My answers to the Review #2 (given in Times New Roman script)

The main problems to be addressed are as follows:
1. The title should be revised. 'Modelling positions of glacier termini and equilibrium line altitude of mountain glaciers in north-eastern Russia using ECHM4 GCM data' will be more informative and appropriate.

I can't fully agree since the outputs are not only new ELA and termini line, but balance components and areas. Also Kamchatka is not north-eastern Russia, better to say North-eastern Asia.

So, the title could be: Modelling of glaciologic parameters of mountain glacier regions of North-eastern Asia for near future by ECHAM4 climate development scenario

2. The abstract is not informative. Please outline the main results.
New version:

Abstract. We studied contrasting glacier systems (regions) in continental (Orulgan, Suntar-Khayata and Chersky ranges located in a region of the lowest temperatures in the Northern Hemisphere'at the contact of Atlantic and Pacific influences and maritime (Kamchatka Peninsula) – under Pacific influence. Our purpose is to present a simple projection method to asses the main parameters of these glacier regions under climate change. To achieve this, constructed vertical profiles of mass balance (accumulation and ablation) based both on meteorological data for 1950–90s (baseline period) and ECHAM4 for 2040–2069 (projected period) are used, the latter – as a climatic scenario. The observations and scenarios were used to define the recent and future equilibrium line altitude (ELA) and glacier termini elevation for each glacier system as well as areas and balance components. The altitudinal distributions of ice areas were determined for present and future, they were used for prediction of the glacier elevation spreading in the system taking into account the correlation between the ELA and glacier-termini level change. We tested two hypotheses of ice distribution versus altitude in mountain (valley) glaciers – "linear" and "non-linear". The results are estimates of the possible changes of the areas and morphological structure of Northeastern Asia glacier systems and their mass balance characteristics for 2049–60. Glaciers of southern parts the North-eastern Siberia and those covered small ranges of Kamchatka will likely disappear under the ECHAM4 scenario, the best preservation of glacier will be attributed to highest volcano peaks of Kamchatka covered with glaciers.
Finally, we compare characteristics of the stability of continental and maritime glacier systems under global warming.

3. It would be useful if the paper could follow Introduction – Study Area –Data and Methods – Results – Discussion – Conclusions structure. Currently, it is difficult to read as discussion of regional climate (temperature and precipitation) appears in Methods rather than Study Area; information on characteristics of meteorological stations is hidden in Present Accumulation / Ablation Calculations section; etc. Currently, one has to skip between sections all the time to find the required information and it does not assist any reader.

The structure of the paper is changed

4. Given how little is published in western literature about glaciers of north-eastern Russia, a more informative summary of the up-to-date research on glacier-climate interaction in the area is required including a review of western (very few papers but Gurney et al., 2008 is relevant), Russian (Koreisha, 1991; various papers by Ananicheva and co-authors) and Japanese (see Bulletin of Glaciological Research) research. It is

essential to provide a good, informative background because few readers outside Russia and Japan are familiar with research conducted in this region. Discussion on page 720 is related to glacier changes in different regions, however, these changes are not discussed previously in the paper and there are no references.

New references are inserted.

5. A more detailed description of study area is required as very little is published on these areas in English. Please discuss climatic conditions and type of glaciers / glacier formation regimes in each of the mountain systems. Include only those aspects that are relevant to the paper. For example, why Arctic advection in winter is highlighted in the description of climate (page 710)? Why is it relevant? The Arctic air masses do deliver warmer air into the landlocked regions of north-eastern Siberia in winter but why is it relevant for climate-glacier interaction and should be mentioned? Include graphs with air temperature and precipitation climatologies for high-altitude stations in each region (include coordinates; altitudes; and periods of observation; avoid pre-1950s precipitation measurements because of the introduction of new rain gauges and associated inconsistencies in measurements). Explain whether these are cold-based glaciers as their response may be different. It would be useful to include a table showing the extent of glaciations in each region (referenced to an approximately the same period(s)) and their characteristics (glacier sizes, classes, position of ELA, altitudes of glacier tongues, etc) or at least a reference to Table 1. Currently this information is spread between sections and is hard to compare. Provide coordinates of each study region and show locations of glaciated regions on Fig. 1 if not all mountain ranges are glaciated.

Coordinates are added. More descriptions of the study regions will make the paper too long. You mentioned in “technical comments” that it is too much for one paper (about other parts of the paper). Climatic peculiarities and tendencies are discussed in the paper. Warming, which is going on up to now in the NE Asia, is a motivation of the projection approach developed in this paper.
The entire data in Table 1 regarding to baseline period is taken from the USSR Glacier Inventory as was indicated (or you may use NSIDC electronic version, the address of the site page is added to the foot note of the paper).

6. ECHAM4 data. How appropriate are the data with 2.8o horizontal resolution for reconstructing glacier mass balance and ELA? This is a fundamental question and should be discussed and limitations / resulting uncertainties should be explained. How are the studied mountain systems represented in ECHAM 4? References are made to grid points in Section 3.3: how many; how does their altitude match reality; etc? Were the data averaged over study regions or was it one grid box vs one given location ?

The ECHAM4 on the time of the work start was the most appropriate for Northern Eurasia (this is an opinion of number of modelers and climatologists, f.ex., John Walsh (US), Vladimir Katsov (Russia), personnel communications. To project the glacier parameters for other mountain glaciers such as Byrranga Mountains, Koryak Upland we use ECHAM5 outputs. The gridpoints are more dense in this output realization that is crucial for projection and the model is adwanced.
The data from the ECHAM4 were presented in points, however we made interpolation between these points by the spatial pattern of temperature and precipitation using the corresponding maps of World Snow and Ice Resources Atlas (1997) based on contemporary climate data

7. Time slices and comparisons between the baseline and future climates. It follows from the Abstract that the authors compare observations (1950-1990s) with modelled data for 2040-2069. Is it indeed so? If yes, than the whole analysis is hardly valid as this comparison incorporates not only changes in climate but also model uncertainties. The rule of thumb is to compare modelled baseline climate against modelled future climate assuming that model uncertainties are consistent. On page 715, it appears that modelled 1950-90 data are used. So what is used?! Also, the time frame of

the analysis is not clear from page 714: when talking about temperature increase in 2040-69, what exactly do the authors discuss, temperature change from the mid-20th century to the mid-21st century or temperature change during the 2040-69 period? I suggest that the authors should put in a table or outline bullet-point style which exactly time slices were used, what types of data (observed or modelled) were used, and what was compared.
The baseline period is 1950-90s, the period for projection is 2049-60
Values of temperature change (warming) are given in comparison with GCM (ECHAM 4) for 2040-2069 and approved by WMO baseline "contemporary period"- 1960-1990. Models do not involve individual years (this is for them like "white noise"). Averaged over 30 years values are useful because this period is close to the time of adaptation of glaciers to climate (J´ohannesson at al, 1989). The sizes of glaciers of the SE Siberia are those that the ratio of their thickness to ablation gives 30-50 years as a time of adaptation. For this case the hypothesis of the ELA being in the middle between the highest and lowest point of glacier system (mentioned in our paper) is valid.

J´ohannesson, T., Raymond, C.F., and Waddington, E.D.: Timescale for adjustments of glaciers to changes in mass balance, J. Glaciol., 35(121), 355-369, 1989

In fact, we don't say about the warming process between 2040 and 2069. While considering the temperature diapason from 3.1 to 4.0 °C, it means the verity of temperature between spaces (regions).

8. How well does perform in north-eastern Russia? Model outputs should be validated against observations or reanalyses (NCEP/NCAR and ERA40) and uncertainties discussed. This is especially important with regard to precipitation intensity.
Note that uncertainties in [especially cold season] precipitation measurements should also be addressed (see Groisman and Rankova, 2001) as they are a likely source of bias. Currently, the modelled climate data are used without any validation. When validating model outputs against observations, pay attention to differences between model domain elevation and station elevations as this is a source of discrepancy.

All AOGCMs have uncertainties, however they are the only approved scenarios for the future. What other scenarios you can offer? Our purpose is to present the METHOD for any scenarios and we have tested our approach on the ECHAM4 outputs as the best for the North Eurasia.
Our approach involves only weather stations data that minimize the errors. NCEP/NCAR and ERA40 are not good for the mountain regions, it is common opinion. We used the precipitation (and temperature) data provided by A. Rankova. She made necessary improvements in row observation records. This data is also distributed through the HydroMetSurvice of the RF.

9. As stated in Section 3.2, accumulation is calculated from solid precipitation. What exactly does it mean? Solid precipitation throughout the year and if yes, how this information was obtained? In section 3.1, solid fraction of precipitation is calculated using Bogdanova method (Bogdanova, 1976; Bogdanova et al., 2002 quoted in the text). Briefly outline the method. Surely solid and liquid fractions of precipitation are provided by ECHAM. Why not use it? Or is it precipitation for months with sub-zero temperatures? If yes, how important is this source of accumulation for glaciers accumulating mass through the formation of superimposed ice (e.g. Chersky) ? This issue is briefly mentioned in Section 3.2 but needs more attention.

We analyzed mean summer temperature (calendar) as the main indicator of melting (ablation) and solid precipitation as the parameter responsible for accumulation. The latter were calculated by laborious but reliable method of E.G. Bogdanova, which involves the relationship between monthly proportion (fracton) of solid precipitation (in total amount) and mean monthly air temperature for definite elevation diapason (1000, 2000, 3000 m a.s.l).
No, ECHAM4 provides only total precipitation (and even the ratio between projected and baseline values); so, we have to calculate by Bogdanova method the projected solid precipitation.

The formation of superimposed ice in our case affects the usage of the formula – dependence of ablation at the ELA on mean summer temperature. We have to calibrate the formula by the data of measurements of ablation on Glacier 31 in sutu.

10. The cold-based and temperate glaciers are discussed together in the paper. Is there a difference in their reaction to climatic warming?

The temperate glaciers are attributed basically to Kamchatka, and even not to all its glacier systems. The Sredinny Range, northern part is characteristic for relatively cold-based glaciers. However due to warming in the NE Asia cold-based glaciers are slowly transforming into temperate types. Yes, the reaction is different that is reflected in the different resulting outputs of our method application.

11. Separate Data from Methods. Methodology should be clearly explained step by step. Currently it is mixed with other issues and is hard to follow.

Done

12. Error evaluation of ELA using aerial photography requires a more detailed discussion. Which images were used? How was ELA derived from aerial photos (reference to an authoritative methodological paper might be enough here); how many glaciers were assessed for error evaluation, etc.

The areal photography of 1945 (Suntar-Khayata) and 1970 (Chersky) were used by the authors of the USSR Glacier Inventory, published in 1960-80s. The ELA were derived by analysis of photo images stereo-pairs, I guess. The method and qualification of the scientists-carthographers were very high. The overwhelming majority of the glaciers of the studied mountain countries were analyzed by areal photography.

13. What is the quality of accumulation data “calculated from Glacier Inventory data or obtained from their maps”? And how was it calculated? This needs an explanation.

Not clear. The accumulation=ablation at the ELA, the World Snow and Ice Resources Atlas contains the maps of accumulation at the ELA for all glacier regions of the USSR, calculated by A.N. Krenke (the co-author of the paper).
The method is described in the Text volume to the Atlas (in English). It involves weather stations, temperature laps rates data, and relationship between Tsum and A, which is used in our paper.

Specific and technical comments:
p. 708; Abstract: replace ‘Pole of Cold’ with ‘a region of the lowest temperatures in the Northern Hemisphere’

Done

p.708; Abstract: “Also for selected key glacier systems other models were applied for comparison” What does it mean? Unclear; please specify.

For 4 key regions within the NE Asia we applied also Hadly Center Model and Japanise model scenarios But I omitted this by your advice, see also below.

p.710: “Observations are available from one or two glaciers”. Please name the glaciers (Koryto for Kamchatka and N31 for Suntar-Khayata?), list observed variables (winter and summer mass balances, ELA), periods of observations and provide references were these data are published. It would be useful to show time series of the observed values. How were aerial photographs were used to derive accumulation, ablation andELA? The USSR Glacier Inventory is now a part of the World Glacier Inventory (WGI)

from the National Snow and Ice Data Center in Boulder, Colorado (NSIDC, 1999; http://nsidc.org/). Please quote this reference too as it is more accessible to readers than the published Russian-language sources.
In Kamchatka:
Kozelsky Glacier - Fluctuations of glaciers, vol. IV- VII. (http://www.geo.uzh.ch/wgms/fog.html)

Koryto Glacier:
Muravyev Y.D., Shiraiwa T., Yamaguchi S., Matsumoto T., Nishimura K., Koshima S. and A.A. Ovsyannikov. Mass balance of glacier in conditions of maritime climate - Koryto glacier in Kamchatka, Russia // Cryospheric Studies in Kamchatka, V.2. 1999. 51-61

In North-Eastern Siberia

Glacier 31:

Ananicheva, M.D. Suntar-Khayata and Chersky ranges in the Chapter "Glaciation fluctuations" In: Glaciation in North and Central Eurasia in the Recent at present time. Ed. V.M. Kotlyakov. Moscow, "Nauka" , 2006, 198-204

This glacier was studied only in the IGY, 1957-59, and then in 2001-2006 by the author of the paper within mutual Russian-Japanese project (Shuhei Takahashi, a leader from Japanese side, Kitami Technological Institute, Hokkaido, Japan)

T. Yamada, Sh. Takahashi, T. Shiraiwa, Y. Fudjii, Yu.M. Kononov, M.D., Ananicheva, M.M. Koreisha, Ya. D. Muraviev, T.V. Samborsky, 2002. Reconnaissance of the 31 Glacier in the Suntar-Khayata Range, Sakha Republic, Russian Federation. // Japanese Society of Snow and Ice. Bulletin of Glaciologic research. N19. - P.101-106

p. 710: Quote IPCC 2007 instead of IPCC 1995. It surely confirms the warming trends for Siberia.
Done (see new version)

p. 710 Section 2: explain 'regime types'.

Changed on mass exchange for simplicity

p. 710; Section 2.2: Why "a number of ridges" mentioned ? What is unusual or important about it? What is NE66? What is ELA 68?
Removed

The glaciated part of Chesky Range does not appear to be located much closer to the Aleutian low than the Suntar-Khayata; if anything Chersky is further away from the coast and the Sea of Okhotsk is more important than the northern Pacific in terms of moisture supply. Explain, why the Aleutian low is important. When and to what extent does it control precipitation in the region (April-October?); how does this influence differ between the Chersky and Suntar-Khayata and is it actually important for glaciers? It is useful to briefly explain and compare precipitation regimes and controlling factors (possibly other than the Aleutian low). Note that capital L is not used in 'low'; this is 'low' not 'Low'.

In Chersky Range glacier accumulation increase to the south that indicates the sea of Okhotsk as a main precipitation source. The spatial pattern of the ELA shows the maximum in the center of the mountain system. It is explained by equal conditions of accumulation and ablation. Advection of precipitation from Pacific Ocean gives more than 500 mm annually. Aleutian low may be responsible for advection of moisture in winter period in this severe climate region.

In Suntar-Khayata Range accumulation like in Chersky Range increases to the south due to effect of Okhotsk Sea. The ELA spatial pattern here corresponds to the accumulation one – an indicator of critical role of nourishment condition on the glacier development of the region. Precipitation in glacier belt reaches 600-700 mm.

p. 711; Section 2.4: reference is required after the statement on the extent of Kamchatka glaciers. Why is it important for glaciers that volcanism is Quaternary? Omit if irrelevant.

Done

p. 711: rather than stating that Kamchatka receives the highest precipitation across Russia (which may just as well be on the eastern Black Sea coast), state the amount of precipitation and maybe long-term accumulation values from Koryto Glacier (a WGMS reference glacier). As mentioned above, time series of the observed winter and summer mass balances and ELA might be useful.

The figure:

Cumulative mass balance curves for 3 Kamchatka glaciers – Grechshkin (Sredinny range), Koryto Glacier (Kronotsky Peninsular) and Kozelsky Glacier (Avachiskaya Volcano Group)
(The figure is not published yet, the author – Ya. D. Muraviev)

Though the glaciers are located in different areas of Kamchatka they all undergone considerable retreat due to climate warming and ablation increase. High precipitation is unable to compensate melting of glacier ice.

p. 712; Section 3: "The method is consistent with both GCM and palaeo-analogue scenarios". What does it mean? Explain and provide references.

That means the method offers the algorithm which can work both with GCM scenarios of climate development and paleo-climate scenarious providing paleo temperature and precipitation, for example
- Atlas of paleoclimates and paleoenvironments of the Northern Hemisphere. Late Pleistocene-Holocene. - Ed. By B. Frenzel, M. Pecsi, A.A. Velichko. Budapest. - 1992.

The author used similar approach to the reconstruction of the ELA and glacier termini line of glaciers of Suntar-Khayata for Holocene Optimum in

Ananicheva M.D., Davidovich N.V. Glaciation of the Suntar-Khayata Ridge at climatic optima. – *Proceeding of the International Symposium "Atmosphere-Ocean-Cryosphere interaction in the Okhotsk sea and surrounding environment"*, Sapporo, 12-19 December 2000, Japan.

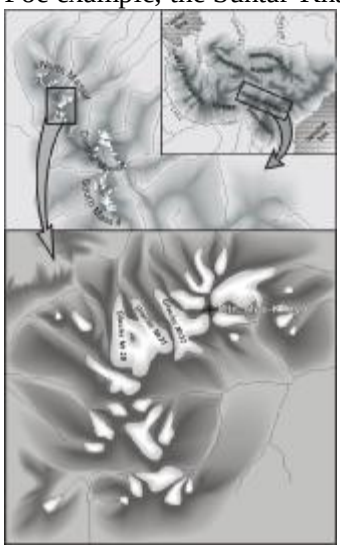
p. 712; Section 3: Provide details of GGa11 scenario: what are the CO2 levels under this scenario ?

Global-Mean Temperature, Precipitation and CO_2 Changes (w.r.t. 1961 - 1990) for the ECHAM4 Integrations

	2020s				2050s				2080s			
	ΔT (°C)	ΔP (%)	ΔSL (cm)	CO_2 (ppmv) *	ΔT (°C)	ΔP (%)	ΔSL (cm)	CO_2 (ppmv) *	ΔT (°C)	Δ P (%)	ΔSL (cm)	CO_2 (ppmv) *
GGa	1.22	0.7	NA	447	2.13	1.4	NA	554	3.02	2.1	NA	697

p. 712: It would be useful to show on a map where the 17 studied regions are located.

In general the map shows the study region and main glacier regions. To indicate all 17 glacier systems require a set of maps of various scale.
Foe example, the Suntar-Khayata glacier systems can be seen on this figure:



p.712: A paper by Cogley and McIntyre (2003) 'Hess Altitudes and Other Morphological Estimators of Glacier Equilibrium' might be useful in the context of the method of ELA estimation.

Yes, I agree

p. 713; Section 3.1: Description of climate should be given in the Study Area section not in Methods.

The section is titled Method and DATA, so I think the description of data is more up to place here than in Study region, since it is not just description of climate condition. Data pretty much defines the approach (method).

p. 713; Section 3.1: "The Chersky and Suntar-Khayata Ranges occupy an intermediate position in terms of glacier accumulation-ablation rate". Support this statement with data and references. Again, this should be in Study Area section not in Methods.

Reference is inserted

p. 713; Section 3.1: Glacier retreat from the 1950s: this again should be in Study Area section. The statement on 'appreciable changes' is too general (discussion on p. 720 refers to these changes too without any statistics). Specify how much of glacier surface area was lost and where. For example, Gurney et al. (2008) conclude that a half of glaciers in the Buordakh Massif of the Chersky Mountains have not retreated since the end of the Little Ice Age. Papers by Ananicheva et al. and Japanese scientists, many in English or with English abstracts, are useful.

Inserted some lines in the text and a reference which has English abstract and figure captions.

p. 713; Section 3.1: 200-500 m glacier thickness is a rather high value. How were they obtained? Specify and give a reference.

Reference is inserted. The ice thickness estimates are obtained from measurements *in situ* of Glacier 31, and assessed by the ratio of area/thickness for the glaciers of such types in other regions where measurements of thickness were available.

p. 714 and Fig. 3. Temperature changes in the mountains: There is an inconsistency between the text and Fig. 3. Fig. 3 reveals greater warming in winter (also confirmed in many other studies) while the text states that summer warming prevails. Also, there is nothing in Fig. 3 about autumn and spring. Please clarify. Given the low temperatures observed in the region, is it worth referring to standard seasons? If you do referto standard seasons, use abbreviations DJF (Dec-Jan-Feb) etc rather than standard seasons for clarity. 'Sources of intensification': spatial distribution of winter trends is consistent with the weakening of the Siberian high; see Panagiotopoulos et al., 2005. Do you really need to discuss changes in winter temperatures? Are they relevant to glacier change? Changes in June-July-August (JJA) and, possibly September (as a marginal ablation month) are important and deserve an in-depth discussion; winter is less important in the context of this study.

I have changed the text to be more clear. Inserted the seasonal abbreviations. Thank you.

p. 714: Why are precipitation changes not illustrated? Provide time series or spatial distribution of annual, October-May and JJA precipitation. It would be useful to see a discussion of changes in solid and liquid fractions of precipitation and their influence on ablation. Can trends in solid and liquid precipitation be derived using Bogdanova's method quoted in the paper and discussed here?

In this part (page 714) we discuss the precipitation given in the output of ECHAM4 scenario.
The Bogdanova method allows deriving monthly solid precipitation from the total sum if the monthly temperature and elevation of the site is known.
The line about values of the trend of solid precipitation is added on page 713.

pp. 714-715: Provide figures to illustrate projected changes in climate: show monthly baseline values and projected values of temperature; precipitation intensity; solid and liquid precipitation fractions for different regions.

It is just numbers: one pair is mean summer temperature (baseline and projected), the other - solid precipitation for each glacier system. I can't imagine how to construct a figure of this.

p. 715: Sparse high-altitude met data: would be good to have a table listing stations with coordinates, altitudes, and periods of observations.

I think such tables will not add much sense to the paper, the weather stations data can be obtained from the site www.meteo.ru

p. 717: Define 'coefficient of concentration'.

The coefficient (Kc) takes into account accumulation/redistribution of solid precipitation over glaciers due to snow drift, avalanches, snow falls from the moraine slopes. It is empiric depending on morphological type of glacier and its size. So, solid precipitation value multiplying on Kc gives the accumulation on glacier surface.

p. 717: Assessment of snow drift, avalanche snow transfer and drift from volcanic slopes required very detailed input data which are likely to be characterised by a strong

spatial heterogeneity. How was this problem addressed?

For special volcanic types of glaciers Kc are different from glacier types, spread in non-volcanic regions

p. 718: Increase in solid precipitation in north-eastern Siberia: quantify the change (related to the above comment on graphical presentation of data). What will it be in mm per months and will it be large enough to have an impact on glacier behaviour given the low values of winter precipitation? In which months will it occur and how will the timing affect glacier behaviour? Will the impacts be the same for the cold-basedand temperate glaciers?

As it indicated in the text the ratio between baseline solid precipitation and projected varies from 1.09 to 1.46 for all glacier systems of North-Eastern Siberia (continental climate type of glaciers) except for the southern massif of Suntar-Khayata (0.99). They are annual values, i.e. all months with solid precipitation are accounted. We need annual solid precipitation values since we deal with annual accumulation one, not monthly.
For Kamchatka glacier systems (temperate and even maritime for Kronotsky Peninsular) these ratios are less than 1 (0.74–0.96), solid precipitation by the ECHAM4 scenario will decrease.

p. 719: Why is the assumption that solid / liquid precipitation fractions will not change with altitude under the warmer climate valid?

The FRACTION should not change in near future, the temperature will rise but temperature lapse rate will not change so the fraction dependent on temperature for the same altitude belt should be stable.

p. 720: Discussion on glacier change needs at least references.

This is our new results….

PP 722-723: This section needs re-writing; not clear what the authors are trying to say. Section 5.1 should be omitted in my view or it will require a very substantial improvement and expansion including validation of the modelled climate data. Why use HadCM2 when later versions of the Hadley Centre models are available? This is too much for one paper.

Done
The section concerning the tests of other models is omitted.

I have not addressed the linguistic issues here; these are numerous and should be dealt with be a copy editor.

You are right, of course
My co-author, Prof. Roger Barry is American and he has edited the text.

References
Cogley, J.G. and M.S. McIntyre (2003) Hess Altitudes and Other Morphological Estimators of Glacier Equilibrium. Arctic, Antarctic, and Alpine Research., 35 (4): 482-488. Groisman, P.Y. and E.Y. Rankova (2001) Precipitation trends over the Russian permafrost-free zone: Removing the artefacts of pre-processing. International Journal of Climatology, 21: 657–678. Gurney, S.D. et al. (2008) A Glacier Inventory for the Buordakh Massif, Cherskiy Range, North East Siberia, and Evidence for Recent Glacier Recession. Arctic, Antarctic, and Alpine Research, 40 (1): 81-88. Koreisha, M.M. (1991) Oledenenie Verhoyansko-Kolymskoi oblasti (Glaciation in the Verkhoyansk-Kolyma Region). Nauka Publishers, Moscow. 114 pp. In Russian. Panagiotopoulos, F. et al. (2005) Observed Trends and Teleconnections of the Siberian High, a Recently Declining Centre of Action. Journal of Climate, 18: 1411-22.

Thank you very much for your work and references!

Maria Ananicheva