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Glacial retreat in the Baspa basin, Himalaya, monitored with satellite stereo data

The Himalaya contain one of the largest concentrations of glaciers outside of the polar regions. Meltwater from these glaciers forms an important source of run-off in northern India during the summer months. This run-off is likely to change, as extensive glacier retreat is reported in the Himalaya and other parts of the world (Dhobal and others, 1995; Holmlund and Fuenzalida, 1995). Himalayan glacier retreat is normally difficult to study due to the rugged, mountainous terrain, but remote sensing offers a useful tool that can be used to assess information about glacier features such as accumulation area, snowline and moraine-dammed lakes (Kulkarni, 1991). In this investigation, glacial retreat was estimated using high-resolution (5.8 m) stereo data from the Indian Remote Sensing Satellite-1C for the Baspa basin, a tributary of the Satluj River (Fig. 1).

An ortho-image is a map-aligned satellite image corrected for height distortion. The raw images contain geometric distortions due to satellite orbit, altitude variations, sensor geometry, tilt angle and terrain relief, but we correct for these distortions using ground-control points (GCP). GCP are stable ground features, which can easily be identified on topographic maps and satellite images. Digital photogrammetric techniques were used to generate a digital elevation model and ortho-images from raw images and the GCP.

Monitoring of glacier advance and retreat requires correct identification of the glacier snout. The snout is often an abrupt ice wall that can easily be identified when the glacier is viewed in a satellite stereo pair. Once identified, its location can be transferred to a topographic map by relating the snout position to nearby streams, lakes or other features. Snout positions for this study were verified with field observations carried out at Shaune Garang glacier.

The positions of glacier snouts for 1997–98 and 1962–63 were obtained from satellite images (Fig. 2) and Survey of India maps, respectively. All eight glaciers studied in the Baspa basin (Table 1) were in retreat. Retreat varied from 90 to 923 m. The lowest amount (90 m) was observed at Bilare Bange glacier, a small, low-altitude glacier. On satellite images it has a rough texture suggesting an extensive debris cover. Excessive debris can retard melting and protect a glacier from retreat (Colbeck, 1988). Heavy debris cover makes small glaciers in the Himalaya less sensitive to climate change, in contrast to the Alps and Trans-Himalaya, where small glaciers react more quickly to changes in mass balance and climate change (Ding and Haeberli, 1996).

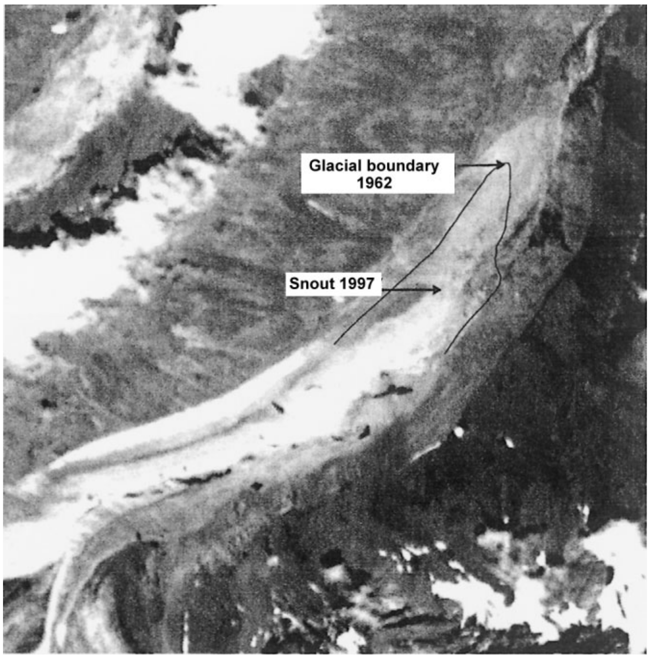

Fig. 2. Retreat of Janapa Garang glacier.

Medium-size glaciers such as Naradu and Shaune Garang retreated 550–923 m. The mass balance on these glaciers is influenced by their area–altitude distribution. From 1987 to 1995 the equilibrium-line altitude (ELA) for Naradu glacier was 5030 m and its accumulation–area ratio (AAR) was 0.71, while the lower-altitude Shaune Garang glacier had an ELA of 4740 m and an AAR of 0.42, leading to a faster retreat rate on the lower glacier. Large glaciers such as Jorya Garang and Baspa Bamak retreated even less (425 and 380 m) than the medium-sized glaciers.

This study suggests that the $0.6 \pm 0.2^{\circ}C$ increase in global

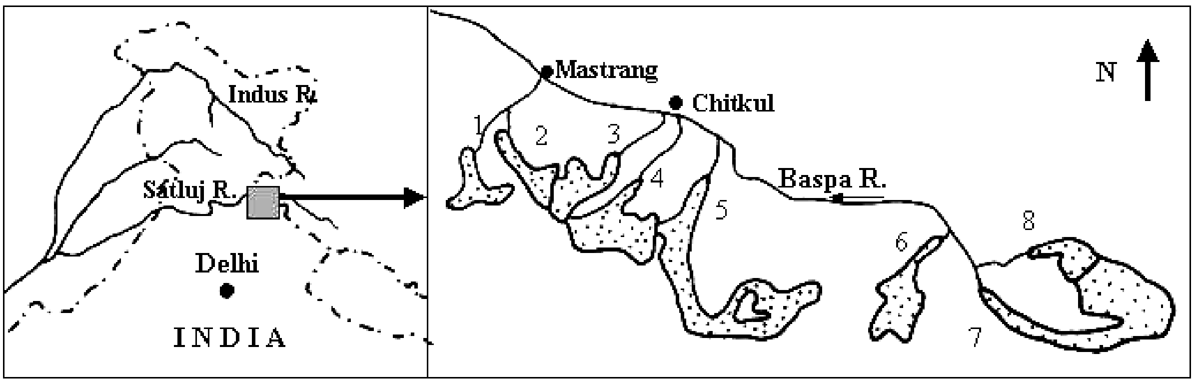

Fig. 1. Baspa basin and glaciers. 1, Shaune Garang; 2, Bilare Bange; 3, Naradu Garang; 4, Janapa Garang; 5, Jorya Garang; 6, Karu Garang; 7, Baspa Bamak; 8, 53I11008.

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Table 1. General characteristics and retreat of glaciers in the Baspa valley

Glacier	*Area*	*Max. length*	*Max. altitude*	*Altitude of snout*		*Retreat*
				1962	*1997–98*	
	km^2	km	m			m
Bilare Bange	2.8	5.05	5000	4240	4255	90
Naradu Garang	6.5	6.75	5400	4320	4360	550
53I1008	7.3	5.5	–	4860	4900	585
Karu Garang	7.4	5.75	5600	4570	4660	800
Shaune Garang	8.8	6.35	5280	4370	4420	923
Janapa Garang	12.3	6.95	5600	4200	4250	696
Baspa Bamak	32.8	15.65	–	4320	4350	380
Jorya Garang	42.7	11.30	5800	4160	4220	425

temperature of the last century (Houghton and others, 2001) has started to affect glaciers in the Himalaya. The rate of retreat is influenced by glacier size, area–altitude distribution and debris cover. In addition, the investigation has shown that satellite stereo data and ortho-images are useful for monitoring glacier retreat.

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