Warming has been observed in most boreholes in New England (Pollack and Chapman, 1993) and Canada (Beltrami and Mareschal, 1992; Wang *et al.*, 1992; Wang *et al.*, 1994), and the increase in GST suggested for the last century is very similar to the observed change in regional air temperatures during the same period (e.g., Beltrami and Mareschal, 1991). In temperate western North America (up to 62°N in the Yukon), however, the GST has remained relatively constant over the last century (e.g., Lewis and Wang, 1993) even though most glaciers have retreated. Further north, GSTs have increased over the last century on the Alaskan north slope (Judge *et al.*, 1983; Lachenbruch and Marshall, 1986) and in Canada's north-eastern Arctic Islands (Taylor, 1991), and there has been a retreat of the permafrost (Kwong and Gan, 1994). There are indications of increasing GSTs in the northern USA prairies (Gosnold *et al.*, 1992) and the Canadian prairies (Majorowicz, 1993). Cermak *et al.* (1992) have reported climatic warming in Cuba of 2-3°C over the last 200–300 years. Some borehole sites have indicated no recent change or cooling, e.g., in Utah (Chapman *et al.*, 1992). Deming (1995) assessed all the North American studies and concluded that all averages inferred from groups of boreholes revealed warming (ranging between 0.3 and 4.0°C) since the 19th century. The warming appears to have started in the middle of the 19th century in the eastern half of North America, whereas the warming in the west appears to have started near the beginning of the 20th century or even later.

In France, Mareschal and Vasseur (1992) made independent analyses of two boreholes and derived similar GST histories with peak warmth around 1000 AD, cooling to a minimum at 1700 AD, and warming starting at 1800 AD (see Section 3.6.2). Borehole temperatures also indicate increasing GST over the last century or two in Australia (Hyndman *et al.*, 1969) and the Ukrainian Shield (Diment, 1965), but an influence of deforestation was suspected. Where no ice was present in western Siberia, analyses indicate the most recent warming started 400 years ago in the south, and much earlier in the north (Duchkov and Devyatkin, 1992). Borehole measurements in New Zealand (Whiteford, 1993; Whiteford *et al.*, 1994) indicate cooling to a minimum around 1800 AD, followed by warming averaging 0.9°C over the past century.

Borehole temperature studies have also been conducted on ice sheets, and, especially those in Arctic regions, clearly show a warming since a cool period in the 1800s (e.g., Cuffey *et al.*, 1994).

3.2.5.3 Sea ice extent and mass

Neither hemisphere has exhibited significant trends in seaice extent since 1973 when satellite measurements began

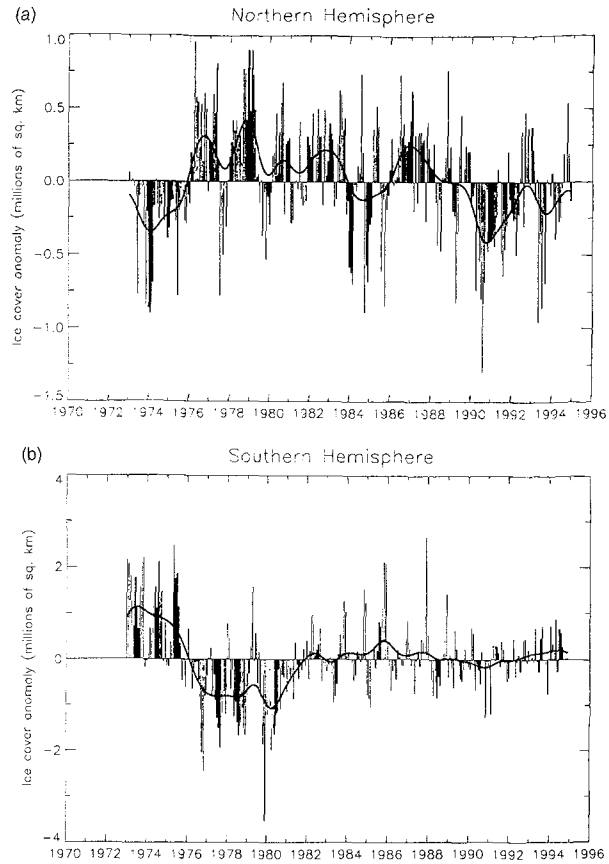

Figure 3.8: Sea ice extent anomalies relative to 1973–1994 for (a) the Northern Hemisphere and (b) the Southern Hemisphere. Data from NOAA (USA). Smooth lines generated from a 128-point binomial filter applied to the monthly anomalies. Heavy bars represent December–February in the Northern Hemisphere or June–August in the Southern Hemisphere.

(Figure 3.8). There has been below average extent in the Northern Hemisphere in the early 1990s, except for the second half of 1992 when the atmosphere was cooler. Coverage in the Southern Hemisphere has remained close to average. Jones (1995a) noted that the lack of sea ice variations around Antarctica seems unconnected to regional temperatures. For instance, sea ice did not increase during 1993 and 1994, despite low temperatures.

Sea ice total mass may be a more sensitive indicator of climate change than extent alone. Limited data on Arctic ice thickness, from upward sonar profiling from submarines and from moored subsurface sonar instruments, show large interannual variability but no trends from 1979 to 1990 (McLaren *et al.*, 1992).

3.2.5.4 Coral bleaching

Bleaching of coral reefs may result from high temperatures