

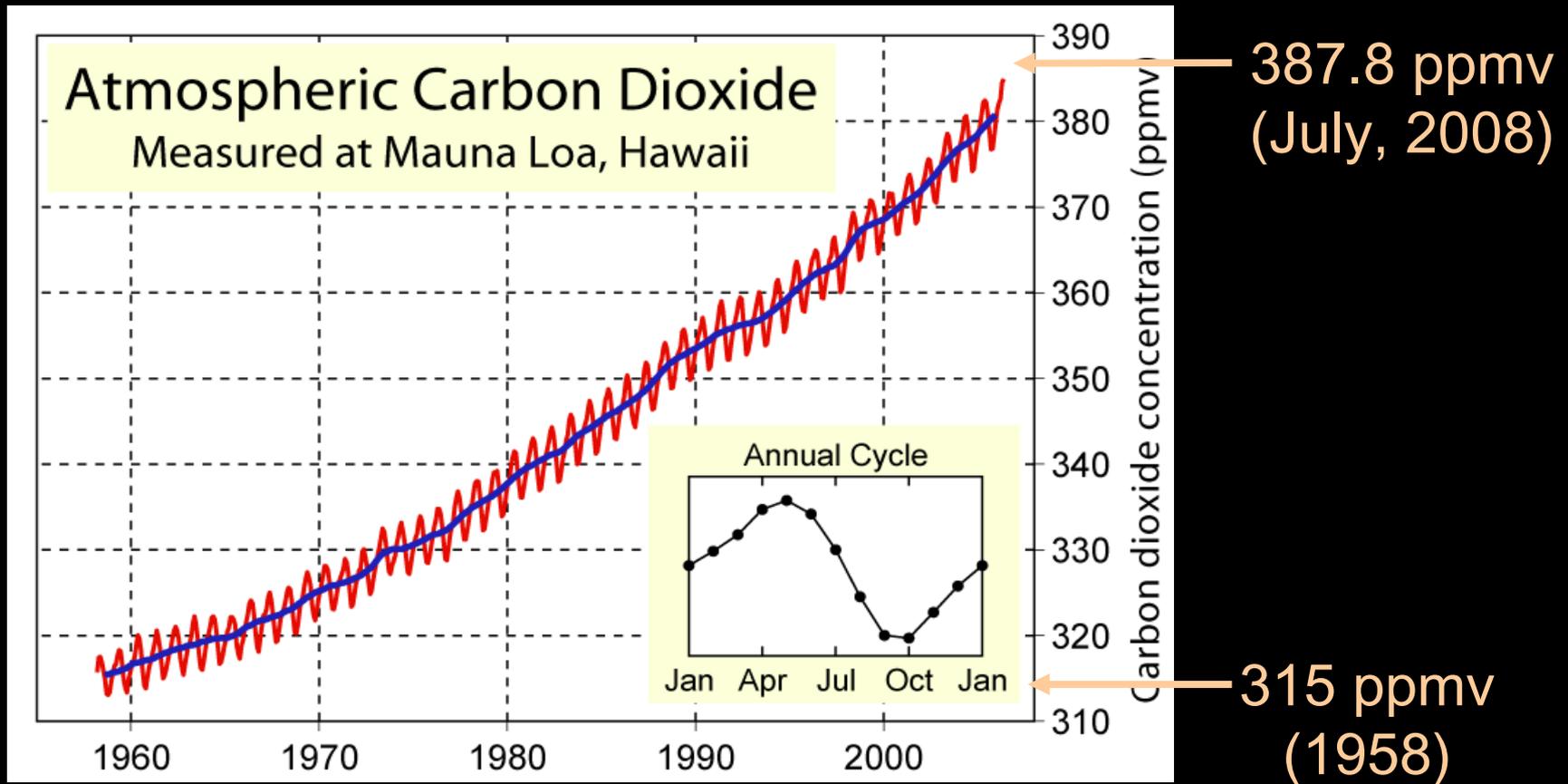
Earth 002

Chapter 1

**Present and
past global
change**



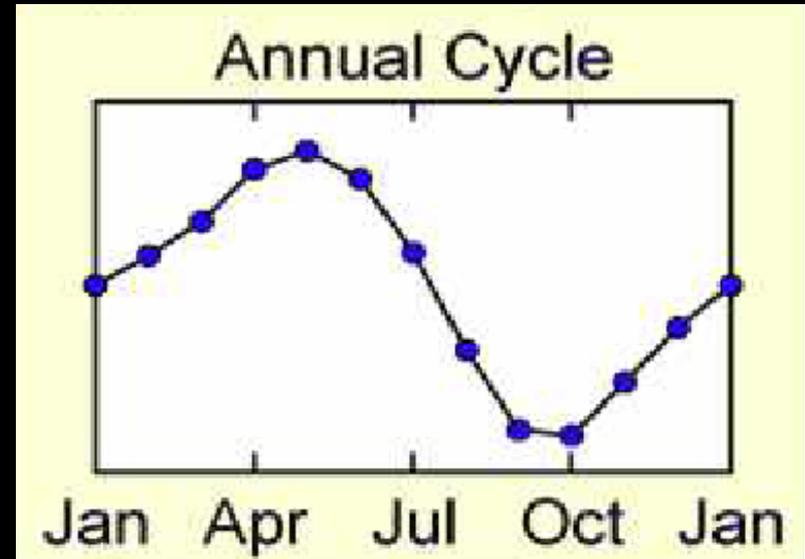
Keeling curve (Mauna Loa)



Source: <http://scrippsco2.ucsd.edu/>
(Graph from Wikipedia)

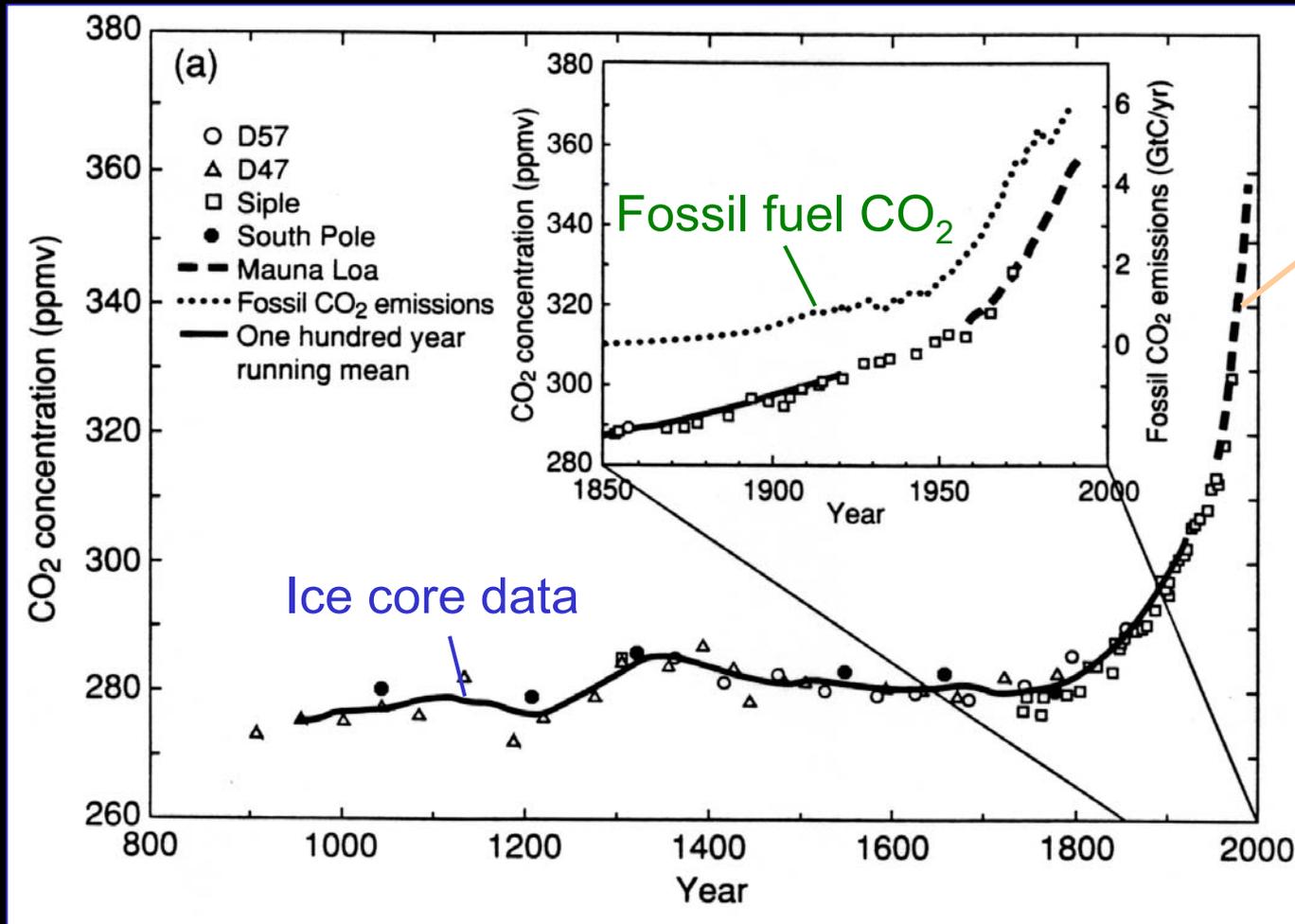
Keeling curve interpretation

- 5-6 ppm seasonal cycle
- “Breathing” of northern hemisphere forests
$$\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{CH}_2\text{O} + \text{O}_2$$
- Hawaii is at 19°N, so
 - CO₂ is low in the fall (following summertime photosynthesis)
 - CO₂ is high in the spring (following wintertime respiration)



Graph from Wikipedia

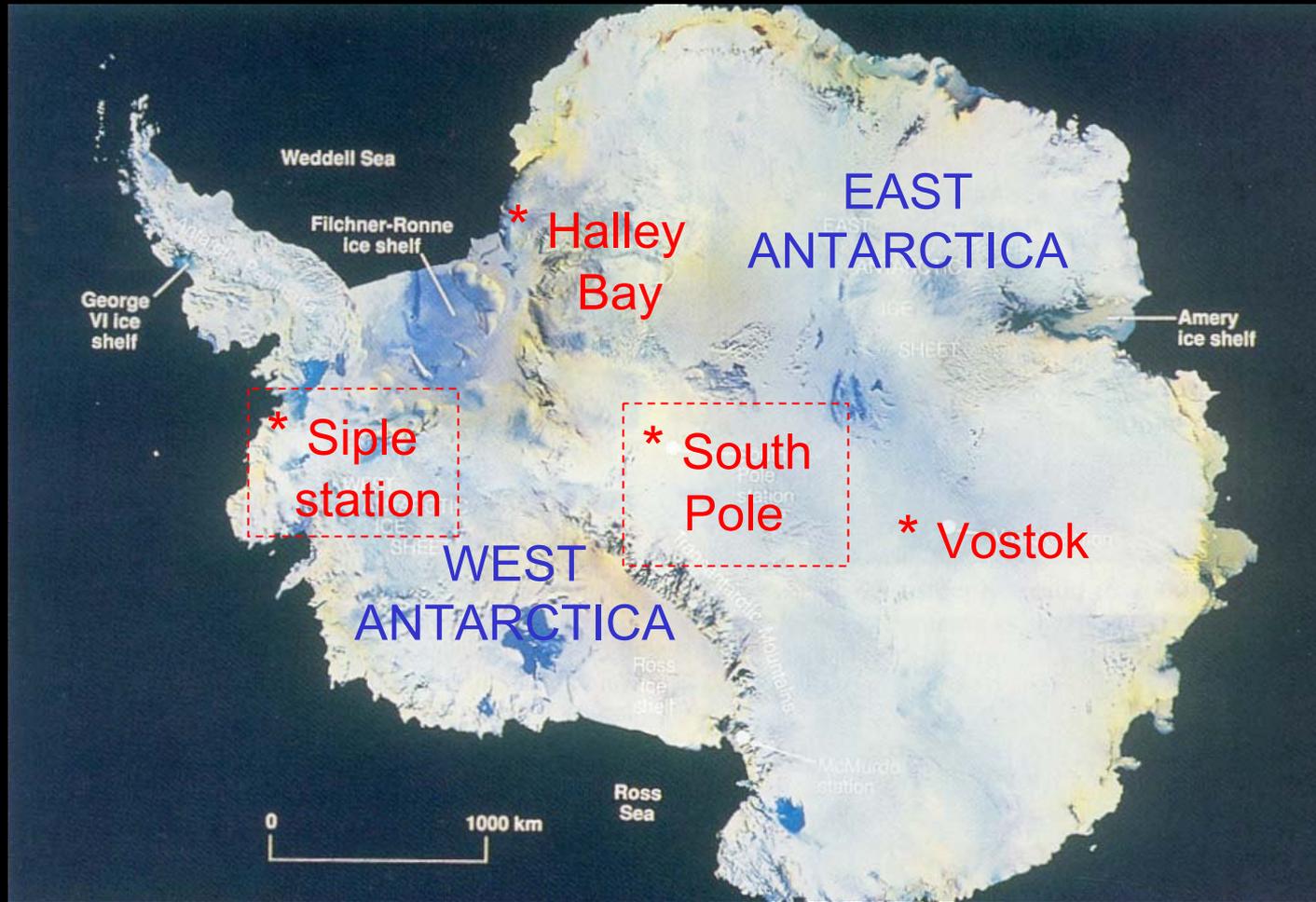
Ice core CO₂/Keeling curve



Source: *Climate Change 1994* (IPCC)

See also *The Earth System*, ed. 2, Fig. 1-3

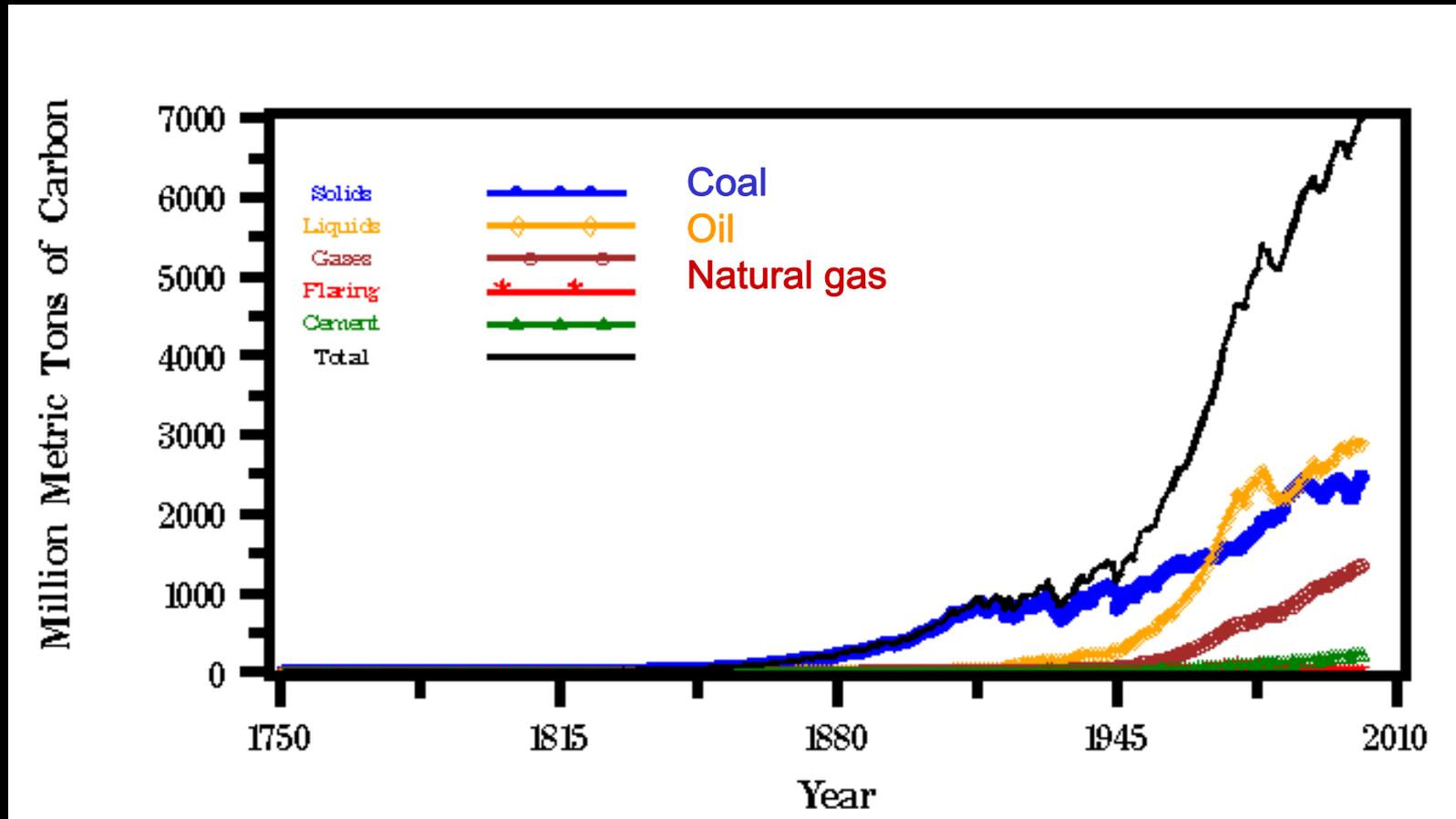
Antarctic research stations



From Skinner and Porter, *The Blue Planet* (1995)

- We *know* where the CO₂ is coming from...

Global CO₂ emissions

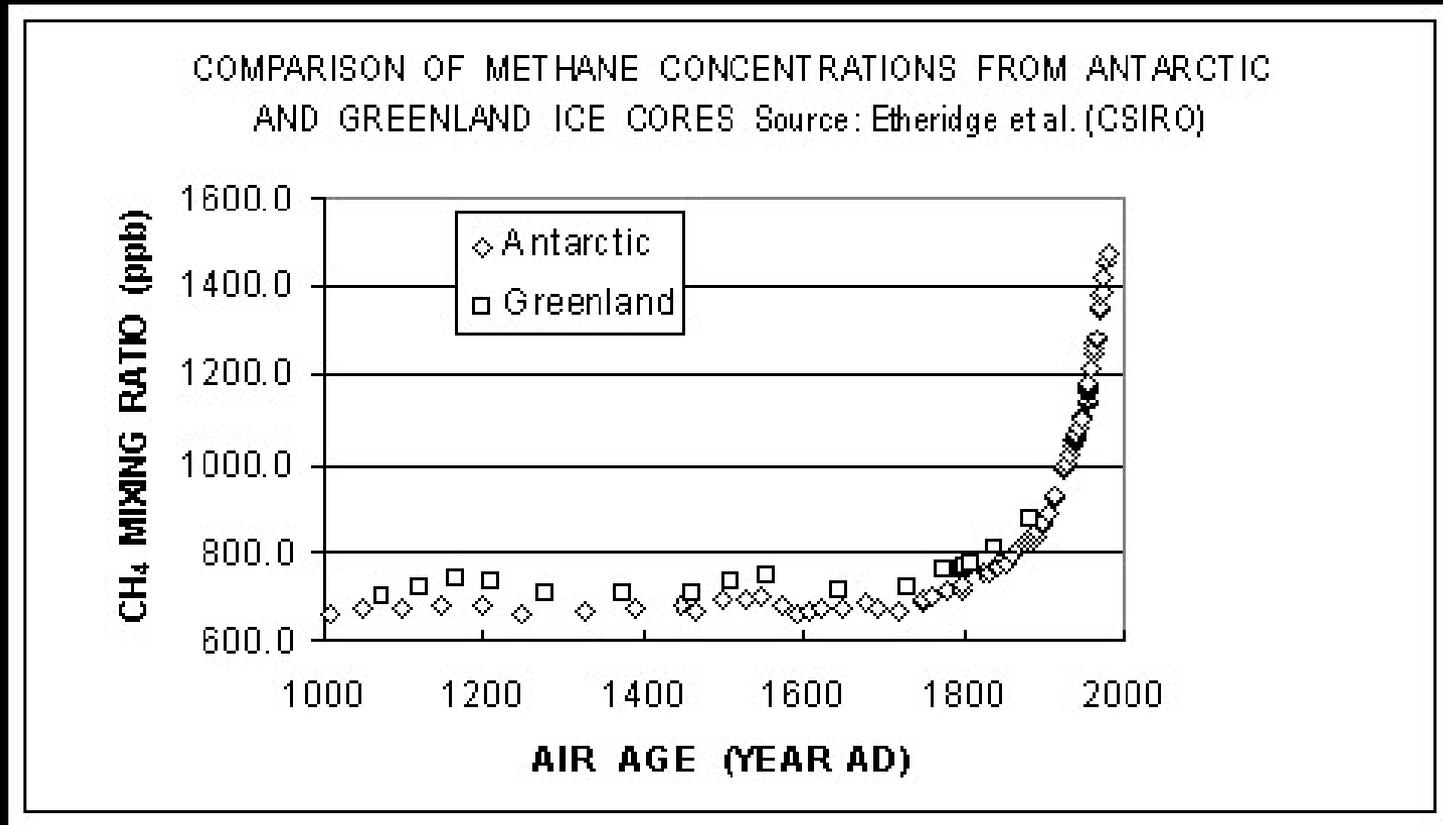


Source: Carbon Dioxide Information Analysis Center (CDIAC)

See also *The Earth System*, ed. 2, Fig. 16-2

- Other greenhouse gases are increasing in concentration, as well

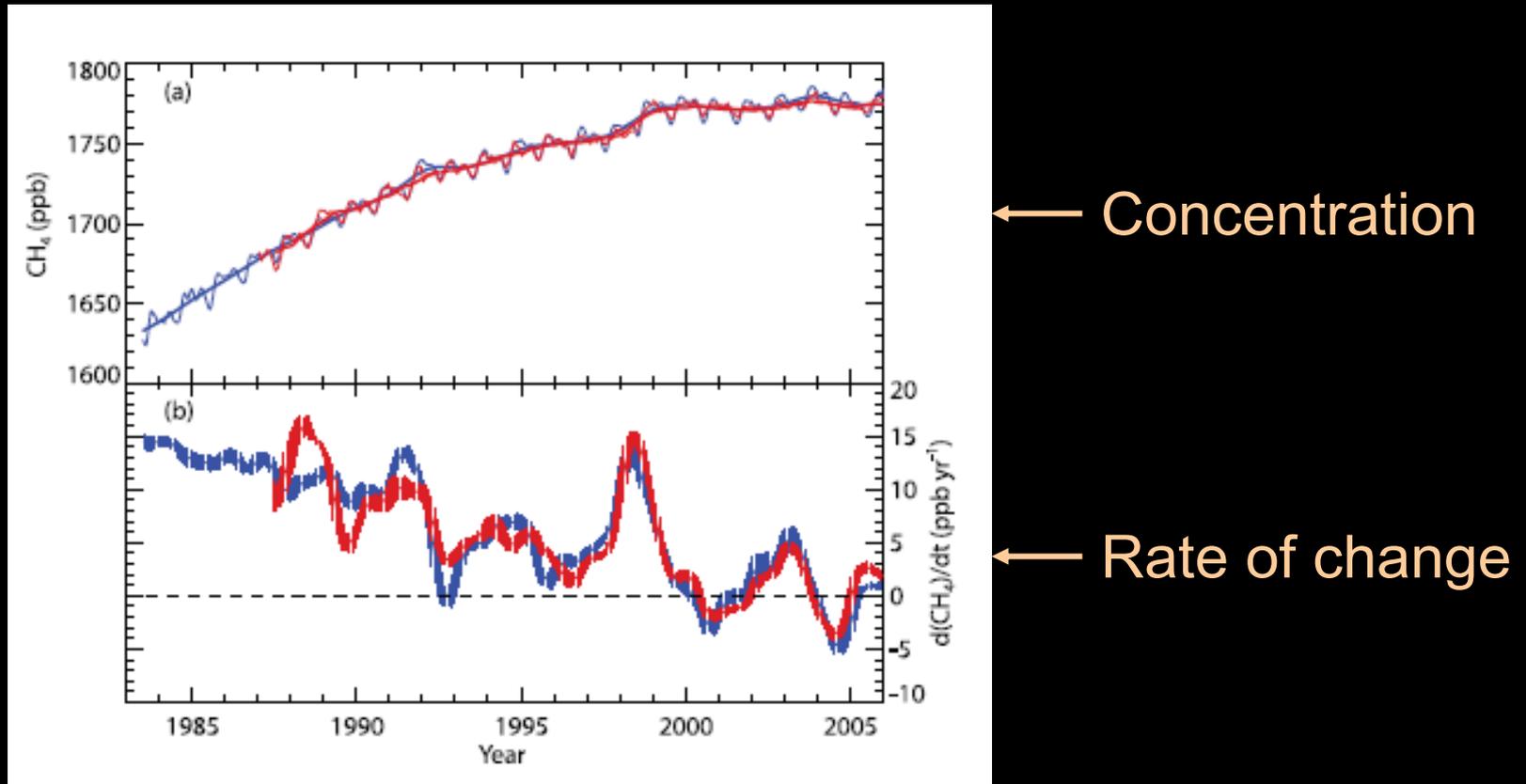
Methane from ice cores



The Earth System, ed. 2, Fig. 16-4

- Methane concentrations have more than *doubled* since the preindustrial era

Methane (CH₄) measurements



- Methane increased steadily up until about the year 2000
- It now appears to be leveling off!
-- Does this make sense?

- To answer this question, one must think about where methane comes from...

Sources of methane ?

Agricultural

- Rice paddies
- Cows, and some *people*...☺
 - Methane is probably leveling out because food production has nearly stabilized



Other sources

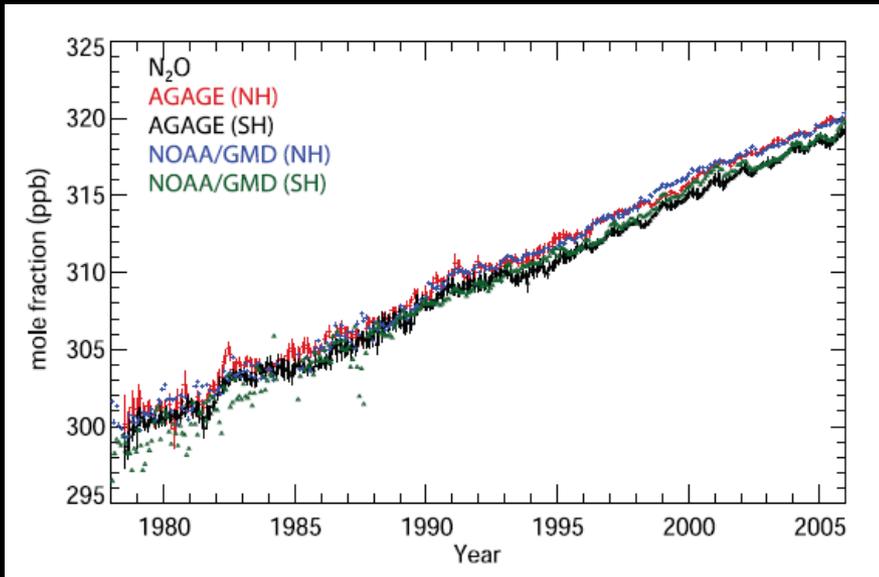
- Termites
- Natural gas leaks/venting from oil wells

Question: What do the first 3 of these sources have in common?



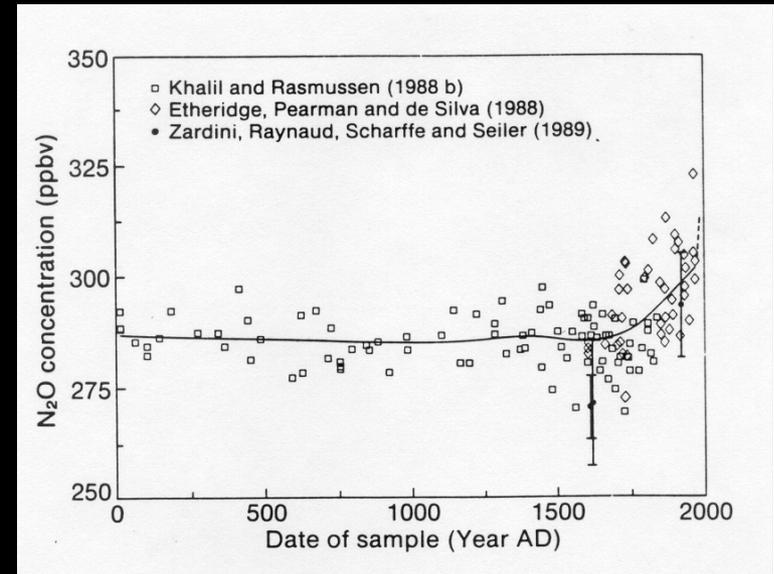
Answer: They all have *anaerobic* microenvironments where methanogenic bacteria (**methanogens**) can live

Nitrous oxide (N₂O) measurements



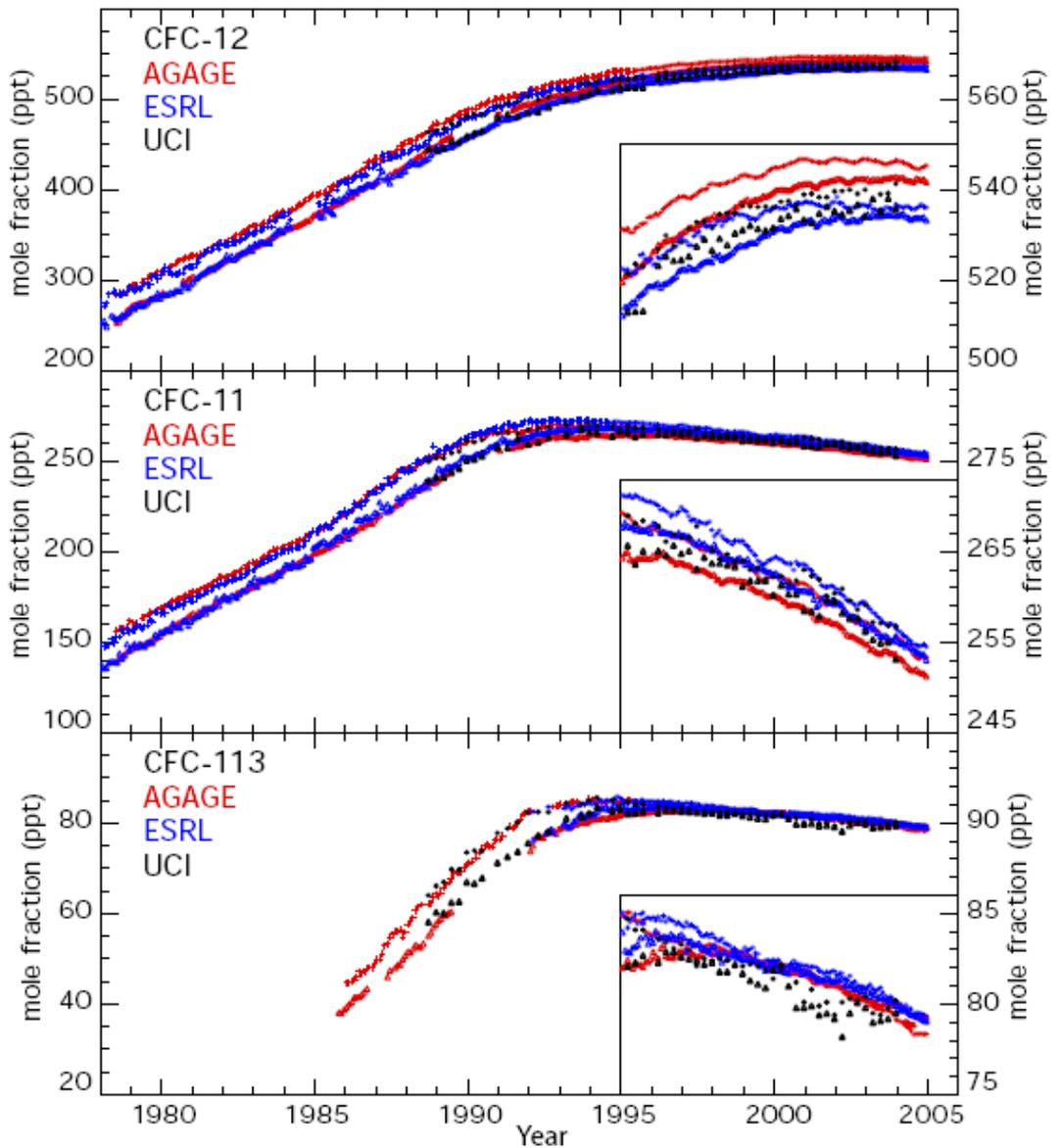
Atmospheric measurements

IPCC 2007, Chapter 2, Fig. 2.5



Ice core data

The Earth System, ed. 2, Fig. 16-4



Freon-12
 (Refrigerators,
 air conditioners)

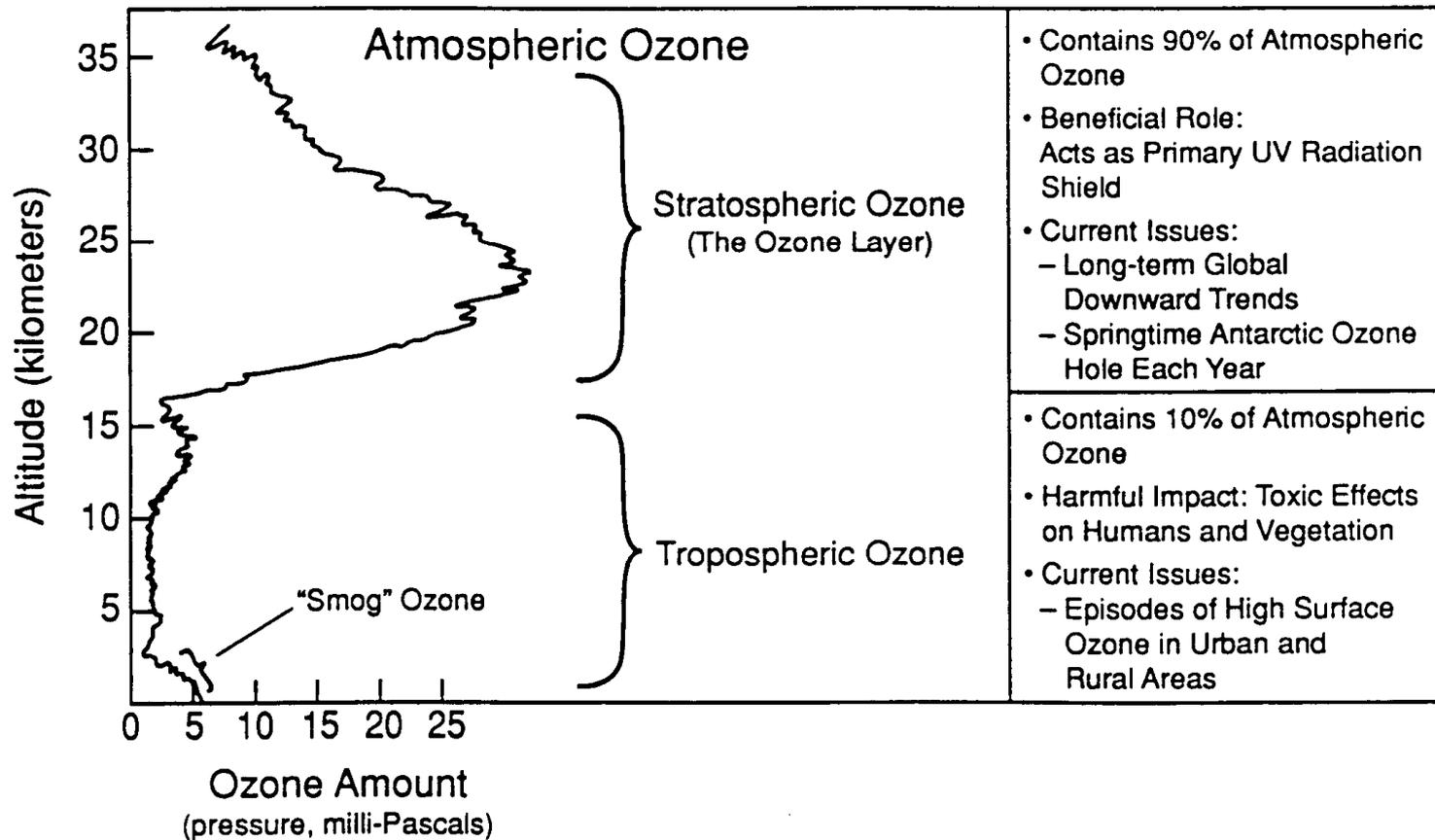


Freon-11
 (Spray cans, blowing
 agent for foams, cleaning
 semi-conductor chips)

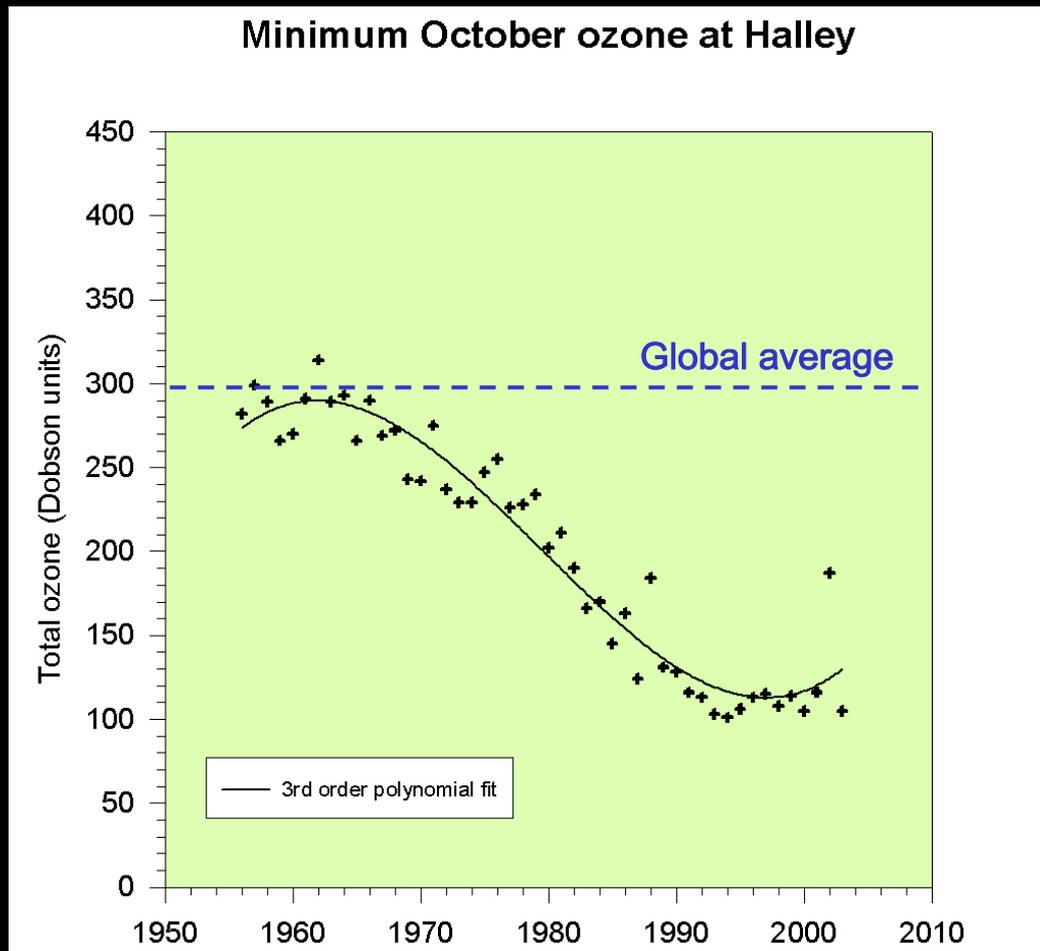
Source: Scientific Assessment of Ozone
 Depletion: 2006, World Meteorological
 Organization, Geneva, Switzerland (2006)

Freons are greenhouse gases but, more importantly, they also affect ozone...

The Ozone "Layer"

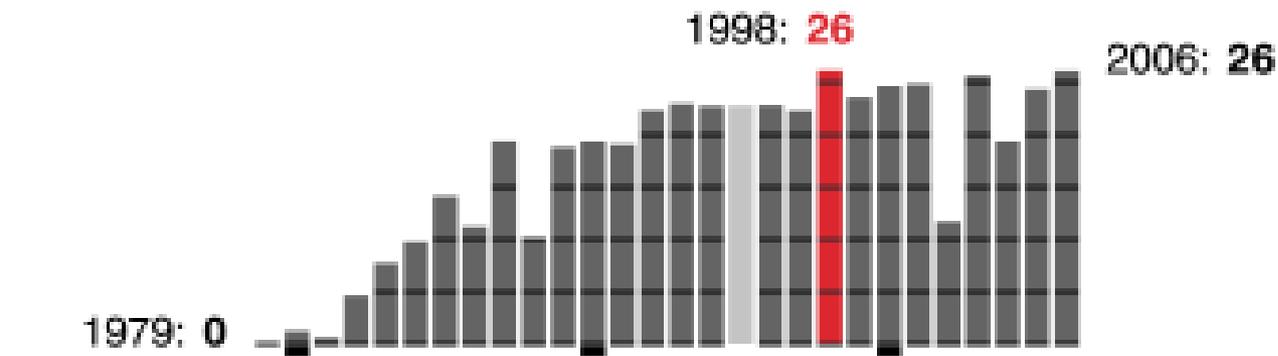


Ozone record: Halley Bay

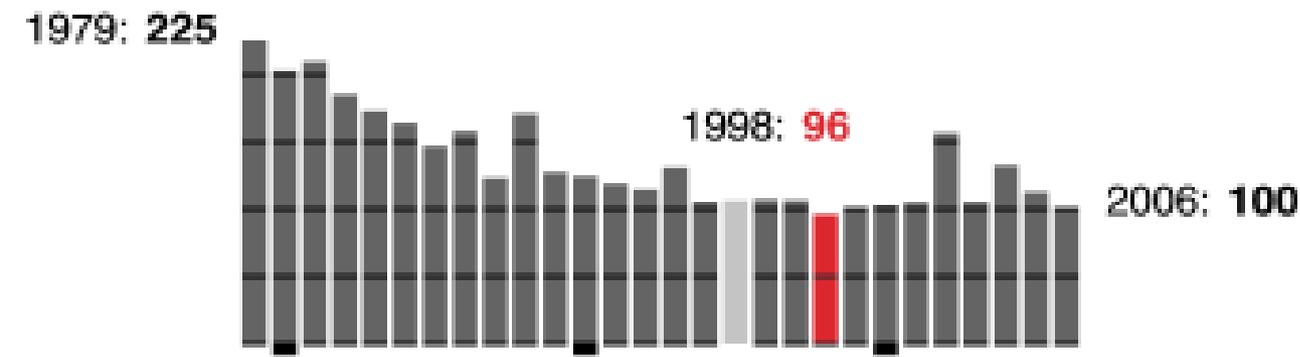


- Ozone column depth (thickness) over Antarctica in October decreased steadily from 1960 to 1995
- This, of course, is known as the “ozone hole”
- Since then, it has stabilized, and may even have started to recover

<http://www.antarctica.ac.uk/met/jds/ozone/images/zminoct.JPG>



Average (Sep. 7 - Oct. 13) ozone hole area (millions of km²)



Average (Sep. 21 - Oct. 16) minimum ozone (Dobson Units)



Note: No data were acquired during the 1995 season

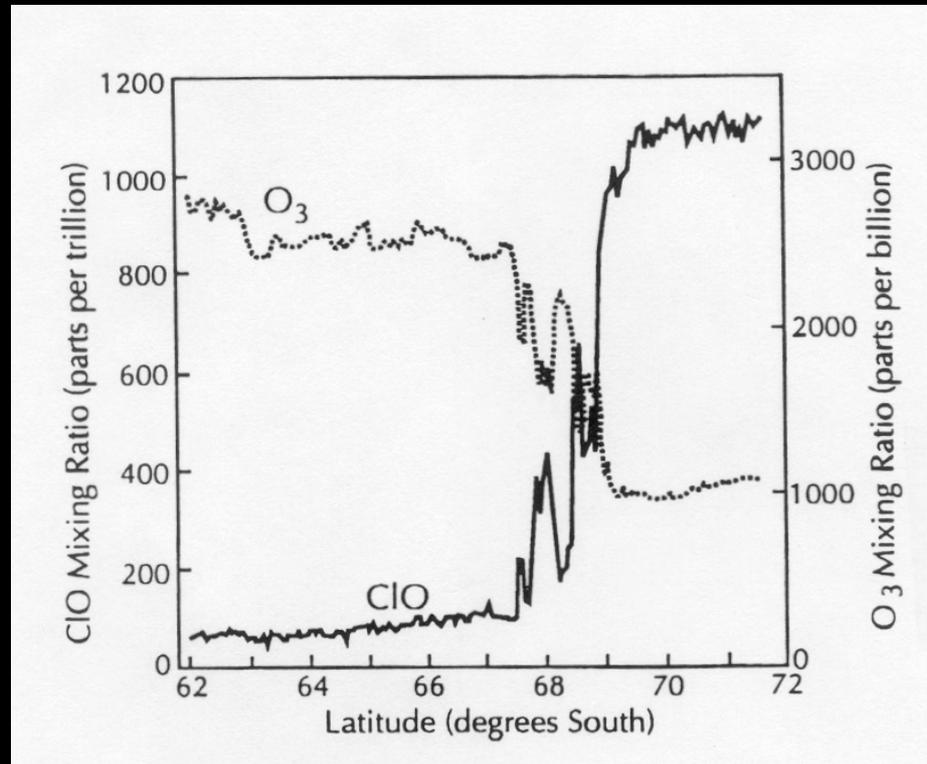
<http://ozonewatch.gsfc.nasa.gov/>

← Area

← Minimum
ozone
concentration

- The hole *area* also appears to have stabilized...

O₃ and ClO flying into the ozone hole

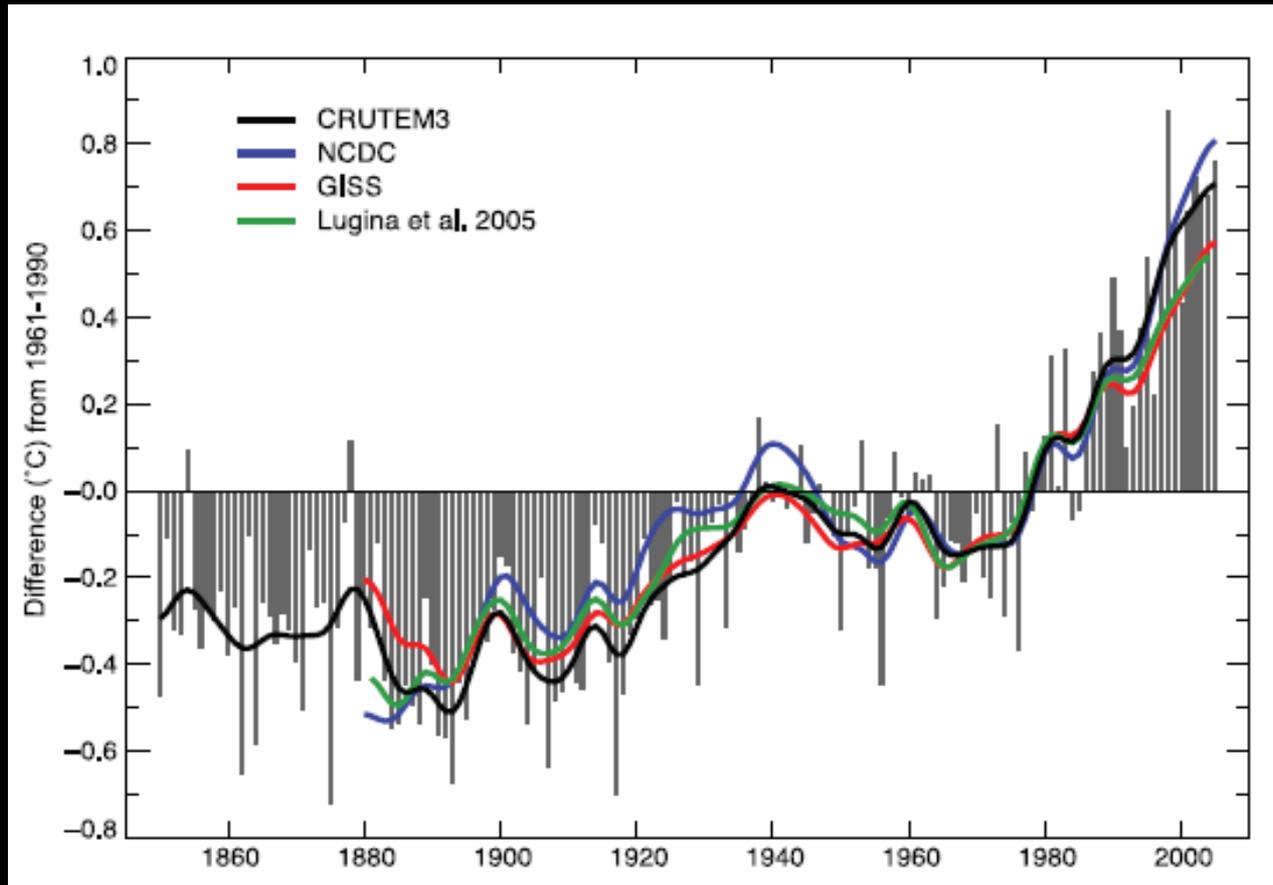


See *The Earth System*, ed. 2, Fig. 1-6

- Bill Brune, chairman of our Meteorology department, played an integral role in making these measurements

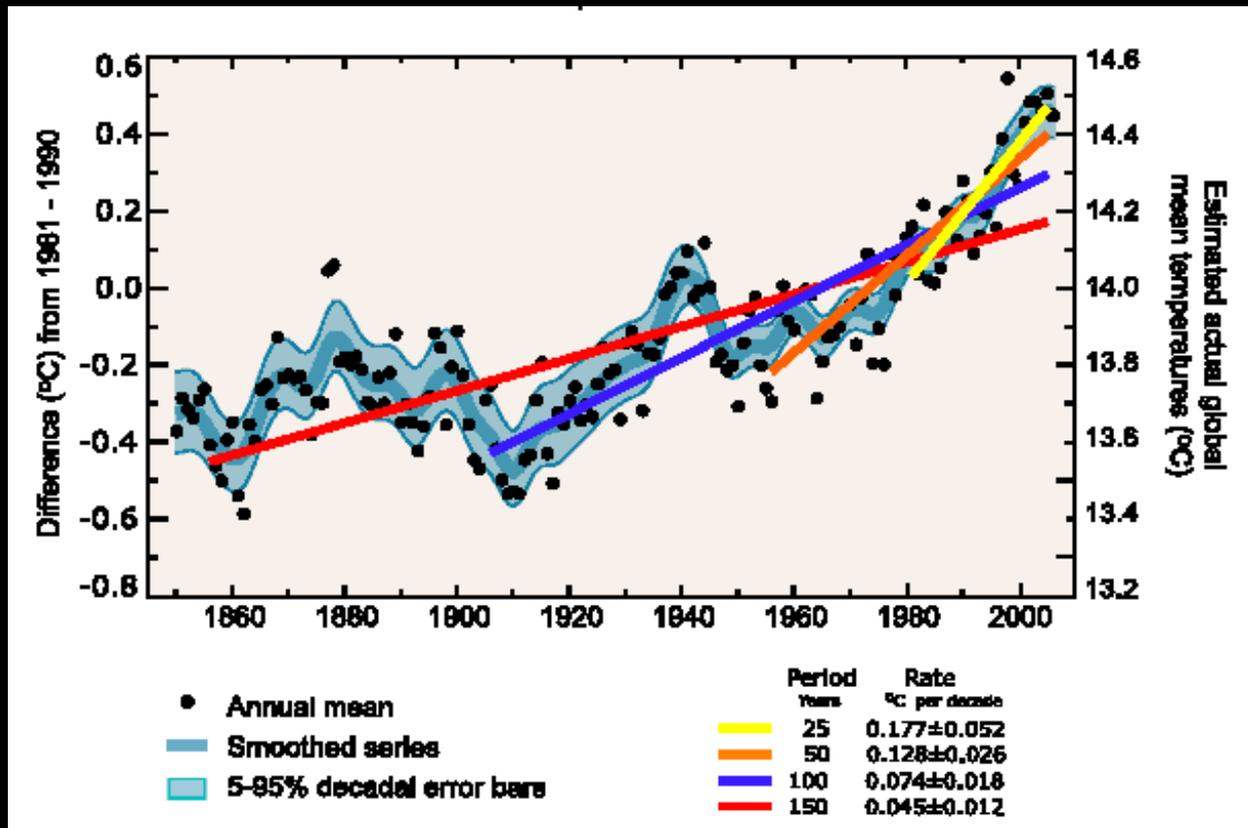
Back to climate...

Recent surface temperatures



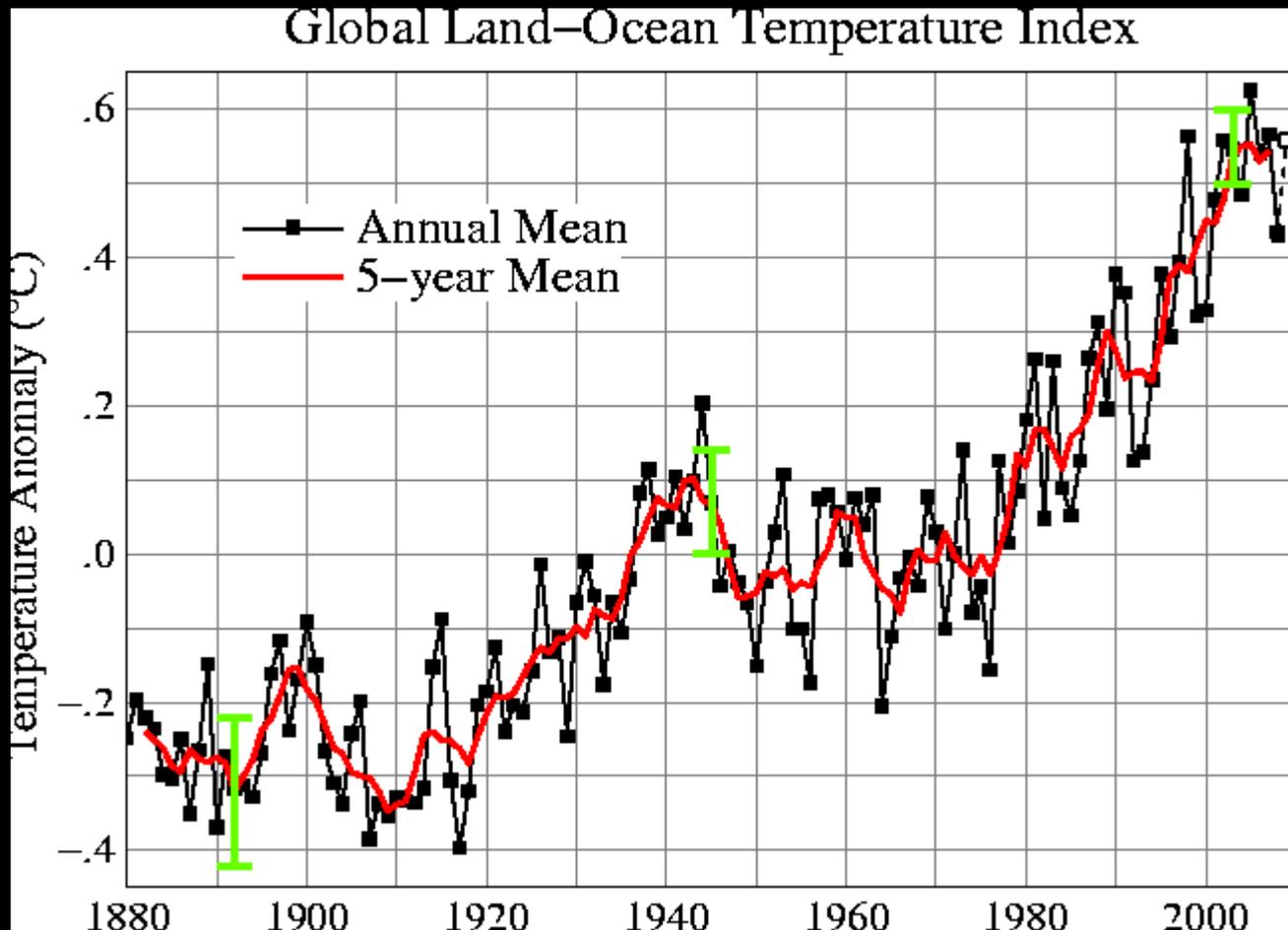
Source: IPCC 2007 report, Ch. 3, p. 241
See also *The Earth System*, ed. 2, Fig. 1-4

Surface temperature trends



Source: 2007 IPCC report (<http://www.ipcc.ch/>)

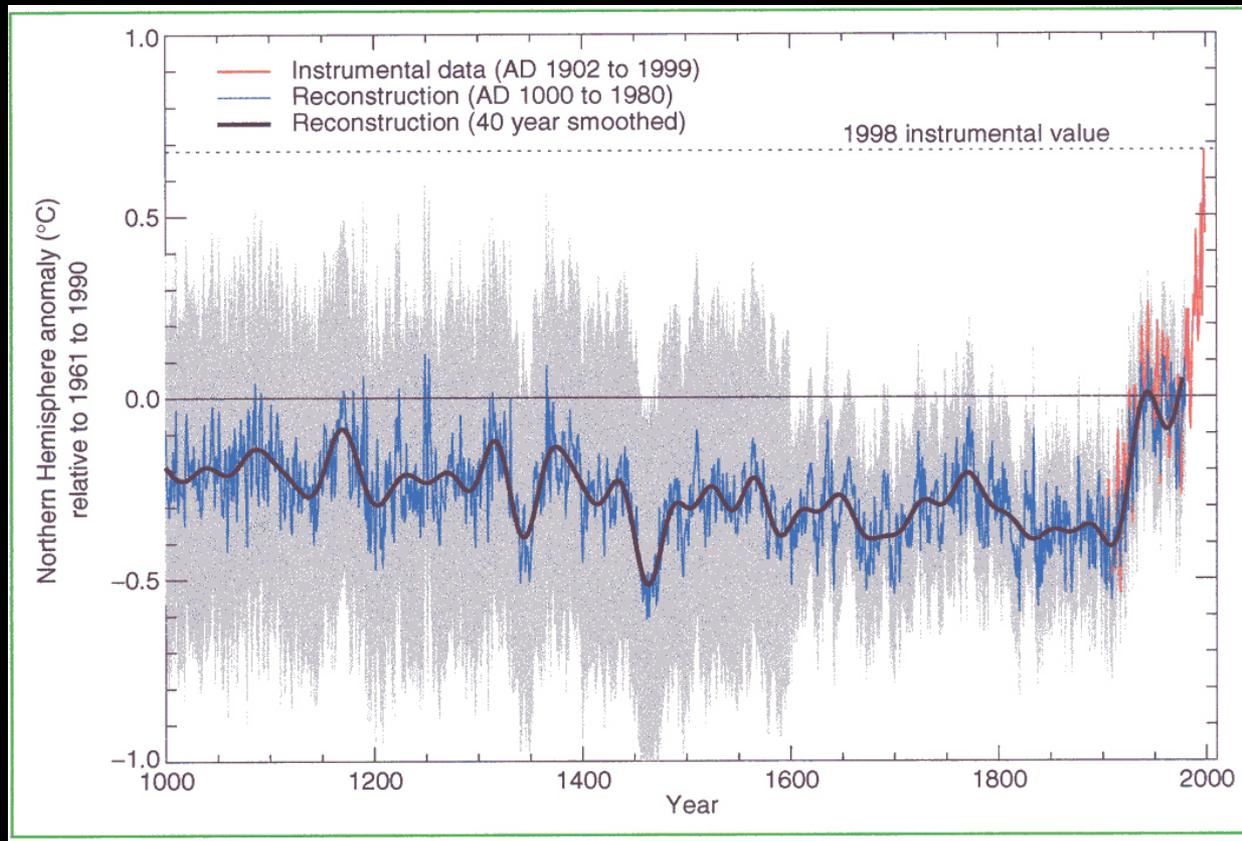
- There is also statistical evidence that the *rate* of surface temperature increase is also increasing



<http://data.giss.nasa.gov/gistemp/graphs/>

- Climate skeptics have pointed out that *the rate of warming appears to have decreased over the last decade*
- The IPCC counters, though, that this is within the range of normal inter-decadal variability

Millennial surface temperatures ("hockey stick" diagram)



Source: *Climate Change 2001* (IPCC)

- Michael Mann, Penn State professor of meteorology, was instrumental in creating this diagram

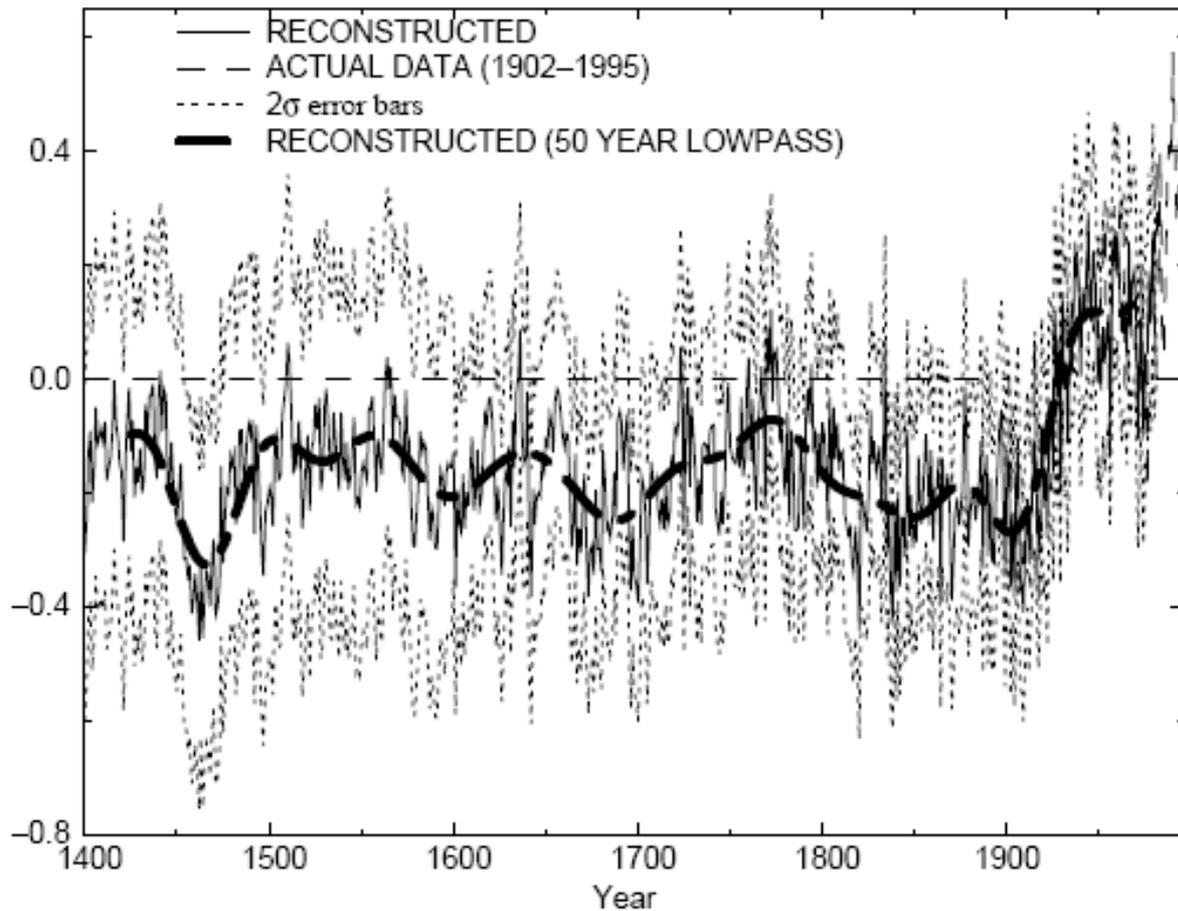
Hacked e-mails attack research (Centre Daily Times, Nov. 26, 2009)

- The climate change debate has grown even more political just recently
- Hackers broke into a computer system at the University of East Anglia in Great Britain and stole hundreds of climate-related emails and internal documents
- When read selectively and out of context, some of these messages make it appear as if there is indeed a global climate conspiracy



Michael Mann
Prof. of Meteorology
PSU

b



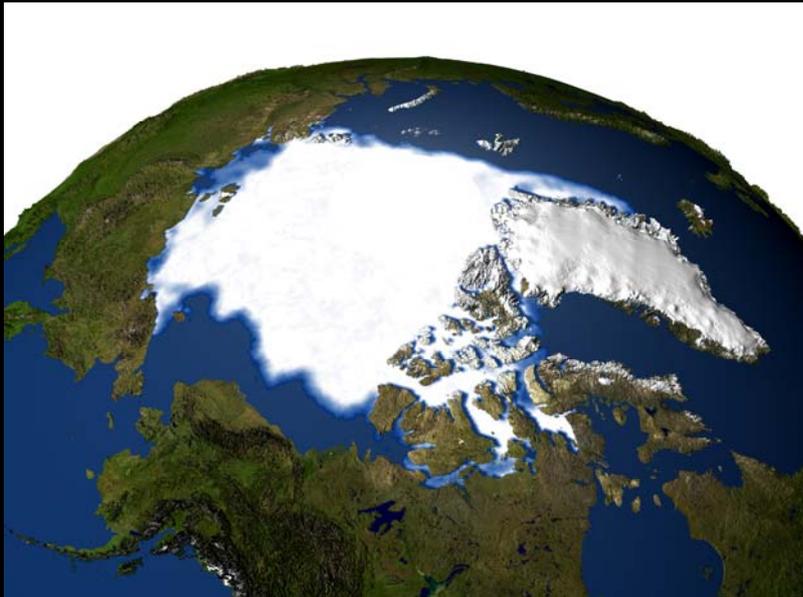
The controversial plot., aka “the hockeystick diagram”

Mann et al., Nature (1998)

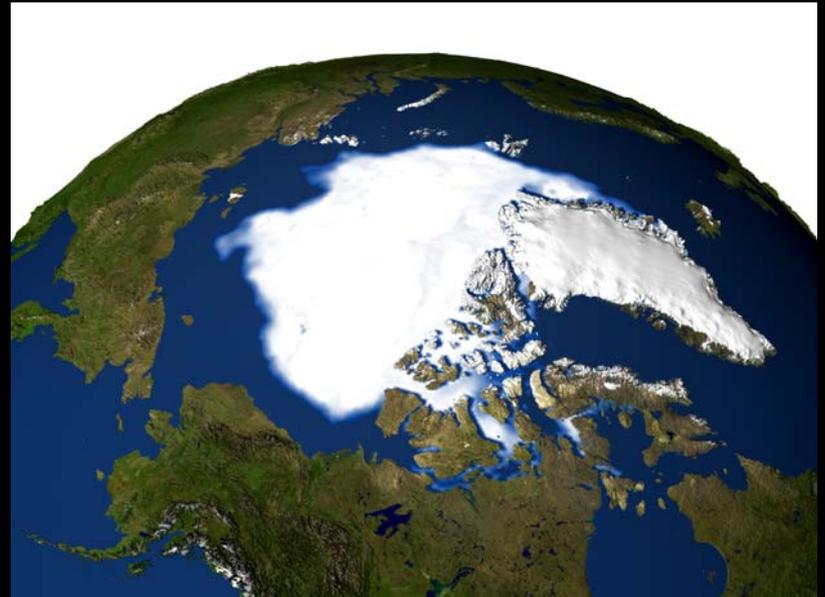
“I’ve just completed Mike’s Nature trick of adding in the real temps to each series for the last 20 years (i.e. from 1981 onwards) and from 1961 for Keith’s to hide the decline.” –Phil Jones, Climate Research Unit, Univ. of East Anglia

- The evidence that climate change is real is particularly strong in the Arctic (because of ice-albedo feedback) \Rightarrow

Changes in Arctic sea ice



Sea ice minimum--1979



Sea ice minimum--2005

- Arctic sea ice has diminished in extent during recent summers
- The fabled Northwest Passage, long sought by explorers, is now open briefly in the early Fall

2007 Arctic sea ice minimum

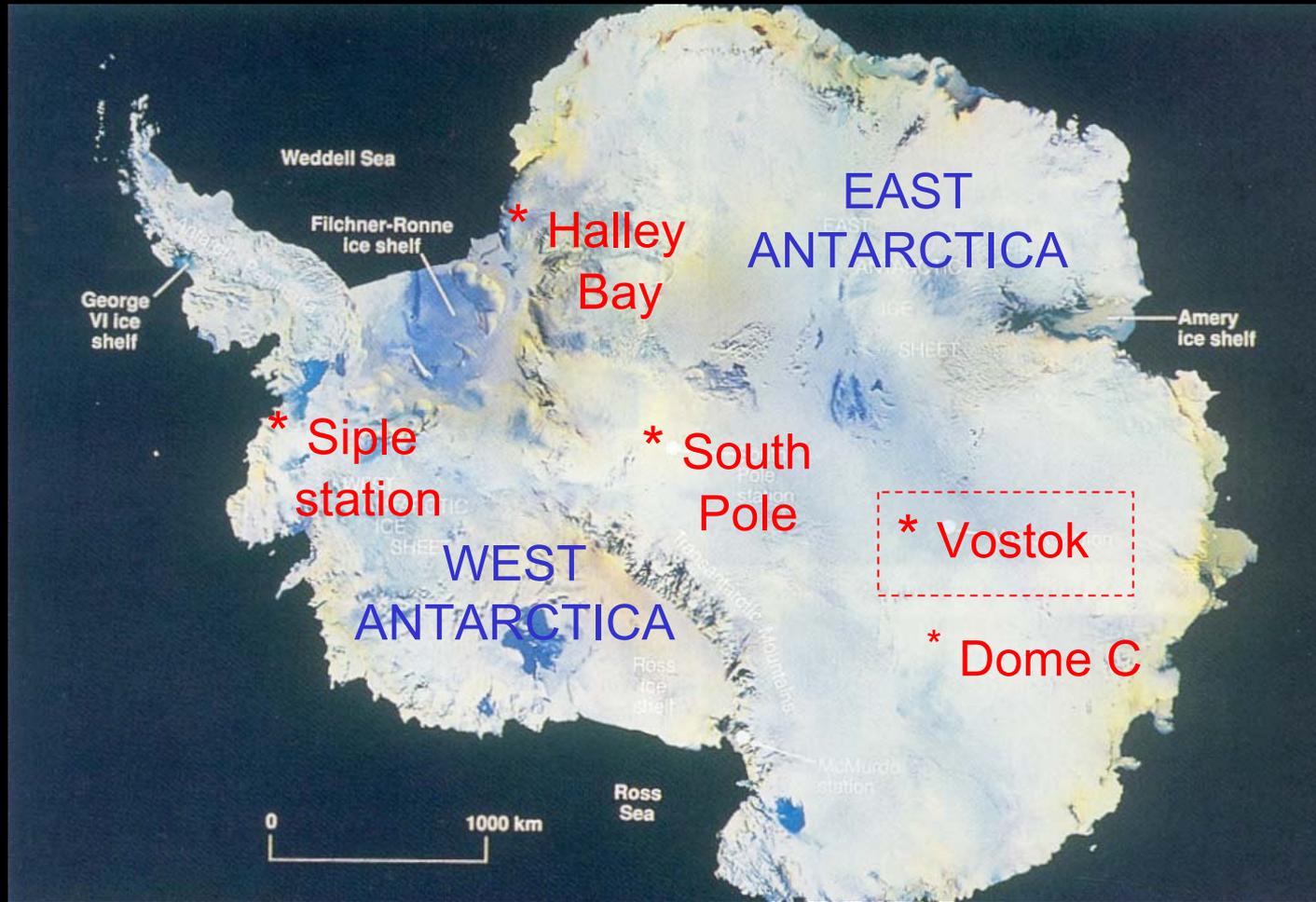


http://www.nasa.gov/images/content/190554main_AMSR_E_09_14_2007_r1.1536.tif

- The **2007** Arctic sea ice pack was the smallest yet...

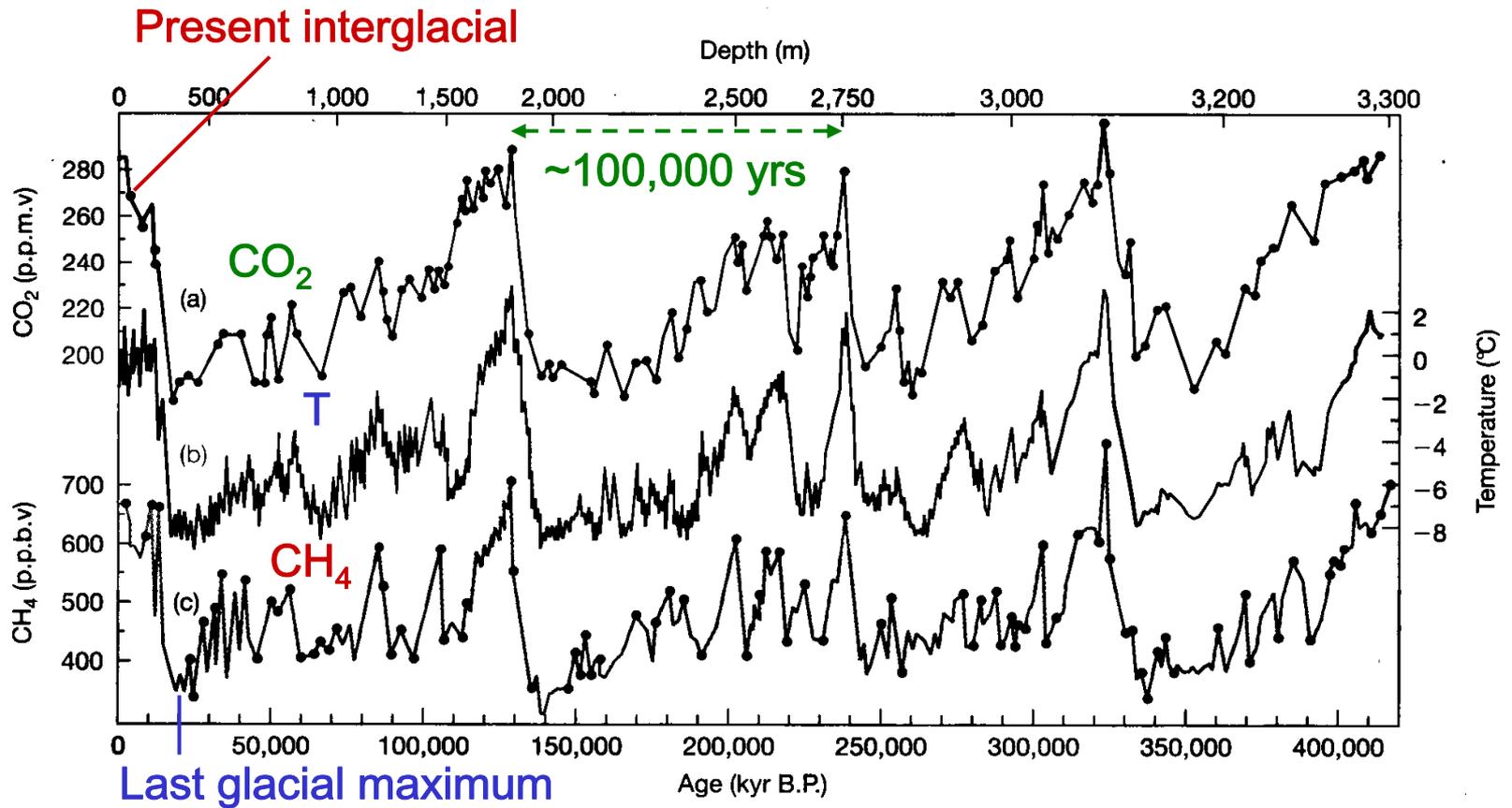
- In this course, we will look at climate on longer time scales as well. Let's go back to Antarctica ⇒

Antarctic research stations



From: Skinner and Porter, *The Blue Planet* (1995)

Vostok ice core measurements

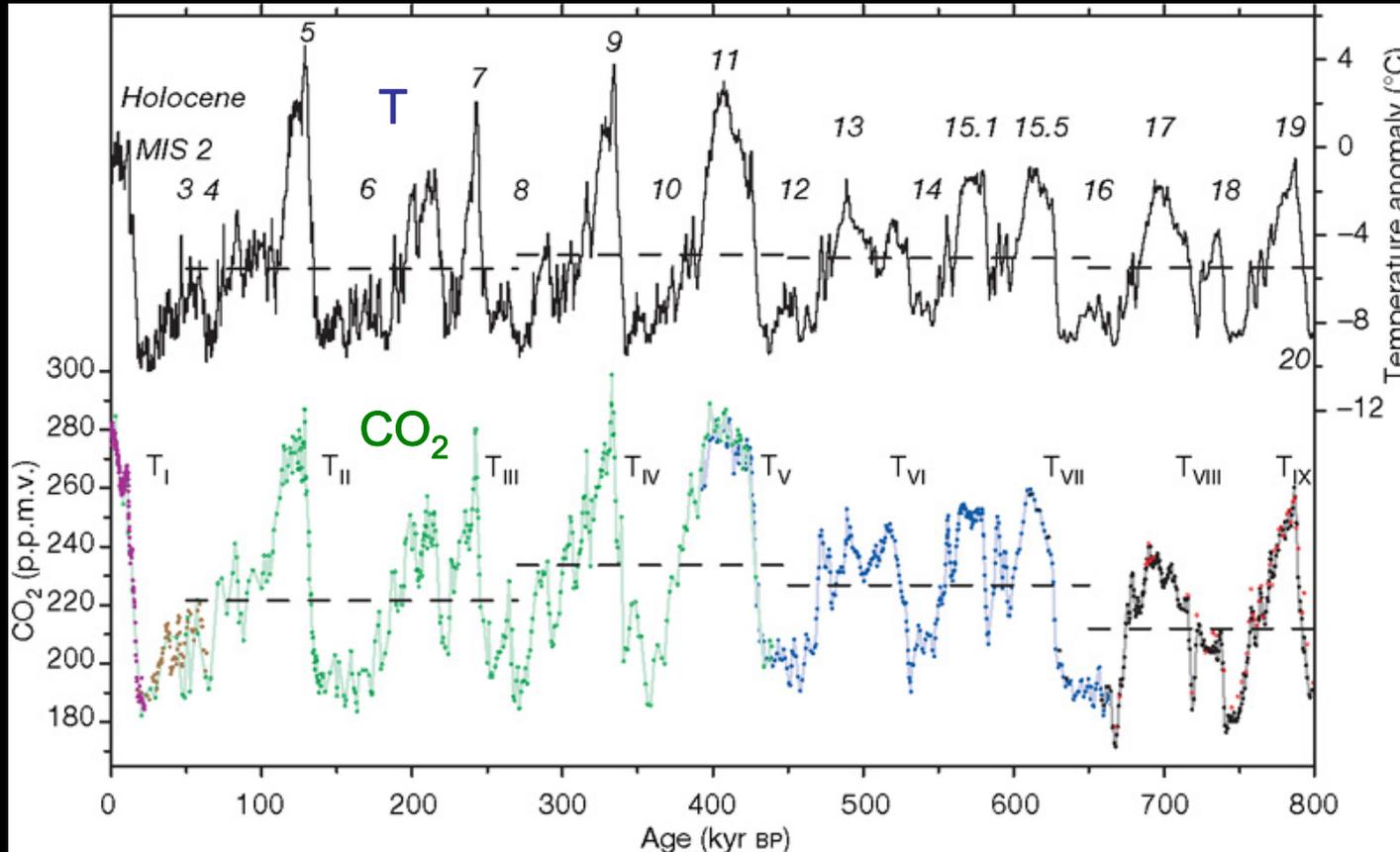


See *The Earth System*, ed. 2, Fig. 1-9

How ice-core paleotemperatures are derived: hydrogen isotopes

- Normal hydrogen: ^1H 1p
- Deuterium: ^2H (or D) 1p, 1n
- Tritium: ^3H (or T) 1p, 2n
 - This last one is radioactive, and so is *not* used in paleotemperature studies
- Seawater, mostly H_2O , contains a fraction 1.6×10^{-4} of HDO. HDO is harder to evaporate, especially when the water is cold. Hence, polar ice is *depleted* in HDO relative to H_2O , and it becomes even more depleted when the climate gets colder.

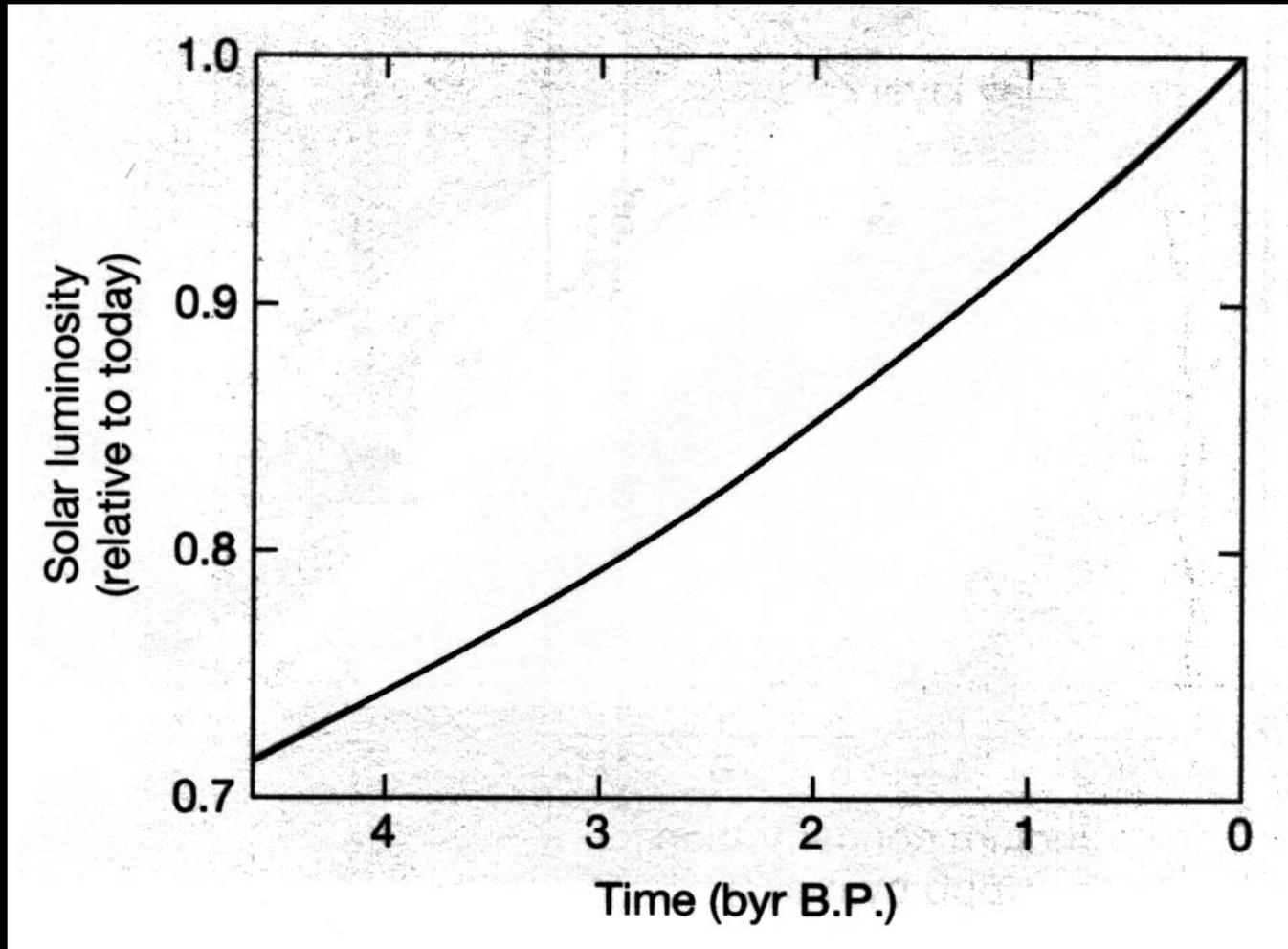
Dome C record



- Both the Vostok and Dome C records indicate that surface temperature and atmospheric CO₂ covary on this time scale

- Finally, much of my own research concerns climate change on *really* long time scales

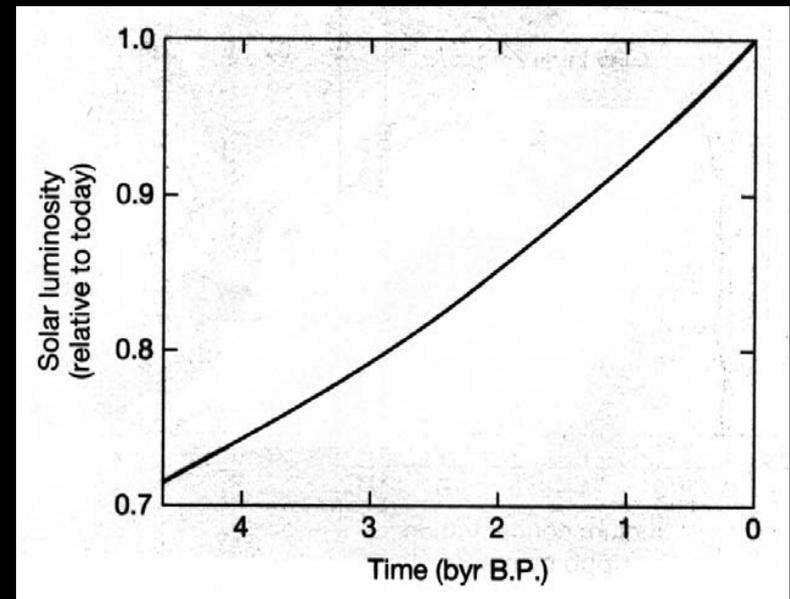
Solar luminosity versus time



See *The Earth System*, ed. 2, Fig. 1-12

Why the Sun gets brighter with time

- H fuses to form He in the core
- Core becomes denser
- Core contracts and heats up
- Fusion reactions proceed faster
- More energy is produced
⇒ more energy needs to be emitted



Question:

- How did Earth remain habitable during its early history when the Sun was less bright? Was it **Gaia**, or was it something else?