Are water resources in the western Himalaya sensitive to global warming?

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The world has warmed by 0.74°C over the last century according to the latest report from the Intergovernmental Panel on Climate Change[1]. However, this warming has not been globally uniform. The high latitudes of the Northern Hemisphere have been disproportionately affected and reconstructions of past temperatures suggest that the late 20th century warming is unprecedented[2]. In addition, all climate models predict a warming trend due to rising levels of greenhouse gases in the atmosphere. Substantial impacts are predicted for snowmelt-dominated regional water resources such as those in the Himalaya[3].

The confluence of the Rivers Indus and Gilgit, Pakistan (David Archer)

In general, it is thought that the warming of global temperatures will cause an 'intensification' of the hydrological cycle – increasing rainfall and snowfall and thus, perhaps, water availability. However, in snowfall-dominated regions where summer water resource availability is related to winter snowfall and summer melt, changes in temperature may have more complex impacts upon water supplies. More than one-sixth of the Earth's population rely on glaciers and seasonal snow packs for their

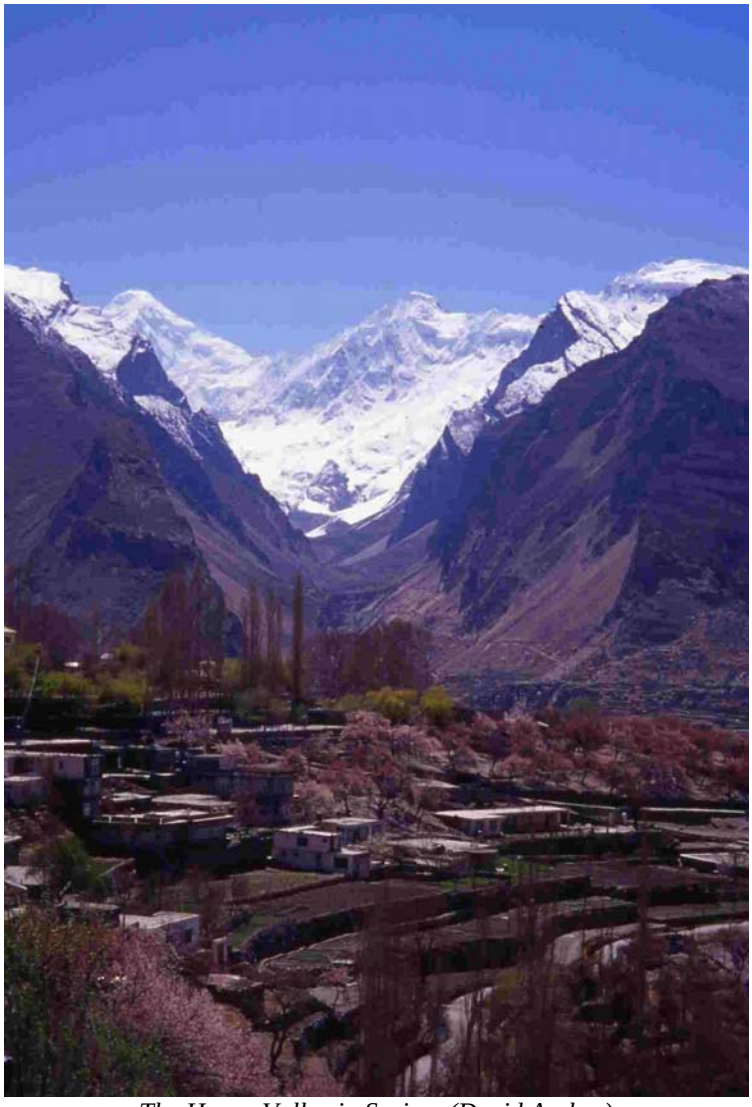
[1] IPCC (Intergovernmental Panel on Climate Change) 2007: Climate Change 2007:The Physical Science Basis, Cambridge University Press, Cambridge CB2 2RU, UK

[2] Jones, P. D. & Moberg, A. 2003: Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. *J. Climate*, **16,** 206-223.

[3] Barnett, T. P. & Pennell, W. 2004. (eds) Impact of global warming on Western US water supplies. *Climatic Change*, **62** (Spec. Vol.)

water supply. A warmer world may mean lower accumulations of snow in the winter and earlier and more extensive melting in the summer months[4]. In some regions this already appears to be happening[5].

The Hindu Kush-Himalaya (HKH) region provides a critical source of water for 50 to 60% of the world's population in India, China, Pakistan and parts of Asia. The ice mass in the region is the third largest on Earth, and melting snow and ice form the key source of water to the region's rivers in summer months: as much as 70% of the summer flow in the Ganges and 50 to 60% of flows in the other major rivers. The Himalayas may therefore be one of the most sensitive areas to global warming as change in temperature has a more marked effect on hydrology and water availability in snow-dominated areas than changes in precipitation[4].



The Hunza Valley in Spring (David Archer)

Most of the world's mountain glaciers have been shrinking for at least the last thirty years[6], including those in the neighbouring Greater Himalaya, and China. The entire

[4] Barnett, T.P., Adam, J.C. & Lettenmaier, D.P. (2005) Potential impacts of a warming climate on water availability in snow-dominated regions, Nature 438, 303-309.
[5] Mote, P. W., Hamlet, A. F., Clark, M. P. & Lettenmaier, D. P. Declining mountain snow pack in western North America. Bull. Am. Met. Soc. 86, 39–49 (2005).
[6] World Glacier Monitoring Service. 2000. Glacier mass balance data 1998/99 (www.geo.unizh.ch).

HKH ice mass is estimated to have decreased in the last two decades and the rate of melting seems to be accelerating[7]. However, widespread expansion of larger glaciers is reported[8] for the Central Karakoram, accompanied by an exceptional number of glacier surges. This contrast in the behaviour of glaciers suggests a pattern of climatic change in Karakoram and Hindu Kush different from that in the Greater Himalaya or, indeed, the rest of the world.

Our research in the HKH region suggests that there have been increases in winter, summer and annual precipitation (rain or snow fall)[9], increases in winter temperatures and cooling of summer temperatures[10] since 1961. Many of these trends are statistically significant and the findings are important as trends in temperature, rain and snow in the HKH also impact on the water availability for more than 50 million Pakistani people. Indeed, these trends have combined to reduce summer water availability in the region[11] and may have caused the recent expansion of large glaciers. The amount of summer 'runoff' in the region's rivers depends on the elaborate interplay of weather conditions. One third of the runoff – that which comes from the higher mountain regions – is largely dependent on the temperature in the summer. Specifically, the fall of one degree centigrade in mean summer temperature since 1961 is thought to have caused the observed 20 per cent decrease in runoff into the higher mountain rivers. Yet two-thirds of runoff – that from the lower mountain regions – is dependent on the amount of snow falling in the previous winter. Heavy winter snowfall is followed by a greater volume of summer runoff.

Hunza Valley in Winter (David Archer)

[7] Meier, M. & Dyurgerov, M. 2002. Deciphering complex changes in snow and ice. *Science* **297**, 350–-351.
[8] Hewitt, K. 1998. Glaciers receive a surge of attention in the Karakoram Himalaya. *EOS Transactions, American Geophysical Union* **79/8**, February 24, 104-105.
[9] Archer, D. R. and H. J. Fowler, 2004: Spatial and temporal variations in precipitation in the upper Indus basin, global teleconnections and hydrological implications. *Hydrol. Earth Syst. Sci.*, **8**, 47-61.
[10] Fowler, H.J. and Archer, D.R. 2006: Conflicting signals of climatic change in the Upper Indus Basin. *J. Climate*, **19**, 4276–4293..
[11] Fowler, H.J. and Archer, D.R. 2005. Hydro-climatological variability in the Upper Indus Basin and implications for water resources. In: Wagener, T. et al. (Eds.) *Regional Hydrological Impacts of Climatic Change – Impact Assessment and Decision Making*, **IAHS Publication 295**, pp. 131-138.

Melt water from the previous winter's snow and existing glaciers supplies water for the summer runoff which feeds irrigation both in the mountains and in the plains of Pakistan. The vast Indus Basin Irrigation System is the mainstay of the national economy of Pakistan, which has 170,000 square kilometres of irrigated land, an area greater than the size of England and Wales combined. Being able to predict trends in climate and water availability could contribute to more effective, forward-thinking management of the two major dams in the Upper Indus Basin –the Mangla and the Tarbela Dams – and thus allow a better long-term control of water for irrigation and power supplies. These dams have the capacity to produce around 5,000 Megawatts of electric power.

Very little research has been carried out in the HKH region to date. Yet the findings from our work have implications for the water supplies of around 50 million people in Pakistan who are dependent on melt water from seasonal snowfall. Our research suggests we may be able to predict in advance the volume of summer runoff, which is very useful in planning ahead for water resources and also the output from the dams. A 2005 Nature article[4] concluded that the HKH region is "*headed for a water supply crisis*" due to the potential impacts of a warming climate on water availability in this snow-dominated region. It is suggested that "*better water management techniques can help, but cannot solve the problem without significant changes to agriculture, industry and lifestyle. Detailed studies of the future impact of global warming on water resources in [this region] are long overdue."*[4]

Hushe result of GLOF (David Archer)

The River Hushe at Kande: a glacial outburst flood in 2000 destroyed the village of 124 houses. This is the village school covered in debris - luckily no-one was killed from the village as they heard the water thundering down the valley and escaped up the valley sides.

It is hoped that our research will help us to understand the impacts of global warming and provide practical solutions for seasonal forecasting of water resource availability for the HKH region of Pakistan. Information on year by year climatic variability is perhaps more important for the current management of the water resource system as it helps forecast inflow into reservoirs and allows for better planning of water use for irrigation. However, information on the impacts of climatic change is important for the longer term management of water resources and to help us understand what is happening in the mountains under global warming. *"Time is running out for nations in sensitive areas, particularly those whose water supplies are dependent on mid-latitude glaciers, to understand just what the future might hold for them."*[4]

Locals helping with the study of the glacial outburst flood (David Archer)