Acta Sci. Pol.,
Geodesia et Descriptio Terrarum 6(2) 2007, 5-13

THE EXPERIENCE OF THE COMPLEX MAPPING OF THE HIGH MOUNTAINS OF THE GREATER CAUCASUS*

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Abstract. The paper presents the novel complex methods of thematic mapping for the purpose of revealing the impact of geologic, geomorfological and climatic factors on the spatial distribution of vegetation communities in the alpine belt of the Greater Caucasus. Combined application of remote sensing and GIS methods is particularly effective for a complex survey and mapping in the regions difficult to access.

Key words: thematic mapping, remote sensing, GIS-technologies, geologic and geomorfological factors, climatic conditions, vegetation of alpine belt

INTRODUCTION

The Greater Caucasus is the well known nature model for in-depth study of the young mountains of the Alpine-Himalayan orogenic system. The region is characterized by rich and original nature. It is known as the center of ancient civilizations. The intensive landuse began long time ago. Due to the high relief complexity, significant diversity and patchiness of the vegetative cover the influence of impact can be considerable and be a reason of the irretrievable consequences. In this connection the complex study and monitoring of the ecological situation in the region is very actual and takes on special significance.

The alpine belt is considered to be an object of the thorough study, and it is not occasionally. One of the main traditional landuse in the Greater Caucasus is cattle breeding on distant pastures. Thus, the high mountains with its splendid summer pastures plays very important role for the local population. Nevertheless, no special investigation on the ecological situation in the alpine belt was ever pursued. For this reason partly the maps (especially geobotanical maps) of the Greater Caucasus are very general and present the alpine belt without any differentiation.

* This project is supported by the Russian Foundation for Basic Research (grant N 04-04-49266 and N 04-05-64611).

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That is why thematic mapping, the main aim of which to reveal the relationship between the spatial heterogeneity of plant communities and environmental factors (climatic and geomorphologic) in the alpine belt of the Greater Caucasus, is very essential and will help to solve the problem of the environment evaluation and working-out of the recommendations on the sustainable development of the region.

The new approach to vegetation analyses based on the floristic classification, the development and application of remote sensing methods and GIS-technologies open wide possibilities for studying the regularities and spatial heterogeneity of nature components in the alpine belt. These approaches are particularly effective in the complex researches and thematic mapping in the high mountains regions difficult to access, where some missing parameters have to be modeled.

MATERIALS AND METHODS

The Greater Caucasus extends southeastward across the Caucasian isthmus from the Taman Peninsula, which separates the Black Sea from the Sea of Azov, to the Apsheron Peninsula, which juts into the Caspian Sea. The massif (of 1260 km in length, after Gerasimov and Galabov 1984) is asymmetric, with a long and gentle northern slope composed of parallel mountain ranges and ridges, and a short and steep southern slope. Traditionally the Greater Caucasus is divided into three regions: the Western, Central and Eastern Caucasus. The border between the Western and the Central parts passes along the Kuban-river valley, through the Elbrus peak (5642 m a.s.l.) and then along the Nenokra-river valley. The border between the Central and Eastern Caucasus is led along the Terek-river valley, through the Kazbek peak (5033 m a.s.l.) and along the Aragvi-river valley (Fig. 1).

The study comprises field observations of geobotanical and geomorphological elements, the modeling of cartographic and climatic parameters, and the use of remote sensing and GIS-technologies. The investigations were realized in the three key areas only reflecting the environmental specificity of various parts of the Greater Caucasus: the Cheget-Chat Range in Western Caucasus; the Adylsu-river valley in Central Caucasus, and the mountain Guton in Eastern Caucasus (Fig. 1).

For these key areas a detailed interpretation of the relief was done using the multispectral satellite images from the space system ‘Resurs- ‘F’ (three color filters, at 1:200 000 scale). More precise results were obtained by aerial photographs (at 1:30 000). In consequence, the geomorphological maps were created (at 1:30 000 and 1:200 000 scales) [Asoyan et al. 2001a,b]. The fragments of the topographic map (at 1:200 000) have been digitized on 300 dpi raster images with Easy Trace 4.0 software. The digitized data were then converted to the ARC\INFO format and topologic and attributive data (presented in the form of thematic layers), were jointly processed by ARCVIEW GIS 3.2 (moduls Spatial Analyst and 3D Analyst). The control points (27 on the Chaget-Chat ridge, 49 in the Adylsu-river valley, and 35 on Guton-mountain) were recorded on the maps [Asoyan et al. 2002].

The main climatic parameters for the key areas had to be extrapolated because of irregularity in the network of weather stations in the Caucasus. These are situated mainly in the foothills, in low and middle vegetation belts, but rarely in the alpine belt or higher (Fig. 1). [Handbook on climate… 1966a,b, 1967, 1968b, 1969, 1970]. On the basis of climatic data the altitudinal gradients of mean July and January temperature, mean annual temperature, sums of the temperature above +5° C and the amplitude of annual temperature were calculated. They are presented in relation to absolute altitude.

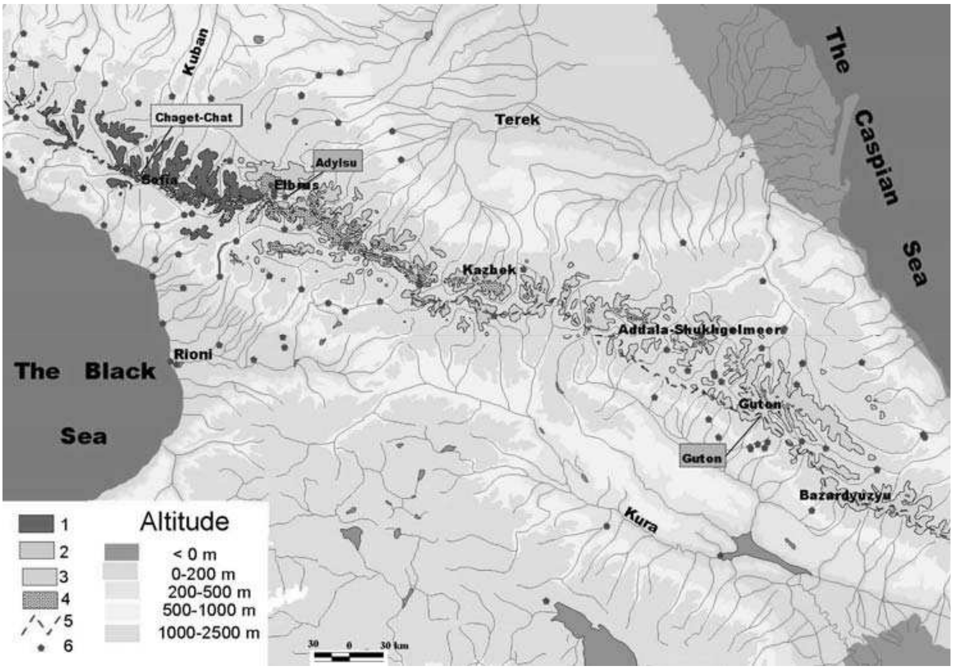

Fig. 1. The alpine belt of the Greater Caucasus, 1:3,000,000. The digital version of the map: A. Kachalin, E. Belonovskaya E. and D. Asoyan. 1 – 3 Alpine belt of Western, Central and Eastern Caucasus respectively; 4 – glaciers; 5 – Main Caucasian Range; 6 – Weather-stations

Rys. 1. Piętro alpejskie Wielkiego Kaukazu, skala 1:3 000 000. Wersja cyfrowa mapy: A. Kachalin, E. Belonovskaya E. i D. Asoyan. 1 – 3 piętro alpejskie odpowiednio zachodniego, środkowego i wschodniego kaukazu; 4 – lodowce; 5 – główny grzbiet kaukazu; 6 – stacje pogodowe

Annual and seasonal totals of precipitation (including that in the active vegetation period from May to July) and relative humidity in relation to the altitude and slope exposure to the prevalent moisture-laden air transport in the alpine belt of the Western and Central Caucasus were simulated on the basis of data from 14 weather stations situated in the Chaget-Chat ridge and the Adylsu-river valley. Data on the Eastern Caucasus were taken from 9 weather stations situated at a distance of 6–10 km from the Guton mountain in Dagestan, Georgia and Azerbaijan. As a result, various statistical models of dependence of the precipitations on absolute altitude were determined for the key areas.

For every studied site the geobotanical releve was done and the altitude, aspect and inclination of slope, as well as the cover of bare rocks and detritus were defined. All the releves were related to the hierarchical syntaxonomical classification of the alpine vegetation of the Greater Caucasus [Korotkov and Belonovskaya 2000, Belonovskaya and Korotkov 2002].

The combined results of complex field observations and chamber studies underlay the thematic maps' series for the key areas. The digital map of the alpine belt was made up on the base of the digitized hypsometric map of the Greater Caucasus (at 1:3 000 000) with 500 m step contour lines. For key areas a digital model of terrain was made with 100 m step contour [Belonovskaya et al. 2004].

RESULTS

The application of the mentioned approaches for the complex mapping is shown on the example of the Adylsu-river key area.

This area is situated on the south-western slope of the valley in the upper part of the Baksan-river basin within the limits of the nival, alpine, subalpine and forest altitudinal belts. The watersheds reach the heights of 2704 m and 4045 m a.s.l. The valley was developed within the alpine mountain morphostructure composed of Prejurassic rocks of Proterozoic and Palaeozoic folded basement (crystalline schists, quartzites, gneisses, marbles, dolomites). The relief developed through the denudation processes and linear and channel erosion. The inclination of slopes in their upper part attains 20-25º and in the glacial cirques exceeds 35º. The slope is divided by parallel erosion channels with permanent streams. Proluvium is developed in the upper and middle parts of the slope, while the bottom is composed of talus deposits. The slope surface is covered either by turf or by large fragmental rocks and fine debris. The rock crevices are met in the middle part of the slope, mainly near the streams. In the upper part of the Adylsu-river valley the glaciers developed in the well made up cirques with the moraines at the bottom of the slopes.

On the stereoscopic airphotos the relief is expressed by form, texture, shadows, size and density of images, while the screes by fine texture and glacier relief forms (moraines) by fine spots. Some higher hills are represented as oval-shapped forms with shadows. On the multispectral satellite images the exposed and turf-covered slope surfaces differ by various tints corresponding with various densities of grass cover. On the multispectral satellite images of the Adylsu-river key area the following altitudinal belts are shown (Figs. 2 and 3):

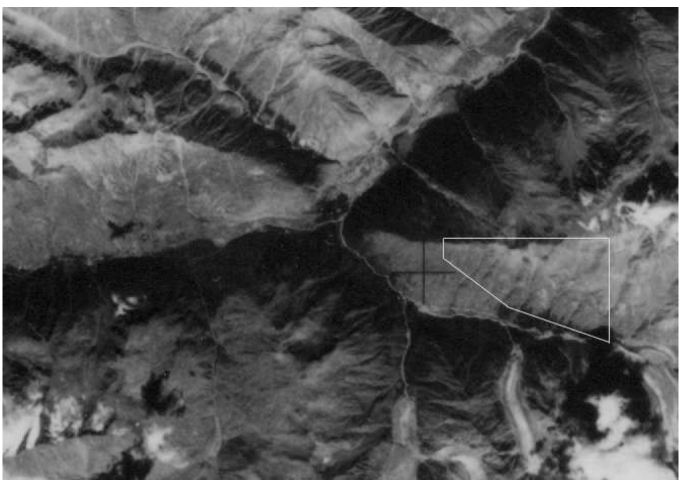

Fig. 2.
The multispectral space image of the Adylsu-river valley
Rys. 2.
Wielospektralne zdjęcie satelitarne doliny rzeki Adylsu

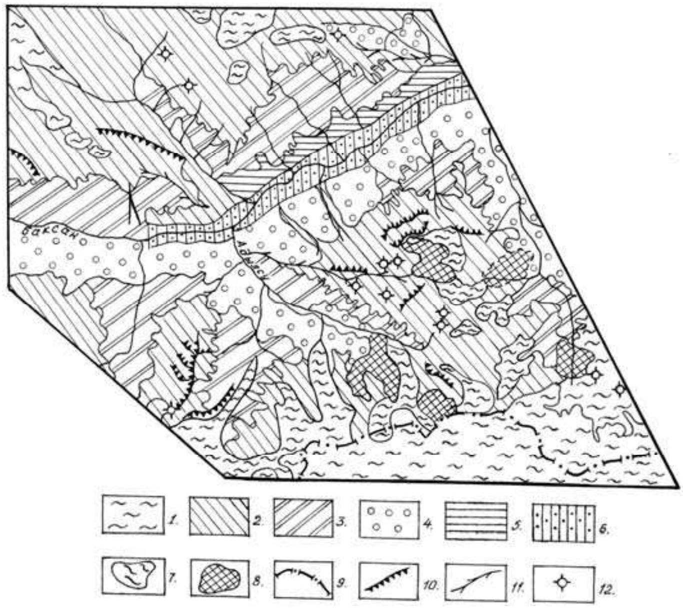

Fig. 3. Geomorphological and geobotanical map of the high mountains of the Adylsu-river valley. The map by D. Asoyan and E. Belonovskaya, digitalized by A. Kachalin.
1 – nival belt: eternal snow, glaciers, avalanches, ice and stone mudflow (at 4,045 to 3,800m); 2 – alpine belt: alpine meadows and mats; groupings on screes, rock crevices, primitive soils (at 3,800-2,800m); 3 – subalpine belt: subalpine tall grasses meadows (at 2,800-2,400m); 4 – forest belt: birch elfin woodlands, pine forests (at 2,400–1,800m); 5 – meadow-steppe belt: mountain steppes (at 1700-800m); 6 – intrazonal landscapes: vegetation in the river valleys; 7 – glaciers; 8 – clouds and their shadows; 9 – the state border; 10 – narrow watersheds; 11 – summits

Rys. 3. Geomorfologiczna i geobotaniczna mapa gór wysokich doliny rzeki Adylsu. Mapa wg D. Asoyan, E. Belonovskaya, zdigitalizowana przez A. Kachalina.
1 – piętro niwalne: wieczny śnieg, lodowce, lawiny, lód i osypiska kamienne (od 4045 do 3800 m); 2 – piętro alpejskie: łąki alpejskie i fragmenty łąk, grupy piargów, szczeliny skalne, prymitywne gleby strukturalne (od 3800 do 2800 m); 3 – piętro subalpejskie: łąki sublapejskie (hale z wysoką trawą) (od 2800 do 2400 m); 4 – piętro lasu: zbiorowiska brzozy karłowatej, lasy sosnowe (od 2400 do 1800 m); 5 – piętro łąk stepowiejących (hal): stepy górskie (od 1700 do 800 m); 6 – krajobrazy śródstrefowe: zbiorowiska roślinne w dolinach rzecznych; 7 – lodowce; 8 – chmury i ich cienie; 9 – granica państwa; 10 – wyraźne krawędzie; 11 – wąskie działy wodne; 12 – szczyty

- Mountain Pine (Pinus kochiana) forest is characterized by a low reflectance of the tree layer (0.2-0.3) and rather high density of the herb layer (mean total cover of 50%). This belt is marked with dark-green.
- Subalpine birch (Betula litwinowii)elfin woodlands occurring mainly on the northern slopes and moraines. The herb layer consisting of forest plant species, tall grass and subalpine meadow plants (total cover of 40 to 85%) is developed under comparably sparse tree layer (density of 0.3 to 0.6). On the satellite images these communities are in green.

- The subalpine meadows belt is developed above the treeline (i.e. above 2640 m a.s.l) and characterized by a high density (total cover of 100%) and rich composition of species. These meadows are on the satellite images in light-green.
- The alpine belt extends above 2800 m a.s.l. and is characterized by plants of low height (of 10 to 15 cm), as well as a low density of herb layer (total covering is of 40-50% on average). On the satellite images this belt is in light-brown.
- The nival belt is nearly white on the images.

In the high mountains the differences in air temperature (on 2 m above the ground) depend mostly on the absolute altitude of the control points. Factors such as slope characteristics (e.g. inclination) create differences in the radiation input and temperature in the narrow near-ground air layer. The simulated vertical gradients of the air temperature were extrapolated for the whole area of the Adylsu-river. Linear dependence on altitude of air temperature was be used to define the belts' limits. Exponential dependence of precipitation on altitude enables to draw a map of the spatial distribution of precipitation in the alpine belt of the key area (Figs. 4 and 5).

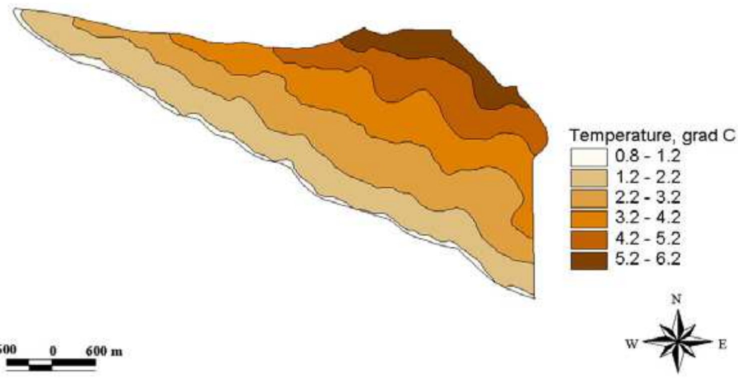

Fig. 4. Spatial distribution of mean annual temperature in the Adylsu-river valley key-area. The digital version by A. Kachalin and E. Beryoza

Rys. 4. Rozkład przestrzenny średniej temperatury rocznej w badanej dolinie rzeki Adylsu. Wersja cyfrowa wg A. Kachalin i E. Beryoza

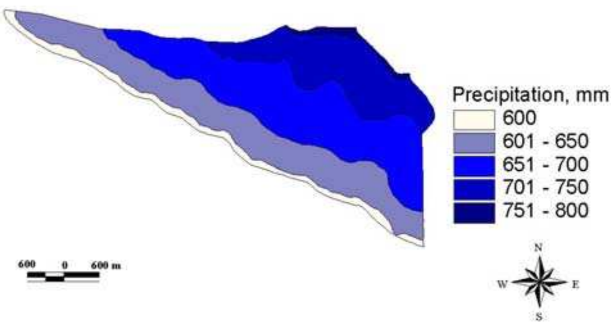

Fig. 5. The spatial regularities of warm period (June-August) precipitations in the Adylsu-river valley key-area. The digital version by A. Kachalin A. and E. Beryoza

Rys. 5. Przestrzenna regularność rozkładu opadów atmosferycznych okresu ciepłegi (czerwiec-sierpień) w badanych obszarze doliny rzeki Adylsu. Wersja cyfrowa wg A. Kachalin i E. Beryoza

The last map (Fig. 6) based on field observations and remote sensing, presents the spatial distribution of plant communities in relation to the relief of the area.

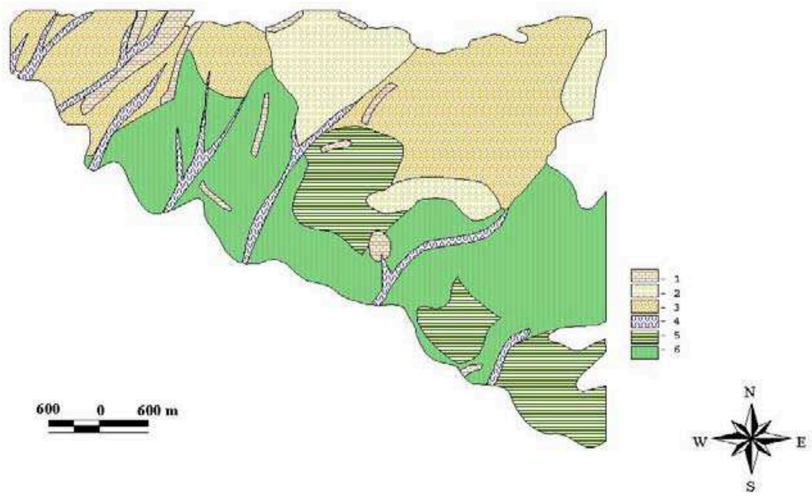

Fig. 6. The vegetation cover of the Adylsu-river valley key-area. The digital version of the map: A. Kachalin, E. Belonovskaya E. and D. Asoyan.
1 – Gypsophilo tenuifoliae-Saxifragetum juniperifoliae on rock crevices; 2 – Alopecuro sericei-Cerastietum alpinae on screes; 3 – plant groupings on primitive soils; 4 – Primulo auriculatae-Cardaminetum raphanifoliae Korotkov 1990 along spring beds; 5 – Carici atratae-Anthoxanthetum odorati on gentle parts of slope; 6 – ass. Polygono vivipari-Kobresietum bellardii on the steep parts of slope

Rys. 6. Pokrycie szatą roślinną badanej doliny rzeki Adylsu. Wersja cyfrowa wg A. Kachalin, E. Belonovskaya E. i D. Asoyan.
1 – Gypsophilo tenuifoliae-Saxifragetum juniperifoliae w szczelinach skalnych; 2 – Alopecuro sericei-Cerastietum alpinae na rumowiskach skalnych; 3 – roślinność zgrupowana na prymitywnych glebach górskich; 4 – Primulo auriculatae-Cardaminetum raphanifoliae Korotkov 1990 wzdłuż nisz źródliskowych; 5 – Carici atratae-Anthoxanthetum odorati na łagodnych partiach stoków; 6 – ass. Polygono vivipari-Kobresietum bellardii na stromych partiach zboczy

CONCLUSIONS

On the basis of complex field observations, the use of remote sensing and GIS-technologies on the Adylsu-river and other key areas, it might be supposed that the regularities presented above concern the whole Greater Caucasus.

All analyzed indices of temperature depend linearly on the altitude and coincide with the corresponding belts limits. In the Western and Central Caucasus, the amount of precipitation on the same altitude is independent of slope characteristics, but in the Eastern Caucasus in winter time the leeward slopes get precipitation less abundant (by 30-50mm) than the windward ones. The deficit in snow cover explains why the alpine meadows are met mainly on the leeward northern and eastern slopes.

The geomorphological factors such as relief forms (with its micro-and nanorelief) and slope orientation and inclination, influence precipitation and solar radiation and through it the air temperature in near ground air layer. All these factors determine the allocation of the types of plant communities inside the belt, especially locally. Alpine meadows and heaths prefer bulged steep diverse slopes of the Western and Central Caucasus and cold northern slopes of the Eastern Caucasus. Alpine carpet-like meadows or mats occupy mainly concave and aligned parts of gentle slopes. It should be noted that the nanorelief itself constitutes the basic factor of the spatial distribution of these two wide spread alpine vegetation types. However, this could not be expressed exactly on a topographic map (even at of 1:25,000 or 1:10,000 scales). The distribution of plant groupings on screes and rock-crevices is associated with special substrates and it is relatively easy to identify them on topographic maps of a high quality or by satellite and aerial photographs.

To conclude, the combined application of remote sensing and GIS-technologies for thematic digital mapping enables the revealing of the spatial regularities in the leading factors of the alpine plant communities. It also improves the objectivity and precision in the determination of the mountain belts limits, the monitoring of their dynamics and therefore exactness of the environment evaluation in the high mountain regions. This new approach could change the type of studies from laborious and expensive field observations in the regions difficult of access into the almost chamber studies.

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DOŚWIADCZENIA KOMPLEKSOWEGO KARTOWANIA GÓR WYSOKICH NA PRZYKŁADZIE KAUKAZU WIELKIEGO

Streszczenie. Artykuł opisuje nowatorskie, kompleksowe metody kartowania tematycznego, mającego na celu określenie wpływu czynników geologicznych, geomorfologicznych oraz klimatycznych na rozkład przestrzenny zbiorowisk roślinnych w piętrze alpejskim Kaukazu Wielkiego. Połączenie metod i technik teledetekcyjnych z technologią GIS jest szczególnie efektywne do kompleksowego badania oraz kartowania rejonów trudno dostępnych dla człowieka.

Słowa kluczowe: kartowanie tematyczne, teledetekcja, technologie GIS, czynniki geologiczne i geomorfologiczne, warunki klimatyczne, roślinność piętra alpejskiego

Accepted for print – Zaakceptowano do druku: 24.06.2007