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Proceedings of the 24th Annual Conference and Exhibition of the Remote Sensing Society
The University of Greenwich
9-11 September 1998
MAPPING GLACIATED KARST TERRAIN IN MEDITERRANEAN MOUNTAIN ENVIRONMENTS USING SPOT AND TM DATA

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Abstract: This paper evaluates the utility of both SPOT and TM data for glacial feature mapping in the Pindus Mountains of Northwest Greece. The glaciated part of the study area is dominated by limestone from which the majority of glacial landforms and sediments are derived. Several processing procedures, including band composites, Intensity-Hue-Saturation (IHS) transforms and supervised Maximum Likelihood Classifications (MLC) have been employed. We discuss the results of these and provide an assessment of the glacial geomorphic content of the two images. These results form the basis for some general recommendations for the satellite-based mapping of glaciated Mediterranean mountain environments.
CARTOGRAPHIE DE TERRAIN KARSTIQUE GLACIAIRE DANS LES MILIEUX MONTAGNEUX MÉDITERRANÉENS À L'AIDE DE DONNÉES SPOT ET TM

Résumé : Des essais antérieurs pour dresser la carte de formes terrestres et de dépôts glaciaires à partir d'images satellite ont été pour la plupart effectués avec des données Landsat TM. Par contre les données SPOT ont été rarement utilisées dans ces examens à cause de leurs possibilités spectrales limitées et du coût plus élevé par rapport aux données TM. Cependant, étant donné leur résolution spatiale supérieure, les images SPOT devraient être idéales pour la détection et la cartographie de, par exemple, les formes terrestres glaciaires à petite échelle qui sont caractéristiques des terrains glaciaires dans beaucoup de milieux montagneux européens et méditerranéens. Cet article considère ces problèmes et évalue l'utilité des données SPOT et TM pour le tracé de carte des caractères glaciaires et un survol de reconnaissance dans un milieu montagneux méditerranéen. Le terrain glaciaire en examen est un milieu très karstique dans les Montagnes du Pindos du nord ouest de la Grèce, où l'altitude dépasse localement 2400 m. Cette zone contient une suite de sédiments et de formes terrestres glaciaires du Pléistocène tardif bien conservés comportant des cirques à lit rocheux érodés par la glace et des moraines à crêtes pointues. Nous estimons l'aptitude des données multispectrales SPOT (pixels 20 m) à détecter des formes terrestres individuelles dans ce terrain calcaire caractéristique et comparons ses performances à Landsat TM. L'utilité d'une seule bande et d'images complexes (SPOT et TM) est discutée à partir des résultats de l'interprétation visuelle et de la discrimination des traits et suites de formes terrestres glaciaires individuels. Une stratégie pour la cartographie de terrains glaciaires dans les milieux montagneux méditerranéens est présentée. Des Classification de Probabilité Maximale ont été exécutées à l'aide des données SPOT et TM et les cartes thématiques résultantes comparées et testées quant à leur exactitude vis-à-vis des photographies aériennes et des reconnaissances sur le terrain. Les résultats de l'interprétation des images et des étapes de classification à partir de cette étude sont discutés et plusieurs recommandations générales sont faites pour la télédétection satellite de formes terrestres et de dépôts du Pléistocène dans un milieu montagneux.
1. INTRODUCTION

Many mountain catchments in the Mediterranean region were glaciated during the Late Pleistocene (cf. Messerli, 1967), yet detailed mapping of most of these areas has not been conducted (Woodward, et al. 1995). Satellite imagery offers the potential to improve our understanding of these environments and this paper evaluates the utility of both SPOT and TM data for mapping a glaciated karst terrain in the Pindus Mountains of Northwest Greece. The area under investigation represents one of the most southerly examples of Pleistocene glacial activity in Europe and is therefore of considerable palaeoclimatic significance.

To date, most satellite remote sensing applications in glacial geomorphology have utilised Landsat MSS or TM data (Clark, 1997). Much of this work has employed MSS data in palaeo-ice sheet reconstruction at regional and sub-continental scales where large synoptic coverage and good spectral resolution are essential. In contrast, satellite sensors such as SPOT - which have limited spectral resolution and are comparatively expensive (Sabins, 1997) - have not been widely employed in glacial geomorphological investigations. However, in order to map the much smaller-scale glacial terrains and landforms that are characteristic of the Mediterranean mountains, the finer spatial resolution of SPOT data (20 m with XS) offers practical advantages (cf. Woodward et al. 1995). We have evaluated the utility of both SPOT and TM imagery - both in terms of spectral and spatial resolution - in glacial landform identification and geomorphic mapping in NW Greece.

2. THE STUDY AREA

The study area is an alpine karst environment in the headwaters of the Voidomatis River basin in NW Greece. Several peaks exceed 2400 m and the area has been described in detail in Bailey et al. (1997). Late Pleistocene glacial landforms and sediments including cirques, ice-scoured bedrock pavements, lateral and terminal moraine complexes and extensive scree slopes form an important part of the landscape (Lewin et al., 1991). Glaciated topography is particularly well developed on the mountain slopes in the vicinity of the villages of Tsepelovon (20°49' N, 39°54' E) and Skamnelli (20°51' N, 39°55' E). In common with other mountain ranges in the Mediterranean region, limestone is the dominant lithology and as the glacial sediments and landforms are developed on or from limestone bedrock, their spectral characteristics cover a limited range. Flysch rocks are extensive at lower elevations south of the Voidomatis River beyond the limits of recent glacial activity (Bailey et al., 1997).

3. DIGITAL IMAGE PROCESSING AND MAPPING OF GLACIATED TERRAIN FROM SPOT AND TM DATA

In view of the complexity of terrain and low spectral variability within much of the study area, several Digital Image Processing (DIP) procedures were employed. The results of each procedure and the relative merits of the two data sets are discussed below. All image processing results from the satellite data sets have been verified using 1:30 000 panchromatic aerial photographs and were checked against field observations. DIP procedures were employed to differentiate between the following landscape features:
a) Sharp-crested moraines;
b) Weathered moraines;
c) Scree formations;
d) Flysch bedrock;
e) Ice-scoured bedrock and limestone pavement.

These features were used in the classification procedure discussed in 3.3 below.

3.1 Visual Interpretation Of Single Bands And Composite Images

All SPOT XS bands and non-thermal Landsat TM bands were used in image interpretation. Histogram equalisation stretches were used in the analysis of single bands and band composites to improve visual interpretation of the glaciated terrain.

3.1.1 Individual Spectral Bands

A distinctive suite of steep sharp-crested moraines is present north of the village of Skannelli and these landforms are clearly represented in all three SPOT bands (Figure 1A). This complex comprises a series of sharp-crested lateral and terminal moraines that are largely unweathered and free from vegetation cover. These moraines are clearly defined on the SPOT image, particularly in band 1 (0.50-0.59µm). The TM data, in contrast, do not perform as well in mapping these landforms. The limited lithological variability is expressed by poor image contrast between features, and the fact that landform changes (i.e. moraine spacing) in this area can occur over distances of tens of metres means the 30m resolution TM data is not as effective as the SPOT imagery. In contrast, at lower elevations below the two villages (where tree and shrub cover is much more extensive), discrimination between scree and bedrock surfaces for example, and full detection of weathered and vegetated glacial landforms becomes difficult with the SPOT data. However, all of these features are clear on TM bands 1-5 and 7 (especially within reflected IR bands).

3.1.2 Composite Images

The creation of image composites from the SPOT and TM images has further enhanced the geomorphic target features listed above. In this case the most effective composite image created from SPOT was 2-3-1 (RGB). The TM data allowed more composites to be created and the most useful of these included both reflected IR bands 5 and 7 (i.e. TM combinations 7-5-4, 7-5-3 and 5-4-3).

The finer resolution of the SPOT data proved effective for mapping individual landforms and intra-moraine morphology within the sharp-crested Skannelli moraine complex. While there is limited spectral variation from the 2-3-1 SPOT combination, the finer pixels allow the crests and boundaries of the moraines to be delineated. This is further highlighted by the fact that small recessional and/or readvance features within the Skannelli complex can be mapped with more confidence from SPOT (Figure 1A). The TM data, however, performs poorly in comparison and does not allow such accurate mapping of the fresher non-vegetated landforms (Figure 1B).

However, the TM data does excel in mapping the larger weathered and heavily vegetated moraine systems at lower elevations. This is apparent in the enhancement of two
lateral moraines that extend downslope to the main channel of the Voidomatis River. The
shape and length of these features can be detected from the TM data, whereas the SPOT data
are limited to the detection of highly distinctive creamy-white exposures cut through these
moraines by the local road network (Figure 2A & 2B). Only limited information can be
derived from the SPOT data concerning the shape and size of these landforms.

Figure 1. Sharp-crested moraines above Skamnelli (see Figure 3)
1A SPOT (2-3-1), 1B TM (5-4-3), scenes approx. 1.5 x 1.5 km.

Figure 2. Weathered moraines below Tsepelovon (see Figure 3)
2A SPOT (2-3-1), 2B TM (7-5-3), scenes approx. 1 x 1 km.

3.2 Intensity-Hue-Saturation (IHS)

The IHS transforms were particularly effective in improving the geomorphic content of both
images. This was evident in an improved delineation of the limestone cirques and more clearly defined spectral variation between limestone scree deposits and karst bedrock surfaces. The improved detection of the cirques is partly a result of the strong depiction of scree slopes as the lower cirque headwalls are commonly flanked by extensive scree.

3.3 Maximum Likelihood Classification

A supervised classification was performed using the Maximum Likelihood Classifier (MLC) decision rule. All classes were selected from airphoto analysis and field observations. The classes are: sharp-crested (non-vegetated) moraines; weathered (vegetated) moraines; scree formations; flysch bedrock; and ice-scoured bedrock and limestone pavement. An extra class (cloud and shadowed ground) was used for the classification of the partially cloud obscured SPOT image. SPOT bands 1-2-3 and TM bands 1-5 and 7 were used in the classification procedure, and the results shown in Table 1 and Figure 3.

Table 1. Supervised MLC results of SPOT and TM images

<table>
<thead>
<tr>
<th>Class</th>
<th>SPOT % Image</th>
<th>Class</th>
<th>TM % Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp-crested moraines</td>
<td>13.60</td>
<td>Sharp-crested moraines</td>
<td>15.77</td>
</tr>
<tr>
<td>Weathered moraines</td>
<td>15.46</td>
<td>Weathered moraines</td>
<td>19.80</td>
</tr>
<tr>
<td>Scree formations</td>
<td>03.23</td>
<td>Scree formations</td>
<td>05.21</td>
</tr>
<tr>
<td>Flysch bedrock</td>
<td>33.87</td>
<td>Flysch bedrock</td>
<td>32.89</td>
</tr>
<tr>
<td>Ice-scoured bedrock &amp; limestone pavement</td>
<td>20.54</td>
<td>Ice-scoured bedrock &amp; limestone pavement</td>
<td>26.33</td>
</tr>
<tr>
<td>Cloud</td>
<td>13.30</td>
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<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>100.00</td>
<td>TOTAL</td>
<td>100.00</td>
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</tbody>
</table>

Figure 3. Supervised classification of TM image, scene approx. 8.2 x 8.5 km.
The SPOT and TM scenes provided similar classification results, notwithstanding the cloud cover on the SPOT scene. The supervised classification provides a good overview of the broad glacial geomorphology of the area. However, there is a significant level of misclassification in both SPOT and TM classified images. This is mainly the result of inadequate spectral contrast between different geomorphic landforms and problems commonly associated with pixel-based classifiers. This is shown by the overestimation of percentage image cover for weathered moraines, and several sharp-moraines that were misclassified as limestone bedrock.

4. DISCUSSION

The SPOT and TM data both performed well in the mapping of landforms in this high relief glaciokarst landscape. Interestingly, this preliminary investigation has identified several areas where SPOT outperforms TM data, and vice-versa.

SPOT data are more suited to the delineation of the sharper, non-vegetated glacial landforms while many boundaries between moraine and intra-moraine areas could not be delineated with confidence from the TM data. TM data outperformed SPOT in discriminating between well-vegetated weathered moraines and ice-scoured bedrock surfaces at lower elevations. The spectral capabilities of SPOT did not allow the discrimination of these glacial deposits from non-glacial (vegetated) terrain. IHS transforms were useful in discriminating between scree and ice-scoured bedrock. The MLC results provided valuable maps, although a critical level of misclassification was identified which may be improved upon by access to sub-pixel scale information from soft classifiers such as fuzzy clustering methods or artificial neural networks.

This project has used both SPOT and TM data sets to map a complex glaciated environment in Northwest Greece. Work is in progress to establish the sequence and age of these features. Geomorphic mapping of other glaciated mountain catchments in the Mediterranean - particularly where karst is important - could benefit from a combined SPOT-TM approach.

ACKNOWLEDGEMENTS

The authors thank IGME Greece for permission to undertake fieldwork.

REFERENCES


