

*Excerpt from the introductory discourse of
"Les Variations périodiques des Glaciers" by Forel (1895).*

L'œuvre que la Commission internationale des glaciers a devant elle est grande et intéressante; elle est difficile. Abordons-la avec calme, courage et dévouement. Pour commencer, traitons le problème le plus simplement possible et bornons-nous à récolter tous les faits historiques qui peuvent nous faire connaître les variations glaciaires dans le passé', et à instituer des observations qui nous les fassent connaître dans le présent et dans l'avenir. Quand cette base aura été solidement établie, les questions subsidiaires de cause, d'effet, de relations avec d'autres phénomènes, les questions théoriques, etc., se présenteront tout naturellement à nos études, et nous, ou nos successeurs, les traiterons à mesure qu'elles se développeront devant nous.

Foreword by UNEP Executive Director



Climate change is now clearly at the top of the world's agenda. This momentum was generated in large part by the *Intergovernmental Panel on Climate Change* (IPCC), which made clear that climate change is already happening and accelerating. As a result of the remarkable efforts of last year, the international community is armed with a powerful combination of authoritative and compelling science, a far-reaching and rising tide of public concern, and powerful declarations of political will voiced at the Bali *Climate Change Conference* held in December 2007.

The *United Nations Development Programme* (UNDP) *2007/2008 Human Development Report* highlighted the devastating effects climate change is already having on the poorest and most vulnerable, making the achievement of the *Millennium Development Goals* more challenging. UNEP's flagship *Global Environment Outlook* report (GEO-4), published in October 2007, concludes that: "Tackling climate change globally will demand political will and leadership, and strong stakeholder engagement. Adaptation to the changes expected is now a global priority. Improved monitoring is needed, and it is urgent to enhance our scientific understanding of the potential tipping points beyond which reversibility is not assured."

Glaciers are a critical component of the earth's system and the current accelerated melting and retreat of glaciers have severe impacts on the environment and human well-being, including vegetation patterns, economic livelihoods, natural disasters, and the water and energy supply. Monitoring glacier changes and providing

scientifically-sound, consistent and illustrative facts and figures on glaciers are therefore critical functions in today's world. Glaciers and ice caps are now also one of the *Essential Climate Variables*, a set of core variables in support of the work of organizations such as the *United Nations Framework Convention on Climate Change* (UNFCCC) and the IPCC.

Under the auspices of the *International Council for Science* (FAGS/ICSU), the *International Union of Geodesy and Geophysics* (IACS/IUGG), the *United Nations Educational, Scientific and Cultural Organisation* (UNESCO), the *World Meteorological Organisation* (WMO), and the UNEP, the *World Glacier Monitoring Service* (WGMS) collects and compiles the basic glacier data from all parts of the world and provides information on the state and trends of glaciers in almost all mountain regions. The current publication follows the *Global Outlook for Ice and Snow* that was published by UNEP at the occasion of *World Environment Day 2007* and complements regular reports by WGMS on *Fluctuations of Glaciers* and *Glacier Mass Balances*. It presents basic information on a range of glaciers and ice caps throughout the world in a concise and illustrative format, serving as a miniature atlas on global glacier changes for a wide range of audiences.

UNEP commends the work of WGMS and partners on this very important global issue and is grateful to all those who contributed to this current comprehensive and illustrative publication on the dramatic changes affecting so many glaciers in so many parts of the world.

Achim Steiner
United Nations Under-Secretary-General and
Executive Director, United Nations Environment Programme

Foreword by WGMS Director



In 2006, a new record annual mass loss was measured on the reference glaciers under observation, whose mass balance has been recorded since the late 1940s as part of internationally coordinated glacier observation programmes. The average annual melting rate of mountain glaciers appears to have doubled after the turn of the millennium in comparison with the already accelerated melting rates observed in the two decades before. The previous record loss in the year 1998 has already been exceeded three times, i.e., in the years 2003, 2004 and 2006, with the losses in 2004 and 2006 being almost twice as high as the previous 1998 record loss. Glaciers and ice caps are indeed key indicators and unique demonstration objects of ongoing climate change. Their shrinkage and, in many cases, even complete disappearance leaves no doubt about the fact that the climate is changing at a global scale and at a fast if not accelerating rate. Anyone can see the changes in glacier extent and understand the basic physical principle of snow and ice melting as temperatures continue to rise: as the glaciers and ice caps on earth grow smaller, the energy content in the climate system and in the environment on which we depend becomes greater.

The task of scientific glacier monitoring networks is to coordinate the worldwide collection of standardised data in order to quantify the rate of change, to compare its magnitude with the range of variability during the pre-industrial times of the Holocene period, to validate projections of possible future climate change based on general circulation and regional climate models, and to anticipate and assess impacts on the environment, the economy and on society. By looking at glaciers or what is left of them, future generations will be able to discern clearly which climate scenario is being played out at the present time. The consequences of snow and ice disappearance for landscape characteristics and natural hazards in high mountain areas will be felt at local to regional scales, while the changes in the water cycle will also affect continental-scale water supply and global-scale sea levels. The degree of glacier vanishing indeed reflects the increasing distance from dynamic equilibrium conditions of the climate system.

Glaciers and ice caps constitute *Essential Climate Variables* (ECV) within the *Global Climate Observing System* (GCOS) and its terrestrial component, the *Global Terrestrial Observing System* (GTOS), as related to the *United Nations Framework Convention on Climate Change* (UNFCCC). The corresponding *Global Terrestrial Network for Glaciers* (GTN-G) is run by the *World Glacier Monitoring Service* (WGMS) at the *University of Zurich*, Switzerland, in cooperation with the *National Snow and Ice Data Center* (NSIDC) at Boulder, Colorado, and the *Global Land Ice Measurement from Space* (GLIMS) initiative. The collected data form the basis for international assessments such as IPCC, or UNEP's recent *Global Outlook for Ice and Snow*. They are frequently analysed and discussed at scientific conferences and in related publications.

It is the task and responsibility of the WGMS to collect and disseminate standardised data on glacier changes worldwide. The standards are documented in the periodical WGMS publications (*Fluctuations of Glaciers* at 5-yearly intervals and the biennial *Glacier Mass Balance Bulletin*) as well as by the corresponding forms and requests for data submission through the national correspondents and principal investigators. The present publication aims at providing a commented and illustrated overview of the distribution and development of glaciers and ice caps based on the currently available database and selected satellite imagery. It was compiled in collaboration with the WGMS network of national correspondents and principal investigators and reviewed by regional glacier experts.

Our sincere thanks go to all the colleagues and friends who generously provided materials, ideas and expertise. It is with their help and with the support of the sponsoring agencies at national and international levels that the glacier community has been able to build up, for more than a century now, a unique treasury of information on the fluctuations in space and time of glaciers and ice caps on earth.

Wilfried Haerberli
Director, World Glacier Monitoring Service

Summary

Changes in glaciers and ice caps provide some of the clearest evidence of climate change, and as such they constitute key variables for early detection strategies in global climate-related observations. These changes have impacts on global sea level fluctuations, the regional to local natural hazard situation, as well as on societies dependent on glacier meltwater. Internationally coordinated collection and publication of standardised information about ongoing glacier changes was initiated back in 1894. The compiled data sets on the global distribution and changes in glaciers and ice caps provide the backbone of the numerous scientific publications on the latest findings about surface ice on land. Since the very beginning, the compiled data has been published by the *World Glacier Monitoring Service* and its predecessor organisations. However, the corresponding data tables, formats and meta-data are mainly of use to specialists.

It is in order to fill the gaps in access to glacier data and related background information that this publication aims to provide an illustrated global view of the available data sets related to glaciers and ice caps, their distribution around the globe, and the changes that have occurred since the maximum extents of the so-called Little Ice Age (LIA).

International glacier monitoring has produced a range of unprecedented data compilations including some 36 000 length change observations and roughly 3 400 mass balance measurements for approximately 1 800 and 230 glaciers, respectively. The observation series are drawn from around the globe; however, there is a strong bias towards the Northern Hemisphere and Europe. A first attempt to compile a world glacier inventory was made in the 1970s based mainly on aerial photographs and maps. It has resulted to date in a detailed inventory of more than 100 000 glaciers covering an area of about 240 000 km² and in preliminary estimates, for the remaining ice cover of some 445 000 km² for the second half of the 20th century. This inventory task continues through the present day, based mainly on satellite images.

The moraines formed towards the end of the Little Ice Age, between the 17th and the second half of the 19th century, are prominent features of the landscape, and mark Holocene glacier maximum extents in many mountain ranges around the globe. From these positions, glaciers worldwide have been shrinking significantly, with strong glacier retreats in the 1940s, stable or growing conditions around the 1920s and 1970s, and again increasing rates of ice loss since the mid 1980s. However, on a time scale of decades, glaciers in various mountain ranges have shown intermittent re-advances. When looking at individual fluctuation series, one finds a high rate of variability and sometimes widely contrasting behaviour of neighbouring ice bodies.

In the current scenarios of climate change, the ongoing trend of worldwide and rapid, if not accelerating, glacier shrinkage on the century time scale is most likely of a non-periodic nature, and may lead to the deglaciation of large parts of many mountain ranges in the coming decades. Such rapid environmental changes require that the international glacier monitoring efforts make use of the swiftly developing new technologies, such as remote sensing and geo-informatics, and relate them to the more traditional field observations, in order to better face the challenges of the 21st century.



Fig. 0.1a Morteratsch Glacier, 1985



Fig. 0.1b Morteratsch Glacier, 2007

Fig. 0.1a—b Recession of Morteratsch Glacier, Switzerland, between 1985 and 2007. Source: J. Alean, *SwissEduc* (www.swisseduc.ch) / *Glaciers online* (www.glaciers-online.net).