

7 Conclusions

The internationally coordinated collection of information about ongoing glacier changes since 1894 and the efforts towards the compilation of a world glacier inventory have resulted in unprecedented data sets. Several generations of glaciologists around the world have contributed with their data to the present state of knowledge. For the second half of the 20th century, preliminary estimates of the global distribution of glaciers and ice caps covering some 685 000 km², are available, including detailed information on about 100 000 glaciers, and digital outlines for about 62 000 glaciers. The database on glacier fluctuations includes 36 240 length change observations from 1803 glaciers as far back as the late 19th century, as well as about 3 400 annual mass balance measurements from 226 glaciers covering the past six decades. All data is digitally made available by the WGMS and its cooperation partners, the NSIDC and the GLIMS initiative.

The glacier moraines formed during the end of the LIA, between the 17th and the second half of the 19th century, mark Holocene maximum extents of glaciers in most of the world's mountain ranges. From these positions, glaciers around the globe have been shrinking significantly, with strong glacier retreats in the 1940s, stable or growing conditions around the 1970s, and again increasing rates of ice loss since the mid 1980s. On a shorter time scale, glaciers in various mountain ranges have shown intermittent re-advances. Looking at individual fluctuation series, a high variability and sometimes contradictory behaviour of neighbouring ice bodies are found which can be explained by the different glacier characteristics. The early mass balance measurements indicate strong ice losses as early as the 1940s and 1950s, followed by a moderate ice loss between 1966 and 1985, and accelerating ice losses until present. The global average annual mass loss of more than half a metre water equivalent during the decade of 1996 to 2005 represents twice the ice loss of the previous decade (1986–95) and over four times the rate of the decade from 1976 to 1985. Prominent periods

of regional mass gains are found in the Alps in the late 1970s and early 1980s and in coastal Scandinavia and New Zealand in the 1990s. Under current IPCC climate scenarios, the ongoing trend of worldwide and rapid, if not accelerating, glacier shrinkage on the century time scale is most likely to be of a non-periodic nature, and may lead to the deglaciation of large parts of many mountain ranges by the end of the 21st century.

In view of the incompleteness of the detailed inventory of glaciers and ice caps and the spatio-temporal bias of the available fluctuation series towards the Northern Hemisphere and Europe, it is of critical importance that glacier monitoring in the 21st century:

- continues long-term fluctuation series (i.e., length change and mass balance) in combination with decadal determinations of volume/thickness and length changes from geodetic methods in order to verify the annual field observations,
- re-initiates interrupted long-term series in strategically important regions and strengthens the current monitoring network in the regions which are currently sparsely covered (e.g. Tropics, South America, Asia, and the polar regions),
- integrates reconstructed glacier states and variations into the present monitoring system in order to extend the historical set of length change data and to put the measured glacier fluctuations of the last 150 years into context with glacier variations during the Holocene,
- replaces long-term monitoring series of vanishing glaciers with timely starting parallel observations on larger or higher-reaching glaciers,
- concentrates the extent of the field observation network mainly on (seasonal) mass balance measurements, because they are the most direct indication of glacier reaction to climate changes,

- makes use of decadal digital elevation model differencing, and similar techniques, to extend and understand the representativeness of the field measurements to/for the regional ice changes,
- completes a global glacier inventory, e.g., for the 1970s (cf. WGMS 1989),
- defines key regions, where the glacier cover is relevant to climate change, sea level rise, hydrological issues and natural hazards, and in which repeated detailed inventories assess glacier changes (e.g., from the trim lines of the LIA) around 2000, and of the coming decades, with respect to the global baseline inventory, and
- periodically re-evaluates the feasibility and relevance of the monitoring strategy and its implementation.

The potentially dramatic climate changes, as sketched for the 21st century by IPCC (2007) refer to glacier changes of historical dimensions with strong impacts on landscape evolution, fresh water supply, natural hazards and sea level changes. This requires that international glacier monitoring makes use of the rapidly developing new technologies (remote sensing and geoinformatics) and relate them to the more traditional field observations, in order to face the challenges of the 21st century.



Fig. 7.1a Muir Glacier, 1941



Fig. 7.1b Muir Glacier, 2004

Fig. 7.1a–b Photo comparison of Muir Glacier, Alaska, which is a typical tidewater glacier. The photo 7.1a was taken on 13 August 1941 by W. O. Field; the photo 7.1b was taken on 31 August 2004 by B. F. Molnia of the *United States Geological Survey*. Source: *US National Snow and Ice Data Center*.