(ppb yr-1)
(b)
1985
1990
1995
2000
2005
Year

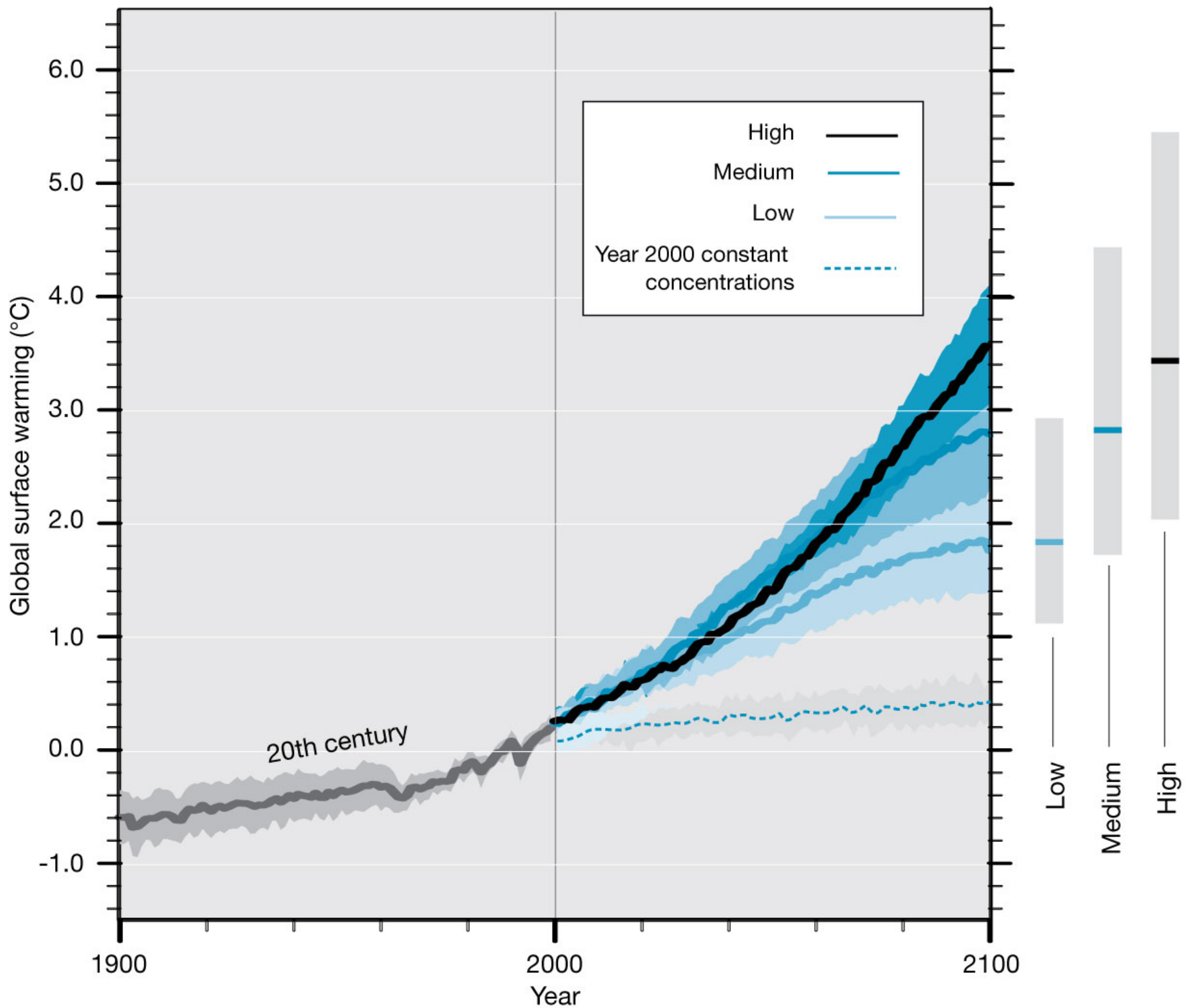

325
320
315
310
305
300
295
N2O concentration
1980
1985
1990
1995
2000
2005
Year
AGAGE (NH)
AGAGE (SH)
NOAA.GMD (NH)
NOAA/GMD (SH)

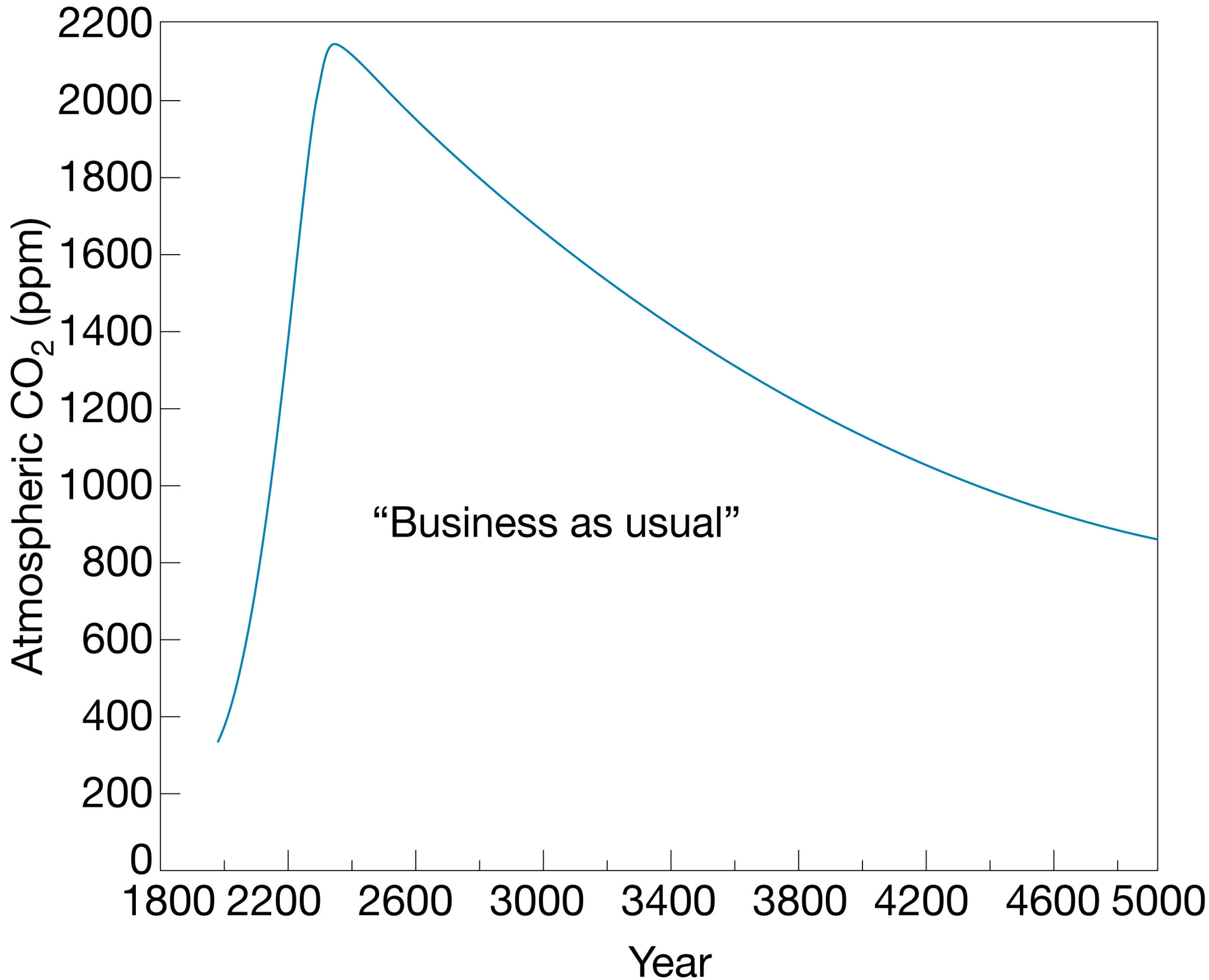


Long-lived greenhouse gases
CO2
N2O
CH4
Halo-carbons
Ozone
Stratospheric
Tropospheric
Stratospheric water vapor from CH4
Surface albedo
Land use
Black carbon on snow
Total Aerosol
Direct effect
Cloud albedo effect
Linear contrails
Solar irradiance
Anthropogenic
Natural
(a)
Terms
-2
-1
0
1
2
Radiative forcing (Wm-2)
Climatic Efficiency
Time scale
Spatial scale
Scientific understanding
1.0
Global
High
1.0-1.2
10-100 years
Global
High
0.5-2.0
Weeks-100 years
Continent to global
Med.
1.0
10 years
Global
Low
10-100 years
Local to continent
Med. Low
0.7-1.1
Days
Continent to global
Med. Low
1.0-2.0
Hours-days
Continent to global
Low
0.6
Hours
Continent
Low
0.7-1.0
10-100 years
Global
Low

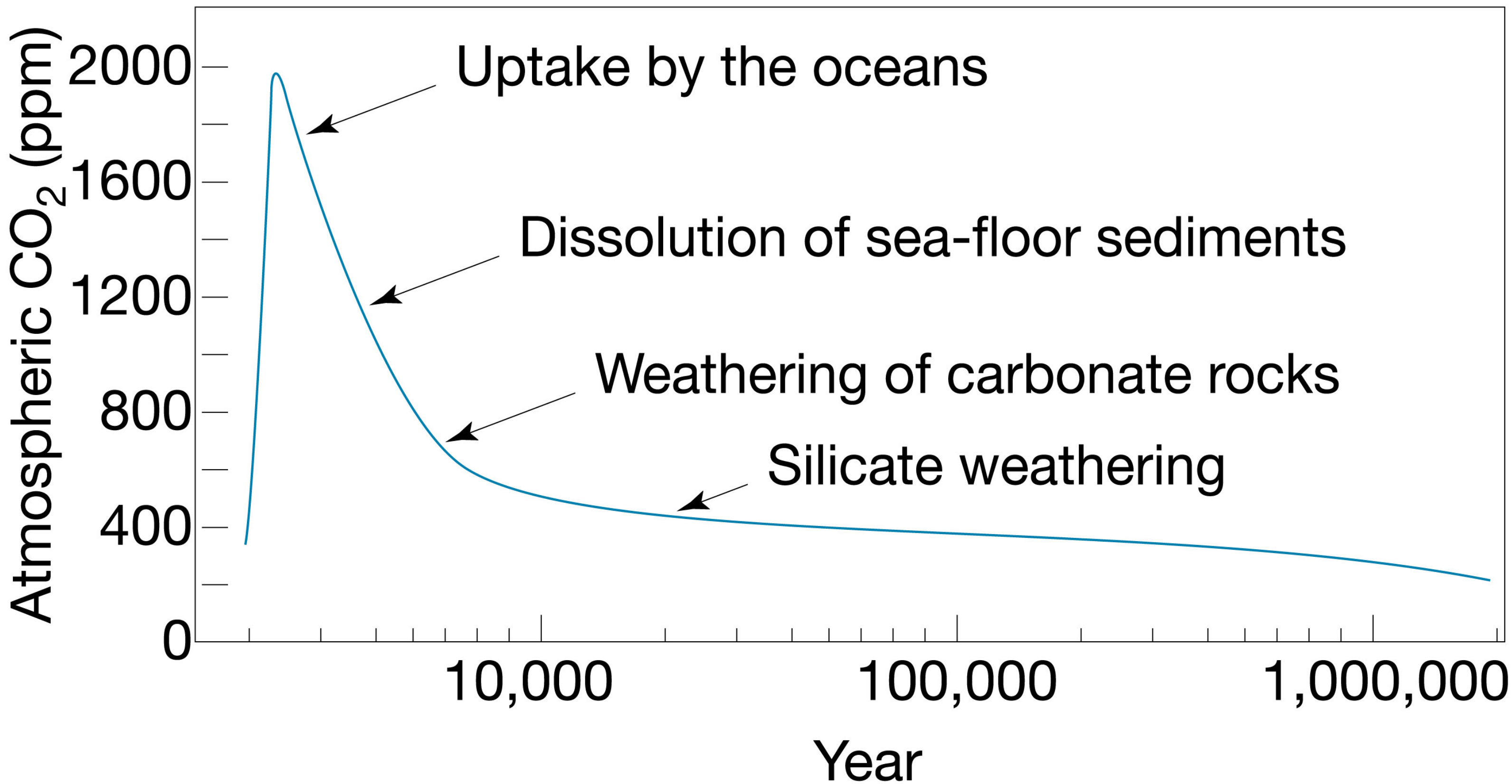

Cooling
Warming
Total aerosol
Total anthropogenic
Greenhouse gases
and ozone
Relative probability
2
1
0
(b)
-3
-2
-1
0
1
2
3
4
Radiative forcing (Wm -2)


Horizontal Grid *(Latitude-Longitude)*
Vertical Grid *(Height or Pressure)*
Physical Process in a Model
solar radiation
terrestrial radiation
ATMOSPHERE
advection
snow
momentum
heat
water
sea ice
mixed layer ocean
CONTINENT
advection
OCEAN


High
Medium
Low
Year 2000 constant concentrations
20th century
Global surface warming (°C)
Year
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
1900
2000
2100
Low
Medium
High


2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Atmospheric CO_2 (ppm)
"Business as usual"
1800 2200 2600 3000 3400 3800 4200 4600 5000
Year

(a)


Atmospheric CO_2 (ppm)
2000
1600
1200
800
400
0
Uptake by the oceans
Dissolution of sea-floor sediments
Weathering of carbonate rocks
Silicate weathering
10,000
100,000
1,000,000
Year

(b)