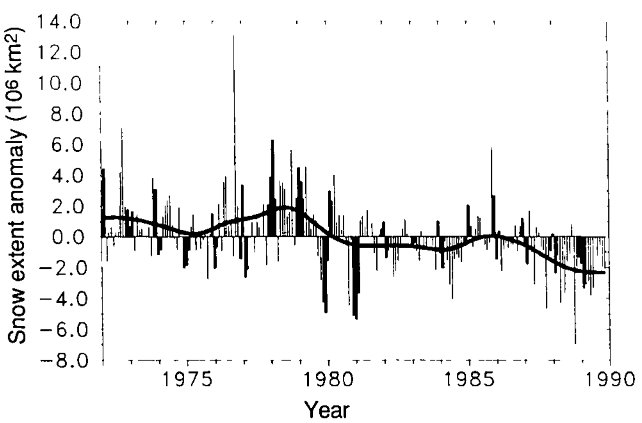

Figure 7.19: Northern Hemisphere snow extent anomalies. Data from NOAA (USA).

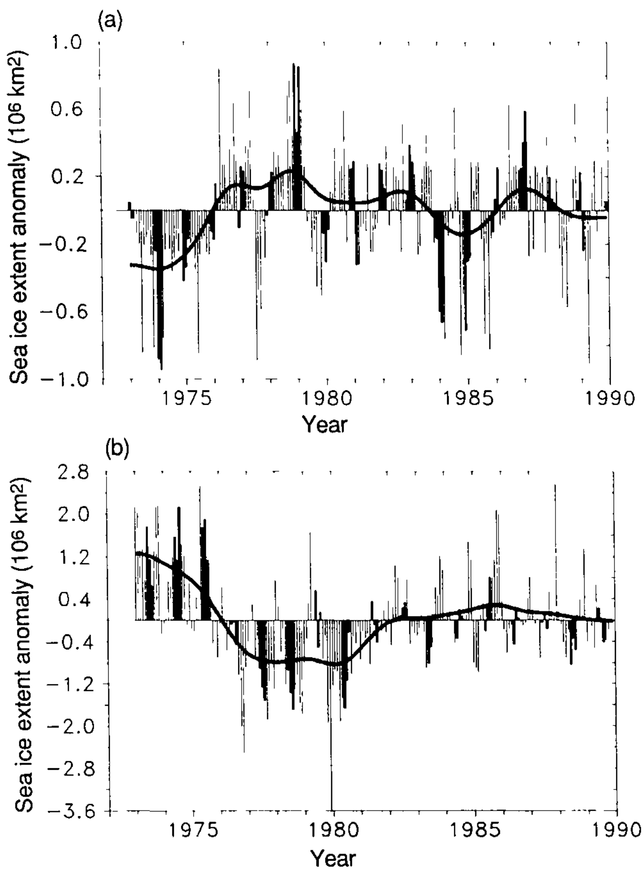

Figure 7.20: (a) Northern Hemisphere, and (b) Southern Hemisphere sea-ice extent anomalies. Data from NOAA (USA).

surface limits; the seasonal variation of sunlight limits polar coverage in the visible wavelengths; and scattered mountain snows are omitted because of the coarse grid resolution. Data are believed to be usable from 1972 with caution, but are better from 1975 onwards.

Consistent with the surface and tropospheric temperature measurements is the rapid decrease in snow cover extent around 1980 (Figure 7.19). This decrease is largest during the transition seasons. Robinson and Dewey (1990) note that the reduction in snow cover extent during the 1980s is largest in Eurasia where they calculate decreases during autumn and spring of about 13% and 9% respectively relative to the 1970s.

7.8.2 Sea-ice Extent and Thickness

There has been considerable interest in the temporal variability of global sea-ice in both the Arctic and Antarctic (for example, Walsh and Sater, 1981; Sturman and Anderson, 1985). This interest has been increased by general circulation model results suggesting that greenhouse warming may be largest at high latitudes in the Northern Hemisphere. It must be recognized, though, that sea-ice is strongly influenced by surface winds and ocean currents so that the consequences of global warming for changes in sea-ice extent and thickness are unlikely to be straightforward.

Sea-ice limits have long been observed by ships, and harbour logs often contain reported dates of the appearance and disappearance of harbour and coastal ice. These observations present many problems of interpretation (Barry, 1986) though they are thought to be more reliable after about 1950. Changes and fluctuations in Arctic sea-ice extent have been analysed by Mysak and Manak (1989); they find no long term trends in sea-ice extent between 1953 and 1984 in a number of Arctic ocean regions but substantial decadal time scale variability was evident in the Atlantic sector. These variations were found to be consistent with the development, movement and decay of the "Great Salinity Anomaly" noted in Section 7.7.

Sea-ice conditions are now reported regularly in marine synoptic observations, as well as by special reconnaissance flights, and coastal radar. Especially importantly, satellite observations have been used to map sea-ice extent routinely since the early 1970s. The American Navy Joint Ice Center has produced weekly charts which have been digitised by NOAA. These data are summarized in Figure 7.20 which is based on analyses carried out on a 1° latitude x 2.5° longitude grid. Sea-ice is defined to be present when its concentration exceeds 10% (Ropelewski, 1983). Since about 1976 the areal extent of sea-ice in the Northern Hemisphere has varied about a constant climatological level but in 1972-1975 sea-ice extent was significantly less. In the Southern Hemisphere since about 1981, sea-ice extent has also varied about a constant level. Between 1973 and 1980 there were periods of several years when Southern Hemisphere sea-ice extent was either appreciably more than or less than that typical in the 1980s.

Gloersen and Campbell (1988) have analysed the Scanning Multi-channel (dual polarization) Microwave Radiometer data from the Nimbus 7 satellite from 1978-1987. They find little change in total global ice area but a significant decrease of open water within the ice. Their time series is short, and it is uncertain whether the decrease is real.

Sea-ice thickness is an important parameter but it is much more difficult to measure than sea-ice extent. The heat flux from the underlying ocean into the atmosphere depends on sea-ice thickness. Trends in thickness over the Arctic Ocean as a whole could be a sensitive indicator of global warming. The only practical method of making extensive measurements is by upward-looking sonar from submarines. Apart from a very recent deployment of moorings, data gathering has been carried out on voyages by military submarines. In the past, repeated tracks carried out in summer have either found no change in mean thickness (Wadhams, 1989) or variations that can be ascribed to interannual variability in summer ice limits and ice concentration (McLaren, 1989). Recently however, Wadhams (1990) found a 15% or larger decrease in mean sea-ice thickness between October 1976 and May 1987 over a large region north of Greenland. Lack of a continuous set of observations makes it impossible to assess whether the change is part of a long term trend. In the Antarctic no measurements of thickness variability exist and so far only one geographically extensive set of sea-ice thickness data is available (Wadhams et al., 1987).

7.8.3 Land Ice (Mountain Glaciers)

Measurements of glacial ice volume and mass balance are more informative about climatic change than those of the extent of glacial ice, but they are considerably scarcer. Ice volume can be determined from transects of bedrock and ice surface elevation using airborne radio-echo sounding measurements. Mass balance studies performed by measuring winter accumulation and summer ablation are slow and approximate, though widely used. Section 9 discusses changes in the Greenland and Antarctic ice-caps so attention is confined here to mountain glaciers.

A substantial, but not continuous, recession of mountain glaciers has taken place almost everywhere since the latter half of the nineteenth century (Grove, 1988). This conclusion is based on a combination of mass balance analyses and changes in glacial terminus positions, mostly the latter. The recession is shown in Figure 7.2, evidence for glacial retreat is found in the Alps, Scandinavia, Iceland, the Canadian Rockies, Alaska, Central Asia, the Himalayas, on the Equator, in tropical South America, New Guinea, New Zealand, Patagonia, the sub-Antarctic islands and the Antarctic Peninsula (Grove, 1988). The rate of recession appears to have been generally largest between about 1920 and 1960.

Glacial advance and retreat is influenced by temperature, precipitation, and cloudiness. For example, at a given latitude glaciers tend to extend to lower altitudes in wetter, cloudier, maritime regions with cooler summers than in continental regions. The complex relation between glaciers and climate makes their ubiquitous recession since the nineteenth century remarkable: temperature changes appear to be the only plausible common factor (Oerlemans, 1988). The response time of a glacier to changes in environmental conditions varies with its size so that the larger the glacier the slower is the response (Haeberli et al., 1989). In recent decades glacial recession has slowed in some regions. Makarevich and Rototaeva (1986) show that between 1955 and 1980 about 27% of 104 North American glaciers were advancing and 53% were retreating, whereas over Asia only about 5% of nearly 350 glaciers were advancing. Wood (1988) found that from 1960 to 1980 the number of retreating glaciers decreased. This may be related to the relatively cool period in the Northern Hemisphere over much of this time (Figure 7.10). However, Patzelt (1989) finds that the proportion of retreating Alpine glaciers has increased sharply since the early 1980s so that retreat has dominated since 1985 in this region. A similar analysis for other mountain regions after 1980 is not yet available.

7.8.4 Permafrost

Permafrost may occur where the mean annual air temperatures are less than −1°C and is generally continuous where mean annual temperature is less than −7°C. The vertical profile of temperature measurements in permafrost that is obtained by drilling boreholes can indicate integrated changes of temperature over decades and longer. However, interpretation of the profiles requires knowledge of the ground conditions as well as natural or human-induced changes in vegetation cover. Lachenbruch and Marshall (1986) provide evidence that a 2 to 4°C warming has taken place in the coastal plain of Alaska at the permafrost surface over the last 75 to 100 years, but much of this rise is probably associated with warming prior to the 1930s. Since the 1930s there is little evidence for sustained warming in the Alaskan Arctic (see Figure 7.12a and Michaels, 1990). A fuller understanding of the relationship between permafrost and temperature requires better information on changes in snow cover, seasonal variations of ground temperature, and the impact of the inevitable disturbances associated with the act of drilling the bore holes (Barry, 1988).

7.9 Variations and Changes in Atmospheric Circulation

The atmospheric circulation is the main control behind regional changes in wind, temperature, precipitation, soil moisture and other climatic variables. Variations in many