

ATMS 321. 1 April 2009

THE SUN.

Radius 700,000 km; i.e. about 100 times the Earth's radius (6400 km)

Earth-Sun distance 150,000,000 km

Temperature

surface 6000 K

center 15,000,000 K

Composition

75% (by mass) Hydrogen (H)

25% Helium (He)

Nuclear reaction for stars on the "main sequence" (hydrogen-burning stars)

$4 \text{ H} \rightarrow 1 \text{ He} + \text{energy}$

Expected lifetime of the Sun as a "main-sequence" star is 12×10^9 years. We're now at about 4.5×10^9 yr, i.e. less than half gone. After leaving the main sequence, Sun will become a red giant, then a white dwarf.

Sun gets brighter with time. It has brightened 20-40% since the origin of the solar system. It brightens by about 0.7% every 100 million years.

Variable features on the Sun (a small fraction of total energy)

Sunspots, flares, corona (visible during eclipses)

Solar energy:

Energy coming out of the Sun is in the form of "electromagnetic" radiation: Xrays, ultraviolet, visible, infrared, microwaves, radiowaves.

The Sun radiates all these wavelengths, but most of the solar energy is in the *ultraviolet (UV), visible, and infrared* spectral regions: "sunlight"

The Solar Constant.

Radiation energy leaving the Sun spreads out as it travels away from the Sun. At the distance of the Earth's orbit (150,000,000 km), the rate at which solar energy is received, by a surface oriented perpendicular to the Sun's direction, is called the **solar constant**.

The solar constant is measured to be 1370 W m^{-2} . [The most accurate measurements are made by satellites circling the Earth, because they are outside the atmosphere.] So a black solar collector of area one square meter, situated just above the Earth's atmosphere and oriented perpendicular to the solar beam, will collect solar energy at the rate of 1370 Watts.

How "constant" is it?

1. It's different for each planet.
2. It varies over the course of the year because the Earth's orbit is eccentric. Earth-Sun distance R varies by $\pm 1.75\%$ (Earth is closest to Sun in January, farthest in July). For convenience the "solar constant" is defined for the average Earth-Sun distance.
3. It varies as the Sun rotates (29-day cycle), bringing sunspot groups across the Earth-facing side of the Sun (see Figure).
4. It varies by 0.1% over the 11-year solar cycle. Maximum at sunspot maximum, (1979, 1990, 2001); minimum at sunspot minimum (1985, 1996).
5. It increases as the Sun ages: about 20-40% in 5 billion years.
6. It has been speculated to vary with the "envelope" of the sunspot cycle (see Figure). The "Little Ice Age" coincided with a time of few sunspots (1600s).

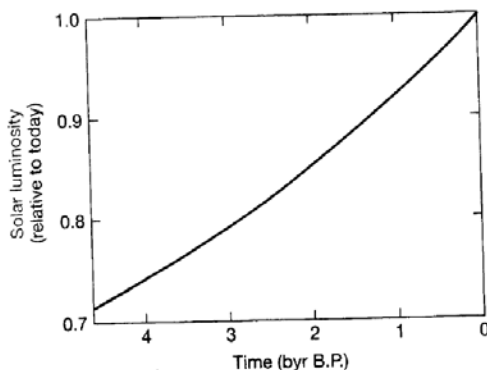


FIGURE 1-12

Estimated change in solar luminosity with time. The unit of age on the horizontal axis, byr B.P., stands for "billions of years before the present." (After D.O. Gough, *Solar Physics* 74, p. 21, 1981.)

[Kump et al., 2004]

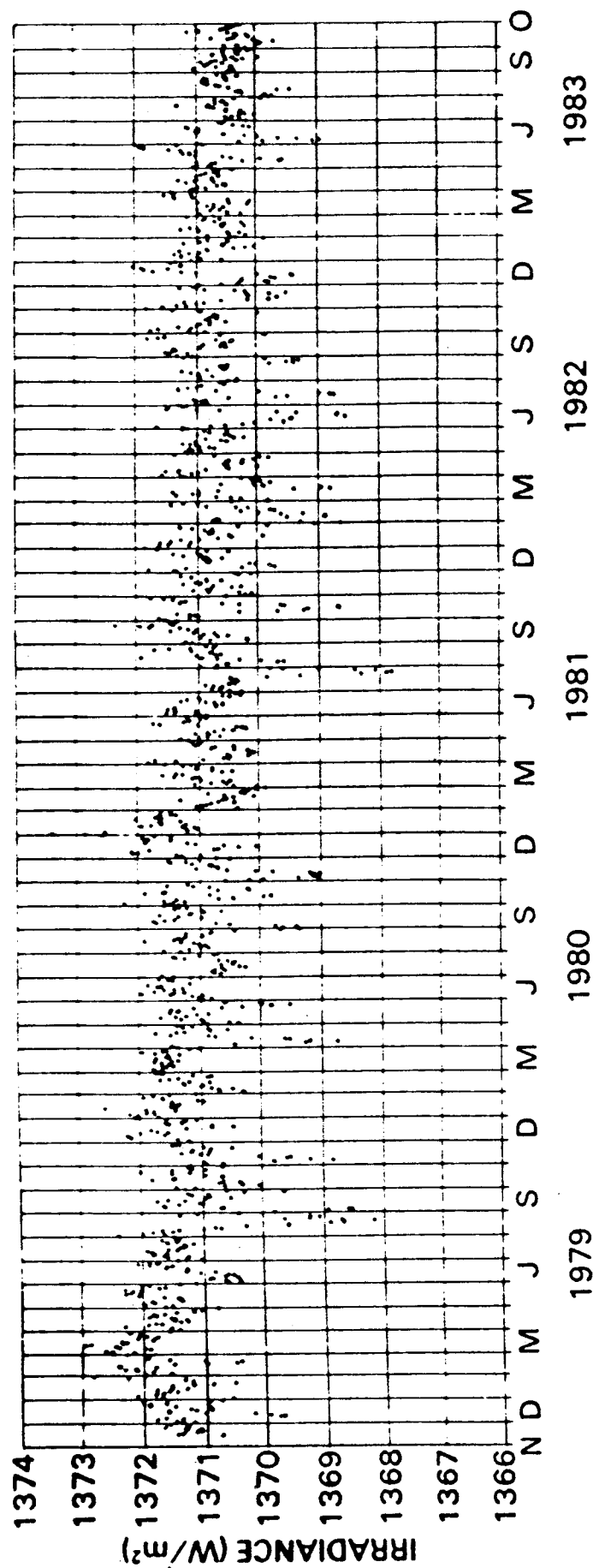


FIG. 1. Five years of measurements of the solar constant by the *Nimbus-7* ERB channel 10c. Note the short-term excursions and the small long-term downward trend.

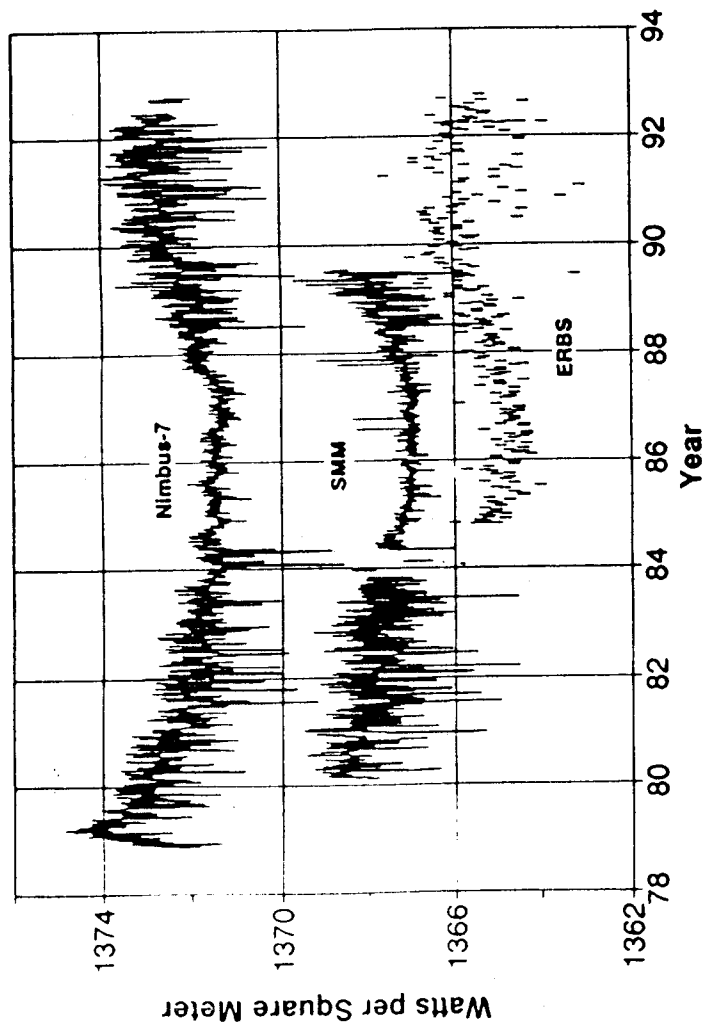
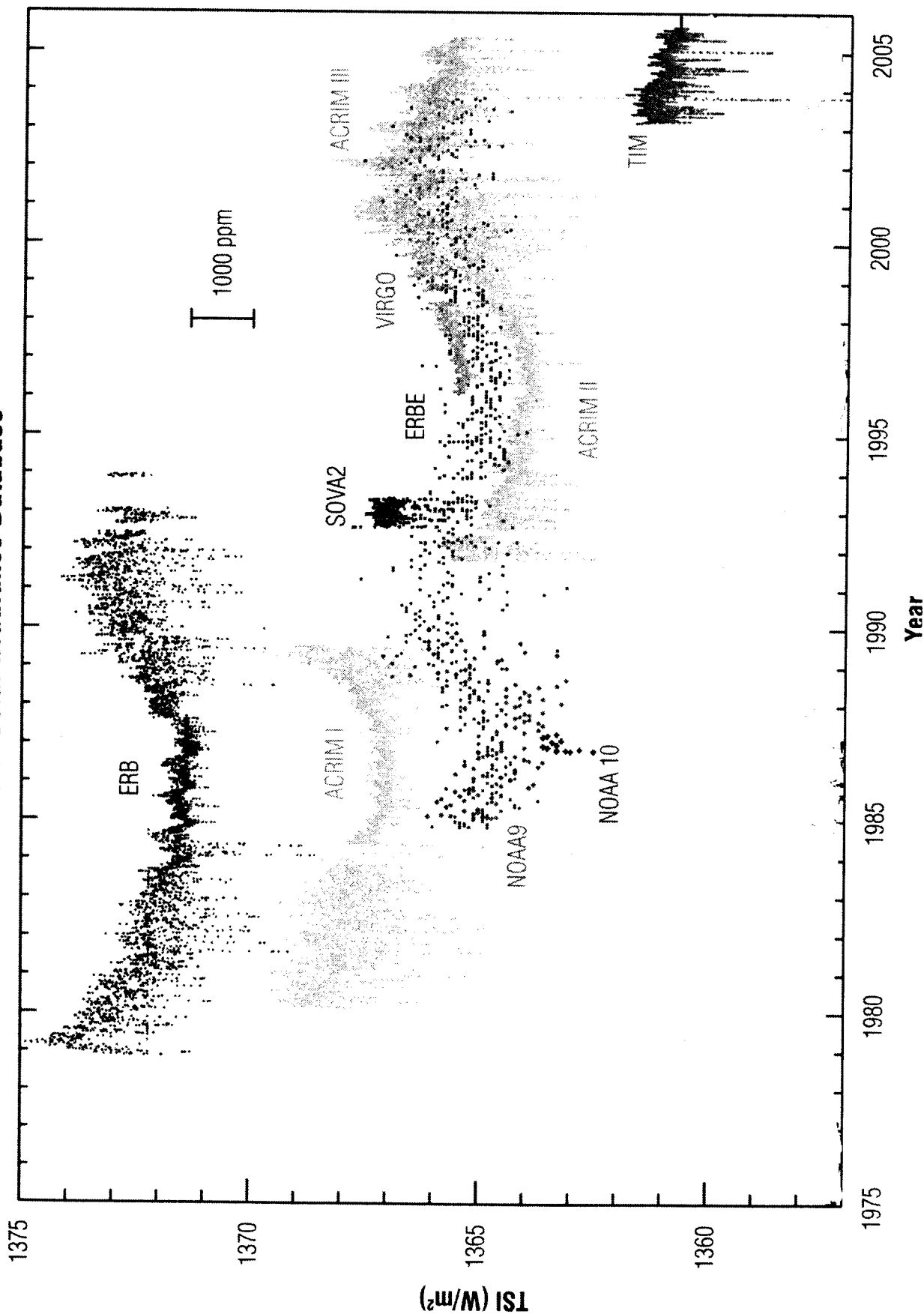


Fig. 1. Daily irradiance values are plotted for three independent satellite sensors: the *Nimbus-7* ERB (November 1978 to September 1992), SMM ACRIM (February 1980 to June 1989), and ERBS solar sensor (October 1984 to October 1992). The vertical displacements between the measurements are caused by uncertainties in the three absolute calibrations. (Courtesy of L. Kyle)

Figure 2: Total solar irradiance (TSI) measurement record for 3 solar cycles (from G. Kopp).

Total Solar Irradiance Database



"EARTH OBSERVER" Nov 2005

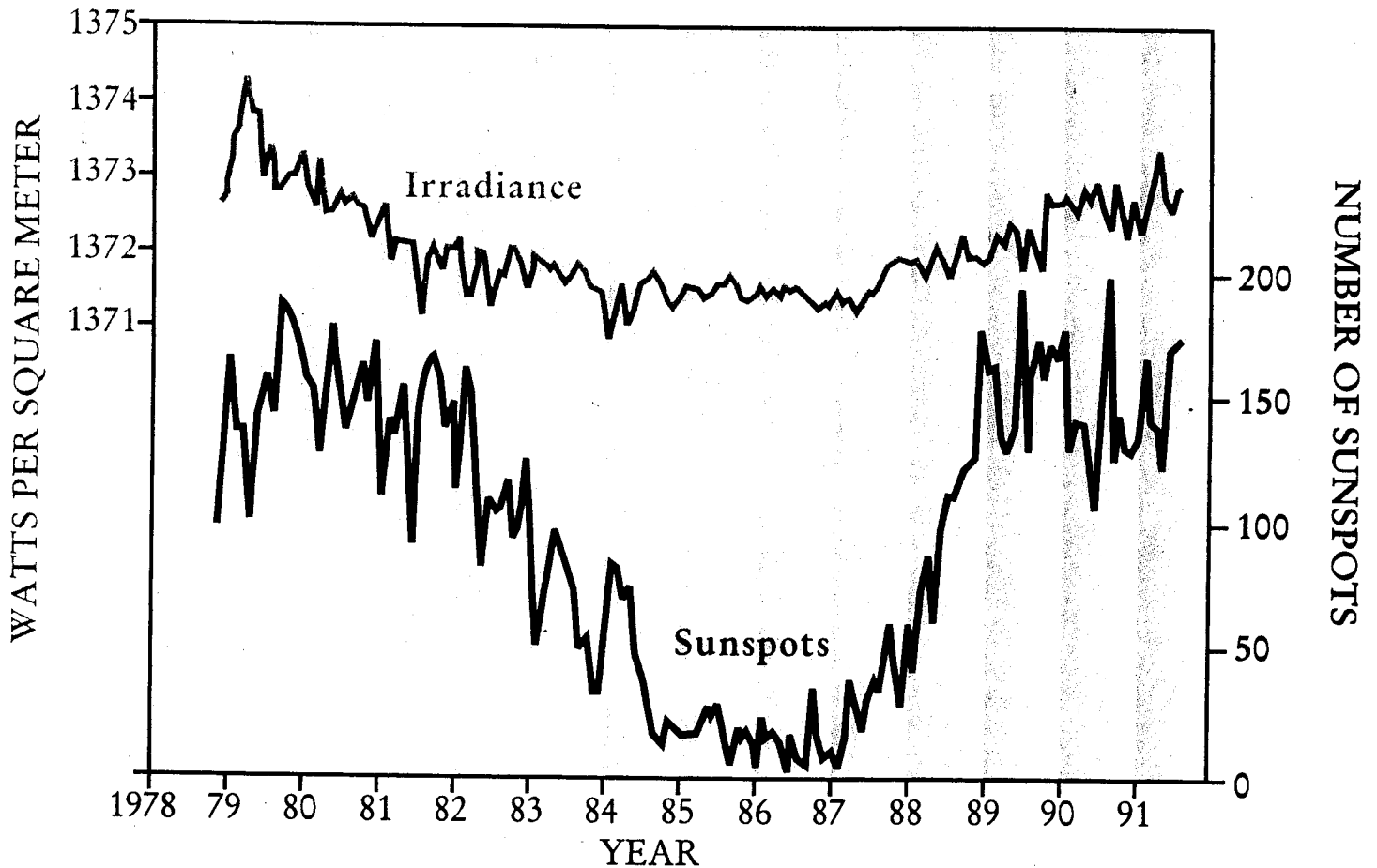


FIGURE 6. LUMINOSITY AND MAGNETIC activity. The upper curve shows the Sun's monthly mean irradiance, recorded by the NASA Nimbus 7 spacecraft. The lower curve shows the sunspot numbers. The correlation between these quantities is evident, but not at all understood. (From ref. 14.)

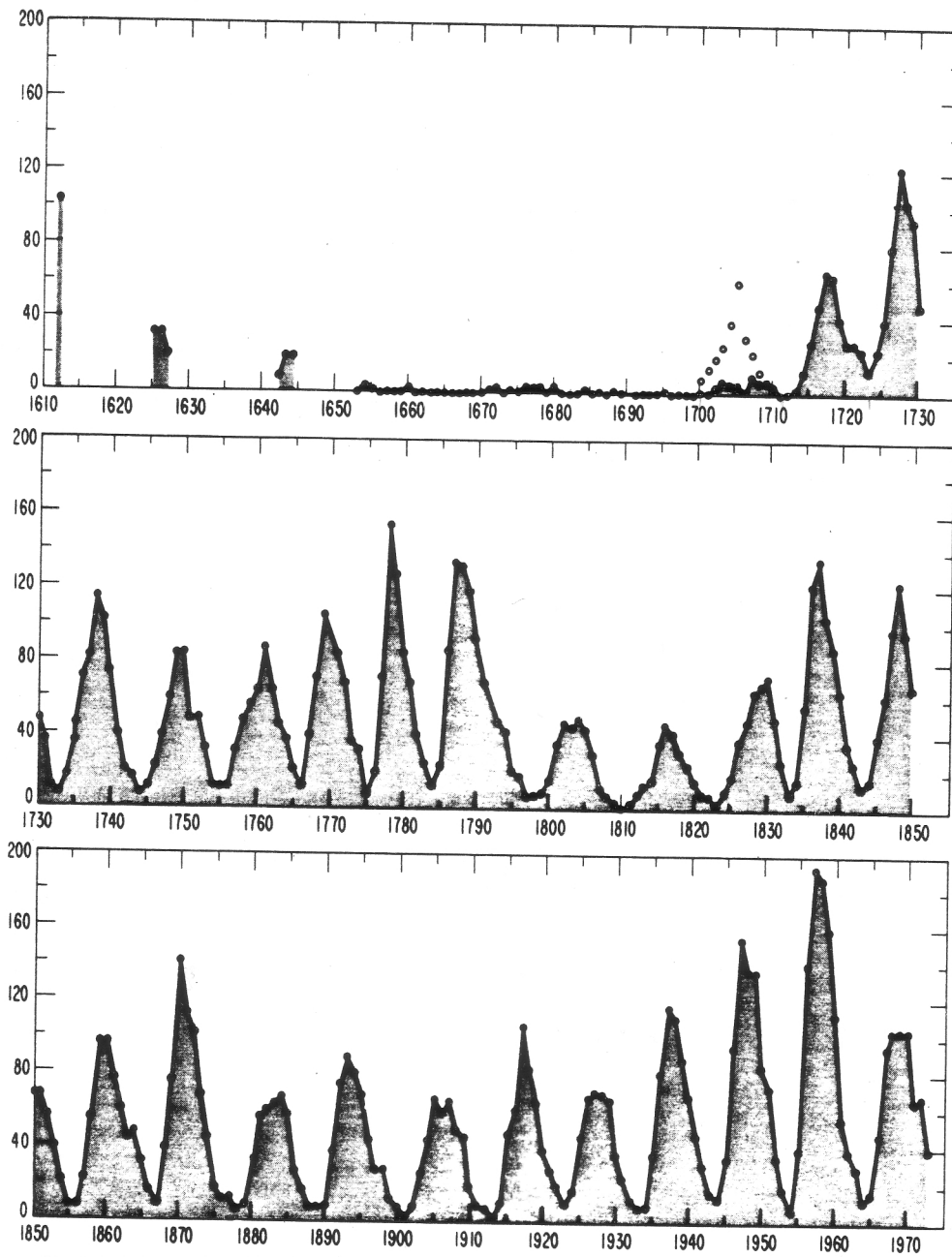
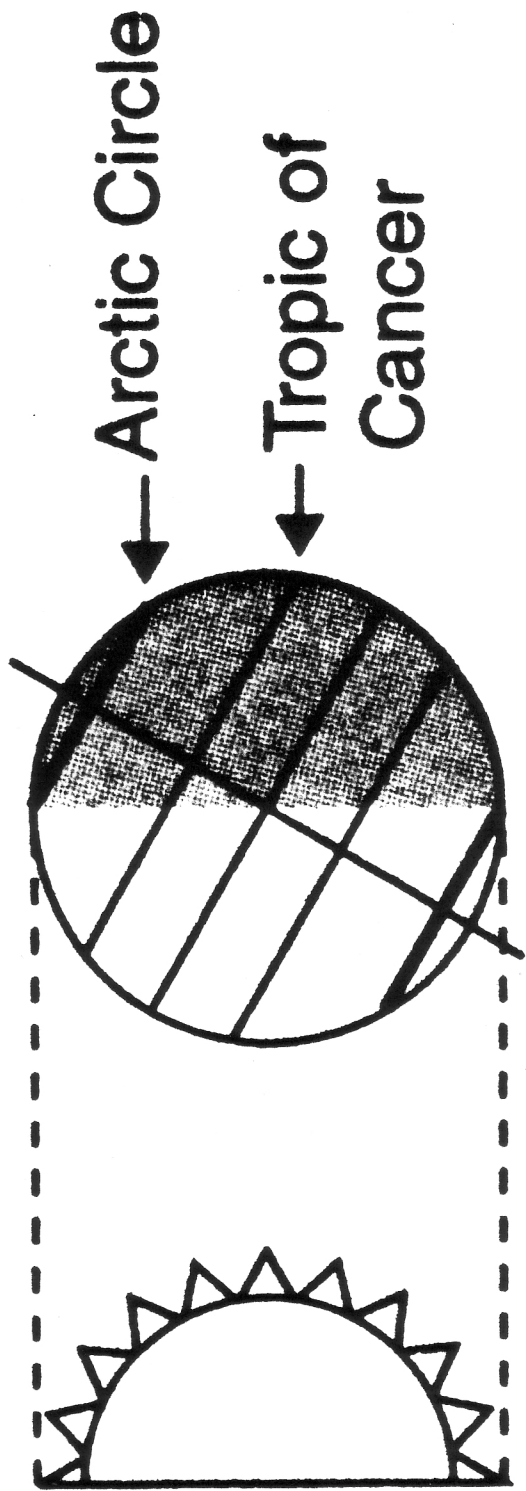
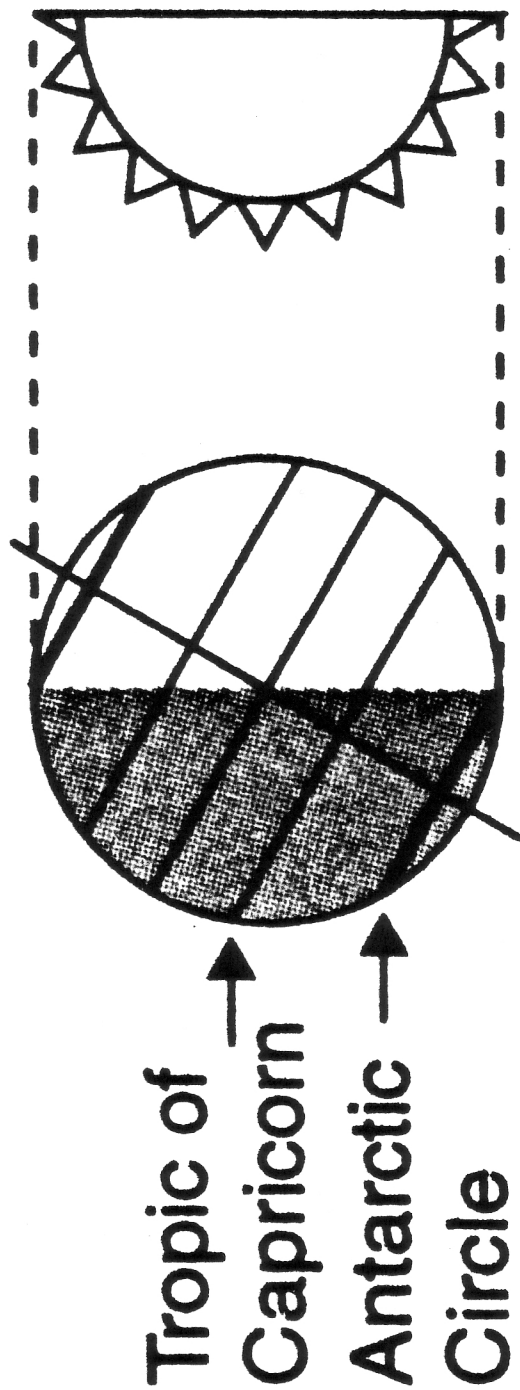


Fig. 7.4 Time series of annual average sunspot number. The lack of sunspot activity during the 17th century is believed to be real. (Courtesy of J. A. Eddy.)



(b)



(c)

Hardy Figure 1.4