MAPPING OF GLACIER EXTENT CHANGES IN THE MOUNTAIN REGIONS USING SPACE IMAGES AND GLACIER INVENTORIES.

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1. Introduction

Glaciers are widely recognized as key indicators of climate change. Recent evidence suggests an acceleration of glacier mass loss in several key mountain regions. On the territory of the former Soviet Union (fSU), for example, glaciers are retreating in all mountain regions. A more comprehensive evaluation of glacier changes is imperative to assess ice contributions to global sea level rise and the future of water resources from glacierized basins.

Global Land Ice Measurements from Space (GLIMS) is an international project with the goal of surveying a majority of the world's estimated 160,000 glaciers (http://www.glims.org/). GLIMS uses data collected primarily by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument aboard the Terra satellite and the LandSat Enhanced Thematic Mapper Plus (ETM+).The National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS) provide the satellite data and support the GLIMS coordination and data management effort. With NASA funding, the National Snow and Ice Data Center (NSIDC) has developed the GLIMS Glacier Database. GLIMS regional center has been established in the Institute of Geography Russian Academy of Sciences in Moscow. With support under a NASA REASoN CAN more than 10000 glacier outlines for Caucasus, Altay, Pamir, Siberia and Tien-Shan have been derived from ASTER and Landsat images and provided in a standard form for ingest into the GLIMS database. Statistical analysis has been developed to estimate number of glaciers and their areas in comparison with data of World glacier inventory and other historical data sets. Here we perform the results of the study changes in glacier areas in the Caucasus from the beginning to the mid of XX century   and from the mid of XX century   to the beginning of XXI century.

Geographical settings and data

Caucasus Mountains extend west-north to east-southeast between the Black sea and the Caspian Sea. (Fig.1). This is one of the regions with alpine glaciers in the world. The glaciers exist in two main regions: The Big Caucasus (Bolshoi Kavkaz) and The Transcaucasia plateau (Zakavkazskoye nagorie). The main part of glaciers is situated in the Big Caucasus (98% of number and 99,7 % of area).

The Glacier Inventory by K.I. Podozerski is the first information about glacier numbers and areas in the Caucasus. This Inventory based on the ordnance survey in 1887-1910 and was published in 1911 in Russia (Podozerski, K.I. 1911).

The second inventory of the Caucasus glaciers contains the original aerial photographs and topographic maps (1957) and a manual evaluation of various glacier parameters. (Katalog lednikov USSR, 1967-77). Five images for our study were obtained. Two Landsat ETM+ and , five ASTERs. These images cover more than 90% of glacierized area in the Caucasus. (Fig.2)

In this paper we used results produced for GLIMS data base to estimate changes of more than 1200 glaciers in Caucasus between three glacier inventories: Podozerski (1881/1910), World glacier inventory (1965/1976) and GLIMS data base (2001/2004). These three inventories provide the basis for the comparison of glacier changes over a period of almost 100 years

Methods

Five images for our study were obtained. Two Landsat ETM+ for 12th September 2000 and for 18th August 1999, five ASTERs : two for 15th September 2001, two for 15th August 2004, one for 25th September. These images cover more than 90% of glacierized area in the Caucasus and were used for GLIMS data base creation. (Fig.2) The glacier outlines for each data item were digitized manually. To do the digitization GLIMSView software was used (Fig 3).

In cases of difficulty in distinguishing between glacier surfaces and thin superimposed ice cover on adjacent slopes we took into account the morphological patterns of the surface and also used air photos. To delineate glaciers in problem areas, resulting from debris-covered termini and shadows, thermal bands and stereo control were used. World glacier inventory IDs were added to each poly line item with GLIMS ID using paper and digital versions of WGI. The graphics were exported from GLIMS View to ARC shape files. All information were prepared for submission and submitted to GLIMS Data Base.

The method of joint statistical analysis of glacier data derived from ASTER and Landsat images and glacier data from WGI and early glacier Inventory was used to detect glacier areas change in Caucasus.

Resulted poly line shape files were processed in ARC/GIS software with purpose to get polygonal topology and calculate areas of glacier polygons. To estimate area for each glacier polygon outlines in GLIMS format were transformed into Gaus Kruger projection which was used for Soviet Union topographic map. In GLIMS database format there are 4 types of shape files. Information about glacier outliners (graphics) stores in Segments.shp (Poly line) files while information about glaciers attributes (GLIMS ID, WGI ID and etceteras) stores in Glaciers.shp (Points) files. GeoProcessing module of ARC/view, option "Assign Data by Location", was used

to assign data from Glaciers.shp tables to Segments.shp tables. This operation joins only the data for features of two different themes which share the same location. As a result, the attribute tables with field "WGI ID" were received for glacier polygons. Attributive tables of ARC/GIS coverage were jointed with World Glacier Inventory and Podozerski Inventory tables based on WGI ID field. Podozersky Inventory was also transformed into digital tables with WGI ID field. As a result, dynamic attributive tables were created. They are dynamically connected with glacier polygons (Fig.4). The analysis has been done by river basin that the glaciers are in (Fig.5). 21 river basins were calculated totally.

Results

The total area for Caucasus glaciers in 1911, 1957 and 2000 was calculated. The number of glaciers and glaciers area were also calculated for South and North slopes of Caucasus, Western, Eastern and Central parts of North and South slopes.

It was found out that the glacier area decreased from the beginning to the middle of the XX century on 24.7% and from the middle of the XX century to the beginning of the XXI century on 17.7%. For Elbrus glaciers we received 14.8% and 6.28% respectively.

The analysis shows that the glacier retreat in Caucasus was faster during the first part of the XX century than during the second part. These results correspond well with other studies that have been done for Caucasus (Panov, V.D., 1993, 2001).

However there is a difference between North and South slopes of the Caucasus. Glacier area change on the North slope is 30 % for the first part of XX century and 17.9 % for the second part. As for South slope, analysis shows 12% and 28 % respectively.

Discussion

The changes between two Inventories, Podozerski Inventory and former Soviet Union glacier Inventory, were analyzed by different authors (Katalog lednikov SSSR, 1967-77, Panov, 1993). The main result of all studies is the glaciers recession in the Caucasus. There is also widespread evidence of glacier recession in this region since the end of the Little Ice Age (Solomina, 2000). Some studies declare strong retreat trend for a few glaciers between 1972 and 1986 (Panov, 1993, 2000). Last decade marks the wide application of remote sensing methods for estimation glacier changes in different regions of the world (Kaab, 2002; Paul, 2000, 2002; Khromova and others, 2003, 2006). Some studies have been done for the Caucasus (Stokes and others, 2006) revealed that 94% of 113 selected glaciers have retreated between 1985 and 2000. It was concluded that the decrease in glacier area appear to be primarily driven by increasing temperatures since the

1970s and especially since mid-1990s. This paper shows the decrease in glacier area in the Caucasus during all XX century.

We should to note that annual temperatures at Pyatigorsk , North Caucasus, from 1891 to 1997 do not show any general liner trend. While summer air temperatures gently decrease and winter ones increase during XX century. (Fig. 6)

The difference in the rate of recession in the North and South slopes of Big Caucasus has been revealed. Different river basins show a range of glacier area changes from 5 – 60%. The main reason of the wide range of changes is a very complex picture of local climate conditions.

Conclusion

Glaciers are dynamically unstable systems and react very quickly to climate change. Recent evidence suggests an acceleration of glacier mass loss in several key regions. All available long-term reconstructions of mass balance time series indicate negative values almost for all northen Eurasia glaciers during the 20th century. One of the urgent steps is a full inventory of all ice bodies, their volume and changes (Barry, 2003). This paper reports about result of statistical analysis performed for Caucasus for three time periods covered more than 100 years.

With the new Caucasus glacier GLIMS inventory an excellent basis exists for the investigation of glacier changes during XX century. For the study of the future evolution of the glaciers in the Caucasus this inventory will also provide an important baseline. Important conclusions could be done from the comparison of the three existing inventories. The XX century has shown a strong area reduction for almost all glacier regions in Caucasus. There is, however, a rather large variability in degree of reduction very much depending on special local conditions.

This study has been carried out in the framework of the GLIMS project. Resent satellite data provide a unique opportunity to look at the world's glaciers. But in order to assess glacier changes we need to take account of historical glaciological data. This study illustrates the application of historical data and high resolution space images to monitor changes in glacier extent in one of the glacier regions of the world. The results correspond well with other studies performed for Caucasus (Panov, 2001) and elsewhere.
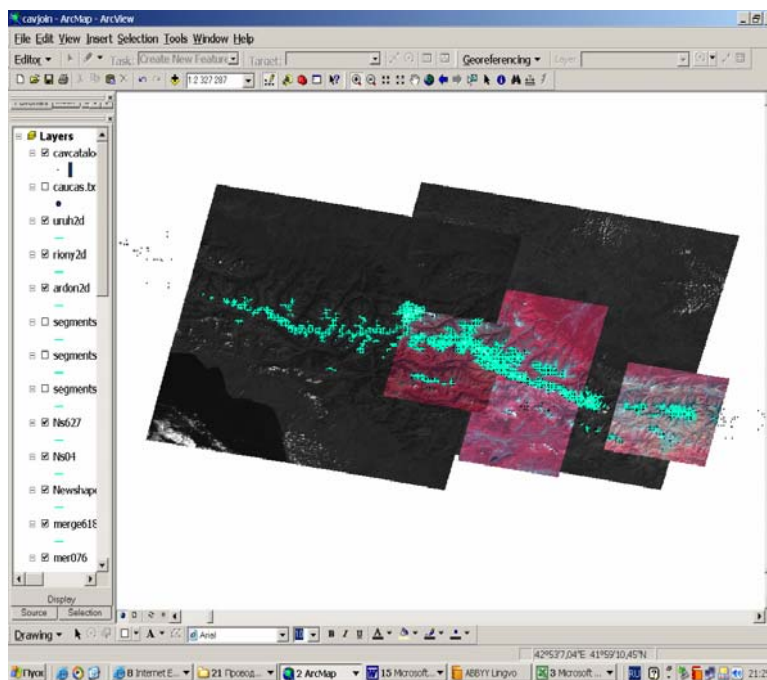
Fig 1. Caucasus Mountains

Fig 2. Images used for the analysis: Landsat ETM+ for 12th September 2000 and for 18th August 1999, ASTERs for 15th September 2001, 15th August 2004, 25th September.
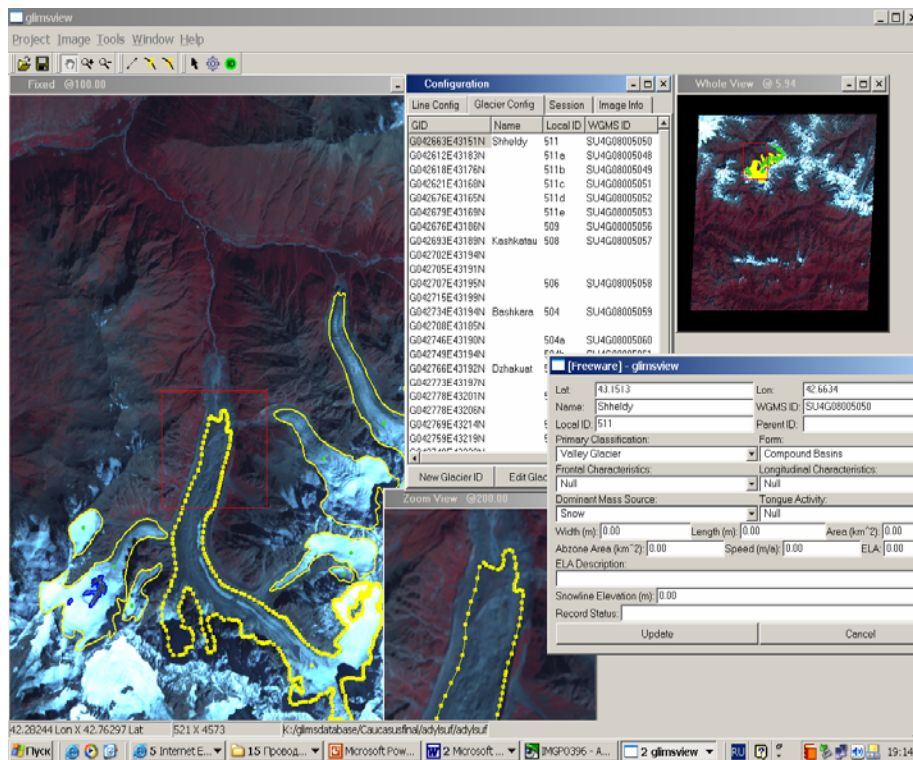
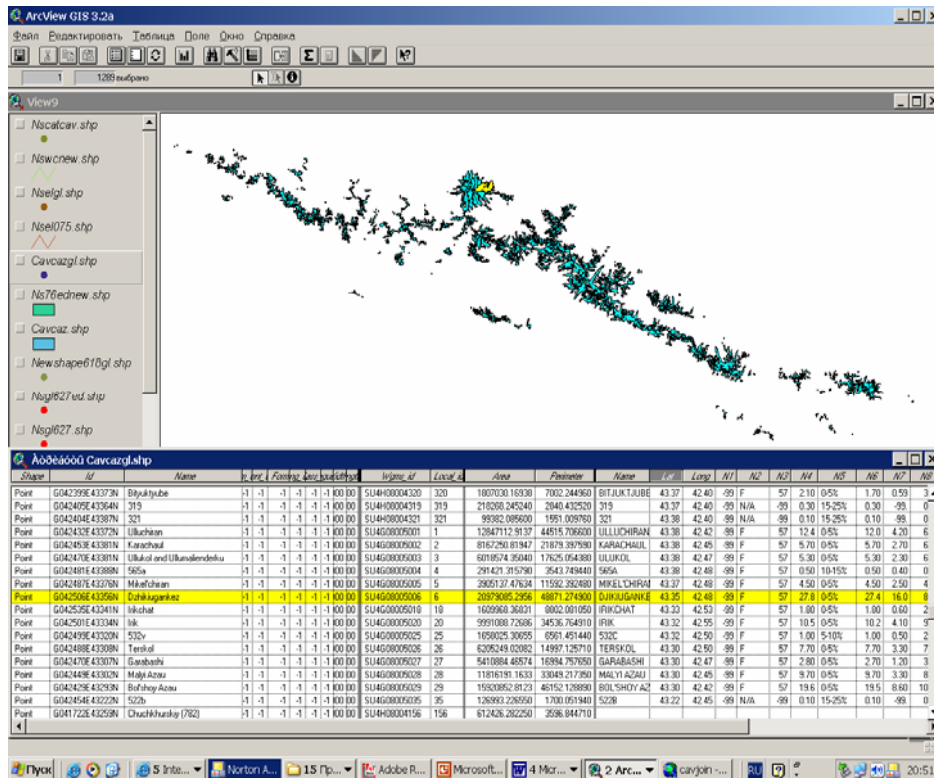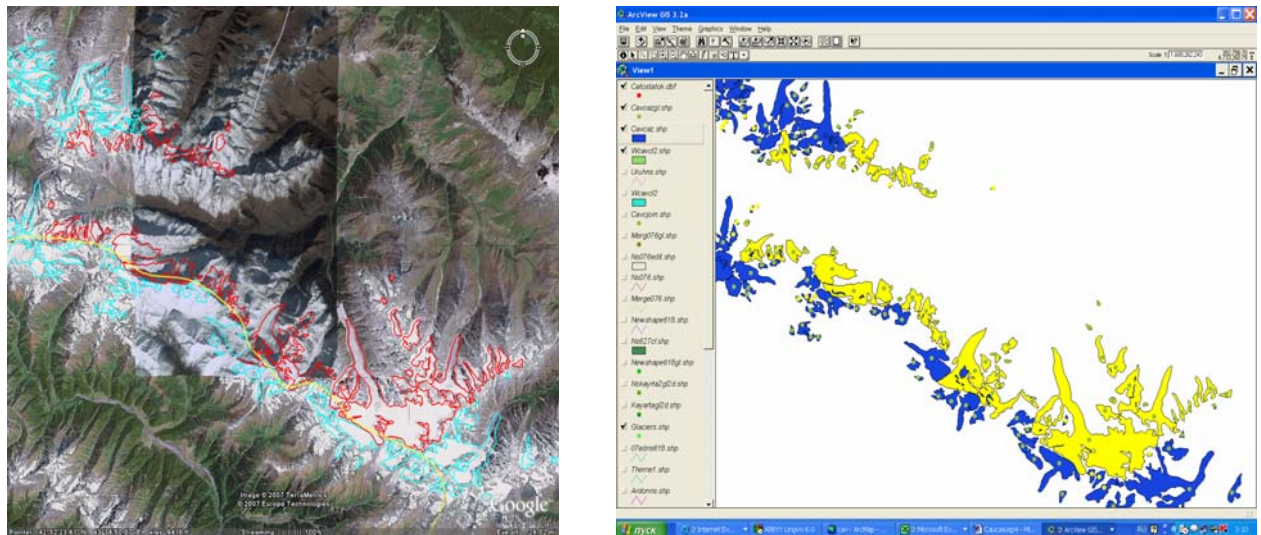**Fig.3** The digitization in GLIMSView software.

Fig 4 Joint attributive table dynamically connected with glacier polygons.

| Slope | aspects | region | Catalog issue | River basin | Area decreasing% | |
					1881-1910/1965-76	1965-76/2001-04
North	N,NE,NW	Central Caucasus	Volume 8 Part 08	Uruh	45.19	8.09

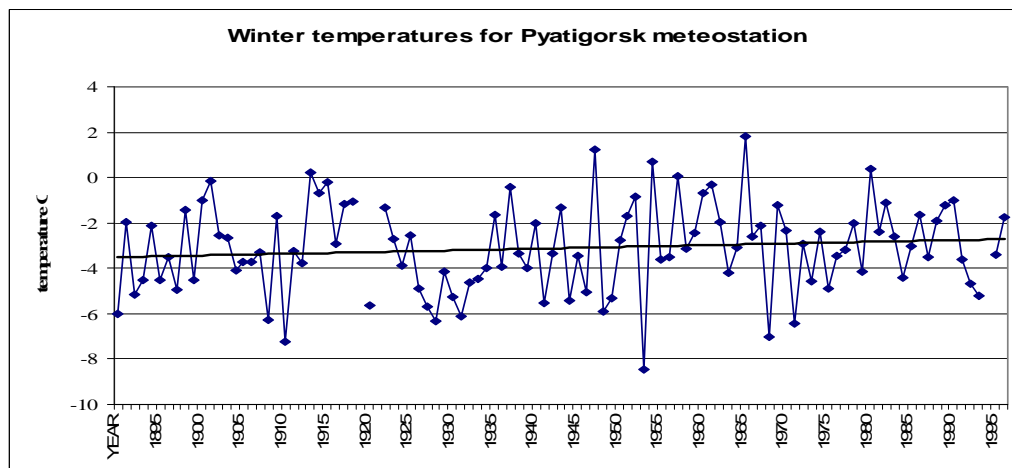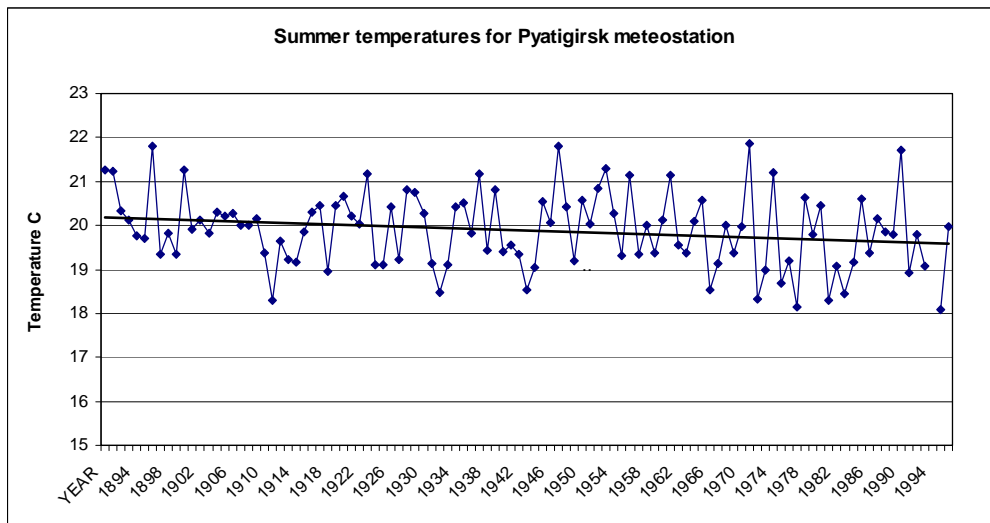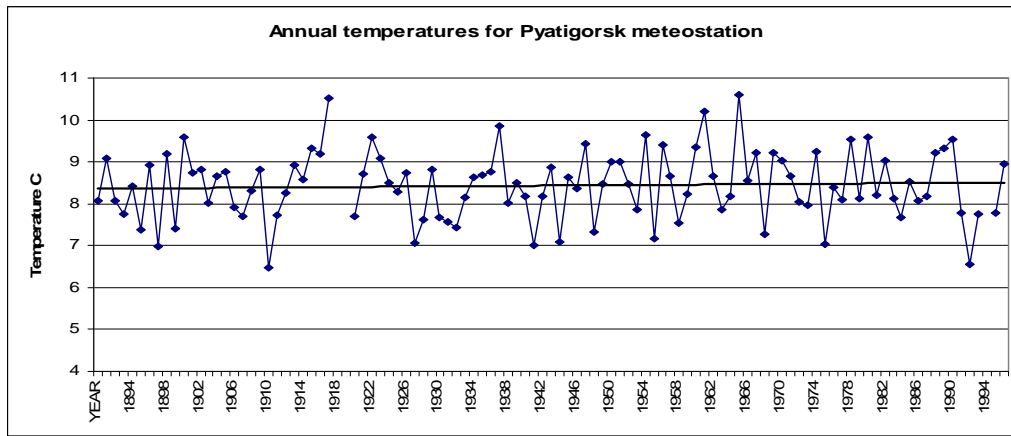Fig 5. Example of statistical analysis by River basins. River Uruh

Fig.6. Time series of average temperatures for Pyatigorsk

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