Journal of Hydrology 412–413 (2012) 291–296

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Impacts of climatic change on water and associated economic activities in the Swiss Alps

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ARTICLE INFO

Article history:
Available online 11 August 2010

Keywords:
Climatic change
Swiss Alps
Glaciers
Snow
Rhone river
Climate impacts

SUMMARY

The European Alps are one region of the world where climate-driven changes are already perceptible, as exemplified by the general retreat of mountain glaciers over past decades. Temperatures have risen by up to 2 °C since 1900 particularly at high elevations, a rate that is roughly three times the global-average 20th century warming. Regional climate models suggest that by 2100, winters in Switzerland may warm by 3–5 °C and summers by 6–7 °C according to greenhouse-gas emissions scenarios, while precipitation is projected to increase in winter and sharply decrease in summer. The impacts of these levels of climatic change will affect both the natural environment and a number of economic activities. Alpine glaciers may lose between 50% and 90% of their current volume and the average snowline will rise by 150 m for each degree of warming. Hydrological systems will respond in quantity and seasonality to changing precipitation patterns and to the timing of snow-melt in the Alps, with a greater risk of flooding during the spring and droughts in summer and fall. The direct and indirect impacts of a warming climate will affect key economic sectors such as tourism, hydropower, agriculture and the insurance industry that will be confronted to more frequent natural disasters. This paper will thus provide an overview of the current state of knowledge on climatic change and its impacts on the Alpine world.

1. Introduction

This paper is a contribution to a special issue of the Journal of Hydrology based on the Hydrology Conference 2010 in San Diego (October 11–14, 2010). Its aim is to report on various physical and socio-economic aspects of climate impacts on water regimes in the Alpine part of the Rhone river in Switzerland on the basis of existing knowledge and emerging results from the European large integrating project ‘‘ACQWA’’ (see below) initiated and coordinated by the author. As such, this contribution should not be viewed as a research article *per se* but more as an attempt to highlight some of the issues that are emerging from increasingly-accurate projections of changes in the determinants of the hydrological cycle in a warming climate, the impacts that these changes will exert on a number of key economic sectors in the region, and the possible implications for improved water governance to avert possible rivalries between economic actors. By providing a succinct overview of these issues, the paper thus seeks to emphasize the complex interlinks between the natural sciences and the social and economic sciences.

As the evidence for human induced climate change becomes clearer, so too does the realization that its effects will have a range of impacts on socio-economic systems and important elements of the environment such as water. Some regions are likely to be more vulnerable than others, both to expected physical changes and to the consequences they will have for ways of life. Mountains are recognized as particularly sensitive physical environments where climatic change would considerably influence the runoff regime of the rivers downstream and the related water availability. Increasing evidence of glacier retreat, permafrost reduction and snowfall decrease have been observed in many mountain regions, with consequent alterations of stream-flow regimes. If these trends accelerate in the future, they would in turn threaten the availability of water resources, increase downstream landslide and flood risk, and impact hydropower generation, agriculture, forestry, tourism and aquatic ecosystems. As a consequence, socio-economic structures of populations living downstream would also be impacted, calling for better preparedness and improved water governance.

Regional climate models have over the past decade provided the essential information on shifting precipitation and temperature patterns, while snow, ice, hydrological models and biosphere models are now beginning to allow coupled system approaches in order to assess the changes in basin hydrology and seasonality, amount, and incidence of extreme events in various catchment areas.

A major EU project (ACQWA: Assessing Climate change impacts on the quality and quality of water, Framework Programme 7, contract 212250; www.acqwa.ch), coordinated by the Institute of

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0022-1694/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhydrol.2010.06.046

Environmental Sciences at the University of Geneva, is currently underway (duration: from October 2008–September 2013) to investigate not only the physical response of mountain hydrological systems, but also the environmental and socio-economic responses to changes in water availability. This involves focusing on a range of impacts, such as natural hazards, aquatic ecosystems, hydropower, tourism, agriculture, and the health implications of changing water quality. Attention is also being devoted to the interactions between land-use/land cover changes, and changing or conflicting water resource demands. Integration of the information from all these sectors and the impacts on economies will ultimately provide the basis for EU-wide decision making in terms of water supply and demand.

While the ACQWA project focuses on several river basins in the Alps, the Andes in Chile, and Argentina, and the mountains of Central Asia, the present paper will look primarily at the Rhone river in its Alpine setting within Switzerland (see Fig. 1). Indeed, the Rhone represents an excellent and "test ground" for model investigations, where different methodological approaches converge to the basin scale through appropriate up- or down-scaling techniques. The Rhone catchment constitutes an ideal case-study region, because it includes all the elements of the natural environment to be modelled (snow, ice, vegetation, hydrology). At the same time, it is highly regulated, with water uptake for hydropower, irrigated agriculture, and tourism activities in the context of a climate that is at the borderline between Mediterranean and continental, thus, as shown inter alia by Beniston (2000), particularly vulnerable to climatic change.

2. Methodology, modelling sub-components of river basin response to climatic change

Within the European Union project PRUDENCE (Christensen et al., 2002), a suite of regional climate models have been applied to the investigation of climatic change over Europe for both the baseline reference climate (1961–1990) and the last 30 years of the 21st century, enabling an insight into possible changes in the extremes of temperature by 2100.

One technique that was pioneered in the early 1990s and refined by Giorgi and Mearns (1999) and has since become commonplace in the climate modelling arena is that of "nested modelling". This technique was initially used to address the problems related to insufficient grid resolution in Global Climate Models (GCMs), in order to enhance climate information over particular regions and to provide climate data at an appropriate resolution for impacts studies, for example. In the original procedure, results from a GCM are used as initial and boundary conditions for regional climate models (RCMs) that operate at much higher resolution and with generally more detailed physical parameterizations. A regional model can thus be considered to be an "intelligent interpolator" that can help fill whatever data gaps require attention, since it is based on the physical mechanisms governing climatic processes and serves to enhance the regional detail lacking in Global Climate Models.

When analyzing the results for temperature in Europe, the different RCM simulations broadly agree on the magnitude of change in mean, maximum, and minimum temperatures; Deque et al. (2005) have highlighted the clustering of model results that constitutes one measure of the uncertainty or reliability of the regional-scale simulations. Precipitation, on the other hand, is a more complex variable to compute, because it is generally related to processes that take place at scales smaller than the grid-mesh of even a fine-scale climate model. The precision of precipitation estimates is thus highly sensitive to the parametric scheme used and to the manner in which surface-atmosphere interactions are taken into account (e.g., the representation of land-use, soil moisture, topography, etc.).

Recent studies of changes in temperature and rainfall regimes (e.g., those reported by EU projects such as "PRUDENCE" – http://prudence.dmi.dk) have shown that quite a number of models exhibit genuine skill in reproducing observed precipitation and even the complex precipitation characteristic of complex topography as in the Alps. The HIRHAM regional climate model (RCM) of the Danish Meteorological Institute (Christensen et al., 1998) is one such model whose results correspond well with those of the other RCMs used in PRUDENCE. Furthermore, simulations of the reference climate period 1961–1990 has shown that HIRHAM exhibits

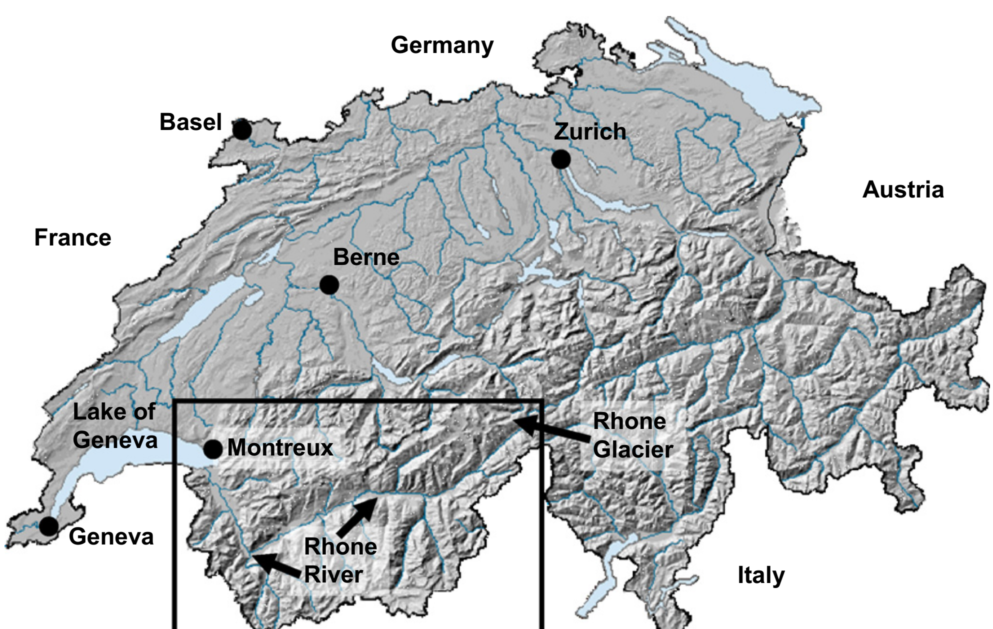

Fig. 1. Map of Switzerland showing the geographical location of the upper course of the Rhone river, from its source in the Rhone Glacier to the Lake of Geneva near Montreux.