RUSSIAN ACADEMY OF SCIENCES

NATIONAL GEOPHYSICAL COMMITTEE

РОССИЙСКАЯ АКАДЕМИЯ НАУК

НАЦИОНАЛЬНЫЙ ГЕОФИЗИЧЕСКИЙ КОМИТЕТ

NATIONAL REPORT

for the

International Association of Cryospheric Sciences

of the

International Union of Geodesy and Geophysics

2011–2014

НАЦИОНАЛЬНЫЙ ОТЧЕТ

для

Международной ассоциации криосферных наук

Международного

геодезического и геофизического союза

2011–2014

Москва 2015 Moscow

Presented to the XXVI General Assembly
of the
International Union of Geodesy and Geophysics

К XXVI Генеральной ассамблее
Международного геодезического и геофизического
союза

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In this National Report are given major results of researches conducted by Russian glaciologists in 2011–2014 on the topics of the International Association of Cryospheric Sciences (IACS) of the International Union of Geodesy and Geophysics (IUGG). This report is prepared by the Section of Cryospheric Sciences of the National Geophysical Committee of Russia to the XXVI General Assembly of the IUGG. Glaciological symposiums are held every two years, the last one took place in January 2013 in Novosibirsk. Since 2010, the Russian Academy of Sciences publishes journal “Ice and Snow” which is a continuation of the issues “Materials of glaciological studies” (since 1961) and since 1967, the scientific journal “Earth's Cryosphere”. Some main results of 2011–2014 are presented on the following topics: The “Earth's Cryosphere” and “Ice and Snow” journals, Glaciers and ice sheets, Permafrost, Paleo glaciology and paleo climate, Snow cover and snow avalanches, Sea, river and lake ice, Cryo data management.

В данном Национальном отчете представлены основные результаты исследований, проводимых российскими гляциологами в 2011—2014 гг., по темам, соответветствующим направлениям деятельности Международной ассоциации криосферных наук (МАКН) Международного геодезического и геофизического союза (МГГС). Данный отчет подготовлен Секцией криосферных наук Национального геофизического комитета Российской академии наук к XXVI Генеральной ассамблее Международного геодезического и геофизического союза. Гляциологические симпозиумы проходят каждые два года, последний был организован в январе 2013 г. в Новосибирске. С 2010 г. Российской академией наук издается журнал «Снег и лед», являющийся продолжением издания «Материалы гляциологических исследований» (с 1961 г.), а с 1967 г. — научного журнала «Криосфера Земли». Представлены некоторые основные результаты исследований в 2011—2014 гг. по следующим темам: журналы «Криосфера Земли» и «Снег и лед», ледники, вечная мерзлота, палеогляциология и палеоклимат, снежный покров и лавинные процессы, морские, речные и озерные льды, работа с крио-данными.

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Foreword

This report containing a review of the selected activities and scientific researches in 2011-2015 in Russia has been compiled for the presentation to the International Association of Cryosphere Science at the XXVI General Assembly of IUGG.

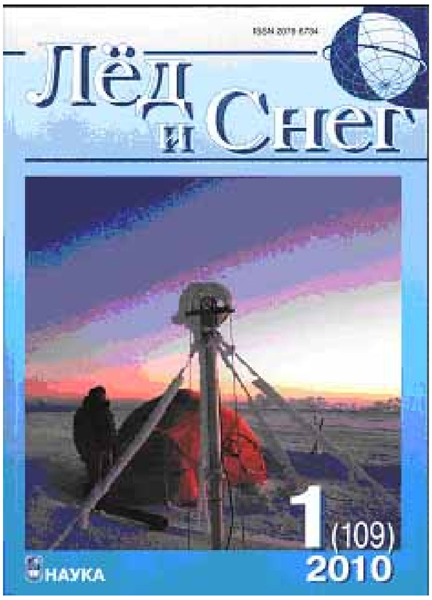
The preparation of this report has been organized by the Section of Cryosphere Science of the Russian National Geophysical Committee as a collective effort of the team of authors. Only minimal editorial work has been done when putting all these parts together, preserving, thus the diversity in styles and approaches.

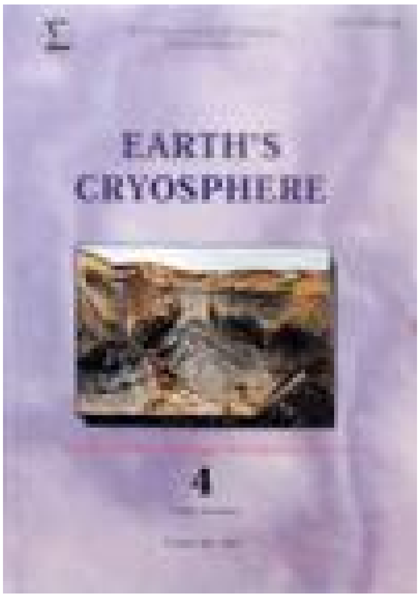
The report cannot be considered as comprehensive review of the principal achievements during this period of time in this field of science in Russia. Moreover, some arbitrariness in the choice of the material makes the report far from being complete. Many important results are not mentioned at all. Bearing in mind all these restrictive circumstances we hope that the readers who are interested in this field of science can find useful sources of information in this report.

THE “EARTH'S CRYOSPHERE” AND “ICE AND SNOW” JOURNALS

The journals “Earth's Cryosphere” (http://www.izdatgeo.ru/index.php?action=journal&id=2) and «Ice and Snow» (http://ice-snow.igras.ru/) are professional academic periodical publications. The scientific journal Earth's Cryosphere founded in January 1997 is included in the journals list of Supreme Attestation Commission of Russia. The main subject areas of published articles are Land hydrology, GEOLOGY, Complex and special section mechanics, GEOGRAPHY, Earth and Planetary Sciences (all). It publishes results of original theoretical and methodological research concerned with various permafrost (cryosphere) issues: structure of cryosphere zones, characteristics and evolution of cryogenic features, problems of cryogenesis, methods and results of modeling for permafrost components, methods for studying permafrost on the Earth and other planets, advanced trends and approaches in permafrost science, with reference to interdisciplinary studies.

The Journal «Ice and Snow» is professional academic periodical publication in the field of glaciology. It continues the series «Data of Glaciological Studies» that was started in 1961 by the Section of Glaciology of the Geophysical Committee at the Presidium of the USSR Academy of Sciences (now the Russian Academy of Sciences – RAS). 108 issues of the series were published since that time. Two to four issues regularly published the journal with this title in a year, and the each one contained about 240 pages in volume and 500 copies in printing. More than 250 copies were sent abroad, to libraries of leading glaciological organizations and many universities. This series became rather popular among professional Russian glaciologists.





Since 2010, instead of the former «Data of Glaciological Studies» the «Ice and Snow» journal that continues traditions established during almost a half of century of the previous publication is published. Its themes cover the whole of the glaciology area, including studies of the atmospheric ice, snow cover and avalanches, mountain glaciers and polar ice sheets, sea, river, lake and underground ices, glacial flows (torrents) and icings as well as past glaciations on the Earth and possible cooling in future. Its scope contains also an applied direction, embracing processes of icing, snow storms and drifts, movements of surging glaciers and glacier floods, like the known catastrophe of 2002 on the Caucasus Kolka Glacier.

Founders of the journal are Institute of Geography of the RAS, Glaciological Association, and the Publisher «Nauka». Its editorial board includes leading glaciologists from Russia and neighboring countries, its electronic version together with appropriate Internet site are being created. There is the present-day system of reviewing and contacts with authors via electronic mail. The journal retains numbering from the «Data of Glaciological Studies», and it will be published four times in a year, i.e. in spring, summer, autumn, and winter. Articles are published in the Russian language with summary in English (explanations of figures are given in two languages as well). Some papers can be published in English with extended summary in Russian. This journal has been registered by Russian Federal Agency for Press and Mass Communication, and it is included into the special list, that the Main Certifying Commission of the Ministry of Education and Science of the Russian Federation approve as a source of publication for dissertations. Volume of each issue will contain not less than 120 pages in the A4 format, and figures will be colorful.

There are the following permanent sections in the journal: glaciers and ice sheets; snow cover and avalanches; sea, river, and lake ices; underground ice and icings; palaeoglaciology; applied problems; criticism and bibliography; reviews and chronicles. Annual annotated bibliography of the Russian glaciological literature will be continuing to publish. The journal issues are to be prepared in the Institute of Geography RAS, where its editorial board and office are located. Editor – in – Chief is Academician Vladimir M. Kotlyakov..

GLACIERS AND ICE SHEETS

Antarctic

Geophysical studies in Antarctica. Recent *aerial-geophysical studies* are carried out on the Princess Elizabeth Land. They include airborne geophysical surveys on a scale 1: 500 000 together with magnetic and radar measurements. Results of these observations are used to construct maps and schemes showing the glacier structure, the subglacial landscape, and features of deep structure of the region under investigation. In particular, it had been found out that in the area of the Westfol oasis, in 300 km from the sea coast there is a wide 50 km trough, its depth down to 400 m.

Ground-based radar investigations of the last years were concentrated along a route of trips between stations Progress and Vostok. Here, the glacier structure and subglacial landscape were studied, and the geo-radar investigations of upper parts of the snow-and-firn thickness and geological cross-section of the Larsemann hills had been performed. Near the Vostok station, the wave-like (undulating) occurrence of layers inside the snow depth had been revealed with the wave amplitude up to 2 m. In the area of the Larsemann hills, the basic features of the glacier structure and the near-bottom part of the fresh-water water bodies had been also revealed.

Seismic studies by means of refraction shooting are carried out around the Vostok Lake since 2008. It was determined during these works that in the near-bottom part of the lake depression there are sedimentary deposits with their depths from 400 m in the northern part up to

1200 m in the southern one. The crystalline basement underlies them (*S.V. Popov, Marine Geological Expedition, St. Petersburg*).

Fluctuations of the Antarctic ice sheet surface altitude. Results of satellite lidar altimeter (system ICESat, accuracy of measurements of 3–5 cm) obtained with periodicity of 4 months during 2003–2008 made it possible to reveal a new phenomenon, namely, periodic fluctuations of altitude of the Antarctic ice sheet surface. It is supposed that this phenomenon is related to behavior of subglacial lakes. Motion of subglacial water is reflected in changes in the surface altitude above subglacial lakes. There was revealed indication of interrupted equilibrium in subglacial lakes, and, in particular in the Vostok Lake that is pronounced in abrupt change of the glacier surface altitude. Cascades of subglacial lakes were also found. Shifting of phases of vertical motions of glacier surface in the cascades may be interpreted as a result of influence of the subglacial runoff. These researches are continued with the use of new space system CRYOSat 2 equipped with the radar (frequency 2.5 cm) measuring altitudes of the Antarctic ice sheet surface (*L.N. Vasiliev, V.M. Kotlyakov, M.Yu. Moskalevsky, Institute of Geography RAS, Moscow*).

The studies of Antarctic ice sheet surface above subglacial lakes using ICESat data. Progress in understanding the surface dynamics above the subglacial Lake Vostok is achieved owing to use of the ICESat satellite laser elevation measurements, which enabled us to determine surface fluctuations with precision up to 3 cm. The position of projections for orbits (tracks) above Lake Vostok is exhibited in Fig. 1 in both ascending and descending circuits. Surface fluctuation along track 071 is shown in Fig. 2, which demonstrates a sequence of the vertical profile position. Variations of the profile are manifested in both common raising or lowering and in a simultaneous local deformation of the surface. A new idea on punctuated equilibrium of the surface above Lake Vostok is elaborated; this idea is concluded in irregular, sharp vertical displacements of the ice surface by up to 40 cm. Deformation of the surface is accompanied with a common raising or lowering, and with local vertical displacements up to 20 cm in amplitude. It has been proved experimentally that snow transport on the surface above the lake causes only redistribution of snow and forms fractal structures that do not have any effect on surface deformation. The form of the surface is not an inclined plane due to many bends that are particularly related to ice flowing on the lake water area. [1].

Improving in understanding cascades of subglacial lakes in Antarctica and in the dynamics of their surface was derived using satellite laser altimetry measurements ICESat in Recovery ice stream catchment, East Antarctica. The morphological and dynamical signs indicate subglacial lakes and the positions of their shore lines. Surface oscillations above the subglacial lakes are accompanied by ice sheet surface deformations and elevation change in

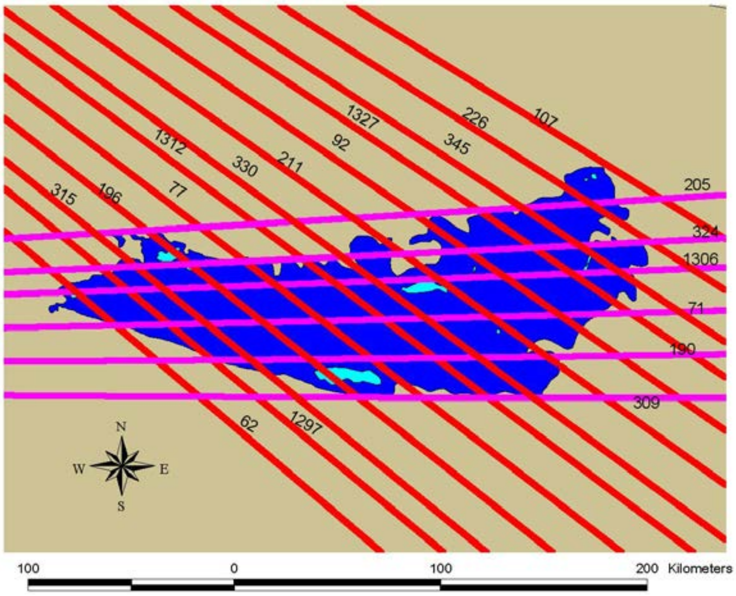


Fig. 1. Contour of Lake Vostok and position of the ICESat tracks. The order numbers of ascending (red) and descending orbits (rose).

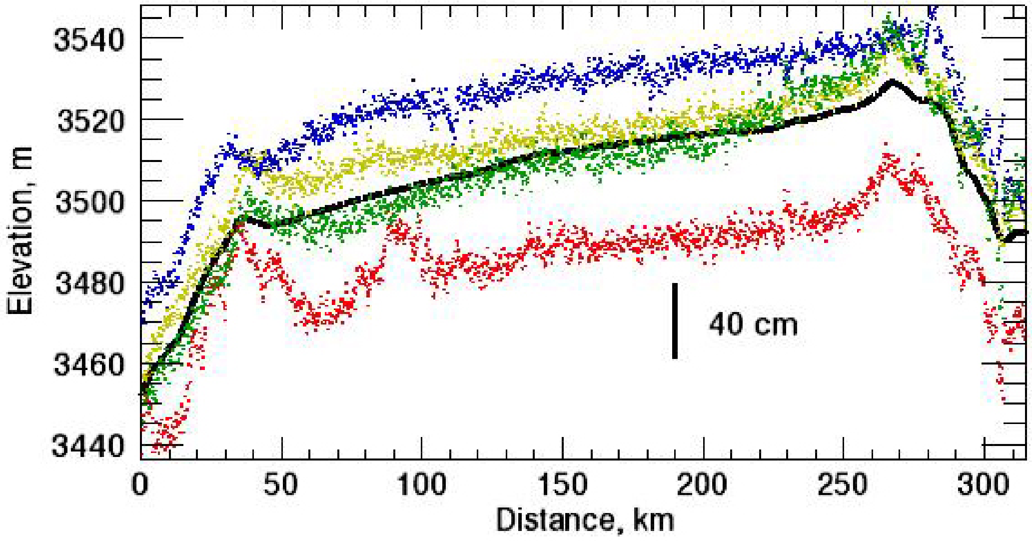


Fig. 2. Variations of surface elevation above Lake Vostok along the vertical profile along the track 071 in the period since February 2004 until February 2006. Elevation variations shown on the bar are magnified 50-fold for greater clarity. Surface position on 2003 is marked in solid black line.

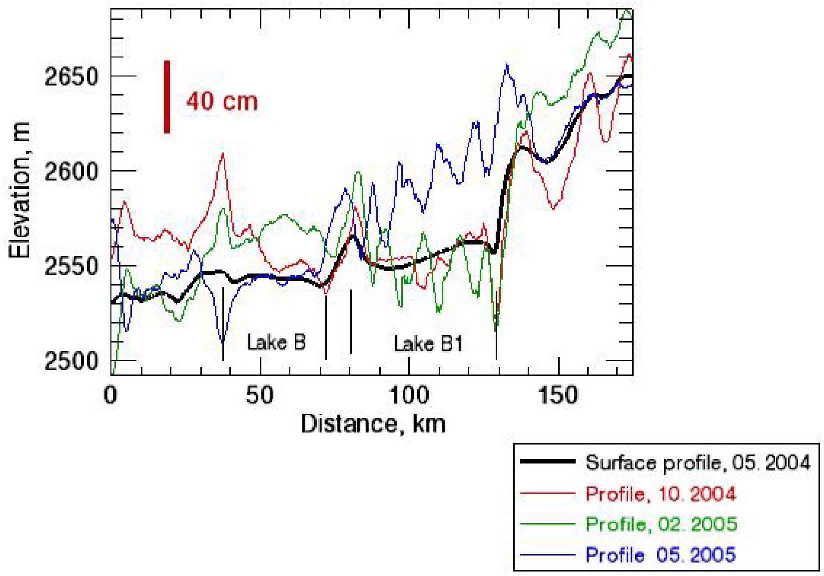


Fig. 3. Fluctuations of ice sheet elevation above the cascade of subglacial lakes B and B1 (Recovery ice stream catchment, East Antarctica) along track 199. Boundaries of shore lines are marked by black vertical lines. Oscillation of elevation in transition zones with high amplitudes is out of the phase. Ice surface deformations above the lakes and the difference in the change of ice sheet elevation are identified. Elevation variations shown in the bar are magnified 100-fold for greater clarity.

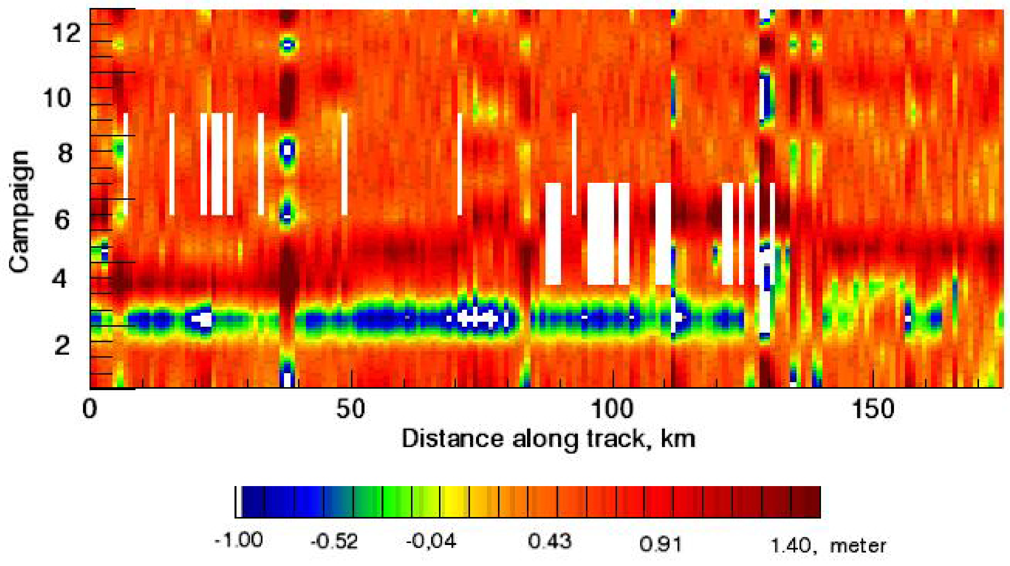


Fig. 4. Spectrogram of elevation change in the cascade of subglacial lakes B and B1 (Recovery ice stream catchment) based on the vertical profile along track 199 for the period of 13 campaigns from April 2004 until February 2008. The abscissa axis is analogous to the horizontal axis in Fig. 3. The ordinate axis corresponds to the time of measurements (campaigns). For better visual representation, the time scale is magnified tenfold due to interpolation of measurements between the campaigns. The coordinates of the transition zones are 37, 73, 82, and 128 km. The marginal transition zones with opposite phase oscillations and the amplitudes of elevation change above the lakes occur in the interval from –0.7 to 0.7 m. The amplitudes of glacier surface oscillations above the subglacial lakes are significantly lower. The difference between

ice_sheet elevation change above subglacial lakes B and B1 is up to 0.3 m, and the peak value was reached only twice during all the campaigns, in February and May 2005.

Complete insight into the cascade process and fluctuations of surface above the adjacent lakes in space and time has been derived using transition zones in the range about 1 m (Fig. 3). spectrogram (Fig. 4).The given values in the vertical profile were acquired from satellite laser altimetry after 13 campaigns along track 199. All the measurements are presented in the form of horizontal lines.

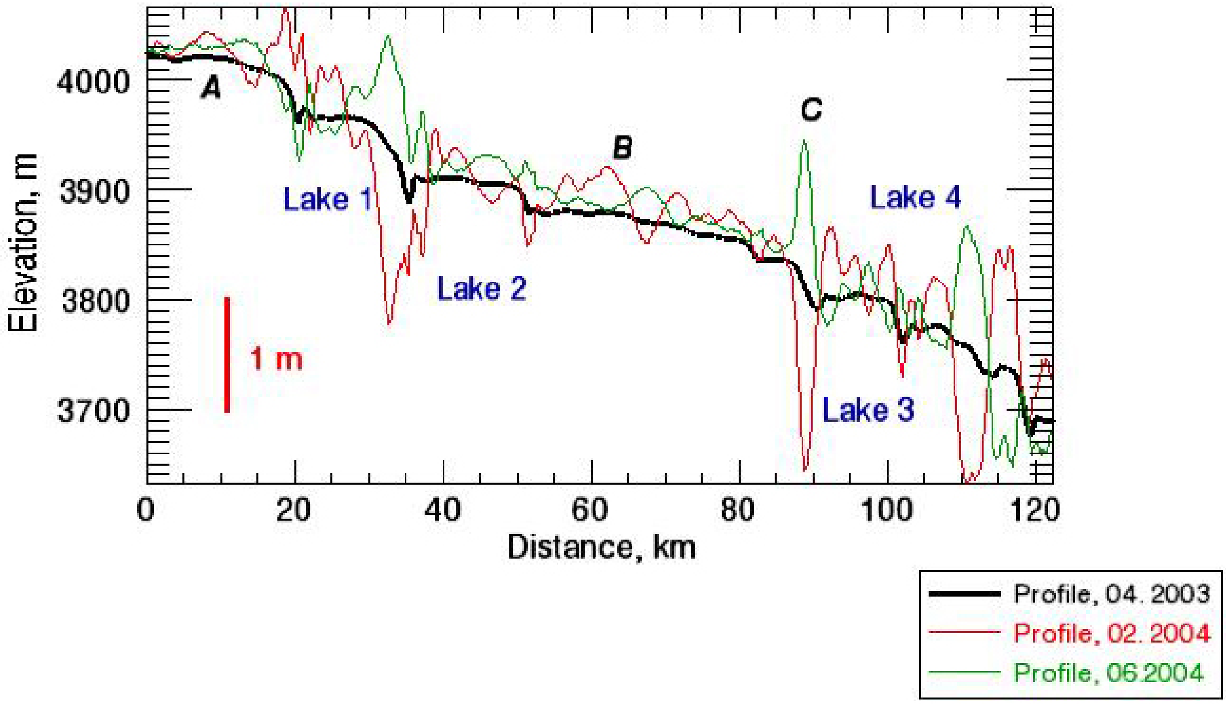


Fig. 5. The cascade of subglacial lakes in the area of Dome A along track 1352 and the changes of the ice sheet elevation. The greatest oscillations occur in transition zones at the grounding line. The values of oscillations in transition zones are out of phase. *A*, *B*, and *C* are the vertical profiles measured in April 2003, February and June 2004, respectively. Elevation variations shown in the bar are magnified 100-fold for greater clarity.

The sequence of lines along the ordinate axis characterizes elevation change of profile points in time. In the spectrogram, the dynamics of surfaces above the subglacial lakes B and B1 is presented in terms of both time and space. It is clear from the spectrogram that surface oscillations are periodic in transition zones, while changes in elevation above the subglacial lakes are random. In this case, elevation change in a lake cascade occurs out of phase. Significant changes in the surface elevation were recorded a couple of times over five years of observations.

Cascade distribution of the subglacial lakes was also found near the Dome A, East Antarctica (Fig. 5). They are characterized both by the morphological features of the surface and the dynamics in transition zones what can be seen on the spectrogram (Fig. 6). In comparison with the dynamics of the surface elevation above the subglacial lakes in the Recovery ice stream catchment, these lakes have a smaller amplitude of oscillations. Comparison between the dynamics for lake cascades in the Recovery ice stream catchment and near Dome A indicates that the elevation changes above the lakes near Dome A occur in phase; in contrast, elevation changes are asynchronous in the Recovery ice stream catchment and they can be spontaneously out of phase. At the same time it should be noticed that considered morphological and dynamical pattern and behavior above transition zones are similar. In the sense of technology, the method of mapping subglacial lakes based on satellite laser measurements of elevation is initiated. [2, 3].

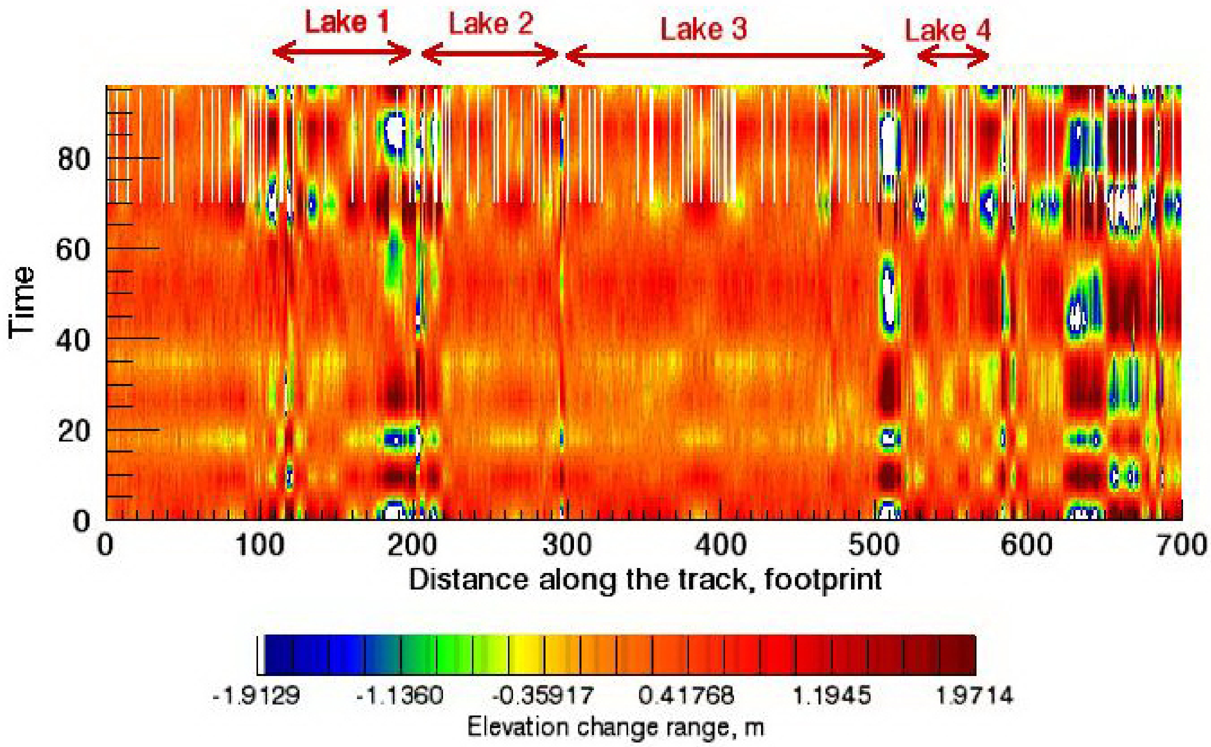


Fig. 6. Spectrogram of elevation change along track 1352 on Dome A, corresponding Fig. 5, but represents pattern of surface elevation behaviour on the cascade of lakes during five years (2004–2008). Surface dynamic and fluctuation in transition zones are clearly to be seen

Phenomenological and experimental arguments that ice sheet surface fluctuation in Antarctica is mediated by ice velocity and subglacial water flow are provided. To understand this link we use temporal coherence to refer to the comparison between vertical profile and a shifted profile along the repeat ICESat track. A profile shift due to ice velocity is determined from cross-correlation between initial and shifted profiles (Fig.7). Ice velocity induced fluctuation in surface elevation and deformation of the vertical profile. The degree of coherence indicates a decrease in similarity of moving vertical profiles and their deformation (Fig. 8). Some features that water flow beneath the ice sheet and over the subglacial lakes generates irregular rise and fall of the surface were found. Observations in area of Dome A and its slope have revealed such behavior of surface, where the surface is placid and ice velocity is measly 2-5 m/y. [4]. (*L.N. Vasiliev, V.M. Kotlyakov, M.Yu. Moskalevsky, Institute of Geography RAS, Moscow*).

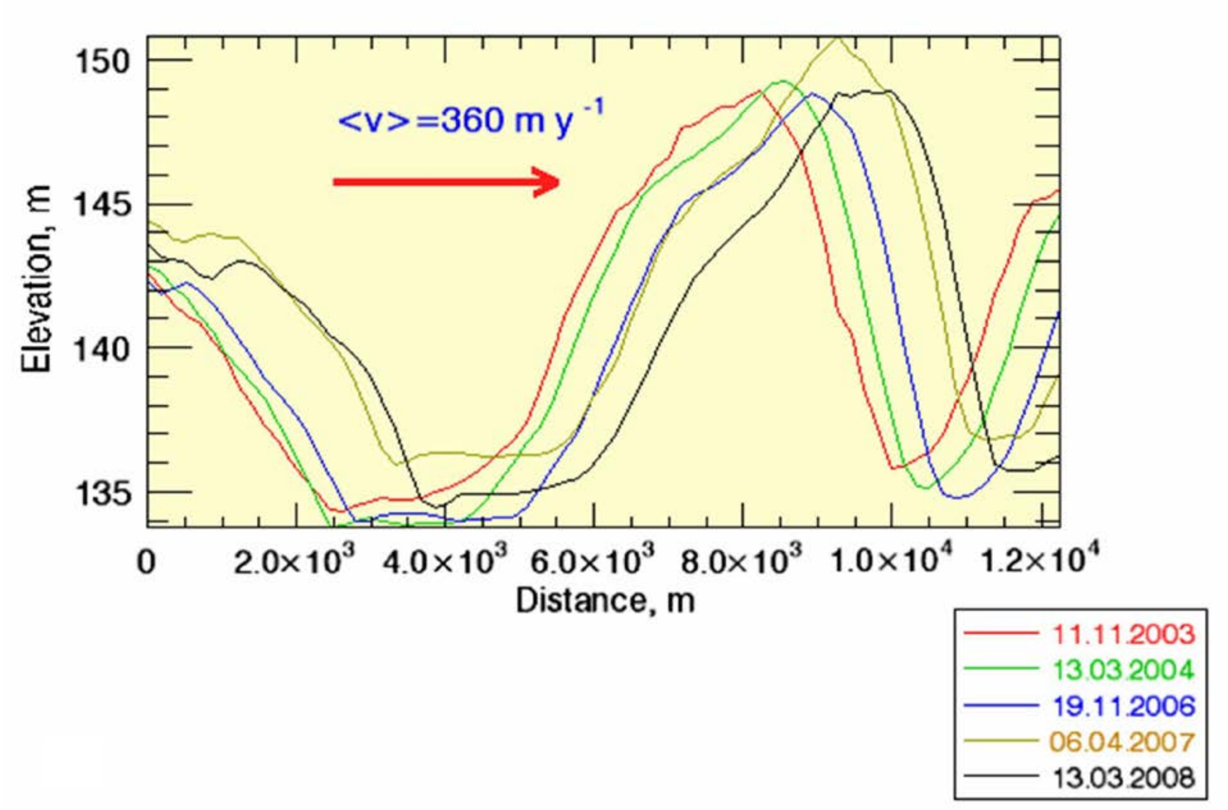


Fig. 7. Ice flow represented in the vertical profile moving with velocity 360 m/yr along track 302 in the Lambert Glacier catchment, transition zone. Level of coherence $\gamma 1,2(\Delta x) = 0.94$, standard deviation of elevation $\sigma = 74$ cm

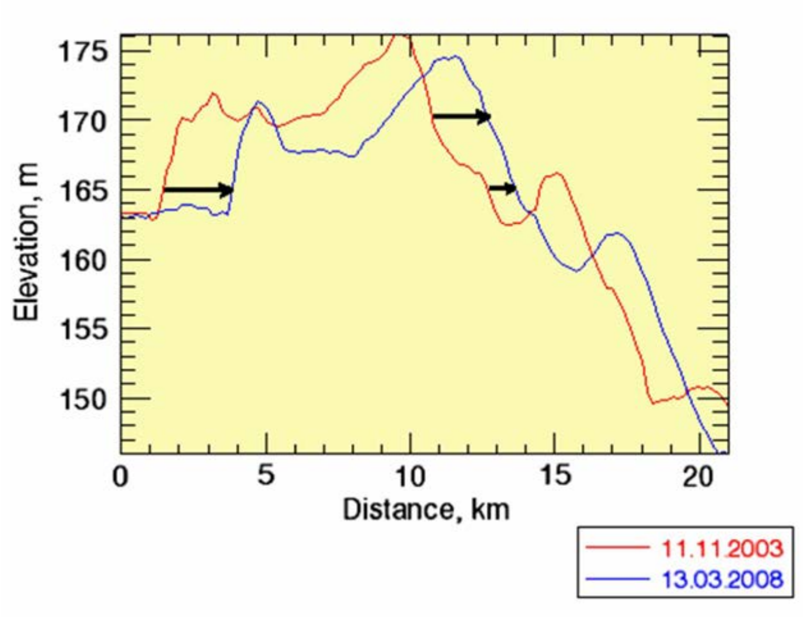


Fig. 8. Comparison of two vertical profiles: initial (red) and shifted (blue) along track 302 in the Lambert Glacier catchment. Plot shows shift of vertical profile by ice flow with degree of partial coherence $\gamma 1,2(\Delta x) = 0.83$; ice velocity caused ice body to deform sharply $\sigma = 2.54$ m; the arrows show different shifts of parts on the profile.

Investigation of snow-firn thickness and ground in the East Antarctica by means of geophysical radar. The field investigations of snow-and-firn thickness and ground structures per-formed with the use of geophysical radar GPR (Ground-Penetrating Radar) have been done. Industrial radar GSSI SIR10B (Geophysical Survey Systems, Inc., USA) with «5106» antenna (pulses frequency of 200 MHz) was used. Its mean wavelength is 1.57±0.18 km. The main purpose of this work was to test this new technique for solution of glaciological and geolog-ical problems. The works were done during the austral summer season of 2012–2013 (58th Rus-sian Antarctic Expedition) in the Eastern Antarctica and mainly concentrated in the vicinity of the Lake Vostok, between the Russian stations Vostok and Progress (the Larsemann Hills). The GPR sounding was carried out together with precise geodetic measurements. The electromagnet-ic wave propagation in the snow-firn layer was analyzed using the data on density obtained from the 5G borehole at the Vostok Station. Investigations near the Vostok Station focused on a huge snow ridge or so-called "megadune" located eastward from the station at a distance of 30 km. About 80 km of the GPR cross-sections were collected there. Eight internal layers were traced. They demonstrated wavy forms with amplitudes of about 10 m high which corresponded to the megadunes. Main result of GPR investigations in the Larsemann Hills was our understanding of the snow-firn and ground structures in this region. The GPR data collected on structures of cre-vasses near Progress-1, shallow glacier near the Progress-3, and ground not far from Progress-2 are also discussed. Methodological recommendations on using the GPR under conditions of the Eastern Antarctica were developed. *(S.V. Popov, Polar Marine Geological Survey Expedition, Sankt-Petersburg;)*

Lake Vostok, East Antarctica: ice thickness, depth of lake, subglacial and bedrock relief. This work presents a compilation of the Russian ground-based (collected in 1995–2008) and American (collected in 2000/01) airborne geophysical data. The models of the ice thickness, ice base and bedrock topography and the Vostok Subglacial Lake (VSL) depth were formed based on the joined set of radio-echo sounding and reflection seismic data. Ice thickness of the VSL area varies within 1950–4350 m. Absolute heights of the VSL water-table are changed approximately from –600 m in northern part to –150 m in the southern part. The volume of the water in the lake is about 6100 cubic km; the average depth is about 400 m. (S.V.Popov, Polar Marine Geological Survey Expedition, V. N. Masolov, V. V. Lukin, Arctic and Antarctic research institute Sankt-Petersburg)

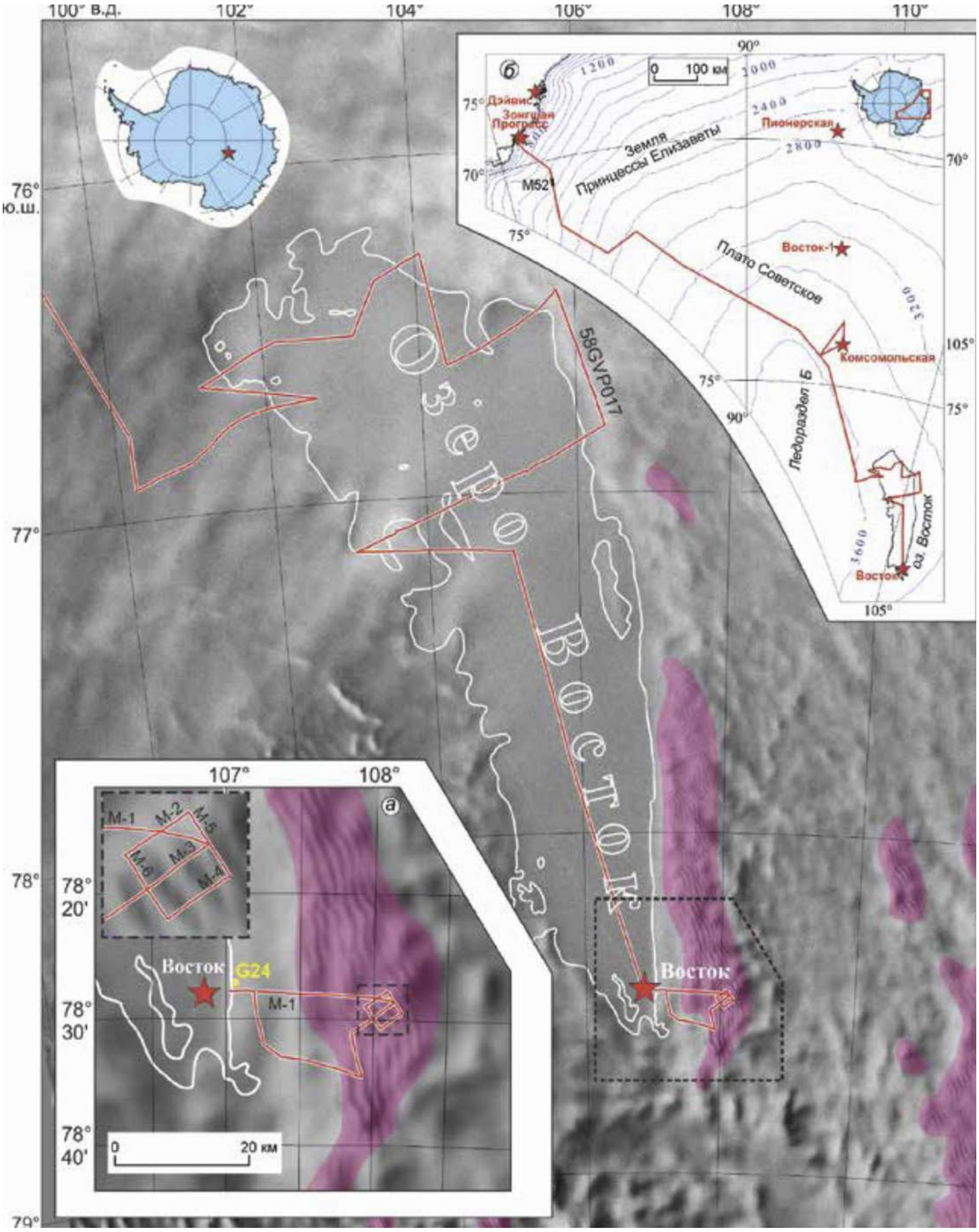


Fig.9 Location of GPR profiles in the Lake Vostok area and between Vostok and Progress stations.Red line is the GPR profiles; Lake Vostok coastline is depicted by white; megadune region is depicted by magenta area; point of the glaciological measurements G24 is marked by yellow circle;

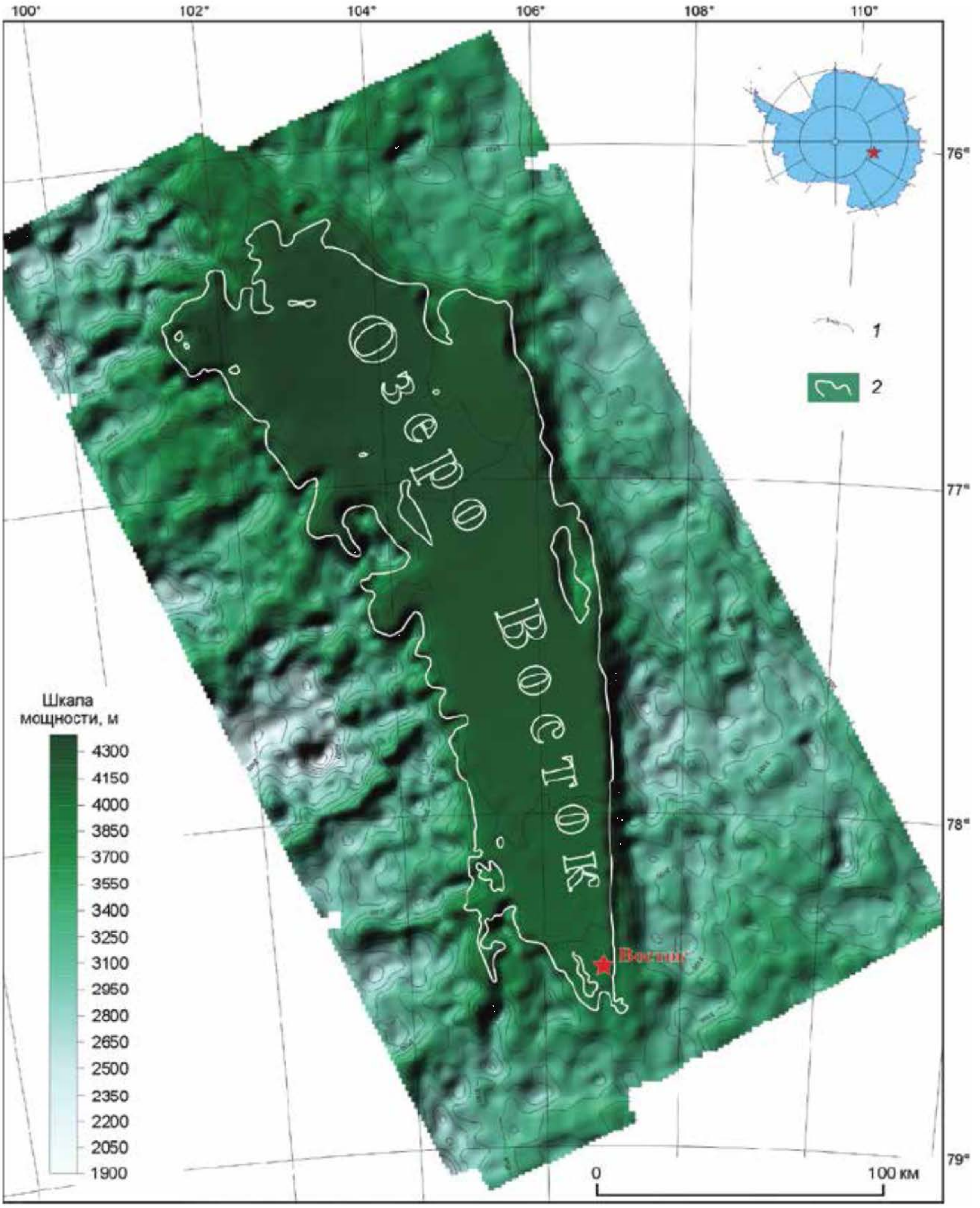


Fig. 10. Ice thickness of the Vostok Subglacial Lake area:
1 – ice thickness contours in meters; the contour space is 150 m; *2* – Lake Vostok shoreline

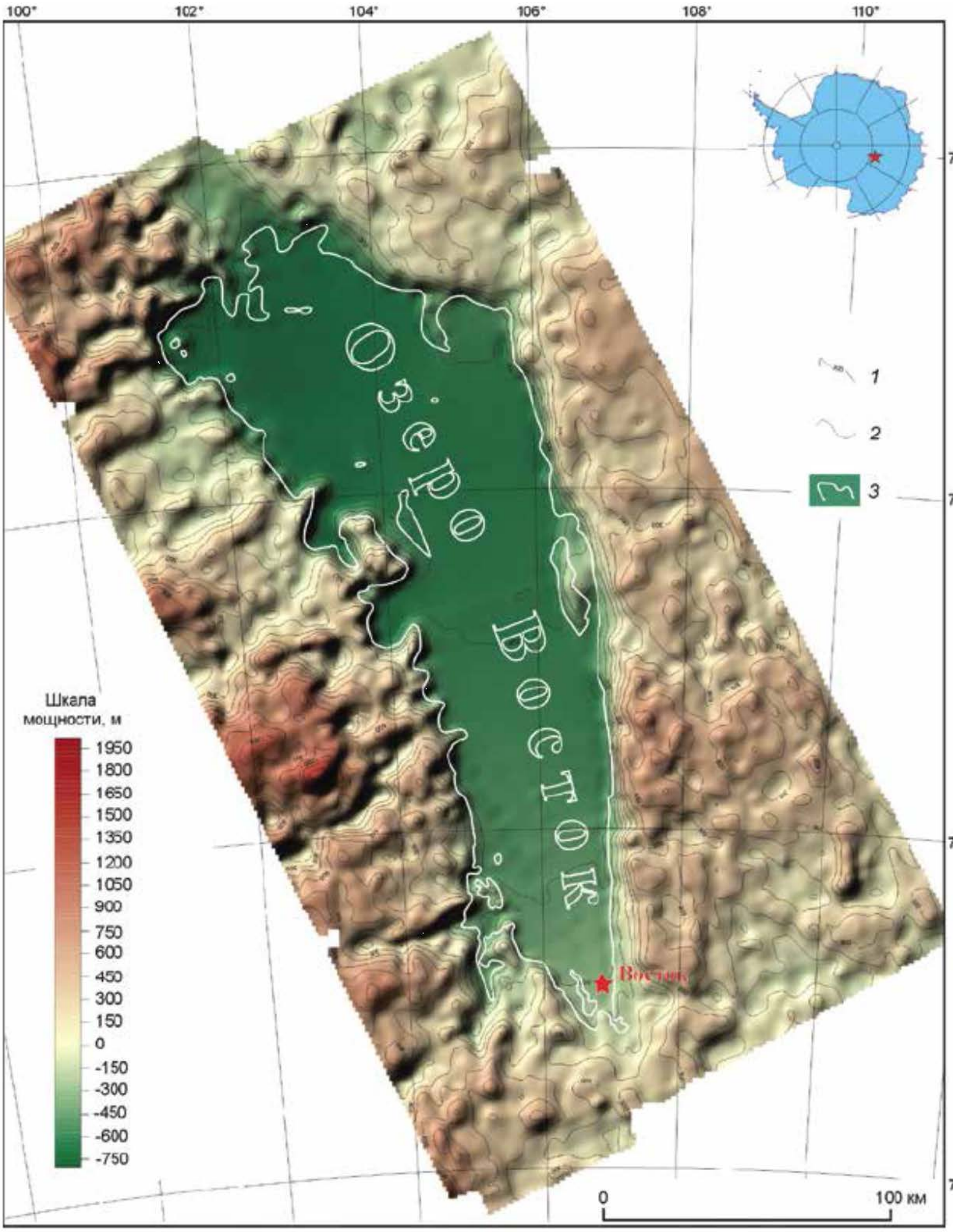


Fig. 11. Ice base of the Vostok Subglacial Lake area:*1* – ice base contours in meters; the contour space is 150 m; *2* – sea level (surface of WGS-84); *3* – water-table of Lake Vostok

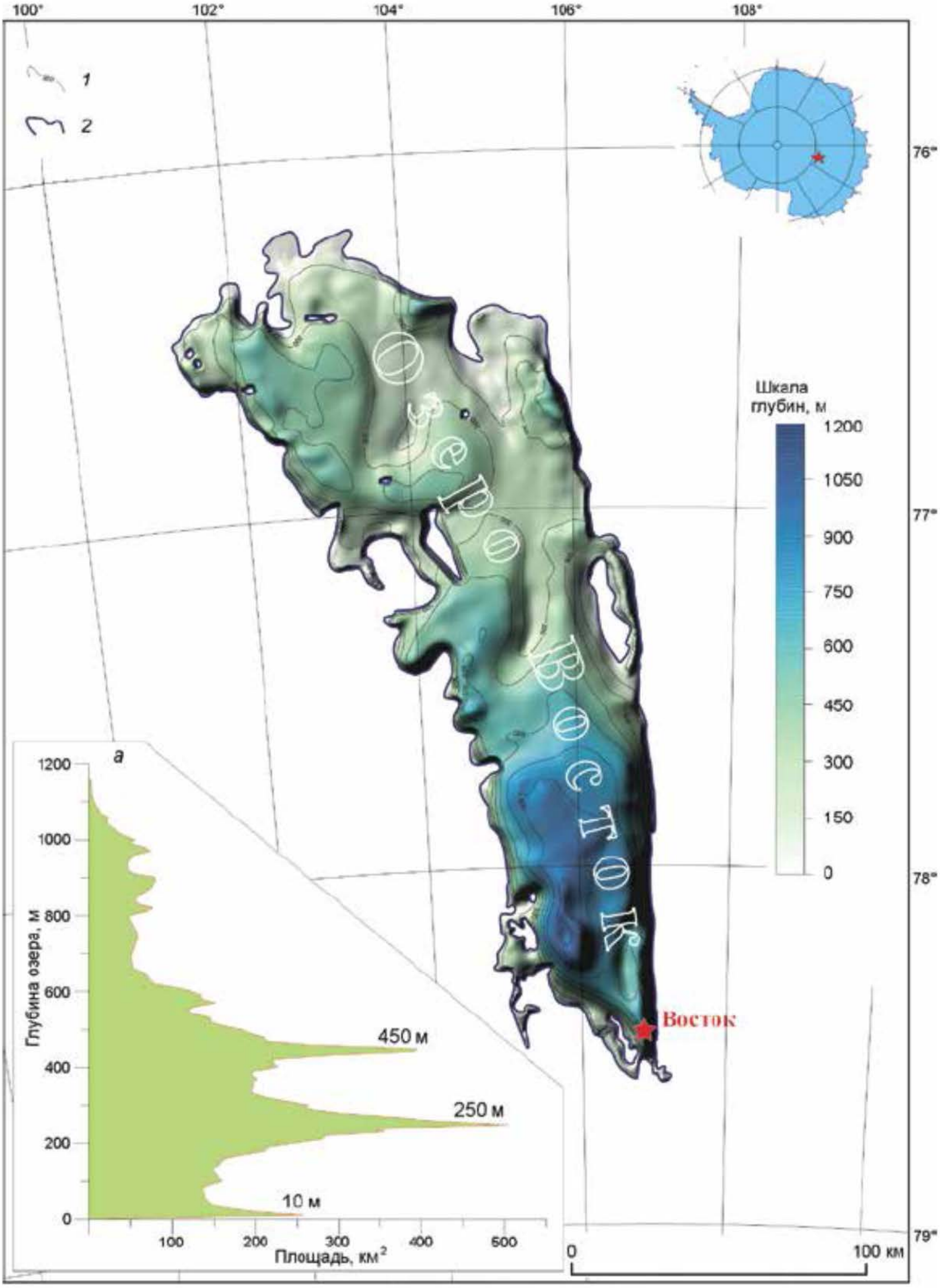


Fig. 12. Depth of Vostok Subglacial Lake:*a* – dependence between the lake depth and area of the depth; *1* – water depth contours in meters; the contour space is 150 m; *2* – water-table of Lake Vostok

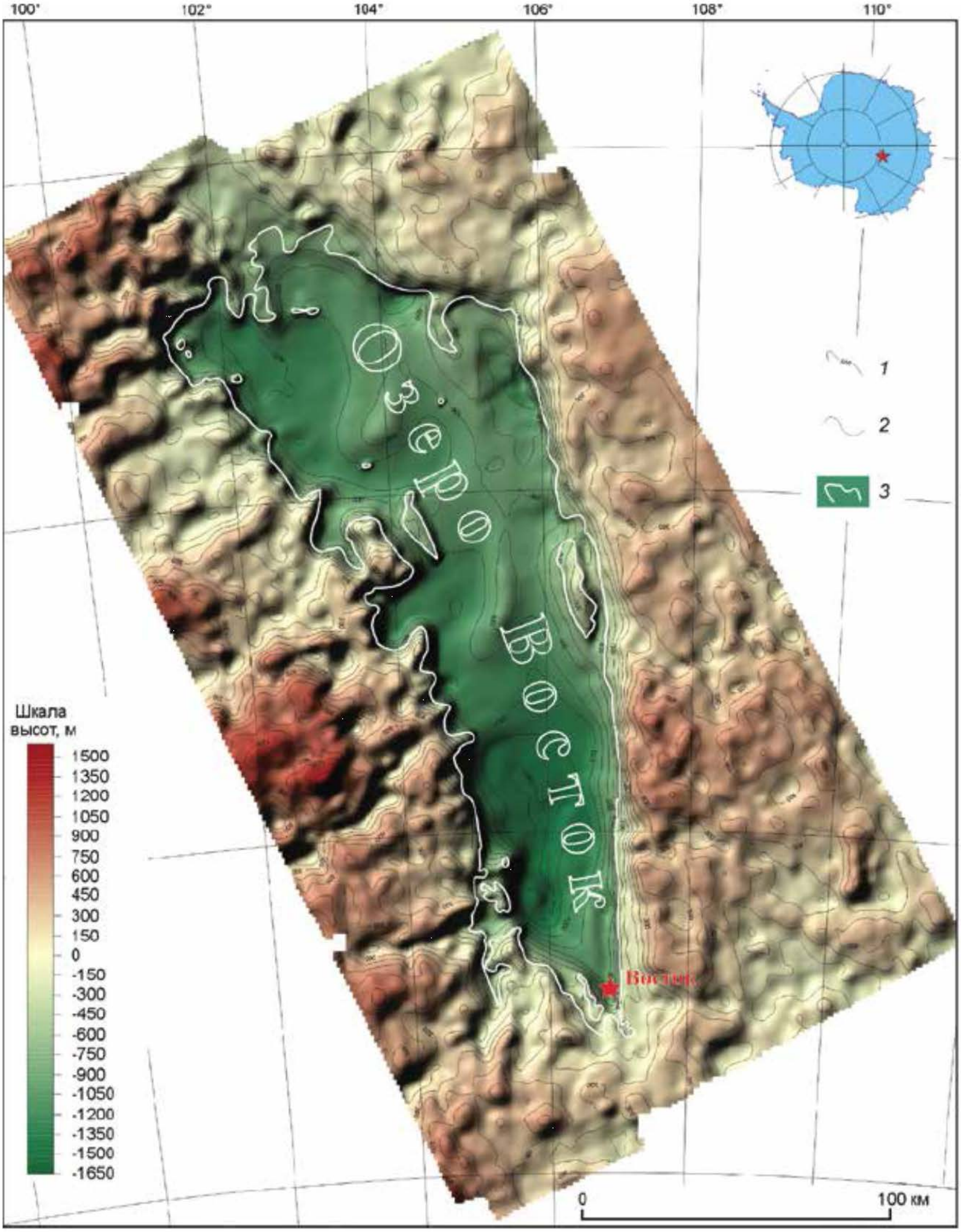


Fig. 13. Bedrock topography of the Vostok Subglacial Lake area:
1 – bedrock topography contours in meters; the contour space is 150 m; *2* – sea level (surface of WGS-84); *3* – Lake Vostok shoreline

ARCTIC

Studies of glaciers on Svalbard. Started in 2010 studies of glaciers Eastern Grønfjordbreen and Fridtjovbreen on the Nordenskiöld Land were continued in following years. On the basis of data obtained by ground-based radar sounding (20 MHz frequency) and thermal sounding of boreholes 10-20 m deep it was found that both these glaciers are polythermal. In the Eastern Grønfjordbreen portions of cold and warm ice are respectively 83 and 17%, the same data for the Fridtjovbreen Glacier are 26 и 74%. According to the rate of radiowave propagation the water content in the warm ice amounts to 2–5%. For the last 30 years, average thickness of cold ice in the Eastern Grønfjordbreen decreased by 34 m, while that of warm by only 9 m. As for the Fritjof glacier, the cold ice became there thinner by 87 m, but in contrast the warm one thicker by 48 m. These differences in changes in hydro-thermal structure of adjacent glaciers when their losses of thicknesses in 35–45 m are similar, can be related to the fact that changes in the Eastern Grønfjordbreen glacier took place against the background of its shortening under conditions of the climate warming. At the same time, similar changes in the Fridtjovbreen Glacier were complicated by its surge in 1991–1997 (*N.F. Glazovsky, I.I. Lavrientjev, Yu.Ya. Macheret, Institute of Geography RAS*).

Changes of hydrothermal structure of Austre Gronfjordbreen and Fridtjovbreen Glaciers in Svalbard. The results of ground-based RES studies (20 MHz) at the Austre Grønfjordbreen and Fridtjovbreen glaciers on Nordenskiöld Land, Svalbard, spring 2010–2012, were compared with previous airborne RES data (620 MHz) of 1979 to understand the hydrothermal structure and its changes with time for these twinned glaciers. Temperature measurements in 9 shallow ice bore holes (down to 20 m) of spring 2013, and other RES and bore-hole data (1977–2005) were also considered. Both glaciers now are polythermal ones. The ratio of cold/temperate ice volumes in Austre Grønfjordbreen is 83 and 17 per cent, and in Fridtjovbreen is 26 and 74 per cent. The water content in temperate ice estimated from radio wave velocity is ca. 2–5%. Total water content in temperate ice of Austre Grønfjordbreen is estimated as $1{,}8–4{,}5 \cdot 10^{-3}$ km^3, and in Fridtjovbreen as $74–85 \cdot 10^{-3}$ km^3. Over the past 33 years (1979–2012) the average thickness of the cold ice in Austre Grønfjordbreen decreased by about 34 m, and thickness of temperate ice by 9 m. In Fridtjovbreen the cold ice has thinned by 87 m, but the temperate ice became thicker by 48 m. These differences in hydrothermal structure changes of the neighboring glaciers with common climatic history are attributed to the additional effect of Fridtjovbreen surge in 1991–1997 resulted in its additional internal heating. ([1]*E.V. Vasilenko, [2]A.F. Glazovsky, [2]I.I. Lavrentiev, [2]Yu.Ya. Macheret[1]Institute "Academpribor", National Academy of Scinces, Uzbekistan, Tashkent; [2]Institute of Geography, Russian Academy of Sciences, Moscow*)

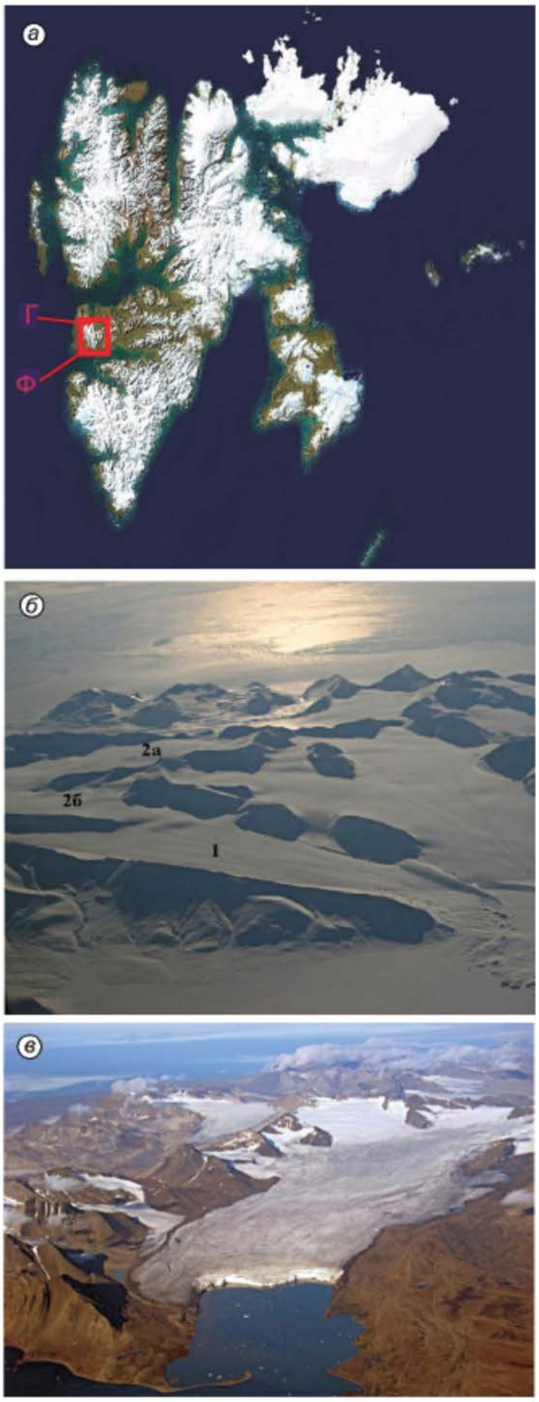


Fig. 14. Location map of Austre Gronfjordbreen (Г) and Fridtjovbreen (Ф) glaciers in Svalbard – *а*; glaciers of western Nordenskiold Land in 2007 – *б*; the western and eastern branches of Fridtjovbreen in 2010 after its surge in 1990-s – *в* (photo by V. Kobzar): 1 – Austre Gronfjordbreen; 2а – the western branch of Fridtjovbreen; 2б – the eastern branch of Fridtjovbreen

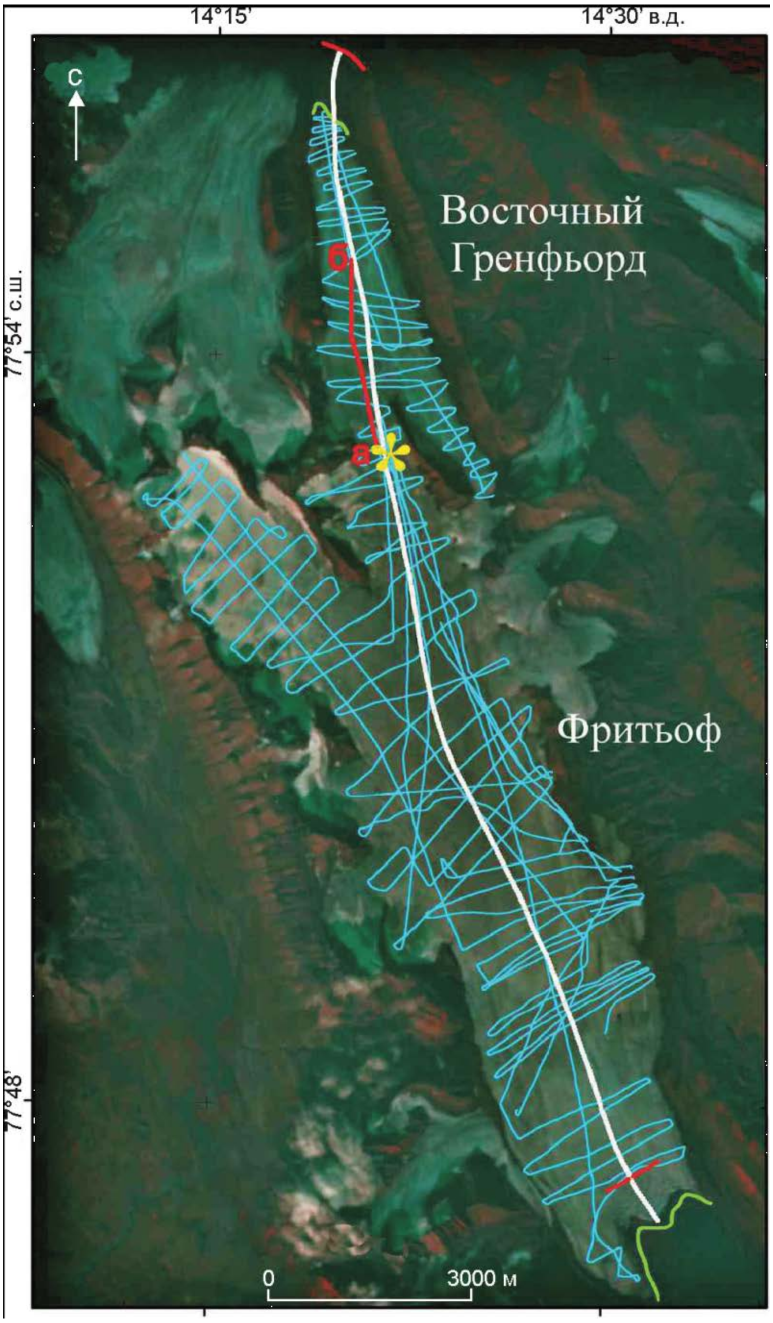


Fig. 15. Ground-based 20 MHz radar measurements of 2010–2012 at Austre Gronfjordbreen and Fridtjovbreen glaciers – blue lines and the approximate position of the longitudinal airborne 620 MHz track of 1979 – white line, see also Fig. 10.Red-color section а–б shown in Fig. 3; terminus position of glaciers in 1979 – red lines, in 2012 – green lines; ice divide position in 2012 is indicated by asterisk

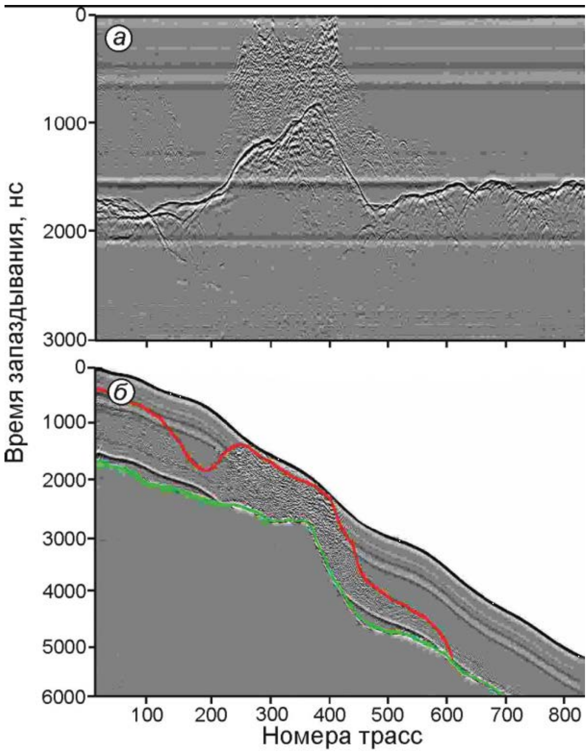


Fig. 16. An example of the original (*a*) and migrated (*б*) radarograms recorded with 20 MHz VIRL-6 monopulse radar along the Austre Gronfjordbreen longitudinal profile. Reflections from the bed and the cold and temperate ice surface (CTS) are shown in green and red; the profile location is shown in Fig. 2

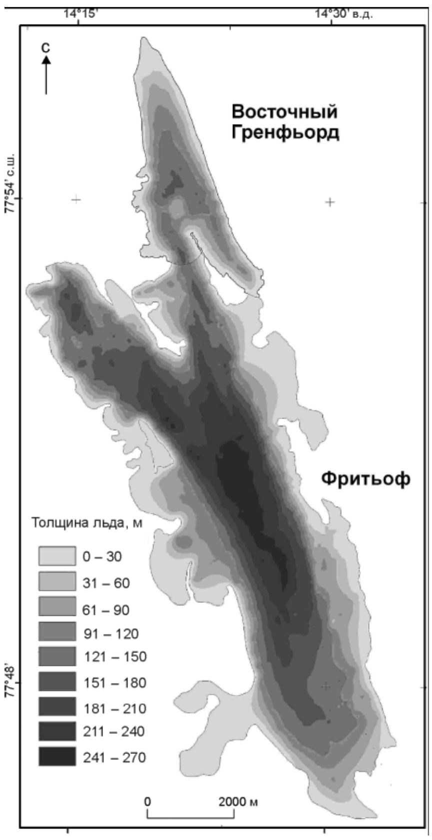


Fig. 17. Ice thickness of Austre Gronfjordbreen and Fridtjovbreen glaciers from ground-based 20 MHz radio echo sounding, 2010–2012

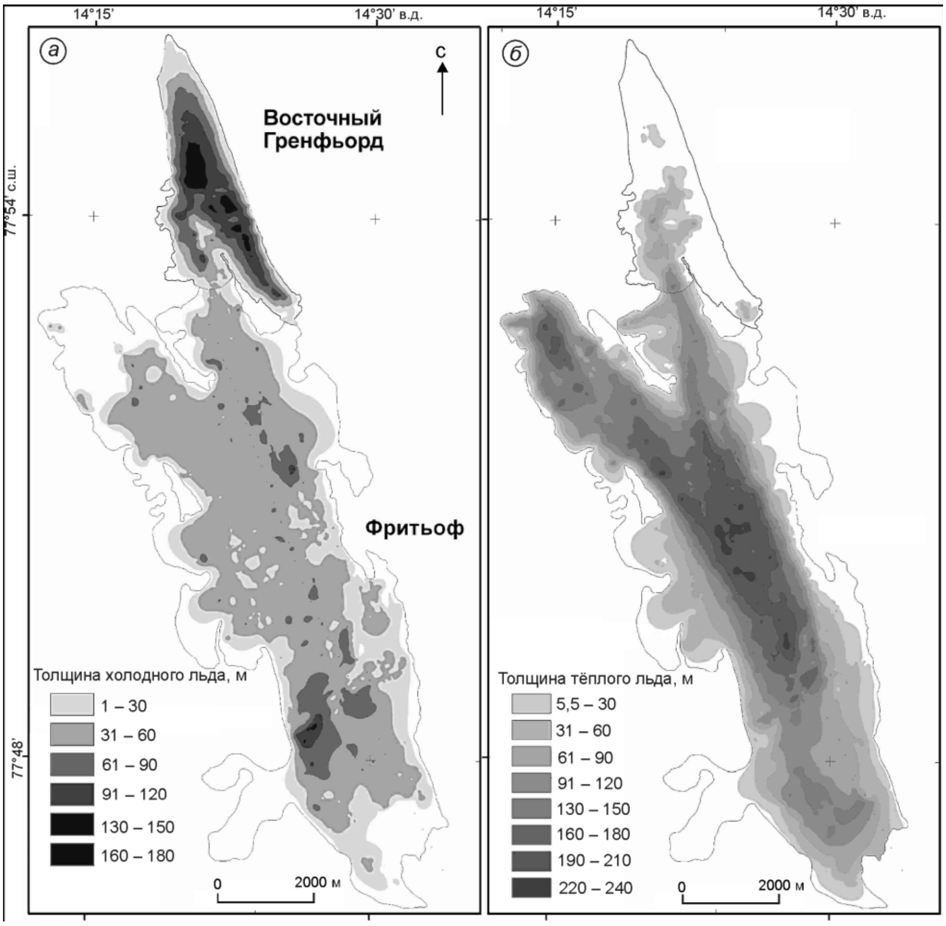


Fig. 18. Hydrothermal structure of Austre Gronfjordbreen and Fridtjovbreen glaciers from 20 MHz RES data 2010–2012: *a* – thickness of the upper cold ice layer; *б* – the lower temperate ice layer; the thin line shows the glacier margins from ASTER image 2011

MOUNTAIN GLACIERS

Investigations of evolution of mountain glacier systems of North Eurasia under present-day climate conditions. In framework of the GLIMS project we estimated current state as well as changes happening to glacier systems of North Eurasia mountain regions since time when the USSR Glacier Inventory had been compiled. Materials of satellite ASTER surveys were used as the main source of new data. General tendency of reduction of the glacier areas for the last decades is as follows: Polar Urals – 23,5%, Caucasus – 17,7%, Tien Shan – 12,6%, Altai – 19,7%, Suntar-Khayata – 27%, Sredinny (Central) Ridge in Kamchatka – 16,6%. Almost everywhere this reduction took place against the background of the summer temperatures rise by 1.5–2 ºC (*G.A. Nosenko, T.E. Khromova, Institute of Geography RAS*).

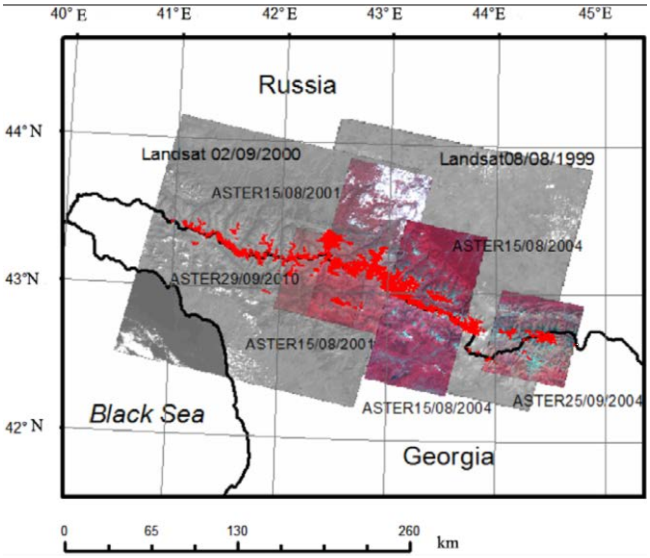


Fig.19.Caucasus glacier outlines (in red) derived from Landsat and ASTER imagery.

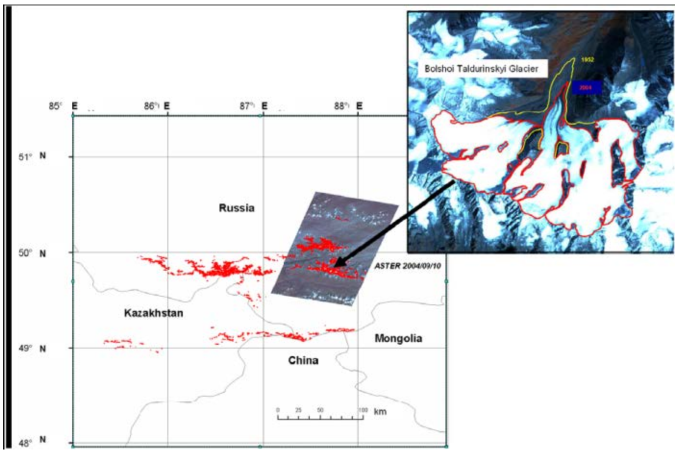


Fig.20 Altai glaciers delineated from space imagery and ASTER 09/10/2004 used for the evaluation of changes in the surface area of glaciers in the North and South Chuya Ridges in 1952–2004 (main map). Retreat of the Bolshoi Taldurinkyi glacier, the South Chuya Ridge, between 1952 (air photos) and 2004 (ASTER) (inset map).

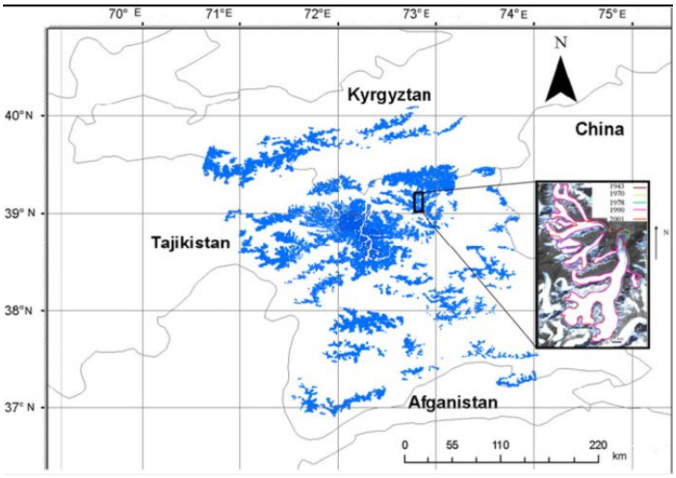


Fig.21. Pamir Alay glaciers delineated from space imagery (2000–2012) for the GLIMS project (http://glims.org). Black rectangle shows location of study glaciers in Zulumart Range (inset map).

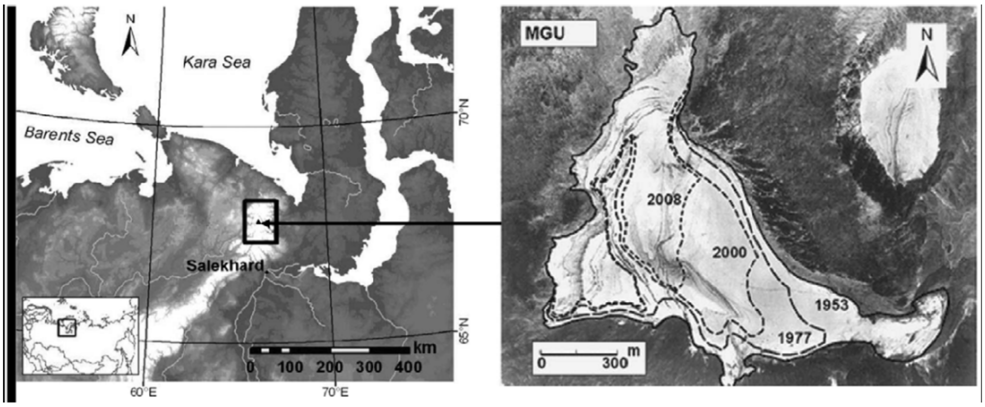


Fig.22(a) Geographical location of the Polar Urals glaciers. Black rectangles show location of the Polar Urals (inset map) and glacierized study area (main map). (b) Changes in map area of the MGU glacier of the Polar Urals between 1953 and 2008. An aerial
photograph from 1953 is used as background.

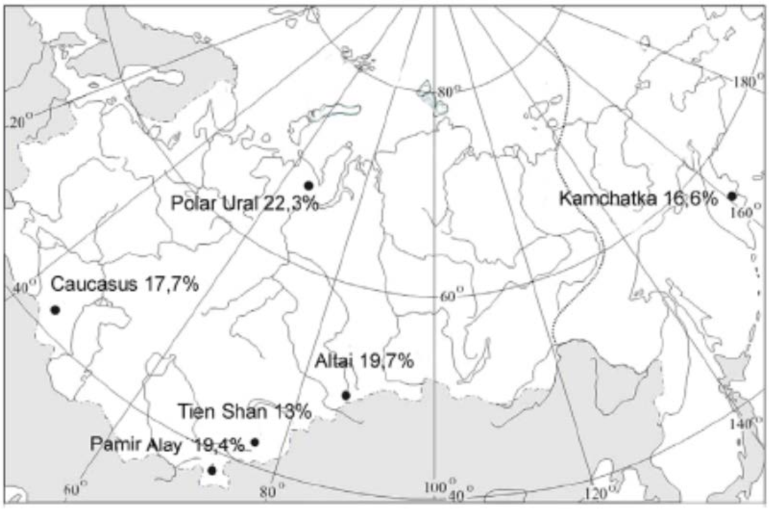


Fig.23. Glacier area shrinkage (in per cent) in the studied mountain regions of Northern Eurasia in the second part of the 20th century.

Glacier area and volume changes in the Mountain Altai (Russia) since the mid-twentieth century from space imagery data. To examine changes in the area and volume of the Katun river basin glaciers, North and South Chu glaciers of the Altai Mountains since the beginning of the USSR glaciers inventarization to the present, USSR Glaciers Inventory data, space imagery – CORONA-1968, ALOS PRISM-2008, Landsat and ASTER 2000–2012 have been used. In total, glaciers have lost 172.4 km^2(27.4%) of its area.

During the period from 1952 to 2008, glaciers of Mountain Altai were investigated that allowed estimating current changes in their areas and volumes. Areas of glaciers shortened during the whole this period. By 2008, glaciers of the Katun, North and South Chu ranges did lost 172.4 km^2 of their area, or 27.4%. Total decrease of their volumes amounted to 8.8 km^3. Comparison between space images of 2004 and 2012 with data for a middle of the last century made it possible to make a conclusion that for the last decade the rate of the glacier shortening increased by a factor 1.5–2. Contraction of each individual glacier depends on a combination of both the relief and climate factors which determine its structure, size, altitude range, and orientation relative to air flows carrying moisture. For the period from 1968 to 2012, even for large valley glaciers of the mountain Belukha massif the contraction falls within the range 3.1–15.1 km^2. Analysis of distribution of the glacier contraction by sizes and morphological types allows the supposition that the valley or corrie-valley glaciers with their areas from 1 to 5 km^2 are the most representative ones for this glacier system. Data of meteorological stations Kara-Tyurek (2600 m), Akkem (2050 m), and Aktru (2025 m) located in the immediate vicinity to this glacier zone show continuous rise of summer air temperatures and the precipitation increasing. Nowadays, similar situations take place in other mountain regions (Caucasus, Polar Urals, non-volcanic areas of the Kamchatka Peninsula) where summer temperature rise is not compensated by increase of precipitation. It is probable that in such case the summer temperature rise is the main factor of shortening of the Mountain Altai glaciers.(*G.A. Nosenko*, *S.A. Nikitin*, *T.E. Khromova* Institute of Geography, Russian Academy of Sciences, Moscow)

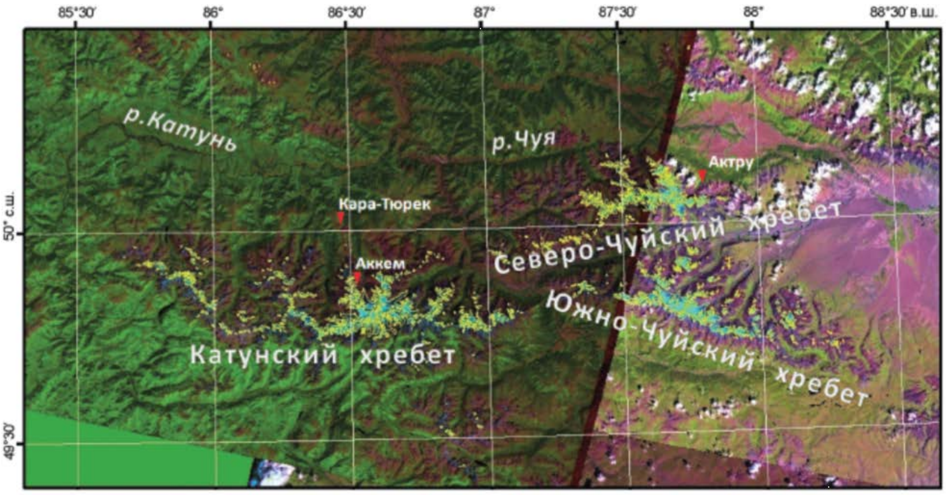


Fig. 24. Research area – Glaciers of Gorny Altai on satellite images

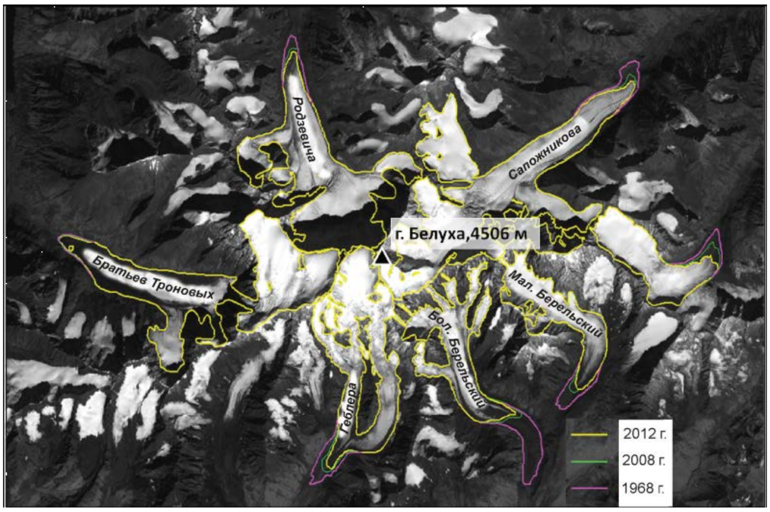


Fig. 25. Changing the boundaries of the largest glaciers on the Belukha Massif from 1968 to 2012

Glaciation changes in the northern part of Sredinny (Central) Ridge on the Kamchatka Peninsula in second half of the XX century. The changes in area of glaciers in the north of Sredinny Ridge (Kamchatka Peninsula) occurred from the 1950s to the present time were examined. For this purpose, ASTER satellite imageries (2002), data of the USSR Glacier Inventory and aerial photographs of 1950 were used. Vector boundaries of the glacier maps were constructed by the decoding of ASTER images. The estimates obtained demonstrate degradations of glaciers in this area of Kamchatka. The glacier area of this ridge, presented in the USSR Glacier Inventory, have decreased by16.6%. Reduced glacier area is a subject to change major climatic factors. During this period the average summer air temperatures elevated and the amount of solid precipitation reduced (*A.Ya. Muraviev, G.A. Nosenko, Institute of Geography RAS*).

Glacier size changes in Kronotsky Peninsula and Alney-Chashakondzha Massif, Kamchatka Peninsula in the second half of XX century and the beginning of XXI century

Changes in areas of glaciers located on the Kronotsky Peninsula and in the Alney-Chashakondzha volcanic cluster (Kamchatka Peninsula) are analyzed over the period since 1950 till 2013. Pictures from satellites WorldView-2 и Landsat of 2010–2013, data from the USSR Glacier Inventory (1950–1955), and aerial photographs of 1950 were used for this study. According to the results, area of glaciers on the Kronotsky Peninsula reduced by 22.9% (for glaciers larger 0.5 km^2), while the Alney-Chashakondzha glaciers reduced by 19.2%.

As it is known from recent investigations 448 glaciers are situated on the Kamchatka Peninsula, their total area are about 905 km^2 . More than 80% of them are glaciers of the Sredinny Range and the Klyuchevskaya group that is explained by large altitudes of them. Glaciers of the Kronotsky Penisula are less studied since this territory is practically not influenced by present-day volcanic processes. The results of investigation of changes in glaciations of the Kronotsky Peninsula and the mountain mass Alney-Chashakondzha have been recievd (Fig. 1).

The following materials are used: 1) the Landsat satellite picture of September 2nd, 2013; 2) pictures from satellite WorldView-2 of July 20th, 2010, and of August 1st, 2012 with spatial resolution of about 1 m; 3) aerial photographs made in August of 1950; 4) topographic maps of the 1:100 000 scale; 5) data from the USSR Glacier Inventory; 6) results of observations at hydrometeorological stations (HMS) Klyuchi and Kronoki (1950–2006) (www.meteo.ru).

According to data from the USSR Glacier Inventory 32 glaciers were situated on the *Kronotsky Peninsula*, their total area 91.9 km^2. By 2013, six glaciers disintegrated. Deciphering of the Landsat pictures did show 50 glaciers. Among them 23 glaciers are presented in the Inventory and they still hold their wholeness; 13 glaciers are segments of six disintegrated ones; 14 glaciers found in the pictures are not presented in the Inventory. Changes in areas of the Kronotsky Peninsula glaciers for period 1950–2013 in dependence on their sizes and expositions are shown in Tables 1 and 2.

According to the Inventory 26 glaciers were situated in region of the *Alney-Chashakondzha massif*, their total area 61.4 km^2. By 2010, four of them disintegrated. Deciphering of the World-View-2 picture of July 2010 did show 45 glaciers: 20 glaciers are consistent with the Inventory, and they hold their wholeness; 9 glaciers are segments of four disintegrated ones; 16 glaciers found in the pictures are not presented in the Inventory. Glaciers on the Kronotsky Peninsula and the Alney-Chashakondzha massif shrink. Since 1950 to 2013 area of Kronotsky glaciers reduced by 18.8 km^2, or by 22.9% (for glaciers with areas larger 0.5 km^2). Area of the Alney-Chashakondzha glaciers reduced for the period since 1950 to 2010 by 11.6 km^2, or by 19.2%, that is comparable to similar characteristics of glacier systems of Altai, Tien Shan, and Caucasus, and this contraction correlates with changes of basic climatic variations, i.e. rising of summer air temperature and decreasing of solid precipitation. (*A.Ya. Muravjev Institute of Geography, Russian Academy of Sciences, Moscow)*

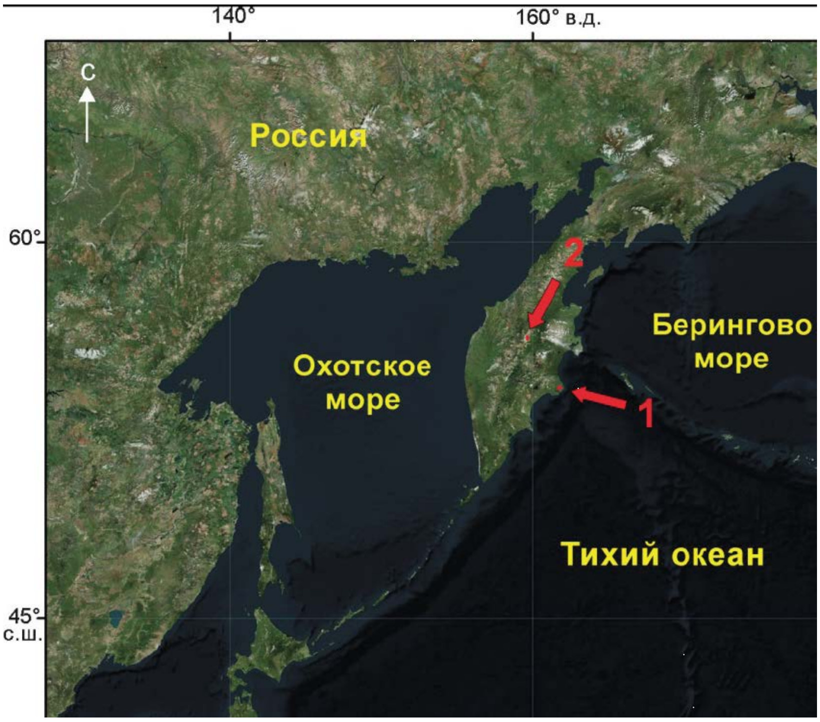


Fig. 26 Location of the regions: *1* – Kronotsky Peninsula; *2* – Alney-Chashakondzha volcanic massif

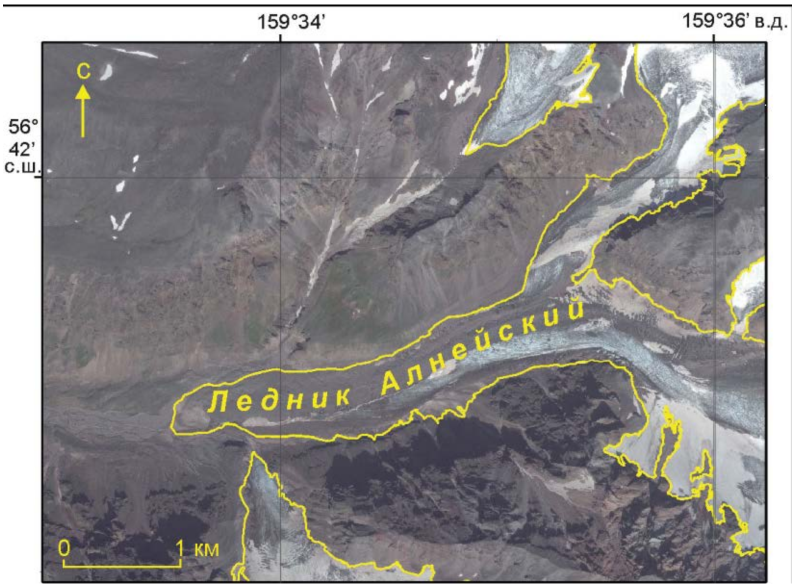


Fig. 27. Alneisky Glacier on the World-View-2 image (20.07.2010)

Volcanic-glacial interactions: GIS applications to the assessment of lahar haz-ards (case study of Kamchatka). Large-scale GIS «Hazards of lahars (volcanogenic mudflows)» has been developed in framework of the GIS «Volcanic hazard of the Kuril-Kamchatka island arc». This database is aimed at mapping of surrounding territories and estimating a hazard of lahars. As an example, results of calculations and forecast estimates for central part of the Klyuchevskaya volcanic group are discussed in the article.

On the Kamchatka peninsula, lahars or volcanogenic mudflows arise as a result of intensive snow melting caused by incandescent material ejected by volcanoes onto the surface. Such flows carrying volcanic ash and cinders together with lava fragments and blocks move with a speed up to 70 km/h that can result in significant destructions and even human victims. Formation of such water flows is possible during the whole year.
Large-scale GIS «Hazards of lahars (volcanogenic mudflows)» has been developed for some volcano group as well as for individual volcanoes on the peninsula in framework of the GIS «Volcanic hazard of the Kuril-Kamchatka island arc». Main components of this database are the following: physic-geographical information on region of active volcanism and adjacent areas, on human settlements; data on the mudflow activity; data on distribution of the snow and ice reserves. This database is aimed at mapping of surrounding territories and estimating a hazard of lahars.

For illustration the paper presents a map of the lahar hazards, results of calculations of the distances of ejects and maximal area of ejected material spreading in dependence on a character and power of an eruption. In future we plan to perform operational calculations of maximal possible volumes of such flows and areas of their spreading. The calculations will be made on the basis of the GIS «Volcanic hazard of the Kuril-Kamchatka island arc».
A volume of hard material carried by lahars onto slopes and down to foot of the Kluchevskaya volcanic massif is estimated on the basis of data on the snow and ice reserves on volcano slopes. On the average for many years, the snow accumulation in zones of the mudflow formations their volume often reaches 15–17 millions of cubic meters. Depending on the snowfall activity in different years this value may vary within 50% relative to the norm. Further on, calcu-lations of maximal possible volume of such flows will be performed in a real time regime with regard for a character of power of a volcano eruption and reserves of snow and ice in the mud-flow-forming basins. The main objective of this work is an effort to reduce a risk of a mudflow formation and to prevent possible damages. *(Ya.D. Muraviev[1], E.S. Klimenko[2]. [1]Institute of Volcanology and Seismology, Pacific Branch of the Russian Academy of Sciences, Petropavlovsk-Kamchatskiy; [2]Moscow State University)*

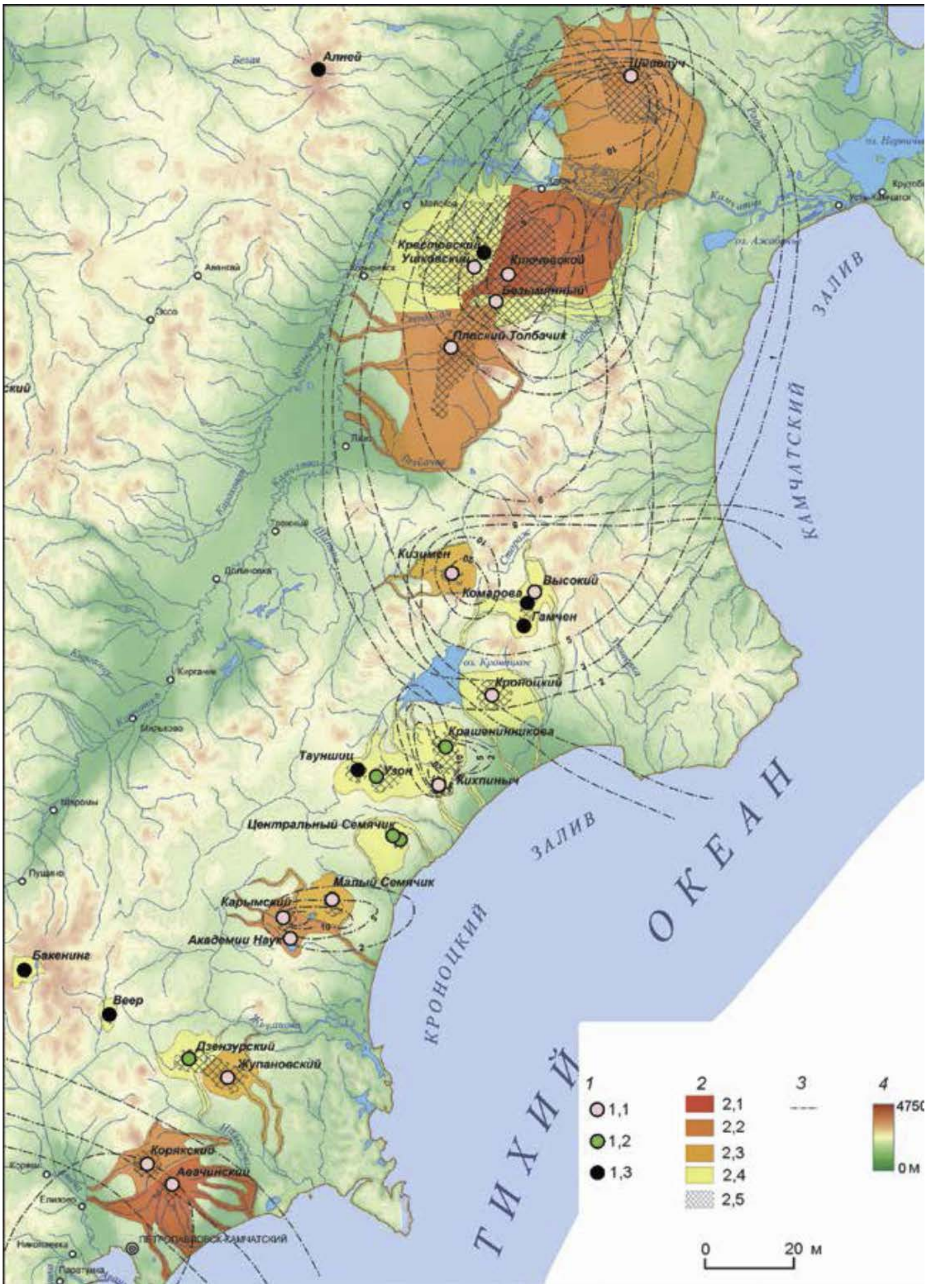


Fig. 28. Map of volcanic hazard of Eastern Range volcanoes (Kamchatka). Main directions of large lahars are shown along river valleys.
1 – active volcanoes: *1.1* – whose eruptions were observed in historical time, *1.2* – which are in solfatarum stage of activity, *1.3* – potential□
ly active volcanoes; *2* – hazard zoned, distinguished by the probability of eruption occurrence: *2.1* – one time in 5–10 years, *2.2* – one time
in 10–50 years, *2.3* – one time in 50–100 years, *2.4* – one time in more than 100 years, *2.5* – zone with the highest danger level; *3* – tephra
distribution, shown with isopaches; *4* – hypsometrical bar

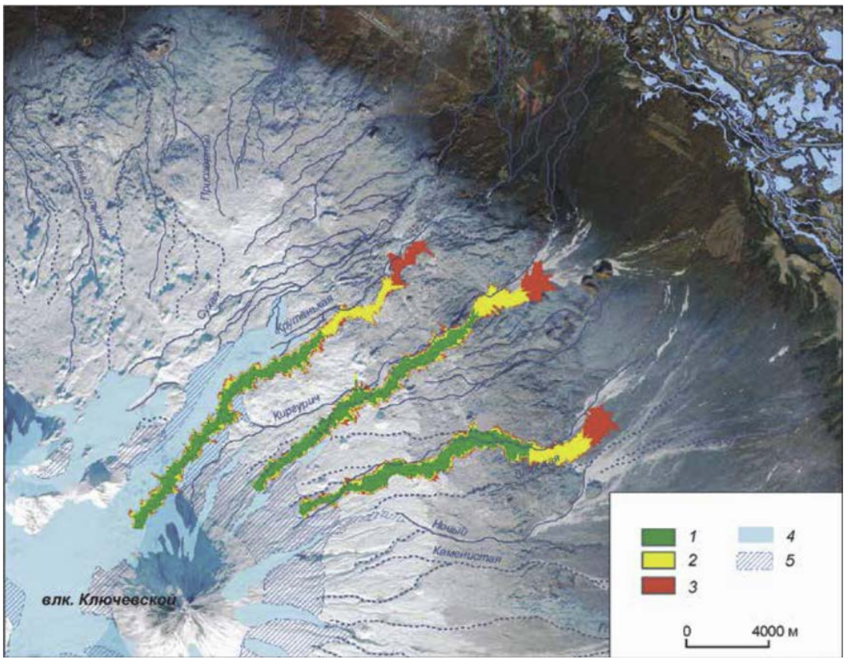


Fig. 29. LAHARZ program outcome-inundation zones by lahars of different volumes in three valleys on the northeast slope of Klyuchevsky volcano.
Volumes of possible lahars, mil m3: *1* – 7, *2* – 14, *3* – 21; *4* – glaciers; *5* – passive and dead ice

Investigations of the Caucasus glaciers. The objective in the investigations is to extend the long-term series of every-year mass balance measurements at two reference glaciers of the Caucasus those are Garabashi on southern slope of Elbrus (since 1982) and Djankuat in the Baksan river basin (since 1968). The data are published in bulletins of International Service of the glacier monitoring. Ground-based radar measurements of ice thickness and surveying of the glacier surfaces by means of dual-frequency differential GPS-receiver were performed on glaciers Garabashi and Marukh (in West Caucasus). Laboratory analysis of the dust particles, abundantly precipitated in some years onto the Elbrus snow slope, together with materials of synchronous space surveys made it possible to locate (determine) sources of the dust transport which were western regions of the Sahara desert and the Arabian Peninsula (this work was performed jointly with the Reading University). Equilibrium lines are integral indicator of conditions of glacier existence. So, a map of the present-day boundaries of equilibrium lines has been built for comparison with their positions in the middle of XX century taken from the USSR Glacier Inventory. Analysis of parameters and times of mud-flow occurrences for the last 50 years in the glacial zone of Kabardino-Balkaria allowed constructing empirical relationship between the mud-flow activity and morphometric characteristics of river basins (*O.V. Rototaeva, G.A. Nosenko, S.S. Kutuzov, Institute of Geography RAS*).

Dynamics of glacier terminuses in the Caucasus. Monitoring of terminuses and changes in surface and deep structures of glaciers in Central and West Caucasus, including ice sheet of the Elbrus volcanic cluster is continued using both ground-based methods and remote sensing. Images from satellites ASTER and Landsat of 2001–2013, materials of aerial photographic surveys of 1953 and 1987, DGPS-survey as well as the mass balance measurements on the reference glaciers were used for this study. To define the present-day glacier boundaries in areas of alimentation the digital models of relief GDEM, built from stereopairs (double images) from the satellite ASTER, were used. Actually, catastrophic melting of the last decade resulted in serious changes in parameters of almost all Elbrus glaciers that manifested by lowering of surfaces and glacier tongue retreating. Changes in glacier boundaries for two periods, namely for 1987–1999 and 2000–2013, were compared. A rate of the tongue retreat is now almost twice greater, the areas are reduced by 5%, and that is well correlating with rising of summer temperatures in the region as well as is supported by balance observations on the Garabashi Glacier. Now, intensity of the Caucasus glaciers melting reaches the extremely high (record) values for the whole period of direct *in situ* observations and reconstructions since 1905 to 2013 (*G.A. Nosenko, Institute of Geography RAS*).

Radio-echo sounding and modelling of ice thickness of the Djankuat Glacier. In 2012–2013, more than 20 km of radio-echo sounding profiles covering the main area of the glacier were obtained using monopulse radar VIRL-6 with its central frequency of 20 MHz. The first detailed maps of the ice-thickness and the bedrock topography were constructed these data. According to the measurements the maximum and average values of the ice thickness are 105 m and 31 m, respectively.

Radio-echo sounding and modelling of ice thickness of the Djankuat Glacier has been done. This glacier is the reference one for the Central Caucasus and was earlier studied comprehensively, but direct ice thickness measurements survey were not made so far. In 2012–2013, more than 20 km of ice-thickness measurement profiles were obtained using monopulse ground radar VIRL-6 with its central frequency of 20 MHz. Standard error of the ice-thickness measurement was 2.5%. Detailed maps of the ice-thickness and the bedrock topography based on these direct measurements were constructed for the first time. Its average ice-thickness is 31 m with the maximum of 105 m. Djankuat Glacier ice volume is 0.077±0.002 km^3 when Djantugan plateau is not taken into account. Ice thickness map was supplemented by results of the ice thickness modelling using the GlabTop model. It was shown that the model reproduces the ice thickness distribution correctly, and a special approach was developed to correct model parameters using ice thickness measurements. Further on, we plan to use corrected GlabTop model for estimation glaciations of the Caucasus as well as to carry out ground radar sounding of the Djantugan plateau.

(I.I. Lavrentiev[1], S.S. Kutuzov[1], D.A. Petrakov[2], G.A. Popov[2], V.V. Popovnin[2] [1]Institute of Geography, Russian Academy of Sciences, Moscow; [2]Moscow State University)

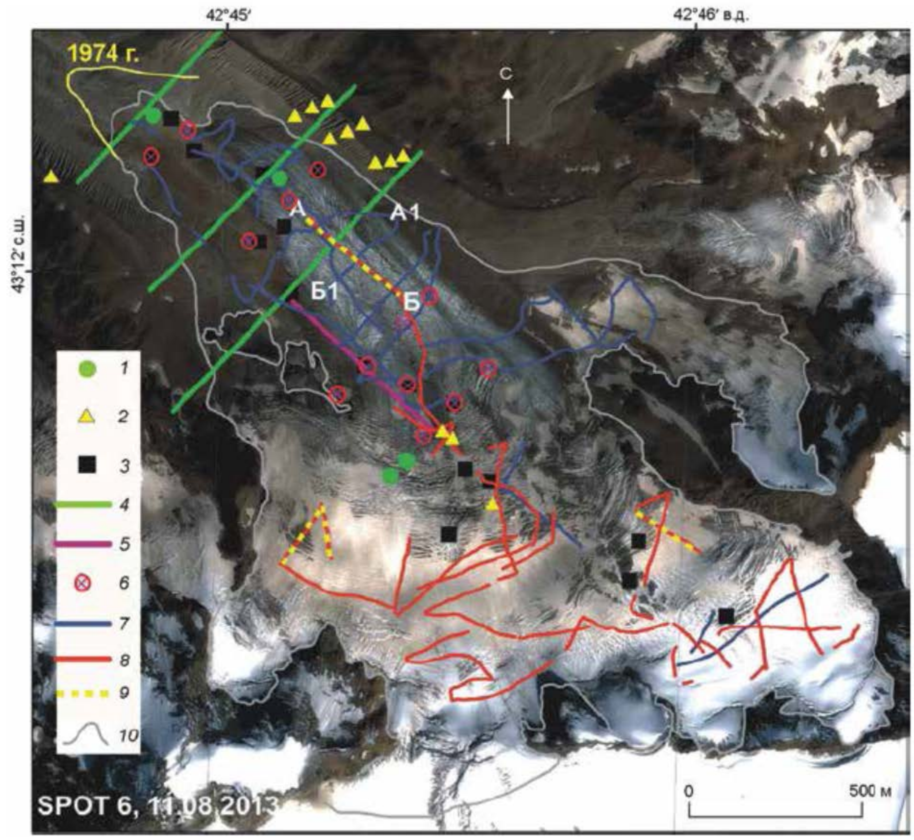


Fig. 30a. Sites and routes of geophysical surveys at Djankuat Glacier in 1960–70th* and 2012–2013: *1* – VIS sites; *2* – VES sites; *3* – thermo drilling sites; *4* – ground base gravimetric profiles; *5* – 1974 RES profiles; *6* – 1974 RES sites; *7*,
8 – 2012 and 2013 RES profiles; *9* – RES profiles with double reflection from bedrock; *10* – 2013 glacier boundary.*There are no profiles of seismic survey in accumulation area shown here and in [12]; points *1–6* taken from [12]

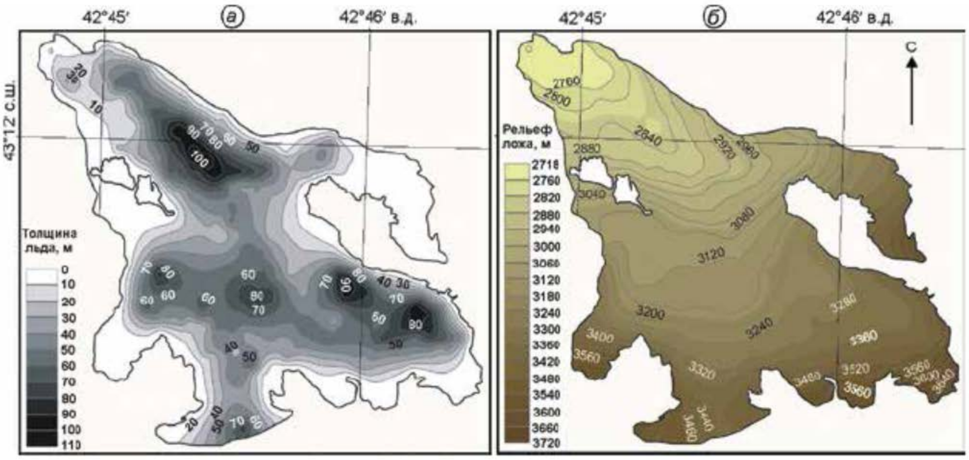


Fig. 30b. Ice thickness (*a*) and bedrock topography (*б*) of Djankuat Glacier from radio-echo sounding and ASTERGDEMV.2

Estimation of the Greater Caucasus glaciers volume, using radio-echo sounding data and modelling. The results of ice-thicknessmeasurements and modelling of the Greater Caucasus glaciers, using radio-echo sounding data, GlabTop model and satellite imagery, are presented and discussed. Ground and airborne radio-echo sounding measurements were conducted at selected Caucasus glaciers, including the biggest Bezengi glacier, reference glaciers Djankuat and Marukh as well as glaciers of the southern and eastern slopes of Mt. Elbrus in 2011–2013. The GlabTop model was calibrated using the measured ice-thickness data and ice-thickness and bedrock topography maps were completed for 224 glaciers (13 %) which cover 719 km2 or 64 % of the total glacier area in Caucasus. New dataset of the Caucasus glaciers outlines was completed using available satellite imagery. There were 1713 glaciers with the surface area of (1121 ± 30) km2 in Caucasus in 2010–2013. Obtained data were used to calibrate volume-area scaling relationship and to calculate the total volume of Greater Caucasus glaciers which is (43.5 ± 5.0) km3. (S. Kutuzov, I. Lavrentiev, E. Vasilenko, Y.Y. Macheret, D. A. Petrakov, G.V. Popov, [1]*Institute of Geography, Russian Academy of Sciences, Moscow;* [2]*Moscow State Universit)*https://www.researchgate.net/publication/273770256_ESTIMATION_OF_THE_GREATER_CAUCASUS_GLACIERS_VOLUME_USING_RADIO-ECHO_SOUNDING_DATA_AND_MODELLING [accessed May 21, 2015].

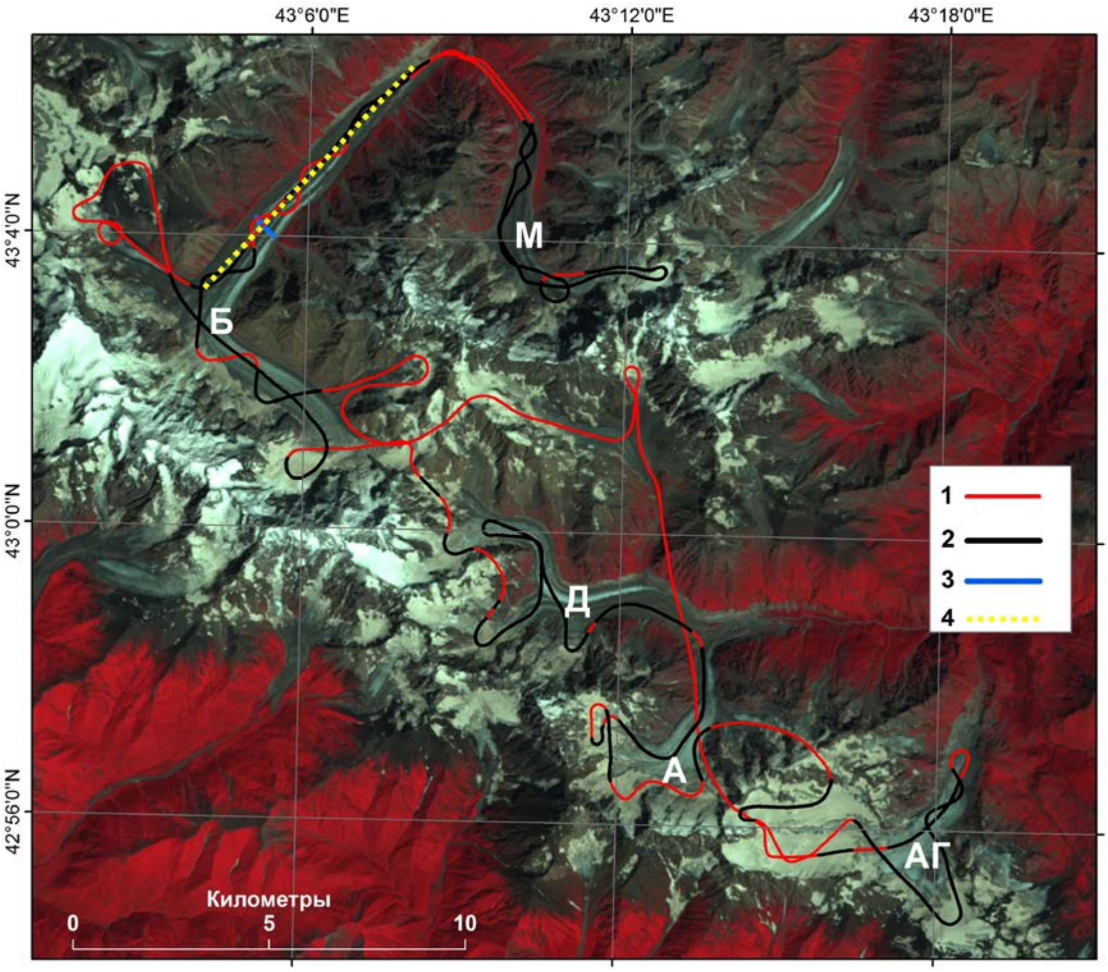


Fig.31 Aerial radio echo sounding profiles at Central Caucasus glaciers: Б-Bezengi, M – Migirgi, Д-Dyh-Su, A – Aylama, АГ - Agashtan. 1 –flight route; 2 – profiles with reliable bedrock reflection; 3-ground RES survey; 4 – longitudinal profile with multiple side walls reflections. Landsat (2011).

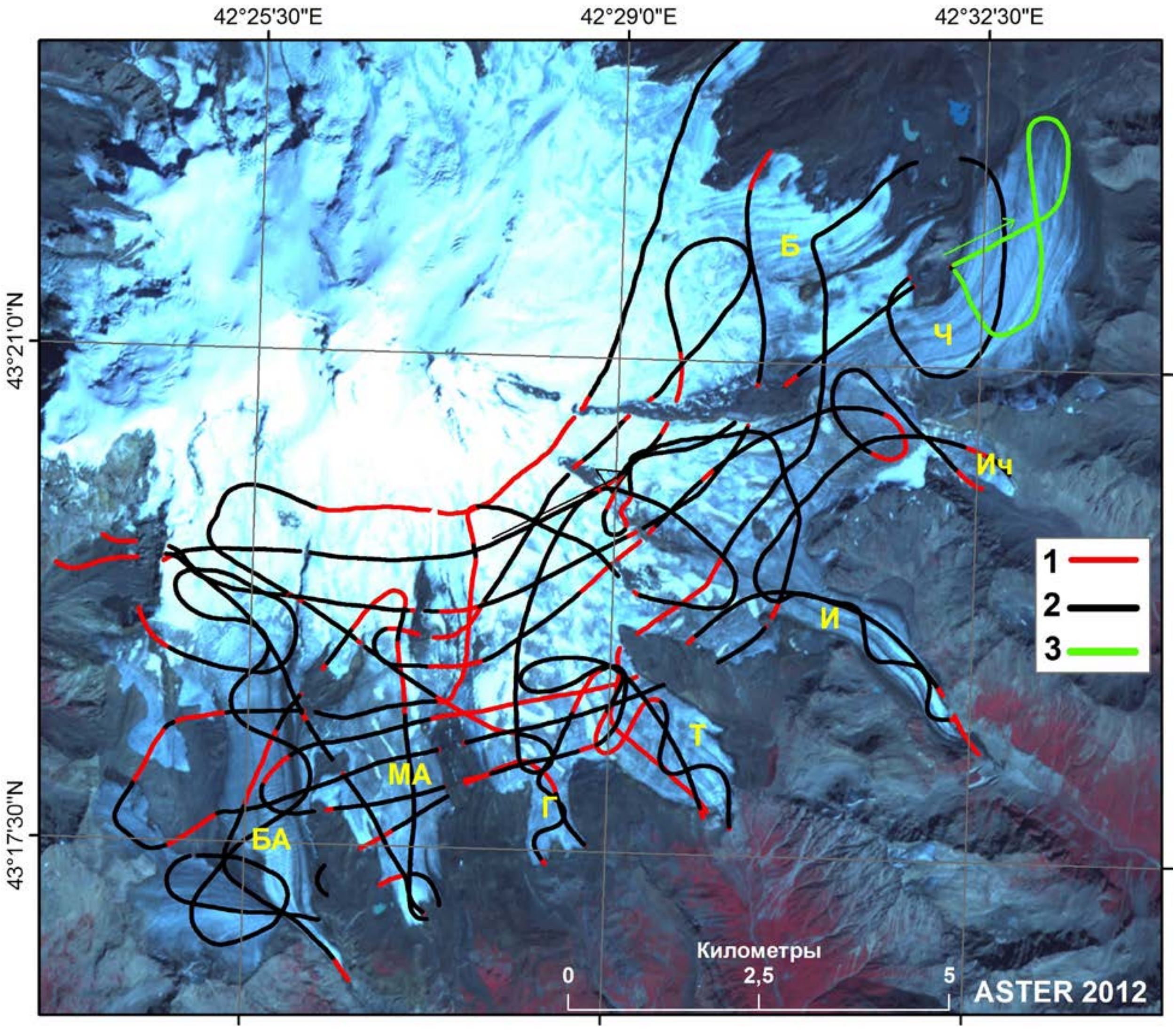


Fig.32 Aerial radio echo sounding profiles at the southern slope of Elbrus. БА-B. Azau, МА-M. Azau, Г - Garabashy, Т - Terskol, И -Irik, Ич - Irikchat, Ч - Chunrurchatchiran, Б - Birzhalychiran. 1 –flight route; 2 – profiles with reliable bedrock reflection; 3-profile at the Dzhykiugankez plateu;

Study of surging Kolka Glacier on the Caucasus. In September of 2002, small glacier Kolka located on Northern slope of the Kazbek-Djmaray massif had been completely "thrown out" of its bed. As a consequence of that a huge mass of ice, stones, and water, being immediately turned into high-speed destructive stream, for several minutes rushed 16 km down the valley and created in the Karmadon valley a gigantic ice-stone obstruction 4 km long. For next 22 years, a great volume of data of geological, geophysical, glaciological explorations has been obtained together with space surveys of different times. All that made it possible to substantiate the version of Institute of Geography RAS on causes of the Kolka Glacier breakdown as a combination of complex of simultaneously acting extreme factors. Main ones of them were intensification of tectonic and volcanogenic processes in the region, and the great scale of the catastrophe was determined by large water volume accumulated under the glacier. Observations made to follow the course of restoration in the empty circus of the Kolka Glacier allow understanding (establishing) that in the rear part of the circus a new glacier body is formed due to active avalanche alimentation and partial motions of former hanging tributaries of this glacier. By the end of 2012, its area reached 0.6 km^2. During the last three years its frontal part became stable (*O.V. Rototaeva, Institute of Geography RAS*).

Study of glaciarization of Suntar-Khayata Mountains, Siberia. Glacial-cryogenic complexes of the Suntar Khayata Mountains were studied, and this work continued explorations of local glaciers started in 1957–1959 (IGY). Degree of the glacierization of the Northern mass of Suntar Khayata Mountains for the last 60–80 years was estimated by means of comparison of the following information: data from the USSR Glacier Inventory, aerial photographic survey of 1945, satellite pictures Landsat of 2010, Bing Maps 2011, and digital surface of relief AsterDEM. In 2012 and 2013, Institute of Permafrost of Siberian Branch (SB) of the Russian Academy of Sciences together with Institute of Global Changes, Japan, and Institute of Geography RAS carried out field explorations on some reference glaciers from the mountain massif Mus-Khaya. These works included GPS-survey of present-day boundaries of glaciers, investigation of their morphology, measurements of thawing on the glacier surfaces, ice sampling for analysis of their isotope composition. This complex of investigations made it possible to estimate reduction of glacier areas in the region, changes in their altitudes, and rising of equilibrium line in comparison with a middle of last century. To estimate the moraine age starting from the little ice age the moraine complexes were investigated; series of lichenometric dating results and tests of residual strength of the surface were obtained. Main conclusion is that glaciers of Suntar-Khayata Mountains are in the stage of degradation. During the last summer they were completely located in the area of ablation (*A.A. Galanin, Institute of Permafrost, SB RAS, Yakutsk; M.D. Ananicheva, Institute of Geography RAS*).

The assessment of the present state of glacier systems in the Northeast of Russia. Remotely sensed glacier inventories of the Byrranga, Suntar-Khayata, and Chersky ranges (2003), Koryak Highland and Chukotka mountains (2008) analysed with data from the Inventory of Glaciers of the USSR (1945–1985). We studied changes in glacier area since the Inventory, which was primarily based on aerial photos and field research. The glaciers have been classified by orientation (aspect) and morphological type. Overall the glacierization of the Chersky Range (1970–2003), Suntar-Khayata (1945–2003), Byrranga (1967–2003), Koryak Highland (1950–2003) and Meynypilginsky Range (1984–2008) reduced by about 30, 20, 15, 60 (debatable value) and 25% respectively due to summer temperature rise. Calculation of glacier volumes for the dates indicated in the USSR Glacier Inventory and satellite imagery: during this period in sum for 5 studied glacier regions the area, covered by ice, has decreased by 225.2 km^2, and ice volume – by 8.7 Gtg. Construction of spatial patterns (maps) of current ELA for 3 different by climate mountain regions – the Suntar-Khayata Mountains– Chersky Range, and Meynypilgynsky Range (North Far East), showed that despite of retreat of the glaciers, the mean ELA change for the first studied region is not large compared with the data from the Glacier Inventory (100 m), and significant for the second (100–150 m). (Maria D AnanichevaInstitute of Geography RAS, Moscow)

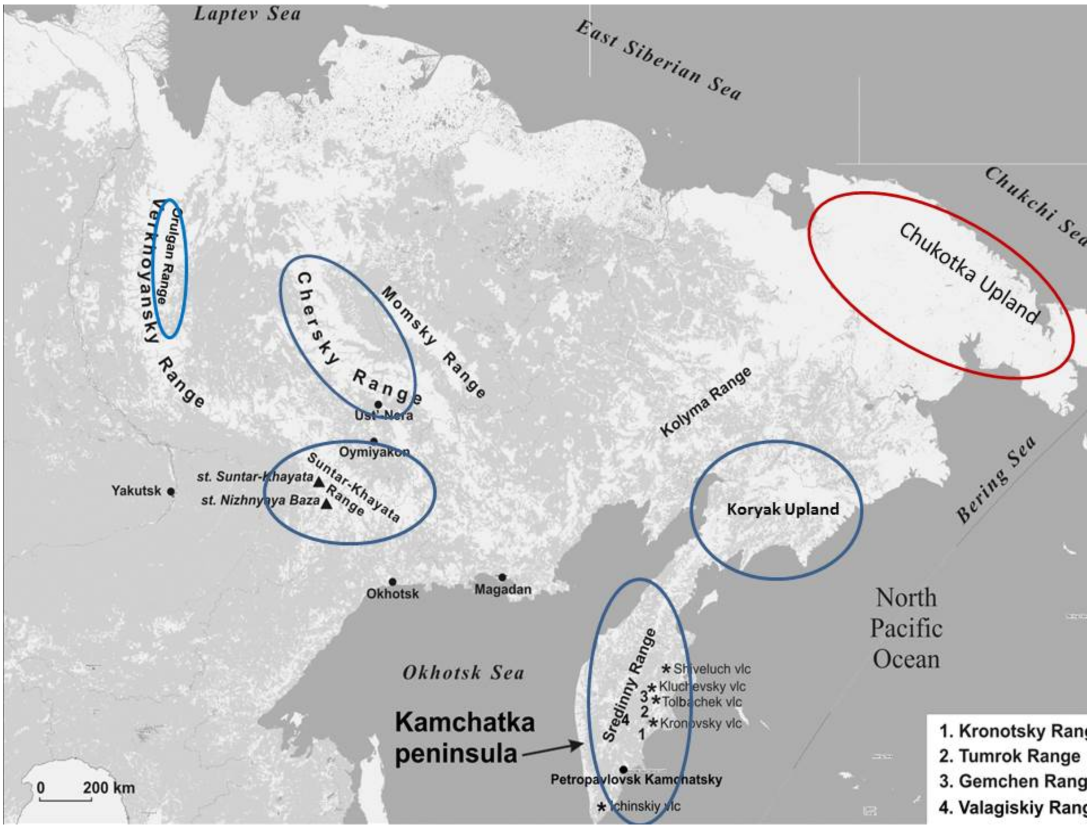


Fig. 33 Study regions where estimation of the mountain glaciers state was conducted (blue ovals) and is poropsed for the future work (red oval)

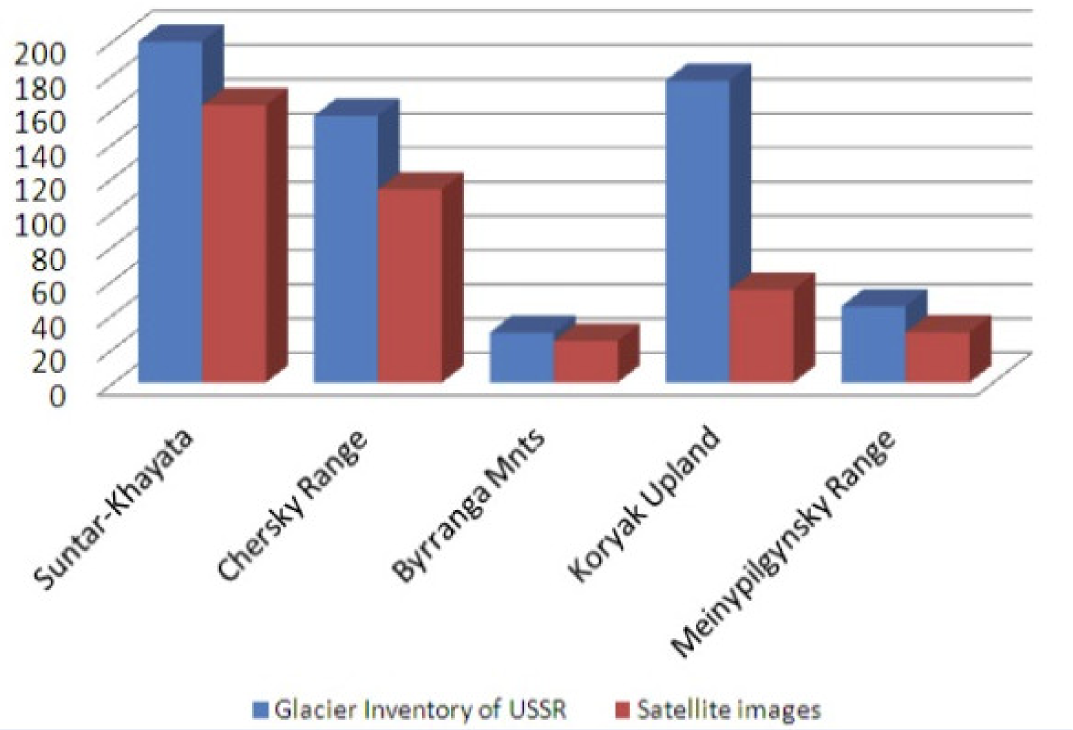


Fig 34 Total reduction of glacier areas, km2, % all glacier regions till present: Suntar-Khayata Range, since 1945, Chersky Range, since 1970, Byrranga Mountains, since 1967, Meinypylginsky Range, since revised in 1980-s

Current state and changes of glaciers in the Tavan Bogd Mountains (Mongolia)

Current state and dynamics of main glaciers (located) on the eastern slopes of the Tavan Bogd mountain massif (Mongolia) is investigated on the basis of results obtained in 2013 field survey with use of remote sensing as well. According to our estimates, areas of these glaciers did not significantly changed since 1989 however a certain regression of the glacier tongues had been fixed. Ablation–accumulation value amounts to 110 g/cm^2 at mean summer temperature on the equilibrium line of 1 °C.

This study is the first stage of detailed investigation of large glaciers located in the Tavan-Bogd Mountains. The main task of this work is to estimate a current state and dynamics of glaciers and to update glacier and rock-glacier inventory. Basing on results of 2013 field survey together with remote sensing data the main glaciers located on eastern slopes of the Tavan Bogd mountain massif in the Tsagan-Us and Tsagan-Gol river basins are described (these glaciers are Potanin, Alexandra, Grane, Kozlov, and Krylov ones). In order to monitor regime of glacier systems the geodetic survey of glaciers and rock-glacier edges was carried out using Trimble GNSS system and the ranging mark system. The Landsat satellite images made taken in August-September of 1989, 2006, and 2013, their spatial resolution 15–30 m, were used to map areas of debris-free glaciers and to estimate the glacier changes between 1989 and 2013. Pictures were taken from the USGS site, the ArcGIS software was used for this work. In addition, the high-resolution satellite pictures with resolution of 0.5–2.5 m made at the end of the ablation season if 2008 (CARTOSAT-1) and 2010 (Geoeye-1 and SPOT-5) were also used to analyze current conditions and changes of the above glaciers and to improve visual estimation of the Landsat imagery. In 2013, the study included 26 glaciers with the debris-free glacier area of 67 km^2 in the Tsagan-Gol river basin and 37 glaciers with area of 30 km^2 in the Tsagan-Us river basin. According to our estimates, areas of these glaciers did not significantly changed since 1989 however a certain regression of the glacier tongues had been fixed. The Kozlov glacier retreated with average rate of 21 m/year between 2001 and 2013. Retreat of the Potanin glacier was slower and between 1989 and 2001 the average rate was equal to 5 m/year, but between 2001 and 2013 it became more active and its average rate reached 24 m/year. One of the largest One of the largest rock-glacier of the Tavan Bogd Mountains was found in the Tsagan-Us valley on its south-eastern slope, its area was estimated 1.2 km^2, length – 3 km, steep front height – 20–25 m. Indirect indicators of its activity such as transverse and longitudinal furrows were noticed. Using data of local weather station data we calculated some climatic characteristics needed to monitor equilibrium line for end of the 2013 ablation season. Mean summer temperature on the weighted mean equilibrium line of five glaciers (3250 m a.s.l.) was defined as 1.0 °C. Ablation–accumulation value was estimated 110 g/cm^2 and the mean annual snowfall on the equilibrium line as 785 mm.(*M.V. Syromyatina[1], Yu.N. Kurochkin[1], K.V. Chistyakov[1], Ch. Ayurzana[2]*
[1]Saint-Petersburg State University, [2]Khovd University, Mongolia)

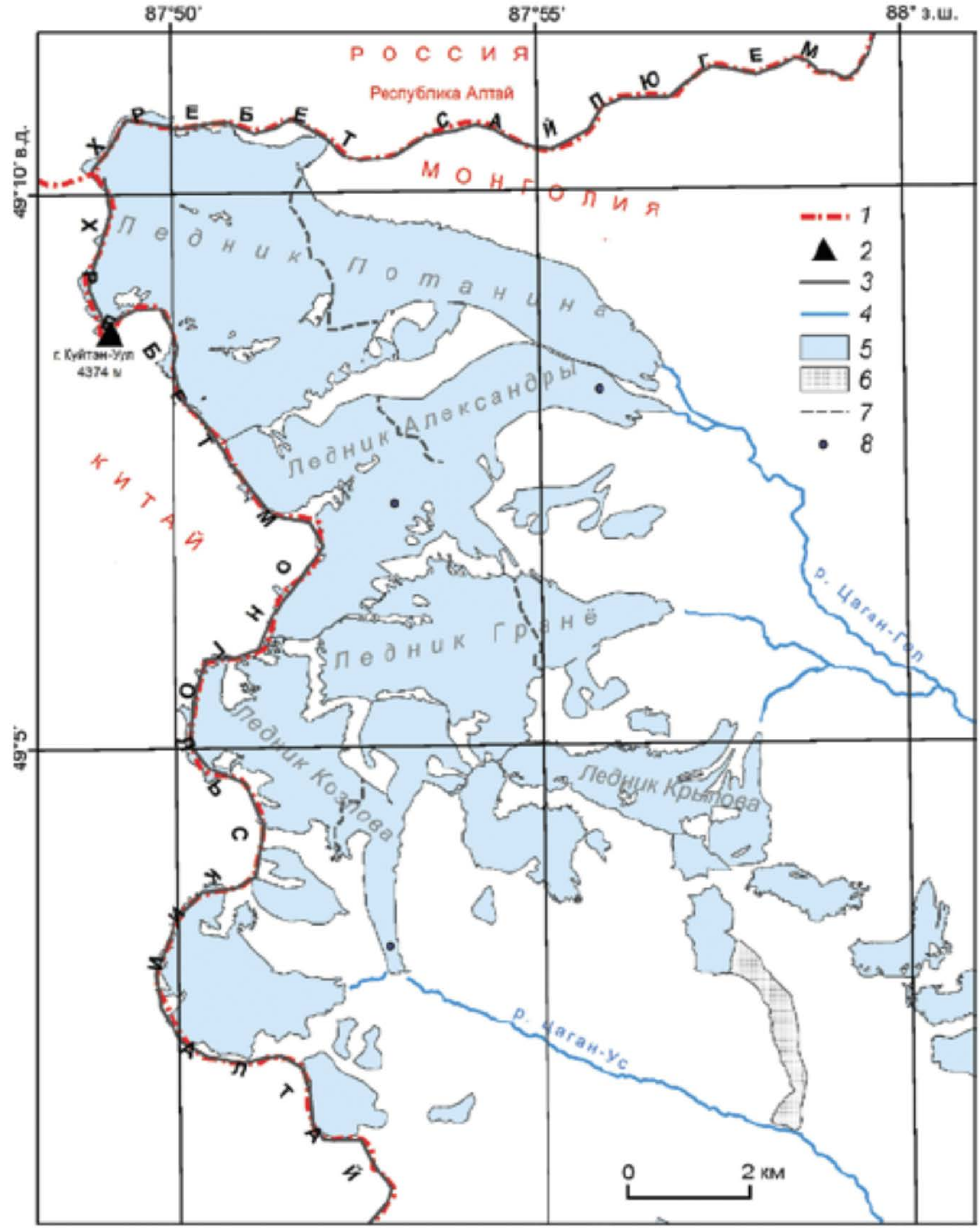


Fig. 35 Study area:*1* – state boundary; *2* – peaks; *3* –ranges; *4* – rivers; *5* – glaciers; *6* – rock glaciers; *7* – equilibrium line; *8* – temperature sensor locations. Equilibrium line position corresponds to the end of the 2013 ablation season

PERMAFROST

Potential impact of methane emission from thawing terrestrial and sub-aquatic permafrost on global climate: synthesis of observations and modeling for the Russian Arctic. Research group from the Russian State Hydrological Institute studied the potential impact of methane emission from thawing terrestrial and sub-aquatic permafrost on global climate using synthesis of observations and modeling for the Russian Arctic. We used numerical modeling to calculate the past, present and future state of the Northern Eurasian terrestrial and sub-aquatic permafrost, to quantify the contribution to the global methane balance, and to evaluate the climate feedback. GIS analysis of small-scale digital topographic maps indicated that the total area of Siberian wetlands was approximately 0.7 million km^2, of which 0.35 million km^2 were located in permafrost regions. Estimated net flux of methane from the frozen wetlands under the current climatic conditions amounts to almost 28.5 Mt/y. According to our model results, projected to the mid-21st century, changes in the volume of the seasonally thawing organic-rich soils and higher soil temperatures can increase the methane flux from Siberian frozen wetlands by 6–10 Mt/y, and, thus, increase the atmospheric concentration by 100 Mt and lead to ca. 0.01 °C global temperature rise.

We also used a comprehensive dynamical permafrost model forced with the transient regional climatic scenario to calculate the state of permafrost and the depth to the boundaries of hydrate stability zone (HSZ) at ESAS over the period from the last glacial maximum 18–20 Ky b.p. up to the end of the millennium. The model is based on the heat transfer equation and explicitly accounts for the effect of salt diffusion in the bottom sediments by coupling the thermal and mass fluxes. We used a climate scenario suggesting that at the time of inundation (ca 8 Ky BP) the top sediment layer warmed by ca. 12 °C from –13.5 °C (mean annual air temperature) to –1.5 °C (bottom water temperature). Temperature was set to this constant value until 1985. Since then in accordance with modern observations we impose 0.09°C/year trend until 2100, and afterwards prescribe the temperature to constant value of 11.5 °C. The rate of temperature change in the XXI century in this schematic scenario by far exceeds all IPCC projections. It has been made intentionally to explore the likelihood of the so-called “methane bomb” concept under the most favorable, though highly unrealistic, climate conditions (*Oleg Anisimov, Hydrological Institute, St. Petersburg*).

Possible causes of methane release from the East Arctic seas shelf. Data on methane concentration in the water and lower atmosphere over the shelf of the East Siberian Arctic Seas, which were obtained using marine, terrestrial, and satellite observations, are analyzed in the paper. This study is targeted towards attribution of the enhanced concentrations of methane above the latitudinal-mean, which have been detected at selected locations of these seas. Our results reject the hypothesis of methane catastrophe on the East Siberian Arctic Seas shelf over the foreseeable future. We analyze data on methane concentration in the water and lower atmosphere over the shelf of the East Siberian Arctic Seas, which were obtained using marine, terrestrial, and satellite observations. Our study is targeted towards attribution of the enhanced concentrations of methane above the latitudinal-mean, which have been detected at selected locations of these seas. We compare two hypothesis, which attribute it to the effect of modern changes of the sub aquatic permafrost, and to geological factors (tectonics, presence of fault zones and paleo river beds in the study region). Our analysis showed that the methane concentration in sea water are directly related to the distance to the nearest fault zone or paleo river bed, where permafrost is absent and bottom sediments are perforated allowing methane to escape from the deep layers containing gas hydrates. This result indicate that the enhanced emission of methane, which was observed at selected locations of the shelf, is not related to the modern climate change. Earlier study, which was based on mathematical modeling, did not find intensive development of taliks as well as other processes that lead to increased gas permeability of the bottom sediments. Taken together, these results reject the hypothesis of methane catastrophe on the East Siberian Arctic Seas shelf over the foreseeable future. *(O.A. Anisimov*[1], *Yu.G. Zaboikina*[1]*, V.A. Kokorev*[1]*, L.N. Yurganov*[2][1]State Hydrological Institute, Sankt-Petersburg, [2]State Maryland University, Baltimore, USA)

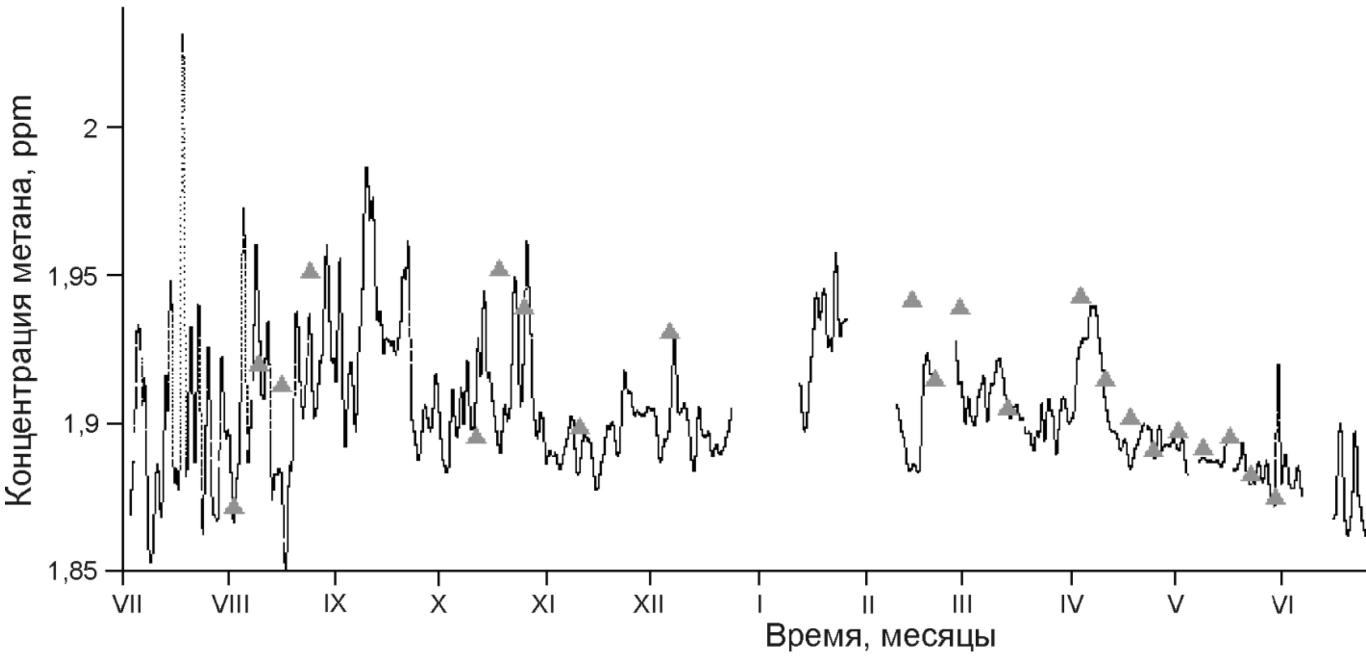


Fig. 36 Observed atmospheric methane concentration in Tiksi, 2010–2011 data. Curve represents automated observations, gaps are due to the electric power outage. Flask sampling data are indicated by triangles

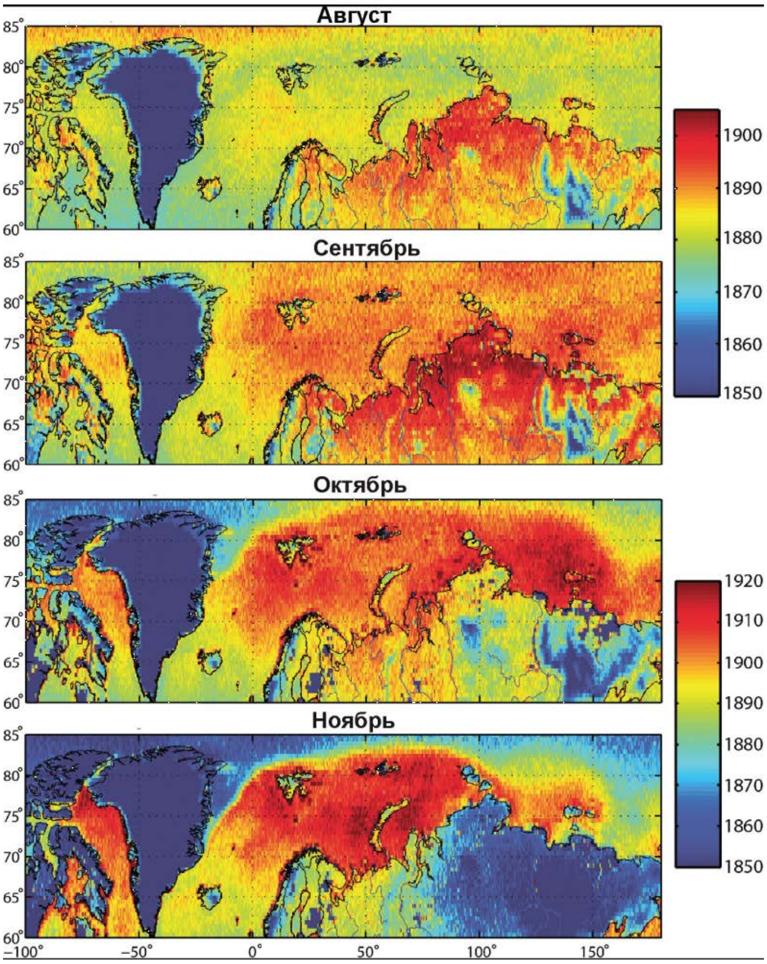


Fig. 37. Averaged over the 2009–2013 period mean monthly methane concentrations (ppb) in the lower atmosphere (0–4 km) for August–November. Maps are based on IASI-1/Metop-A satellite data (http://www.nsof.class.noaa.gov/saa/products/welcome). Data obtained under cloudy conditions were discarded

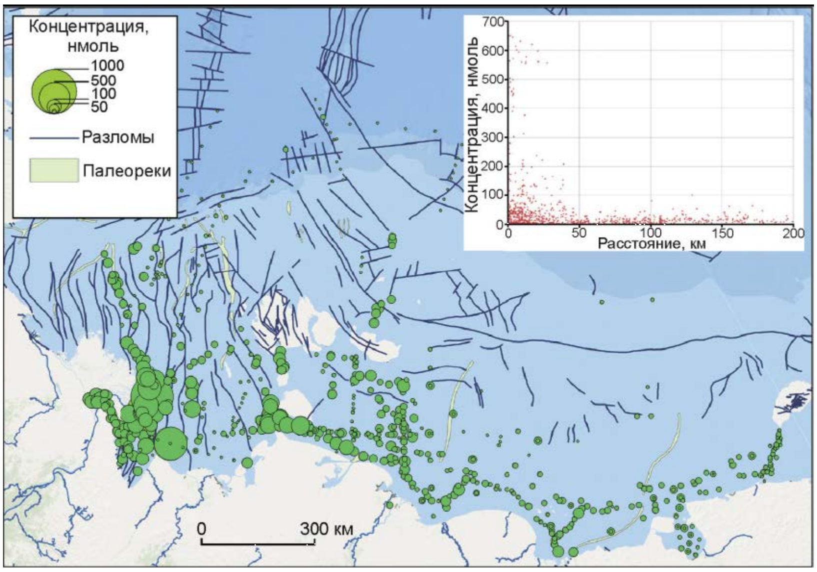


Fig. 38. Map of the fault zones,pale river beds, and water sampling in the shelf of the East Siberian Arctic Seas.Symbol size is proportional tomethane content in the water.Graph in the insert illustrates the relation between the methane concentration and the distance to the nearest fault zone or paleo river bed

Aufeises of the Siberian permafrost zone and increase of the river channel nets.

Unique phenomenon of the permafrost zone that is aufeises (surface icings) formed by groundwater outflows is analyzed in this work. Total area of such aufeises in the permafrost zone (total area F = 7.6 million km^2) of East Siberia and Far East roughly amounts to 50 000 km^2 (i.e. 0.66% of the whole territory), and the quantity exceeds 60 thousand. There is a specific channel-forming process in this area which is expressed in creation of new runoff channels due to influence of newly formed aufeises. This results in a certain increase of a river channel net relative to the river course higher and lower of an aufeis glade. Increase of the net with respect to one aufeis changes from 3.5 km in mountains in south of East Siberia up to 23 km in the Verkhoyansk-Kolyma mountain area and on the Chukchi Peninsula.

Aufeises (surface icings) formed by groundwater outflows are widespread on the territory of East Siberia and Far East. By their number, sizes, and the channel-forming role they considerably exceed the “classical” (sedimentary-metamorphic) form of glaciations. Relative coverage of territory by aufeises estimated with regard for parameters of more than 10 000 ice fields is 0.66% (50 000 km^2). On rivers which lengths are shorter 500 km, the aufeis sizes depend on waterflow orders. The largest quantity of giant groundwater aufeises is formed in river valleys of 3–4 orders.

Cumulative channel-forming effect of the aufeis phenomena is expressed by a value of increase of the river channel net relative to its characteristics higher and lower an aufeis glade. This value is well-correlating with the aufeis coverage of river basins as well as with morphostructure, permafrost, and hydro-geological conditions of these territories. Increase of the net with respect to one aufeis changes from 3.5 km in mountains in south of East Siberia up to 23 km in the Verkhoyansk-Kolyma mountain area and on the Chukchi Peninsula. On the average, increase of a channel net with respect to one large groundwater aufeis amounts to 12.2 km while in areas of both continuous and discontinuous permafrost (total area F = 7.6 million km^2) the total increase is estimated as 690 thousand km.

Our calculations testify extremely great role of the aufeises in transformation of river channel nets and structures of valley landscapes as a whole. It is possible to see in mountains that small and middle rivers are characterized by a system of many channels caused by the aufeis influence, and such system can exist continuously for tens km along a river course. For further understanding of regulations of formation and spreading of aufeises and the aufeis channel-forming processes future long-term investigations are needed and they should be performed with use of large-scale aerial and space surveys as well as regular observations on special aufeis sites.*(V.R. AlekseevInstitute of Permafrost, Siberian Branch of the Russian Academy of Sciences, Yakutsk;Institute of Geography, Siberian Branch of the Russian Academy of Sciences, Irkutsk)*

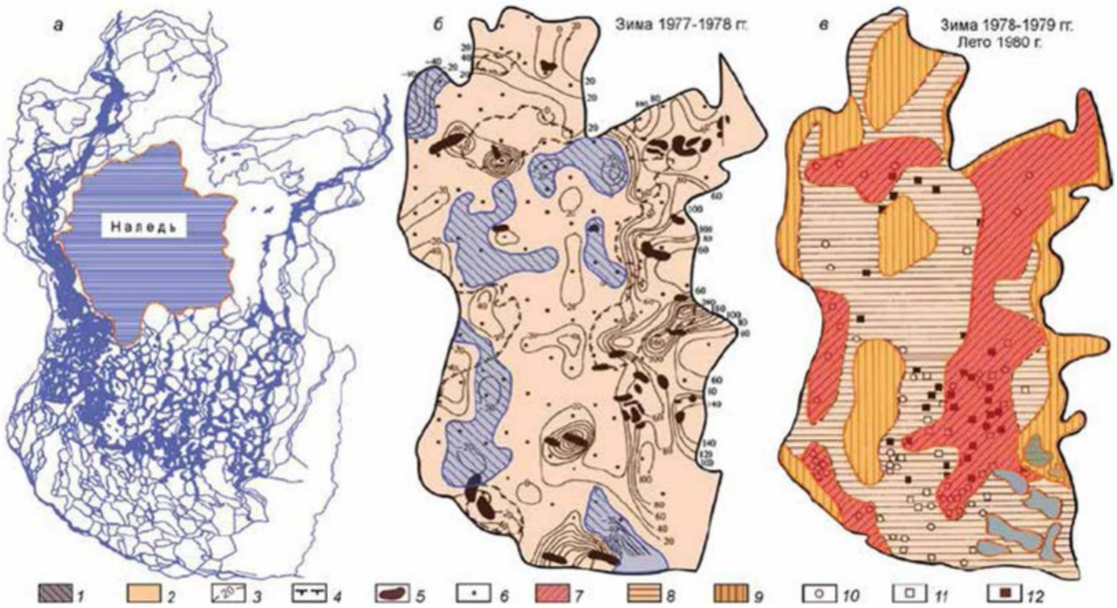


Fig.39 Channel network on the aufeis glade and cryogenic movement of grounds during process of the gigantic Mururinskaya aufeis formation in the north of Transbaikalia:
а – channel network at a period of incomplete destruction of aufeis; *б* – situation according to observational data reported by V.N. Kolotaev [13] in winter of 1977/78: *1* – zone
of lowering of surface of the aufeis bed; *2* – zone of elevation of the rock surfaces; *3* – contour lines of elevation of the ground surfaces, m; *4* – zone of formation of water-ice
ridges; *5* – aufeis frost mound; *6* – measuring poles; *в* – situation according to observational data reported by B.N. Deikina [9] in winter of 1978/79 and summer of 1980: *7* –
zone of active water exchange and intense ground elevations during formation of injected ices with average thickness of 0.73 m; *8* – zone of moderate water exchange and mod☐
erate elevation of land surface during formation of injected ice with average thickness of 0.45 m; 9 – zone of weak development of injected ice or its absence; *10–12* – pits and
profiles made in 1979 (*10*) and 1980 on plots of natural outcrops of injected ice (*11*), and within layer of ice-containing alluvial deposits (*12*)

Permafrost response to climate warming, The response of permafrost to global Late Pleistocene–Holocene warming has been investigated in the ice complex of Yakutia. Thermokarst erosion of the complex was found out to depend on the properties of landscape and its components that change as a consequence of warming. In addition to the degradation tendency, aggradational stabilization in ice complex remnants may occur in certain conditions as formation of a protective layer. (V.N. Konishchev Lomonosov Moscow State University, Department of Geography, 1, Leninskie Gory, Moscow, 119991 Russia; vkonish@mail.ru)

Fig. 40. Map of ice complex. Compiled by V.N. Konishchev and N.A. Koroleva after [*Romanovsky, 1993; Konishchev, 1997; Kunitsky, 2007; Streletskaya et al., 2007*].

PALEO GLACIOLOGY AND PALEO CLIMATE

Investigation of the palaeoclimate variations at the millenniums scale. The studies were based on the isotope analysis of carbon (carbonate of hydroxylapatite) contained in bones of plant-eating animals, mainly mammoths; the isotope composition was used as a palaeoclimatic indicator for the Polar Regions. For this purpose the bones were taken out of animals which belonged to the late Pleistocene time and were found in the river Lena mouth; then the isotope composition of the bone carbonate was examined by the radiocarbon method allowing reliable dating. Results of these analyses made it possible to reveal instability of the late Pleistocene climate that was expressed in drastic short-time (500–2000 years) irregular episodes of mild climate, i.e. interstadials. Both causes and the changes in the mammoth fauna themselves in Arctic regions were studied for the time between Pleistocene and Holocene (V.I. Nikolaev, Institute of Geography RAS).

Garabashi Glacier (Central Caucasus) mass balance reconstructions inferred from tree-rings. The exploration whether tree-ring data can be efficiently applied for the glacier mass balance reconstruction in Caucasus was the main goal of this research. Tree-ring width and maximum density chronologies of pine (*Pinus sylvestris L.*) at seven high-elevation sites in Northern Caucasus were explored for this purpose. Tree-ring maximum density in Caucasus has a clear climate response to summer temperatures and allowed the reconstruction of April–September temperatures since 1800s. Instrumental mass balance records of Garabashi Glacier started since 1983. Maximum density chronology has statistically significant correlation with mass balance variations owing to sensitivity of tree growth to summer temperature and great input of ablation to total mass balance variations. To include into the reconstruction different climatically sensitive parameters, stepwise multiple regression model was used. The strongest relation between two ring-width and one maximum density chronologies was identified. Cross-validation test confirmed model adequacy and this made it possible to reconstruct Garabashi Glacier mass balance changes for 1800–2005. Reconstructed and instrumental mass balance values coincide well except the most recent period of 2000s, when the reconstructed mass balance slightly exceeds its real values. However even in this period it remained negative similar to the instrumental records. Both reconstructions have good inter-annual agreement particularly for the period between 1975 and 2005. According to the reconstruction two distinct periods of positive mass balance occurred in 1830s and 1860s (*O.N. Solomina, E.A. Dolgova, Institute of Geography RAS*).

Mt. Elbrus ice core studies. Intermediate depth ice core (181.8 m) has been recovered on the Western Plateau of the Mt. Elbrus (43°20’53.9” N, 42°25’36.0” E; 5150 m a.s.l.) in the Caucasus, Russia in 2009. The ice core has been partly analyzed for stable isotopes ($\delta^{18}O$ and δD), microparticle concentration, major ions (K^+, Na^+, Ca^{2+}, Mg^{2+}, NH_4^+, SO_4^{2-}, NO_3^-, Cl^-), black carbon (BC), methane (CH_4) concentration, and tritium content. The mean annual net accumulation derived from distinct annual oscillations of $\delta^{18}O$, δD, and NH_4^+ is 1200 mm w.e. Records of desert dust deposition events were also analyzed. On average, dust deposition events occur in the Elbrus area 3–6 times a year. Major dust sources of dust were the deserts of northern Sahara and the Middle East. Temperatures were measured in the boreholes on the of the Western

Elbrus Plateau in 2009 and ranged from –17°C at 10 meters depth and up to –2.4°C at 182 m. According to radar measurements the glacier thickness ranged from 45 meters near marginal zone of the plateau to 255 m at the central part. Age-depth relationship has been constructed for the upper 100 m of the ice core on the basis of simple annual layer counting, 1963 tritium peak and good dated known volcanic eruption (Katmai, 1912). Preliminary dating of basal glacier layers using 2D ice flow model shows 400-450 years (*V.N. Mikhalenko, Institute of Geography, RAS*).

Holocene glacier variations and their potential orbital, solar, volcanic and anthropogenic forcings. Early Holocene glacier advances in several regions correspond to Bond's cycles (11.1, 10.3, 9.4, 8.1 ka BP) and climatically effective volcanic eruptions (11.0, 9.5–9.7, 9.1–9.3, 8.0–8.1 ka BP). Orbital forcing over the Holocene is driving the long-term glacier variation trends in the high and mid latitudes of the Northern Hemisphere. In these regions glaciers were generally smaller than now until the beginning of the Neoglacial period (ca 4.0 ka BP). Modern rapid global glacier retreat disagrees with the orbital forcing and is most probably driven by both increase of solar activity and anthropogenic impact.

The magnitude of glacier advances generally increased in the Northern Hemisphere and decreased in the Southern Hemisphere over the Holocene. This trend can be explained be the orbital forcings. The exceptions are in some regions of the high Asia. 10–4 ka BP and during the 1th Century CE to the early 13th century CE the glaciers were close by sizes to the modern ones or even smaller. The pattern is confirmed by the upper and Northern tree line advances in the Northern Hemisphere. The period with generally «small glaciers» (5–7 ka) coincides with the lack of the major volcanic eruptions, and with the low solar activity. The Early Holocene moraines cluster in seven groups (from 11.1 to 8.1 ka BP). They coincide with all Early Holocene Bond cycles (11.1, 10.3, 9.4, 8.1 ka) and all major volcanic eruptions (11.0, 9.5–9.7, 9.1–9.3, 8.0–8.1). Due to the coincidence of several eruptions with the Bond cycles (solar minima) it is difficult to distinguish between the solar and volcanic signals in the Early Holocene records. The coupling between the glacial and solar/volcanic forcings in the mid Holocene is less evident, but it become strong again in the last 2 ka (1.4 ka and LIA events). The modern glacier retreat disagrees with the actual orbital forcings and is due to both solar and anthropogenic influence. Glacier variations at the moment do not provide proofs for any cycles or global synchronism through the Holocene. However the lack of such evidences can be also explained by the limitations of these records (discontinuous, incomplete, of low accuracy, showing a mixture of advances triggered by both temperature and precipitation). *(O.N. Solomina.Institute of Geography, Russian Academy of Sciences, Moscow; Tomsk State University*)

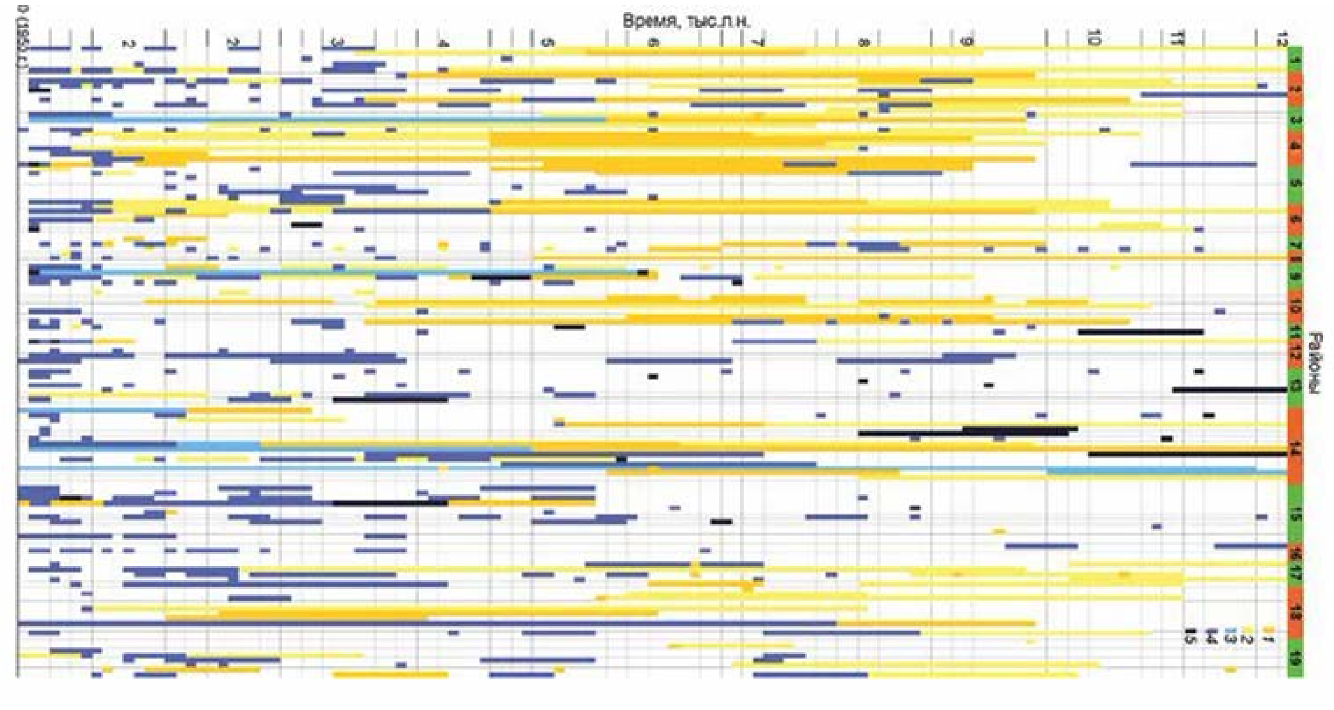


Fig. 41 Glacier fluctuations in the Holocene.
1 – glaciers are smaller or equal to the modern ones; *2* – glaciers were retreating but the precise sizes are unknown; *3* – the glaciers existed; but there is no infor□mation on their sizes; *4* – glaciers advanced; *5* – maximum glacier advances in the Holocene; glaciers regions are in the upper column,

The Greenland Ice Sheet at the peak of warming during the previous Interglacial

The Last Interglacial (LIG or the Eemian) between ca. 130 and 115 kyr BP is probably the best analogue for future climate warming for which increasingly better proxy data are becoming available. The volume of the Greenland Ice Sheet (GrIS) during this period is of particular interest to better assess how much and how fast sea-level can rise in a future Earth undergoing gradual climatic warming. Sea-level during the LIG is inferred to have been up to 9 meter higher than today, but contribution of the GrIS into this rise remains unclear. Various ice-sheet modeling studies have come up with a very broad range of the LIG volume loss by the GrIS to between 60 cm and 6 m of equivalent sea-level rise. This wide range is explained by the sensitivity of GrIS models to the imposed climatic conditions and to poor knowledge of the LIG climate itself in terms of the magnitude and precise timing of the maximum warming, as well as in terms of spatial and annual patterns. To partially circumvent these uncertainties we made use of the newest temperature record over the Central Greenland reconstructed from the isotopic composition of the recently obtained NEEM ice core containing undisturbed LIG segment to build the climatic forcing of the model. The NEEM record unequivocally indicates times of the start and of the end of the LIG warming in Greenland as well as the duration of the warmest time period within the Eemian. Using a three-dimensional thermomechanical ice-sheet model, we produced an ensemble of possible LIG configurations by varying only four key parameters for temperature, precipitation rate, surface melting magnitude and melting pattern within realistic bounds. The outcome of a series of the numerical experiments is a variety of glaciologically consistent GrIS geometries corresponding to a wide range of possible «climates». To constrain the ensemble of GrIS geometries, we used data inferred from 5 Greenland ice cores such as the presence or absence of LIG ice, borehole temperature and isotopic composition. Lagrangian backtracing of particles was used to calculate non-climatic biases in isotopic records introduced by horizontal advection, systematic latitudinal contrast and local elevation changes. Comparison of model-generated ice-core characteristics with the observed data enabled to narrow down the ensemble to a bound on the GrIS contribution to the LIG sea-level rise of between 1.3 and 2.9 m with the best choice of 1.8–2.2 m. This conclusion in general supports the point of view about the modest GrIS contribution to global sea level rise during the LIG.

To constrain the ensemble of Greenland Ice Sheet geometries, we used data inferred from five Greenland ice cores such as the presence or absence of Last Interglacial ice, borehole temperature and isotopic composition. Lagrangian backtracing of particles was used to calculate non-climatic biases in isotopic records introduced by horizontal advection, systematic latitudinal contrast and local elevation changes. Comparison of model-generated ice-core characteristics with the observed data enabled to narrow down the ensemble to a bound on the Greenland Ice Sheet contribution to the Last Interglacial sea-level rise of between 1.3 and 2.9 m with the best choice of 1.8–2.2 m. *(O.O. Rybak, F. Hoebrects Earth System Sciences and Departement Geografie, Vrije Universiteit Brussel; Sochi Scientific Center, Russian Academy of Sciences;[3]Institute of Nature-Technical Systems, Russian Academy of Sciences, Sochi)*

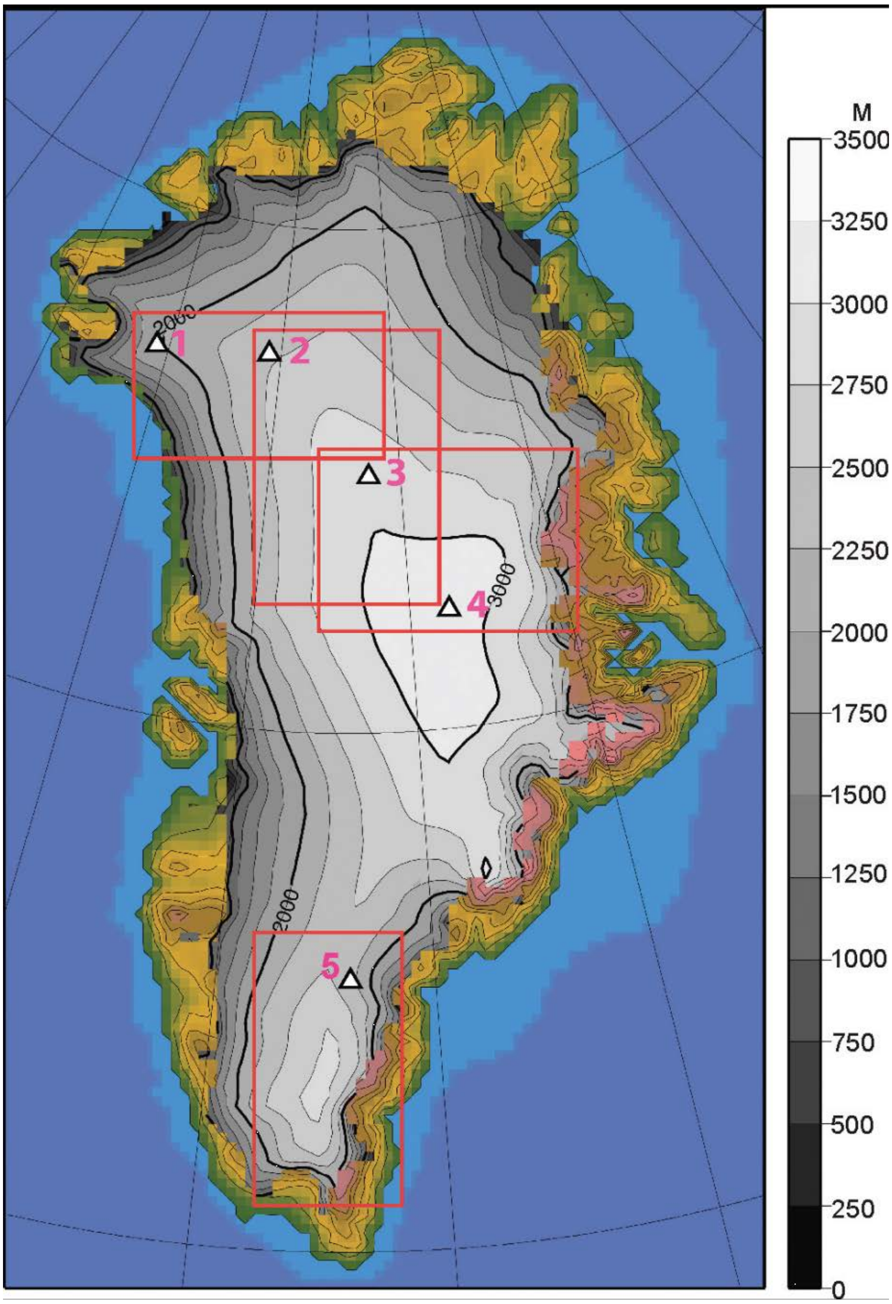


Fig. 42. Present-day absolute surface elevation of Greenland and the GrIS (shown in grey), m. Figures indicate deep-drilling sites: 1 – Camp Century; 2 – NEEM; 3 – NGRIP; 4 – GRIP; 5 – Dye3. Red frames indicate domains used to store data in numerical experiments for further computation of times and places of origin of ice particles in cores 1–5

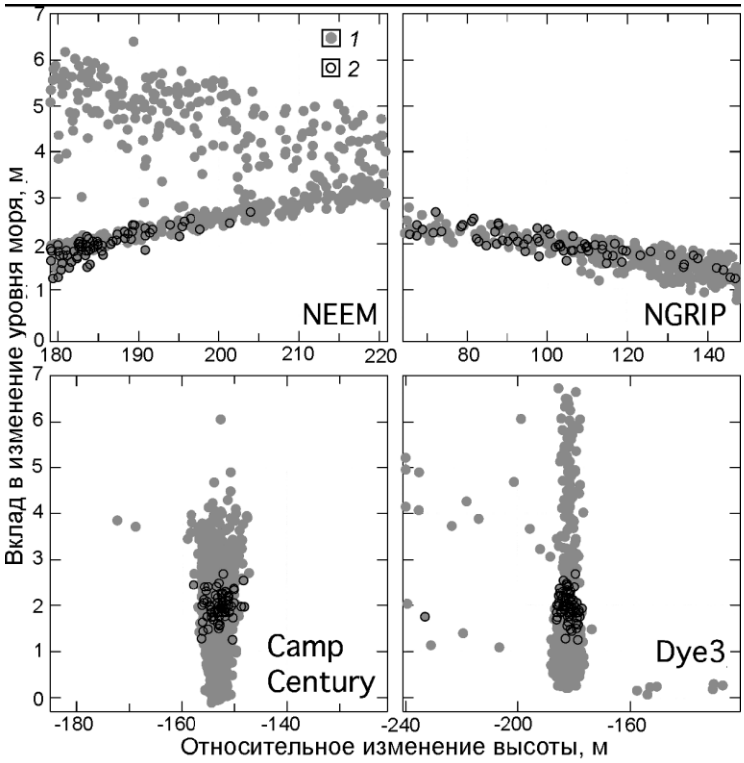


Fig. 43. Maximum Greenland ice sheet contribution to the global sea-level change during the Eemian vs relative elevation changes in four reference virtual ice cores (NEEM, NGRIP, Camp Century и Dye3). *1* – are the members of the initial manifold of the model results fitting to the relative elevation change intervals determined in table; *2* – the members of the submanifold fitting to all four ice cores

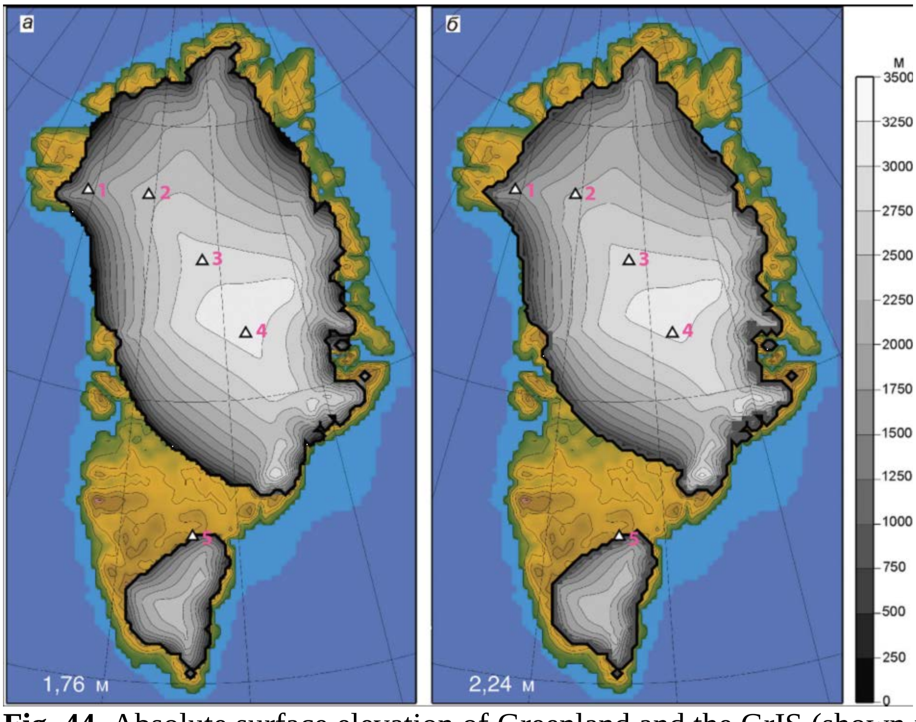


Fig. 44. Absolute surface elevation of Greenland and the GrIS (shown in grey), m, 119.2 kyr ago in two numerical experiments with ψ < 0.7 °C with the minimum (*а*) and maximum (*б*) contribution in global SL change. Figures indicate deep-drilling sites: 1 – Camp Century; 2 – NEEM; 3 – NGRIP; 4 – GRIP; 5 – Dye3

SNOW COVER AND SNOW AVALANCHES

Climatic characteristics of snow cover of Northern Eurasia and their variations during the last decades. Statistical analysis was made on characteristics of snow cover in North Eurasia for the base climatic period 1951–1980 and during the recent climate warming in 1989–2006. The changes in the snow cover over the subcontinent are related to the mechanisms of atmospheric circulation revealed earlier. Maximum of snow accumulation occurs in the east of Kamchatka peninsula. According to indirect data, resources of solid precipitation are even greater on the ranges near Black sea, in the Krasnaya Polyana area. In the continental part of North Eurasia, the snow depth has its maximum in the middle part of Yenisey basin. Maxima of the snow accumulation in the East European Plain are located near the Urals and in the Mezen river basin. Minima on the scale of entire sub-continent are located in Trans-Baikal region and in the south of East European Plain. During the last decades, the North Eurasia snow accumulation increased as a whole. The largest increase takes place in the south of Kamchatka, in the south of Sakhalin, in the east of European part of Russia and in West Siberia. The seasonal dynamics of the snow depth from the end of October until the end of April was analyzed. Significant increase of frequency of the weather situations, favorable for fast snow melting and sharp peak of runoff occurs in the Pechora river basin, and according to some estimates, in the upper parts of Vychegda and Kama basins, near the Gulf of Finland, in the middle part of Ob basin and in Anabar river basin (*A.B. Shmakin, Institute of Geography RAS*).

Snow cover onset dates in the north of Eurasia: relations and feedback to the macro-scale atmospheric circulation. Variations of snow cover setting-up data in 1950–2008 based are analyzed in order to reveal climatic norms, relations with macro-scale atmospheric circulation and influence of snow cover anomalies on strengthening/weakening of westerly basing on observational data and results of simulation using model Planet Simulator, as well. Patterns of mean snow cover onset data and their correlation coefficients with circulation indices in the terms of Northern Hemisphere Teleconnection Patterns, as well as relation revealed between snow cover extent anomalies for the second decade of October and winter atmospheric circulation regime over North Eurasia, are presented.

Variations of snow cover onset data in 1950–2008 based on daily snow depth data collected at first-order meteorological stations of the former USSR compiled at the Russia Institute of Hydrometeorological Information are analyzed in order to reveal climatic norms, relations with macro-scale atmospheric circulation and influence of snow cover anomalies on strengthening/weakening of westerly basing on observational data and results of simulation using model Planet Simulator, as well. Patterns of mean snow cover setting-up data and their correlation with temperature of the Northern Hemisphere extra-tropical land presented in Fig. 1 show that the most sensible changes observed in last decade are caused by temperature trend since 1990th. For the most portion of the studied territory variations of snow cover setting-up data may be explained by the circulation indices in the terms of Northern Hemisphere Teleconnection Patterns: Scand, EA–WR, WP and NAO (Fig. 2). Role of the Scand and EA–WR (see Fig. 2, *а*, *в*, *г*) is recognized as the most significant.

Changes of snow cover extent calculated on the base of snow cover onset data over the Russia territory, and its western and eastern parts as well, for the second decade of October (Fig. 3) demonstrate significant difference in variability between eastern and western regions. Eastern part of territory essentially differs by lower both year-to-year and long-term variations in the contrast to the western part, characterized by high variance including long-term tendencies: increase in 1950–70th and decrease in 1970–80 and during last six years. Nevertheless relations between snow cover anomalies and Arctic Oscillation (AO) index appear to be significant exceptionally for the eastern part of the territory. In the same time negative linear correlation revealed between snow extent and AO index changes during 1950–2008 from statistically insignificant values (in 1950–70 and 1996–2008) to coefficient values −0.82 ÷ −0.85 in 1973–1994 (Fig. 4, *а,б*). Results of numerical experiments on simulation of observed October snow cover anomaly in 1976 and its impact on Northern Hemisphere sea level pressure in winter months approved potential ability of abrupt increase of albedo caused by snow cover onset to influence on weakening of westerly and negative temperature anomalies in North Eurasia (Fig. 5). Evidently, based on observational data and results of modeling one should conclude that autumn snow cover anomalies in North are able to effect on macro-scale circulation regime in winter, but in condition of weakening of other major factors influencing on circulation, for example sea surface temperature over the oceans. In any case, correlation analysis of earth observations shows that snow cover extent anomalies could not be recognized as cause of negative AO anomalies and severe winters in North Eurasia in last decade.*(V.V. Popova, A.V. Shiryaeva, P.A. Morozova. Institute of Geography, Russian Academy of Sciences, Moscow)*

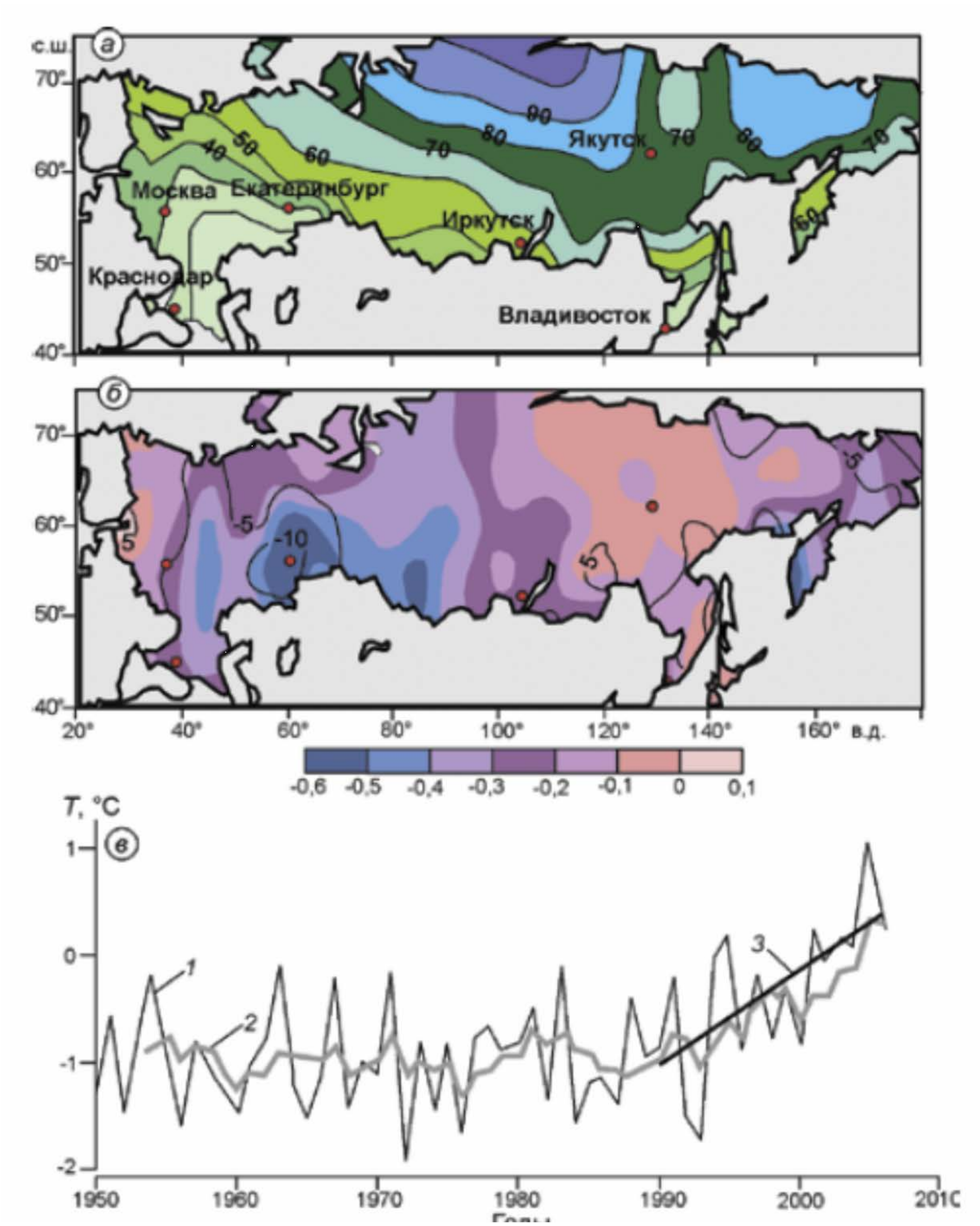


Fig. 45. Norms of snow cover onset dates and their relations with temperature of the Northern Hemisphere extra-tropical land in 1950–2008: a – norms of snow cover onset dates, in days to the end of year; б – changes (isolines) of snow cover onset dates in 1999–2008 as compared with 1951–2008, in days, and correlation coefficients (color scale) between snow cover onset dates and temperature of the Northern Hemisphere extratropical land; в – autumn averaged tempera□ ture, °C, of the Northern Hemisphere extra-trop□ ical land: 1 – annual values; 2 – 5□year running means; 3 – linear trend for 1990–2008, and its parameters (in the top) are shown

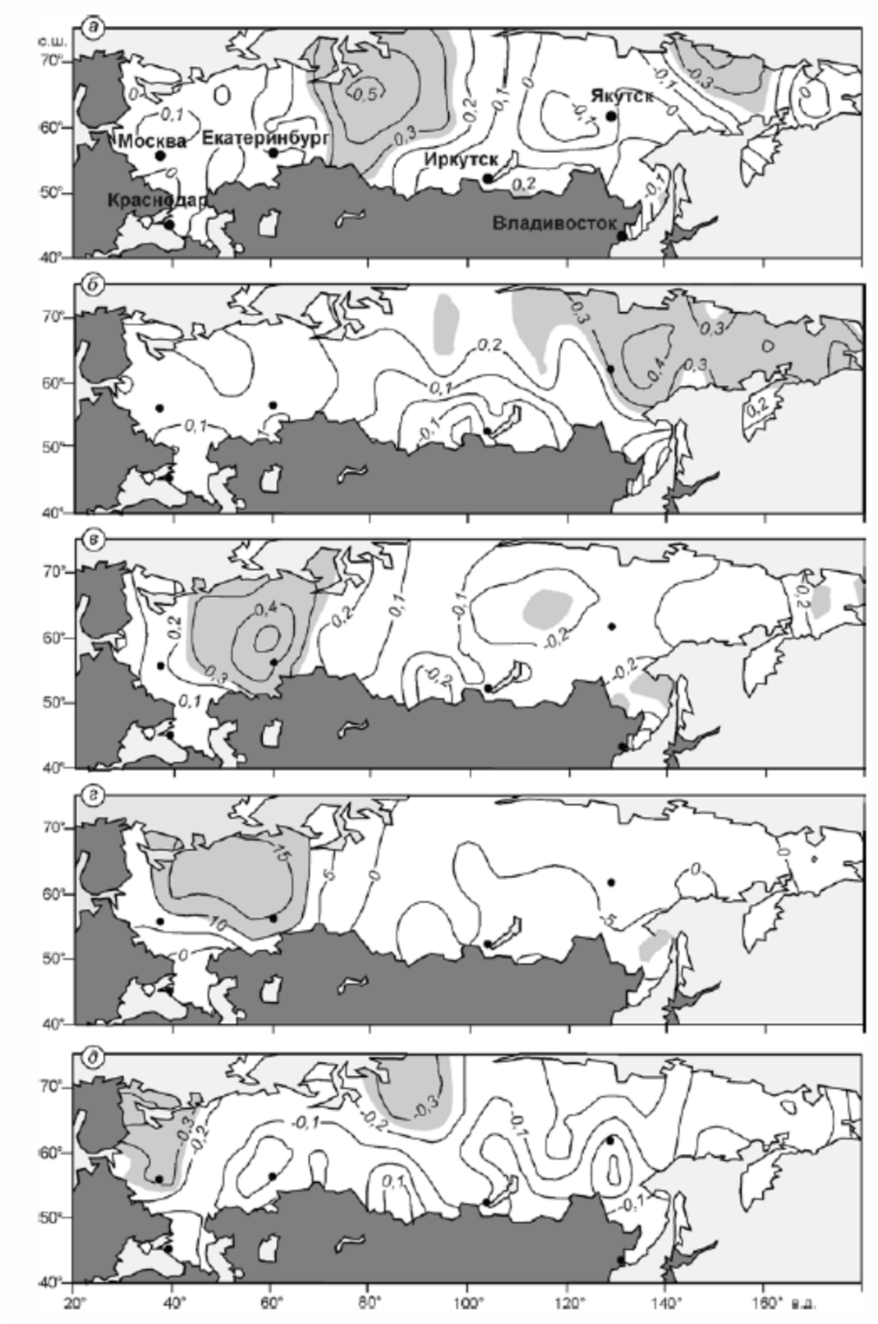


Fig. 46. Relations between snow cover onset dates and macro-scale circulation variations. Coefficients of correlation between indices: Scand (а), WP (б), EA–WR (в) и NAO (д), averaged for September–November, and snow cover onset dates in 1950–2008: differences between average snow cover onset dates, in days, during 8 years positive and negative anomalies of index EA–WR (г). Gray color indicates areas of statistically significant ($p \leq 0{,}05$)

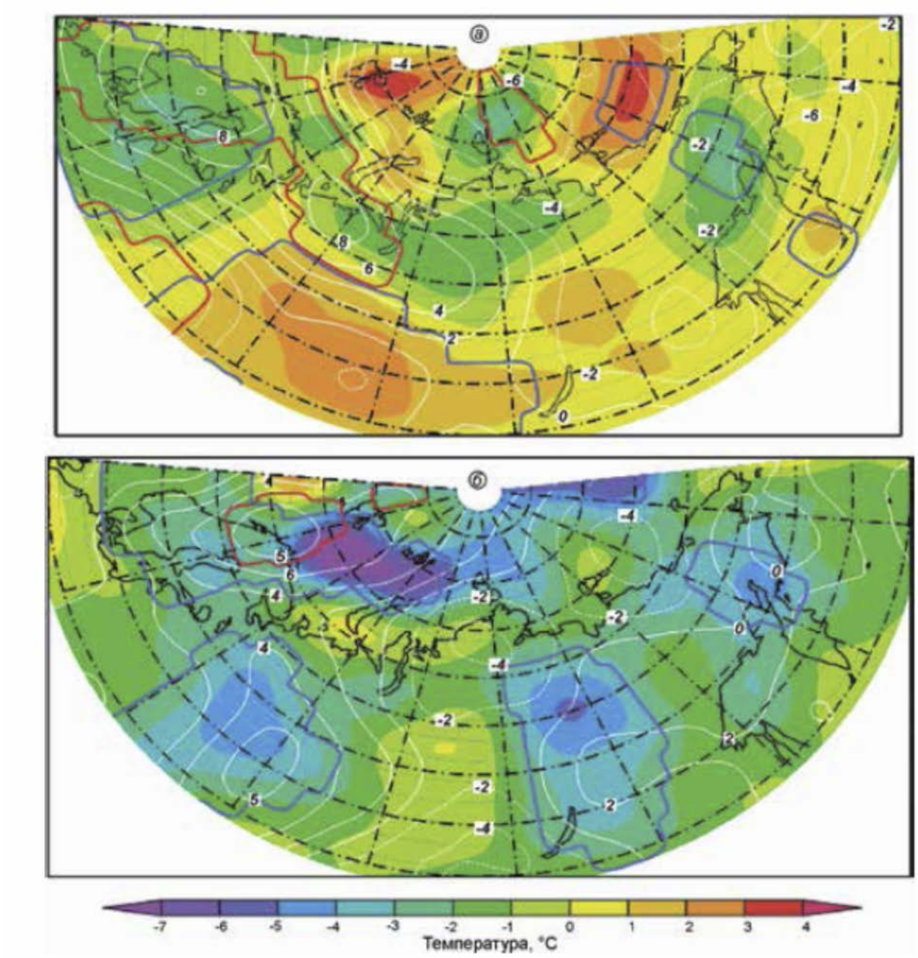


Fig. 47. Results of experiment on revealing of the climate system response on positive snow cover extent anomalies in the mid of autumn, using model Planet Simulator. Anomalies of earth surface temperature (°C, color scale) and sea level pressure (white isolines, hPa), simulated as a result of experiment with albedo changed in accordance with positive anomaly snow cover extent in October 1976 as compared with base experiment. Red (blue) curves indicate areas of statistically significant ($p \leq 0,05$) pressure (temperature) anomalies

Impact of snowfall measurement deficiencies on quantification of precipitation and its trends over Northern Eurasia

Instead of «ground truth» precipitation, rain gauges at meteorological stations estimate a function of several variables. In addition to precipitation, these variables include temperature, wind, humidity, gauge type, state of the gauge exposure, and observational practices. Their impact and changes hamper our efforts to estimate precipitation changes alone. For example, wind-induced negative biases for snowfall measurements are higher than for other precipitation types and a redistribution of these types during regional warming can cause an artificial increase in *measured* precipitation. In such conditions, the only way to properly estimate actual climatic changes of precipitation would be a use of precipitation time series that are corrected for all known systematic biases. Methodology of such corrections has been developed and recently implemented for Northern Eurasia for the past 50+ years (up to 2010). With the focus on Russia, we assess differences that emerge when officially reported precipitation in the cold season is compared to corrected precipitation time series at the same network. It is shown that conclusions

about trend patterns over the country are quite different when all sources of inhomogeneity of precipitation time series are removed and impact of all factors unrelated to the precipitation process are accounted for. In particular, we do not see statistically significant increases of the cold season precipitation over most of the Russian Federation and in Arctic Asia it significantly decreases. *(P.Ya. Groisman[1], E.G. Bogdanova[2], V.A. Alexeev[3], J.E. Cherry[3], O.N. Bulygina[4]*
[1]University Corporation for Atmospheric Research/National Climatic Data Center, Asheville, North Carolina, USA;[2]Voeikov Main Geophysical Observatory, Sankt-Petersburg; [3]International Arctic Research Center, University of Alaska-Fairbanks, Fairbanks, Alaska, USA; [4]All-Russia Institute for Hydrometeorological Information, Obninsk)

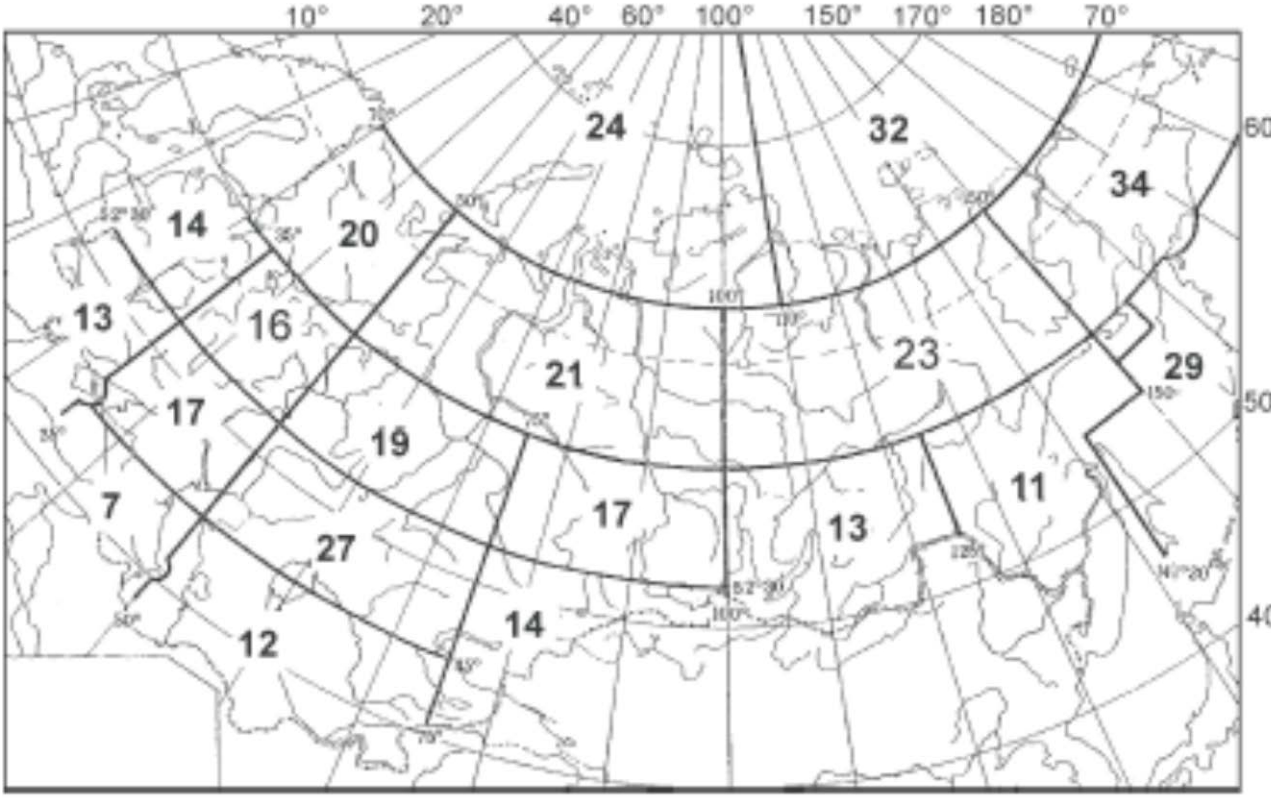


Fig. 48. Increase (%) in mean annual precipitation totals throughout the former USSR during the 1961–1990 period compared to measured precipitation, *P*0 (data source: [35]

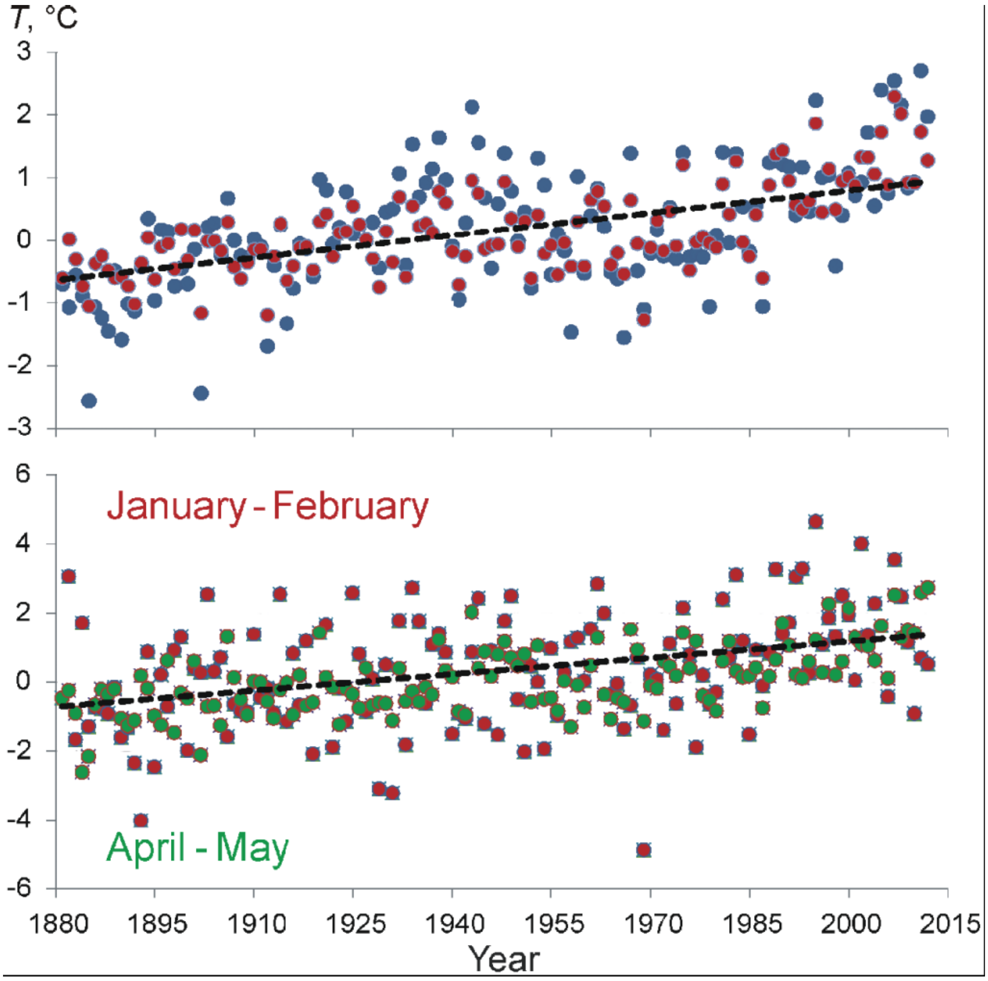


Fig. 49. ***Top***. Annual surface air temperature anomalies area averaged over Northern Eurasia north of 40°N (red dots) and north of 60°N (blue dots). Century-long linear trends for both these time series practically coincide being equal to 1.75 °C per 132 years. For the1958–2012 period, the linear trend estimate for the «red» time series is equal to 1.75 °C per 55 years. ***Bottom***. Seasonal (two-monthly) surface air temperature anomalies area averaged over Northern Eurasia north of 40°N for mid-winter (red dots) and late spring (green dots). Century-long linear trends for both these time series also coincide being equal to 2.1 °C per 132 years; however, for the late spring season, linear trend is more visible and describes 36% of interannual variance of the time series (versus 13% for the mid-winter time series). The 1881–2012 period; Anomalies from the mean values for the 1951–1975 period. Source: Lugina et al. archive [32], updated

Dynamic-stochastic modeling of snow cover formation on the European territory of Russia

A dynamic-stochastic model, which combines a deterministic model of snow cover formation with a stochastic weather generator, has been developed. The deterministic snow model describes temporal change of the snow depth, content of ice and liquid water, snow density, snowmelt, sublimation, re-freezing of melt water, and snow metamorphism. The model has been calibrated and validated against the long-term data of snow measurements over the territory of the European Russia. The model showed good performance in simulating time series of the snow water equivalent and snow depth. The developed weather generator (NEsted Weather Generator, NewGen) includes nested generators of annual, monthly and daily time series of weather variables (namely, precipitation, air temperature, and air humidity). The parameters of the NewGen have been adjusted through calibration against the long-term meteorological data in the European Russia. A disaggregation procedure has been proposed for transforming parameters of the annual weather generator into the parameters of the monthly one and, subsequently, into the parameters of the daily generator. Multi-year time series of the simulated daily weather variables have been used as an input to the snow model. Probability properties of the snow cover, such as snow water equivalent and snow depth for return periods of 25 and 100 years, have been estimated against the observed data, showing good correlation coefficients. The described model has been applied to different landscapes of European Russia, from steppe to taiga regions, to show the robustness of the proposed technique. *(A.N. Gelfan, V.M. Moreido Institute of Water Problems, Russian Academy of Sciences, Moscow)*

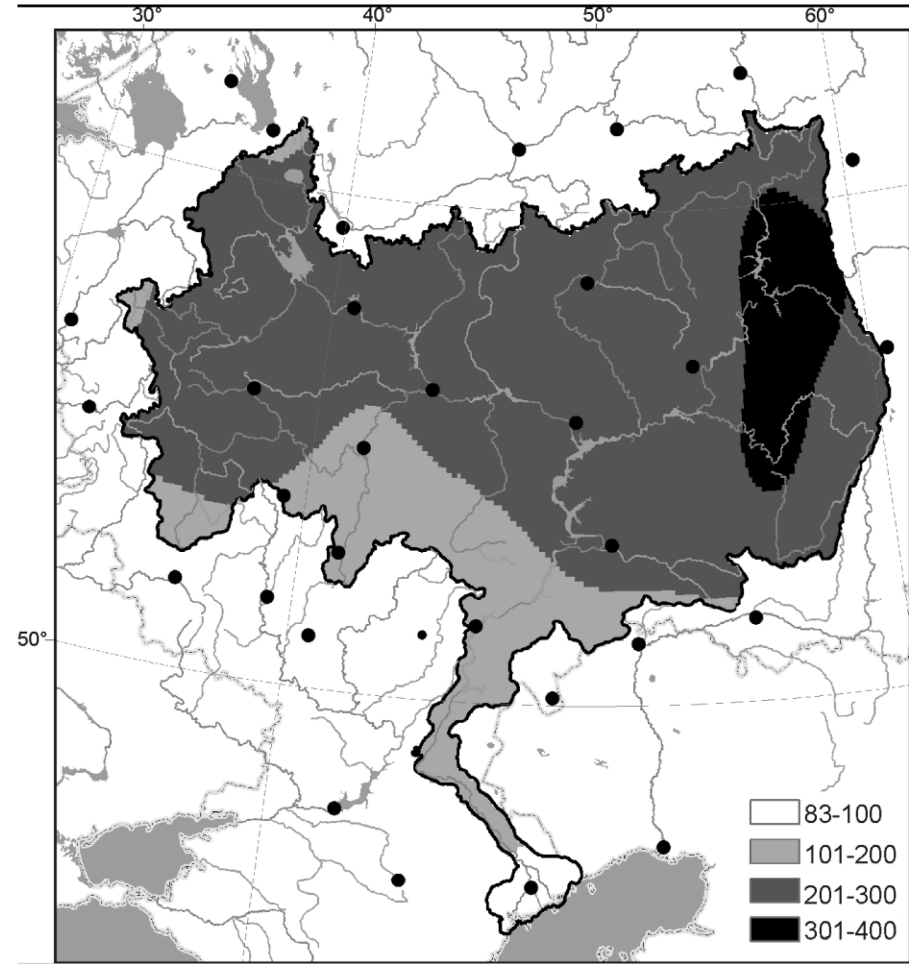


Fig. 50. Map of maximum SWE for 25-year return period. Dots are meteorological station locations, gradient fill – SWE classes in mm

Studies of snow avalanches. Since 1968, *Scientific-educational Elbrus station* carries out regular stationary observations of snow cover, avalanches, heavy snowfalls, catastrophic natural events and their dynamics with respect to the present-day climate change in the Caucasus region. As it was determined, the very snowy (abounding with snow) period at the end of XX century has been changed by years (two last decades) with noticeable decrease of the snowfalls and accumulations and rising of winter temperatures. Winter of 2012/13 happened to be with the least snow for the whole observational period here.

Research Laboratory of Snow Avalanches and Mudflows (Lomonosov MSU) supplies the electronic base by additional data on occurrence of avalanches and conditions of their formation along the Russia's territory. Modeling of snow avalanches and calculations of their dynamic characteristics were performed on the key sites in Khibiny Mountains, near Elbrus, and on Krasnaya Polyana (Red Glade); the Switzerland software RAMMS was used for this purpose. We reveal influence of parameters of the avalanche model, stipulated by climatic factors, upon dynamic characteristics and sizes of the avalanche deposits. A model has been developed for short-term forecasting of snowstorm avalanches for the Khibiny region.

In June 2013, a school seminar was hold together with Switzerland Federal Institute of Avalanche Research where participants presented principles of work and possibilities of the RAMMS software for two-dimensional dynamic modeling of snow avalanches and mudflows under conditions of 3D relief. Procedures for predicting the avalanche risks at mountain-ski resorts of Northern Caucasus is in progress; they are developed on the large-scale with the use of geoinformatic modeling (*N.V. Volodicheva, Lomonosov State University*).

Catastrophic avalanches and methods of their control. Definition of such phenomenon as "catastrophic avalanche" is presented in this arti-cle. Several situations with releases of catastrophic avalanches in mountains of Caucasus, Alps, and Central Asia are investigated. Materials of snow-avalanche ob-servations performed since 1960s at the Elbrus station of the Lomonosov Moscow State University (Central Caucasus) were used for this work. Complex-valued measures of engineering protection demonstrating different efficiencies are consid-ered.

The paper is devoted to investigation of catastrophic avalanches. Every year tens of them rush down in different regions of the world and result in large-scale disastrous phenomena. Great expenses are required for engineering protection of different industrial and social objects against such avalanches. Definition of the phenomenon "catastrophic avalanche" is given. Data on catastrophic avalanches in different mountain regions together with conditions of formation of them are analyzed. Materials of snow-avalanche observations performed since 1960s at the Elbrus station of the Lomonosov Moscow State University (Central Caucasus) were used for this work. The most well-known events of catastrophic avalanche releases in mountain regions of Caucasus, Alps, and Central Asia are considered. Complex-valued measures of engineering protection are discussed with respect to different efficiencies of them.
In the second half of 20th century, increase of recurrence of especially large avalanches with 1% provision was noted. Such avalanches became serial since they were recorded in winters of 1967/68, 1973/74, 1975/76, 1986/87. But at the beginning of 21nd century, the avalanche activity became smaller and recurrence of their releases did also decrease. Under conditions of growing climate instability and increase of anomalously warm winters, the catastrophic avalanches of advective type are mostly observed. Relative to avalanches from newly fallen snow they have smaller run-out distance but they also have significant destroying power. It means that if such snow avalanches rush out far outside their normal limits they bring the threat for population and

buildings. (*N.A. Volodicheva, A.D. Oleynikov, N.N. Volodicheva. Moscow State University*)

Studies of avalanche and snow processes on the Sakhalin Island. In 2010–2013, avalanche processes were observed and investigated on the Sakhalin Island, Kuril Isls, Transbaikalia, and on West Caucasus (Krasnaya Polyana). It was established on the basis of these observations that velocities, distance of fall-out as well as specific features of the avalanche motions depend on genetic type of an avalanche much more than on its volume. Seven genetic types of avalanches distinguishing by their dynamics were isolated. Basing on results of investigations of avalanche complexes on marine terraces of South Sakhalin and avalanche processes on plain territories, it was determined that avalanche complexes on marine terraces had a number of features which allowed considering them as a specific class of avalanche complexes. Eight types of the terrace avalanche complexes were isolated, and regularities of their structure were determined for the purpose to calculate parameters of the avalanche processes on marine terraces and on plains in cases when data of observations are insufficient.

In winter 2013, observations of changes in rate of structure and texture of genetically homogeneous snow layer were performed on Southern Sakhalin. It was determined that ice crystals in the stage of constructive metamorphism can appear in the snow layer in already 3 days after it had been formed during a snowfall. Crystals of skeleton class can be formed in already 8 days while the bar texture – only in 9 days after the layer formation. In this way it was determined that the avalanche-danger layers can be formed in a snow thickness in 8-10 days after a snowfall.

Investigations of electric properties of snow were continued. It was revealed that electric charge of an icy crystal depends on its size and form (i.e. on a stage of its metamorphism), and a charge of snow layer depends on its structure and texture. Ice crystals being placed into artificial electric field arrange into vertical clusters similar to those which are observed in snow layers with filamentary texture. This testifies that a separation of surface charges takes place on the crystals while a crystal itself in such case should be characterized as a dipole. A model has been developed which presents a snow cover in its natural state as an electrodynamic system (*N.A. Kazakov, Far-Eastern Geological Institute, Far-East Branch of RAS*).

SEA, RIVER AND LAKE ICE

Formation and distribution of water masses on the shelf and continental slope around Antarctica. The field studies of the last decades show that the structure and characteristics of the waters on the continental shelf of Antarctica have significant spatial differences. On the all shelves of the East and, partly, the West Antarctica (from the Weddell Sea to the Ross Sea, inclusive), Antarctic Shelf Water is found having different volumes and different salinities. On the shelves of most part of West Antarctica (in the Amundsen and Bellingshausen Seas and at the western shelf of the Antarctic Penin-sula) the Antarctic Shelf Water is not found.
During the IPY 2007/2008 and post-IPY period the oceanographic sections were made from the AARI research vessels in the Prydz Bay, Amundsen and Bellingshausen Seas. Sections with high horizontal resolution (~2–3 miles between stations) at the continental slope allowed us to obtain a detailed picture of the water structure in the area of interaction of shelf and deep ocean water – at the Antarctic Slope Front. It is shown that the principal difference in the water characteristics and the front structure between the seas is determined by the peculiarities of large-scale circulation and the physical-geographical features of the regions (shelf and continental slope parameters, coastline configuration, presence and size of the ice shelves). Using modern and historical data, it is shown that the most fundamental characteristic, dividing the Antarctic shelf into two regions, is the presence (or absence) in the area of the Antarctic Shelf Water which usually occupies the bottom layer of the water column and has the temperature close to the freezing point. On all shelves of the East and, partly, the West Antarctica (from the Weddell Sea to the Ross Sea, in-clusive), this water mass was found having different volumes and different salinities. On the shelves of most part of West Antarctica (in the Amundsen and Bellingshausen Seas and at the western shelf of the Antarctic Peninsula) the shelf water is not found. The consequence of these features is fundamentally different role of these two regions in the processes that affect the cli-mate processes, namely, the formation of Antarctic Bottom Water and the role of warm Circum-polar Deep Water in the melting of the ice shelves. *(A.V. Klepikov, N.N. Antipov Arctic and Antarctic Research Institute, St. Petersburg).*

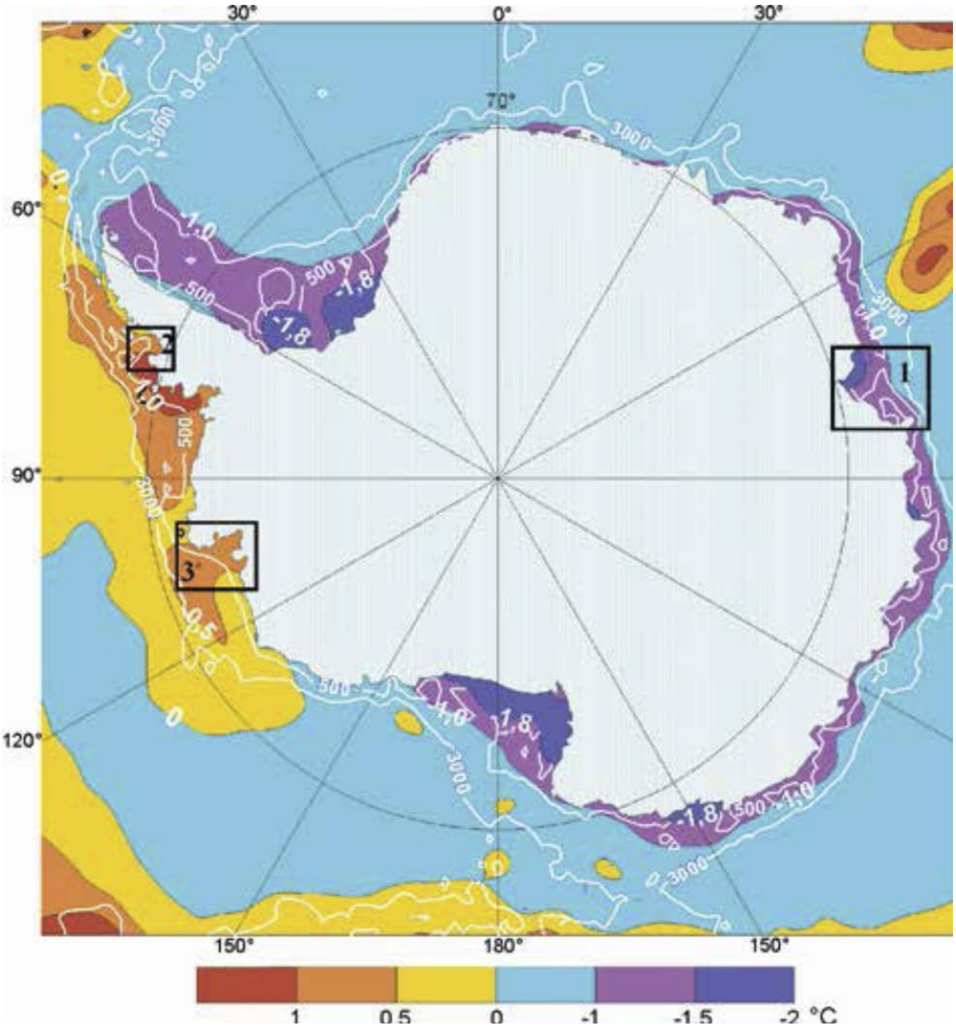


Fig.51 Potential temperature of the sea water in the bottom 50 m thick layer in the Antarctic zone of the Southern Ocean. 500 m (corresponds to the outer boundary of the shelf) and 3,000 m (corresponds to the base of the continental slope) isobaths are shown. Numbers indicate the areas considered in this paper: 1 – Prydz Bay; 2 – Marguerite Bay; 3 – Amundsen Sea

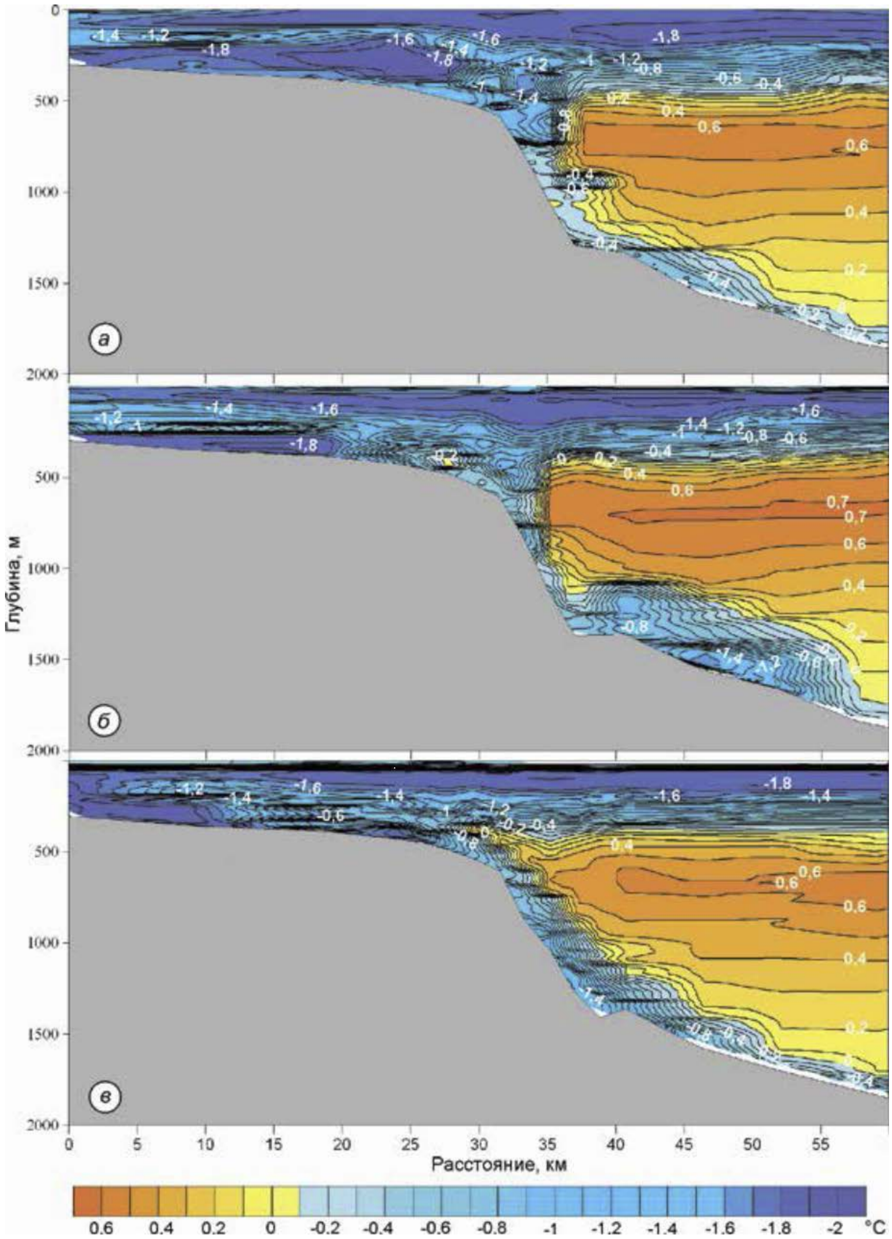


Fig.52 Potential temperature of water at 70⁻ E section performed in the same coordinates as in 2011 (*a*), 2012 (*б*), and 2013 (*в*),respectively.The position of the section is shown in Fig. 2.

Imitation modeling of ice dams (case study of Tom' River, Western Siberia)

Problems of localization of the ice jams in the lower flow of the Tom River (Siberia) are discussed. A length of the main channel under investigation is about 120 km. The 1D model HEC-RAS 4.0 was used for the analysis. The 2D hydrodynamic model of the Tom River channel system in the SMS 9.2 modeling system has been developed. The model makes it possible to simulate effects of ice jams occurring in different sections of the river bed on redistribution of the river run-off between the main channel and other river branches.

The factors of ice jam formations in the lower flow of the Tom River (Siberia) are investigated. A length of the main channel under investigation is about 120 km. Approaches to solution of the problem of the jam formation control and, as a consequence, the jam induced floods are considered on the basis of the imitative computer modeling of stream dynamics and ice jams. The simulation makes it possible to analyze different scenarios of initial forcing and to predict reactions of the river bed system to the effects. On the basis of 1D models developed in the HEC-RAS 4.0 modeling system for the Tom River at the city of Tomsk we investigated a possibility of the ice jam localization, probability of which at different parts of river flow varies in time according to change of the river water discharge, stream hydraulics, and ice cover thickness. The 2D hydrodynamic model of the Tom River channel system in the SMS 9.2 modeling system has been developed. It allows simulating effects of ice jams located in different sections of the river flow on the run-off redistribution between the main channel and other river branches. It makes possible to estimate hazards and risks of ice jam floods and probable effects of ice jams on formation of the river channel system. As a result it becomes possible to regulate the safe spring ice transit through populated areas.

Analysis of factors of the ice jam formations has demonstrated that due to increasing anthropogenic influence changes of hydro-meteorological and geomorphologic conditions lead to more frequent occurrence of jam floods for the last 25 years as compared to previous 40-year period. The imitative computer models are proposed to be used for planning anti-jam measures since they make possible to create a whole system of the channel structure, a relief of channel and floodplain, a flow velocity field including dangerous hydrologic processes. Similar system would allow predicting both consequences of local anthropogenic influences and their synergic effects. A change of a pressure head along the river course under fixed water discharges at initial hydraulic section can be calculated with the 1D flow model so that to determine places of the most probable localization of the ice jams. A computer simulation of jams in the river channel system with use of preassigned increased roughness coefficients allows quantitative estimating of the runoff redistribution within the channel system under certain scenarios of a spring flood in the jam-dangerous parts of branching river channels. It is important to preserve such branches, and they should be cut by any dam from a main channel.*(V.A. Zemtsov, D.A. Vershinin, N.G. Inishev. Tomsk State University)*

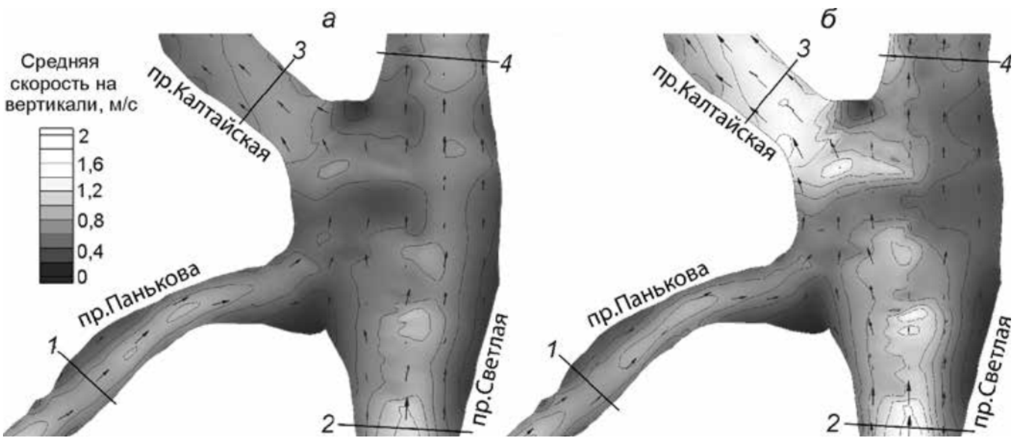


Fig..53 Fields of depth averaged velocities at the junction of the Tom River side channels Svetlaya, Kaltayskaya and Pankova corre□sponding to the scenarios in Fig. 4, a and в in the cases of the absence (a) and presence (б) of the ice dams in the main channel and the Svetlaya side channel. Digits indicate the modeled cross sections located in the side channels

Arctic dimension of global warming

A brief assessment of the global warming in the Arctic climate system with the emphasis on sea ice is presented. The Arctic region is coupled to the global climate system by the atmosphere and ocean circulation that provides a major contribution to the Arctic energy budget. On this basis using of special indices it is shown that amplification of warming in the Arctic is associated with the increasing of meridional heat transport from the low latitudes. At the same time, the zonal heat transport influences the warming in the middle latitudes. Moreover global warming is partly associated with an increase of the heat transport. Increase of incoming longwave radiation also contributes to the arctic warming due to an increase of humidity and cloudiness in the Arctic atmosphere. From October to January the warming is additionally amplified by retreat of ice edge from the Siberian and Alaska coast and the consequent heating of expanded volume of sea water. The scheme of the Arctic amplification in response to the increasing meridional heat and moisture transport from low latitudes and originated feedbacks in the Arctic climate system is presented. *(G.V. AlekseevArctic and Antarctic Research Institute, Sankt-Petersburg)*

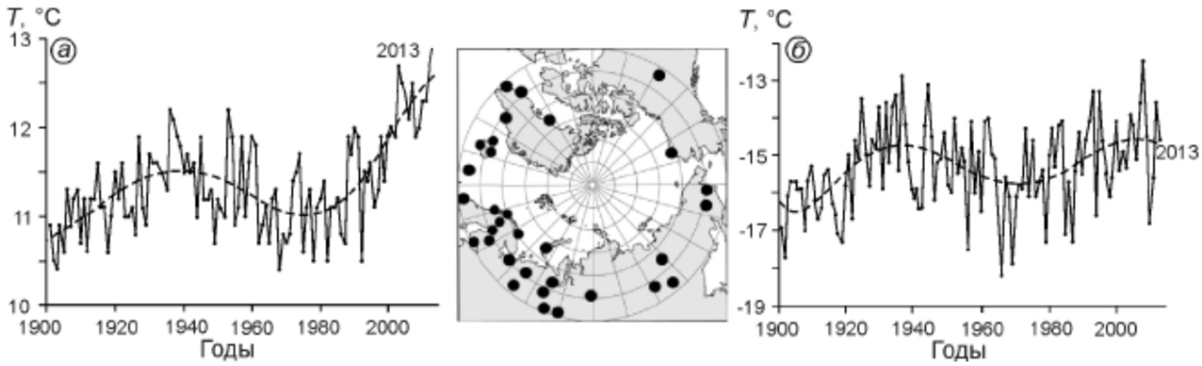


Fig. 54. Average from 32 stations north to 60°N surface air temperature in summer (*a*) and winter (*б*). At the centre – map of station sites; dotted line is a six degree orthogonal polynomial approximation (coefficient of determination $R2$ = 0.22 и 0.53 respectively)

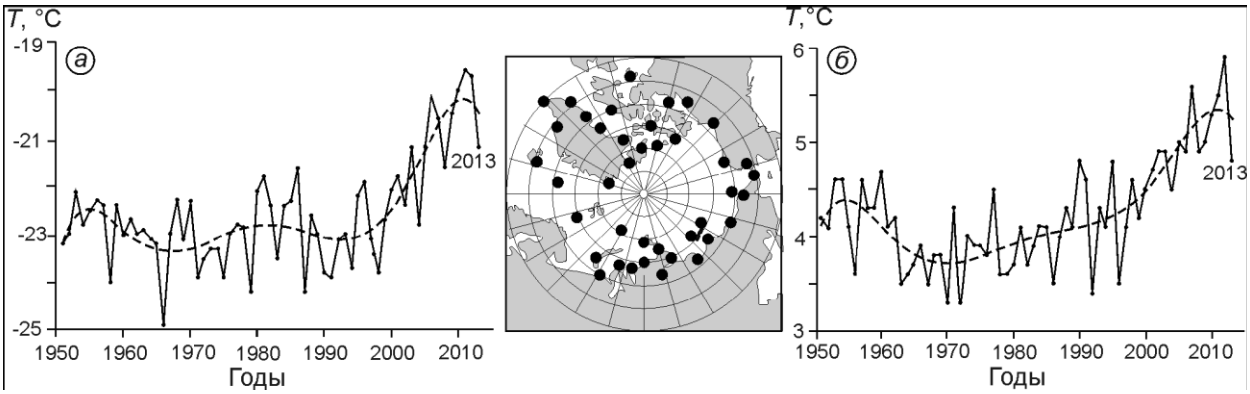


Fig. 55 Change of mean surface air temperature in the marine Arctic during 1951–2013 in winter (*a*) and summer (*б*); at the centre – map of station sites; dotted line is a six degree orthogonal polynomial approximation (coefficient of determination $R2$ = 0.65 и 0.66 respectively)

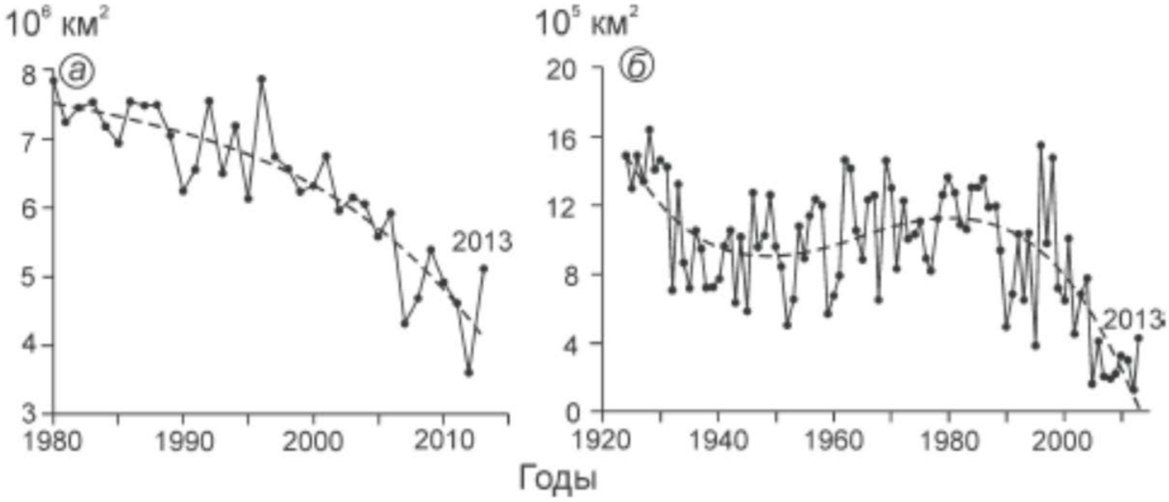


Fig. 56. Monthly mean sea ice extent (SIE) in September in the Arctic on data from NSIDC [99] for 1980–2013 (*a*) and the same in Siberian Arctic Seas (Kara, Laptev, East-Siberian and Chuckchi Seas) on data from AARI (*б*). Dotted line is a three degree orthogonal polynomial approximation

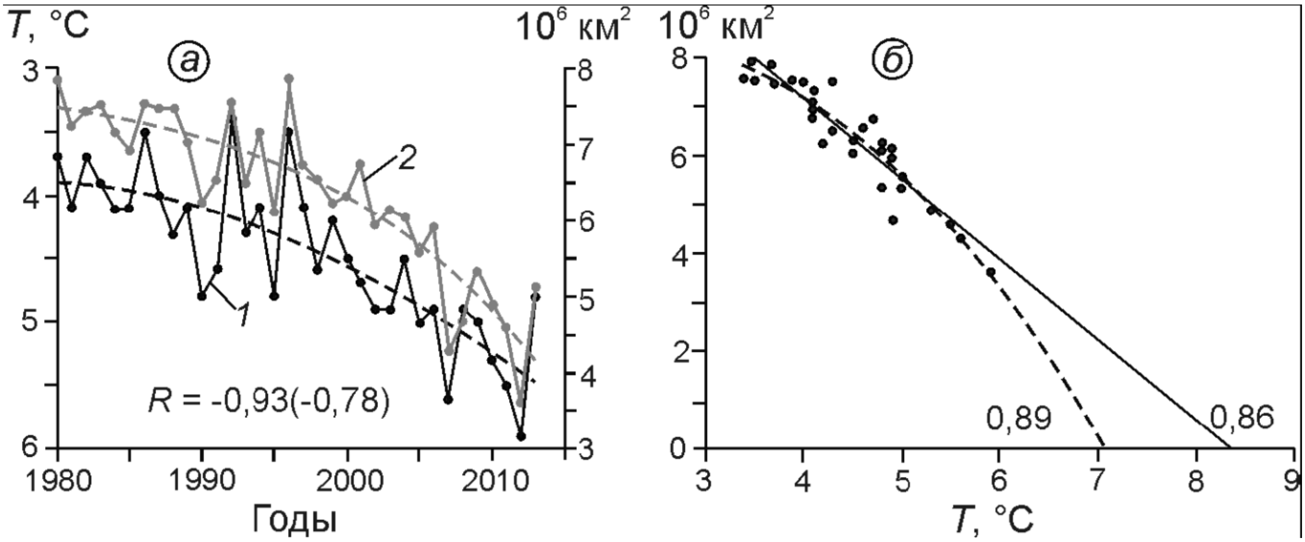


Fig. 57. *a* – summer surface air temperature (*1*) and September sea ice extent (*2*) in the marine Arctic. The scale of temperature is inversed; dotted line is a three degree orthogonal polynomial approximation. Insert figures are correlation coefficients between surface air temperature and sea ice extent and between their deviations from polynomials (in brackets). *б* – quadratic (dotted) and linear (straight line) approximations of connection between surface air temperature and sea ice extent; insert figures are coefficients of determination

CRYO DATA MANAGEMENT

The spatial glaciological data infrastructure

Thematic infrastructure of spatial data on the glaciological resources that has been developed in the Institute of Geography of the Russian Academy of Sciences (IGRAS) is presented in the paper. The infrastructure is based on the geoportal solu-tions and integration technologies. It includes informational resources of glaciology accumulated in distributed systems in the forms of data and metadata bases, struc-tured and objective data files as well as the digital atlases. Examples of how to real-ize the approaches proposed in the paper such as the portal «Geography», the portal «IPY–IGRAS», the digital atlas «Snow and Ice on the Earth», and regional data ba-ses for the Caucasus and the Antarctic Continent areas are considered.

Substantial and rapid environmental changes require developing methods which could be able to manage huge information flows, to optimize processes of the data acquisition, storage, analysis, and exchange. Such facilities can be provided by the newly developed GIS technologies. Digital data bases are used as the key component of the GIS methods. We present the system of glaciological data management, developed in the Institute of Geography of Russian Academy of Sciences (IGRAS). Digital Atlas «Snow and Ice on the Earth», glacier inventories and digital library are the basic structures making possible objective presentation of the glaciolog-ical knowledge and data. The system provides the data integration, access to the data base, and makes possible using the GIS techniques for analysis. Data integration technologies are designed to form the united information space of subject areas of the spatial data. The objects of integra-tion in our study are the information resources of glaciology, accumulated in a distributed system of data on the IGRAS web servers and geoportals in forms of data and metadata bases, struc-tured (in a particular format) data files, object data files (plain text, documents, images, etc.), and electronic atlases. The best option for formation of a large-scale distributed environment, integra-tion of many information resources of glaciology is to provide the so-called interoperability of data. This refers to compliance with certain rules or usage of additional software tools that allows interaction between various spatial data. These are standards to which the integrated information resources of glaciology should satisfy. The result of integration of the glaciological data technol-ogy application is the series of software and technology solutions. The main result of this work is creation of geoportals «Electronic Earth» (www.webgeo.ru), «The Nature and Resources of the Russian North» (www.north.webgeo.ru), «IPY-IGRAS» (www.mpg.igras.ru), all based on the spatial glaciological data. Another result is the digital and web-atlas «Snow and Ice of the Earth», presenting the example of open source of the spatial data on glaciology in the multi-program environment. Regional data bases created for regions of the Caucasus and the Antarctic Continent make it possible to develop various GIS models and to analyze interrelations, status and dynamics of glaciological parameters. The system of links provides easy access to distributed resources. (*T.Y. Khromova, A.A. Medvedev Institute of Geography, Russian Academy of Siences, Moscow)*

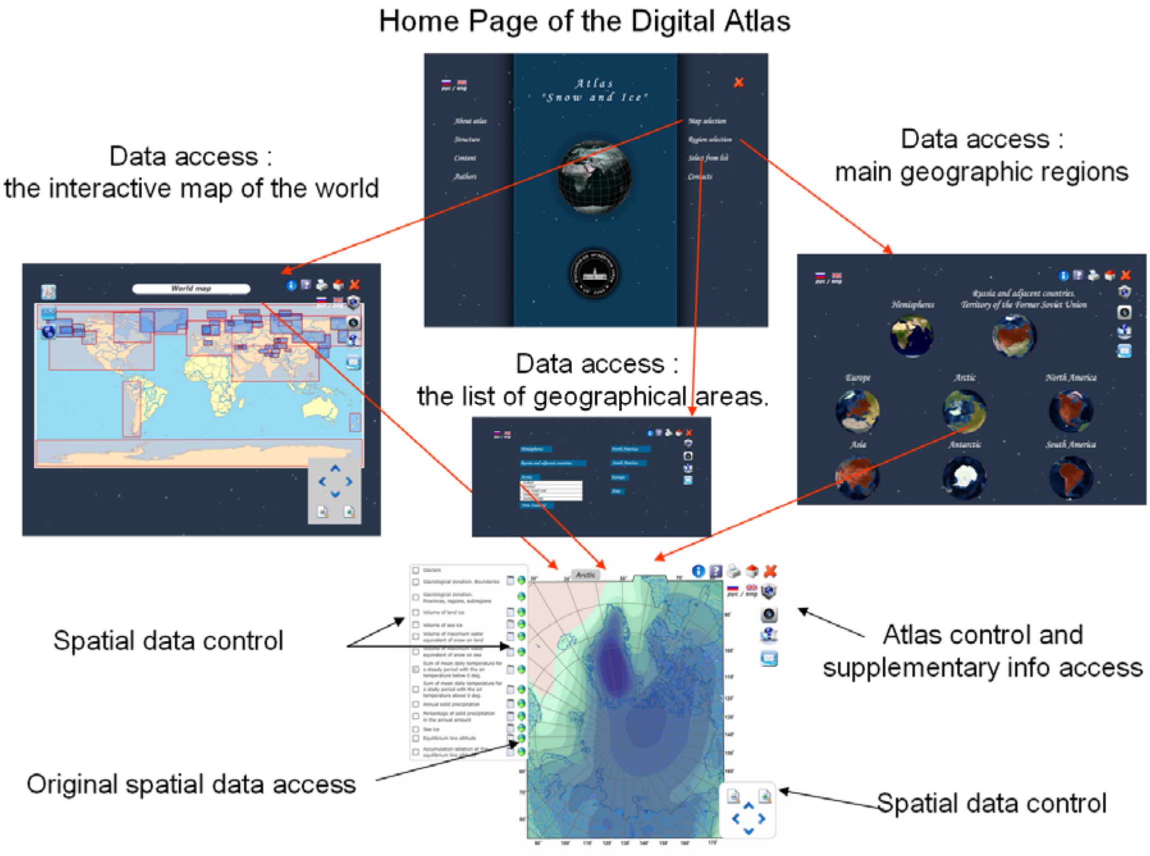


Fig 58 Home page of Dgital glaciological atlas.

List of selected publications.

1. Aleynikov A.A., Volodicheva N.N., Oleynikov A.D., Petrakov D.A. Glacier and avalanche dan-ger for the recreation complex “Chegetskaya Polyana” in the Elbrus area. Led i Sneg. Ice and Snow. 2011, 2 (114): 45–53. [In Russian].
2. *Alekseev V.R.* Influence of aufeises to the river channel net. *Led i Sneg.* Ice and Snow. 2013, 4 (124): 95–106. [In Russian].
3. *Alekseev V.R., Gorin V.V., Kotov S.V.* Aufeises of North Chukotka. *Led i Sneg.* Ice and Snow. 2011, 4 (116): 85–93. [In Russian].
4. Alexeev G.V., Ivanov N.E., Pnyushkov A.B., Kharlanenkova N.E. Climate changes in the marine Arctic during beginning of XXI century. Meteorologicheskie i geofizicyeskie issledovaniya. Meteorology and Geophysics Studies. Moscow, 2011: 3–25. [In Russian].
5. Ananicheve M.D. Present-day state of glaciers in the Koryak Highland and assessment of their evolution to the middle of current century. Led i Sneg. Ice and Snow. 2012, 1 (117):15–24. [In Russian].
6. Ananicheva M.D., Kapustin G.A. Assessment of glacier changes in the Byrranga Mountains according to space images and USSR Glacier Inventory. Led i Sneg. Ice and Snow. 2010, 3 (111): 19–24. [In Russian].
7. Ananicheva M.D., Kapustin G.A., Mikhaylov A.Yu. Glacier of Meinypilgyn Range: modern state and prediction of glacier systems evolution. Led i Sneg. Ice and Snow. 2012, 2 (118): 47–57. [In Russian].
8. Andreev A.S., Volodicheva N.N., Puzenko M.L. Protection from big avalanches in the Elbrus area. Materialy Glyatsiologicheskikh Issledovaniy. Data of Glaciological Studies. 2012-1: 38–44. [In Russian].
9. Anisimov O.A., Reneva S.A. Carbon balance in the cryolithozone of Russia and global climate: modern condition and prognosis based on modeling. Polyarnaya kriosfera i vody sushi. Polar Cryosphere and Land Water. Ed. V.M. Kotlyakov. Moscow – Sankt-Petersburg: Paulsen, 2011: 122–140. [In Russian].
10. Anisimov O.A., Anokhin A., Lavrov S.A., Malkova G.V., Pavlov A.V., Romanovskiy V.E., Streletskiy D.A., Kholodov A.L., Shiklomanov N.I. Continental multiyear permafrost. Metody izucheniya posledstviy izmeneniy klimata dlya prirodnykh system. Methods of study the sequences of climate changes for nature systems. Ed. S.M.
11. Semenov. Moscow: VNIIGMI, 2012: 268–328. [In Russian]. Anisimov O.A., Borzenkova I.I., Lavrov S.A., Strel’chenko Yu.G. Modern dynamics of underwater permafrost and methane emission at the shelf of East Arctic in the context of the last and future climate changes. Led I Sneg. Ice and Snow. 2012, 2 (118): 97–105. [In Russian].
12. Antipov N.N., Klepikov A.V. On the interaction of the shelf and deep ocean waters over the continental slope of Antarctica. Vklad Rossii v Mezhdunarodnyi polyarnyi god 2007/08. Rus-sia's contribution to the International Polar Year 2007/08. Oceanography and sea ice. Ed. I.E. Frolov. Moscow: Paulsen, 2011: 291–305. [In Russian].
13. Bulygina O.N., Korshunova N.N., Razuvaev V.N. Changing of wind regime at the territory of Russia for the last decades. Trudy GGO. Proc. of the Main Geophysical Observatory. 2013, 568: 156–172 [available at: http://voeikovmgo.ru/images/stories/publications/568.pdf]. [In Russian].
14. Bulygina O.N., Veselov V.M., Razuvaev V.N., Aleksandrova T.M.. Dataset of hourly meteorological variables observed at the Russian meteorological network, 2012: http://meteo.ru/english/climate/descrip12.htm or http://meteo.ru/data/163-basic-parameters
15. *Chalov R.S. Ruslovedenie. Teoriya, geografiya, praktika.* River channel science. Theory, geography, practice. V. 2. Morphodynamics of river channels. 2011: 960 p. [In Russian].

16. Dmitrenko I.A., Kirillov S.A., Tremblay B., Kassens H., Anisimov O.A., Lavrov S.A., Razumov S.O., Grigoriev M.N. Recent changes in shelf hydrography in the Siberian Arctic: Potential for subsea permafrost instability. Journ. of Geophys. Research. 2011, 116: C10027. doi:10.1029/2011JC007218.
17. Doklad ob osobennostyakh klimata na territorii Rossiyskoy Federatsii. Report on climate peculiarities at the territory of Russian Federation in 2012 (chapter “Snow cover in the winter 2011/12”). Moscow: Roshydromet, 2013: 32–41. [In Russian].
18. Ekaykin A.A., Lipenkov V.Y., Petit J.R., Johnsen S., Jouzel J., Masson-Delmotte V. Insights into hydrological regime of Lake Vostok from differential behavior of deuterium and oxygen-18 in accreted ice. Journ. of Geophys. Research. 2010, 115. C05003: 1–14. Doi: 10.1029/2009JC005329.
19. Eliseev A.V., Denisov S.N., Arzhanov M.M., Mokhov I.I. Climate-methane cycle feedback in global climate model simulations forced by RCP scenarios. Geophys. Research Abstracts. EGU General Assembly, 2013.
20. Frolov I.E. Okeanografiya i morskoy led. Oceanography and sea ice. Series: Contribution of Russia to the International Polar Year 2007/2008. Moscow – Sankt-Petersburg: “Paulsen”, 2011: 431 p. [In Russian].
21. *Galakhov V.P., Lovtskaya O.V., Samoilova S.Yu., Ayursana J., Otgonbayar D. Otsenka srednego mnogoletnego uvlazhneniya i poverkgnostnogo stoka besstochnogo basseyna reki Khovd (Zapadnaya Mongoliya).* Estimation of the mean annual humidification and surface runoff of the Khovd closed drainage basin (West Mongolia). Barnaul, 2013: 109 p. [In Russian].
22. Galanin A.A., Lytkin V.M., Fedorov A.N., Kadota T. Recession of glaciers in the Suntar-Khayata Mountains and methodological considerations of its assessment Led I Sneg. Ice and Snow. 2013, 4 (124): 30–42. [In Russian].
23. *Ganyushkin D.A. Sovremennoe i drevnee oledenenie gornogo massiva Mongun-Tayga.* Modern and ancient glaciation of Mongun-Tayga Mounatin region. LAP, 2012: 278 p. [In Russian].
24. Golovin P.N., Antipov N.N., Klepikov A.V. Downflow of the Antarctic Shelf Water at the Shelf and Continental Slope of the Commonwealth Sea in the Summer Season and its Effect on the Bottom Water Formation in the Southern Ocean. Okeanologiya. Oceanology. 2011, 51 (3): 393-408. [In Russian].
25. Golovin P.N., Antipov N.N., Klepikov A.V. Investigation of the stability of the Antarctic slope front in the Commonwealth Sea. Meteorologiya i gidrologiya. Meteorology and Hydrology. 2013, 11: 64–78. [In Russian].
26. *Gordeev I.N.* Vertical gradients of the air temperature in the basin of the Sayan-Shushenskoe water reservoir. [In Russian]. *Vestnik TGU.* Herald of the Tomsk State University. 2011, 346: 181–184.
27. *Gorbunov A.P., Gorbunova I.A. Geografiya kamennykh gletchrov mira.* Geography of rock glaciers in the World. Moscow, 2010: 131 p. [In Russian].
28. Izrael’ Yu.A., Bedritskiy A.I., Frolov A.V., Blinov V.G., Gruza G.V., Semenov S.M., Anokhin A., Gitarskiy M.L., Romanovskaya A.A., Yasyukevich V.V., Boltneva L.I., Zelenov A.S., Egorov V.I., Karaban’ R.T., Kukhta A.E., Nakhutin A.I., Sedyakin V.P., Yakovlev A.F., Gershinkova D.A., Artemov E.M. Pyatoe natsionalnoe soobshchenie Rossiyskoy Federatsii. Fifth national report of the Russian Federation. Moscow: Roshydromet, 2010: 196 p. [In Russian].
29. Kazko G.V., Antipov N.N., Klepikov A.V. On deep convection on the continental slope of Prydz Bay. Problemy Arktiki i Antarktiki. Problems of the Arctic and Antarctic. 2012, 92: 95–112. [In Russian].
30. Khromova T.Y. GIS For Cryosphere Studies. Materials of the Partnership conference «Geo-physical observatories, multifunctional GIS and data mining». Geoinf. Res. Papers.

2013. BS1004. doi:10.2205/2013BS012_Kaluga. http://ebooks.wdcb.ru/2013/2013BS012/SESSION_3/Khromova.pdf.

31. Tatiana Khromova, Gennady Nosenko, Stanislav Kutuzov, Anton Muraviev and Ludmila Chernova. Glacier area changes in Northern Eurasia // Environmental Research Letters. Vol. 9. №1. 2014. DOI:10.1088/1748-9326/9/1/015003
32. Klepikov A.V. Resnyansky Yu.D., Antipov N.N., Danilov A.I., Kazko G.V. Oceanographic pro-cesses in Antarctic waters. Vklad Rossii v Mezhdunarodnyi polyarnyi god 2007/08. Russia's contribution to the International Polar Year 2007/08. Oceanography and sea ice. Ed. I.E. Frolov. Moscow: Paulsen, 2011: 306–318. [In Russian].
33. *Koroleva N.A. Merzlotno-ekologicheskoe kartografirovanie kriolitozony Rossii.* Permafrost-ecological mapping of cryolithozone of Russia. Ph. D. Thesis. Moscow State University, 2011: 24 p. [In Russian].
34. Korotkova V.M., Vershinin D.A. Studies of a process of low ridge formation at the ramified part of the Tom' River, taking into account peculiarities of its water and ice regimes. *Vestnik TGU.* Herald of the Tomsk State University. 2011, 351: 175–180. [In Russian].
35. Kotlyakov V.M., Khromova T.E., Zverkova N.M., Chernova L.P. The Unified AccumulationAblation Field on Glaciers of the Northern Hemisphere // ISSN 1028_334X, Doklady Earth Sciences, 2013, 449, Part 2, pp. 439-444
36. V. M. Kotlyakov, L. P. Chernov, N. M. Zverkova, and T. E. Khromova The One_and_a_Half_Century Reduction of Altai Glaciers in Russia and Kazakhstan
37. Received June 20, 2014 *ISSN 1028_334X, Doklady Earth Sciences, 2014, Vol. 458, Part 2, pp. 1307–1311. © Pleiades Publishing, Ltd., 2014.* DOI: 10.1134/S1028334X14100286
38. V. M. Kotlyakov, L. N. Vasiliev, A. B. Kachalin, M. Yu. Moskalevsky, and A. S. Tyuflin. 2011. Punctuated Equilibrium of the Surface above Subglacial Lake Vostok in Antarctica. Doklady Earth Sciences, Volume 438. P. 649-651.
39. Kotlyakov V.M., Moskalevsky M.Y., Vasiliev L.N. Changes of Antarctic Ice Sheet mass balance for the 50 years. Doklady Akademii Nauk. Proc. of the Academy of Sciences. 2011, 438 (2): 263–266. [In Russian].
40. V. M. Kotlyakov, L. N. Vasiliev, A. B. Kachalin, M. Yu. Moskalevsky, and A. S. Tyuflin. 2012. Cascades of Subglacial Lakes in Antarctica. Doklady Earth Sciences, Volume 443. P. 509-512.
41. Kulakov M.Yu., Makshtas A.P., Shutilin S.V. AARI–IOCM – join model of water and ice circulation in the Arctic Ocean. Problemy Arktiki i Antarktiki. Problems of Arctic and Antarctic. 2012, 2 (92): 6–18. [In Russian].
42. Kutuzov, S. 2012. Glacier area and volume changes in the Terskei Ala-Tau Range for the second part of XX century. *Ice and Snow*. No.1 (117), 5–15. In Russian
43. S. Kutuzov, I. Lavrentiev, E. Vasilenko, Y.Y. Macheret, D. A. Petrakov, G.V. Popov Estimation of the greater caucasus glaciers volume, using radio-echo sounding data and modelling. Earth's Cryosphere 2015; XIX(1):78-88.
44. from: https://www.researchgate.net/publication/273770256_ESTIMATION_OF_THE_GREATER_CAUCASUS_GLACIERS_VOLUME_USING_RADIOECHO_SOUNDING_DATA_AND_MODELLING [accessed May 21, 2015].
45. Kutuzov S.S., Lavrentiev I.I., Macheret Yu.Ya., Petrakov D.A. Changes of Marukh Glacier from 1945 until 2011. Led i Sneg. Ice and Snow. 2012, 1 (117): 123–127. [In Russian].
46. Lavrentiev I.I., Mikhakenko V.N., Kutuzov S.S. Ice thickness and subglacial relief of the West glacier plateau of Elbrus. Led i Sneg. Ice and Snow. 2010, 2 (110):12–18. [In Russian].

47. Macheret Yu.Ya., Glazovsky A.F. Formation and development of drainage systems in glaciers. Led i Sneg. Ice and Snow. 2011, 3 (115): 34–40. [In Russian].
48. *Muraviev A.Ya., Nosenko G.A.* Changes of glacierization in the Northern part of the Sredinnyi Ridge on Kamchatka Peninsula in the second half of XX century. *Led i Sneg.*Ice and Snow. 2013, 2 (122): 5–11. [In Russian].
49. *Nazarov A.N., Solomina O.N., Myglan V.S.* Variations of the Tree Line and Glaciers in the Central and Eastern Altai Regions in the Holocene *Doklady Akademii Nauk.* Proc. of the Academy of Sciences. 2012, 444 (2): 787–790. [In Russian].
50. Nikolsky D.J., Romanovsky V.E., Romanovskii N.N., Kholodov A.L., Shakhova N.E., Semiletov I.P. Modeling sub-sea permafrost in the East Siberian Arctic Shelf: The Laptev Sea region. Journ. of Geophys. Research. 2012, 117: F03028. doi:10.1029/2012JF002358.
51. Nosenko, G., T.Khromova, O. Rototaeva, M. Shahgedanova. 2013. Respond of glaciers in Central Caucasus to temperature and precipitations changes in 2001-2010. Ice and Snow. Vol.1(121), 26-24. In Russian.
52. Nosenko G, Khromova T, Muravyev A, Narozhny Y, Shahgedanova M, 2010. Using historical data and modern space imagery for assessment of glacier area changes in Altai mountains. Ice and Snow. No.2 (120), 19–24. In Russian.
53. Pastukhov V.G. Polnyi massoobmen lednika Djankuat. Total mass-exchange of Djankuat Glacier. Diploma. Geographical Faculty of MSU. 2011: 185 p. [In Russian].
54. *Popova V.V., Shmakin A.B., Mikhailov A.Yu.* Regional structure of winter air temperature fluctuations at the land of extratropical zone of Northern Hemisphere in the second half of XX and in beginning of XXI centuries. *Problemy ekologicheskogo monitoring i modelirovaniya ekosistem.* Problems of ecological monitoring and modeling of ecosystems. V. XXIV. Moscow, 2011: 371–392. [In Russian].
55. *Popova V.V., Polyakova I.F.* Changes of dates of snow cover lost in the north of Eurasia in 1936–2008: influence of global warming and role of large-scale atmospheric circulation. *Led i Sneg.* Ice and Snow. 2013, 2 (122): 29–40. [In Russian].
56. Reshetnikov A.I., Ivakhov V.M. Results of permanent observation for the methane concentration at the Tiksi observatory (comparison with data of ship's observations at the shelf of Laptev Sea). Trudy GGO. Proc. of the Main Geophysical observatory. Ed. V.M.Katsov, V.P. Meleshko. Sankt-Petersburg: Hydrometeoizdat, 2012: 257–269. [In Russian].
57. Reshetnikov A.I., Makshtas A.P. Arctic Hydrometeorological Observatory "Tiksi". Trudy GGO. Proc. of the Main Geophysical observatory. Ed. V.M. Katsov, V.P. Meleshko. Sankt-Petersburg: Hydrometeoizdat, 2012: 267–283. [In Russian].
58. Rybak O.O., Fürst J.J., Huybrechts P. Mathematical modeling of ice flow in the north-western Greenland and interpretation of deep drilling data at the NEEM camp. Led i Sneg. Ice and Snow. 2013, 1 (121): 16–25. [In Russian].
59. Rodionov G.P., Zagorovski V.I. Infrastructure of Russian Federation spatial data: experience, technology, peculiarities. ArcReview. 2012, 4 (63). http://esri-cis.ru/news/arcreview/detail.php?ID=8297&SECTION_ID=265. [In Russian].
60. Seliverstov Yu.G. On changes of avalanche activity and avalanche risqué at the Russian terri-tory. Materialy Glyatsiologicheskikh Issledovaniy. Data of Glaciological Studies. 2012-1: 45–50. [In Russian
61. Semenov V.A. Changes of recurrence and correlation of dangerous hydrometeorological phenomena at the Asian territory of Russia.*Klimatologiya i glyatsiologiya Sibiri.* Climatology and glaciology of Siberia. Tomsk, 2012: 274–276. [In Russian].
62. Semiletov I.P., Shakhova N.E., Sergienko V.I., Pipko I.I., Dudarev O.V. On carbon transport and fate in the East Siberian Arctic land-shelf-atmosphere system. Environmental Research Letters. 2012, 7: 1–13.

63. Sergienko V.I., Dudarev O.V., Dmitrievskiy N.N., Shakhova N.E., Nikol'skyi N.N., Nikiforov S.L., Salomatin A.S., Salyuk R.A., Karnaukh V.V., Chernykh D.B., Tumskoy V.E., Chuvilin E.M., Bukhanov B.A. Degradation of submarine permafrost and a destruction of hydrates at the shelf of the Eastern Arctic seas as a possible cause of "methane catastrophe": some results of the 2011 observations. Doklady Akademii Nauk. Proc. of the Academy of Sciences. 2012, 445 (3): 330–335. [In Russian].
64. Shakhova N., Semiletov I., Leifer I., Rekant P., Salyuk A., Kosmach D. Geochemical and geophysical evidence of methane release from the inner East Siberian Shelf. Journ. of Geophys. Research. 2013; 115. Doi: 10.1029/2009JC005602.
65. Shakhova N., Semiletov I., Leifer I., Sergienko V., Salyuk A., Kosmach D., Chernykh D., Stubbs C., Nikolsky D., Tumskoy V., Gustafsson O. Ebullition and storm-induced methane release from the East Siberian Arctic Shelf. Nature Geoscience. November 2013, 24: 1–7.
66. Shahgedanova M, Khromova T, Nosenko G, Muravyev A 2010 Glacier Shrinkage and Climatic Change in the Russian Altai from the mid-20th Century: An Assessment Using Remote Sensing and PRECIS Regional Climate Model. *J. Geophys. Res. Atmos.*, 115: D16107, doi 2009JD012976
67. Shahgedanova M, Nosenko G, Bushueva I, Ivanov M2012 Changes in area and geodetic mass balance of small glaciers, Polar Urals, Russia, 1950-2008. *J. Glaciol.*Vol. 58, No.211, 2012
68. Shmakin A.B. Climatic characteristics of snow cover in the Northern Eurasia and their changes in the last decades. Led i Sneg. Ice and Snow. 2010, 1 (109): 43–58. [In Russian].
69. Vasilenko E.V., Glazovsky A.F., Lavrenriev I.I., Macheret Yu.Ya. Changes of hydrothermal structure of Austre Grønfjordbreen and Fridtjovbreen glaciers in Svalbard. Led i Sneg. Ice and Snow. 2014, 1 (125): 5–19. [In Russian
70. *Vershinin D.A., Zemtsov V.A., Inishev N.G.* Factors of formation of the ice dam phenomena at rivers on the border of mountain and plain territories (Tom' River as an example). *Okhrana okruzhayushchey sredy i prirodnykh resursov stran Bol'shogo Altaya.*Protection of the environment and natural resources in the Great Altai countries. Barnaul – Gorno-Altaysk, 2013: 55–58. [In Russian].
71. *Verchinin D.A., Tatarnikov A.V., Orlov E.I.* Possibilities of the ice dams prediction at the basis of digital models of a river channel.*Vestnik TGU.* Herald of the Tomsk State University, 2011 (352): 221–224. [In Russian].