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# APPLICATION OF DIGITAL ELEVATION MODEL AND ORTHOIMAGES DERIVED FROM IRS-1C PAN STEREO DATA IN MONITORING VARIATIONS IN GLACIAL DIMENSIONS

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**ABSTRACT**

An attempt has been made to study variations in the glacier extent over a period of time using digital elevation model (DEM) and orthoimages derived from IRS-1C PAN stereo pairs of 1997-98 and topographical map surveyed during 1962-63. DEM and orthoimages have been generated using integrated software developed for processing of IRS1C/1D panchromatic stereo data using the softcopy photogrammetric workstation. Case studies of two glaciers, i.e. the Janapa garang and Shaune garang glaciers of the Basapa basin, a sub-basin of Satluj River in India, have been presented here. Generation of DEM has been followed by the estimation of its accuracy. PAN images were interpreted for identification of the snout of the glaciers. The geographical locations of the snouts on the images were compared with the location as mapped on the topographical map of the study area. To verify satellite observations, field investigations were carried out at Shaune garang glacier area. The Janapa garang and the Shaune garang are observed to have retreat of 596m and 923 m respectively. Reduction in the thickness of ice in the deglaciated part of the Shaune garang glacier was estimated on the basis of change in the elevations of the glacial surface from 1963 to 1998.

## Introduction

Indian Remote Sensing satellites IRS 1C and 1D carry onboard a pushbroom linear CCD scanner camera in panchromatic mode capable of providing high-resolution i.e. 5.8 m imagery of the earth surface. This camera can be steered up to 26° across track on either side of orbit. Thus by acquiring imagery of the same ground area from multiple orbits due to oblique viewing capability of PAN payload, a stereoscopic coverage can be obtained. Using this tilting mechanism of the camera stereo pairs can be acquired for the required area. Terrain height profiles can be generated by using a suitable software for

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processing of stereo data (Rao *et al.*, 1996; Srivastava *et al.*, 1996; Al-Rousan *et al.*, 1997). The IRS1C and 1D missions thus provide both plannimetric and elevation information.

The plannimetric and elevation information of a glacier snout can be used in monitoring the retreat or advance of glaciers. The retreat or advance of glaciers closely depends upon the conditions of replenishment of accumulation of snow and the intensity of ablation or melting (Sugden and John, 1976; Paterson, 1994). In case of equilibrium between replenishment and ablation, the position of the lower boundary of a glacier becomes stationary and the dimensions of the glacier remain more or less constant. If the rate of accumulation increases while melting and evaporation remain unchanged the glacier advances and its dimensions increase. Such glacier is said to be advancing. The picture is reversed when replenishment diminishes and wastage increases. In that case the glacier will grow shorter until the snout (the front end of glacier) reaches a stationary position corresponding to new equilibrium of replenishment and ablation. This is known as retreat of glacier.

An attempt has been made to study variations in glacier extent over a period of time using DEM and orthoimages derived from IRS-1C PAN stereo pair of 1997 and 1998 and Survey of India (SOI) topographical map surveyed during 1962-63. Orthoimages are important for measurements of geographical positions in highly undulating terrains because of plannimetric and vertical distortions (Ganas and Athanassiou, 2000).

## Data and Methodology

Case studies of two glaciers i.e. the Janapa and Shaune garang glaciers of Basapa basin, a sub-basin of Satluj river in India (Fig. 1), have been presented here. The glaciers can be identified on SOI topographical map No. 53I/7. Two stereo pairs of IRS 1C PAN images were utilised for this work. Specifications of stereo pairs have been given in table 1.

**Table 1:** Specifications of IRS PAN stereo data covering parts of Basapa valley, Himachal Pradesh

| Glaciers | Janapa garang glacier | | Shaune garang glacier | |
|---|---|---|---|---|
| Stereo images | Left Image | Right Image | Left Image | Right Image |
| Path-Row | 97-49 | 96-49 | 97-49 | 96-49 |
| Sub-scene | A5 | B5 | A5 | B5 |
| Dates | 20-07-97 | 14-10-96 | 20-07-97 | 29-09-98 |
| View angle | -15.961900 | 2.2360 | 15.961900 | 7.336000 |

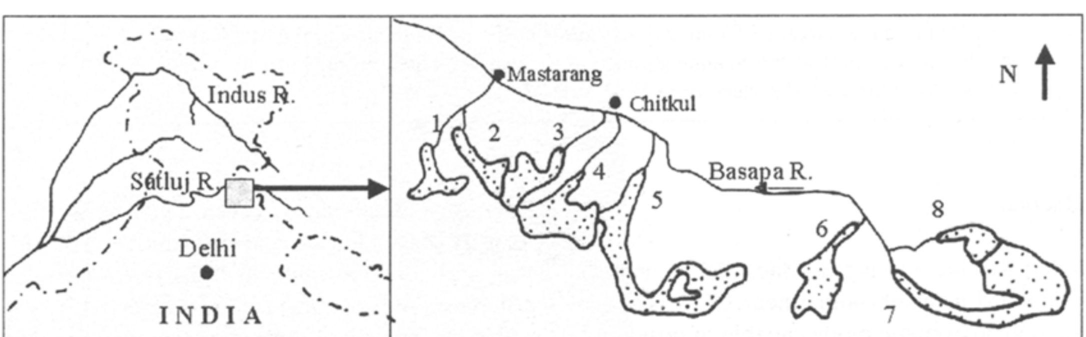


**Fig. 1.** Location of Janapa and Shaune garang glaciers with respect to a few other glaciers of Basapa valley; 1-Shaune garang, 2-Bilare bange, 3-Naradu garang, 4-Janapa garang, 5-Jorya garang, 6-Karu garang, 7-Basapa bamak, 8-A tributary glacier of Basapa bamak.

### DEM and Orthoimage Generation

DEM and orthoimages have been generated using integrated software developed for processing of IRS1C/1D panchromatic stereo data in digital mode using the softcopy photogrammetric workstation (Gopalakrishna *et al.*, 1998; Srivastava *et al.*, 1998). This package uses a semiautomatic mode of operation for deriving DEM. It requires identification of few GCPs based on which initial orientation of six orbital elements is updated using the collinearty conditions which state that perspective center, image point and corresponding ground control point lie in straight line at the time of imaging. The coordinates of the points can be computed in the object space using inverse collinearty equations. Each image point in the overlapping images defines a ray from each image intersecting at a point at an object point. Space intersection generates an irregular grid of DEM at conjugate points determined by automatic matching process. In order to compute heights at regularly spaced grid points of specified interval a height interpolation is to be performed. Interpolation an algorithm in the model is based on weighted average technique in which weights are calculated for each neighborhood points of the unknown depending upon the Euclidean distance. After getting a regular grid of DEM a median filter is applied to remove spurious peaks of heights. The median threshold can be set externally depending on the height variations of the area under considerations.

### Interpretation of PAN Data

Monitoring of the glacier advance and retreat needs correct identification of the glacial snout on the images. The snout is normally associated with ice wall and it produces elevation difference. This difference is normally abrupt and it can be seen on three-dimensional perception using stereo coverages. The location of glacial snout on the images was also confirmed based on the clues from associated features such as location of origin of stream from glacier and occurrence of moraine-dammed lake(s) apart from tonal and textural differences. Field investigations were carried out at the Shaune garang glacier to validate these observations.

### Accuracy Estimation

A set of GCPs for the model has been generated from SOI topographical maps (Everest datum) at 1:50000. Since there are no or rarely any cultural features in high altitude region, GCPs were based mainly on intersections or sharp bends of streams. Elevations of the GCPs were based on interpolated values with in elevation contours of 40-meter interval (table 2). Contour interval of non-hilly region in topographical map is 20m. Since the present study involves change detection, it is essential to find out accuracy of estimation of elevations with respect to SOI topographical maps. Accuracy estimation of DEM has been carried out by comparing coordinates in the nonglaciated part of the valley. In order to check plannimetric accuracies, co-ordinates were compared for the identified features on the image and map. Elevations from DEM were checked for corresponding points on the map. GCPs with minimum RMS errors have been taken as base for the model.

**Table 2:** GCP model error of DEMs generated for Janapa arang glacier and Shaune garang glacier

| **Janapa garang glacier** | | | |
|---|---|---|---|
| **GCPs** | **Easting (m)** | **Northing (m)** | **Height (m)** |
| 1 | 13.06 | 9.01 | -21.15 |
| 2 | 11.52 | 53.62 | 3.01 |
| 3 | -32.38 | -49.56 | -8.32 |
| 4 | -4.80 | 12.71 | 32.10 |
| 5 | -21.73 | -17.71 | -2.35 |
| 6 | 34.24 | -7.90 | 1.52 |
| **RMSE** | **23** | **32** | **16** |
| **Shaune garang glacier** | | | |
| **GCPs** | **Easting (m)** | **Northing (m)** | **Height (m)** |
| 1 | 3.72 | 21.36 | 3.38 |
| 2 | 32.03 | 26.24 | -2.26 |
| 3 | -3.80 | -4.99 | -10.56 |
| **RMSE** | **26.88** | **35.5** | **8.88** |

***Retreat of Glaciers***

The geographical location and altitudes of snouts of the two glaciers derived from stereo data based DEM with respect to location mapped in SOI topographical map surveyed during 1962-63 were compared to estimate retreat. Points lying on contours between snout position of 1998 and 1963 were also compared and corrected for mean difference in the elevation of the DEM and topographical map. The change in thickness of ice could be studied by comparing the elevation profiles in the deglaciated valley of glacier derived from stereo data based DEM and the SOI topographical map.

**Results and Discussion**

It has been observed that DEM and orthoimages generated using stereo pair are highly useful for glacial studies. GCP model error and image matching (Gopalakrishna, 2000) determine the accuracy of DEM. For image matching, the acquisition of the data should be carried out during end of ablation period i.e. September month. During this period snow cover is at minimum. Snow cover causes poor image matching due to saturation of radiance over snow-covered regions. Therefore DEM was generated for smaller areas having more area of ice and non-glaciated terrain and less area of accumulation zone (snow covered). In the present study DEM was generated for parts of valley of individual glaciers instead of taking all the area of overlap of two images.

Comparison of elevations for points lying on contours outside the deglaciated valley of two glaciers is indicative of differences of elevation ranging from 0 to 30m, however, in most of the instances it is up to 15m (table 3). In all the cases a positive bias has been observed which may be due to difference in the datums of the two sources of elevations.

**Table 3:** Comparison of elevation for checkpoints derived from stereo data based DEM and SOI topographical map

| Check Points | Elevation Map (m) | Elevation DEM (m) | Error (m) |
|---|---|---|---|
| Janapa garang glacier area | | | |
| 1 | 4240 | 4339 | -1 |
| 3 | 4240 | 4250 | +10 |
| 4 | 4240 | 4247 | +7 |
| 5 | 4240 | 4240 | 0 |
| 6 | 4240 | 4242 | +2 |
| 7 | 4200 | 4200 | 0 |
| 8 | 4200 | 4205 | +5 |
| 9 | 4160 | 4191 | +31 |
| 10 | 4120 | 4138 | +18 |
| 11 | 4120 | 4138 | +18 |
| 12 | 4120 | 4125 | +5 |
| Shaune garang glacier area | | | |
| 1 | 4200 | 4209 | +9 |
| 2 | 4240 | 4240 | 0 |
| 3 | 4240 | 4240 | 0 |
| 4 | 4280 | 4299 | +19 |
| 5 | 4280 | 4287 | +7 |
| 6 | 4280 | 4280 | 0 |
| 7 | 4320 | 4334 | +14 |
| 8 | 4320 | 4321 | +1 |
| 9 | 4320 | 4321 | +1 |
| 10 | 4360 | 4375 | +15 |

The plannimetric measurements of the snout indicate retreat for about 696 m of the Janapa garang and 923 m for the Shaune garang glacier respectively (Fig. 2). The altitude of snout has been observed to be 4250 m and 4420 m for the two glaciers respectively during 1998. The difference in the elevations of glacial surface for Janapa garang glacier show an average change of about 15 m. It indicates the occurrence of 15 m thick ice before deglaciation. It was observed that the Shaune garang glacier had about 35 m thick ice in middle of the valley before deglaciation (Fig. 3). Field verifications in the valley of Shaune garang glacier support this view (Fig. 4). The shape of elevation profile after deglaciation fits well with the shape of a typical glacier valley.

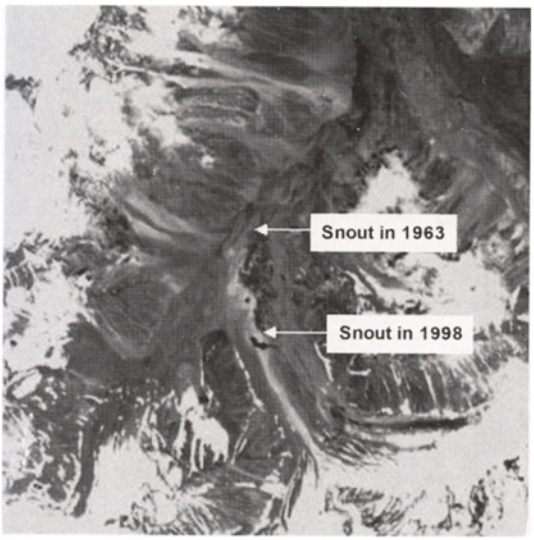


**Fig. 2.** IRS PAN orthoimage showing the position of snout of Shaune garang glacier in 1963 and 1997.

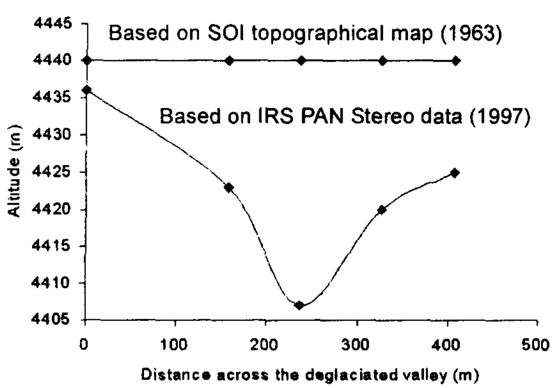


**Fig. 3.** Elevation profiles based on DEM derived from IRS PAN stereo data and corresponding Survey of India (SOI) topographical map of 1962-63 across the deglaciated valley of the Shaune Garang glacier.


**Fig. 4.** Field photograph showing ablation zone and deglaciated valley of the Shaune garang glacier.

An altitude forms an important component of glacier inventory for individual glaciers. Glacier inventory has been carried out according to the system suggested by UNESCO/TTS for world glacial inventory of the International Commission of Snow and Ice (Muller, 1978). The data of inventory is organized in a pre-defined format for individual glaciers. A few of the important features of inventory are altitude of snow line, altitude of snout of glacier, highest altitude of glacier, altitude of moraine-dammed lakes and altitude of moraines, etc. This information is obtained from the SOI topographical maps. Sometimes the maps are very old or otherwise not available. In such a situation stereo data can be used.

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