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Possibilities of applying CORONA archive satellite images in forest cover change detection – example of the Fruška Gora mountain

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Abstract

This paper examines the possibilities, advantages and limitations of the use of high resolution archive satellite images in evaluation of forest and other land cover changes, based on research in the sample area of the Fruška Gora mountain (Serbia). Satellite images available from the declassified archives of CORONA program were used to assess the extent of forest cover in the past. By comparing the resulting datasets with newer images, changes in the forest coverage can be detected and reconstructed for a period of more than 40 years. Despite many limiting factors, the images provided valuable information about the state of the forest cover in the past. The methodology used can be utilised in other similar areas, where no other, more precise source is available about forest coverage, as a means of reasonably inexpensive and time efficient assessment of forest cover and other land use changes in the past five decades.

Key words: forest cover change detection, archive satellite images, CORONA program, Fruška Gora mountain.

Introduction

The aim of this paper is to evaluate the overall usability and feasibility of applying high resolution archive satellite images from the CORONA program in forest cover change detection and analysis, based on the research conducted in the area of the Fruška Gora mountain.

Monitoring natural and human caused land cover and forest changes, disturbance processes, and spatial pattern is relevant for the conservation of forest landscapes and their inhabitants (Balmford, et al., 2003). Remote sensing has long been identified as an effective and efficient tool in forestry studies, such as forest inventory, forest health and nutrition, forest sustainability, forest growth, and forest ecology (Köhl, et al., 2006). Remote sensing provides rapid coverage of large areas, permanent and objective records, map-like products, efficiency in time and money, and access to inaccessible areas (Shao, Raynolds, 2006). Remote sensing and geographical information systems (GIS) have emerged as key geospatial tools — together with models of all kinds and descriptions — to satisfy increasing information needs of resource managers (Franklin, 2001). Archive satellite images provide potentially valuable sources for assessment of the condition of forest cover, which can serve as a reference base for comparison with the recent state. Archive satellite and aerial images are also particularly well suited for studying the extent of the forest cover in the past and long term trends in cover change. Although images with greater temporal, spatial and spectral resolution appeared from the beginning of 1980s, in some cases sources of older high resolution

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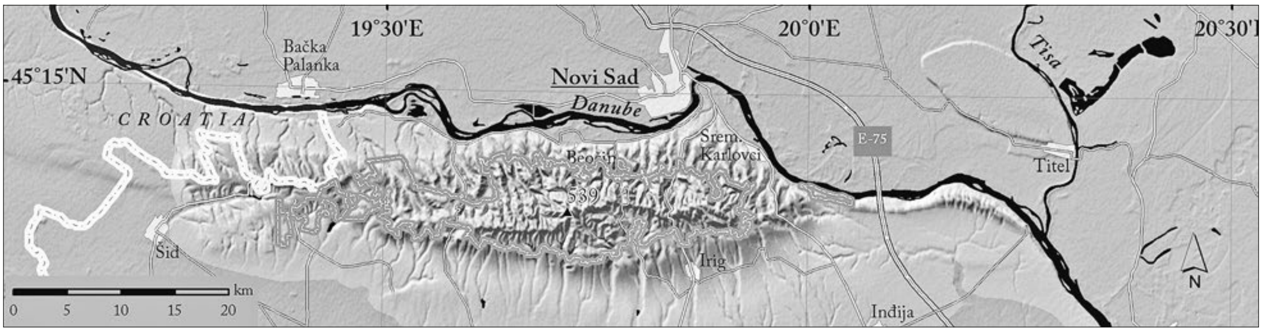

Figure 1. The research area

images are available. An example of such an archive is the relatively unknown CORONA program, which is an excellent source of information about surface change, especially for southeast Europe.

The Corona program was used from 1960 to 1972 by the USA, for satellite surveillance and mapping of the Soviet Union, China, countries of the eastern bloc, and other areas of interest around the world. Trough the gradual evolution of this experimental remote imaging program, higher quality stereographic images with a resolution of 2.75 m and with a larger spatial coverage became available near the end of the 1960s (Cloud, 2001). In 1995 the archive of images was declassified and made available to the wider community (Cloud, 2001; Dashora, et al., 2007). These satellite photographs have been used in various fields since, although to somewhat limited extent due to technical difficulties with standardized image processing. The CORONA satellite images were utilized in land cover change analysis (Gray, et al., 2000, Hamandawana, 2004), forest change detection (Rigina, 2003), archaeology (Goossens, et al., 2001), digital elevation model extraction (Altmaier, Kany, 2002; Mészáros, et al., 2008), coastline change reconstruction (Bayram, et al., 2004).

Research area

The Fruška Gora is a low (539 m) mountain with rolling hills, extending about 80 km length in the E-W direction, south of the Danube and the city of Novi Sad, with a maximal width of 15 km. Forest covers most of the highest central parts of the mountain (about 40 km in lenght) which lie within the boundaries of the Fruška Gora National park. The rich and diverse mixed forests are the most important protected value of the Fruška Gora National park, which is under constant and increasing pressure from surrounding urban areas, building, traffic, agriculture and economic use. Within the constraints of existing protective measures, controlled forest exploitation represents also an important source of revenue for the Fruška Gora National Park. Monitoring the changes occurring in forest coverage over longer period is thus an important part of forest and ecological management.

Materials and methods

The Fruška Gora mountain was selected for testing the process of forest cover change identification from CORONA satellite images for its very favourable characteristic:

- Optimal size and land cover structure of the research area (about 260 km2), with a continuous and relatively homogenous forest cover (mainly deciduous forest).
- Availability of good quality CORONA images, with convenient image strip orientation (the 95% of research area fitting on one film strip).
- Sufficient number of landmarks recognizable on images for georeferencing.
- No other readily available detailed sources of information about the forest cover.

The stereo image pair used for the reconstruction of forest cover on the Fruška Gora was taken on February 8th 1969 (Figure 2, Table 1). The angle of stereo camera is 30° (Table 1), which allows stereographic 3D visualisation and surface height reconstruction (Altmaier, Kany, 2002; Mészáros, et al., 2008).

Table 1. *The main technical features of the cameras and film used during the KH-4B mission*

System	Corona KH-4B
Time of recording	08.02.1969.
Mission no.	1106
Orbit height (nominal)	150 km
Camera type	panoramic
Angle of twin cameras	30°
Focal length	609.6 mm
Film type	panchromatic
Film resolution	160 line/mm
Actually usable film size	55.37 x 756.9 mm (mm × mm)
Area covered	14x188 km
Scale	1:247500
Field resolution	1.83 m

Source: Mészáros, et al., 2008

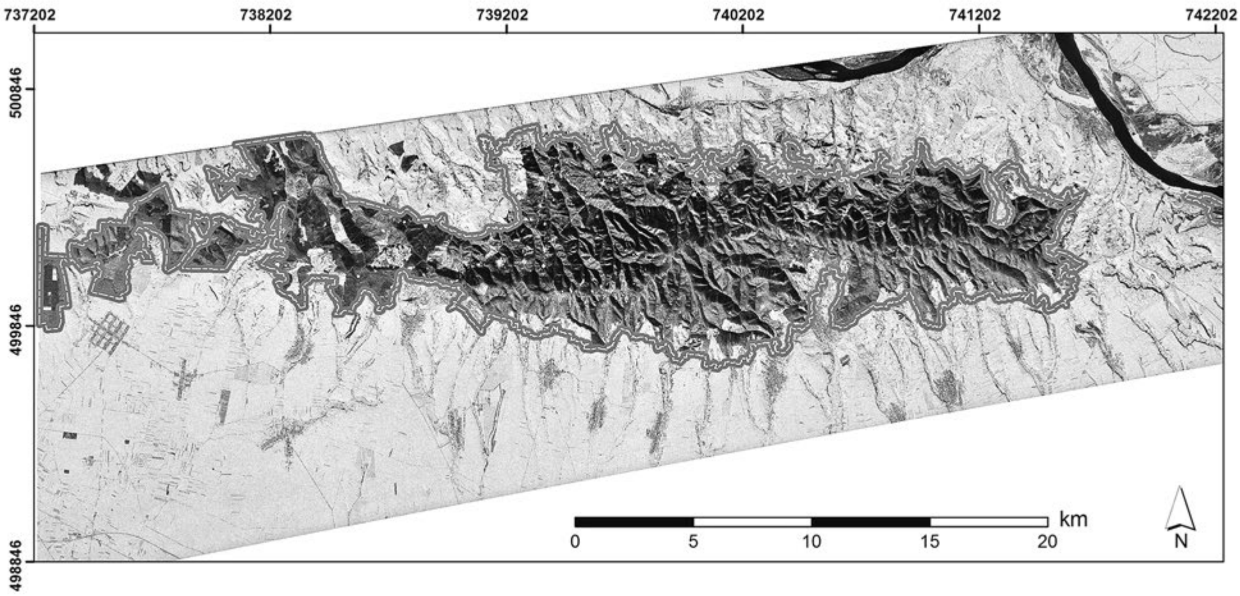

Figure 2. The research area shown on the CORONA satellite image

The images were obtained on a non-standard size film strip of 757 x 70 mm, and were scanned on a special scanner at a resolution of 12 μm. According to a detailed experimental study on CORONA image scanning by Leachtenauer (Leachtenauer, et al., 1998) 4 μm is required for lossless digitizing, which assuming a film resolution of 120 to 140 lp/mm is approximately equivalent to two samples per line pair. The same study concludes that a standard 21 μm flatbed scanner can produce acceptable results. Recently the images can be ordered also in a scanned digital format (14 μm for missions KH1-KH3, and 7 μm for missions KH4-KH4b).

The high resolution image was georeferenced in ArcGIS using more than 200 ground control points recognizable on the original CORONA images as well as on recent aerial photographs. After testing various transformation methods, the rubber sheeting method for coordinate transformation provided the most acceptable results, in accordance with suggestions from other authors (Hamandawana, 2010). The georeferenced images were manually digitised. Because of the snow cover, the enhanced contrast between the forest and surrounding areas facilitated the manual digitalisation. Continuous areas fully covered with forest were very clearly recognizable.

Results and discussion

Forest cover change detection and analysis

For the analysis of forest cover changes the CORONA images were compared with available recent, high resolution (0.5 m) aerial images (from December 2003). The images were visually interpreted and the forest boundaries were manually digitized. The central parts of the mountain were included in the analysis, extending about 230 km².

Table 2. *Changes in areas with forest cover between 1969 and 2003*

Description	Area (km²)
Research area	230
forest cover in 1969 - CORONA image	207
forest cover in 2003 - aerial image	224

The results show an actual increase of the areas covered by forest on the Fruška Gora mountain (Figure 3 and 4), which seemingly contradicts the picture of intensive forest exploitation that was visible in recent years on some parts of the mountain. The largest increase can be observed on the peripheral parts of the central forest area (Figure 5). This could be explained in part by the above mentioned limitations of the method in identifying low, sparse, young and transitional forest areas.

In order to estimate the feasibility of archive satellite image analysis in forest change detection, the advantages and limitations of the method have to be ascertained and compared. Several of the advantages of the procedure are clear. The low cost of archive satellite images and increasing quality of publicly available sources of aerial and high resolution satellite images (for e.g. Google earth and other similar services) for comparison offer a relatively cost effective and simple solution for forest cover evolution research. The CORONA archive images represent a snapshot of large

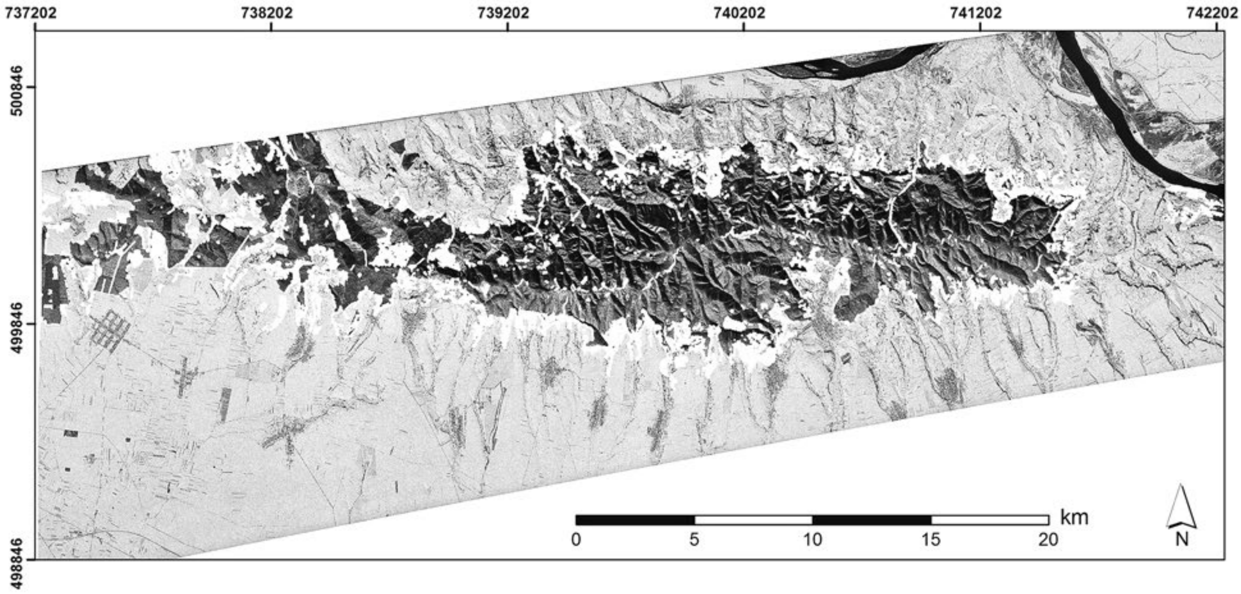

Figure 3. Areas detected with forest gain 1969

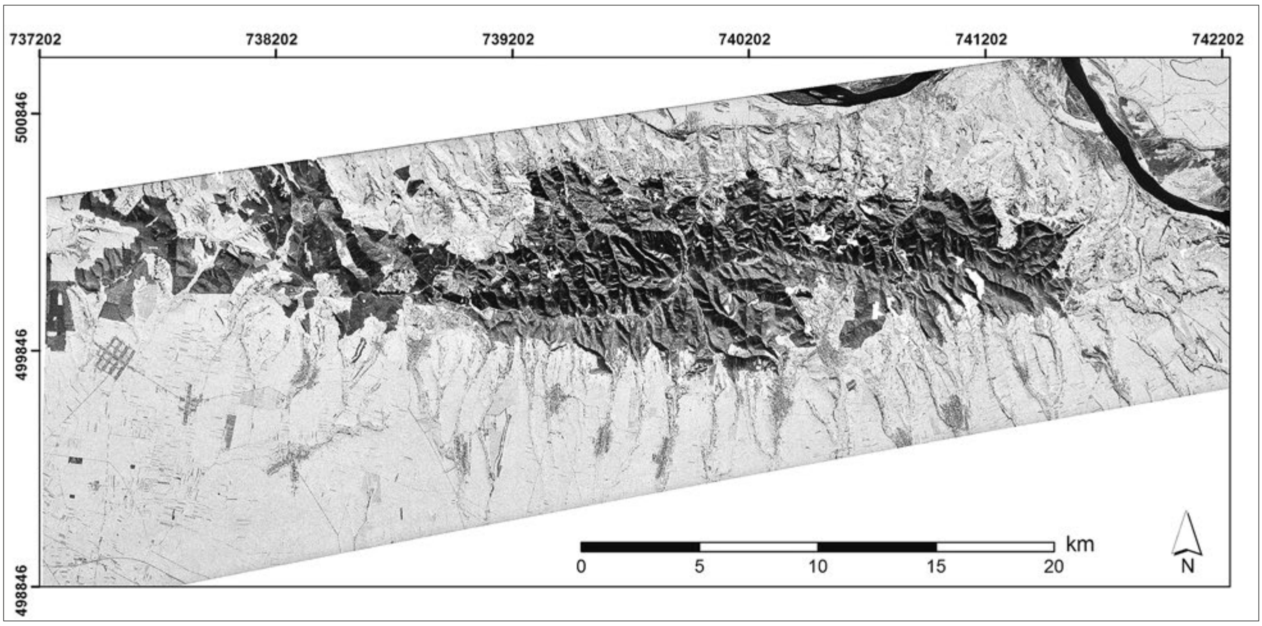

Figure 4. Areas with forest detected loss since 1969

areas in a nearly single time instant, under similar physical conditions (cloud cover, air humidity, position of the sun and the imaging platform relative to the ground) which is rarely achievable in aerial photography. In areas where few or no other sources exist, archive satellite images provide an invaluable view in the past. Beside these obvious advantages, the CORONA images can in some cases provide additional information about the forest cover. Based on the stereo camera pairs from the CORONA images digital surface model (DSM) can be generated, allowing indirect methods of forest cover analysis. In combination with a high precision digital elevation model, by subtracting it from the DSM a rough estimation of forest height and biomass volume becomes possible. The vertical precision of the generated DSM of 10-25 m (Mészáros, et al., 2008) makes the analysis suitable only in case of higher, homogenous forest vegetation, which forms a relatively dense and continuous canopy surface. The need for control points with known height of the surface for more precise DSM generation can make this approach difficult to implement. With all constraints mentioned above, by using this method, the state of the forest cover in the past can be obtained, with relatively high details for a large area. Therefore, the most important advantages of CORO-

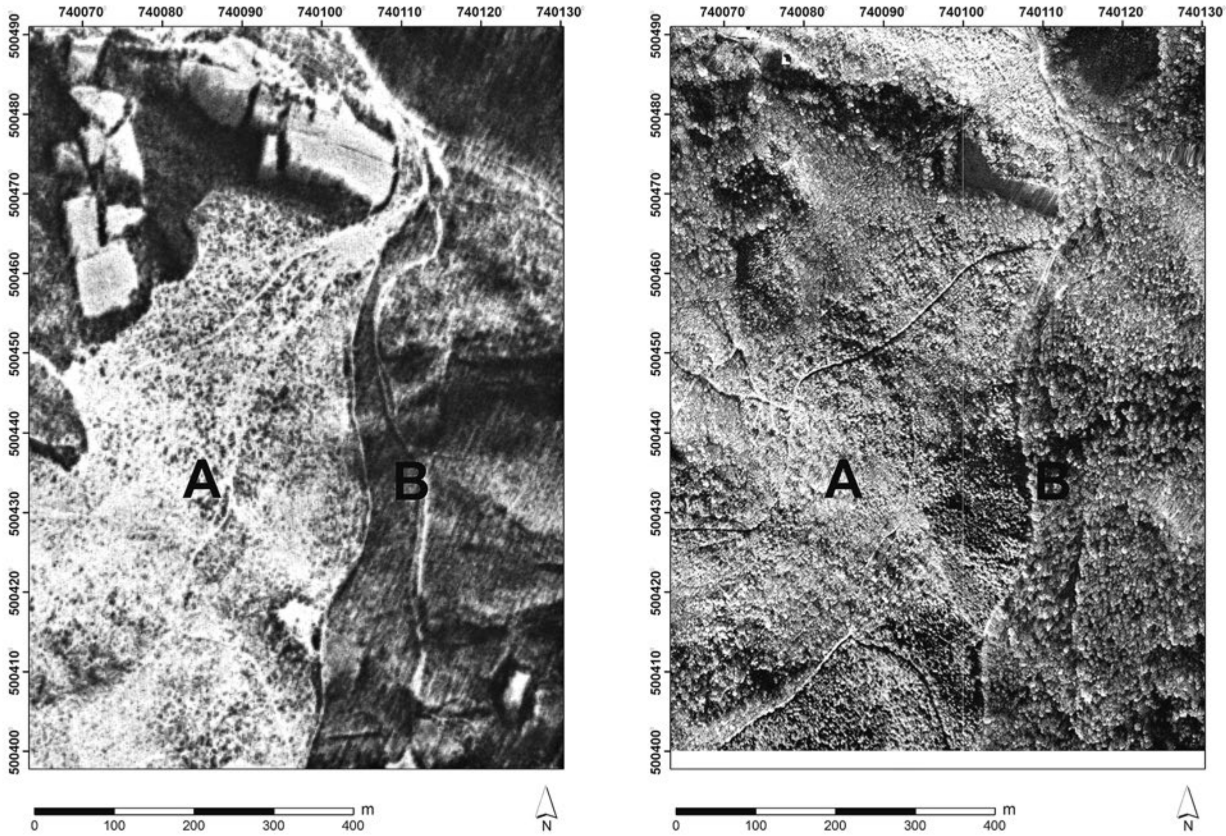

Figure 5. Difficult identification of areas with sparse forest vegetation. CORONA image (Left), aerial image from 2003 (right). A - transitional area with sparse forest vegetation B - dense forest area

NA satellite image application in forest cover change detection can be summarized as follows:

- relatively low cost of the images
- high resolution of images
- coverage of areas and periods where no other information exist about the state of the forest cover
- coverage of larger areas in a single timeframe, under similar physical, imaging conditions
- stereographic images for 3D surface visualization and analysis

During the process of image acquisition, interpretation and digitalization a number of problems were encountered, limiting the usability of these satellite images. The main problems are similar to the limitations of other satellite images and include:

- finding cloud free and technically correct coverage of the selected area. For some locations, especially for larger areas, the choice of available images may be limited, inadequate and its quality insufficient. Earlier missions of the CORONA program were especially error prone.
- problems with visibility and identification of young, developing forests, deciduous forest outside the vegetation period, when the size of the tree trunk and crown is below the image optical resolution.
- difficulties in differentiation from other types of vegetation (shrub vegetation, orchards, plantations) and distinction of smaller patches of forest vegetation and other, visually similar land cover types.
- automated pixel classification for forest cover change detection is practically impossible on monochromatic image, requiring manual interpretation, which in turn increases the time and resources necessary for data acquisition and processing. The quality of manual interpretation depends thus on the experience of the interpreting researcher.
- difficulty detecting changes in forest density and delineating exactly the boundary of the forest area, because of the resolution.

Conclusion

The analysis of forest cover changes on the Fruška Gora mountain using CORONA archive satellite images showed the most important advantages and deficiencies of this method, as the selected research area can be considered optimal for the used procedure. According to these findings, the overall feasibility of using the CORONA satellite images can thus be evaluated based on the following factors:

- The size of the research area, as larger areas make the process of finding technically adequate images, georeferencing control points and digitalization for the entire extent more difficult, not feasible or impossible.
- The number and quality of CORONA images available for the research area, as the availability and quality of images varies in certain areas.
- The number of available landmarks recognizable on images that are required for georeferencing of image strips. In some cases, especially in large, remote, uninhabited regions there may be not sufficient recognizable landmarks for image georeferencing.
- The complexity of land cover and forest type. If the vegetation cover is very complex (fragmented patches of mixed vegetation types or other visually similar land cover), the identification and digitalization of such areas may be too difficult and resource consuming.
- Availability of other archive resources (more detailed and accessible aerial images, large scale topographic maps, forestry surveys) makes the application of CORONA images less feasible, but in certain situations can also serve as a means of cross validation with other sources.

Despite the above mentioned constrains, the CORONA satellite images can be considered a very useful and cost effective resource of studying forest cover changes in the past. Further and more detailed research of forest cover change detection on the Fruška Gora mountain using CORONA satellite images may become possible when georeferenced archive forestry databases become available. Together with the application of high resolution DEM and the digital surface model generated from the CORONA images the approach for tree height and biomass estimation can be tested on the area of the Fruška Gora.

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