1 Introduction

Glaciers, ice caps and continental ice sheets cover some ten per cent of the earth's land surface at the present time, whereas during the ice ages, they covered about three times this amount (Paterson 1994, Benn and Evans 1998). The present ice cover corresponds to about three-quarter of the world's total freshwater resources (Reinwarth and Stäblein 1972). If all land ice melted away, the sea level would rise by almost 65 m, with the ice sheets of Antarctica and Greenland contributing about 57 and 7 metres, respectively, and all other glaciers and ice caps roughly half a metre to this rise (IPCC 2007). Glaciers are an inherent component of the culture, landscape, and environment in high mountain and polar regions. They represent a unique source of freshwater for agricultural, industrial and domestic use, an important economic component of tourism and hydro-electric power production, yet they can also constitute a serious natural hazard. Because they are close to the melting point they react strongly to climate change, and thereby provide some of the clearest evidence of climate change and are essential variables within global climate-related monitoring programmes (GCOS 2004).

The cryosphere, derived from the Greek word *kryo* for cold, consists of snow, river and lake ice, sea ice, glaciers and ice caps, ice shelves and ice sheets, and frozen ground (Fig. 1.1). The different cryospheric components can be categorised in a) seasonal and perennial ice, b) surface and subsurface ice c) ice in the sea, in rivers, in lakes and on land. When referring to perennial surface ice on land, one usually differentiates between ice sheets, ice shelves, glaciers and ice caps (Box 1.1). There are fundamental differences in time-scales and processes involved between the different components of the perennial surface-ice on land. Due to the large volumes and areas, the two continental ice sheets actively influence the global climate over time scales of months to millennia. Glaciers and ice caps, with their smaller volumes and areas, react to climatic forcing at typical time scales from years to centuries. The focus of the present publication is on glaciers and ice caps. Good overviews on the state of knowledge concerning all cryospheric components can be found in IGOS (2007), IPCC (2007) and UNEP (2007).

Internationally coordinated glacier monitoring was initiated already as early as 1894 (Box 1.2). To the present day, the active international compilation and publication of standardised glacier data has resulted in unprecedented data sets on the distribution and changes of glaciers and ice caps. These data derived from field measurements and remote sensing provide a fundamental basis for the scientific studies which constitute the present state of knowledge on glacier changes in time and space. Usually, scientific articles report on the methods and main results of glacier investigations. The raw data and meta-data are compiled, published in standardised formats and made readily available in printed and digital form by the World Glacier Monitoring Service (WGMS) and its cooperation partners. These are the US National Snow and Ice Data Center (NSIDC), which is one of the World Data Centers for Glaciology, and the Global Land Ice Measurements from Space (GLIMS) initiative. So far, a status report on the World Glacier Inventory (WGI) was published in 1989 (WGMS 1989) whereas detailed information on glacier fluctuations has been compiled every five years (WGMS 2008, and earlier volumes) and on glacier mass balance every other year (WGMS 2007, and earlier volumes). With the exception of the latter, these products present the data in tabular form with related meta-data, usually comprehensible to specialists.

The aim of this publication is to provide an illustrated global view of (a) the available data basis related to the monitoring of glaciers and ice caps, (b) their worldwide distribution, and (c) their changes since the maximum extents of the Little Ice Age (LIA).

Box 1.1 Perennial surface ice on land

Ice sheet: a mass of land ice of continental size, and thick enough to cover the underlying bedrock topography. Its shape is mainly determined by the dynamics of its outward flow. There are only two continental ice sheets in the modern world, on Greenland and Antarctica; during glacial periods there were others.

Ice shelf: a thick, floating slab of freshwater ice extending from the coast, nourished by land ice. Nearly all ice shelves are located in Antarctica.

Glacier: a mass of surface-ice on land which flows downhill under gravity and is constrained by internal stress and friction at the base and sides. In general, a glacier is formed and maintained by accumulation of snow at high altitudes, balanced by melting at low altitudes or discharge into lakes or the sea.

Ice cap: dome-shaped ice mass with radial flow, usually covering the underlying topography.

Note that drawing a distinction between ice sheets on one hand, and glaciers and ice caps on the other, is in accordance with the definition of the *Essential Climate Variables* as put forth by GCOS (2004). The term 'glacier' is used in this context as a synonym for different types of surface land ice masses including outlet glaciers, valley glaciers, mountain glaciers and glacierets.

Sources: WGMS 1989, WGMS 2005a,b, IPCC 2007, UNEP 2007.

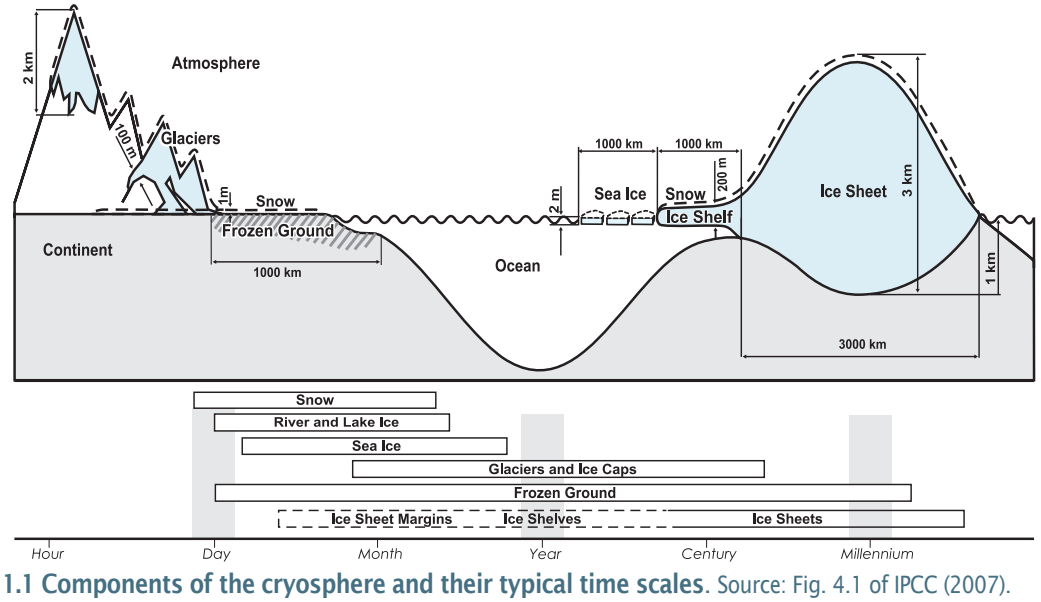

Fig. 1.1 Components of the cryosphere and their typical time scales. Source: Fig. 4.1 of IPCC (2007).

Box 1.2 International glacier monitoring

Worldwide collection of information about ongoing glacier changes was initiated in 1894 with the foundation of the *Commission Internationale des Glaciers* at the *6th International Geological Congress* in Zurich, Switzerland. Today, the *World Glacier Monitoring Service* (WGMS) continues the collection and publication of standardised information on distribution and ongoing changes in glaciers and ice caps. The WGMS is a service of the *International Association of the Cryospheric Sciences* of the *International Union of Geodesy and Geophysics* (IACS, IUGG) and the *Federation of Astronomical and Geophysical Data Analysis Services* of the *International Council for Science* (FAGS, ICSU) and maintains a network of local investigators and national correspondents in all the countries involved in glacier monitoring. In cooperation with the *US National Snow and Ice Data Center* (NSIDC) in Boulder and the *Global Land Ice Measurements from Space* (GLIMS) initiative, the WGMS is in charge of the *Global Terrestrial Network for Glaciers* (GTN-G) within the *Global Climate/Terrestrial Observing System* (GCOS/GTOS). GTN-G aims to combine (a) field observations with remotely sensed data, (b) process understanding with global coverage, and (c) traditional measurements with new technologies by using an integrated and multi-level monitoring strategy.

More information on the history of international glacier monitoring is found in Haeberli (2007). The GTN-G monitoring strategy is discussed in detail in Haeberli et al. (2000) and Haeberli (2004), with updates on the present state in the biennial GTOS reports (GTOS 2006, GTOS 2008), and illustrated using the example of the European Alps in Haeberli et al. (2007).

Federation of Astronomical and Geophysical Data Analysis Services: www.icsu-fags.org
Global Land Ice Measurements from Space: www.glims.org
Global Terrestrial Network for Glaciers: www.fao.org/gtos/gt-netGLA.html
Global Climate Observing System: www.wmo.ch/pages/prog/gcos/
Global Terrestrial Observing System: www.fao.org/gtos/
International Association of Cryospheric Sciences: www.cryosphericsciences.org
United Nations Environment Programme: www.unep.org
United Nations Educational, Scientific and Cultural Organization: www.unesco.org
US National Snow and Ice Data Center: www.nsidc.org
World Glacier Monitoring Service: www.wgms.ch
World Meteorological Organization: www.wmo.ch