a)

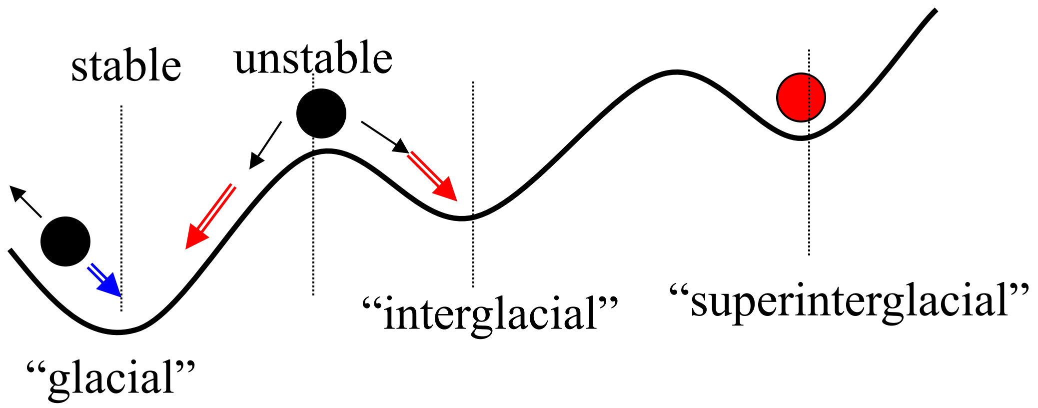


Figure 4.18. a) Idealized "ball bearing" model of the stability of the climate system, showing positive (red arrow) and negative (blue arrow) feedbacks to a perturbation (black arrow). Positive feedbacks amplify a perturbation, destabilizing the system away from equilibrium, while negative feedbacks oppose a perturbation, returning the system to normal, thereby stabilizing the system. Three possible climate states are suggested.

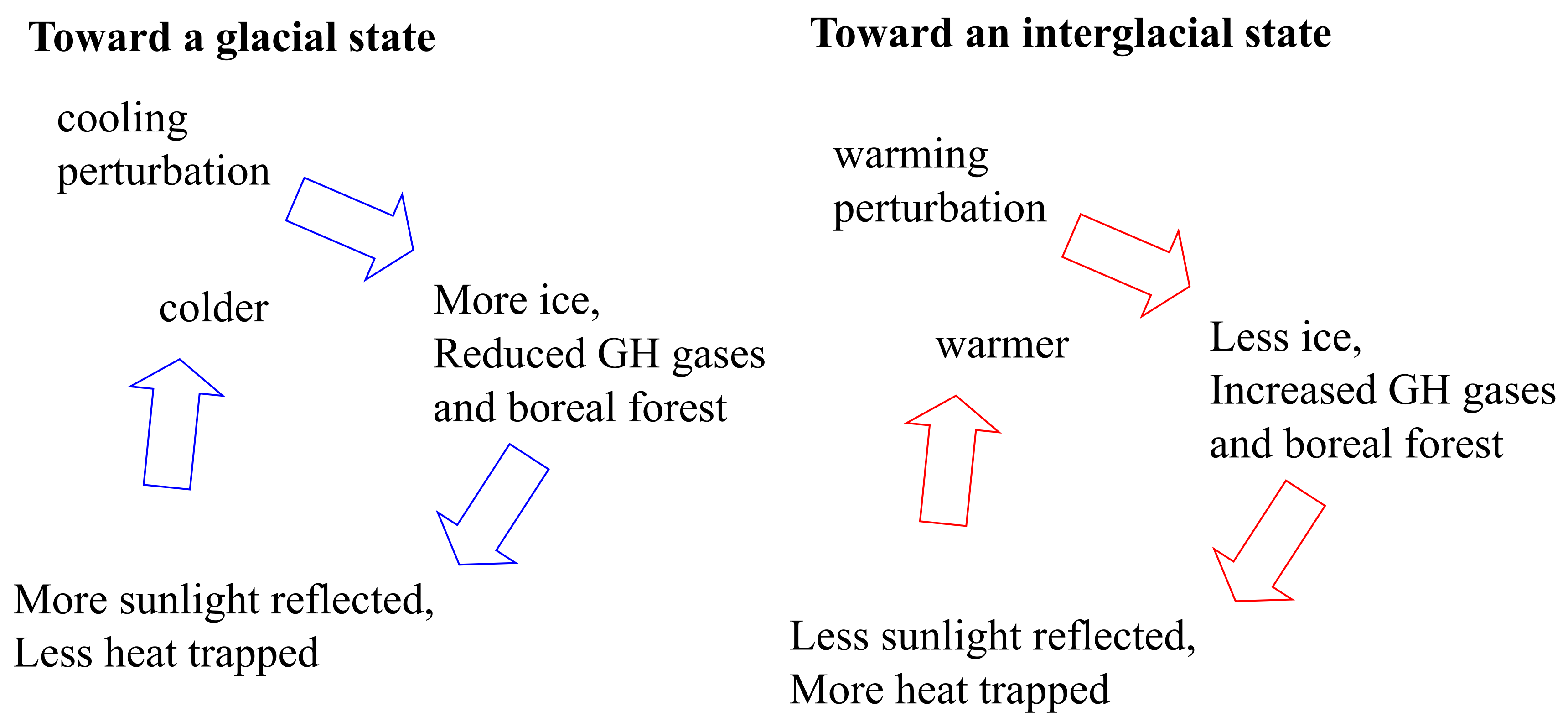


Figure 4.18b. Positive feedbacks in the climate system help cause it to go into an ice age or into an interglacial, acting to amplify a temperature perturbation of either sign. These include the ice albedo feedback, greenhouse gas feedbacks, and the boreal forest feedback.

4.3. The Paleoclimate Record

Paleoclimate phenomena and corresponding time scales of interest include

- the *faint young sun paradox* (billions of years),
- periodic extinctions and the *Oort cloud* (27 million-year periodicity),
- the *Cretaceous warm period* (145-65 Mybp),
- Antarctic continental drift (10 Mybp),
- glacial /interglacial cycles (last million years),
- the *Emian interglacial* (130-115 kybp),
- *Wisconsin glacial maximum* (20 kybp),
- the *Bolling/Allerod* warm period (14.6-12.9 kybp)
- the *Younger Dryas* cold event (12.9-11.6 kybp),
- Heinrich and *Dansgaard-Oeschger events* (millennial cycles),
- the *Holocene maximum* (2-8 kybp),
- the *Medieval Optimum* (600-1100 ypb; 900-1400 A.D.),
- and the *Little Ice Age* (130-620 ybp; 1400-1890 A.D.)

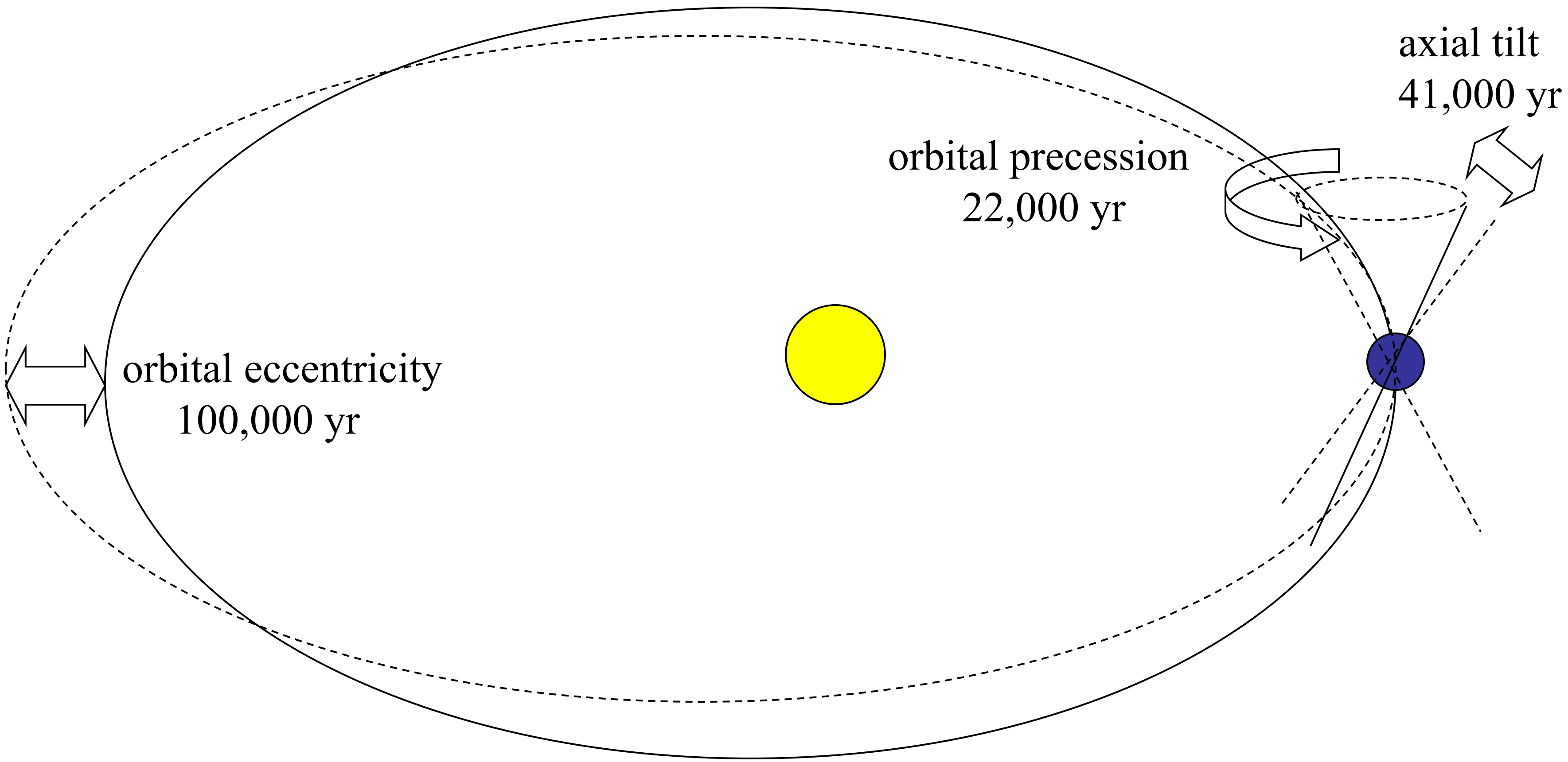


Figure 4.16. Variation in earth orbital parameters as the basis for the Milankovich theory of glacial / interglacial cycles.

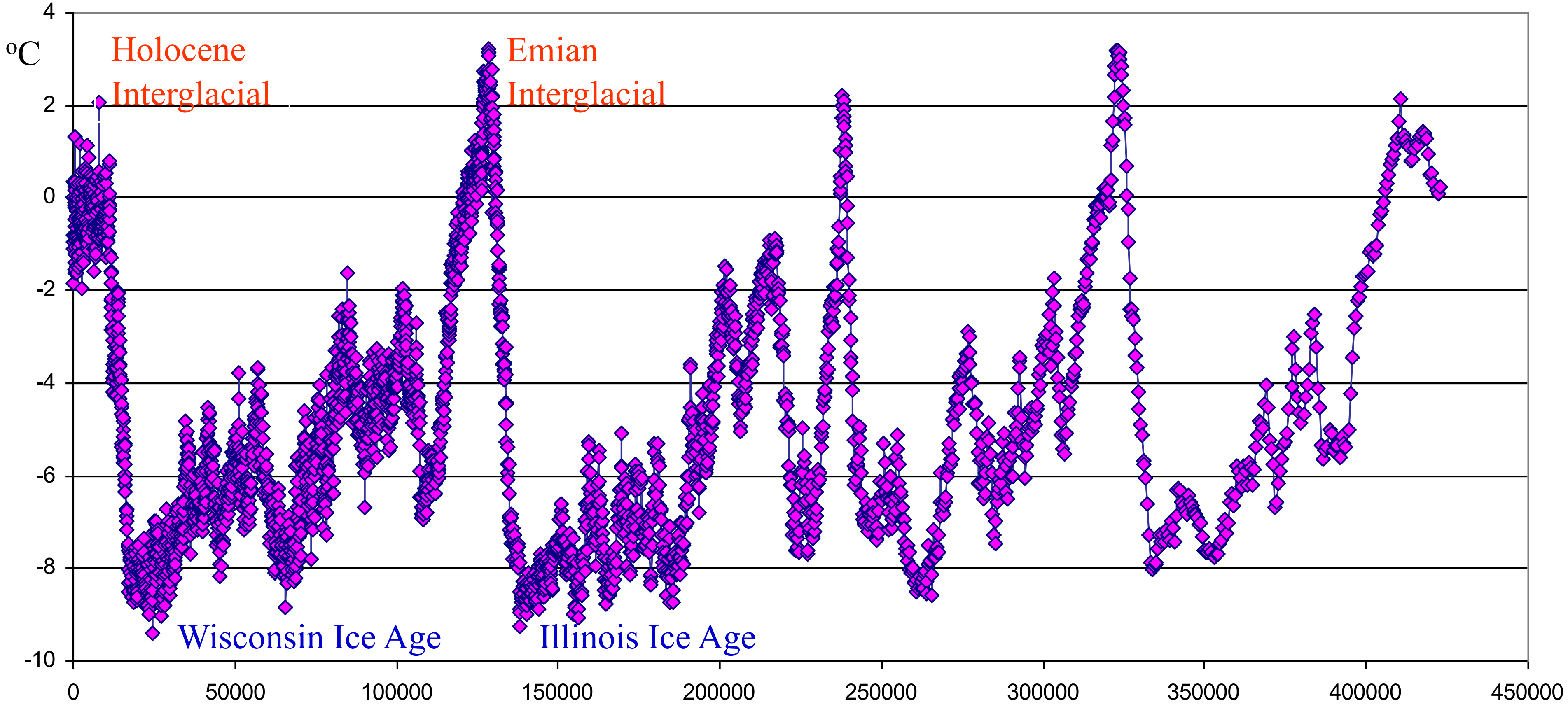


Figure 4.2. Global temperature variations over the last four glacial / interglacial cycles inferred from Vostok deuterium [Petit et al. 2001; data from www.ncdc.noaa.gov/paleo].

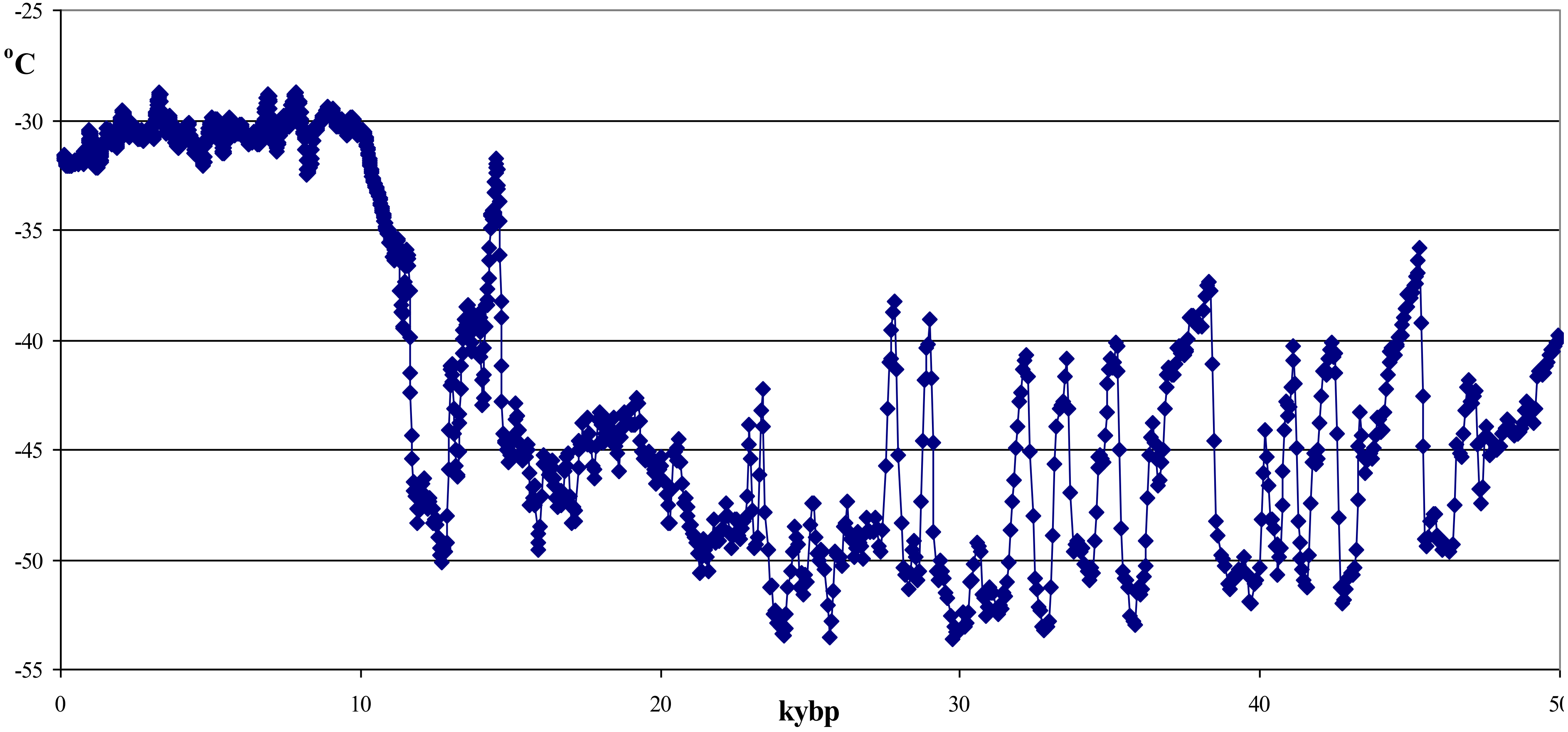


Figure 4.3. Variations in Greenland surface temperature (°C) at GISP2 over the past 50,000 years. Note the common occurrence of Dansgaard-Oeschger events during the Wisconsin Ice Age, but not during the Holocene [Alley et al. 2000, 2004, www.ncdc.noaa.gov/paleo].

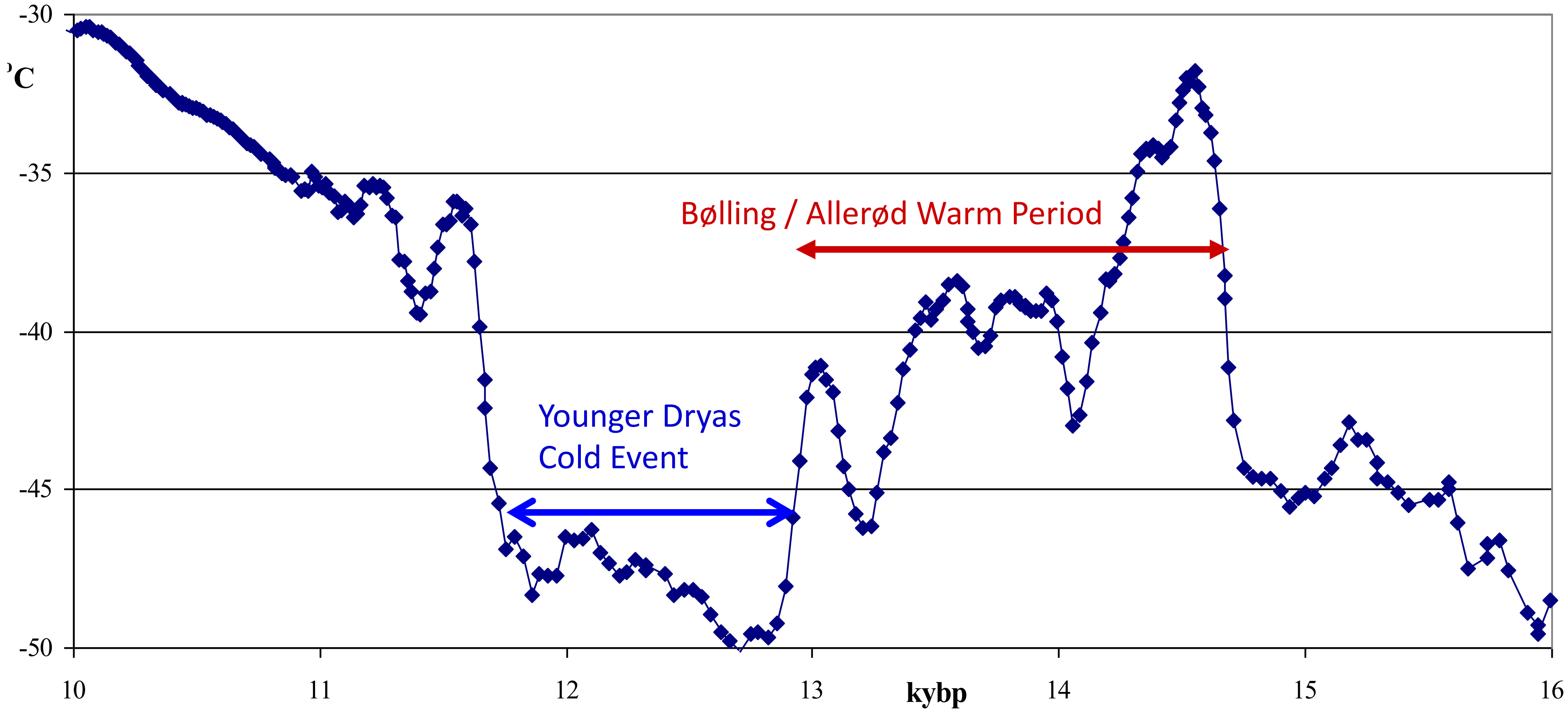


Figure 4.5. Variation in Greenland surface temperature during 16 – 10 kybp [Alley et al. 2000, 2004, www.ncdc.noaa.gov/paleo]. The Bølling / Allerød period (14.6 – 12.9 kybp) began with, and the Younger Dryas period (12.9 - 11.6 kybp) ended with rapid warming.

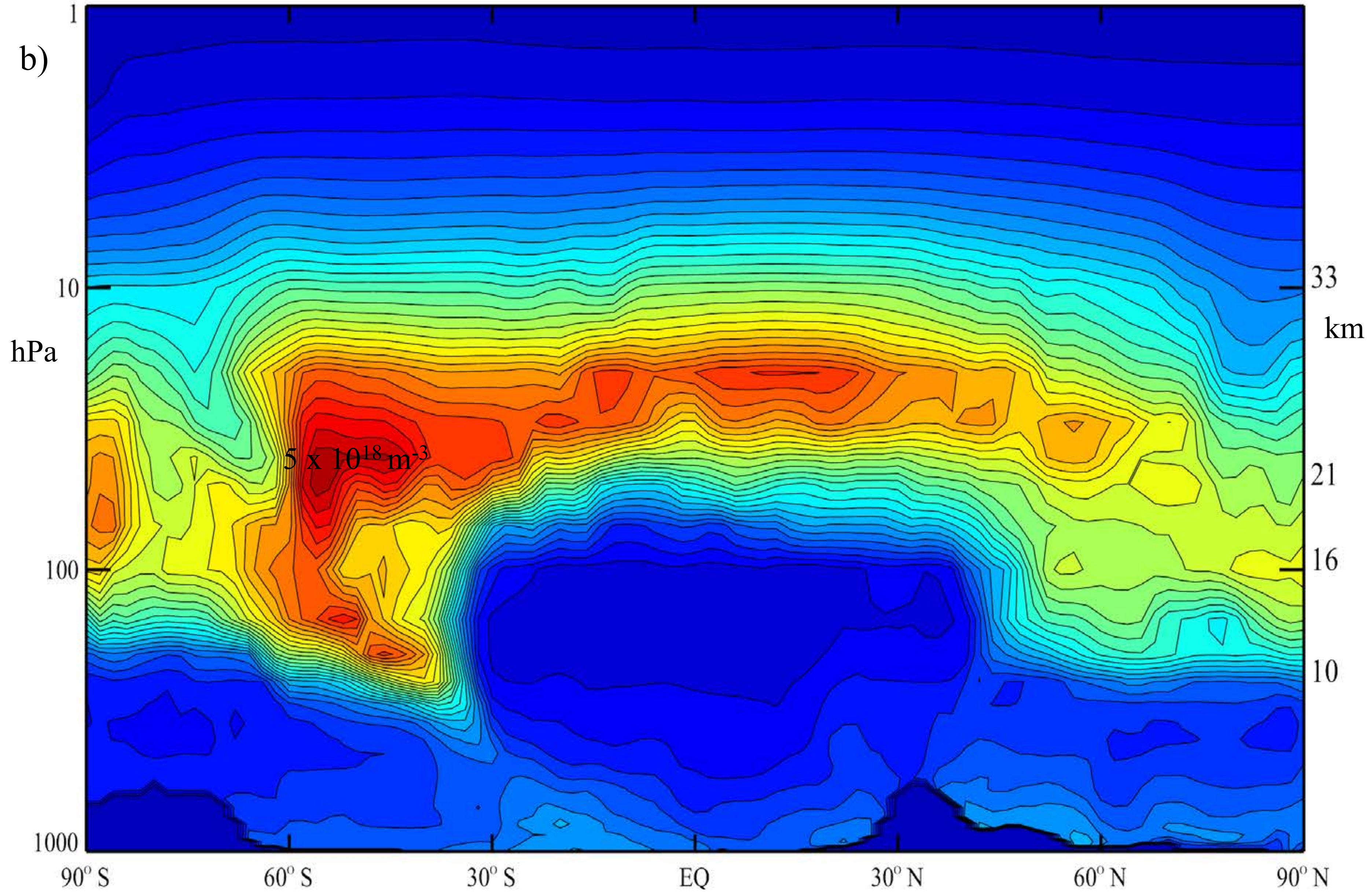


Figure 5.1b. Latitude-altitude section of ozone number density along 95°E on August 24, 2000, contour interval 1.5 x 10^{17} molecules m^{-3}.

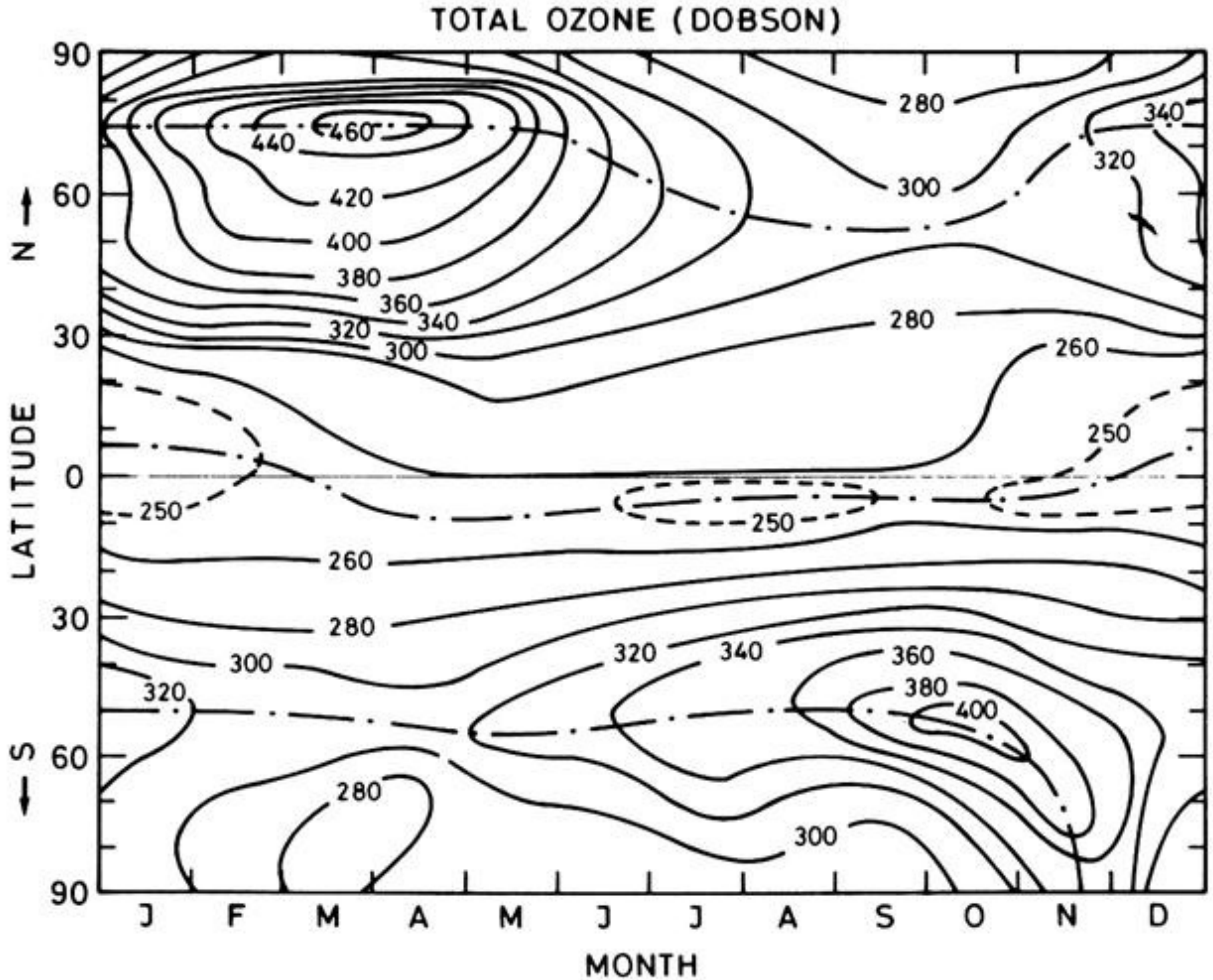
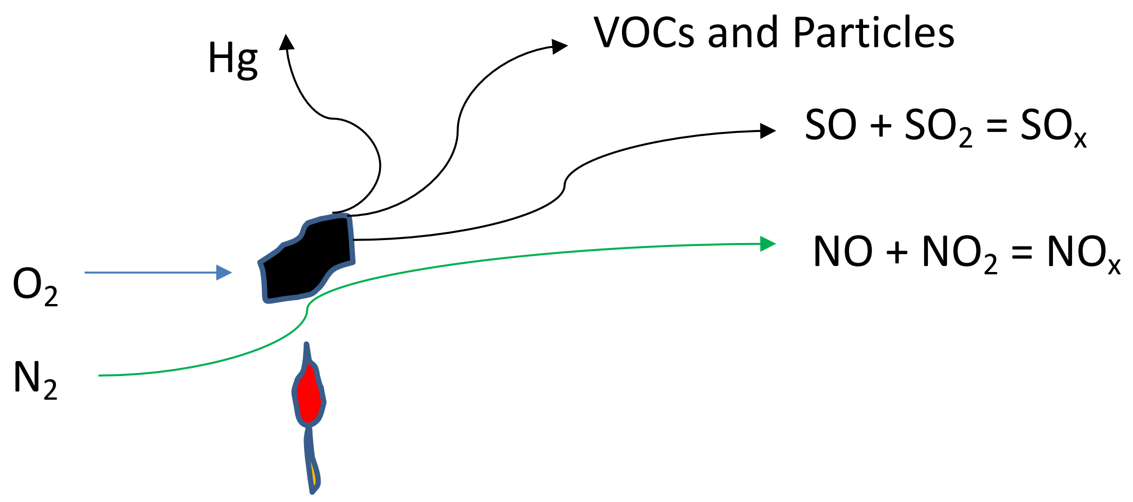
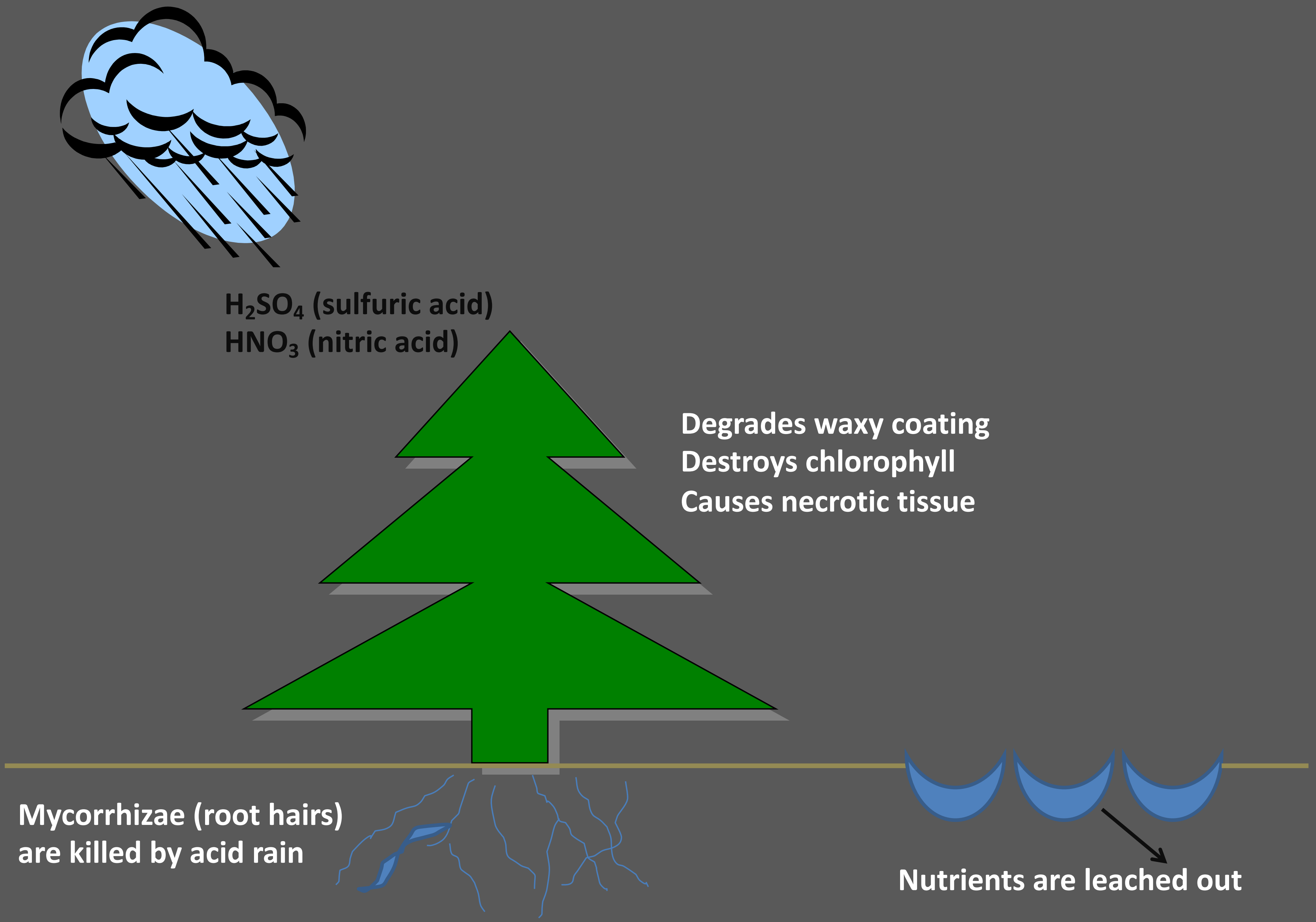


Figure 5.2 Variation of column ozone with latitude and season (London 1980).

Burning Fossil Fuels



Particles → lungs
Ozone → eyes and lungs
EPA 188 compounds poisonous at any level (e.g., Hg, VOCs)
PM2.5 "bright line" 35 $\mu g/m^3$ (65 recently)
Ozone "bright line" 80 ppbv (60 ppbv in Canada and Japan)
1990 Clean Air Act benefits to health care, ecosystems, buildings
U.S.: 100 tons/yr Hg (40% power plants, 60% vehicles)
600,000 babies/yr noticeable effects of Hg poisoning (Johnson 2005)
~30×10^6 tons/yr each NO_x, SO_x, VOCs
1 pound of coal = 1 kW-hr electricity
Family 10,000 kW-hr → 10,000 lb coal ~ 100 ft^3


H2SO4 (sulfuric acid)
HNO3 (nitric acid)
Degrades waxy coating
Destroys chlorophyll
Causes necrotic tissue
Mycorrhizae (root hairs)
are killed by acid rain
Nutrients are leached out

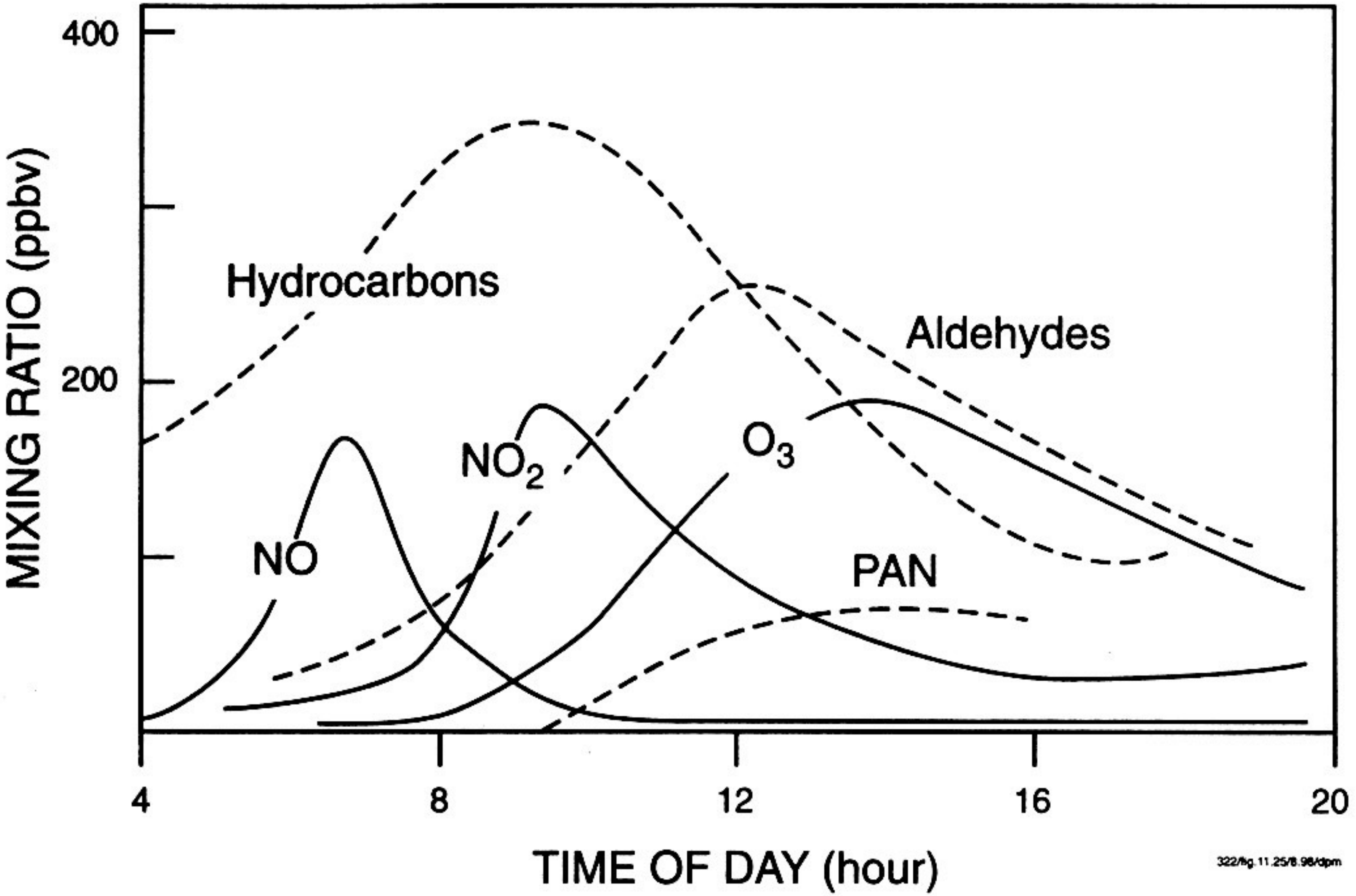
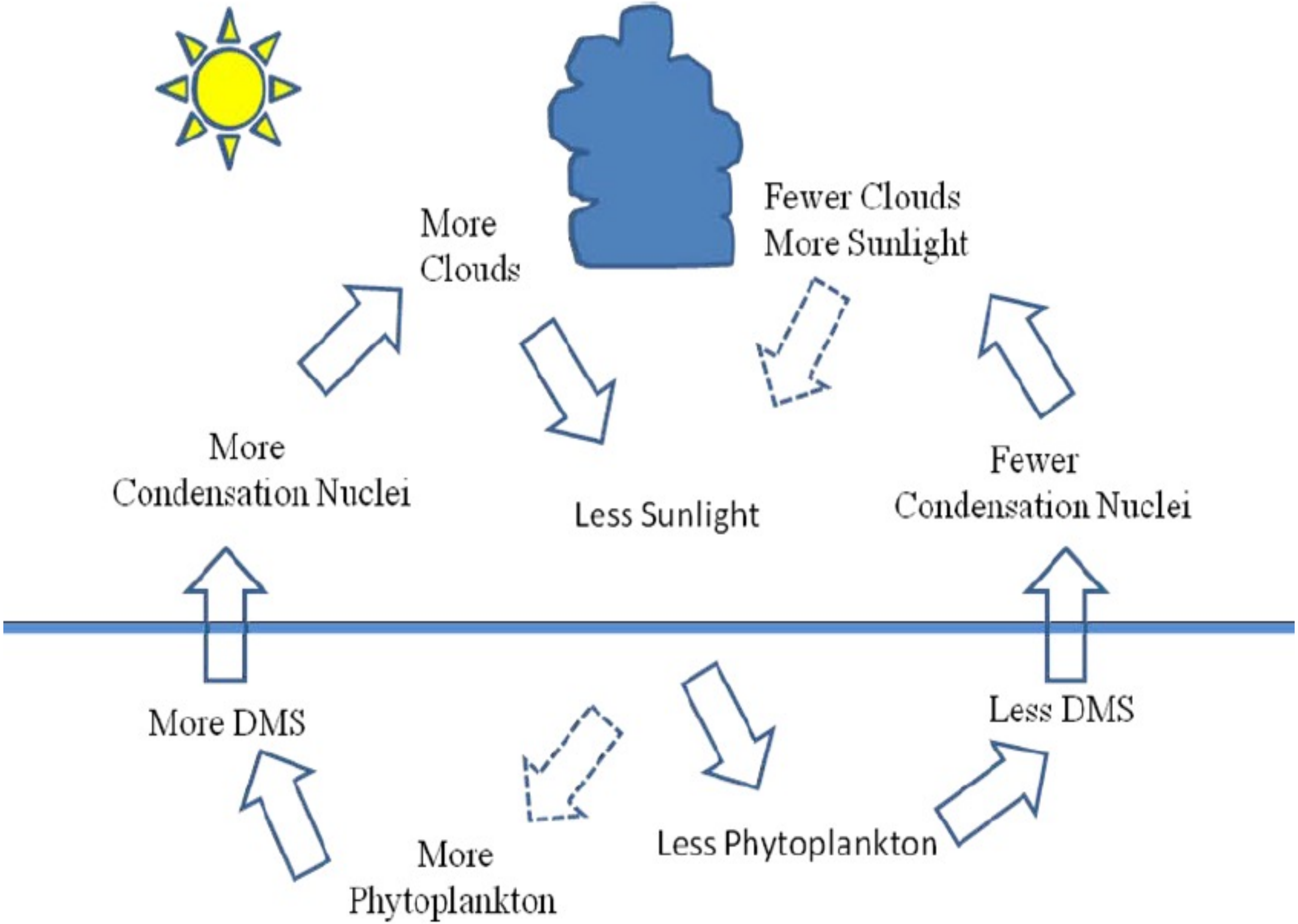


Figure 13.7. *Evolution of the chemical composition of the lower atmosphere during a smog event (Goody, 1995).*



More
Clouds
Fewer Clouds
More Sunlight
More
Condensation Nuclei
Less Sunlight
Fewer
Condensation Nuclei
More DMS
Less DMS
More
Phytoplankton
Less Phytoplankton

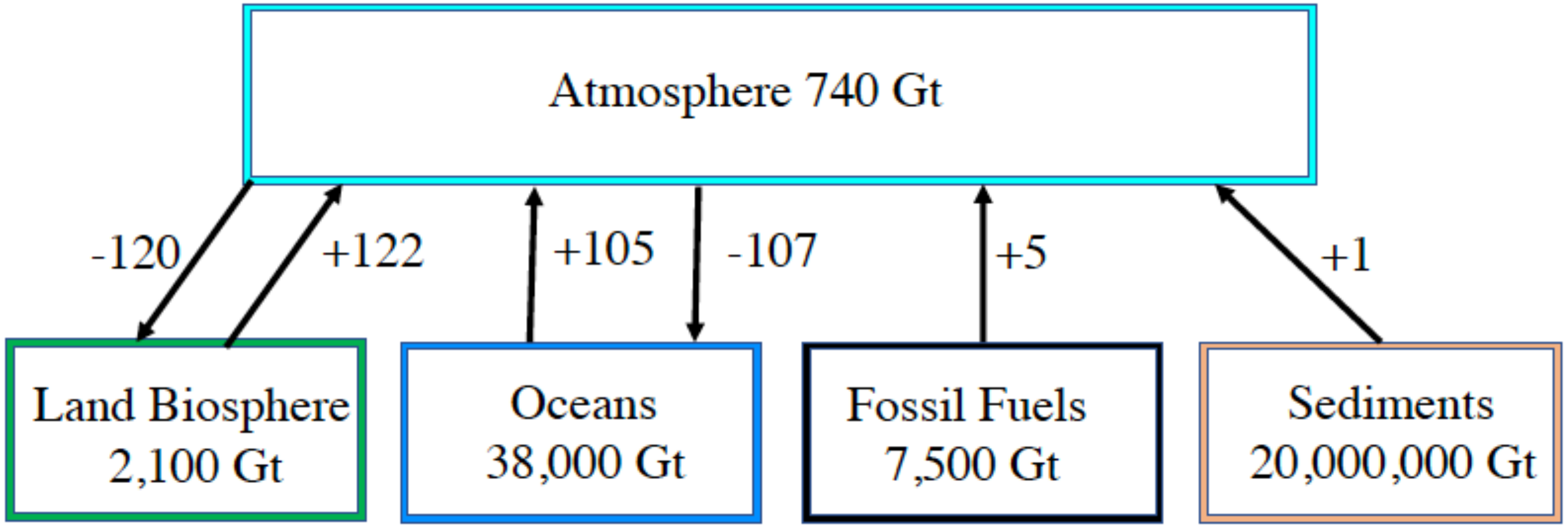


Figure 9.1. Global carbon reservoirs in Gt with fluxes in Gt/yr estimated circa 1990. The land biosphere was estimated to absorb and emit 120 Gt/yr through photosynthesis and respiration, with a net source to the atmosphere of 2 Gt/yr extra due to deforestation. The ocean was estimated to absorb 107 Gt/yr due to photosynthesis and emit 105 Gt/yr due to respiration, with a net sink to the atmosphere of 2 Gt/yr, due to the "biological pump". Fossil fuel burning was estimated to be emitting 5 Gt/yr, with cement making added another 1 Gt/yr.

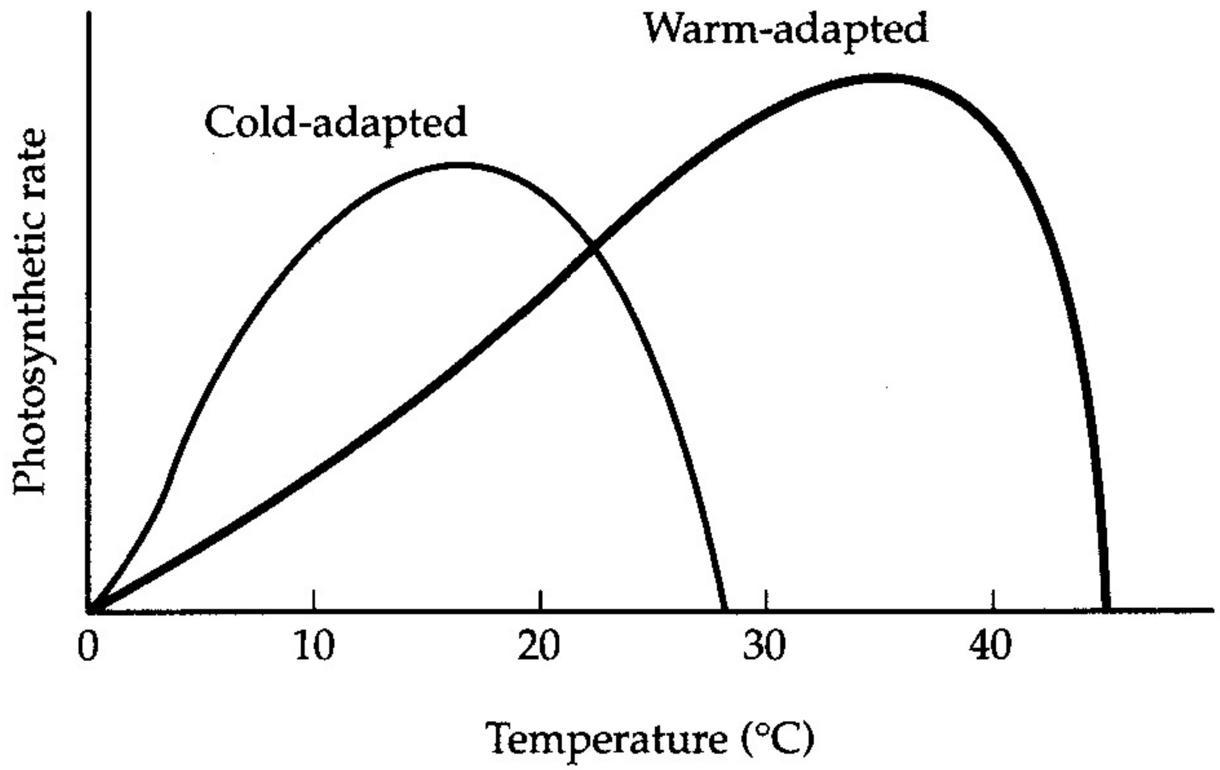


FIGURE 4 **Photosynthetic rate as a function of temperature for a warm-adapted and a cold-adapted plant. (From Gates, 1985a.)**

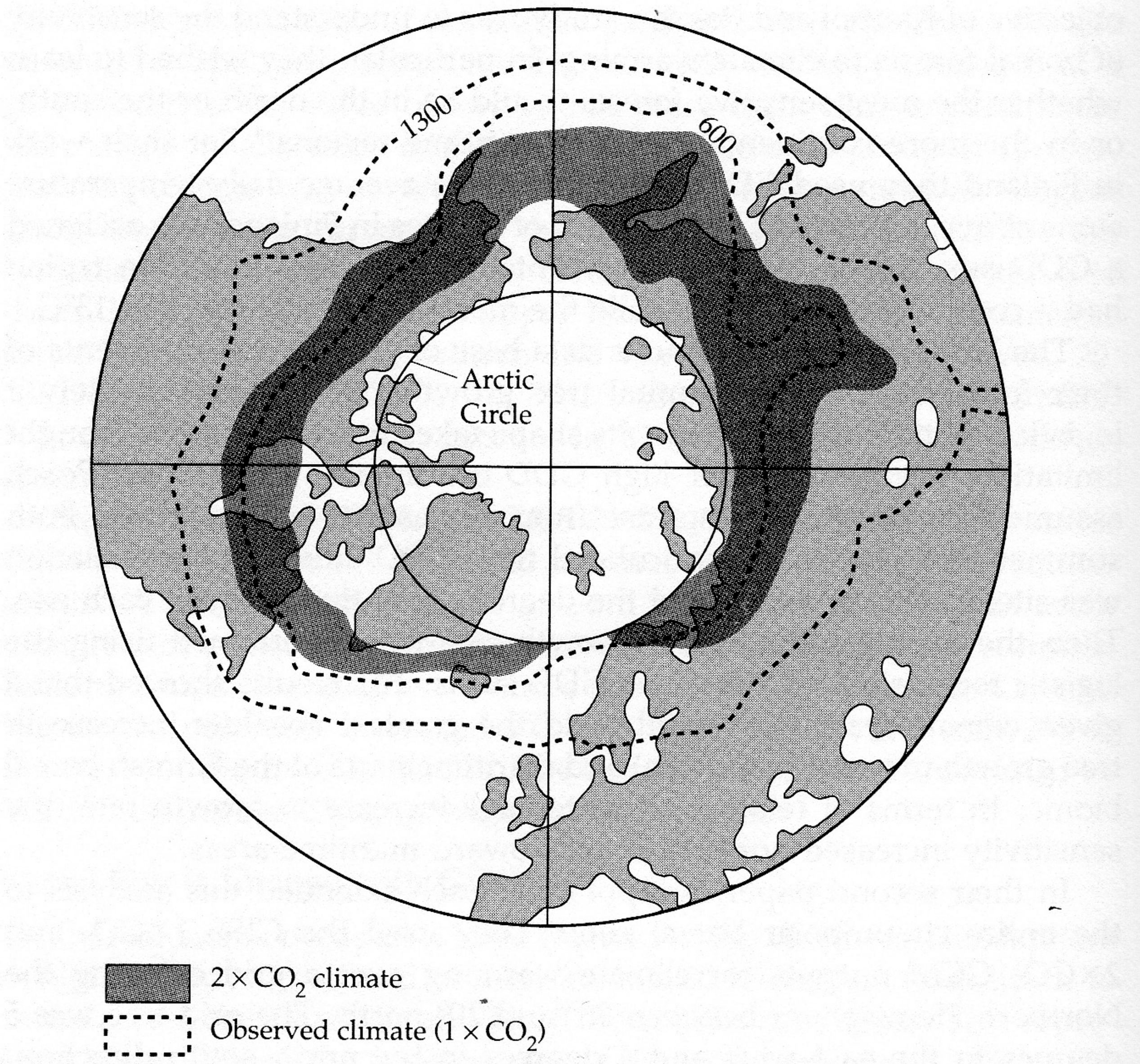
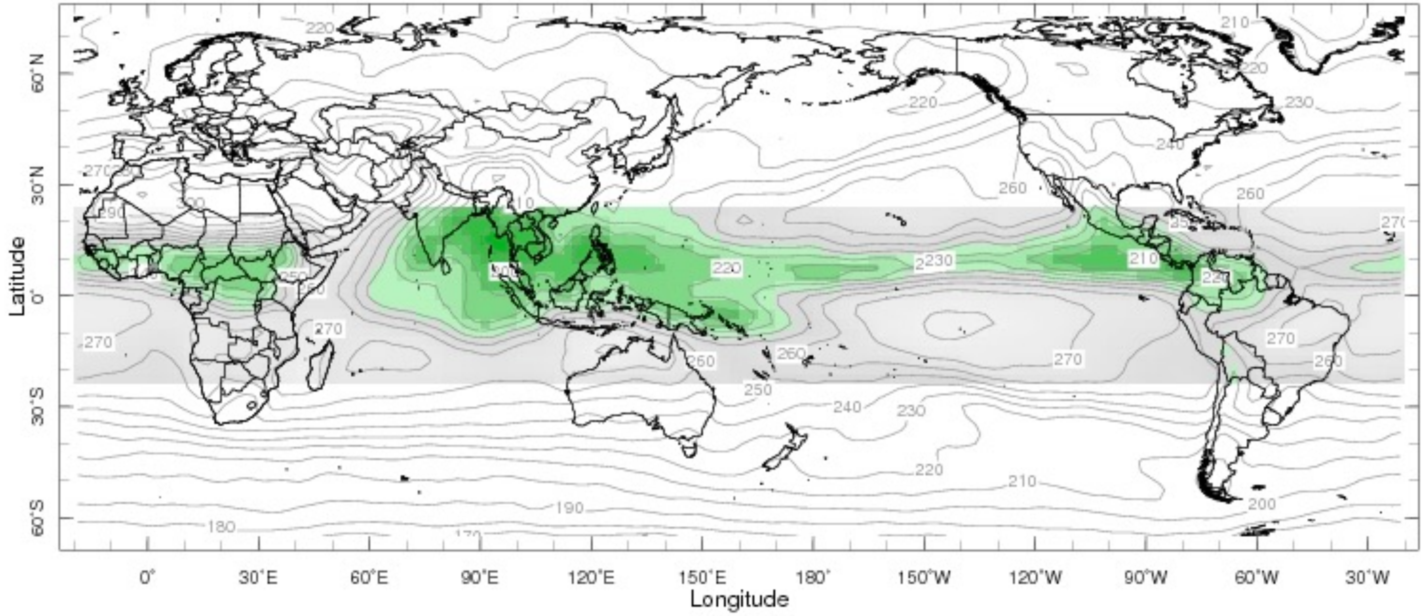


FIGURE 17 The northern and southern boundaries of the boreal forest are approximately defined by the 600 and 1300 growing degree-day isopleths. These are shown in their current positions and in the positions they would occupy under a 2×CO_2 climate warming. (From Kauppi and Posch, 1988.)

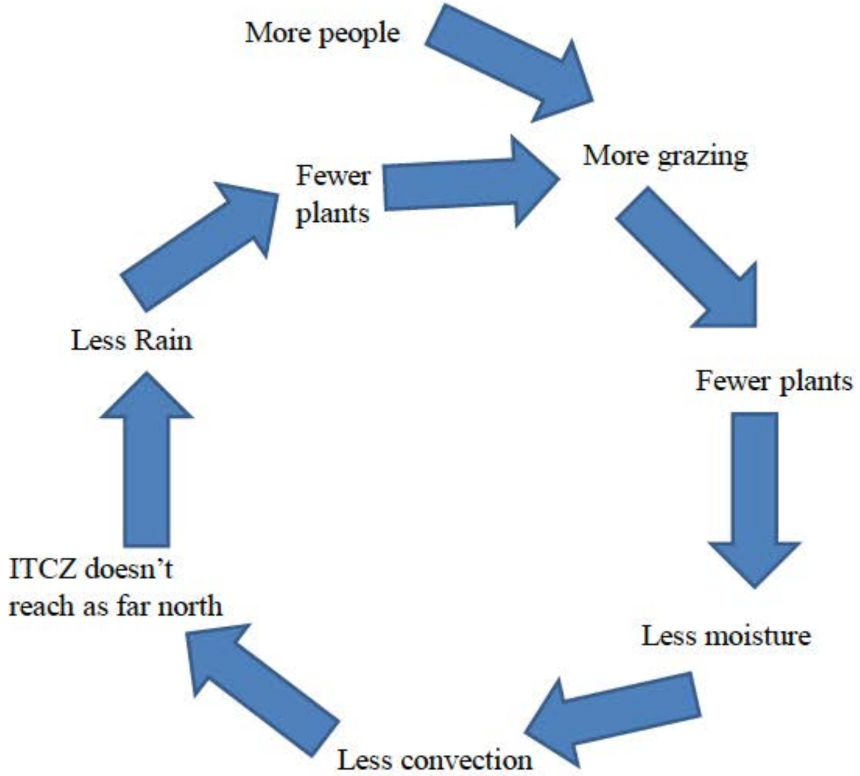
Boreal
Forest

Spruce


Latitude
60°N
30°N
0°
30°S
60°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
Longitude

Jun-Aug 2014


The African Sahel
Sahara Desert
The Sahel
0 750 mi
0 750 km
©2004 MAPS.com
Geography in the News 1/2/04
Source: H. G. Mensching, Desertifikation. Darmstadt, 1990. p. 55
P. Larkins


More people
More grazing
Fewer plants
Less moisture
Less convection
ITCZ doesn't reach as far north
Less Rain
Fewer plants