

Long-term glacier monitoring in Switzerland as part of global climate-related observing systems: challenges for the 21st century.

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Systematic long-term glacier observations in Switzerland officially started in 1893 and served as a model for internationally coordinated monitoring of glacier fluctuations established one year later, in 1894, by the 6th International Geological Congress in Zurich. During the 20th century, the international network experienced several deep crises. Since about 1990, however, the significance of glacier changes as key indication and unique demonstration object of fast and worldwide climate change has been increasingly recognised far beyond scientific circles. This development is a consequence of important facts (Haeberli 2006):

- Concern is growing that the ongoing trend of worldwide and fast if not accelerating glacier shrinkage at the century time scale is of non-cyclic nature – there is hardly a question any more of the originally envisaged „variations périodiques des glaciers“.
- Under the growing influence of human impacts on the climate system (enhanced greenhouse effect), dramatic scenarios of future developments – including complete deglaciation of entire mountain ranges – must be taken into consideration (Zemp et al. 2006, IPCC 2001).
- Such future scenarios may lead far beyond the range of historical/holocene variability and most likely introduce processes (extent and rate of glacier vanishing, distance to equilibrium conditions) without precedence in the Holocene.
- A broad and worldwide public today recognizes glacier changes as a key indication of regional and global climate and environment change.
- Observational strategies established by expert groups within international monitoring programmes build on advanced process understanding and include extreme perspectives.
- These strategies make use of the fast development of new technologies and relate them to traditional approaches in order to apply integrated, multilevel concepts (in situ measurements to remote sensing, local-process oriented to regional and global coverage), within which individual observational components (length, area, volume/mass change) fit together enabling a comprehensive view.

Within the Global Climate Observing System (GCOS; <http://www.wmo.ch/web/gcos/gcoshome.html>) established in 1992, the Global Terrestrial Network for Glaciers (GTN-G) combines the World Glacier Monitoring Service (WGMS) in Zurich, Switzerland (<http://www.wgms.ch>), the Global Land Ice Measurement from Space project (GLIMS; <http://www.glims.org/>) and the National Snow and Ice Data Center at Boulder, Colorado (<http://nsidc.org/NOAA/index.html>) and adopts

an integrated tier system, which links investigations across a range of scales. Observations include

- extensive and process-oriented glacier mass balance and flow studies at selected glaciers for developing and calibrating numerical models;
- regional glacier mass changes within major mountain systems, observed with strategically selected index stakes combined with precision mapping, and/or repeated laser altimetry, DEM comparison etc.;
- long-term observations of glacier length changes representing different glacier sizes and dynamic responses for intercomparison of geometrically similar glaciers, dynamic fitting of glacier flow models to long time series of measured cumulative length change and mass-change reconstructions using concepts of mass conservation;
- glacier inventories repeated at time intervals of several years to a few decades by using photogrammetry or (in most cases) satellite remote sensing for analysing the evolution of large glacier ensembles in entire mountain chains and for reaching global coverage.

In the meantime, glacier observations in Switzerland have developed in a rather uncoordinated way. The publicly available maps compiled and periodically updated by the Federal Office of Topography (swisstopo) represent a unique, high-precision documentation of all glacier changes and must be fully integrated into the monitoring strategy. Historical and modern/satellite-based inventories (Maisch et al. 2000, Paul et al. 2004) are world-top products, which should be combined with in-situ measurements for integrative analysis and assessment. The in-situ measurements comprise various components which need understandable scientific concepts leading to recognisable and scientifically significant results. The length change measurements initiated in 1893, for instance, require careful reflection in view to fast developments in nature (downwasting, collapse and disintegration rather than „retreat“ of glacier margins with accelerating temperature rise) and technology (high-resolution satellite imagery, digital terrain information, numerical models). Seasonal observations of mass change (Clariden index stakes) and flow measurements (Unteraar, Corbassière) should be concentrated within the framework of mass balance measurements (calibrated Gries and Basodino, uncalibrated Silvretta) rather than being disconnected on separate glaciers. Another rather principal problem is the possible vanishing of long-observed mass balance glaciers within the coming decades. Adequate approaches have to be developed for replacing such fundamentally important core parts of glacier monitoring systems. Modern technologies and numerical models will thereby undoubtedly play a key role.

Recognizing such problems and needs, the Swiss Academy of Sciences through their Geosciences now established a new group on cryosphere monitoring. One first-priority task of this group will consist in the integration of the various components of glacier observations and corresponding representatives from research groups and federal authorities in order to develop a coherent and scientifically sound network as part of internationally coordinated and future-oriented climate-related observing systems.

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