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Timberline change detection using topographic map and satellite imagery: a critique

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Abstract: Remote sensing is a valuable tool for geo-spatial bio-resource mapping and monitoring land use / land cover changes. Change detection using remote sensing, especially in the rugged mountains such as higher Himalaya, requires a series of careful steps including selection of appropriate methodology and sufficient ground knowledge. Based on remote sensing techniques a recent study by Panigrahy *et al.* (2010) reported an upward shift of timberline vegetation by 300 m and a considerable reduction in snow cover in Nanda Devi Biosphere Reserve (NDBR), Garhwal Himalaya. Their study has overlooked a number of methodological issues and misinterpreted some of the vegetation classes. In this communication we provide a brief critique on the methodology adopted by these authors and suggest certain precautions while undertaking change detection studies in the Himalayan region using remote sensing techniques.

Resumen: La percepción remota es una herramienta valiosa para el mapeo geo-espacial de recursos bióticos y el monitoreo de cambios de uso y cobertura del suelo. La detección de cambios por medio de percepción remota, especialmente en las montañas escarpadas como los Himalaya superiores, requiere una serie de pasos cuidadosos, incluyendo una selección del método apropiado y suficiente material base. Con base en técnicas de percepción remota, el estudio reciente de Panigrahy et al. (2010) reportó un desplazamiento hacia arriba de la vegetación asociada al límite arbóreo de 300 m y una reducción considerable de la cubierta de nieve en la Reserva de la Biosfera Nanda Devi, Garhwal Himalaya. Su estudio pasó por alto un número de cuestiones metodológicas y malinterpretó algunas de las clases de vegetación. En este trabajo ofrecemos una breve crítica sobre el método adoptado por estos autores y sugerimos ciertas precauciones para la conducción de estudios de detección de cambios en la región de los Himalaya por medio de técnicas de percepción remota.

Resumo: A detecção remota é uma ferramenta valiosa para o mapeamento geo-espacial dos recursos biológicos e monitorização do uso da terra / alterações na sua cobertura. A detecção das mudanças, com o recurso à detecção remota, especialmente nas montanhas agrestes, tais como as zonas cimeiras dos Himalaias, exige uma série de passos cuidadosos, incluindo a selecção de uma metodologia adequada e o conhecimento suficiente do terreno. Com base nas técnicas de detecção remota, um estudo recente de Panigrahy et al. (2010) documenta uma mudança ascendente da linha de vegetação em cerca de 300 m e uma redução considerável na cobertura de neve na Reserva da Biosfera de Nanda Devi (NDBR), Garhwal Himalaias. O estudo daqueles autores negligenciou um certo número de questões metodológicas e interpretou incorrectamente algumas das classes de vegetação. Nesta comunicação apresentamos uma breve crítica à metodologia adoptada por aqueles autores e sugere-se um certo número de precauções a ter quanto se efectuam estudos de alterações na região dos Himalaias com recurso às técnicas de detecção remota.

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Temporal remotely sensed data are extremely valuable for detecting changes in vegetation cover, land use/cover classes, snow, water bodies and other terrestrial features. However, the process of change detection involves a number of methodological considerations such as proper ortho-rectification of remotely sensed data, minimizing errors on account of varying phenophases which influence reflectance / radiometry, and availability of snow/ cloud free images (Roy 2000). In general, a change detection based on remote sensing technique involves image acquisition, data preprocessing, and selection of relevant algorithm and accuracy estimation. According to Coppin *et al.* (2004) acquisition of imagery for appropriate dates, choice of sensor(s) and change detection algorithms are extremely crucial for detecting temporal changes in vegetation. Specific dates or windows are often used to minimize the differences in reflectance caused by seasonal variation in functional attributes of vegetation and differences due to sun angle. Even within anniversary windows, phenological differences due to year to year variation in snow fall and exposition may lead to erroneous conclusions unless sufficient ground information is used for interpretation of images.

Change detection using remote sensing data in the Himalayan region is particularly challenging due to complexity of terrain, phenological constraints, varying aspects and slopes. The last two parameters strongly influence shadows which are major sources of error. Although, there is no suitable method to completely remove the effect of shadows, the error can be minimized with the help of ancillary data, such as Normalized Difference Vegetation Index (NDVI) and Digital Elevation Model (DEM) as additional layers with multispectral bands (Coppin & Bauer 1996; Saha *et al.* 2005). Application of post-classification refinement based on the knowledge of specific land cover classes and topographic factors can also help in minimizing the errors (Lu & Weng 2007).

Recently, Panigrahy *et al.* (2010) have reported an upward shift of timberline vegetation by 300 m in Nanda Devi Biosphere Reserve (NDBR), Garhwal Himalaya since 1960. Based on the analysis of multi-temporal remote sensing data, these authors have also concluded that there is 61 % decrease in snow cover and 23 % increase in vegetation cover between 1986 and 2004 in the above area. We note that the authors have overlooked several methodological issues and made sweeping generalizations. In this communication we point out a few problems in the interpretation of remote sensing data by theses authors and suggest certain precautions while undertaking change detection studies in high altitude vegetation based on such techniques.

Panigrahy *et al.* (2010) have used satellite data of March to detect timberline changes in the sub-alpine vegetation. It is to be noted that birch (*Betula utilis* D. Don), one of the common trees around timberline in this part of Himalaya, is a deciduous species and sprouts only after May (Rawal *et al.* 1991). Hence, satellite data of March is unsuitable to detect scattered birch around timberline ecotone. One of the prominent timberline tree species in other parts of NDBR is high altitude fir, *Abies spectabilis* (D. Don) Spach. Being an evergreen species, this species is easier to detect in the remotely sensed data. The authors could have compared fir patches to see the changes in timberline vegetation. Further, the authors seem to have combined sub-alpine forests with alpine scrub (*Rhododendron - Juniper* community) into a single class of vegetation. Adhikari (2004) has reported extensive patches of alpine scrub in the same locality which does not figure out in the analysis by these authors. The ground truth information from above locality confirms misinterpretation of vegetation types mentioned in the paper (Fig. 1a-f). The authors have not provided sufficient information regarding image preprocessing steps which is considered necessary for any change detection study.

Of the various requirements of preprocessing for change detection, multi-temporal image registration and radiometric and atmospheric corrections are the most important (Lu & Weng 2007). While analyzing the impact of mis-registration on change detection, Townshend *et al.* (1992) concluded that significant variance in pixel values could be avoided using a Root Mean Square (RMS) error of less than 0.2 pixels in case of densely vegetated areas, and a RMS error between 0.5 and 1 pixel was necessary for sparsely vegetated areas. How-

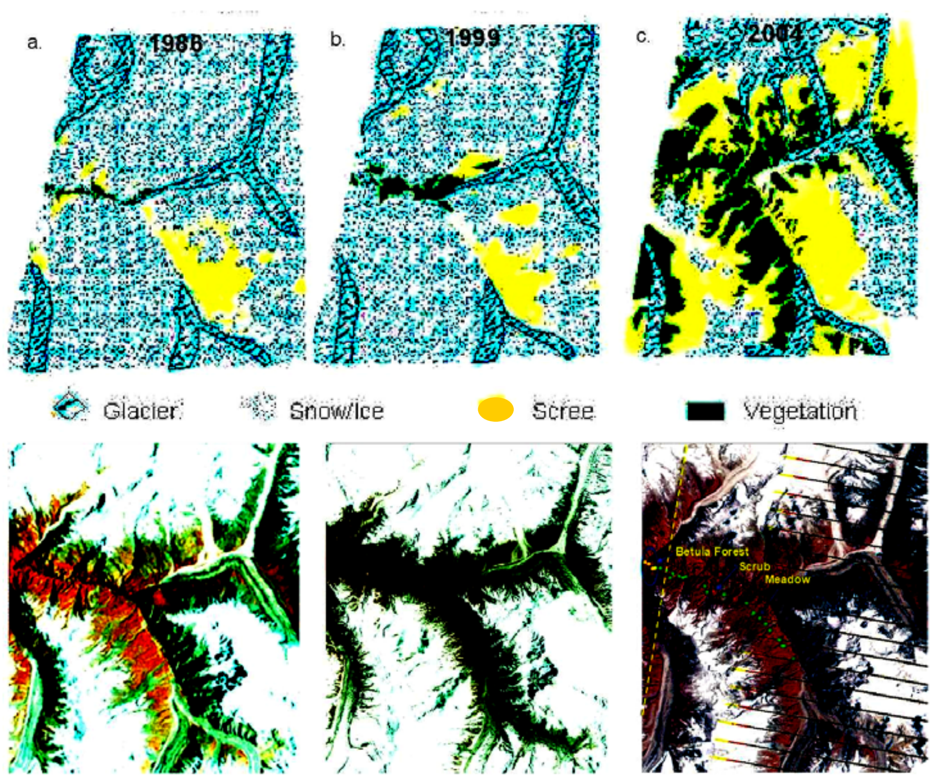

Fig. 1. a-c: Interpretation of alpine vegetation in NDBR by Panigrahy *et al.* (2010); d-f: Landsat images showing vegetation classes (*Betula*, alpine scrub & meadows, Adhikari 2004 which have been overlooked in above study. Dotted line separating the area not included in the above thematic map (f). Note the extent of vegetation (dark red) in image d as compared to a and b.

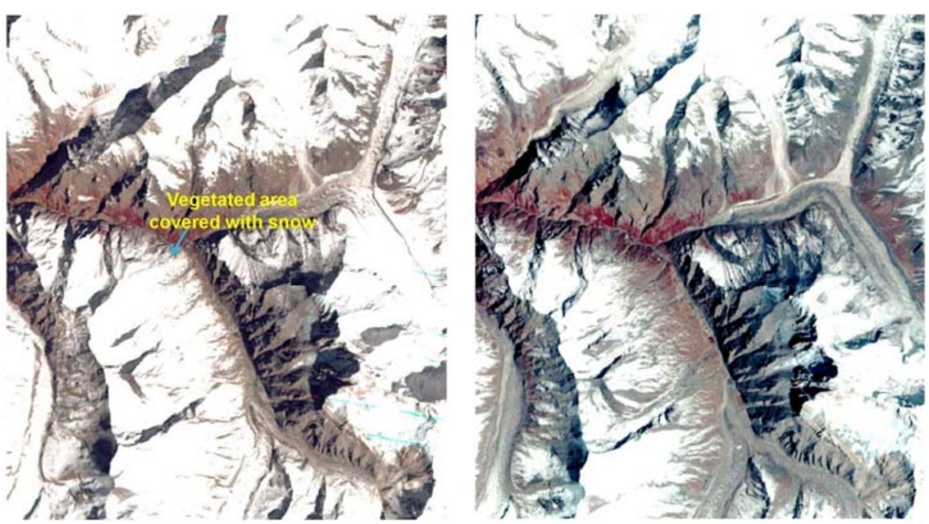

Fig. 2. Monthly variation in snow free areas in alpine zone of NDBR based on Landsat images.

ever, post classification comparison method does not require atmospheric correction, use of dark object subtraction method can be applied to improve the quality of image. To reduce the error due to various atmospheric conditions at different dates of image acquisition conversion of digital number to Top-of-Atmosphere (TOA) reflectance is suggested by Chavez (1996). In the absence of data required for atmospheric correction relative radiometric normalization as suggested by Elvidge *et al.* (1995) can be applied.

Bitemporal change detection using post-classification comparison is one of the most widely accepted methods *albeit,* it has some limitations (Macleod & Congalton 1998; Stow 1995). This is because the comparison of land cover classification for different dates does not allow the detection of subtle changes (Biging *et al.* 1998). The accuracy of post-classification comparison is totally dependent on the accuracy of cover classes. Misinterpretation of land cover classes in combination with image registration error may produce unsatisfactory results leading to erroneous conclusions (Howarth & Wickware 1981). In the referred study, the base map of study area was derived from the topographic map that does not differentiate various categories of sub-alpine and alpine vegetation. Moreover, the authors have not mentioned the classification method (supervised or unsupervised) and the criteria used to define different density classes. The quality of image analysis depends largely on the ecological knowledge such as seasonal patterns of phenological attributes and ecological data (e.g. plant community structure and composition) from sources outside the images (Schneider 2002). The paper in question does not refer to any ground truth verification and accuracy estimation which are integral part of any change detection. Hence, the studies without these components are liable to be questioned. In the absence of ground truth information or geo-referenced data, visual interpretation method as followed by Cohen *et al.* (1998) can be used for accuracy estimation.

There is a great deal of variation in inter and intra-annual snow fall and snow cover in the alpine areas. For example, the Landsat image of June 1980 shows more snow free areas in NDBR as compared to that of 1998 (Fig. 1 d,e). The Landsat images of 1998-2009 also clearly show low snow cover in the above mentioned area during March 2004 (http://edcsns17.cr.usgs.gov/EarthExplorer). It appears that all snow free areas in 2004 have been interpreted as vegetation by Panigrahy *et al.* (2010). This could have also influenced the results on vegetation cover in the study by these authors (Fig 2). It is surprising that the authors did not verify their findings using freely available Landsat images. On the contrary, the TM image used by the authors is not available online. Generalizing the elevation of timberline based on toposheet and comparing with contours derived from Shuttle Radar Topography Mission (SRTM) DEM for change detection as used by Panigrahy *et al.* (2010) can be another source of error. The reported errors in horizontal and vertical accuracies of globally available 90 m SRTM DEM are 20 and 16 m respectively, while in extremely rugged terrain accuracy may decline up to two to four times at higher degree of slopes (Gorokhovich & Voustianiouk 2006). In the referred study, use of digitized contours from toposheet instead of using SRTM DEM derived contours could have given more reliable results.

Given the significance of ecological monitoring in NDBR, core area of which has been designated as national park and World Heritage Site, it would be desirable to use reliable and more robust techniques for change detection. We recommend use of Temporal Trajectory Analysis (TTA) as suggested by Coppin *et al.* (2004) for detecting changes due to different phenophases and suggest detailed (large scale) mapping of major vegetation categories using remote sensing and ground truth verification so that subtle changes in vegetation can be detected in future more accurately.

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