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Mountain cryospheric studies and the WCRP climate and cryosphere (CliC) project

Roger G. Barry

NSIDC/CIRES, University of Colorado, Boulder, CO 80309-0449, USA

Abstract

A new element of the World Climate Research Programme (WCRP) has been inaugurated addressing the role of the cryosphere in climate. A Science and Co-ordination Plan has been issued for the Climate and Cryosphere (CliC) project. Topics of concern for high mountain hydrology are; ice caps and glaciers, seasonal snow cover, freshwater ice, and seasonally frozen ground and permafrost. The principal scientific questions relating to the cryosphere in mountain regions are reviewed. CliC wil also examine the role of cryospheric components as indicators of climate variability and change building on ongoing programs of glacier and permaforst monitoring.

The impacts of global change on elements of the cryosphere in mountains are expected to have significant social and economic ramifications. Examples of needs and initiatives in these areas are also presented.

1. Introduction

A series of formal discussions within the World Climate Research Programmer (WCRP) over the interval 1997-1999 have been directed at the question of the role of the cryosphere in the climate system. The Arctic Climate System (ACSYS) Scientific Steering Group through a Task Group developed a comprehensive proposal for the overall organization and integration of climatically important aspects of cryospheric research. A Science and Co-ordination Plan for Climate and the Cryosphere (CliC) (Allison et al., 2001) was approved by the WCRP Joint Scientific Committee in March 2000. The concept of this plan, and topics of concern for high mountain hydrology, are discussed here. This paper outlines scientific questions relating to the cryosphere in mountain regions and ways in which the CliC project hopes to contribute to their solution. The impacts of global change on elements of the cryosphere are expected to have significant social and economic ramifications in mountain regions of the world. In mountain areas and their surrounding lowlands, changes in seasonal snow cover and in the extent of glacierization will modify the hydrological regime and impact water resources.

2. Rationale and scope of the CliC project

The cryosphere embraces all forms of snow and ice. Of relevance here are: ice caps and glaciers, seasonal snow cover, freshwater ice, and seasonally frozen ground and permafrost. Many cryospheric elements and processes are already the subject of international co-operative research. But, with the notable exception of ACSYS, these are generally outside the framework of the WCRP. Also, many of the projects are regional and links with global climate research are limited. The WCRP Global Energy and Water Cycle Experiment

E-mail address: rbarry@kryos.colorado.edu (R.G. Barry).

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(GEWEX) project includes some cryospheric components related to the hydrological cycle in high latitudes and on the Tibetan Plateau, but these are secondary to the broader aims. External programs include: the International Geosphere Biosphere Programme (IGBP) Biospheric Aspects of the Hydrological Cycle (BAHC) focus on Altitudinal Gradient Studies, the International Arctic Science Committee, project on the Mass Balance of Arctic Glaciers and Ice Caps, and other international and regional efforts such as the Global Land Ice Measurements from Space, Permafrost and Climate in Europe, and the Cryospheric System in Canada.

Integration of existing cryospheric projects within a global research structure, and new efforts addressing current gaps, are required in order to:

- enhance links between studies of regional and global climatic components,
- promote appropriate treatment of cryospheric processes in climate models,
- assemble quality controlled, well-documented and comprehensive global gridded data sets needed for driving and validating climate models.

CliC will also examine the role of cryospheric variables as indicators of climate variability and change. Ongoing programs of glacier and permafrost monitoring are already providing information for the Global Terrestrial Networks of the Global Climate and Global Terrestrial Observing System (GCOS and GTOS, respectively).

3. Scientific questions relevant to mountains and their significance

Almost a quarter of the global land surface is made up of mountains and, apart from the permanent residents and dense populations in many of the adjacent lowlands, there are larger numbers of visitors to high altitude year-round. Mountains are, therefore, especially significant in terms of the water cycle, water resources and snow and ice cover. Principal scientific questions relating to the cryosphere in mountain region concern:

- glacier contributions to global sea level change,
- the energy and water cycle in regions with land ice, snow cover and frozen ground,
- the regional and global interactions of snow cover and seasonally frozen ground.

The effects of global warming on the cryosphere in mountain areas are most visibly manifested in the shrinkage of mountain glaciers and in reduced snow cover duration. Examples of such changes are now presented.

3.1. Glacier loss

Reductions in ice volume in the two major ice sheets, as well as in mountain glaciers and ice caps, are of both scientific and public concern. Melt of mountain glaciers contributed about 15–20% of the rise in global sea level during the second half of the twentieth century (Dyurgerov, 2003). Reduction of ice volume also affects the amount and timing of runoff in glacierized basins. Glacier shrinkage and down-wasting also has a negative scenic impact and may reduce summer tourism. Observations of glacier length and mass balance during the second half of the twentieth century show general reductions for glaciers located in continental climates, but local increases in maritime locations such as Norway, southern Alaska and coastal areas of the Pacific Northwest in Canada and the United States. A recent rise in freezing level in the Tropics, as well as changes in atmospheric humidity in some cases, has given rise to progressive reduction in mountain glaciers and ice caps over the last century (Diaz and Graham, 1996). Particularly dramatic changes are evident in East Africa where there has been a 75% decrease in ice area on Mount Kilimanjaro since the early 1900s (Hastenrath and Greischer, 1997). Essentially all the ice cover on East African summits will be lost within twenty years or so, unless there is a dramatic shift in climatic conditions.

Indirect evidence of century-scale changes in glacier size can be acquired by the analysis of glacier moraines dated by lichenometry and carbon-14. Accounts from various mountain regions exemplify these results (Luckman and Villalba, 2001; Solomina, 1999; Kaser, 1999). These proxy data sources become even more important in mountain regions that lack direct records, or where these are of short duration as in the Andes and other tropical regions (Barry, 1990; Barry and Seimon, 2000).

Large responses are also expected in terms of the annual hydrologic regime of rivers where the runoff comprises a significant proportion from melt of snow cover and from wastage of ice in heavily glacierized basins. Runoff models under global warming scenarios project a higher and earlier peak of spring runoff from snowmelt and reduced summer flows (Rango and Martinec, 1998). Winter rainfall events are likely to increase in frequency. For the upper Rhône, Collins (1987) found discharge correlated with mean summer temperature; a 1 °C cooling between 1941–1950 and 1968–1977 led to a 26% decrease in mean summer discharge. Conversely, warming trends will initially increase the discharge. However, a dominant component of runoff change in heavily glacierized basins is attributable to the reduction in ice area. Chen and Ohmura (1990) calculated an 11% decrease in runoff from a basin of the upper Rhône drainage where the ice cover decreased from 71 to 66% between 1922–1929 and 1968–1972. This compares with a 6 percent decrease in runoff between 1910–1919 and 1968–72 in another sub-basin where the ice cover decreased from 17 to 14%. In the latter case, the Rhône at Porte du Scex, runoff changes also responded to a decrease in basin precipitation. However, this was offset by the effect of warmer summers increasing the ice melt. Such regime changes are likely to have major consequences for water resource management for agricultural, industrial, domestic, and hydropower use. There are also issues of changes in water quality associated with changes in snow chemistry.

Direct effects associated with a shorter snow season and shallower snow cover will include the reduction or loss of winter sports facilities, or the necessity for enhanced reliance on snowmaking capabilities, with attendant losses of income and costs of adaptation. From the 1850s to the 1980s snowline in the Graubunden (Grisons) canton of eastern Switzerland rose by 177 ± 51 m (Maisch, 1990). For the Austrian Alps, losses to the skiing industry will be exacerbated at lower elevations (Breiling and Charanza, 1999). Secondary effects resulting from this change may include the loss of related service activities and income at mountain resorts. Summer tourism may also be affected as scenic mountain glaciers shrink and waste away.

3.2. Frozen ground

Global warming is being reflected in increases in ground temperature in several mountain areas. In the northern Tien Shan, permafrost ground temperatures have risen by 0.2–0.3 °C over the last 25 years (Gorbunov et al., 2000). The depth of seasonal freezing has not changed significantly in the low mountains, but there has been a decrease in the depth between 1400 and 2700 m, while above 3000 m the depth of seasonal freezing is increasing. In the Swiss Alps, Haeberli (1994) estimated permafrost warming by about 1 °C between 1880 and 1950, then stabilizing, before accelerated warming in the late 1980s until at least 1992. However, a 10-year borehole record analyzed by Vonder Mühll et al. (1998) indicate that warming until 1994 was largely compensated by rapid cooling in 1994–96. Changes in the depth of seasonal ground freeze and its intensity can lead to shifts in ground heave and solifluction processes. Degradation of ground ice can result in slope instability and damage to structures.

3.3. Lake and river ice cover

Observations on an alpine lake near St Moritz in the Engadine, Switzerland show break-up of the ice cover has occurred 7.6 days/century earlier since 1832 (Livingston, 1997). Local and regional air temperatures in April account for 64% of the variance in break-up date. A study by Magnusson et al. (2000) shows that such changes are widespread in the Northern Hemisphere. A warming of about 1.2 °C/century over the last 150 years (1846–1995) has been accompanied by a 5.8 day/century delay in average freeze-up and a 6.5 day/century advance in the average break-update.

4. Implementation

To address the scientific and practical concerns, the CliC Scientific Steering Group is preparing an initial Implementation Plan to set out strategies and approaches that are directed towards the goals of the project. Science priorities take account of both the urgency of the topic and the readiness of the scientific knowledge, measurement and modeling techniques, to undertake studies that can reduce the uncertainties in quantitative understanding of the phenomena.

An urgent topic for consideration is the potential loss of critical ice records from shrinking tropical glaciers within about 15–20 years. Between 1970 and 1986 there was a rise of 100–150 m in the altitude of the freezing level in the atmosphere over the inner tropics (10°N–10°S) based on upper-air balloon soundings (Diaz and Graham, 1996). Thompson et al. (1993) show that on the Quelccaya Ice Cap, at 14°S in Peru, melt water penetration had already obliterated the important climatic record provided by the famous ice core collected earlier from that location.

Over the 21st century, global sea level rise is expected to become a pressing problem. Detailed and more comprehensive studies are needed of the ice volume changes in mountain glaciers and ice caps, as well as in the mass balance of the Greenland and Antarctic ice sheets. An urgent first step is a full inventory of all ice bodies, their volume and changes over the last half century and longer.

5. Next steps

The CliC project will have at least a 15-year (2003–2018) time span. Following completion of the initial Implementation Plan (2002: http://clic.npdar.no/impl/plan.html), several tasks are being addressed. These include:

- encouraging national CliC programs appropriate to each interested country
- seeking funding for them
- coordinating activities with existing programs

Within WCRP, there are several ACSYS elements that will continue; joint working groups may be established with GEWEX. Other related programs include: GCOS/GTOS, the IGBP–BAHC and new Mountain Research Initiative (Becker and Bugmann, 2001). In the latter initiative, an important proposed activity is monitoring and analyzing change in mountains. Cryospheric indicators such as those identified above are noted. They also recognize the need for the assessment of runoff generation under process studies. WCRP-CliC is listed as an important partner in such work. Within the International Council of Science, there is the International Commission on Snow and Ice and the International Permafrost Association. There are numerous other regional cryosphere-related projects within the European Union and elsewhere, and national programs.

The links to other programs and activities may be formalized via representation on steering groups and panels or may simply involve co-sponsorship of meetings and workshops. The work of international CliC planning is carried out through the CliC SSG, an International Project Office at the Norwegian Polar Institute in Tromso, and by a Data Management and Information Panel, an Observation Products Panel and a working group on Polar Products from Re-Analyses; there is also a Numerical Experimentation Group. In spite of all these planning efforts, the ultimate key to success is the willingness of national agencies to support particular tasks appropriate to the focus and scope of their national capabilities and interests.

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