Discrimination of cloud and snow covered regions using IRS-P3 MOS data

The Indian region is geographically divided into the Himalayan, Indo-Gangetic basin and peninsular regions. The Himalayan region has paramount importance in the economic development of the country. All kinds of natural resources are found here. The high topography of the Himalayan region has direct influence on the dynamics of the weather conditions. The major rivers originating from the Himalayan region are the sources of surface and ground water specially for people living in the Indo-Gangetic basin. Monitoring and mapping of the Himalayan region on a day-to-day basis is possible using the broad-band remote sensing sensors. The spatial resolution of microwave sensors is poor compared to visible optical sensors. The visible sensors suffer from the problem of cloud cover, specially in high altitude regions such as the Himalayan region. The spectral reflectance of snow, ice, cloud, vegetation and bare ground have distinct behaviour. However, due to the presence of cloud, the information from the snow, ice, vegetation and bare ground is masked by the high reflectance of the cloud. The effect of the cloud[1] can be distinguished in the Short Wave Infrared (SWIR) band.

The Institute of Space Sensor Technology of the German Aerospace Centre (DLR) has developed a Visible/Near Infrared (VIS/NIR) imaging Spectrometer, named Modular Optoelectronic Scanner (MOS)[2,3], launched on 21 March 1996 on-board the Indian Remote Sensing satellite IRS-P3 (ref. 4) into a sun-synchronous polar orbit at 817 km. MOS sensors consist of two separate imaging spectro-radiometers MOS-A (4 bands) and MOS-B (13 bands) in the VIS and NIR and a CCD-line camera MOS-C (1 band) in the SWIR. The details of MOS-A, B and C sensors[5] are given in Table 1.

Data recorded by MOS are stored as 16-bit digital numbers. The radiance L_{ij} measured by the MOS sensor for a pixel i in channel j is given by Neumann *et al.*[5] as

$$L_{ij} = (U_{ij} - Uo_{ij})f_{ij}k_j, \qquad (1)$$

where i is the pixel number in scan line, 1:140 for MOS-A, 1:384 for MOS-B and 1:300 for MOS-C; j is the channel number (wavelength), 1:4 for MOS-A, 1:13 for MOS-B and 1 for MOS-C; U_{ij} is the readout pixel value (in digital count); Uo_{ij} is the dark value (in digital units, measured during calibration phase); f_{ij} is the sensitivity correction factor; and k_j is the calibration factor.

In level-1B file, the dark-value corrected pixel values multiplied by the sensitivity correction factor $[(U_{ij} - Uo_{ij})f_{ij}]$ is stored as 16-bit digital number (unsigned short format). The calibration factor k_j for each channel of MOS-A, B and C is written in the file header provided by NRSA, Hyderabad behind the keywords ACAL_VAL and BCAL_VAL in the order of the channel numbers. These coefficients are constant up to now from the beginning of the mission. So, multiplying the DN values with the calibration coefficient, one can easily obtain the radiance values. From the radiance values, reflectance is computed using the following equation[5]

$$R_{ij} = [\pi L_{ij}]/[\cos \theta_s e_{0ij}], \qquad (2)$$

where R_{ij} is the reflectance; L_{ij} is the radiance; θ_s is the solar zenith angle; and e_{0ij} is the solar irradiance.

Values of θ_s and e_{0ij} of central pixel of each sub-scene have been provided with the data. The values of θ_s and e_{0ij} for each pixel are assumed to be constant. In Figure 1, colour composite image (Figure 1 *a*) of MOS-B (channels 11, 8 and 7) has been compared with MOS-C (Figure 1 *b*) image (channel 1–1600 nm). After various combinations of channels, we have found colour composite image of channels 11, 8 and 7 giving sharp features to study bare ground, vegetation, snow and cloud surfaces. Figure 1 *a*, *b* represents an area in the Himalayan region, the coordinates of the four corners of the image are shown in

Table 1. Modular Optoelectronic Scanner (MOS)

Parameters	MOS-A	MOS-B	MOS-C
Spectral range (nm)	755–768	408–1010	1610
No. of channels	4	13	1
Wavelength (nm)	756.6	408.0	1600
	760.6	443.6	
	763.5	484.6	
	766.3	520.8	
		570.5	
		615.3	
		650.3	
		685.3	
		749.7	
		814.1	
		868.3	
		942.5	
		1011.1	
Spectral half-width (nm)	1.4	10	100
FOV along track (deg)	0.344	0.094	0.14
FOV across track (deg)	13.6	14.0	13.4
Swath width (km)	195	200	192
No. of pixels	140	384	299
Spatial resolution (m)	1570 × 1400	520 × 520	520 × 640
L_{min} ($\mu W cm^{-2} nm^{-1} sr^{-1}$)	0.1	0.2	0.5
L_{min} ($\mu W cm^{-2} nm^{-1} sr^{-1}$)	40	65	18
Quantization	16 bit	16 bit	16 bit
In-flight calibration	Internal lamp	Internal lamp and sun calibration	

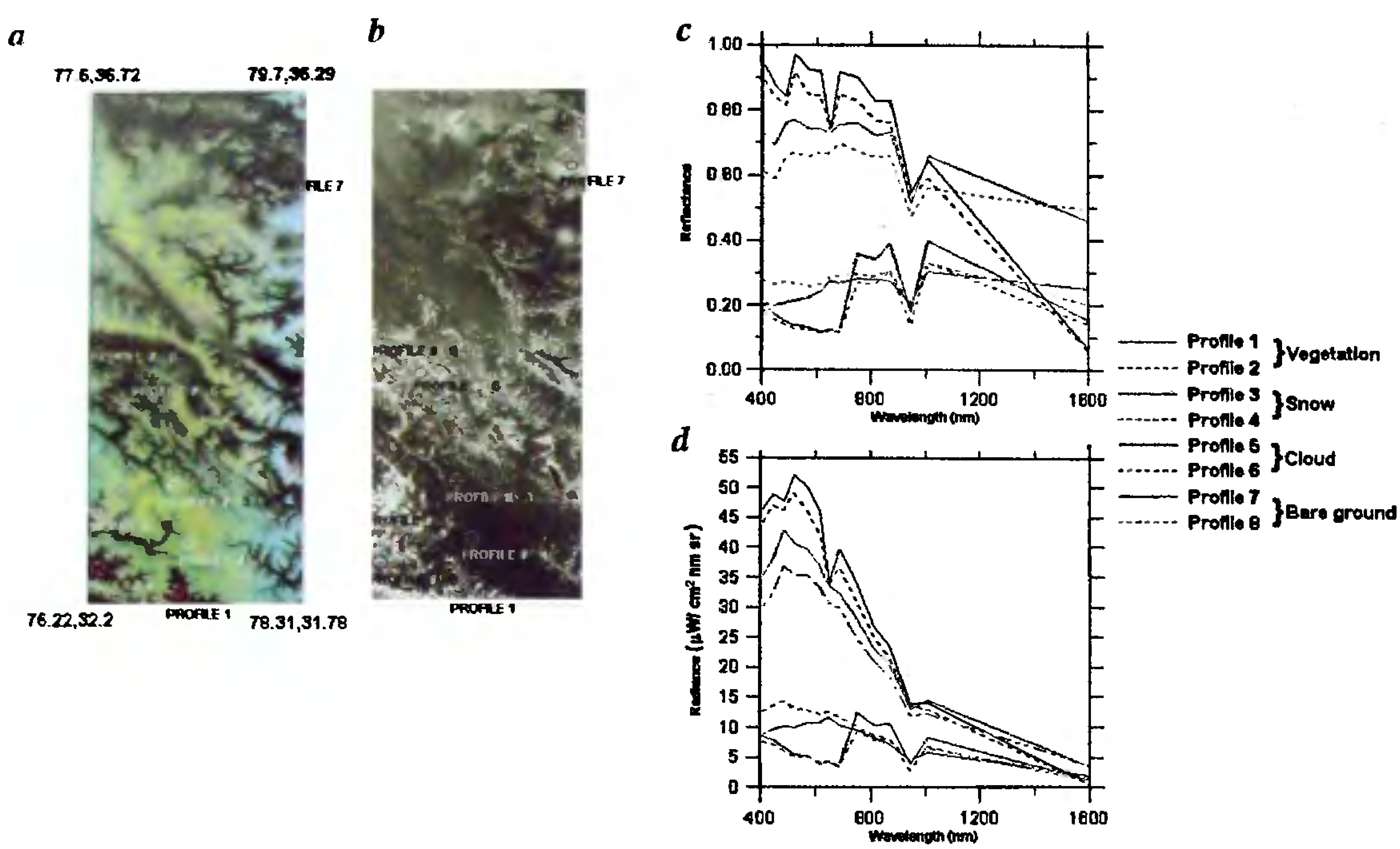

Figure 1. ***a***, Colour composite image of MOS-B (band 11, 8 and 7); ***b***, MOS-C image (band 1–1600 nm); ***c***, Spectral reflectances of snow, cloud, vegetation and bare ground; and ***d***, Spectral radiances of snow, cloud, vegetation and bare ground.

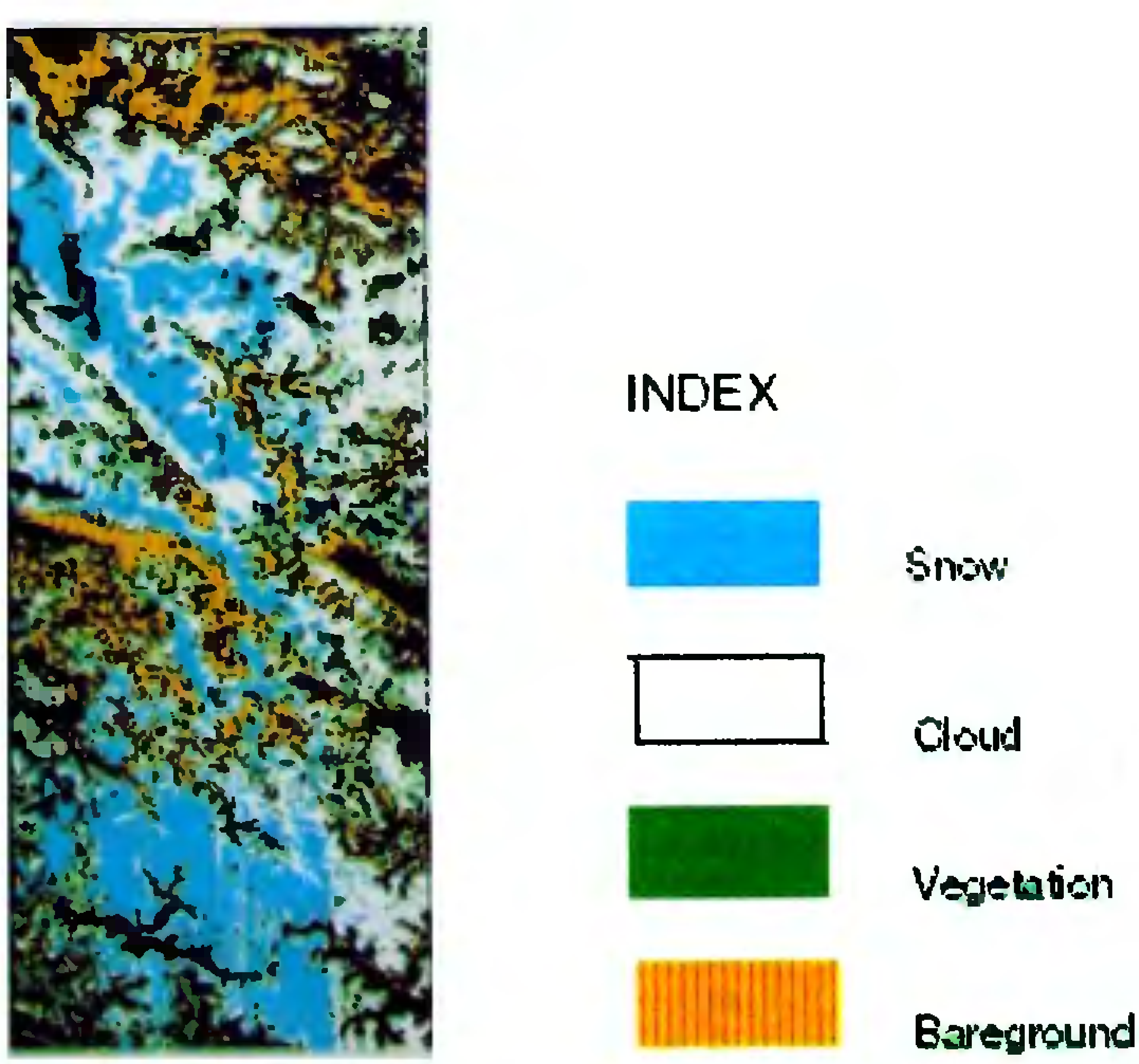

Figure 2. Classified image showing four different classes (snow, cloud, vegetation and bare ground).

Figure 1 *a*. This image is extracted from the full take scene along the path 95 taken on 11 May 1998. The reflectances and radiances at various sites covered with snow, vegetation, cloud, and bare ground have been extracted and are shown in Figure 1 *c*, *d*, respectively. From the texture of the two images, it is clearly seen that the area is covered by the mountain. In the colour composite image (Figure 1 *a*), the red tone reflects vegetation cover. The white patches seen in Figure 1 *a* do not differentiate snow cover from cloud cover. The bare ground is seen with dark tone, which is easily mapped using colour composite image if the cloud cover is not present. However, in the MOS-C image at 1600 nm, snow reflectance is lower than those for land, therefore snow cover is seen darker in the MOS-C image (Figure 1 *b*) than that of cloud cover which has high reflectance, almost nearly the same as in the colour composite image (Figure 1 *a*). Figure 1 *c*, *d* shows the characteristic behaviour of spectral reflectance of snow, cloud, vegetation and bare ground. Higher radiances and higher reflectances over cloud and snow are seen compared to those over vegetation and bare ground in the VIS ranges. In the SWIR (1600 nm) the higher reflectance contrast between cloud and the rest of the surfaces (snow, cloud and bare ground) is seen. In Figure 2, we have shown a classified image of the area. The image has been classified using Maximum Likelihood Supervised Classification method from MOS-B data. In the classified image, four classes (snow, cloud, vegetation and bare ground) are clearly seen. The reflectance values shown in Figure 1 *d* also confirm the presence of different classes in the image. The present study shows that using MOS-B colour composite image, MOS-C image and spectral reflectance values, reliable mapping of snow cover region can be carried out.

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