FIGURE 10.1
(a) is the temperature record of Earth during the past 180 million years; (b) is an expanded representation of the last one million years; and (c) is an expanded view of the last 160,000 years. (After UCAR/OIBS, 1991a.)
FIGURE 12.1 (continued)
(a) Temperature history of Earth during the last 18,000 years. (b) and (c) are expanded versions of the period 1000 to 1900 A.D. and 1870 to 1990 A.D., respectively. Notice the change in scale for temperature in (a), (b), and (c).
(After UCAR/OIES, 1991a, and Houghton, et al., 1990.)
Average Global Temperatures

Cooler

Warmer

Last interglacial
Neanderthals
Glacial threshold
Cave paintings
Cro-Magnons
Farming
Previous glacial maximum
Last glacial maximum

18,000 years before present
**Figure 10.3**

Smoothed (approximate decadal average) global sea surface temperature (SST), nighttime marine air temperature (NMAT), and land surface air temperature (LSAT) anomalies 1861–2000. [IPCC, 2001]. The smooth curves use a 21-point symmetric binomial filter on the annual values. The five beginning and end points are folded over to provide smoothed estimates near the beginning and end points of the time series.

---

(A) Lake Gerzen lime sediments

(B) Dye 3 ice core Greenland

(C) CO₂ concentration

**FIGURE 10.4** Records of the late glacial transition and the Younger Dryas cold event. (A) δ¹⁸O measurements from Lake Gerzen, Switzerland. (B) δ¹⁸O along a 120-meter core from Dye 3, Greenland. (C) Atmospheric CO₂ concentration from gas trapped in polar ice. (After Denker and others, 1980.)
"North Atlantic Oscillator"

Younger Dryas Event ~ 11,000 YBP

\[ T(t) \]

THC ↔ Gyre

\[ \delta T \]

Orbital Parameters

Warmer

Laurentide Ice Sheet Retreats

Fresh Water

To N. Atlantic

Shuts Off Convection

Reduce Gyre Strength

Increased Gyre Strength

Convection Begins

Ice Advances

Colder

saltu

Fig. 10.5
THE LORENZIAN WATERWHEEL. The first, famous chaotic system discovered by Edward Lorenz corresponds exactly to a mechanical device: a waterwheel. This simple device proves capable of surprisingly complicated behavior.

Wobble of axis - 23,000 years.

Tilt of axis - 43,000 years.

Eccentricity of orbit - 100,000 years.

Variations in Earth's Orbital Features
(A) Eccentricity

Past

Future

Precession

Oblivity

Thousand years ago

(B) Ice volume (normalized units)

Orbits only

$\delta^{18}O$ (o/o)

V19-30

Ice volume (normalized units)

Orbits & CO$_2$

Thousand years ago

Fig. 10.8