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CONTENTS

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RECONSTRUCTING PAST TEMPERATURE VARIATIONS: SOME METHODOLOGICAL ASPECTS

ABSTRACT

Three aspects essential for the paleoclimatic reconstructions are considered: calibration of proxy data on an example of tree-ring width records as the main source of proxy paleoclimatic information; taking into consideration an integral nonstationarity of multiscale climatic variations; and use of the empirical orthogonal function expansion for the goal of the past meteorological field reconstruction.

KEY WORDS: paleoclimatic reconstruction, tree-ring width data, past climate normals, empirical orthogonal functions.

INTRODUCTION

During the latest decade several groups of climatologists tried to reconstruct near surface air temperature variations averaged over the almost whole Northern Hemisphere area for the time period 1000–2000 BP [Wang et al., 1996; Mann et al., 1998; Jones et al., 1998; Mann et al., 1999; Crowley and Lowery, 2000; Briffa et al. 2001; Esper et al., 2002; Cook et al., 2004]. All their reconstructions look to be rather similar with each other. In particular, they show the Medieval Warm Period to be less strong in comparison with the Current Warming. The last IPCC report mentions this circumstance as an evidence of the Current Warming unique. But some doubts can be voiced as concern these reconstruction reliability.

Every kind of proxies is a thermometer with an unknown scale. Although these scales are very complex and nonlinear for certain, the above paleoclimatologists calibrated these scales in a simple linear manner comparing a proxy record used for a reconstruction with an instrumental temperature record over a time interval of their overlapping. This interval is short, and so it is quite clear that such calibrations can be meaningful for inter-annual and inter-decadal temperature variations. Spreading these calibrations onto lower-frequency parts of the proxy scales is an inadmissible extrapolation because responses of some proxies to longer-living external (climatic and environmental) variations can differ from those corresponding to the inter-annual and inter-decadal variations.

A PROBLEM OF THE PROXY DATA CALIBRATION ON AN EXAMPLE OF TREE-RING WIDTH RECORDS

Consider some consequences of such extrapolation on an example of tree-rings because it is widely accepted to use tree-ring width records as the main source of paleoclimatic information. Tree-rings are prominent by their annual resolution with a rather good timing, and tree-ring width record samples are very numerous and with broad geographic representative. In spite of these obvious merits, three-ring width proxy data have some drawbacks. In particular, some depressive tree growth observed in many geographic regions during a few recent decades [Briffa et al., 1998; Datsenko, 2005] seems to be a fingerprint of the aforementioned differentiation between higher- and lower-frequency parts of the tree-ring scales. Indeed, the germination of tree seeds is a climate (in particular temperature)-sensitive process. A small per cent of seed crops germinates near the northern and upper forest-limits where tree-rings usually are sampled by dendrochronologists now. Therefore distances between juvenile trees in such a location usually are large, and so other environmental conditions for the tree growth (the sun illumination, soil nutrition etc.) turn out to be rather favorable because of absence of any between-tree competition. However, one can suppose: if climate was much warmer in a past time period these locations were fare from the northern and upper limits of the tree growth, i.e. very within the tree areal of the tree species being sampled. Because of more favourable temperature, the germination of tree seeds became to be abundant, and the excessive forest density resulted from this abundant germination implied a deterioration of the followed tree growth. Thus, assuming a wide range of multiscale climatic variations, two processes of the tree growth must be taken into account: 1) thickening of tree-stems during a number of consequent years of tree life that is well-proportioned to instantaneous temperatures and under condition of an almost constant forest stand, and 2) thickening of tree-stems during essentially longer time intervals that is inversely-proportioned to longer-term forest stand changes.

The difficulty in the tree growth calibration increases even more because the traditional tree-ring width index is an inappropriate measure of the annual wood production. Indeed, the tree-ring width is an age-dependent quantity for both juvenile and mature trees. To remove this dependence the so-called tree-ring standardization is used. Any tree-ring standardization inevitable suppresses responses of trees to longer-living external variations at least partly. The known [Briffa, 1992; Visser, 1995] basal-area increment index (*BAI)* is a better measure in comparison with the standardized tree-ring width index. But *BAI* was used in no recent paleoclimatic reconstructions because, as a rule, there was no reliable information about the value of the innermost radius of tree-ring records (the so-called pith-offset) used, and because the nature of *BAI* is nonlinear and difficult to handle.

However, it is easy to prove that a new modified, similar to *BAI*, index $dR(t) \cdot R(t)$ (where $dR(t)$ is the ring width in the year t, and $R(t)$ is the inner radius of this ring) is a rather good measure of the wood production. This quasi-linear quantity is robust to the geometry of the stem section. Moreover, this quantity seems to be age-independent for mature trees (see: [Biondy and Qeadan, 2008]), and so it can be used without any standardization in principle. Unfortunately, it is not so in reality because some tree species, reveal apparent increase of their uppermost ring widths. By this reason, a kind of standardization must be preserved even if the modified *BAI* is used instead of the traditional ring width index.

Fig. 1 shows a "toy"-chronology created with using this new index for the seven larches from the North-East Siberia (obtained from O.V. Sidorova – a member of E.A. Vaganov's Russian team of dendrochronologists). A comparison of this "toy"-chronology with instrumental temperatures of the region (extracted from [Briffa et al., 2002]) reveals its certain success in reproducing regional temperature variations as it is seen from the calibration graphs shown in Fig. 2. Note a parabolic calibration looks to be preferable in comparison with the linear calibration of this reconstruction. This fact corroborates the existence of two scales in tree growth responses to the external condition variations mentioned above. Even by eye this

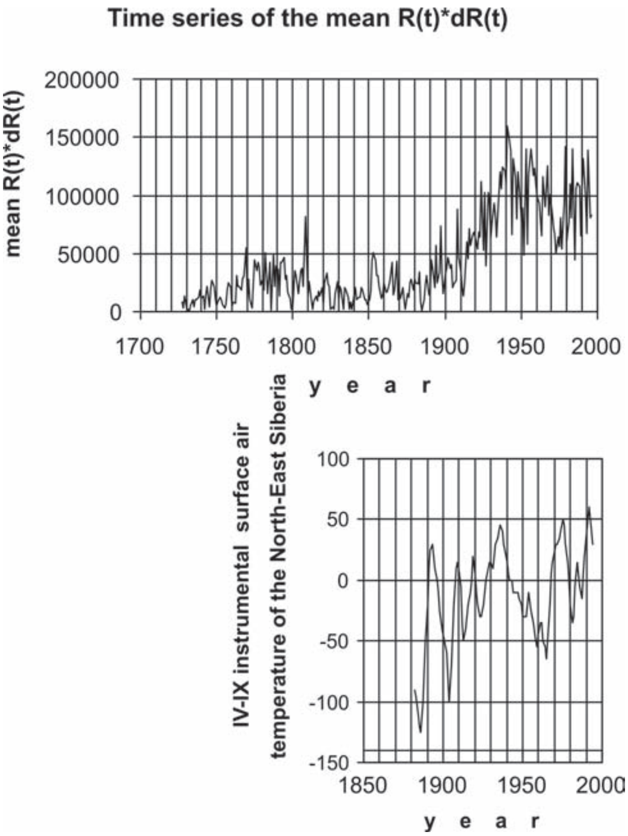

Fig. 1 A "toy"-chronology created with use of the *dR(t)8R(t)*-index time series for seven larches. A general similarity with the mean Northern Hemisphere temperature variations during the instrumental observation period can be seen even by eye

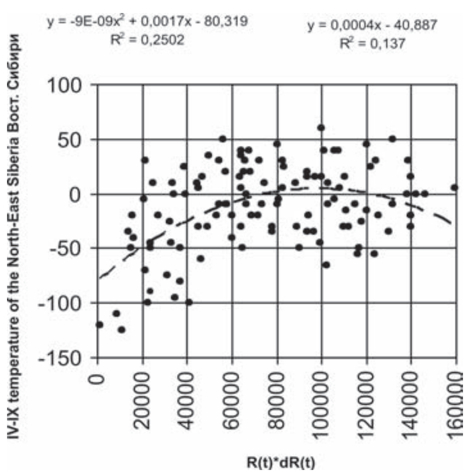

Fig. 2. A graph of correlation between the "toy"-chronology shown in Fig. 1 and the regional instrumental temperatures of the North-east Siberia. Linear and quadratic regression lines are shown together with the respective equations

"toy"-chronology reproduces rather well the Northern Hemisphere temperature variations during the latest 270 years. Its correlation with the mean temperature of the Northern Hemisphere turns out even higher than with regional temperatures because station instrumental temperatures seem to be of rather bad quality. The station data of the region under consideration cover a shorter time intervals, reveal data gaps, and poor representative for their broader vicinity.

Worse quality of regional and local instrumental temperatures in comparison with hemispheric mean temperatures is the general case. By this reason and by the reason of linearity of the calibration procedure as well as the procedure of adding all proxies at the final stage of any reconstruction, it is perhaps better to calibrate proxies with respect to the mean hemispheric temperatures directly.

A PROBLEM OF PRESENT-DAY AND PAST CLIMATIC NORMAL COORDINATION

The next important unsolved problem of the paleoclimatic reconstruction consists in the following. Each real climatic time series is of a finite length. But, the climate dynamics is an integrally nonstationary and locally chaotic process. Therefore, looking at any real climatic time series one can see a trend-like behavior of the moving average of this series almost for certain even if higher-frequency components of the series look to be statistically stationary. As a consequence, the first goal of paleoclimatic reconstruction is to reconstruct macroscale (temporally and spatially very averaged) paleoclimatic variations that can be named the paleoclimatic normal.

Any estimation of such a normal is a kind of biased-, noisy-, and incomplete- data filtering. As a rule, such filtering leads to underestimation of the true magnitude of the normal variations because the spectra of these real variations and errors of proxy data records overlap in the frequency domain. One can suppose that the spectra of the proxy data errors are even redder than the real temperature spectra. By this reason a proclamation of Mann et al. [2005] of an essential lower-frequency temperature variability overestimation in the Moberg et al. [2005] reconstruction is not grounded completely. In order to prove their proclamation Mann et al. [2005] have created tree-ring-like pseudo-proxy records by simple summations of modeled temperature time series with white noise series, and used similar summations of firstly smoothed modeled series with other white noise series to create low-resolution pseudo-proxy records. Such technique of the pseudo-proxy creation is false.

A PROBLEM OF THE USE OF EMPIRICAL ORTHOGONAL FUNCTIONS IN THE PALEOCLIMATIC FIELD RECONSTRUCTION

Finally, it is a misuse to expand proxy records on spatial EOFs calculated on the base of instrumental temperature records by the following reasons:

1) EOFs is a tool to depict variations of anomalies calculated with respect to a certain climatic normal. Any normal as such is out of scope of the EOF-analysis. To overcome this obstacle some paleoclimatologists calculate a normal for the instrumental observation period, and then apply this normal to past climates. Unfortunately the present climate normal is a very bad surrogate of past climate normals. Moreover, it is impossible to hope that past anomalies calculated with respect of the present climate normal can be characterized by the same covariation function, and so the same EOFs which are actual for the present climate anomalies.

2) A covariation matrix of a finite order (instead of a continuous covariation function) can be estimated on the base of instrumental data. Such a matrix depicts covariations between temperatures in finite number of pairs of geographic points corresponding to the present-day meteorological station locations. As a rule, locations of proxy data differ from station locations. Their numbers are also different, and moreover, the proxy data net is temporally nonstationary. Thus, any kind of raw proxy data must be interpolated (extrapolated) into station points before any EOF-analysis can be applied to these proxy data.

3) Spatial covariations of real temperatures relax to almost zero over distances as small as 1000–2000 km [Datsenko et al., 2001]. Therefore, any covariation matrix turns out to be a sparse matrix, i.e. almost all of its elements out of the main diagonal are near zero. It is well known [Datsenko et al., 1983] that the eigen problem for such a matrix is ill-posed and practically unsolvable. It means any calculated set of EOFs is randomly rotated, and so any apparently fruitful approximation of the temperature field variability by a few first EOFs is an artefact of sampling and calculating.

In sum, all benefits of the EOFs use are illusory in the reconstruction problem. If we still wish to apply EOFs the reconstruction procedure must be improved.

Real temperature anomalies look to be more or less homogeneous. By this reason the shapes of their eigen functions corresponding larger eigen values look to be similar to a family of trigonometric functions like the two-dimensional Cos- and Sin- series in the traditional Fourier expansion [Sonechkin, 1971]. The first EOF usually is of the same sign over the entire area of interest. It seems to be an analog of the first constant term in the Fourier expansion. Of course, the eigen functions of real temperature anomalies corresponding smaller eigen values look like fractal fields. But these eigen functions are not essential for any reconstruction. An

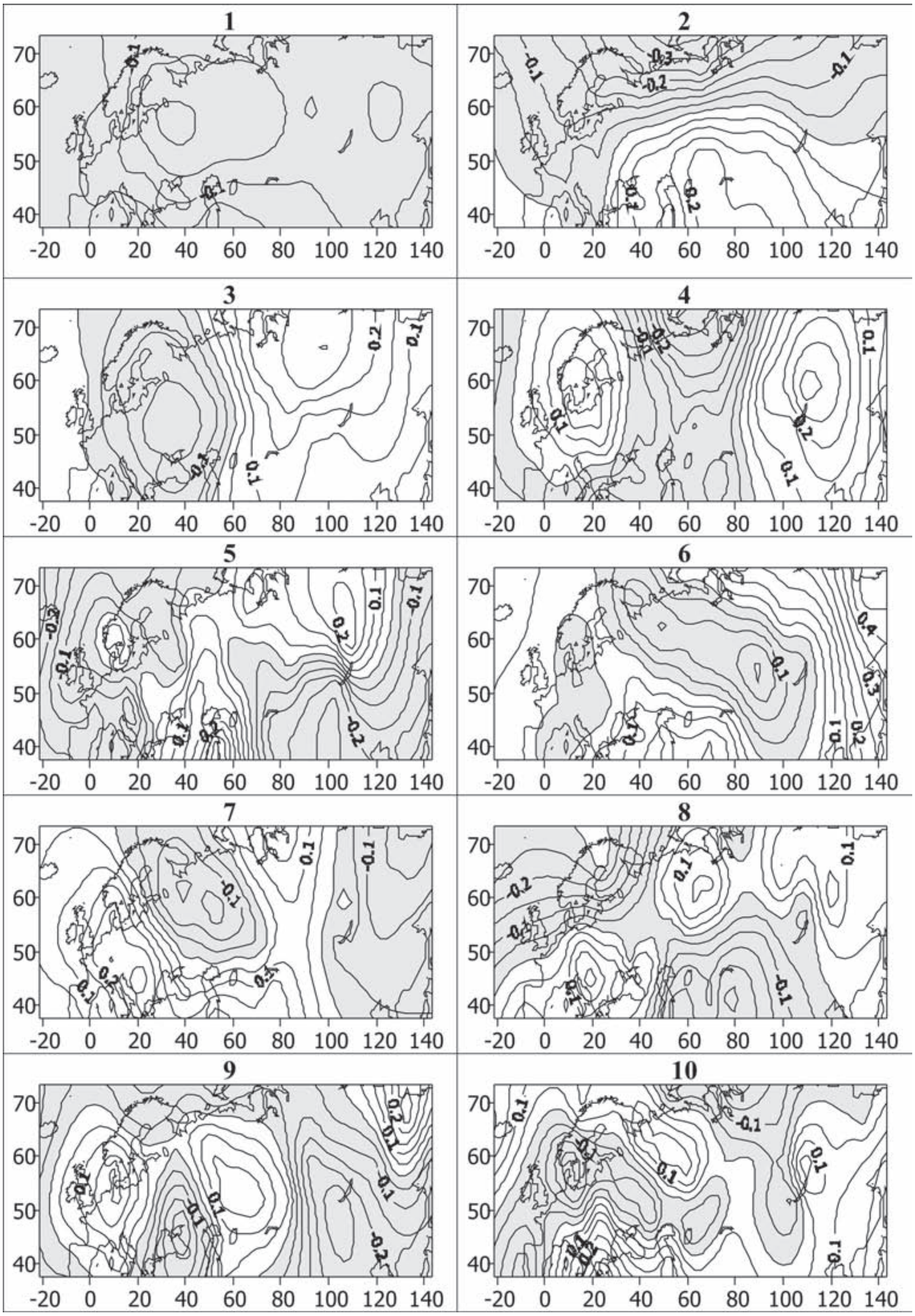

Fig. 3. 1–10: EOFs of the monthly mean temperatures calculated on the base of instrumental observations of the near surface air temperature at 55 stations of the North Atlantic–Europe –North Asia area during the XX century. A similarity of several first EOFs with a family of two-dimensional Cos- and Sin- are evident. The shapes of consequent EOFs look to be more and more dissimilar to the trigonometric functions

example of the 1–10 EOFs for the monthly mean temperatures of the North Atlantic–Europe–North Asia area (from [Monin and Sonechkin, 2005]) illustrating these facts is shown in Fig. 3.

The most important consequence of the trigonometric expansion use consists of a possibility to estimate past climatic normals independently from any present-day normal. It is because the trigonometric family constitutes a function basis. The first (most spatially smooth member of this basis or, it may be, a few number of the first members) can be used to obtain the first guess reconstruction of past climate normals. Some next members can be used for the second guess reconstruction of past climate patterns. There is no problem with temporal nonstationarity of the proxy data nets at this step of reconstructing because a routine least-square procedure can be used to invert the raw proxy data to the trigonometric coefficients. Instead of this latter procedure it is possible firstly to calculate a covariation matrix of coefficients of the trigonometric expansion for the anomalies with respect to earlier reconstructed past climate normals, and secondly to calculate EOFs of this matrix. There is no problem with the ill-posed solubility of the numerical computation of the eigen problem for this matrix because the number of trigonometric coefficients taken into consideration can be limited in advance. Only then the EOF-coefficients (PC) can be calculated and used to reconstruct past climate patterns.

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LES ATLAS, UN NOUVEL ENGOUEMENT DE L'ÉDITION FRANÇAISE

ATLASES – THE NEW FASCINATION OF FRENCH PUBLISHERS

ABSTRACT

Reacting to reader interest in publications of new types of atlases, many French authors and publishers rushed to occupy an emerging publishing niche and created a real fashion of small atlases attracting ever-greater public attention. The paper describes origins and features of this phenomenon.

KEY WORDS: atlas, geopolitics, history of geographical publications

INTRODUCTION

Lancée dans les années 1980, la mode des atlas thématiques, géopolitiques ou géostratégiques ne s'est jamais éteinte depuis. Au contraire, depuis quelques années, les éditeurs européens rivalisent et les publications foisonnent. Qu'elles soient proposées en ouvrages uniques ou en collections, elles ont chacune leur identité, leur style et surtout leur propre approche intellectuelle de l'organisation de la planète, leur propre vision du monde.

Mais la profusion de ces atlas depuis une trentaine d'années nous a fait oublier que la production dans les années 1920 et 1930 fut aussi fort riche. Les noms d'Otto Neurath, Karl Haushofer ou Alexander Rado ne nous disent plus rien, et c'est dommage: ce sont eux qui, à l'époque, ont largement débroussaillé le terrain.

Atlas mondial des vins, de la gastronomie, des fractures sociales en France, des minorités en Europe, du sport mondial, des langues, des mafias, de la sexualité, des guerres napoléoniennes, de la guerre froide, de Moscou, des Vikings... Le catalogue du principal éditeur français d'atlas, les éditions Autrement, donne le tournis. Sa première collection d'atlas (Atlas Monde), créée en 1996, contribua pour beaucoup à relancer les ventes de cet éditeur indépendant et innovant. Aujourd'hui, il décline quatre collections (Monde, Mémoire, Atlas des guerres et Atlas des mégalopoles) qui couvrent une multitude de sujets, depuis les principales régions et pays du globe jusqu'aux thèmes à la mode comme le réchauffement climatique ou les migrations.

UNE FAMILLE EN CROISSANCE

Ce ne sont bien sûr ni Autrement ni la France qui inventèrent les atlas, même si la petite ville de Saint-Dié des Vosges s'enorgueillit d'avoir imprimé la première carte où figure le mot "Amérique" (C'est ce qui a servi de prétexte à la création du remarquable Festival international de géographie, le FIG, point de rencontre annuel des amateurs d'ouvrages et de débats sur la géographie et la géopolitique.

Longtemps, les atlas furent d'abord des recueils de cartes des terres et des mers, permettant aux navigateurs et aux gouvernants, qui commandaient souvent ces cartes, d'organiser leurs voyages et leurs conquêtes. Ces cartes furent alors des outils efficaces pour aider les souverains à affirmer leur contrôle sur ces nouveaux territoires et leurs richesses. De la simple représentation géographique, on passa ultérieurement à celle de l'histoire, avec, depuis le XIXe siècle, la parution d'atlas historiques de l'Europe et du monde.

Les années 1980 marquent cependant un tournant, avec la multiplication d'atlas différents, mettant l'accent non plus sur la simple localisation, la description des terres ou la répartition des hommes et de leurs activités, mais se proposant d'analyser, par le truchement de la cartographie et de ses divers modes de représentation (y compris les graphiques et schémas), des sujets particuliers liés à l'actualité du monde. Prolongeant, sans la connaître, l'œuvre magistrale d'Otto Neurath, grand précurseur de la représentation spatiale par les symboles et son remarquable ouvrage publié à Leipzig en 1930 [Neurath, 1930], les premiers exemples de ces "nouveaux atlas" naissent en Grande-Bretagne, avec en particulier le fameux *The State of the World Atlas*, publié en 1981 par Michael Kidron et Ronald Segal chez Pan Books, puis le *War Atlas,* publié par Kidron et Dan Smith chez Heinemann à Londres en 1983.

Saisissant vite l'intérêt de ces ouvrages d'un type nouveau, plusieurs auteurs et éditeurs français se lancent sur ce créneau éditorial, créant bientôt une véritable mode autour de ces outils de petit format (contrairement aux grands atlas traditionnels, ces livres se présentent souvent avec un nombre de pages réduit – le prix de la quadrichromie limite le volume, dans un format à l'italienne inférieur au A4) qui attirent un public de plus en plus nombreux. Si certains éditeurs (c'est le cas pour les premiers ouvrages de la série d'Autrement) se contentent de traduire les premiers atlas anglo-saxons, d'autres impulsent un renouveau du genre dans le cadre de ce qu'on peut désigner comme la nouvelle école de géopolitique française, inspirée incontestablement par les travaux d'Yves Lacoste, le fondateur en 1976, aux éditions François Maspero, de la revue *Hérodote*.

Le premier ouvrage de ce type est l'Atlas géostratégique que Gérard Chaliand publie avec Jean-Pierre Rageau chez Fayard [Chaliand et Rageau, 1983]. Les cartes en grands aplats colorés sont assez simples mais l'ouvrage est solide, rappelant l'apport des pionniers de la géopolitique, Ratzel et Mackinder, introduisant par la cartographie les grandes données culturelles et historiques (aires, religions, puissances impériales) en insistant sur le contexte historique du XXe siècle, l'héritage du second conflit mondial, la décolonisation et la guerre froide alors loin d'être terminée. L'étude des cas régionaux, qui constitue l'essentiel de l'ouvrage, introduit déjà la notion de perception de leur propre espace géopolitique par différents pays ou puissances mondiales, thème qui sera par la suite largement développé dans d'autres ouvrages (Citons en particulier *L'Atlas des atlas. Le monde vu d'ailleurs, Courrier international,* Artaud, 2008, recueil fascinant de cartes du monde entier exprimant les points de vue des mouvements nationalistes de divers pays). Suivront de près, à partir de 1988, la parution des atlas géopolitiques d'Alexandre de Marenches, ancien chef des services secrets français [Marenches, 1988], et de Jean Touscoz [Touscoz, 1988]. Ces ouvrages sont les derniers de l'ère de la guerre froide. La fin, en 1989, du monde bipolaire, auquel succède un paysage géopolitique multiforme et complexe, dans lequel les alliances sont en permanente recomposition, nécessite d'autres grilles de lecture, et, de fait, dynamise la production d'atlas géostratégiques ou géopolitiques (et même d'émissions de radio et de télévision régulières). Cette production n'a depuis lors cessé de croître.

En 1989 paraissent les premiers ouvrages d'une collection destinée à un public de géographes, d'urbanistes et de décideurs, "Dynamiques du territoire", parrainée par la maison de la Géographie RECLUS et la Documentation française (citons parmi les premiers parus: Denise Pumain et Thérèse

Saint-Julien, *Atlas des villes de France*, puis Didier Paris, *Nord-Pas-de-Calais* et A-M. Lakota et C. Milelli, *Ile-de-France, un nouveau territoire*. Très documentée, basée sur une cartographie multiforme et exigeante, cette collection va s'enrichir de nombreux titres dont *l'Atlas de la Russie et des pays proches,* une excellente mise au point sur l'ex-URSS juste après son éclatement [Brunet et al. 1995] ou le remarquable *Atlas de l'Europe dans le monde* [Didelon et al., 2009] présentant un ensemble complet des modes d'insertion et d'influence de l'Union européenne dans son environnement mondial.

En 1991, les frères André et Jean Sellier publient, aux éditions La Découverte, l'*Atlas des peuples d'Europe centrale*. Le principe est de montrer, par des développements historiques, avec l'appui de nombreuses cartes, la formation au cours des siècles de l'identité des principaux peuples et des Etats correspondants au sein d'une grande aire culturelle. Le succès de ce premier ouvrage lance ce qui devient une série très prisée par un large public intéressé par les convulsions de régions transformées par la fin de la guerre froide [Sellier, 1993–1995].

De nombreux auteurs et éditeurs tentèrent de bénéficier à leur tour du succès de ces pionniers, sans que la qualité des cartes et analyses apporte toujours un renouvellement appréciable des points de vue [Le Robert 1999; Guellec1999]. L'engouement pour le genre aura des prolongements inattendus avec le lancement en 1990 (d'abord sur La Sept, puis sur la chaîne franco-allemande Arte) de l'émission de télévision "Le dessous des cartes", qui devient très populaire. Le format court (7 puis 11 minutes) permet de rendre compte d'un sujet d'actualité brûlante sous une forme attractive avec des cartes animées. *L'Atlas du Dessous des cartes*, publié chez Taillandier en 2005 par le responsable de la série TV, Jean-Christophe Victor, est un vif succès de librairie, même si les cartes, souvent simplistes et peu informatives, n'emportent pas toujours l'adhésion.

Qualifié de "bréviaire contre la mondialisation libérale" (in *Le Monde*, 24 janvier 2003), *l'Atlas du Monde diplomatique* [Monde diplomatique, 2003] tente de rendre compte de l'évolution du monde et de ses conflits en analysant l'ensemble des facteurs qui déterminent les processus en cours, économiques, démographiques, écologiques, stratégiques. Les esquisses cartographiques, réalisées aux crayons de couleurs, représentant par leur aspect inachevé le monde en pleine transformation, connaissent un destin inattendu: en grand format, elles sont exposées comme objets artistiques dans plusieurs musées européens et à la Dokumenta 12 [Kassel, 2009].

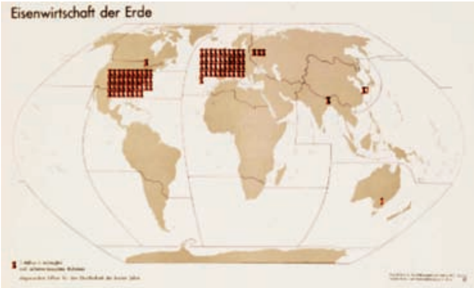
Le père spirituel du renouveau de la géopolitique en France, Yves Lacoste, publie chez Larousse, en 2007, un *Atlas de géopolitique* qui complète son traité de géopolitique [Lacoste 2006, 2009]. Outre la synthèse ainsi présentée de plusieurs dizaines d'années de travail, cette double parution innove sur le plan cartographique par le recours systématique à des représentations simultanées (sur une même page, comme trois couches de dessins à lire en même temps) de processus complexes à trois échelles différentes, de plus en plus précises. Proche, par son esprit, *l'Atlas de la mondialisation* édité par l'équipe de Sciences Po (Marie-Françoise Durand, Philippe Copinschi, Benoit Martin, Patrice Mitrano, Delphine Placidi-Frot) présente différentes "clefs pour la compréhension de l'espace contemporain mondial" en s'intéressant aux processus globaux que sont les territoires contestés, les acteurs transfrontaliers, les nouvelles règles du jeu, etc. La cinquième édition [Presses de Science Po, 2010] comprend un intéressant chapitre sur "La Russie dans la mondialisation".

L'année 2010 a été particulièrement riche en nouveautés d'atlas géopolitiques, comme si les éditeurs se livraient à une course effrénée: Gérard Chaliand et Jean-Pierre Rageau, trente ans après leur premier ouvrage, publient chez Arthaud une *Géopolitique des Empires*; Les journaux *La Vie-Le Monde* s'associent pour publier, sous la houlette du géographe Christian Grataloup, *un Atlas des mondalisations*; Les éditions Robert Laffont sortent un *Atlas des futurs du monde* plus prospectif et incertain, réalisé par une équipe dirigée par Virginie Raisson; enfin le remarquable ouvrage du géographe Michel Foucher, *La bataille des cartes, analyse critique des visions du monde*, livre une passionnante réflexion sur la cartographie. Pour ne citer que les principaux...

LES PRÉCURSEURS

Otto Neurath

Gesellschaft und Wirtschaft, Leipzig, 1930



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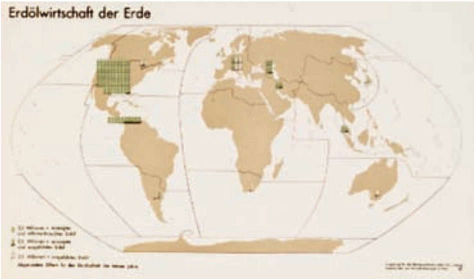
Gesellschaft und Wirtschaft, Leipzig, 1930



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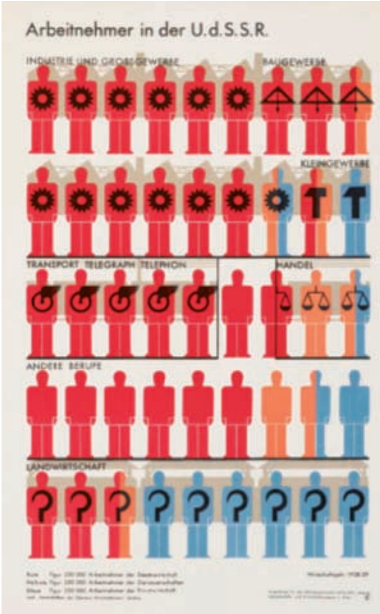

Otto Neurath

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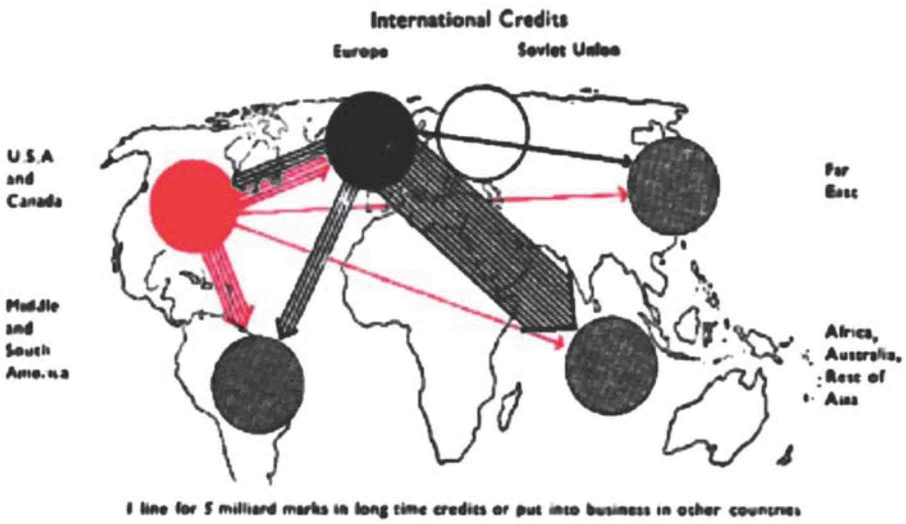
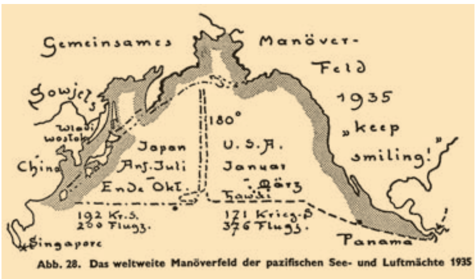


Otto Neurath

Crédits internationaux, 1936 (source inconnue), DR

Karl Haushofer

Geopolitik des Pazifischen Ozeans, Kurt Vowinckel Verlag, Heidelberg et Berlin. Avec nos remerciements à Tjebbe van Tijenet et à son musée de l'imaginaire



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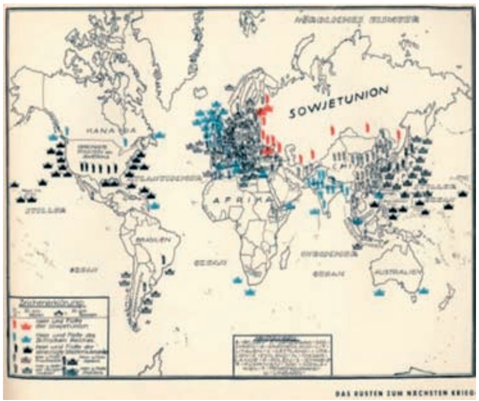

Alexander Rado

Atlas fur Politik Wirtschaft Arbeiterbewegung; "I. Der Imperialismus", Verlag fur Literatur und Politik, Vienne et Berlin, 1930. Avec nos remerciements à Tjebbe van Tijenet et à son musée de l'imaginaire

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CONCLUSION

Ainsi, en quelques années, l'édition française a su s'enrichir d'une solide expérience dans le domaine cartographique et géopolitique, comme en témoignent les nombreuses traductions étrangères que les ouvrages les plus réussis ont suscitées. Peu à peu, cette mode anglo-saxonne, qui a trouvé véritablement un épanouissement à la fois éditorial et intellectuel en France, se répand dans d'autres pays. Il y aura bientôt là matière à études universitaires et commentaires sur un genre bien particulier qu'est devenu la représentation géopolitique de notre planète et ses partis-pris idéologiques et esthétiques. ■

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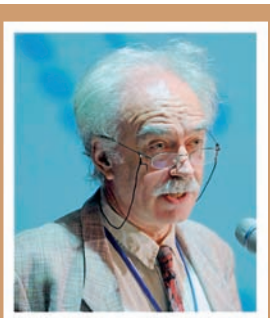

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AEROSOL PROPERTIES IN MOSCOW ACCORDING TO 10 YEARS OF AERONET MEASUREMENTS AT THE METEOROLOGICAL OBSERVATORY OF MOSCOW STATE UNIVERSITY

ABSTRACT

Different microphysical, optical and radiative properties of aerosol were analyzed according to the 10 years of measurements (2001–2010) at the Meteorological Observatory of Moscow State University within the framework of international AERONET program. Volume aerosol size distribution was shown to have a bimodal character with dominating the fine mode aerosol particles at effective radius of $r_{eff\text{-}fine}$ = 0.15 µm. In smoke conditions $r_{eff\text{-}fine}$ was shown to increase to 0.25 µm at extremely large aerosol optical thickness (AOT). Real and imaginary parts of refractive index are characterized by REFR = 1.45, REFI = 0.01 respectively, changing to REFR = = 1.49, REFI = 0.006 for smoke aerosol. AOT seasonal changes are characterized by the increase towards warm period with a local minimum in June. The joint analysis of aerosol characteristics with the NOAA_NCEP_CPC_CAMS_OPI climatology shows the nature of these changes. For typical conditions aerosol single scattering albedo (SSA) is about 0.9 at 675nm and is characterized by a distinct decrease with wavelength while in forest fires conditions it is significantly higher (SSA = 0.95). The interaction between volume aerosol concentration of different aerosol fractions was obtained with a distinct decrease of variation towards large aerosol content.

KEY WORDS: aerosol climatology, Moscow, AERONET, microphysical, optical and radiative aerosol properties, smoke aerosol, aerosol pollution

INTRODUCTION

Atmospheric aerosols are one of the important factors influencing net radiative balance of the atmosphere and hence the whole climate system. However, still there is not enough information on microphysical, optical and radiative aerosol properties which can cause different climate impact even in sign. One of the most widespread ground-based aerosol networks is the Aerosol Robotic Network – AERONET (http://aeronet.gsfc.nasa.gov/) [Holben et al., 1998], which has been in operation since the middle of 1990s with more than 200 sites with continuous measurements all over the world. Accurate multi-channel measurements by CIMEL sun/sky photometer through UV to near-infrared spectral region provide the data for evaluating a spectral dependence of aerosol optical thickness as well as many other inversion products including size distribution, effective radii, aerosol phase function, and different optical and radiative aerosol properties – refractive index, aerosol optical thickness, single scattering albedo, asymmetry factor, etc. [Dubovik and King, 2000].

Meteorological Observatory of Moscow State University (MSU MO) joined the AERONET program in 2001, and since that time regular high quality spectral measurements of aerosol characteristics have been in operation with the instruments calibrated according to the international standards. The 10-year period of continuous measurements provides an excellent dataset for the analysis of different aerosol properties in Moscow. In this paper we analyze typical features of main aerosol parameters, its climatology and some aspects of aerosol characteristics during the severe fire events.

METHOD AND THE DESCRIPTION OF THE DATA

Fig.1 presents a picture of the CIMEL instrument at the roof of the Meteorological Observatory of Moscow State University. Direct Sun measurements are made with 1.2° full field of view collimator at 340, 380, 440, 500, 675, 870, 940 and 1020 nm every 15 minutes during daytime [Holben et al., 1998]. Measurements in the solar almucantar and at the solar principal plane are made with the help of the second 1.2° full field of view collimator in four channels: 440, 670,870 and 1020 nm every hour during daytime. The direct Sun measurements are used to compute aerosol optical thickness (AOT) except that for 940 nm channel, which is used to estimate the total water content W, and Angstrom exponent. The Angstrom wavelength exponent (α) is computed as the slope of the linear regression of $lnAOT_\lambda$ versus $ln\lambda$ using the 440, 500, 675, and 870 nm wavelengths. This is an important characteristic for qualifying the main features of aerosol size distribution and the relative dominance of fine or coarse mode particles. The uncertainty of AOT measurements does not exceed 0.01 in visible range and 0.02 in UV spectral range (Eck

Fig. 1. The Cimel sun/sky photometer at the roof of the Meteorological Observatory of Moscow State University

et al., 1999), which is currently the best achieved quality of measurements in the world.

Both direct and diffuse AERONET measurements are used in an inversion algorithm developed by O. Dubovik and M. King [2000]. This algorithm provides improved aerosol retrievals by fitting the entire measured field of radiances – sun radiance and the angular distribution of sky radiances – at four wavelengths (440, 670, 870 and 1020 nm) to a radiative transfer model. As a result, different microphysical, optical and radiative aerosol properties in the total atmospheric column can be estimated (i.e., aerosol refractive index, volume size distribution in the size range of $0.05 \leqslant r \leqslant 15$ μm, volume concentration, effective radius, etc).

Depending on their quality the AERONET data correspond to different levels. All real-time measurements are assigned to the level 1. Since the instrument is automatically operated, a special system of cloud-screening has been developed [Smirnov et al., 2000]. The data, which successfully pass the procedure of cloud screening, are assigned to the level 1.5. After the second calibration and some additional checks the data are assigned to the final level 2.0. One hour visual cloud observations at the MSU MO provide additional useful information on possible cloud contamination. Some additional criteria based on cloud data has been developed [Uliumdzhieva, Chubarova, and Smirnov, 2005]. This additional filter allows us to improve significantly the quality of the aerosol climatology by avoiding thin uniform cirrus clouds, which are very hard to exclude automatically using the standard cloud screening procedure. As a result, a special software has been developed for processing the AERONET measurements with the additional cloud-screening filters from the MSU MO cloud dataset.

RESULTS

Microphysical and optical aerosol characteristics in Moscow

The AERONET inversion algorithm [Dubovik and King, 2000] provides the retrievals of many important microphysical and optical characteristics of aerosol. Fig. 2 shows the mean volume aerosol size distribution $dV(r)/d\ln r$ (μm³/μm²) for different seasons of the year in the range of particle size 0.05 μm $\leqslant r \leqslant 15$ μm. One can see the presence of both fine ($r < 0.7$ μm) and coarse ($r > 0.7$ μm) aerosol modes. However, in winter the volume size distribution differs from that in other seasons. The distribution of $dV(r)/d\ln r$ in winter is characterized by lower values both for fine and coarse modes and the maximum of fine mode is shifted to the higher values ($r = 0.25$ μm) compared with 0.15μm in other seasons. During spring one can see more pronounced increase in coarse aerosol mode. However, there is a distinct prevalence of fine aerosol mode volume concentration in all seasons. We should note that this distribution is typical for the continental aerosol with some features of urban type, which is characterized by some additional increase in coarse mode [Dubovik et al., 2002]. Our detailed analysis of parallel measurements at the MSU MO and at the Zvenigorod Scientific Station of the Obukhov Institute of Atmospheric Physics RAS in background conditions has revealed a statistically significant increase in concentration

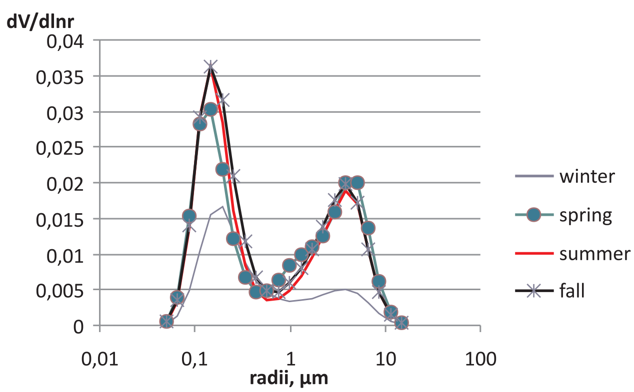


Fig. 2. Mean aerosol volume size distribution in different seasons. Moscow 2001–2010

Table 1. Different microphysical and optical aerosol characteristics from AERONET data

Statistics	Effective radius, µm r_{eff}-fine	Effective radius, µm r_{eff}-coarse	Volume Concentration (µm³/µm²) VolCon-total	Volume Concentration (µm³/µm²) VolCon-fine	Volume Concentration (µm³/µm²) VolCon-coarse	Real part of refractive index, REFR (675 nm)	Imaginary part of refractive index, REFI (675 nm)	Single scattering albedo, SSA (675 nm)	Factor of asymmetry, *g* (675 nm)
Average	0.15	2.34	0.07	0.04	0.03	1.45	0.01	0.90	0.62
Median	0.14	2.37	0.06	0.03	0.03	1.45	0.01	0.90	0.62
Max	0.27	3.74	0.47	0.38	0.24	1.59	0.04	0.98	0.75
Min	0.09	1.07	0.009	0.003	0.001	1.33	0.00	0.72	0.51
Sigma	0.02	0.41	0.05	0.04	0.02	0.06	0.007	0.05	0.04
Case number	1699	1699	1699	1699	1699	292	292	292	1699
Confidence level at 95%	0.001	0.019	0.003	0.002	0.001	0.007	0.001	0.006	0.002

Notes: 1. Effective radius and volume concentration are calculated as follows

$$r_{eff}=\int_{r_{min}}^{r_{max}}(r^3 dN(r)/d\ln r)\,d\ln r \Big/ \int_{r_{min}}^{r_{max}}(r^2\,dN(r)/d\ln r)\,d\ln r\,;\ VolCon=\int_{r_{min}}^{r_{max}}(dV(r)/d\ln r)\,d\ln r\,;$$

r – radius, *N*(*r*) – aerosol number density, *V*(*r*) – volume aerosol concentration.

2. We should note that due to the increase in cloudy overcast situations and relatively small AOT it is almost impossible to retrieve refractive index and single scattering albedo during winter period. As a result, the obtained aerosol characteristics described above mainly characterize spring-summer-fall conditions (more than 92% of cases).

3. The statistics on SSA and refractive index is less due to the necessity of additional restriction on the AOT440 >0.4 in the retrieval algorithm.

of the coarse aerosol mode over Moscow of about 0.005–0.008 μm^3/μm^2 [Chubarova, Sviridenkov, Smirnov, and Holben, 2011].

Table 1 presents the statistics of main microphysical and optical aerosol parameters during 10 years of continuous measurements in Moscow, which include effective radii for fine and coarse modes, volume concentration, real and imaginary part of refractive index. The obtained mean volume aerosol distribution for Moscow conditions corresponds to the mean effective radius of fine mode particle with $r_{eff\text{-}fine}$ = 0.15 μm and to the coarse mode particle with $r_{eff\text{-}coarse}$ = 2.34 μm. However, standard deviation is very high, especially for the coarse mode particles. The frequency distribution of effective radii has a lognormal type with a clear positive asymmetry. Volume aerosol concentration also has a distinct positive asymmetry and varies within a large range from 0.009 to 0.47 μm^3/μm^2 with the mean value of VolCon = 0.07μm^3/μm^2. It is characterized by the prevalence of fine mode particles (about 57% of the total volume concentration).

Mean values of real and imaginary parts of refractive index (REFR and REFI, see Table 1) comprise respectively REFR = 1.45 ± 0.01 and REFI = 0.01 ± 0.01. The frequency distribution of the REFR belongs to a normal law distribution, while that of the REFI is better described by a lognormal type with a positive asymmetry. The typical values of REFR correspond to the non-hydroscopic type of aerosol particles [Dubovik et al., 2002]. This means that changes in meteorological field (for example, in relative humidity) do not significantly influence the change in the aerosol particle size. During the forest fire events of 2002 and 2010, which were accompanied by a high amount of biomass burning smoke aerosol, the REFR values even increase to 1.49, which are in accordance with the results obtained in other regions with biomass burning aerosol [Dubovik et al., 2002]. At the same time in conditions with forest fires the imaginary part of refractive index has a small decrease (REFI = 0.006 ± 0.0004) compared with typical Moscow aerosol conditions.

Radiative characteristics of aerosol

Aerosol optical thickness is the most widely used aerosol parameter for characterizing the aerosol loading within the atmospheric column. It is also used for estimation of the radiative budget of the atmosphere. Fig. 3 presents the seasonal changes of aerosol optical thickness at different wavelengths according to the whole 2001–2010 dataset. There is a distinct spectral dependence in AOT characterized by an AOT increase towards smaller wavelengths due to dominating the fine mode aerosol observed in Moscow conditions (see Fig. 2 and discussion in the previous section). The prevalence of the relatively small aerosol particles according to the Mie theory [Liou, 1980] provides a decrease in an extinction aerosol coefficient with an increase of wavelength. Since AOT is

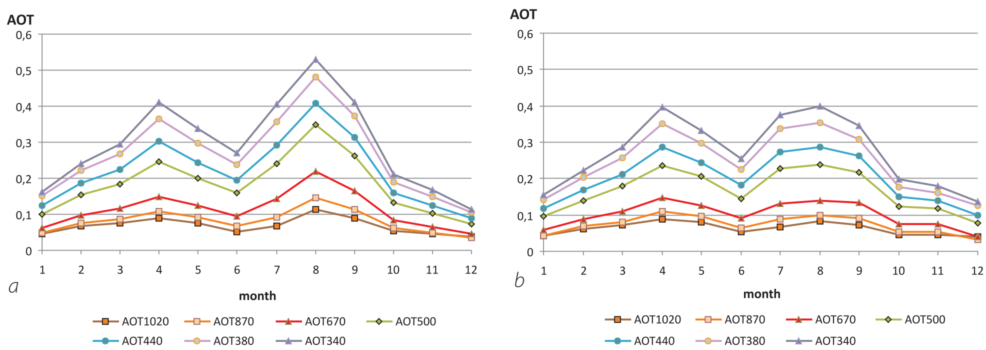


Fig. 3. Seasonal change of mean (*a*) and median (*b*) values of spectral aerosol optical thickness AOT in Moscow for the 2001–2010 period

characterized by lognormal distribution with positive asymmetry for most of the months the median estimates shown in Fig. 3, *b* are more robust. The deviation from normal AOT distribution was also shown in other geographical regions [O'Neill et al. 2000].

In order to characterize spectral AOT dependence we use the Angstrom wave exponent, which can change from zero (for very large, mainly, cloud particles) to 4 (for extremely small aerosol particles with radii much less than the wavelength). Note that this parameter is used only as a first proxy for characterizing particle size distribution, however, since this characteristics can be obtained only via direct Sun measurements we have much more statistics on this parameter than that for volume size distribution retrieved by inverse method. Fig. 4 shows seasonal changes in Angstrom exponent within 440–870nm and in water vapor content W. The values of the Angstrom exponent significantly differ from the value $\alpha = 1$ adopted for continental model [WMO WCRP, 1986]. The joint analysis of Table 2, Fig. 3 and Fig. 4 with seasonal changes in AOT, in Angstrom exponent, and in water vapor content has revealed some interesting features. One can see the existence of the pronounced changes in AOT from month to month with a tendency to increasing AOT towards warm period from less than 0.1 in December to higher than 0.25 in August (median values, see Fig. 3, b). There is also a distinct tendency of Angstrom exponent increase towards warm period from less than 1.4 to more than 1.7. Similar increase in Angstrom exponent (with lower limits

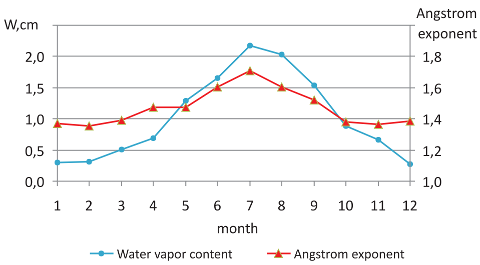


Fig. 4. Seasonal change in Angstrom exponent and water vapor content W. Moscow, the 2001–2010 period

both in summer and in winter) is observed for the Siberian area [Sakerin et al., 2005]. Fig. 4 also shows the changes in water vapor content W which are mainly correspond to air temperature variations. Seasonal AOT changes are characterized by a distinct minimum in May-June and two maxima in April and in August. On average, relative changes from maximum to minimum AOT's are about 4.8 and 3.4 respectively for average and median monthly mean values. For Angstrom parameter the range is about 1.27 and for water vapor content it is close to 8.

The joint analysis of aerosol seasonal parameters with the NCEP CPC CAMS_OPI data from the IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu/res) shows the possible explanation of the observed aerosol changes over the central part of European plane. In winter (December-January) due to strong westerlies and low temperatures the AOT's, Angstrom exponent and water vapor content are the lowest ones. The Angstrom exponent is low (below 1.4) due to possibly relative increase in sea-salt coarse mode particles. However, this can change during the Arctic advection with the prevalence of much smaller particles which sometimes causes relatively high α values (for example 14.01.2003 with $\alpha = 1.94$ in conditions with strong advection from north-west). In February, the increase in AOT in Moscow corresponds well with the ubiquitous increase in the aerosol optical thickness over almost all Europe, except northern areas higher 58°N [Chubarova, 2009]. Central and Eastern Europe are located on the western periphery of Asian anticyclone with low precipitation and favorable conditions for accumulating the aerosol particles. Changes in water vapor content relate mainly to the changes in temperatures, so we have a distinct W growth towards warm period.

In spring (March-April) there is a similar type of atmospheric circulation over Eastern Europe with domination of south-eastern winds from the steppe and desert areas, which is characterized by the lack of precipitation. The beginning of agricultural activity,

Table 2. Several statistics of AOT500, water vapor content and Angstrom exponent for the 2001–2010 period. Monthly mean value, mean variation coefficient, mean minimum and maximum and mean day number

Month	Day number	AOT_500				Water vapor content (cm)				440–870Angstrom			
	Mean N	Mean	Mean Cv,%	Mean Min	Mean Max	Mean	Mean Cv,%	Mean Min	Mean Max	Mean	Mean Cv,%	Mean Min	Mean Max
1	3.3	0.101	44.325	0.049	0.166	0.295	33.133	0.188	0.416	1.370	13.947	1.046	1.664
2	7.2	0.153	40.783	0.053	0.324	0.317	34.191	0.185	0.534	1.354	20.882	0.775	1.765
3	11.9	0.185	61.122	0.050	0.507	0.511	32.136	0.246	0.890	1.391	19.026	0.678	1.813
4	15.7	0.245	61.376	0.071	0.717	0.693	37.747	0.277	1.286	1.474	15.289	0.800	1.875
5	17.8	0.201	54.289	0.063	0.553	1.289	33.549	0.561	2.333	1.474	16.012	0.793	1.897
6	17.7	0.159	49.050	0.057	0.451	1.657	28.761	0.831	2.738	1.606	12.359	0.811	1.988
7	22.3	0.242	53.236	0.063	0.932	2.174	22.102	1.092	3.261	1.711	7.598	0.925	2.029
8	19.1	0.348	60.476	0.058	1.130	2.035	24.021	1.063	3.158	1.605	11.023	0.827	1.937
9	15.1	0.263	59.668	0.052	0.739	1.542	31.370	0.729	2.527	1.520	14.715	0.774	1.873
10	6.5	0.131	36.398	0.052	0.267	0.884	31.308	0.545	1.423	1.379	10.314	0.935	1.682
11	2.9	0.102	24.086	0.062	0.183	0.663	25.412	0.463	0.840	1.366	14.947	1.087	1.596
12	1.6	0.072	14.188	0.058	0.088	0.272	18.524	0.230	0.321	1.386	1.515	1.255	1.458
Year		0.184	46.583	0.057	0.505	1.028	29.355	0.534	1.644	1.470	13.136	0.892	1.798

accompanied usually by the prescribed fires, also creates additional source of fine-mode aerosol (difference in fine mode volume concentration (VolCon-fine) comprises +0.01 $\mu m^3/\mu m^2$) with some decrease in effective radius $r_{eff\text{-}fine}$ from 0.18 to 0.14 μm. In addition, there is an increase in volume concentration of coarse mode particle (difference in VolCon-coarse = +0.026 $\mu m^3/\mu m^2$), which is also accompanied by the decrease in $r_{eff\text{-}coarse}$ from 2.5 to 2.2 µm.

In May there are pronounced changes in the circulation processes over Europe with amplifying the Azore anticyclone and spreading its wedges over the Mediterranean area. At the same time, the aerosol loading over Central and Eastern Europe reduces due to the increase in precipitation, the domination of northern air advection from Scandinavian regions and more intensive uptake of aerosol by grass and leaves. In June further increase of precipitation over the northern Eastern Europe and ceasing the air advection from the south are responsible for distinct local minimum in aerosol optical thickness over the vast territory to the north of 45°N and to the east of 15°E [Chubarova, 2009]. In addition, this local AOT minimum can be attributed to comparatively high water store in soil and vegetation, which can also prevent active mineral dust aerosol formation. In July aerosol optical thickness as well as Angstrom exponent increase due to the additional generation of aerosol fine mode particles from anthropogenic emissions in conditions of high photolysis rates and elevated temperatures in the absence of wet removal of aerosol from the atmosphere. The AOT maximum in August is explained by the effects of forest fires in 2002 and 2010, which have led to extremely high aerosol loading. Excluding these two years from the sample has changed the August AOT to approximately the AOT in July (AOT~0.22 in visible region of spectrum). So the forest fires can be responsible for 1.5 times increase in monthly mean AOT values.

In September lower temperatures and photolysis rates as well as the intensification of westerlies should decrease the aerosol loading. However, relatively high AOT level is also explained by the effects of fires in 2002 and its removing significantly decrease the AOT level by more than 30%. In October-November further cleaning of the atmosphere is observed due to prevailing westerlies, which is consistent with the attenuation of the Angstrom exponent values over the vast area with a distinct tendency to decreasing towards the Atlantic Ocean [Chubarova, 2009].

Fig. 5 demonstrates 3D picture with seasonal and year-to year variations of AOT at 500 nm. One can see high variability in year-to-year AOT changes, some common features of decreasing AOT towards winter in different years can be also observed. There are pronounced maxima in August-September 2002 and in August 2010 during severe fire events. We had an extremely high monthly mean AOT maximum in 2010, which exceed 1.1 (more than 3 times higher than the mean value AOT500 = 0.348). However, in 2002 the period of elevated AOT values was much longer and lasted from the very end of July to the middle of September. The absolute AOT maximum was observed on August, 7th, when AOT500 reached approximately 5! This was one and a half time larger than the absolute maximum observed during the previous mega-fire event in 2002. However, due to the change in atmospheric circulation at the end of August and advection of very clean air from the western regions, the AOT dropped to 0.06 on August 20, 2010.

Another important radiative characteristics of aerosol – an asymmetry factor of the aerosol phase function (g) and aerosol single scattering albedo (SSA) – can be obtained from AERONET inversion algorithm using a combination of direct and diffuse radiance measurements. They are defined according to the following equations:

$$g_\lambda = \frac{\int_{-1}^{1} \cos\theta \cdot P(\theta) d(\cos\theta)}{\int_{-1}^{1} P(\theta) d(\cos\theta)} \qquad (1)$$

where θ is the scattering angle, $P(\theta)$ is the aerosol phase function;

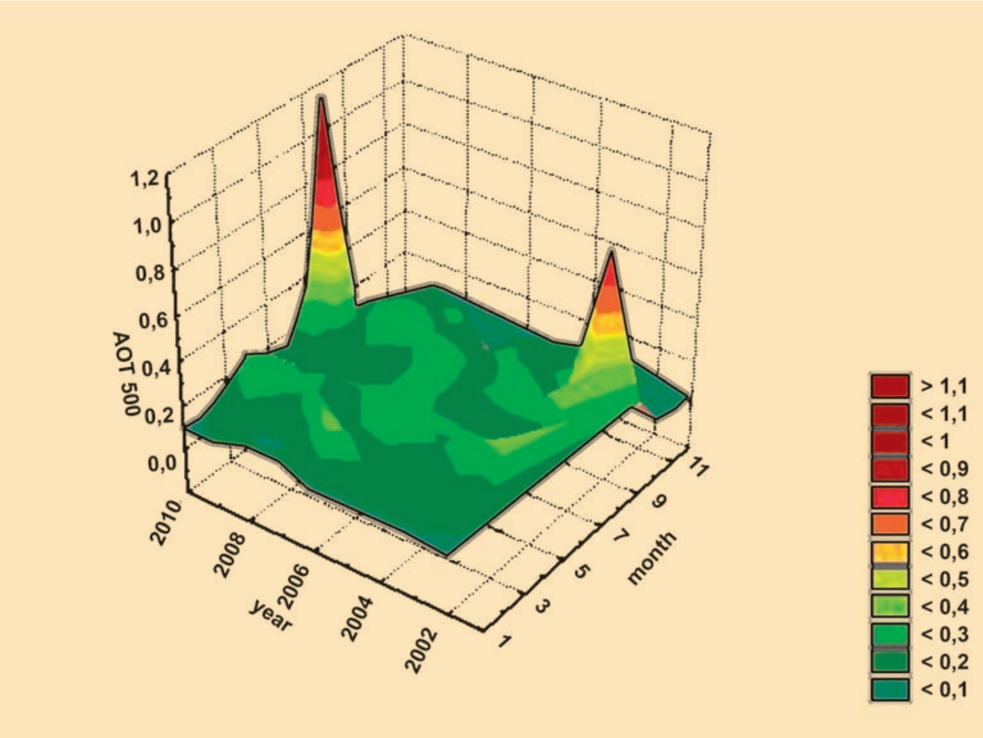


Fig. 5. Variations of monthly mean AOT500 values during the 2001–2010 period of observations

$$SSA_\lambda = \frac{\sigma_\lambda}{\alpha_\lambda} \qquad (2)$$

where α_λ -extinction coefficient (1/c) σ_λ – scattering coefficient (1/cm).

According to the equations the *g* and *SSA* parameters are dimensionless and can change from zero to 1. The asymmetry factor characterizes the shape of phase function and is close to 1 when the size of particles is much higher than wavelength and aerosol phase function has a distinct forward peak of scattering. For example, for visible spectral range this can be observed for large cloud particles (r_{eff} = 7–8 μm). SSA values are close to 1 when the absorption is close to zero and the attenuation is observed only due to scattering processes. The statistics of SSA and factor of asymmetry at 675nm over the whole period of measurements in Moscow are shown in Table 1. Fig. 6 presents the spectral dependence of aerosol asymmetry factor and single scattering albedo. The aerosol asymmetry factor decreases within

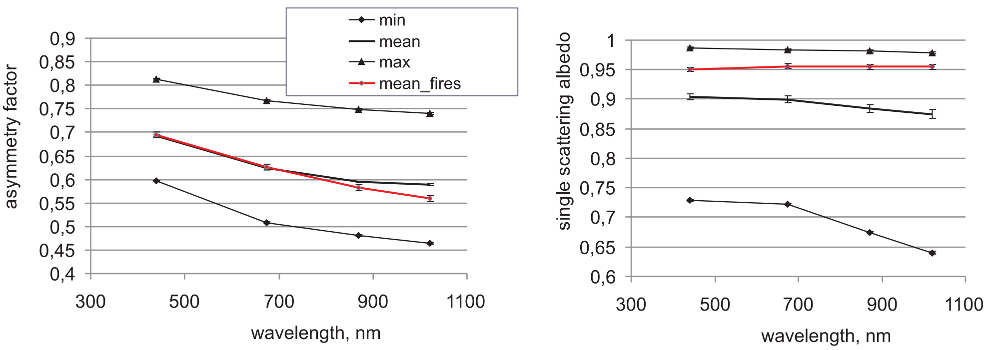


Fig. 6. Spectral dependence of asymmetry factor (a) and single scattering albedo (b)

the 440–1020 nm from 0.69 to 0.59 with decreasing of r_{eff}/λ ratio in accordance with the Mie theory. The range of this characteristic depends mainly on the size distribution with higher values at larger effective radii. In addition, Fig. 6 also includes the conditions of smoke aerosols. Note, that for the smoke aerosol conditions the asymmetry factor is similar to the values observed in typical situations.

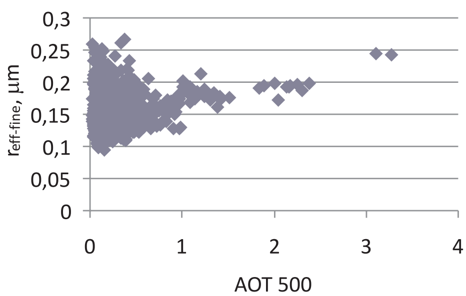
Single scattering albedo decreases from 0.9 to 0.87 within the 440–1020 nm spectral interval. These values are in agreement with the typical continental aerosol SSA values [WMO, WCRP, 1987]. We should mention that urban conditions provide some additional decrease in SSA [Chubarova et al., 2011]. However, this decrease is observed only for small AOT and comprises only 0.02. Quite different values of single scattering albedo have the smoke aerosol. Due to smaller values of imaginary part of refractive index and the prevalence of fine aerosol mode, smoke aerosol has noticeably higher values (SSA ~ 0.95) and is characterized by less spectral dependence. This is also in agreement with the previous results obtained for smouldering fires in Africa and Brasilia [Dubovik et al., 2002, Eck, et al., 2003].

Interaction between microphysical, optical and radiative aerosol properties

One can see some interesting features if compare the relationship of some microphysical, optical, and radiative aerosol properties in real atmospheric conditions. Fig. 7, *a*, *b* shows the dependence of effective radii of fine and coarse mode as a function of aerosol optical thickness at 500nm. We should mention that high AOT500 (AOT500 > 0.8) were observed in situations with forest fires. One can see a significant drop in r_{eff} variation for AOT500 > 0.8 with a tendency to increasing the fine mode effective radii from 0.18 to 0.25 μm and decreasing coarse mode radii towards higher AOT500 from 2.8 to 2.5 μm. At smaller AOT we have an extremely high r_{eff} variation from 0.1 to $r_{eff-fine}$ = 0.26 μm and from 1 to $r_{eff-fine}$ = 3.7 μm at small AOT < 0.15. This happen possibly due to different types and properties of aerosol that can depend on specific type of aerosol. The explanation of this phenomenon should be studied further.

There is also an interesting dependence of different contribution of fine and coarse modes volume concentration to the total volume concentration. Fig. 8 shows the approximately linear dependence of fine mode concentration with AOT while for the coarse mode there is a maximum at AOT less 0.4. The volume concentration of coarse mode has a maximum of about 20% for forest fire smoke aerosol while for other situations it can vary within large range from 8 to 90%.

In addition, there is a distinct decrease in deviation both in real and in imaginary part of refractive index with AOT increase (Fig. 9). There is some REFR increase in fire smoke conditions (REFR = 1.49) compared with typical aerosol conditions (REFR = 1.49). Similar higher REFR values were obtained for other fire episodes described in [Dubovik et al., 2002].



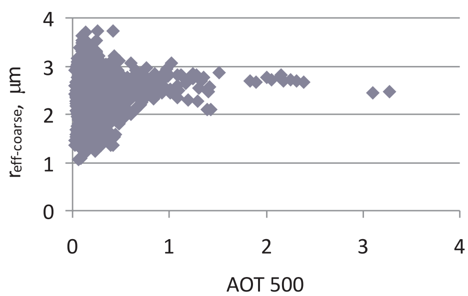


Fig. 7. Aerosol effective radius of fine (a) and coarse (b) mode versus aerosol optical thickness at 500 nm (AOT500)

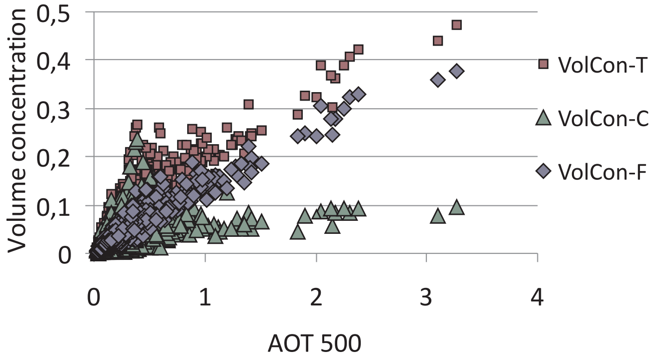


Fig. 8. Volume concentration (µm³/µm²) of fine (VolCon-F), coarse (VolCon-C) modes and total volume concentration (VolCon-T) versus aerosol optical thickness at 500nm (AOT500)

CONCLUSIONS

10 years of continuous aerosol measurements at the MSU MO within the international AERONET program allows us to characterize the different aerosol properties of the atmosphere of the Moscow area.

Several important microphysical and optical characteristics of aerosol have been obtained. Volume aerosol size distribution is characterized by bimodal character with dominating fine mode aerosol particles at effective radius $r_{eff\text{-}fine}$ = 0.15 µm, which is close to modal radius and has a very high deviation. At the same time the smoke aerosol is characterized by effective radius of 0.18–0.25µm increasing towards higher AOT. We have retrieved real and imaginary part of refractive index (REFR = 1.45 ± 0.01, REFI = = 0.01 ± 0.01) for Moscow conditions. Smoke aerosol was shown to have higher REFR (REFR = 1.49) and lower REFI = 0.006 than those values in typical conditions.

Seasonal changes in AOT are characterized by the AOT increase towards warm period with local minimum in June which has been confirmed by our previous results obtained from satellite data for a comparatively large territory and is in agreement with standard actinometrical observations of the transparency characteristics described in [Abakumova and Gorbarenko, 2008]. The joint analysis of aerosol parameters with NOAA_NCEP climatology shows the nature of this effect, which is determined by the change in air advection. The single

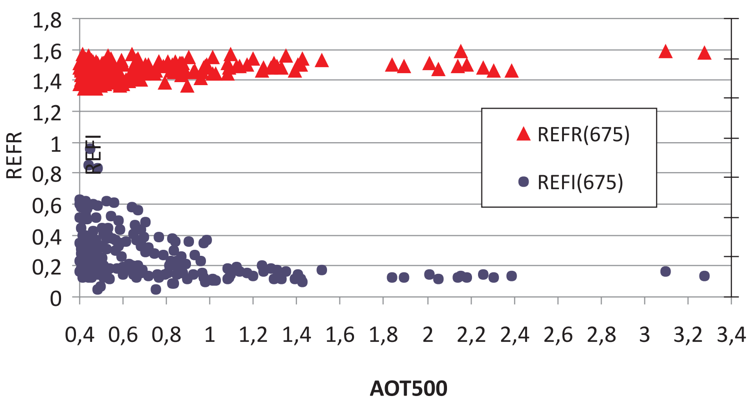


Fig. 9. Real (REFR, left axis)) and imaginary (REFI, right axis) parts of refractive index as a function of aerosol optical thickness at 500nm (AOT500)

scattering albedo was shown to have distinct variations in conditions of typical and of fire smoke aerosol. However, the asymmetry factor does not significantly change for these aerosol types within the range of 440–1020 nm.

Some interactions between volume concentrations of different aerosol fractions were obtained with a distinct decrease in deviation towards larger AOT values.

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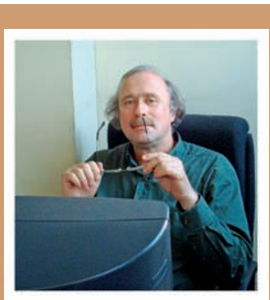

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DISTRIBUTION OF RIVER RUNOFF AND ITS CLIMATE FACTORS IN AVERAGE AND EXTREME YEARS

ABSTRACT

Schematic maps of spatial distribution of seasonal precipitation amounts and average air temperatures were obtained for the areas studied in years with normal and extreme values of annual river runoff. Data on precipitation for January-December (I–XII) and on average air temperatures for June-September (VI-IX) during 1961–1990 collected at 93 meteorological stations located along 30.20–44.08°N and 67.20–82.98°E, altitude 122–4169 m above sea level, were used in the maps' compilation. For each point-element (i.e. a meteorological station with proper data), the ordinates of an integral empirical function of distribution of probabilities P were calculated from these data for a 30-year sample period and for each year were received average values and standard deviations of P. In characteristic years were revealed, significant differences of spatial distribution of climatic factors and runoff. It was found out also that the spatial distribution of the total volume of glaciers melting is less variable in the years with extreme water yields compared to the average years. This peculiarity is very beneficial for hydropower and agriculture sectors because it provides additional natural ability to stabilize water balance of reservoirs. Piecewise multi-factor linear equations were obtained to calculate the statistical probability of glaciers' total melting in low and high flow years as a function of geographical coordinates and the average altitude of firn boundary.

KEY WORDS: river runoff, Central Asia, spatial distribution, precipitation, air temperature, extremes, glaciers melting

THE RESEARCH PROBLEM AND OBJECTIVES

Spatial and temporal variability of river runoff and its climatic factors (i.e., precipitation, air temperature, etc.) play a significant role in understanding of past, current, and future environmental conditions. It is especially true in extreme cases, such as low-water or high-water years that influence strongly water management and consumption and the needs of the population. The essence of the problem may be easily seen after calculating the correlation matrix for river runoff in different watersheds within a certain region. Such matrix describes spatial change of correlation independently from the distance between watersheds and other hydrographic parameters. A matrix obtained for some time interval reflects average conditions of runoff formation in different river basins. It is an essential but limited characteristic. More important is studying: (a) regional homogeneity of climate fields and (b) spatial variability of climate factors in years with extreme and normal volumes of runoff. These were the main objectives of our work. Regular or standard data measurement of precipitation and air temperature at the regional meteorological network were used for the tasks (a–b). Analysis of spatial variability of river runoff, glacier runoff, and their climate factors have to be done in a common system of units. This was achieved by transforming all studied variables into ordinates of integral distribution of probabilities *P* for the corresponding function *X*, i.e. $P(X) = 1 - F(X > x)$.

THE RESEARCH AREA AND BACKGROUND DATA

The studied region is located within of a closed basin of the Aral Sea and includes the Syr Darya, Amu Darya, Tedjen, and Murgab rivers' watersheds. It also incorporates a number of smaller rivers draining the western part of Tien Shan. With regard to administrative divisions, the region embraces the entire areas of Uzbekistan, Tajikistan, Kirghizstan, and parts of northern Afghanistan. The region belongs to the Central Asian territory with the total area of 1765.9 thousands km^2 and 41.686 millions population (Data of 1996). The territory receives considerably more solar energy than any other part of the former USSR. Temperatures during remarkably long summer are high (the average temperature in July is 25–33°C). On the plains of the Aral region, annual precipitation is 90–120 mm. In the piedmont areas, it is 400–500 mm, while it is over 2000 mm on the western slopes of Tien-Shan.

Hydrology

The rivers Syr Darya and Amu Darya are the principal water sources of the Aral Sea. The areas of these rivers' basins are 692.3 and 493.0 thousands km^2, respectively. The surface water resources of the region also include the runoff of the blind drainage rivers Kashka Darya, Zarafshan, Murgab, Tedjen, Chu, Talas, and other smaller rivers flowing within the territory of the former USSR and of the rivers flowing from Afghanistan. The long-time average river runoff is about 116-120 km^3 per year. The primary source of all rivers in the Aral Sea drainage basin is mostly snow/glacier runoff. The runoff formation area is about 25% of the Aral Sea basin. Eighty percent of this area is located in the Amu Darya and Syr Darya river basins. Their runoff formation zones can be estimated at approximately 200 thousands km^2 for Amu Darya and 160 thousands km^2 for Syr Darya. The Amu Darya, a product of the confluence of the Piandj and Vakhsh rivers, is 1,445 km long. The main part of its water resources (72.8%) forms on the territory of Tajikistan and the rest comes from the Afghanistan and Iran (14.6%) and the Uzbekistan (8.5%) territories. Low-water periods of the Amu Darya occur every 4-5 years and high-water periods occur every 6–10 years. The Syr Darya is the longest river in Central Asia (2,790 km). Its average annual runoff is 40.8 km^3.The low-water period is October-March, while the highest water discharge is in June-July. The low-water periods occur every 3–4 years and last 5–6 years. The annual and seasonal runoff of the basins Amu Darya and Syr Darya has multiyear variations. For example, the annual runoff in the Amu Darya basin in 1969, the high-water year, was about 110 km^3. In the low-water year of 1974, it was about 65 km^3. In the Syr Darya basin, in the same high-water year of 1969, the annual runoff was about 70 km^3, and in the low-water year of 1983, it was about 20 km^3. The Aral region has considerable ground water resources. At present, the ground water discharge is 14.7 km^3/yr. The annual water intake in the Aral Sea basin is 117.7 km^3 and irrigation consumes over 90% of this volume.

Hydrometeorological network

The National Hydrometeorological Services of the Central Asia's states carry out collection of operational information on many characteristics of environment including river runoff and climate. The additional source of hydrological data is observations in the network, conducted by the Ministry of Melioration and Water Economy. The longest range of data exceeds 100 years. Like in many other countries, the structure of network, a number of points, methods and technique of measurements are not stable during of 20th century and later. The distribution of sites for measurement of precipitation and air temperature within the Syr Darya and Amu Darya river basins and adjacent territories are shown on Fig. 1.

The highest number of network measurements in the Aral Sea basin was reached by 1985 (Table 1). Since that, there began a constant reduction of the number of observational sites [Chub, 2000].

The time interval 1961–1990 was chosen for our analysis on spatial variability of seasonal (April-September) river runoff, annual precipitation, and mean seasonal values (June-September) of air temperature. The main sources for the data on runoff were [Bodo, 2000] and [Main Hydrological Characteristics 1967–1980]. Minimal and maximal parameters of the watersheds in the sample used are related to the very different conditions of river runoff formation. Thus, the geographical coordinates of the

Table 1. Hydrometeorological network in Central Asia

Measurement types	Number (N), percentage, and density of measurement points				
	years				
	1975	1980	1985	1990	1995
(a) runoff (N)	412	505	530	478	366
(b) suspended sediments (N)	181	270	291	245	108
(c) water level (N)	453	540	558	486	397
(a) relative to 1985 (%)	77.7	95.3	100.0	90.2	69.1
(b) relative to 1985 (%)	62.2	92.8	100.0	84.2	37.1
(c) relative to 1985 (%)	81.2	96.8	100.0	87.1	71.1
density of (a) per 1000 km^2	1.306	1.310	1.313	1.316	1.320
density of (b) per 1000 km^2	0.273	0.334	0.351	0.316	0.242
density of (c) per 1000 km^2	0.120	0.179	0.192	0.162	0.071
(d) precipitation (N)	355	365	361	331	282
(e) air temperature (N)	333	341	335	312	273
(f) soil surface temperature (N)	302	312	306	283	248
(g) vapor pressure (N)	303	313	307	284	248
(h) snow cover (N)	348	354	350	324	255
(d) relative to 1985 (%)	98.3	101.1	100.0	91.7	78.1
(e) relative to 1985 (%)	99.4	101.8	100.0	93.1	81.5
(f) relative to 1985 (%)	98.7	102.0	100.0	92.5	81.0
(g) relative to 1985 (%)	98.7	102.0	100.0	92.5	80.8
(h) relative to 1985 (%)	99.4	101.1	100.0	92.6	72.9
density of (d) per 1000 km^2	0.235	0.241	0.239	0.219	0.187
density of (e) per 1000 km^2	0.220	0.226	0.222	0.206	0.181
density of (f) per 1000 km^2	0.200	0.206	0.202	0.187	0.164
density of (g) per 1000 km^2	0.200	0.207	0.203	0.188	0.164
density of (h) per 1000 km^2	0.230	0.234	0.231	0.214	0.169

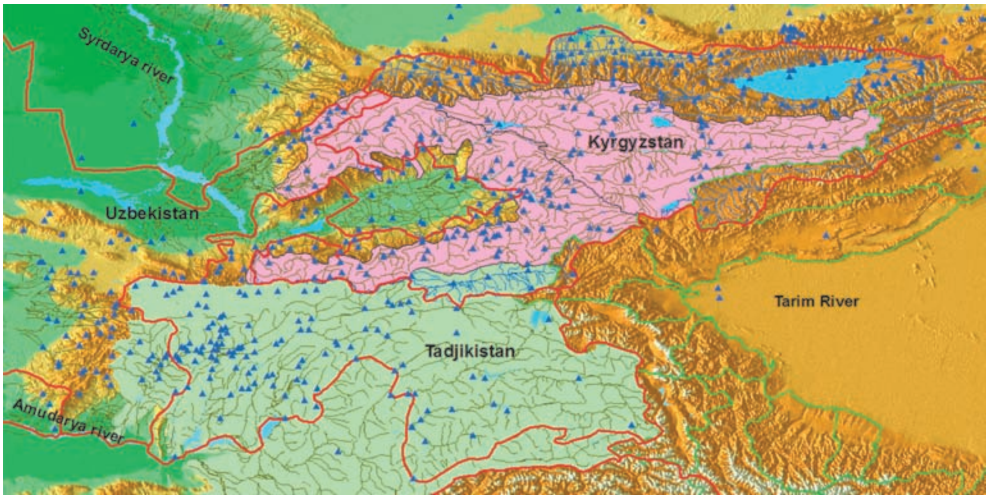

Fig. 1. Points of observation on precipitation and air temperature (blue triangles), red lines – state boundaries. Pink color – the Syr Darya River basin, light green – the Amu Darya River basin

hydrological stations are between 37.20–41.80°N and 66.00–74.00°E, and their elevations vary from 327 m to 3,576 m above sea level (a.s.l.). Most of the hydrological stations located in sub-mountain and high-mountain areas provide the data on runoff not distorted by water management. The area of the watersheds varies from 362 km^2 to 113 thousands km^2, and their mean weighted altitude varies from 1.80 km to 4.20 km above sea level. As climate factors for river runoff, we used precipitation for January-December (here and further this season is abbreviated as I-XII) and the average air temperature for June-September (abbreviated as VI–IX) during 1961–1990 at 93 meteorological stations located along 30.20–44.08°N, 67.20–82.98°E at altitudes of 122–4,169 m a.s.l. The sources of the data were [Former Soviet Union Monthly Precipitation Archive, 1891–1993; Global Historical Climatological Network Database, GHCN, Version 2; Williams, and Konovalov, 2008].

SPATIAL HOMOGENEITY OF AIR TEMPERATURE AND PRECIPITATION

A well-known feature of the Central Asian natural environment, i.e. vertical zonation of landscapes and climate characteristics complicated by latitudinal differences and local peculiarities [Balashova, et al, 1960; Muminov and Inagamova, 1995; Murzaev, 1958], was used to address the research objectives. Let us consider as homogeneous such samples of air temperature *T* and precipitation *Pr* that present objectively the features mentioned above. The coefficient of determination (R^2) for the multifactor equations of linear regression *T* = *T*(Long, Lat, Alt) and *Pr* = *Pr*(Long, Lat, Alt) was adopted as the criterion of spatial homogeneity. Furthermore, these equations were applied to determine spatial variability of norms of the mean monthly air temperature during January-December and the total yearly precipitation. The time interval 1961–1990 was used as a reference period. Here: Long (longitude) and Lat (latitude) – are geographical coordinates of the measurement points and Alt – is their altitude a.s.l.

The samples of 179 meteorological stations for air temperature and 215 meteorological stations for precipitation were selected for determination parameters of regression equations. The contribution of each independent variable for describing variances of the functions *T* = *T*(Long, Lat, Alt) and *Pr* = *Pr*(Long, Lat, Alt) was calculated by formula (1) from [Alexeev, 1971].

$$\beta_j = \frac{|r_{0j}\alpha_{0j}|}{|r_{01}\alpha_{01}| + |r_{02}\alpha_{02}| + |r_{03}\alpha_{03}|}, \qquad (1)$$

where

$$\beta_1 + \beta_2 + \beta_3 = 1. \qquad (2)$$

Table 2. Statistical characteristics of equation $T = T$(Long, Lat, Alt)

Index	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
R^2	0.70	0.75	0.84	0.93	0.97	0.97	0.95	0.93	0.91	0.88	0.82	0.73
β_1(Long),%	6.5	3.2	1.0	2.7	0.8	0.3	2.4	3.1	2.4	0.6	5.0	7.4
β_2(Lat),%	36.3	41.1	27.3	8,1	2.0	1.9	2.1	4.3	7.4	16.6	23.1	30.9
β_3(Alt),%	57.2	55.7	71.7	89.3	97.2	97.7	95.6	92.6	90.2	82.8	71.9	61.8

Note: R^2 – the coefficient of determination (the explained part of variance of dependent variable for the regional equations $T = T$(Long, Lat, Alt); T – mean monthly air temperature, β_1(Long), β_2(Lat), β_3(Alt) – are monthly contributions of longitude, latitude, and altitude in R^2 of multifactor equations $T = T$ (Long, Lat, Alt)

Here, r_{0j} are the coefficients of correlation of the function with each argument and α_{0j} are the coefficients of the normalized multifactor linear regression. Table 2 contains estimations of homogeneity for air temperature in the selected sample of data.

The coefficients of determination in Table 2 show that linear equation $T = T$(Long, Lat, Alt) describes, in 9 cases out of 12, more than 80% of spatial variability of the mean monthly air temperature in the Central Asia region. Moreover, the value of R^2 is $\geqslant$ 0.93 during April-August. The characteristics obtained for equation $T = T$(Long, Lat, Alt) fully correspond to the seasonal conditions of formation of the air temperature field within Central Asia [Balashova et al, 1960]. The main factor in the spring-summer period here is powerful local warming from solar radiation at the local scale and practical absence of latitudinal gradients. Arctic intrusions together with southern cyclones play an essential role during October-March; their influence specifies the latitudinal differentiation of the air temperature field. Equation $T = T$(Long, Lat, Alt) adequately describes these processes. Thus, the field of mean monthly air temperature in May-September at all altitudes should be considered as rather homogeneous inside the Central Asia region.

The analogous analysis for the general formula of precipitation, i.e. $Pr = Pr$(Long, Lat, Alt) showed that its coefficient of determination was only 0.23 and the contributions of longitude, latitude, and altitude were 27.8%, 3.6%, and 68%, respectively. This confirms, once more, significant spatial variability of even mean annual precipitation and inefficiency of the regional empirical formula in the form of a linear function of geographical coordinates and altitude. The search for local dependences for precipitation as a function of altitude and geographical coordinates revealed better estimations of homogeneity and representativeness for initial information. Coefficients of determination for the equation $Pr = Pr$(Long, Lat, Alt) calculated separately for the Chirchik, Naryn, and Zeravshan river basins equaled 0.70, 0.87 and 0.94, respectively. Many examples of similar dependences of satisfactory quality for the Amu Darya and Syr Darya river basins could be found in [Resources…, 1969, 1971].

SPATIAL VARIABILITY OF RIVER RUNOFF AND ITS CLIMATE FACTORS

In hydrological computations, the empirical probabilities of exceeding $X > x_i$ is determined by a rather simply and known procedure [Alexeev, 1971]:

$$p_i(x_i) = \frac{m(x_i) - 0,25}{N_i + 0,5} \cdot 100, \qquad (3)$$

where $m(x_i) = 1, 2, ..., N_i$ are ordinal numbers of the x_i values after their disposition in the descending order.

All temporal ranges of R_{IV-IX} – seasonal runoff for April-September on the selected

Table 3. Parameters of seasonal river runoff within the Amu Darya and Syr Darya watersheds

Index	Probability of R_{IV-IX} in characteristic years and their standard deviation SD		
	1969 – max (high-water)	1974 – min (low-water)	1985 – normal
Mean (%)	11.33	88.19	52.31
Limits (%)	2.46–48.36	61.48–97.54	12.30–84.43
SD	13.95	9.49	17.51

33 hydrological stations in 1961–1990 were processed according to the formula (3). Then, we determined $P(R_{IV-IX})$ which is the mean probability for the 33 values in each year. Years when 15% ⩾ $P(R_{IV-IX})$ ⩾ 85% were subsumed to extreme; and when 45% ⩽ $P(R_{IV-IX})$ ⩽ 55% they were considered as normal or average**.** Table 3 presents the results of identification of average and extreme years and their statistical parameters. Fig. 2, *a*, *b* illustrates

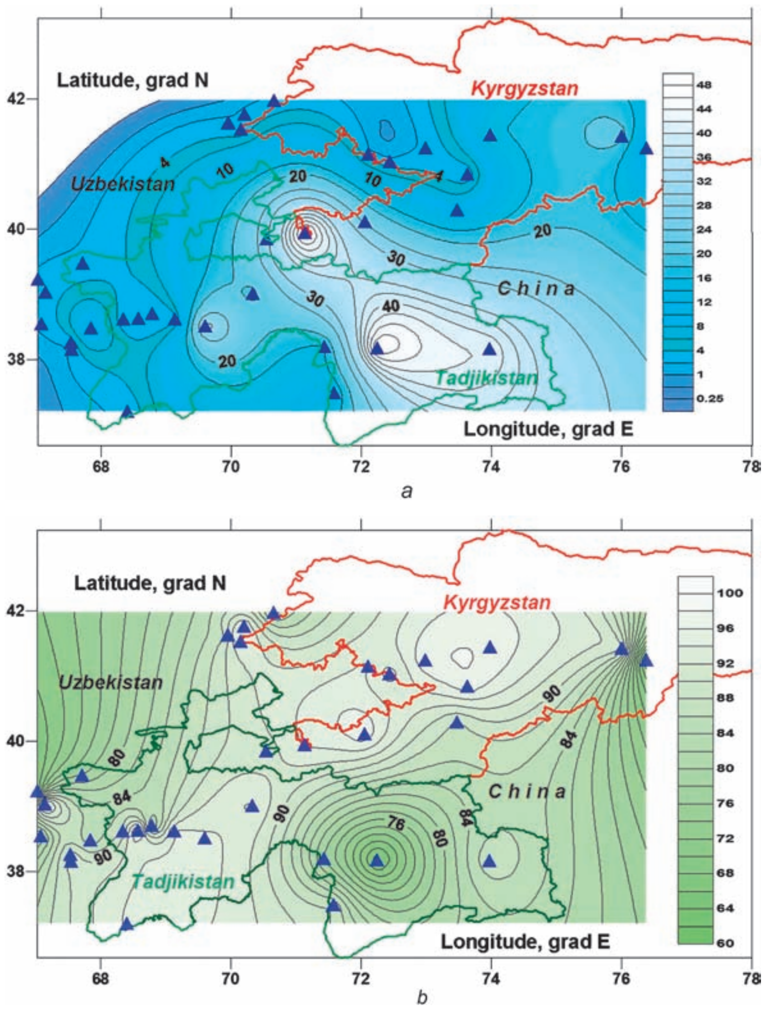

Fig. 2. The spatial distribution of seasonal (April-September) river runoff probability within the Amu Darya and Syr Darya watersheds in 1969 – high-water (*a*) and in 1974 – low-water (*b*) years. Blue triangles are the hydrological stations

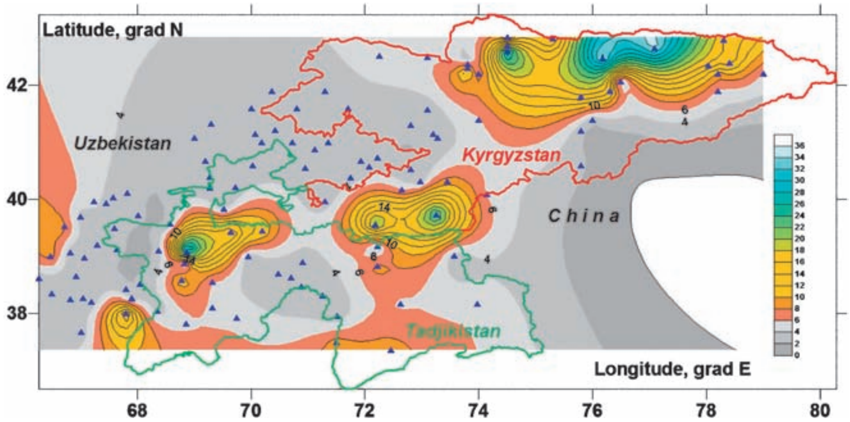

Fig. 3. The spatial distribution of $P(Pr_{I-IX})$ within the Amu Darya and Syr Darya watersheds in high-water year (1969). Average $P(Pr_{I-IX})$ equals 6.14%. Blue triangles are the measurement sites

the spatial distribution of probability of seasonal river runoff within the Amu Darya and Syr Darya watersheds in high-water and low-water years.

For the rivers of the Aral Sea basin, both precipitation and air temperature are used as predictors in order to forecast seasonal and monthly runoff from the upper watersheds. Identification of their role in formation of extreme values of river runoff would help improving methods of hydrological forecasts in critical situations for water users.

Only in 1969 the mean values of probabilities for both runoff – $P(R_{IV-IX})$ and precipitation – $P(Pr_{I-IX})$ could be treated as extremely high, but the same phenomenon is not true for probability of air temperature – $P(T_{VI-IX})$. Below is the example of the regional distribution of extreme precipitation (Fig. 3).

Tables 4–5 contain the probabilities of annual precipitation and seasonal air temperatures and their standard deviation (SD) related to the years that have been previously identified as low, average, and high water based on R_{IV-IX} values (see Table 3). Data in Tables 4–5 are presented as all together (ALL), sorted by Central Asian states (here, KYR – Kyrgyzstan, UZB – Uzbekistan, TAD – Tajikistan), and along altitude Z a.s.l.

In assessing the probabilities of precipitation and air temperatures in the Table 4–5 as climate factors of river flow formation, we may note the following:

- Probabilities of yearly precipitation correspond completely to $P(R_{IV-IX})$ of runoff in high-water, low-water, and normal years. This conclusion is correct not only for the entire territory of the Amu Darya and Syr Darya river basins, but also for its different parts and altitudinal zones. Standard deviation of $P(Pr_{I-IX})$ is significantly less in high-water year compared to low-water and normal years. This feature of precipitation is important for obtaining a generalized estimation of the regional water resources and for improvement of hydrological forecasts and computations.
- Probabilities of seasonal air temperature $P(T_{VI-IX})$ in Table 5 demonstrate the absence of rather evident relationship with seasonal runoff in characteristic years. We may only note a rather cold summer season in the high-water year of 1969. Standard deviation of $P(T_{VI-IX})$ is also significantly less in the high-water year compared to the low-water and normal years.

Thus, in the high-water year, we see rather good synchronism between probabilities of precipitation and runoff, but for the low-water year, the extreme value of the regional mean $P(Pr_{I-IX})$ was in 1971 but not in 1974. Asynchronism between

Table 4. Probabilities (%) of yearly precipitation in the characteristic years of runoff

Data	Index	1969	1974	1985	1969	1974	1985	1969	1974	1985
		$380m \leqslant Z \leqslant 4169m$			$Z \geqslant 2000m$			$Z \geqslant 3000$ m		
ALL	Mean	6.14	67.92	58.37	7.92	58.53	68.03	8.81	58.61	62.30
	Min	2.46	2.46	9.02	2.46	2.46	22.13	2.46	5.74	18.85
	Max	35.25	97.54	97.54	31.97	94.26	97.54	31.97	94.26	94.26
	SD	7.04	26.21	21.94	8.01	28.75	24.28	9.00	31.10	24.61
KYR	Mean	9.09	55.00	63.35	8.70	50.86	80.37	9.02	49.59	77.46
	Min	2.46	2.46	9.02	2.46	2.46	48.36	2.46	5.74	61.48
	Max	35.25	97.54	97.54	28.69	90.98	97.54	25.41	87.70	94.26
	SD	9.15	29.24	20.51	8.35	28.90	16.97	8.76	29.16	13.17
UZB	Mean	3.20	75.56	62.82	2.46	80.33	51.64	–	–	–
	Min	2.46	18.85	22.13	2.46	71.31	31.97	–	–	–
	Max	18.85	97.54	94.26	2.46	87.70	71.31	–	–	–
	SD	2.82	18.60	19.50	0.00	7.27	16.93	–	–	–
TAD	Mean	6.30	75.04	44.40	8.31	63.82	54.22	8.61	67.62	47.13
	Min	2.46	12.30	12.30	2.46	12.30	22.13	2.46	12.30	18.85
	Max	31.97	97.54	90.98	31.97	94.26	97.54	31.97	94.26	90.98
	SD	6.38	24.87	22.12	8.35	29.11	26.08	9.83	32.19	24.47

Table 5. Probabilities (%) of air temperatures for VI-IX in the characteristic years of runoff

Data	Index	1969	1974	1985	1969	1974	1985	1969	1974	1985
		380 m $\leqslant Z \leqslant 4169$ m			$Z \geqslant 2000$ m			$Z \geqslant 3000$ m		
ALL	mean	85.74	76.55	34.07	81.64	77.95	31.72	77.66	81.35	33.40
	Min	48.36	9.02	5.74	48.36	9.02	12.30	61.48	12.30	18.85
	Max	97.54	94.26	68.03	97.54	94.26	68.03	90.98	94.26	68.03
	SD	10.18	17.01	13.21	10.72	20.53	10.46	9.46	18.95	12.50
KYR	mean	85.40	70.34	29.13	82.95	73.28	31.48	81.56	84.02	34.84
	Min	48.36	9.02	12.30	48.36	9.02	12.30	74.59	77.87	18.85
	Max	97.54	94.26	68.03	97.54	94.26	68.03	90.98	94.26	68.03
	SD	9.55	19.70	10.52	11.48	21.02	12.33	5.93	5.38	16.39
UZB	mean	93.53	85.88	47.81	90.16	85.25	42.62	–	–	–
	Min	84.43	81.15	22.13	84.43	81.15	38.52	–	–	–
	Max	97.54	90.98	64.75	94.26	87.70	45.08	–	–	–
	SD	3.65	2.31	11.43	4.92	3.14	3.14	–	–	–
TAD	mean	82.30	78.22	32.32	77.87	81.97	29.30	73.77	78.69	31.97
	Min	48.36	12.30	5.74	61.48	12.30	18.85	61.48	12.30	18.85
	Max	97.54	94.26	68.03	94.26	94.26	45.08	90.98	90.98	45.08
	SD	11.04	15.95	12.09	9.50	21.76	7.21	11.05	26.91	7.84

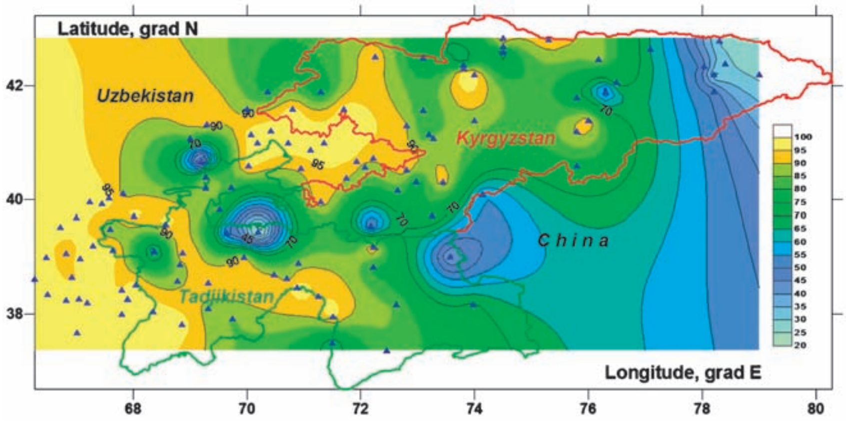

Fig. 4. Spatial distribution of $P(Pr_{I-IX})$ within the Amu Darya and Syr Darya watersheds in 1971 with minimal mean values of precipitation. Average P(PrI–IX) equals 83.29%. This year was defined as extreme in the sample of $P(Pr_{I-IX})$ irrespective of runoff

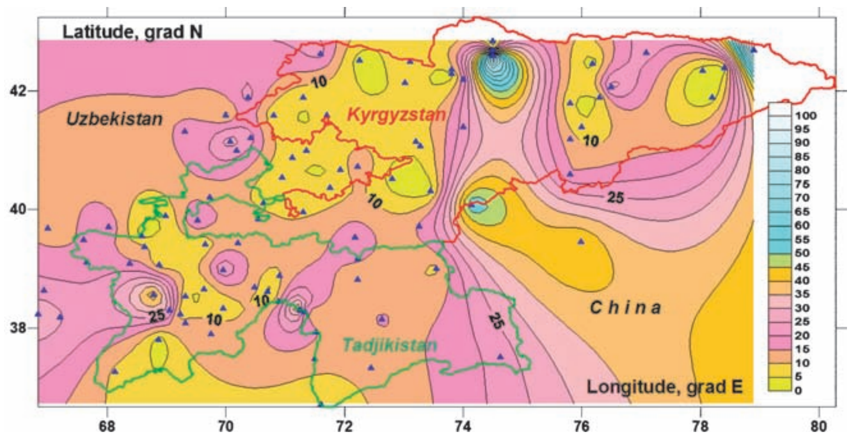

Fig. 5. Spatial distribution of $P(T_{VI-IX})$ inside the Amu Darya and Syr Darya watersheds in 1990 with maximal mean value of air temperature. Average $P(T_{VI-IX})$ equals 15.0%. This year was defined as extreme in the sample of $P(T_{VI-IX})$ irrespective of runoff

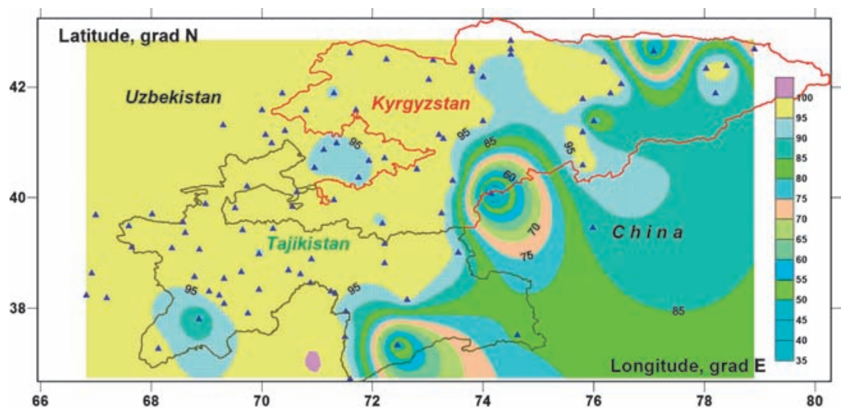

Fig. 6. Spatial distribution of $P(T_{VI-IX})$ in the Amu Darya and Syr Darya watersheds in the 1972 year with minimal air temperature. The average $P(T_{VI-IX})$ equals 94.8%. This year was defined as extreme in the sample of $P(T_{VI-IX})$ irrespective of runoff

the extreme and normal years for runoff and air temperature was identified after calculating $P(T_{vi\text{-}ix})$ independently from $P(R_{IV-IX})$ of runoff in the Table 3. Spatial distribution of $P(T_{VI-IX})$ in the extreme years is shown on Figs. 5, 6.

TOTAL MELTING OF GLACIERS UPSTREAM OF THE AMU DARYA RIVER BASIN

The headwaters of the Amu Darya river basin contains several thousands glaciers [Inventory..., 1971–1978]. These glaciers were regionalized into 138 quasi-homogeneous groups for computing the total volume V_M of their melting, where V_M is the function of meteorological variables and empirical parameters. Each group is characterized by: geographical coordinates; areas of glaciers and solid moraine; altitudinal distribution of area; altitudes of glacier head, terminus and firn boundary; upper limit of solid moraine cover; depth of solid moraine at the end of glacier; and slope and azimuth of glacier surface.

A model, REGMOD, developed as a set of computer programs and data on climate variables [Konovalov 1985, 2006] was used to calculate long-term series of hydrological regime of glaciation. In the model, the formula for determination of total volume of glacier melting v_m in the moment t, has the form:

$$v_m(t) = M_c(\tilde{z}_{im}, t)S_{im} + M(\tilde{z}_i, t)S_i + + M(\tilde{z}_f, t)S_f + M(\tilde{z}_{ws}, t)S_{ws} + M(\tilde{z}_{ss}, t)S_{ss}. \quad (4)$$

Here, M is intensity of melting for open ice or snow, $M_c = Mf(h_c)$ is intensity of ice melting under cover of solid moraine (im) of depth h_c, i is bare ice, f is old firn, ws is winter snow, ss is summer snow, $f(h_c)$ is a function of ice melting decrease under moraine cover of depth h_c, $\tilde{z}$ is mean weighted altitude for the certain S area. In order to obtain the total melt volumes V_M from the equation (4) we used:

$$V_M = \sum_{d_{bp}}^{d_{ep}} v_m(t) \quad (5)$$

where d_{bp} and d_{ep} are the dates of the beginning and the end of the calculation period.

Computations of V_M using the equations (4–5) are based on several numerical methods described in detail in [Konovalov, 1985, 2006]. The REGMOD model and its main subroutines have been successfully tested [Konovalov, 2007]. The total river runoff computed by means of the water balance equation showed a very close coincidence with measured data. The REGMOD model was applied for the selected 138 groups of glaciers during 1935-1994. The set of empirical equations (see below) describing the spatial distribution of volumes V_M in high and low water years was obtained in [Konovalov, 2009] as functions of geographical coordinates (longitude and latitude):

$$V_M(\text{high}) = 7E - 06\text{lat}^5 - 0.0028\text{lat}^4 + + 0.4261\text{lat}^3 - 28.796\text{lat}^2 + 976\text{lat},$$

$$V_M(\text{low}) = -0{,}0001\text{lat}^4 + + 0.037\text{lat}^3 - 3.8553\text{lat}^2 + 186.9\text{lat},$$

$$V_M(\text{high}) = -1E - 06\text{long}^5 + 0.0009\text{long}^4 - - 0{,}1825\text{long}^3 + 13.899\text{long}^2 - 115.36\text{long},$$

$$V_M(\text{low}) = -1E - 06\text{long}^5 + 0.0005\text{long}^4 - - 0.0801\text{long}^3 + 5.1975\text{long}^2 - 32.441\text{long}.$$

In the headwaters of the Amu Darya river basin, the total volume of glacier melting equals to 7.108 km^3 and 26.888 km^3 in the low and high water years, respectively.

It is known [Konovalov 1985, 2006] that V_M depends from the altitude of firn boundary Z_{fg} on glaciers. Therefore, it is necessary to use this parameter for additional studying of changes of V_M. Analysis showed [Schetinnikov, 1998] that the decrease of Z_{fg} along latitude relates to the prevailing (more 76%) concentration of glaciers in the northern part of the region at the altitudes of 3.7 – 4.4 km a.s.l; but in its south, the largest part of the glaciers (62%) are located between 4.0 and 5.0 km a.s.l. The longitudinal increase of Z_{fg} in the same part of the Pamiro-Alai mountain region has been previously shown by [Kotlyakov et al., 1993].

Finally, multi-factor piecewise linear equations were obtained to calculate the statistical probability for the total melting volume of the glaciers in low and high water years as a function of geographical coordinates and average altitude of firn boundary. The general form of the formulae is the following:

$$P(V_m) =$$

$$= a\,Long + b\,Lat + c\,Z_{fg} + \text{Const}\% \qquad (6)$$

Empirical parameters of this formula are given in Table 6.

Principally, enhancing R^2 in the Table 6 is possible by means of using additional independent variables.

CONCLUSIONS

On the presented graphs of the spatial variability for river runoff, precipitation, and air temperature within the Syr Darya and Amu Darya basins, there are certain subareas where the local data are not consistent with the mean value of probability in characteristic years. The reason of such inconsistency is not clear so far. Probably, it is a combined effect of local relief and pattern of atmosphere circulation. Another interesting and important feature of the spatial variability of climatic factors of runoff is their even distribution in high-water years. Both effects have to be taken in consideration at water management, hydrological forecasting, and computations.

Spatial synchronism and asynchronism of air temperature and precipitation extremes are the important characteristics of their fields that strongly influence biota, environment, population, and production. The results presented in Table 7 show high levels of spatial synchronism for minimal air temperature for June-September and maximal precipitation for January-December. This feature of the regional climate has been identified for the first time ever.

Statistics of climatic factors, including integral and differential distributions and spatial

Table 6. Parameters of piecewise multi-factor linear equation for calculation $P(V_m)$

	1-th version of formula (6)				2-nd version of formula (6)				*Br*	R^2
	Const$_1$	a_1	b_1	c_1	**Const$_2$**	a_2	b_2	c_2		
P_1	23.838	–0.196	–0.304	1.084	33.326	0.090	–0.814	0.277	5.085	0.76
P_2	–220.164	1.781	11.804	–70.652	115.416	0.191	–0.933	0.725	91.950	0.88

Note: a_1, b_1, c_1, Const$_1$, a_2, b_2, c_2, and Const$_2$ are parameters for the first and second versions of the formula (6); P_1 – high-water year, P_2 – low-water year, *Long, Lat* – are longitude and latitude in integer and decimal part of degree, respectively; Z_{fg} – firn boundary in km a.s.l., R^2 is explained part of the variance of the function (coefficient of determination), *Br* is the criteria for selection of the empirical equation. When $P_1 \leqslant Br$, computation is performed by the first version of (6), otherwise by the second version, similarly for P_2.

Table 7. The spatial mean of probabilities for $T_{(VI–IX)}$ and $Pr_{(I-XII)}$ in the extreme years

Index	**Air temperature**				**Precipitation**			
	Pmax %	**Year**	**Pmin %**	**Year**	**Pmax %**	**Year**	**Pmin %**	**Year**
ALL	15.00	1990	94.80	1972	6.14	1969	83.29	1971
KYR	11.23	1984	92.31	1972	9.09	1969	79.20	1961
UZB	6.47	1988	96.63	1972	3.20	1969	93.22	1971
TAD	9.46	1984	94.62	1972	6.30	1969	73.23	1971

Note: indexes were explained in the text above after Tables 4-5. Pmax and Pmin are maximal and minimal mean values of probabilities.

correlation functions, provide a much more informative assessment of the impact of climate change on the hydrological regime of the Asian river basins, compared to the determination of average values alone. Efficient application of this conclusion requires the same set of parameters for 1931–1960, 1961–1990, and 1991–2020 time intervals that are not available at present. So far, we have such set only for 1961–1990.

Regional determinations of glacier regimes are necessary for solving problems of water consumption and forecasts of runoff. Intra-seasonal distribution of total melting in glacier areas is closely connected with types of the annual water yields. The glaciers' runoff in the headwaters of the river Amu Darya basin in maximal and average years is concentrated in July-August when winter-spring accumulation of snow has been exhausted outside of glaciers area.

It appeared that the spatial distribution of the total amount of the glaciers' melting is less variable in the years with extreme water yield compared to the average years. This peculiarity is very beneficial for hydropower and agriculture sectors because it provides additional ability to stabilize water balance of reservoirs utilizing natural features of the regional climate. However, the stabilizing role of glacier runoff in the Amu Darya basin is becoming less effective due to shrinking of the glacier area by 2,324 km^2 during 1961–2000. This is very significant and undoubtedly influences the sustainable availability and utilization of river runoff in the Aral Sea basin, especially in low water seasons.

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SPATIAL AND TEMPORAL VARIABILITY OF DRY STEPPES OF EASTERN MONGOLIA

ABSTRACT

Spatial-temporal structure and coenotic diversity of dry steppes of Eastern Mongolia was identified by analyzing characteristics of naturally occurring vegetation connection to the regional landscape structure. Different types of combinations of plant communities (phytocoenochores) were determined in the vegetation structure of the Eastern Steppe Station Tumén-Tsogt (in Sukhebator district). Temporal dynamics of steppe ecosystems was defined from the studies of steppe cover fluctuations in 2008. The coenotic role of eight annual plant species that form synusiae in the steppe communities was shown through analysis of species constancy, projective cover, and activity. Knowledge about the trend of successions and the manifestation of fluctuations in vegetation cover is necessary for the development of science-based system of management options to maintain the number and abundance of different plant groups in plant communities. Monitoring the state of natural ecosystems has a major scientific and practical importance, since steppe ecosystems are the basic component of the pasture's resources of the country.

KEY WORDS: steppe ecosystem, vegetation structure, biodiversity, annual species, fluctuations, dynamics of communities, monitoring

INTRODUCTION

Studying the fundamental properties of vegetation and, above all, its spatial-temporal structure has always been in the spotlight and one of the urgent tasks of biogeography. A variety of natural plant complexes, their distribution patterns (spatial differentiation of steppe communities in relation to the gradients of environmental factors), and temporal dynamics of communities caused by various environmental changes represent a present-day ecological potential of the territory. Steppe ecosystems exist in constant dynamics related to changes of environmental parameters caused by natural and anthropogenic impact. Fluctuations and successional changes are regarded as certain stages of steppe communities in a series of dynamic manifestations. However, the natural invariants of steppe ecosystems have certain average characteristics that determine their primary structure and relative stability to the impact factors. Indigenous communities and their varying components represent a single dynamic system.

Sustainable development of steppe ecosystems is associated with preservation or restoring their natural structure. Vegetation cover is one of the most important indicators of ecological condition of the whole region and serves as an explicit measure of its well-being or as an indicator of existing environmental problems. To solve the pressing problems of balanced (sustainable) development of steppe regions, a reliable information on the current state of natural ecosystems and their base constituent, i.e., biodiversity, is necessary.

In 2008, in practically all communities of the dry-steppe of the Eastern Mongolian steppe biome, significant changes in their organization have been studied. These changes were manifested by strong development of synusiae of annual species and changes in the composition of dominants, structure, products, and physiognomy of the steppe communities. Such stages of steppe ecosystem development represent cyclical changes and relate to the fluctuations caused by changes in climatic parameters (volume and regime of rainfall) in the current and previous years.

A comparative analysis of changes occurring in steppe ecosystem and the modern trends of their further development are of interest to the general scientific studies of steppes and are necessary for developing practical recommendations for their use and conservation.

OBJECTS OF STUDY AND METHODS

The Eastern Steppe Station Tumén-Tsogt (in Sukhebator district) is located in the Herlen River basin and practically coincides with the area of a similarly named Soum of Sukhebator district. The steppes of this territory pertain to the Eastern Mongolian sub-province of the Eurasian steppes according to botanic-geographic demarcation [Lavrenko, 1970]. Studies of the arid steppes of the Eastern Mongolian biome at the Tumén-Tsogt Station have a long history [Volkova, 1988; Khramtsov, Dmitriev, 1995].

The specific feature of the Eastern Mongolian steppes is that they combine features of mountain and plain steppes characteristic of the landscape structure of the territory. The vegetation consists of herb–bunchgrass and dry bunchgrass steppes on chestnut soils whose distribution corresponds well to the geomorphologic structure and the soil cover of the territory. The Station area is about 2000 km^2.

The relief at the territory consists of a hummock denudation plain with a system of uneven-aged hills and of intermontane depressions between the hills. Apical surfaces of the hills vary in morphology depending on lithology of the composing rocks. In the areas with the dominance of weak sandstones, shale, and effusive rocks, there are smooth dome-shaped or flattened tops. Rocky peaks and ridges are formed by outcroppings of granite, quartzite, jasper and limestone (Fig. 1).

The climate of this part of Eastern Mongolia is continental: summers are short (the average July temperature is +20°C), winters are long and almost snow-free (the average January temperature is –20°C). The average annual rainfall is 200-240 mm, reaching 360-460 mm in some years. According to the Underhan

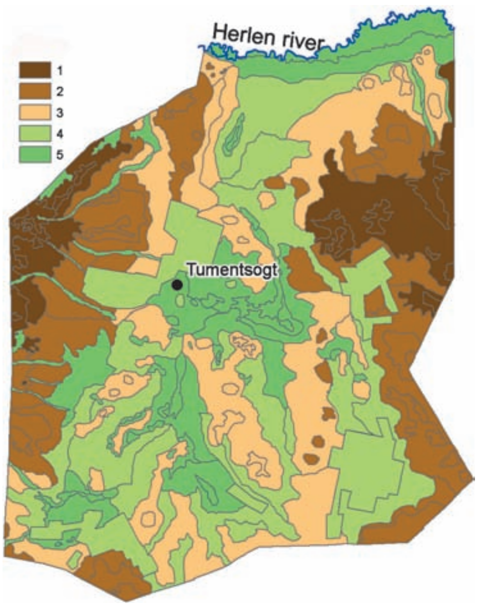

Fig. 1. The types of terrain at the Tumén-Tsogt Station.

1 – high hummocks (1100–1350 m asl), 2 – medium-sized hummocks (1000–1200 m), 3 – low hummocks (950–1000 m), 4 – plains (800–950 m), 5 – depressions (750–800 m) meteorological station, the nearest to the Tumén-Tsogt (47° 19′ N, 110° 38′ E; altitude –1,035 m), the maximum precipitation, as a rule, falls in the second half of July and August; two or three out of each five years are drought (Fig. 2). On average, 160–170 mm falls during the growing season. The survey year (2008) was a wet year in the multiannual cycle; 316.8 mm fell during the growing season (May-August) with most precipitation (208.5 mm) in the early summer (May-June).

There were significant fluctuations of precipitations in the previous years also. Thus, in 2002, 399 mm fell during the growing season, including 245.4 mm in May-June. However, extremely wet years may be preceded by extremely dry. In 2006, only 115 mm fell during the growing season, including 44.6 mm in May-June; in 2007, 41.9 mm fell during the season and 16.0 mm in May-June. These fluctuations of precipitations were the cause of the summer droughts in these years (Fig. 2).

Climatic conditions of 2008 established as a result of this precipitation promoted the development of annual species that prevailed in herb cover in many types of steppes at the Station.

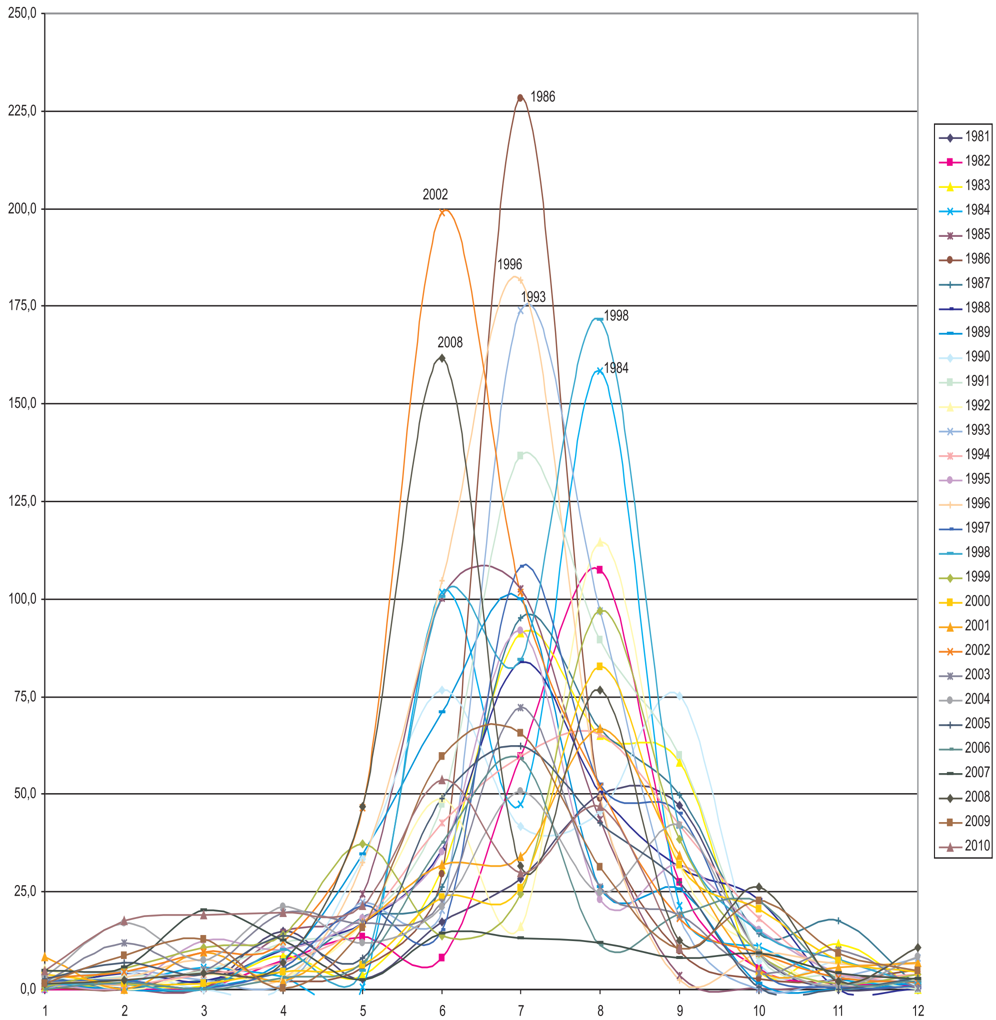

Fig. 2. Precipitation at the Tumén-Tsogt Station in 1981 to 2010 (from the data of the Underhan meteorological station). The horizontal axis: months from January to December; the vertical axis: precipitation (mm)

DISCUSSION OF THE RESULTS

Spatial organization and coenotic diversity of the Eastern Mongolian steppes

Vegetation structure that evolves in the process of its development determines stability and spatial distribution of communities according to natural conditions and geomorphological composition of the territory [Sochava, 1978]. In phytocoenology, there is a notion of the types of territorial units as regular combinations of communities of a certain hierarchical level that compose the optimum spatial vegetation system contributing to its highest stability. Among different elementary chorological units (i.e., phytocoenochores or combinations) of the Eastern Mongolian steppes, several typical structures have been identified. Micro-combinations have a relatively large spatial extent and represent, as a rule, sequential stages of the same ecological range or of the same successional process. These stages may include complexes, ecological ranges or series, and micro-zonal ecological ranges. In meso-combinations, plant components are primarily influenced by orography and they are of a relatively greater spatial extent. Each plant component of meso-combinations may have its own way of development. Meso-combinations include: meso-complexes, phyto-catenae, and expositional combinations of phyto-catenae. Macro-combinations are formed on the hill slopes following a pattern of high level of ecotopic differentiation. The elements of macro- combinations represent a single and complete ecological range, from watershed surfaces to river valleys, that are integrated an phyto-catenae and a composite part of an elementary basin. A macro-geochore may be represented by a geomorphologic or a hummock complex of the steppes. This complex includes serial communities of hill topes, expositional combinations of phyto-catenae of transitional parts of slopes, and homogeneous communities of slope aprons and their accumulation parts.

Phyto-catenae are the main structures of the mountain vegetation. Their definition is based on the concept of runoff-geochemical evolution of landscapes [Glazovskaya, 1988] and slope development [Voskresenskyi, 1971; Ogureeva, 1994]. Within phyto-catanae, the integration of elementary ecosystems of the eluvium, trans-eluvium (transit), and accumulative positions into linked series takes place, defining spatial differentiation of vegetation on the slopes. Functioning together, they are the product of the close interaction between all the components and with the environment. All communities of phyto-catenae are dynamic and, with time, undergo modification of structural and floristic parameters as a result of slope ecotope transformations. Thus, communities of mountain slope represent an integrated, spatially-dynamic system that characterizes an elementary basin. Phyto-catenae on slopes of different exposures form expositional combination of phyto-catenae that are located within altitudinal belt of the vegetation cover. On the Station's territory, the expositional combinations of the steppe phyto-catanae have been isolated for all types of hummocks [Ogureeva and al., 2011].

The steppe complex of the high hummocks. High denudational hummocks and low-mountain massifs with steep erosion-dissected slopes and intermountain valleys are composed of granitoids. They occupy 240.4 km^2 (11.2% of the total Station's area). The maximum absolute elevations reach 1100-1350 m; relative – 200-250 m. Shrub communities consisting of *Betula fusca* are confined to the upper elevations, while *Armeniaca sibirica-Amygdalus pedunculata* communities occupy near-apical sites on the slopes of the high and intermediate hummocks. Petrophytic steppe variants (serial vegetation) occupies rank and rocky surfaces of the apical parts of the hills. *Stipa baicalensis* and *Carex pediformis* dominate in the vegetation cover of the complex. Herb-stipa and herb-sedge steppes represent the most mesophilic types of the Eastern Mongolian steppes with participation of species of forest-steppe herb communities (*Clematis hexapetala*, *Hemerocalis minor*, *Rhaponticum uniflorum*. *Schizonepeta multifida*, and *Stellera chamaejasme*). They occupy the transit parts of the slopes of different exposures forming expositional combination at different altitudinal levels. Meadows are located in the erosion valleys.

The steppe complex of the intermediate hummocks. The hummocks of intermediate height (1000-1200 m) have gentle slopes and dome-shaped tops. They are predominantly composed of Permian effusions, Jurassic tuffaceous sandstones, andesite, and, more rarely, of basalt and granite, and occupy 424.2 km^2 (22.6%).

Bunchgrass steppes dominate the vegetation of the low and intermediate hummocks. On the near-apical parts of the slopes, there are diverse petrophytic series of stipa (*Stipa grandis*, *S. krylovii*, *S. sibirica*). The shrub *Ulmus pumila* formations are characteristic of the rocky stony and rank habitats of the intermediate and low hummocks. The formations of three-stipa steppes (*Stipa grandis*, *S. krylovii*, *S. sibirica*) are the most diverse in their communities' floristic composition. They are typical for the transitional parts of the southern slopes of the intermediate hummocks, forming expositional combinations with the herb-stipa steppe formations of *Stipa grandis* and *S. krylovii* on the slopes of the northern exposure. The herb-grass-stipa (*Festuca lenensis, Stipa krylovii*, *Stipa sibirica*) steppes often contains *Lespedeza dahurica* and *Ephedra sinica*. The herb-three stipa- steppes with *Caragana microphylla*, and *C. stenophylla* form the basis of vegetation cover in the accumulative parts of the slopes of the intermediate and low hummocks.

The steppe complex of the low hummocks. The low hummocks predominate in the area occupying 488.6 km^2 (25.8%). They mainly consist of granites and syenites. Their elevations are 950-1000 m with the highest peaks reaching 1150 m. Relative elevations are 100-150 m. The tops of the hills are occupied by serial steppe vegetation (*Festuca lenensis*, *Koeleria cristata*, *Agropyron cristatum*) and shrubs (*Dasiphora fruticosa*, *Caragana microphylla*, *C. stenophylla*, *Spiraea aquilegifolia*). The slopes of the low hummocks are often covered with xerophytic formations *Stipa krylovii* with: *Leymus chinensis*, *Cleistogenes squarrosa*, *Carex korshinskyi*, *C. duriuscula*, and *Kochia prostrata*. Combinations of arid stipa steppes (*Stipa krylovii* with *Cleistogenes squarrosa*, *Leymus chinensis*) with wormwood (*Artemisia frigida*)–stipa and sedge (Carex duriuscula)–stipa steppes occupy different expositional locations. In the lower parts of the hills near saline depressions, stipa steppes (*Stipa krylovii)* grow together with onion genus (*Allium odorum*, *A. tenuissimum*, *A. bidentatum*)–sedge steppes.

Vegetation of the plains. Gently rugged plains with slight slopes and delluvial aprons (800–950 m) with shallow saline depressions in the axial parts, occupy close to 410.4 km^2 (21.2%) of the somon area. Stipa formation (*Stipa krylovii)* and communities of rhizomous sedges and grasses are characteristic of the plains. Communities of formation *Leymus chinensis* with *Carex duriuscula*, *Artemisia frigida*, and *Kochia prostrata* are spread along the margins of the saline depressions. Communities of sedge formation (*Carex duriuscula*, *C. korshinskyi*) are typical of the aprons and the intermountain plains. There are variants of mesophitic onion–sedge steppes (*A. odorum*, *A. tenuissimum*, *A. bidentatum*) on the plains adjacent to the Herlen River valley.

Vegetation of the depressions. The bottoms of the depressions with adjacent gently sloping alluvial aprons of waterways occupy 376.4 km^2 (19.2%). The depressions have saline complexes of halophytic herbs (*Saussurea salicifolia*, *S. amara*, *Suaeda prostrata*) and communities of grass (*Puccinellla tenuiflora*, *Hordeum brevisabulatum Achnatherum splendens*).

The coenotic diversity of the Steppe Station Tumén-Tsogt has been presented on a large-scale map (1:200 000) of the actual vegetation cover [Ogureeva et al, 2011]. The legend of this map is based on the eco-geographical approach and reflects the connection of the steppes with landscape features of the territory. All typological units of vegetation are grouped according to their spatial location within the terrain.

The map shows the distribution of vegetation as a homogeneous community and as various types of structural units of vegetation at the levels of micro-, meso-, and macro-phytocoenochores (combinations) [Ogureeva et al 2011]. In the vegetation structure of the hummocks, phyto-catenae associated into expositional combinations and petrophytic series of communities are most spread. Serial vegetation covers 66.4 km^2 (3.3% of the Station's area); expositional combinations of phyto-catenae – 1361.5 km^2 (65.2%); bush thickets – 8.1 km^2 (0.4%). On the plains, steppe communities occupy 414.3 km^2 (21.3%), communities of saline habitats – 191.1 km^2 (9.5%), and floodplain series – 12.0 km^2 (0.6%).

The temporal structure of the Eastern Mongolian steppe biome

The 2008 survey of the Eastern Mongolian steppes was a part of the monitoring of the current ecosystem status. This was an important component of the effort to re-map vegetation, which made it possible to identify qualitative and quantitative changes in the vegetation component of the ecosystems, and also to identify the distribution and direction of the main natural and anthropogenic processes. All steppe areas, except for the protected territory of the Khar Yamaat Nature Reserve in the high hummocks west of the Station, were subject to a long-term year-round grazing. Therefore, background anthropogenic pressure throughout the Station is relatively even. The current state of the steppe ecosystems at the Station is assessed as satisfactory on a 5-point scale designed to evaluate ecosystem state [Ecosystems.., 1995].

The role of annual species in the steppe ecosystems.

Traditionally, analysis of the composition of steppe phytocenoses and their classification is based on the characteristics of perennial species substantially resistant to multi-temporal changes under the natural conditions. These species are constantly present in the communities reflecting the specificity of the natural habitat and floristic composition of the primary communities of steppes. The composition of the main components of the steppe communities (bunchgrass and rhizomatous grass) remains practically unchanged; however, from year to year, these species may experience alterations of their life-forms and may play different roles in the community.

The alternation between wet and dry years in the multiyear development of the steppes has led to the fluctuations in the grass cover. Climatic conditions in recent years (drought of 2006–2007; rainfall in the early summer of 2008) contributed to the massive development of annual plant species in all types of these steppes. They provided for a temporary increase in the species richness, projective cover, productivity, and other indicators of the structure and composition of the steppe communities. Annual plants can represent competitors to perennial species for moisture and mineral elements in steppe communities. At the same time, they form the upper phytocoenotic horizon up to 60 cm in height overshading perennial species and favoring their development. Annual species increase the mass of litter and improve the conditions of over-wintering perennials. Mineralization of litter promotes deposition of substances into the nutrient cycling and improves soil conditions of habitats. Simultaneous development of annual species in different types of steppes in extreme years, though smoothes coenotic diversity, does not destroy the natural specificity of steppe communities, whose invariants are preserved.

During the survey of the steppes at the Station in 1994, the average year in terms of moisture indicators (see Fig. 2), it was noted that in the steppes, annual species (*Chenopodium viride*, *C. acuminatum*, *C. aristatum*, *Salsola monophera*, *S. collina,* and *Artemisia palustris*) were present infrequently and in small numbers. However, their role increased locally with the impact of grazing, rodents, and on the fallow lands (Miklyaeva and Lysak, 1996). The 2010 summer sampling survey (also the average year in terms of precipitation during the growing season) of the steppe communities showed that coenotic diversity of the steppes remained the same as in 2008, however the fluctuations of species composition in the form of synusiae of annual species were not manifested. Some of the annual species were present in the communities, but did not play any meaningful coenotic role. Comparison of these materials suggests that temporal conditions (fluctuations) of the steppes occupy a certain place in the multiyear natural dynamics of steppe ecosystems. The fluctuations as cyclic changes in ecosystems represent an integral part of their natural dynamics. Self-regulation of steppe ecosystems restores the original structure of the communities. In the multiyear development cycle of the steppes, their composition is marked with changes at the population level of species-dominants and species-determinants that remain in the communities at all variations of the hydrothermal regime.

Floristic richness of the steppe communities was markedly reduced: in the dry years, from 40-45 species/100m^2 to 12-15 and, rarely, to 7-8 species. As a result of mass development of annual plants, the total projective cover of grass steppes rose to 50-80%, but the true coverage (swarding) was low, not greater than 10-20%. This is typical for the well-defined stages in a series of fluctuating alternations; annual species are the fluctuation dominants in the steppe communities [Rabotnov, 1978] and define their appearance.

In the steppes of the Station in late July – early August of 2008, eight annual species of plants were found. *Chenopodium viride* can develop in the broadest range of conditions. This specie has a wide range from Karelia to the Far East, where it grows in forests and is common in all forest-steppe and steppe regions. Three species are typical to forest-steppe and steppes. *Salsola collina* grows in the areas from the Volg a region and Western Siberia to Altai and Dauria, the Ussuri river valley, and, further, to Mongolia, China, and Tibet. *Axyris amarantoides* grows from Western Siberia and Altai to Dauria and can be found in China, Tibet, and the steppes of Mongolia. The Daur-Mongol species of *Artemisia palustris* grows from Altai to Dauria and Northern China. Two species are typical of steppes. *Chenopodium aristatum* has a wide range and grows from the Middle Dnieper and the Caucasus to Mongolia, China, and Tibet. *Chenopodium acuminatum* occurs from Western Siberia and Trans-Balkhash to Mongolia and China. Two species are found in the steppes and deserts. *Artemisia scoparia* has a wide Eurasian range. Central Asian specie *Salsola monopthera* has a narrower area and occurs in arid and desertified steppes of Mongolia.

These annual species are well adapted to the natural conditions of the steppes of Eastern Mongolia. Their participation in the communities and distribution are determined by specific features of their biology and ecological plasticity. Environmental conditions of plant habitats vary considerably in hypsometric profile influencing the coenotic role of annual species in the communities (Table 1). The coenotic role was assessed based on the constancy and abundance of the species in the communities. Constancy of species is the number of each specie found, expressed as a percentage, in the geo-botanical descriptions at different altitudinal levels of the territory (0–20% – class I of constancy, 21–40% – II, 41–60% – III, 61–80% – IV, and 81-100%-V). Six annual species were recorded in the steppe communities at all elevations. *Chenopodium viride, C. aristatum* and *Salsola collina* had high classes of constancy (IV–V classes) in

Table 1. Constancy and projective cover of the annual plants in the communities at different elevations of the relief

Types of terrain	Hummocks						Plains		Depressions	
	High		Intermediate		Low					
Projective cover (F) Constancy classes (D)	F	D	F	D	F	D	F	D	F	D
Chenopodium viride	1	IV	4	V	4	V	4	V	4	V
Salsola collina	1	I	5	IV	4	V	3	III	3	V
Chenopodium aristatum	2	IV	3	IV	3	V	4	III	3	IV
Salsola monopthera	1	I	1	I	1	I	4	III	3	I
Axiris amaranthoides	3	I	2	II	2	III	2	III	2	II
Chenopodium acumi-natum	1	III	1	II	1	II	1	I	1	I
Artemisia palustris	–	–	1	I	3	II	1	II	4	II
Artemisia scoparia	–	–	1	I	2	I	1	I	2	II

Classes of constancy (D): I – 0–20%, II – 21–40%, III – 41–60%, IV – 61–80%, V – 81–100% (number of recordings in the geo-botanical descriptions, in %).

Projective cover of species (F): 1 – very low (less than 1–5%), 2 – low (6–10%), 3 – intermediate (11–20%), 4 – high (21–40%), and 5 – very high (41–70%).

most communities. Constancy of *Salsola monophera*, *Chenopodium acuminatum,* and *Axyris amaranthoides* did not exceed the average values (III). Wormwoods (*Artemisia palustris* and *A. scoparia*) were not found in the communities of the high hummocks; their permanence in the communities of other altitudinal levels were low and did not exceed the values for class II.

The abundance of plant species was assessed according to their projective cover as a measure of their coenotic role in the structure of the steppe communities at the Station (see Table 1). Two species, i.e., *Salsola collina* and *Chenopodium viride,* contributed the most to the projective cover (21–40%) of the communities of different altitudinal levels. The highest abundance indices were characteristic of Salsola *collina*; its projective cover in shrub steppes (*Caragana microphylla, C. stenophylla*) and three-stipa (*Stipa grandis, S. krylovii, S. sibirica*) steppes on the slopes of the intermediate hummocks reached 60–70% (Fig. 3). The projective cover

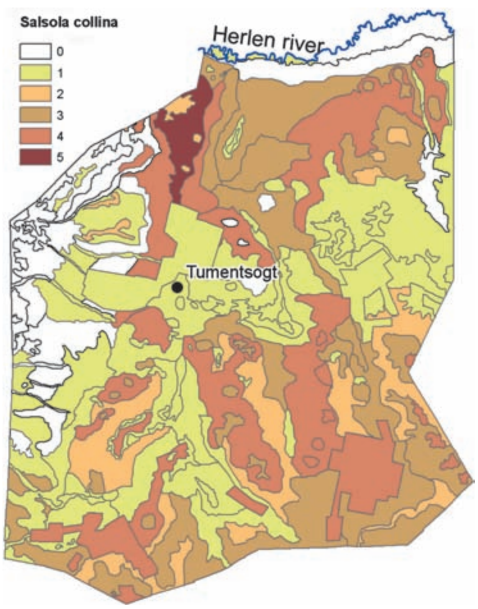

Fig. 3. Coenotic role of *Salsola collina* **(the abundance of species based on the projective cover in %):**

0 – the specie is absent, 1 – up to 5%, 2 – low (6–10%), 3 – intermediate (11–20%), 4 – high (21–40%), and 5 – very high (41–70%)

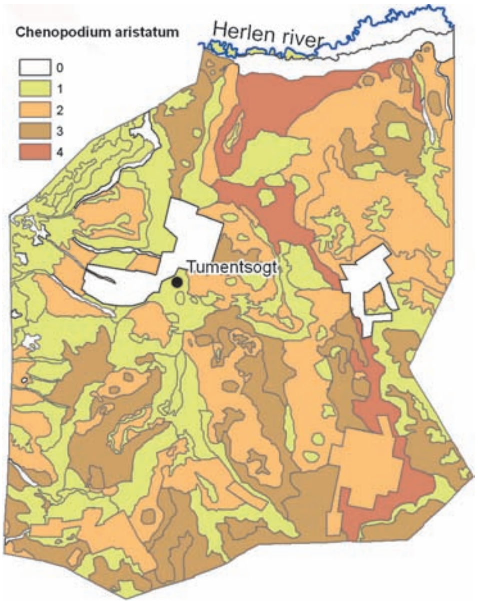

Fig. 4. The coenotic role of *Chenopodium aristatum***:**

0 – the specie is absent, 1 – up to 5%, 2 – low (6–10%), 3 – intermediate (11–20%), and 4 – high (21–40%)

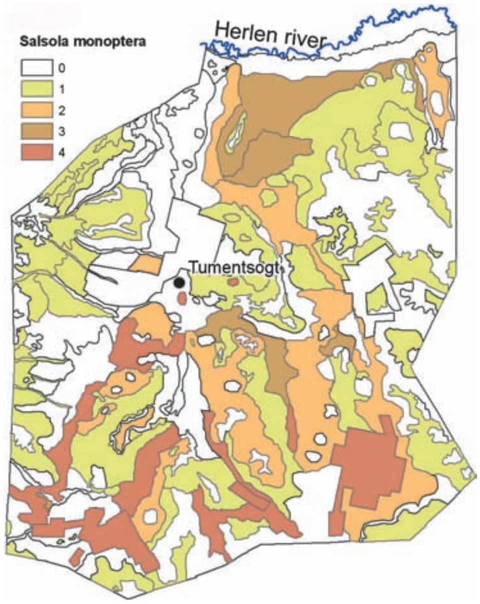

Fig. 5. The coenotic role of *Salsola monophera***:**

0 – the specie is absent, 1 – up to 5%, 2 – low (6-10%), 3 – intermediate (11–20%), and 4 – high (21–40%)

of these species decreased to 11–20% in the communities of the plains and depressions. *Salsola collina* rarely grows in the high hummocks. The ability of *Salsola collina*, along with other annuals, to form the appearance of the steppes of Mongolia in wet years has been previously noted by A.A. Junatov [1954].

The coenotic role of the annual species in communities of the same high-altitudinal level varied considerably (see Table 1). *Chenopodium aristatum* had the greatest coenotic role (projective cover 21–40%) in the communities of the plains in (Fig. 4), while *Salsola monopthera* and *Artemisia palustris* – in the depressions. *Salsola monopthera* had its maximum projective cover (40%) in the stipa (*Stipa krylovii*) steppes on the plains adjacent to the saline depressions (Fig. 5). The high projective cover (40%) was also observed for *Salsola monopthera* in the communities of the fallow land. The coenotic role of other annual species was negligible. Low and very low coenotic importance was found for the species whose projective cover never exceeds 10% – *Axyris amarantoides*, *Chenopodium acuminatum, and Artemisia scoparia* (see Table 1).

Annual plants' activity represents an integral indicator of their role in the steppe communities (Yurtsev, 1968). Activity is calculated as follows:

$$A = \sqrt{FD},$$

where A – activity of a specie, F – average projective cover (%), D – constancy (%).

Classes of activity: I – very active (31–42%), II – high-level (21–30%), III – intermediate (13–20%), IV – low-activity (7–12%), and V – inactive (1 – 6%).

Activity of annual and biennial species varied in different types of steppe mountain complexes (Fig. 6). In the high hummocks, all annual species were inactive; two species – *Artemisia scoparia* and *A. palustris* do not even occur in the steppes at this level. In the intermediate hummocks, there were two species (*Chenopodium viride, C. aristatum*) that

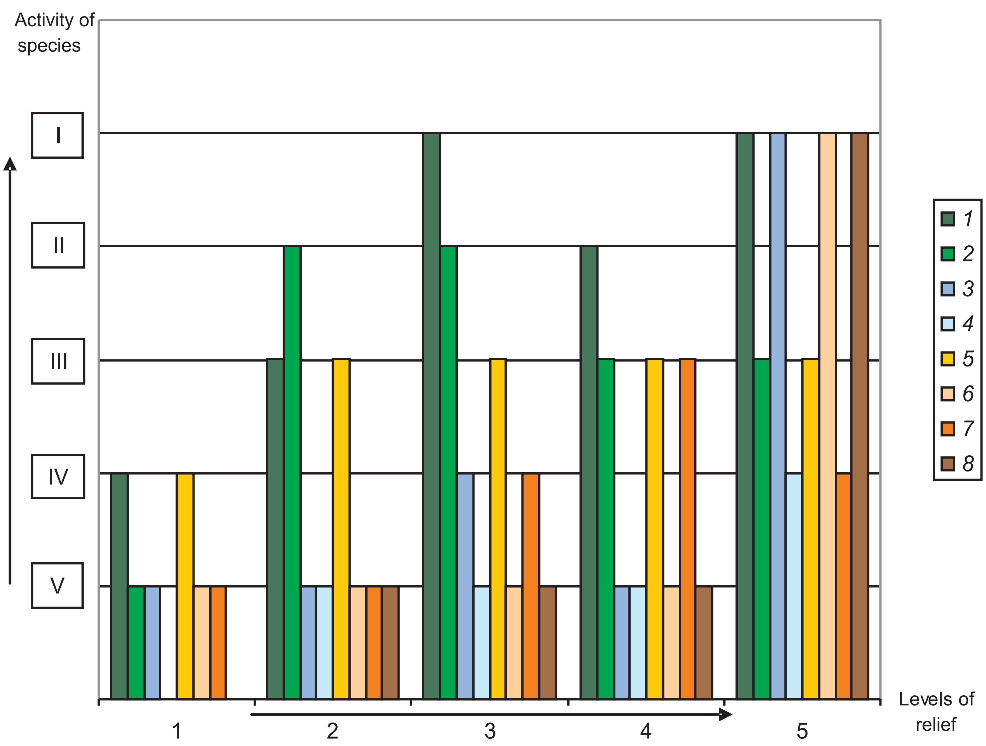

Fig. 6. Activity of annual species in the communities of different types of hummocks.

Types of hummocks: 1 – high, 2 – intermediate, 3 – low, 4 – plains, 5 – depressions.

Activity of species: I – very active, II – highly active, III – intermediate, IV – low active, V – inactive.

Species of annual plants: 1 – Chenopodium viride, 2 – Salsola collina, 3 – Axyris amaranthoides, 4 – Artemisia palustris, 5 – Chenopodium aristatum, 6 – Chenopodium acuminatum, 7 – Artemisia scoparia, and 8 – Salsola monophera

were moderately active (III), and five species that were inactive (V). Activity of *Salsola collina* was mostly high (II) in the steppes of the intermediate and low hummocks. Activity of *Chenopodium viride* had its maximal values (I) in the steppes of the low hummocks. Intermediate activity (III) was observed for *Chenopodium aristatum* in the communities of all elevation levels – from the intermediate hummocks to the depressions. In the steppe communities of plains, high activity (II) was characteristic of *Chenopodium viride,* and intermediate – of *Salsola collina* and *S. monopthera*. High activity in the communities of the depressions was common to all annual species and was maximal in four species.

The steppe communities have been recovering on the abandoned fallow land which occupies 15% of the Station area. The fallow lands are at different stages of the secondary successions. The average age of the fallow land is 15-20 years. The total projective cover of grass is high (50%), while swarding does not exceed 10%. At the initial stages of the secondary successions, indicator species of the former tillage (*Lappula intermedia*, *Setaria viridis*, *Convolvulus arvensis*, *Fallopia convolvulus*, etc.) were present. Most of the grasses were annual species: *Chenopodium viride*, *Salsola collina*, and *Salsola monopthera*. They were constantly present in the grass cover and often form a high-projective cover (21-40%). The fallow lands were characterized by increasing activity of the annual species with *Chenopodium viride*, *C. aristatum*, and *Axyris amarantoides* mostly active, while *Artemisia scoparia*, *A. palustris*, and *Salsola collina* had intermediate (III) activity.

CONCLUSION

The research on spatial-temporal structure of steppes is of special scientific and practical importance and is the basis for studying ecosystems at the current level of their protection and restoration. In extreme years, temporary synusiae appear as a result of varying volume and regime of precipitation. Annual species become fluctuating dominants during this period. [Rabotnov, 1978].

Analysis of the 2008 studies of the current state of the steppe ecosystems showed fluctuations in the sequence of their temporary states with clearly expressed annual species synusiae. Each annual species in a synusia is characterized by a specific ecological range and the coenotic optimum. These species had different ecological amplitude and played different coenotic role in the steppe communities. The species with broader ecological amplitude (*Chenopodium viride, Salsola collina*) in the steppes of Eastern Mongolia played a more significant role in the steppe communities, whereas species with narrower ecological amplitude (*Salsola monophera*) had lesser coenotic significance.

Sustainable use of pasture ecosystem resources depends on obtaining the most complete information about steppe vegetation. Pasture regime should be based on the landscape ecological approach with consideration given to pastures' feeding values and positions in the altitudinal zonal structure.

In order to preserve the invariant steppe communities and to restore steppe ecosystems, measures for improving of the steppe ecosystems should be developed. These measures should be also based on ecological principles that consider the ecosystems' position in vegetation structure of their altitudinal zones (mountains, hummocks, valleys, depressions) and in specific types of vegetation cover.

In this regard, published literature explores different measures aimed at improving floristic composition and structure of steppe ecosystems ensuring their sustainable development and functioning [Ecosystems…, 1995]. Among the proposed measures, in our opinion, the following activities will be most beneficial.

- Management of pasture use regime (schedule and duration of grazing and rotation);
- Regulation of grazing load (modeling of optimal livestock numbers and herd composition depending on the pasture type);
- Restoration of steppe ecosystems (incorporating "rest" of the steppe communities, improving feeding value of pasture by reseeding forage plants);
- Creation of grasslands to establish reserve stocks of feed;
- Organization of a monitoring system of steppes (multiyear observations of steppe plant communities and identification of fluctuations and succession stages);
- Identification and preservation of reserve areas of steppe ecosystems of different altitudinal zones to maintain the gene pool and replenishment of the seed pool of main species-forming steppe communities.

It is also necessary to continue work on developing the ecological framework of Eastern Mongolia for preservation of steppe ecosystems. A network of protected areas, including sanctuaries and a system of standard natural sites, should be developed. The network would link Mongolian steppes and the integrated system of protected areas of the Central Asian steppes, and the centers for biodiversity.

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LANDSLIDES IN A RURAL MOUNTAINOUS REGION: DAMAGING AND RESOURCE-FORMING IMPACTS (SOUTH CAUCASUS, GEORGIA)

ABSTRACT

Catastrophic loss of soils and slope sediments by landslides causes destruction of mountainous environment and outflow of population from affected areas. However, the role of landslides in mountainous regions goes beyond direct destructive activity. The sliding mass expose surfaces for weathering and accumulate loose mineral material, the vital resource for mountain biota and population thus starting new cycles in ecosystems development, forming new habitats for biota and, in some cases, new lands for farming. A chronological sequence of landslides and their adaptation for human needs was studied in Adjara province, the South Caucasus mountainous region, Georgia. As a rule, in 15 years, a thin and compacted soil layer is formed on low and mound surface of a landslide. In 30 years, people start recultivation of the landslide area. After 40 -60 years, the landslide area is used as a hayfield. It usually takes 100 years to transform the area into a fully cultivated landscape typical of Mountainous Adjara.

KEY WORDS: landslides, mountains, mass wasting, soils, the Caucasus.

INTRODUCTION

In mountainous regions, soils and loose sediments and their fine components, in particular, are the life-supporting resource for biota, as well as for the human habitat and economic activities. Slope mantle of loose material, once removed, cannot regenerate within a human life-time or even longer [Targulian, 2008]. The mountainous areas devoid of loose slope cover soon lose their population, and human history manifests a number of such examples [Messerli & Ives, 1997; Ilychev & Gracheva, 1998]. Landslides are among the most disastrous mechanisms of mass wasting and erosion in mountainous areas, causing a complete destruction of soils and regolith by their transport from hillslopes and by sealing lands under the landslide mass.

Even scattered examples show an enormous role of landslides in sediment transport and environmental change. The famous Elm landslide, Switzerland, on 11 September 1881, covered 800,000 m^2 with 3–6 m thick debris. The total volume was estimated at about 0.01 km^3. The landslide caused by Mount St Helens eruption, USA, 1980, had an estimated volume of 2.5–2.8 km^3 and covered the surrounding area with 45–180 m layer of debris [Warburton, 2007]. One of the largest landslides of the past, the Saidmarreh landslide in the Kubir Kuh Mountains, in southwest Iran, occurred about 10,000 years ago and changed land topography of the entire vast region having an exceptional volume of about 20 km^3 [Shoaei & Ghayoumian, 1998]. Hazardous mass movement may also affect the environment due to postponed catastrophes, such as outburst floods of lakes dammed by landslide sediments [Hewitt, 1992; Shuster & Highland, 2007].

Landslides of different magnitudes can cause significant environmental damage. Lanslides can move large volumes of sediments from hillslopes and infringe on forest and agricultural land. Studies to estimate contributions from individual landslide events to loose sediment transport and to assess a short-term response of a 3000 ha catchment area to the intense Bola Cyclone event, 1998, performed in New Zealand [Page et al., 1999] showed that, out of the total 1.35 mln m^3 volume of fine sediment moved during the storm, approximately 89% was from the landslide erosion on the slopes; shallow landslides were responsible for approximately 64% of the sediments at the exit from the catchment area. Even in a few years following the event, suspended sediment concentrations in waterways were 100% greater than before due to the continued erosion of landslide scars and stored sediments. Other data on soil loss can be found in quantitative assessments of losses of soil resources due to landslide activity (e.g., [Schuster & Highland, 2007]).

Heavily populated mountainous regions suffer particularly from landslides, including extremely destructive events. However, in many mountainous regions, people that left their settlements destroyed by a disastrous landslide soon return to the damaged territory. Leaving aside economic, ethnic, and other reasons for such behavior, we have to consider the role of landslides in mountainous regions as much more complex than the apparent hazard for landscapes and humans.

In some cases, landslide deposits are spread out more or less evenly and are not completely eroded and removed by water flows. Part of sliding mass can be stopped and stabilized and it may form new elements of the mountainous topography. These are bench-like or fan-like steps on slopes, at the base of scarps or in river valleys; they store enormous volume of loose material, both coarse and fine. These landforms resulting from sliding, slumping, and other processes of mineral mass movement are found in many mountain regions and in the coastal regions in particular [Easterbrook, 1993]. With time, they may be reclaimed and used for settlements or farming, either for pastures or for crop production [Schuster&Highland, 2007]. Some types of postponed environmental feedback to landslides (positive for humans) are described by Shoaei and Ghayoumian [1998]: the Saidmarreh landslide blocked two rivers forming lakes drained away now, and, at present, the lake sediment provides fertile farmland for the local population. This is of particular importance in densely populated mountain regions with a shortage of usable lands.

In this paper, we consider the dual role of landslides in the mountain environment and society, as a hazard to soil and slope regolith and, on the other hand, as a mechanism of local accumulation of loose mineral material usable for economic needs, with a special reference to Mountainous Adjara, in the western part of the Republic of Georgia, the South Caucasus.

LANDSLIDES IN GEORGIA

Landslide hazard is extremely high in Georgia. More than 2,000 settlements with the population of 200,000 are located in landslide-prone areas, and about 70% of identified landslides occur in developed areas. During the last 50 years, particularly in the last 20 years, the number of landslides has increased dramatically. By 1960, 3,000 landslides were registered; in 1981 and in 1987-1989, there were 10,000 and 30,000, respectively; more than 53,000 landslide events took place in 2006. Most of the landslides occurred in the mountainous regions. The number of buildings damaged by landslides increased from 384 in 1981 to 5,044 in 1988 and was 10,808 in 1990. In 1991-1992, series of earthquakes simultaneous with high rainfalls caused disastrous landslides and rockfalls in the mountains, which affected about 1,500 settlements ([Tzereteli, 2000]; data of official statistics of Georgia).

To assess the extent of landslide hazard, the ratio of the landslide-damaged area to the total area ($K = S_{landslide}/S_{total}$) is usually used [Sheko, 1982].

In terms of the extent of landslide hazard (*K*) and risk assessment, Georgia is divided into 7 zones [Tzereteli, 2000].

1. Mountains of the Black Sea coastal area with K= 0.7-0.9, extremely high risk of landslides.

2. Mountainous Adjara and the foothill belt of Guria, K= 0.5-0.7, high risk of landslides.

3. Northern macroslope of the Trialet Ridge, the Akhaltsikhe depression and the piedmont of the South Caucasus (between the Gori and Aragvi Rivers), *K* = 0.3–0.5, significant risk of landslides

4. The southern macroslope of the Greater Caucasus composed of shale rocks and flysch, alpine zone of the Trialet Ridge, *K* = 0,1–0,3, medium risk of landslides.

5. The southern macroslope of the Greater Caucasus composed of volcanic and carbonate rocks, hills of the Gori upland, *K* = 0.01–0.1, significant risk of rockfalls.

6. The Greater Caucasian zone composed of rocks of crystalline formations, the Javakheti volcanic upland, massifs of Khrami, Loki, and Kelasuri, *K* = 0.01, significant risk of rockfalls.

7. The Colchis Lowland, Inner Kartly, no landslides.

For the study of landslides' role in populated mountainous regions of Georgia, Mountainous Adjara was selected. Adjara demonstrates particularly tight relations between population activity and dangerous natural processes.

LANDSLIDES IN MOUNTAINOUS ADJARA AND THEIR RECLAMATION FOR HUMAN NEEDS

Mountainous Adjara, or Upper Adjara, a part of the Autonomous Republic of Adjara, belongs to the western part of the Adjara-Trialet mountain system. At present, it is a densely populated region with a long history of development [Dzhaoshvili, 1968; Putkaradze, 2005]. The area is bounded by the Meskheti Ridge in the north, by the Shavsheti Ridge in the south, and by the Arsian Ridge in the east; it resembles an amphitheater of stepped configuration descending westwards and to the Adjaristskali river valley. The ridge altitudes vary from 1,000 to 2,000 m above sea level (asl), the highest points (mountain tops and crests) are more than 2,000 m high; the relative heights above the valley floor are about 400–600 m. The mountain slopes are steep, and rockfall slopes are widely distributed in the region, particularly at high elevations. The region is, for the greater part, is composed of Paleogene rocks with widely distributed volcanic formations, such as lava, tuffolava, tuffs, and rocks of mostly intermediate composition (andesites and andesite porphyrites). These are the areas of neotectonic uplifts intensifying erosion and mass-wasting processes. The climate of the area is wet and changes from subtropical to temperate with altitude. The mean annual precipitation is 1,000–1,600 mm. Typical, for the entire area, are summer storms, their intensity, and duration growing with altitude, and a thick snow cover in winter (up to 3–4 m). Prolonged alteration of the rocks under wet mild climate resulted in weathering crusts 3–10 m thick, clayey, loamy, and silty in composition, often with small-size debris and rock fragments.

The presence of every factor controlling sliding processes are characteristic in the region; these are steep slopes, water saturation of slope material during snow melting, frequent rainfalls, and weak slope cover consolidation due to fractured rocks and poorly cemented deeply weathered sediments [Emelyanova, 1964; Tzeretely &

Tzeretely, 1985]. Landslide-prone areas increase eastwards.

There are various types of landslides recorded in the region, including tectonic and shallow landslides, debris flow, earthflow, mudflow, creep, and slumps, often forming a natural landslide complex. The most active removal of loose material takes place on the steep slopes of gorges with stream channels at their base. In typical cases of undisturbed block of soil and regolith, together with forest slumping into the river (Fig. 1), loss of the material is estimated at 100–1200 m^3 (personal communication with specialists of the Adjarian Geologic Survey). All forested slopes display a microrelief of shallow slumps; it is most clearly pronounced on the south-facing slopes where the sites of so-called "drunken forest" are found occasionally. The shallow landslides are distinctly seen in the soil profile. They are mostly responsible for

Fig. 1. A slump block breaking away from the riverbank and irreversible loss of loose slope sediments. The Adjaritskhali River, Mountainous Adjaria, Georgia

buried humus horizons, or for "inverted" layers, with coarser material overlying fine soil.

Due to heavy dissection of the land surface, only 10–11% of the total Mountainous Adjara area is suitable for settlement and agricultural farming. The shortage of cultivable lands is one of the most crucial problems of this region. Many settlements are located on large bodies of regolith slowly moving downslope. In the course of centuries, the inhabitants have been adapting to the landslide hazard. Light wooden pile-supported houses do not require clearing a large building site and laying the foundation. Under land shortage, such a way of building was the most handy and relatively safe.

In the 20th century, the human impact on the environment was increasing dramatically until the 1990s [Gigineishvili & Nahutsrishvili, 1998; Gracheva, 2004]. The population density in the settled and cultivated areas of Keda, Shuakhevi, and Khulo municipalities grew and a network of motor roads was built, often using rock explosions. Upper Adjara was a region of profitable tobacco monoculture and with increase of the population income wooden houses were replaced with heavier structures of brick or stone that required larger sites to be cleared. Water pipes were laid to supply water to all the households and vegetable gardens; the water use, however, was not controlled and water flowed constantly onto the slopes unimpeded.

The 1980s were marked, in Mountainous Adjara, by extremely rapid snow melt and by increase in rain frequency and duration, which triggered sliding and slumping, as well as small mudflows [Berdzenishvili, 2000]. People did not pay attention to the hazard until fissures began to appear in stone walls of their houses; small slumps and slides damaged farmyards, vegetable gardens, and asphalt roads and micro-mudflows blocked water sources. Landslide aggravation may be inferred from the statistics of the residents' appeals to the state agencies, including to those responsible for property damage insurance. Thus, in the spring of 1988, officers of the state agencies visited several households in the Khulo district daily to record damage due to landslides and small mudflows. It is clear enough that though landslides themselves are practically unavoidable, the damage to infrastructure could be far less if better-adapted ways were used in building and road construction and in other economic activities.

In the last 20 years, under current climate changes, the socioeconomic processes act as a catalyst of natural hazards, primarily, of landslides. Single crop tobacco farming fell after the USSR breakdown and unemployment and low income lead to disregard for the nature protection rules and landslide prevention and mitigation. Soil- and water-conservation forests have been subject to intensive illegal cutting, and that is a strong factor of landslide aggravation. At present, more than 250 settlements with about 20,000 households are located in the areas of high risk [Jorbenadze, 2010].

Land shortage forces people to use every available parcel of land. Geomorphological survey in the Skhalta River canyon, the northern macroslope of the Shavsheti Ridge, showed that many settlements and agricultural plots in the lower portions of the valley slopes are located on landslide deposits. A chronological sequence of three landslide bodies along the left riverbank was studied; the time interval between the landslide events was estimated using direct and indirect evidence related to a 40-60 yr time-period. The sequence is as follow:

1. The landslide of April 15, 1988.

2. The landslide that occurred about 60 yrs ago (the age based on the eye witnesses' accounts and the age of the forest on the landslide, main scarp, and zone of depletion).

3. The landslide that occurred about a century ago (dated by circumstantial evidence, including age of the forest on the landslide, main scarp, and zone of depletion].

On April 15, 1988, a large mass of loose sediments slumped from the north-facing slope, impounded the river, and covered the opposite riverbank. A part of Tsablana village was buried under masses of loam and debris.

The slump was detached from the mountain slope at an altitude of about 1800 m, the height of fall was approximately 400 m, and the travel distance exceeded 3 km. The river was impounded with a dam 10-15 m high. Luckily, the dam erosion proceeded at a slow rate, so no catastrophic flood happened downstream. The total volume of the landslide composed mostly of mixed rock fragments, rubble, and clay was roughly estimated at $20x10^4$ m^3. About a half of the volume got into the river and was washed down; some material was moved to the river later, in the process of erosion followed.

Fifteen years later, in 2003, the remnants of the landslide mass deposited at the base of the slope became a cone-shaped body, partly forested, its surface bearing low transverse ridges, hollows infilled with sand and clay, as well as with individual large rock fragments and tree debris (Fig. 2). On the riverbank, there is a distinct line of initial surface buried under the sliding mass; it may be seen that deposits of the landslide toe are unstable and are being eroded by overland flow. The uppermost 5 cm of deposits consisting of mixed small debris and loam with coarse organic matter may be regarded as the initial stage of soil formation. Below the deposits, there are sand, loams, and clay more densely packed and even cemented into non-sorted mixture of rubble, with occasional fragments of solid rocks. As the slope mantle was initially deeply weathered, the debris can be easily crumbled in hands into sandy loam or clay. The landslide scarp has open surface and the zone of depletion is sparsely vegetated; at the time of rain, they yield fine material washed downslope onto the surface of the landslide body.

Fig. 2. The 15-yr old landslide (the photo taken in 2003). The Skhalta River valley, Mountainous Adjaria, Georgia Insertion in the left corner: initial soil profile, stony-loamy non-graded mineral matter

The second, more recent, investigated landslide is located downstream on the same side and topographic position in the Skhalta valley (Fig. 3). It is similar to the above-described landslide in size and configuration, though its surface is more flattened and covered with coniferous forest. In the lower flat portion of the landslide, the forest was clear-cut and the area was converted into a hayfield. Stones removed from the surface and topsoil were piled up in heaps and the surface was repeatedly ploughed and sown with perennial grasses. According to the local residents, the landslide surface recultivation began about 20 years after the event and took approximately 10 years. Stones have to be removed from the area continuously.

As has been shown by field studies, there exists a relatively well developed soil, with a structured humus horizon up to 10 cm thick and a 30–40 cm thick loam horizon; the latter contains debris in small proportion and is penetrated by grass roots. The soil granulometric composition has been altered by farming in order to create favorable soil conditions for the hayfield and in the course of general agricultural landscape development.

The tip of the landslide body is overhanging the river, so the area may be considered landslide-hazardous. The surfaces of the landslide scarp and the zone of depletion are all forested but for several steep scarps; on the slope above the hayfield, under the forest canopy, there are accumulations of stones transported probably from the scar surface.

The landslide of about 100-yr estimated age is located still farther downstream; it is identical to the landslide described above in topographic position and is located on the same riverbank (Fig. 4). Its tongue has

Fig. 3. The landslide of about 60 years age; reclaimed for a hayfield. Insertion in the right corner: newly reclaimed soil profile (50 cm); humic (mull-moder) A horizon, sandy gravel – loamy subsoil

Fig. 4. The landslide of 100-yr estimated age (or older); developed area and farmland. Insertion in the left corner: reclaimed soil profile (50 cm); humic (mull) aggregated A horizon, fine gravel – loamy subsoil

reached the river and the landslide itself is almost undistinguished against the slope background. The main scarp is forested with some open surfaces; the zone of depletion is completely forested. The landslide surface, except for its lowermost part, is covered completely with thick coniferous forest. The lower part presents a cultivated landscape typical of Mountainous Adjara (residential buildings, vegetable gardens, orchards, etc.).

At the cultivated part of the landslide, soils consist of a thick (up to 20–30 cm) humus horizon underlain by a loamy horizon, reaching 60 cm or more and bearing all the signs of alteration by pedogenic processes. The soils are very fertile because of abundance of nutritional minerals supplied by debris weathering and fertilization.

Local residents and authorities explain that the described plots are very suitable for settling and cultivating. Before the event, there were steep forested mountain slopes quite unsuitable for farming and development. The landslides created landforms with relatively gentle slopes and, which is even more important; they accumulated great masses of loose material – a valuable agricultural resource in mountains. Twenty to thirty years after the event, the landslide surface solidified; its sides spread laterally and became gentler. Residents of mountainous regions have become quite accustomed to stone removal from the fields for many centuries, so this does not represent a problem for their activities. Approximately 40 years after the event, the catastrophe is forgotten and the landslide surface is used for residential development and agriculture. The land is regarded as top-quality and, under the shortage of cultivable lands, its origin is not a concern.

There are many other regions of the Caucasus where landslides have been long used for agriculture. Thus, landslide bodies were used for slope development into agricultural terraces in the central part of the North Caucasus, in North Jurassic intermountain depression, where the slopes are composed of schist. As a rule, people use small slumps when almost undisturbed blocks of regolith move and form bench-like steps. People level slump surface, reinforce its base, and use it for growing crops. The slopes transformed in this way are usually resistant to surface wash and erosion, though repeated sliding and slumping cannot be excluded. Terrace steps are identifiable as landslides by preserved scarps upslope. Another evidence of their origin is buried soil preserved locally under the terrace body. In case of a build-up terrace, not resulting from slumping, the original surface soil is usually disturbed.

Studies of soils and deposits buried under landslides allow the event to be dated; besides, they provide insight into environments of the past and the history of the region settlement. The material brought downslope by slumping and sliding covers settlements and makes people leave their territory; at the same time, it seals and preserves information on the past environments and historical events, if it has such a magnitude that the buried surface is preserved and could be discovered later on [Gracheva & Golyeva, 2010].

CONCLUSION

Being a part of the global process of the earth surface denudation, transport of loose material by landslides is of vital importance for particular mountainous areas, their environments, and the population. Such consequences as destruction of cultivated lands, houses, and infrastructure require great efforts for damage compensation. Another consequence is irrecoverable loss of loose material, soils, and their most important constituent – fine earth. Eventually, this loss results in a dramatic reduction of biodiversity, ecosystem productivity, depopulation of the territory, and its turning into badlands. There is information on loose material losses for many landslide events in the world. It is possible to calculate the volume of the lost fine earth washed away by rivers; such calculations have been already performed, though for only few cases. But it is still uncertain whether it is possible to forecast environmental evolution and social development in mountainous regions under catastrophic loss of soil and regolith from vast areas.

It should be noted, however, that the landslide role in mountainous regions extends beyond destructive activity and removal of soil and regolith. By transportation and deposition of loose material, landslides promote rejuvenation of mountainous ecosystems and development of new soils, as well as creation of new sites for settlement. New surfaces become exposed to weathering and new landforms emerge forming new habitats for biota and, thus, starting new cycles in ecosystem development. Stabilized landslide deposits provide a potential resource of loose mineral material and the newly formed landforms are being adapted to the needs of the people.

The case study of a chronological sequence of landslides in the Adjara-Trialet mountainous system presented herein shows that people can colonize and cultivate landslide accumulations within a few decades. Fifty to sixty years after the event, sediments appear to be essentially altered by remediation measures and the resulting soils are suitable for agriculture. This is of great importance in the region deficient in cultivable lands. Thus, the landslide process implies potential for long-term recovery from rapidly inflicted damage.

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CARBON BALANCE OF FOREST ECOSYSTEMS UNDER GLOBAL WARMING: LANDSCAPE-ECOLOGICAL PREDICTIVE MODELING

ABSTRACT

This paper presents the results of application of landscape-ecological methods for evaluation of biotic regulation of the carbon cycle in forest ecosystems. Methods for constructing analytical and cartographic empirical-statistical models for identification of forest associations and zonal/regional types of forest formations capable of stabilizing the continental biosphere under changing climate are described. Possible biotic regulation of the carbon cycle under known scenarios of future greenhouse warming is suggested. The maps on the carbon content and its changes in the forests of the Oka river basin are presented.

KEY WORDS: ecosystem, biogeocoenoses, climatic changes, empirical statistical modeling, cartographic approach, ecological prediction.

INTRODUCTION

Understanding mechanisms of sustainability of the continental biosphere under changing climate is connected, in many respects, with studying the biotic regulation of the carbon cycle in the soil–vegetation–atmosphere system. These problems have already been highlighted in quite a number of papers both in Russia and abroad [Gorshkov, 1994; Climate..., 1996; Aber et al, 2001; Celniker, 2006; etc.]. However, while a strong emphasis is placed on a procedure for determination of carbon pools in different components of phytobiota and in soil, as well as on the functioning of the carbon cycle and the current carbon content in forests, wetlands, and other ecosystems, problems of quantitative assessment of responses of different biotic components of the carbon cycle to global climatic changes are illustrated to a much lesser extent. Thus, there are actually no predictions of the climatogenic dynamics of factors effecting biotic regulation of CO_2 content in the atmosphere.

Further development of the concept of biotic regulation may be achieved through studies of local-regional mechanisms of the biological cycle that provides stability of natural environment in accordance with the Le Chatelier's principle. Biogeocoenoses (landscape facieses), i.e. ecosystems of the topological level, is the most complex and active part of natural environment, i.e., its functional "core" [Sochava, 1974]. This elementary unit of geographical ecology accepted in Russia corresponds to the categories "site", "ecoelement", and "landtype phase" in classifications of Australia-Britain, Canada, and USA, respectively [Klijn and Udo de Haes, 1994]. Spatial diversity of biological cycles is created primarily by structural heterogeneity of biogeocoenoses. The concept of biotic regulation of the carbon cycle in the biosphere has not been yet developed in such statement of the problem.

The forest cover is one of the leading factors providing for the stability of the continental biosphere. Forest ecosystems are the most potent regulators and stabilizers of natural biogeochemical cycles [Sukachev, 1972], including the carbon cycle and the temperature regime of the atmosphere [Gorshkov, 1994]. Global-scale deforestation is considered one of the main causes of the increasing greenhouse effect.

BACKGROUND

This problem was addressed in the previous regional environmental forecast studies of forest ecosystems in the headwater area of the Volga River basin [Kolomyts, 2008]. It has been empirically established that the main channel of connections of regional and local ecosystems with the background climatic system passes through the summer soil moisture which is the most powerful ecological factor predetermining ecosystem territorial distribution and main functional parameters. In turn, this factor itself depends mainly on the average July temperature, while its association with the average January temperature is non-significant. The leading climatic factor of future ecological reconstructions is temperature change during the vegetation period.

Biotic regulation of the carbon cycle under changing climate is determined by the shifts in small biological cycles (phytomass production and degradation). A temporal lag of these functional changes is relatively small. Climatogenic shifts in the rates of phytomass production appear during the first several years in the taiga zone and are completed within a year in the sub-zone of broadleaf forests [8]. Changes in decomposition rates are of the same order, however the total duration of carbon presence in the forest litter, coarse woody debris, and mobile soil humus may take several decades.

THE LANDSCAPE-ECOLOGICAL APPROACH TO THE PROBLEM

The problems of forecasting forest ecosystem dynamics under changing climate have been poorly developed. International prognostic developments [Climate..., 1995; Aber et al, 2001; etc] are mainly small-scale and, hence, cannot reveal basic mechanisms accounting for the spatial variability of responses of forest communities to the same background climatic factors. In addition, behavior of local ecosystems under climatic changes has been poorly studied. The so-called models of landscape mosaic [Forman, 1995] deal with comparatively small areas of the forest cover selected on the basis of functional characteristics of structurally homogeneous areas. However, these models are spatially limited because they describe only typical sites in typical biomes, rather than the entire topological diversity of the ecosystems.

We offer the approach to analysis of biotic regulation phenomena from a broader landscape position. It allows one to identify diverse types of this regulation mechanism determined by the spatial distribution of biogeocoenoses under different zonal/regional conditions. This makes it possible to find the origins of the mechanisms of the phytobiota effect on the carbon exchange between the earth surface and the atmosphere and to identify mechanisms that ensure the resistance of terrestrial ecosystems to climatic changes.

The local landscape-ecological prediction presented herein is based on construction of discrete empirical-statistical models of much more complicated geo-(eco-) systems [Rozenberg, 1984; Kolomyts, 2008]. These models describe behavior of geo-(eco-) systems as the indivisible complex formations in the aspect of the Sukachev's biogeocoenoses concept [Sukachev, 1972]. They make it also possible to work with a small number of the most informative characteristics. The results obtained are probably not as accurate as, for instance, at simulation modeling [Aber et al, 2001], but they have a higher level of spatial resolution.

FIELD DATA FOR MODELING

Materials of large-scale landscape-ecological surveys carried out by the authors at six experimental test sites of the Middle and

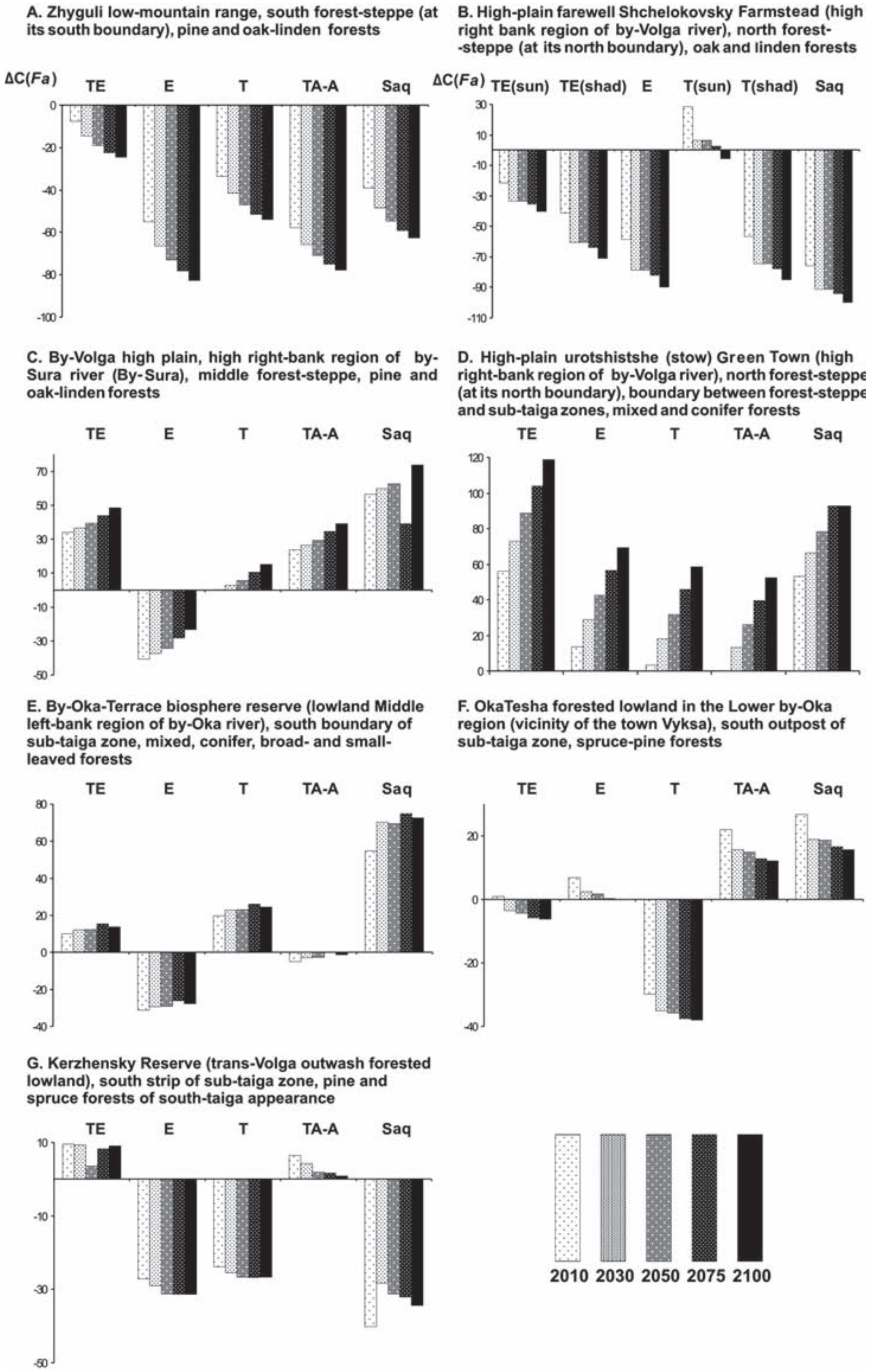


Fig. 1. Landscape couplings of the predicted carbon balance dynamics in forest biogeocoenoses under different zonal/regional conditions of the Middle and Upper Volga Regions, according to the scenarios of HadCM3 model.

ΔC(Fa) – carbon balance (t/ha); TE, E, T,... – local sites (see in the text); solar exposed slopes: sun – sunny, shad – shady and neutral

Upper Volga Region (1987–1998) were used in a method specifically developed for the forecast analysis. These test sites contain a wide range of zonal plant formations, from the southern forest-steppe to mixed forests (Fig. 1). Each of these test sites characterizes a particular *regional ecosystems*, with the corresponding conventional name (Zhyguli, Shchelokovsky Farmstead, By-Sura, Green Town, etc.

Six facies groups that represent general diversity of forest types and test sites have been isolated based on 45–50 sample areas in each of the test sites. The facies groups were located along the vector of the local landscape couplings (microcatenae) in the direction of edaphic moistening increase: from the eluvial (E) and the transeluvial (TE) types of local sites (geotopes) through the slope transit (T) and the transaccumulative (TA) to the accumulative (A) and superaqual (Saq), according to the classification [Glazovskaya, 1964].

A similar system of landscape couplings is characteristic of the mesorelief types at the regional level couplings [Polynov, 1956]. The flat interfluve (placor) group was isolated within the biogeocenoses (this group occupies eluvial locations and represents a local type of zonal bioclimatic norm for a given ecoregion). The biogeocenoses of other geotopes were considered extrazonal, reflecting background condition of other regions, often considerably distant.

The following phytomass parameters (*t/ha*) were used for calculation of the carbon balance: (1) skeletal tree-shrub phytomass, *BS*; (2) root mass, *BR*; (3) total green mass, *BV*; (4) forest litter mass, *ML*; (5) debris – dead skeletal mass (brushwood and dead-wood), *WD*; (6) humus in soil organic-mineral layers, *HU*.

The regional climate scenarios for the period to 2100 were taken from one of the most extreme global coupled atmosphere ocean general circulation models (AOGCMs) [Climate..., 1996] – HadCM3, version A2 (Hadley Centre of Climate Research, UK) [Pope et al, 2000]. Ecological prediction by this model permits one to evaluate the forest ecosystems feedback to global climatic changes that may exceed the level of tree endurance and cause the disintegration of both nemoral and boreal forests within large areas.

The entire forecast period in our analysis included five intervals (20–25 yrs duration): 1985–2010, 2010–2030, 2030–2050, 2050–2075, and 2075–2100. The period of meteorological observation for 1881–1985 represented the baseline. Recent global warming began at the end of this period [Climate ..., 1996]. The model forecasts a 5.5–7.0° increase of the mean July temperature in the Middle Volga Region by the end of the 21st century. According to this scenario, the annual precipitation will remain virtually unchanged; therefore, the humidify factor C_{hum} will decrease from 0.95 to 0.36 in the southern forest-steppe of the Zhyguli region and from 1.37 to 0.65 in sub-taiga of the Volga region. Thus, until the year of 2100, the thermo-arid climatic trend will be developing in the entire Middle Volga Region. We have assumed this scenario as the basis for our analysis of climatogenic dynamics of the functional parameters of forest ecosystems.

METHODS OF FORECAST ANALYSIS

The Le Chatelier's principle for stability of natural environment is expressed by the following postulate [Gorshkov, 1994]: the state of environment will be stable if any spontaneous increase of CO_2 content in the atmosphere is accompanied by an equal enhancement of carbon utilization by the terrestrial and ocean biota. An apparent violation of the Le Chatelier's principle is the transformation of biota from the carbon sink into the carbon source, i.e., the situation when biota releases CO_2 into the atmosphere under external influence.

The potential of biotic regulation has been assessed using hydro-thermal ordination of metabolic characteristics of forest topoecosystems under different zonal/

Table 1. Examples of calculation models that describe changes of biogeocoenotic biological cycle parameters of different regional ecosystems in the Middle Volga Region under trends of changes in soil temperature and soil moisture content during the vegetation period

Model type (calculation formula) *)	**Regional eco-systems (see Fig. 1)**	**Parameters (see in the text)**	**Coefficients**			**Statistical characteristics **)**		
			b_0	b_1	b_2	R	P	S_y
$y = b_0 + b_1x_1 + b_2x_2$	By-Sura	*BV*	21.93	–0.7415	**–0.7135**	0.664	0	3.09
		HU	5.99	0	**55.75**	0.696	0	20.29
	Zeleny	*BR*	8.712	5.838	**–0.0678**	0.582	$0.1 \cdot 10^{-3}$	17.92
					0.07426	0.713	0	
	Gorod Shchelokovsky Hutor	*HU*	16.34	–0.2402				
		ML	27.18	–2.333	**0.04896**	0.717	0	6.51
$y = b_0 + b_1x_1 + b_2x_1^2$	Shchelokovsky Hutor	*WD*	642.1	–114.7	5.142	0.936	0	2.21
$y = b_0 + b_1x_2 + b_2x_2^2$	Zhyguli	*ML*	44.08	–0.3611	0.00091	0.699	0	17.75
	Shchelokovsky Hutor	*BS*	–34.93	0.9472	0.00403	0.769	0	90.49
		HU	12.5	0.1712	0	0.649	0	9.31
	Kerzhenets	*WD*	22.85	–0.2588	0.00149	0.72	0	12.78
		HU	8.84	0.0091	0.0006	0.851	0	8.03
	Prioksko-Terrasny reserve	*BS*	244.6	0.3956	–0.00312	0.557	$0.7 \cdot 10^{-3}$	71.4
		HU	25.31	0.0159	0.00042	0.577	$0.4 \cdot 10^{-3}$	16.32
$y = \exp(b_0 + b_1/x_1)$	Zhyguli	*BS*	3.706	15.42		0.611	0	39.3
		BR	1.768	26.26		0.614	0	12.25
	Zeleny	*ML*	0.0845	35.08		0.506	0	16.0
	Gorod	*WD*	–4.389	64.63		0.642	0	7.0

*) x_1 – soil temperature at 50 cm depth (t_{50}); x_2 – stored soil moisture in 0–50 cm layer (W-50).

**) R — coefficient of correlation; P – significance level (the Pearson criterion);

S_y — coefficients of standard deviation. Significant arguments in equations of multiple regression are shown in the bold font.

regional and local conditions (an empirical simulation of anticipated climatogenic changes of biological cycle). The ordination was performed by soil temperature at the depth of 50 cm and by summer productive moisture reserves of the 0–50 sm soil layer. As can be seen from Table 1, the correlation is not always high, though quite significant ($P \ll 0.05$). At a weak connection, the latter can be interpreted only as a certain general tendency of changes of given parameters under the influence of the geophysical trend.

To assess changes of the carbon content in different biotic components, we used the so-called forestry method based on the dynamics of live and dead phytomass. This method gives the best results at balance assessments of the carbon cycle components for long periods of time [Celniker, 2006]. The change ΔC(*Fa*) of the carbon flow in the soil-plant-atmosphere system was calculated as follows:

$$\Delta C(Fa) = \Delta C(WD) + \Delta C(ML) +$$

$$+\Delta C(HU) - \Delta C(BS) - \Delta C(BV) - \Delta C(BR). \quad (1)$$

This balance equation was used to calculate possible changes of the carbon flows between the soil-plant cover and the atmosphere for different periods of the forecast for each group of facies in all examined six regional ecosystems (mentioned above). Each member of the right part of the equation (1) may have both positive and negative values. At positive values, the first three members of the equation provide for an increase of CO_2 emission from the soil-plant cover to the atmosphere, while the other three members provide for a decrease of this flow. In this case, the dead phytomass pool acts as an additional carbon source, while the live phytomass plays the role of its sink (i.e., deposit).

At negative values of the above parameters, the results are quite the opposite. Thus, the overall balance of changes of carbon exchange between biogeocoenoses and the atmosphere is described by $\Delta C(Fa)$, which shows whether this group of forest ecosystems consumes additional amount of CO_2 from the atmosphere due to the shifts in the biological cycle induced by global warming or, on the contrary, becomes a source of additional CO_2 emissions.

New methods of geomorphometry were used in the cartographic part of the forecast analysis [Shary, 2001; Shary et al, 2002]. Multidimensional environment-forming properties of relief allow interpolation and extrapolation (substantiated during the analysis) of the data measured (or calculated) on representative test sites, thus significantly extending the boundaries of the analyzed territory. The currently known methods of a quantitative relief description are confined to six basic morphometric values. Herein, we used a system of 18 parameters introduced by P. A. Shary [Shary et al, 2002].

At the local level, large-scale mapping (1:50–100,000) was based on predetermined, statistically significant linkages of the structural and functional characteristics of local ecosystems with morphometry of the relief. Morphometric parameters were derived from the NASA data (SRTM3, Shuttle Radar Topography Mission at resolution 3" arc seconds or 90 m on equator, http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/) on the earth surface elevations as matrices with a cell size (grid spacing) of 50 m recalculated into the Gauss-Kruger projection for the 9th 6° zone. For instance, the following multiple regression equations (with the corresponding Spearman correlation coefficient r_S and the level of significance P) were obtained for the Zhyguli ecoregion:

the total C sources of the baseline period –

$$C_{base} = 222.6 - 55.6 \cdot GA - 25.6 \cdot Q - 12.6 \cdot H; \ (r_s = 0.87,\ P < 10^{-6}); \qquad (2)$$

the change in the total C stocks by 2050 –

$$\Delta C2050 = -99.8. + 47.1 \cdot GA + 25.3 \cdot Q + 18.0 \cdot H; \ (r_s = 0.88,\ P < 10\text{–}6). \qquad (3)$$

Here, H – mean curvature; designations of other predictors are given in the note to Table 3.

Regional maps were constructed using the NASA satellite data on the relief: the matrices of earth surface elevations obtained as a result of implementation of SRTM project (SRTM30, Shuttle Radar Topography Mission, at resolution 30" arc seconds or 900 m on equator, http://dds.cr.usgs.gov/srtm/version2_1/SRTM30/).

The Oka river basin was taken as the model territory at the regional level. The matrix for this basin was transformed into the Kavraysky VII INT projection for the European Russia with a 900 m grid. In advance, the statistical analysis of spatial differentiation of changes in the total C content had been performed for predictive periods for the plant formations and their combinations using program "Analytical GIS Eco" [Shary, 2001].

Transition from the local to the regional level of forecast with construction of maps at 1:2,500,000 scale was carried out using our method of induction-hierarchic extrapolation. The method utilizes the empirically established phenomenon of poly-zonality of local geo-(eco-) systems as a form of their response to global climatic changes [Kolomyts, 2008]. The regional systems of local zonality were isolated based on the identified patterns of the influence of local geomorphological and edaphyc factors on the background regional-bioclimatic environment. These regional systems are composed of the vector rows of flat interfluve and extrazonal biogeocoenoses (see above) that correspond to the vector of the predicted climate changes. These rows may serve as a model of the main trends of ecosystem changes.

The procedure of extrapolation was as follows. Each type/subtype of plant formations distinguished on the small-scale geobotanic map was correlated with a certain group of biogeocoenoses from their flat interfluve and extrazonal series in a given ecoregion. This series characterizes the regional spatially ordered system of local zonality (microcatena). Then, each range of a given formation represented as a poly-vector set of mesocatenae was broken into mesosites, i.e., the links of the chain of the regional landscape couplings (E → TE → T → TA, A; see above), with division of the TE and T locations into two solar-exposure gradations (sunny and shady). New methods of geomorphometric statistics were applied. Then, it was possible to create an intermediate map of mesoscale sites for the entire forested area of the region. For the Oka river basin, such map was compiled using multiple regression equations applied to the data of the test sites Shelokovsky Farmstead, Green Town, Vyksa, Kerzhenets, and the Prioksko-Terrasny reserve.

Assuming that in accordance with the B.B. Polynov's conception of landscape couplings [Polynov, 1956] a mesocatena is a homomorphic image of microcatenae, we aggregated the biogeocoenoses of all isolated groups at each test sites into mesogeotopes of a corresponding geobotanical range. Thus obtained the regional phytocatenae mosaic was, then, supplemented with the baseline or predictive metabolic parameters of the biogeocoenoses serving as local representative members of different zonal-regional types/subtypes of the geographic environment. The described algorithm of induction-hierarchic extrapolation is a fundamentally novel method of regional predictive mapping based directly on the materials of field landscape-ecological surveys.

MODELING RESULTS AND THEIR DISCUSSION

Predictions by Analytical Models

The main results of the empirical-statistical prediction are given below (they are described in more detail in our previous publications [e.g., Kolomyts, 2008; Kolomyts and Rozenberg, 2009].

1. The decomposition part of the biological cycle, as a rule, is more sensitive to climatic changes than the productivity part [Kolomyts, 2009]; therefore, the decomposition part should react to climatic changes first. At the same time, during sufficiently long periods of time, the maximal (by absolute values) changes occur not in the decomposition part of the cycle, but in its autotrophic biogenesis part. The skeletal tree-shrub phytomass (BS), mainly increment of woody biomass, represents the greatest part of the shifts of productivity (Table 2). By 2100, changes of the total carbon content [ΔC(*BS*)] in its extreme values will range from – (37–62) *t/ha* in E and TA of oak-linden forests of the Zhiguli and Shchelokovsky Farmstead to + (95-100) t/ha in TE and E of coniferous-broadleaf forest of the Nizhnyi Novgorod Volga region. The extreme values of changes Δ*C*(*Fa*) will comprise from –(78÷100) t/ha to +(115÷120) t/ha. These values represent the potential range of climatogenic changes of the carbon flows in the live skeletal phytomass and in the biogeocenoses in general. The baseline values for the first, second, and the third regions were 140–190, 134–2,112, and 180–243 t/ha, respectively. Therefore, in the coming century, the content of carbon

Table 2. The forecasted component and balance changes in the carbon content (*t/ha*) relative to the baseline period in flat interfluve forest biogeocoenoses under different zonal-regional conditions of the Middle and Upper Volga Regions

Parameters (see in the text)	Base values	Changes in predicted periods				
		2010	2030	2050	2075	2100
a) Zhyguli						
BS	82.78	–23.05	–27.32	–31.55	–35.78	–39.66
BV	4.39	–1.60	–1.77	–1.93	–2.10	–2.26
BR	30.25	–11.90	–14.08	–16.13	–18.06	–19.72
WD	10,24	–6.98	–7.53	–8.02	–8.45	–8.80
ML	5.24	3.56	4.90	6.34	7.78	8.99
HU	61.47	–10.54	–15.29	–18.62	–20.68	–21.66
Balance	198.61	–50.51	–61.09	–69.91	–77.29	–83.11
b) By-Sura						
BS	123.42	–18.99	–14.77	–10.84	–3.31	2.90
BV	5.17	–0.60	–0.61	–0.84	–0.93	–1.13
BR	40.40	–8.88	–8.04	–7.82	–6.46	–5.64
WD	4.90	–1.06	–1.23	–1.46	–1.71	–1.91
ML	5.88	–1.28	–1.60	–2.03	–2.45	–2.79
HU	31.64	–9.76	–11.09	–11.45	–13.53	–14.76
Balance	211.41	–40.56	–37.34	–34.42	–28.39	–23.33
c) Green Town						
BS	134.14	13.73	26.61	38.16	49.82	60.19
BV	6.59	1.90	2.32	2.65	3.01	3.30
BR	39.48	4.44	7.99	11.09	14.28	17.06
WD	4.06	–3.46	–3.63	–3.73	–3.80	–3.84
ML	5.48	–0.13	–1.00	–1.60	–2.05	–2.38
HU	11.16	–1.71	–2.28	–2.65	–3.11	–3.43
Balance	201.36	14.77	30.0	43.91	58.15	70.9
d) Prioksko-Terrasny reserve						
BS	155.09	–27.14	–27.85	–27.76	–27.99	–27.91
BV	6.00	–1.98	–1.88	–1.89	–1.87	–1.88
BR	42.41	–4.11	–4.30	–4.28	–4.34	–4.32
WD	15.66	–7.44	–7.19	–7.21	–7.15	–7.17
ML	7.48	6.58	9.44	9.58	12.69	11.14
HU	12.79	2.84	2.52	2.55	2.48	2.51
Balance	239.43	–31.24	–29.25	–29.0	–26.17	–27.61
e) Kerzhensky reserve						
BS	84.7	–13.00	–12.64	–11.86	–11.85	–11.15
BV	4.41	1.21	1.19	0.82	0.86	0.60
BR	17.08	–9.44	–9.81	–11.68	–11.60	–12.59
WD	7.85	0.40	–0.26	–0.31	–0.40	–0.64
ML	10.15	–3.91	–4.16	–4.71	–4.73	–3.45
HU	13.69	–2.45	–3.41	–3.50	–3.66	–4.09
Balance	137.88	–27.19	–29.09	–33.24	–31.38	–31.32

stored in the skeletal phytomass of the forest ecosystems of the Middle Volga region may change by ±(25–50)% and more on average compared to the baseline values. This fact points to quite a significant regulating role of the regional mixed and nemoral forests' productivity in their carbon exchange with the atmosphere.

2. Global warming will induce, in some cases, an abrupt drop or, in other cases, an increase of similar magnitude of forest productivity, which will directly affect the carbon balance. Zonal-regional contrasts of biotic regulation of the carbon cycle may be evaluated by the value Δ(*Fa*) for the eluvial (flat interfluve) ecosystems (see Table. 2).

Within the territory of the southern and the middle forest-steppe, there will be an unambiguous and quite clear decline of the productivity potential of forest communities. Carbon deposition in the skeletal phytomass will decrease most quickly in flat interfluve mesophilic elm-lime and oak forests of eroded-loamy uplands (see Fig. 1, A–C). Their role as a sink of atmospheric carbon will diminish. The rates of carbon sequestration in the skeletal phytomass within the aqueous-glacial plains of the nemoral-forest sub-zone, the most hydromorphic A and EA–Saq birch-spruce-pine forests will be markedly reduced. At the same time, the rate of carbon sequestration of xeromorphic biogeocoenoses, particularly of forest-meadow-steppe communities on steep sunny slopes and that of pine steppified forests of well-drained watersheds, will change little; therefore, their contribution to the changes in the carbon balance will be insignificant.

At the same time, soil moisture deficit of the zonal forest-steppe ecotones will increase under global warming and impede decomposition and mineralization of the above ground dead organic matter. This will results in the increase of forest litter mass *ML* and debris *BW*. However, there will be even greater mineralization of the humus mass *HU* resulting in additional CO_2 emissions to the atmosphere (see Table 2, *a*).

The primary productivity and reserves of living organic matter of the mixed and dark coniferous forest biogeocoenoses of the forest-steppe zone (at the northern boundary) and of the southern strip of the sub-taiga zone will increase (and quite significantly). Accordingly, conservation of atmospheric carbon in the perennial skeletal phytomass of these topoecosystems will also increase and, as a consequence, the significance of this phytocoenotic pool as a carbon sink will increase as well (see Table 2, *c*, and Fig. 1, D). On the other hand, the thermo-arid trend will intensify the processes of decomposition of dead organic matter even further and, correspondingly, will reduce its mass (including the forest litter) and the humus mass as well. These processes will result in additional release of CO_2 from the soil-plant cover to the atmosphere.

On the outwash forested lowlands of the sub-taiga zone, the thermo-arid trend will induce a decrease of the total annual forest production, which must result in a lower amount of CO_2 bound by photosynthesis. Changes in the detritus part of the biological cycle will be more explicit and intensive. Soil temperature rise and soil drying will increase abruptly degradation of dead organic matter with higher degree of its utilization and additional release of CO_2 to the atmosphere (see Table 2, *e*, and Fig. 1, F, G).

3. Under global warming, two mutually antithetical phenomena of carbon cycle biotic regulation in the soil-vegetation-atmosphere system will be developing on the Russian Plain. The extreme south of the forest zone will be the source of significant additional emissions of carbon to the atmosphere. Accordingly, the natural balance of the carbon cycle as one of the leading stabilizing mechanisms of the continental biosphere will be disturbed. It will inevitably accelerate the process of degradation and disappearance of marginal forests in the southern and typical forest-steppe. The flat interfluve conifer and mixed

forests of the sub-taiga outwash lowlands will play similar negative role in the change of the carbon balance.

The main positive biotic regulation of the carbon exchange between the terrestrial ecosystems and the atmosphere reducing the greenhouse effect (according to the Le Chatellier's principle) will be performed by mixed and coniferous forests of high plains in the nemoral-forest sub-zone and in the southern strip of the sub-taiga zone. Excessively moist forests and extremely dry pine forests of sub-taiga outwash lowlands will be of secondary importance. Probably, this is the only group of formations of boreal forests that will essentially support the stability of continental biosphere under global warming.

Predictive Scenarios in Cartographic Expression

As examples, let us consider the cartographic models of the carbon balance of forests for the period up to 2050. The fragments of C_{base} and $\Delta C(Fa)$ maps of the Zhyguli forests are presented at the local level (Fig. 2). In the baseline period,

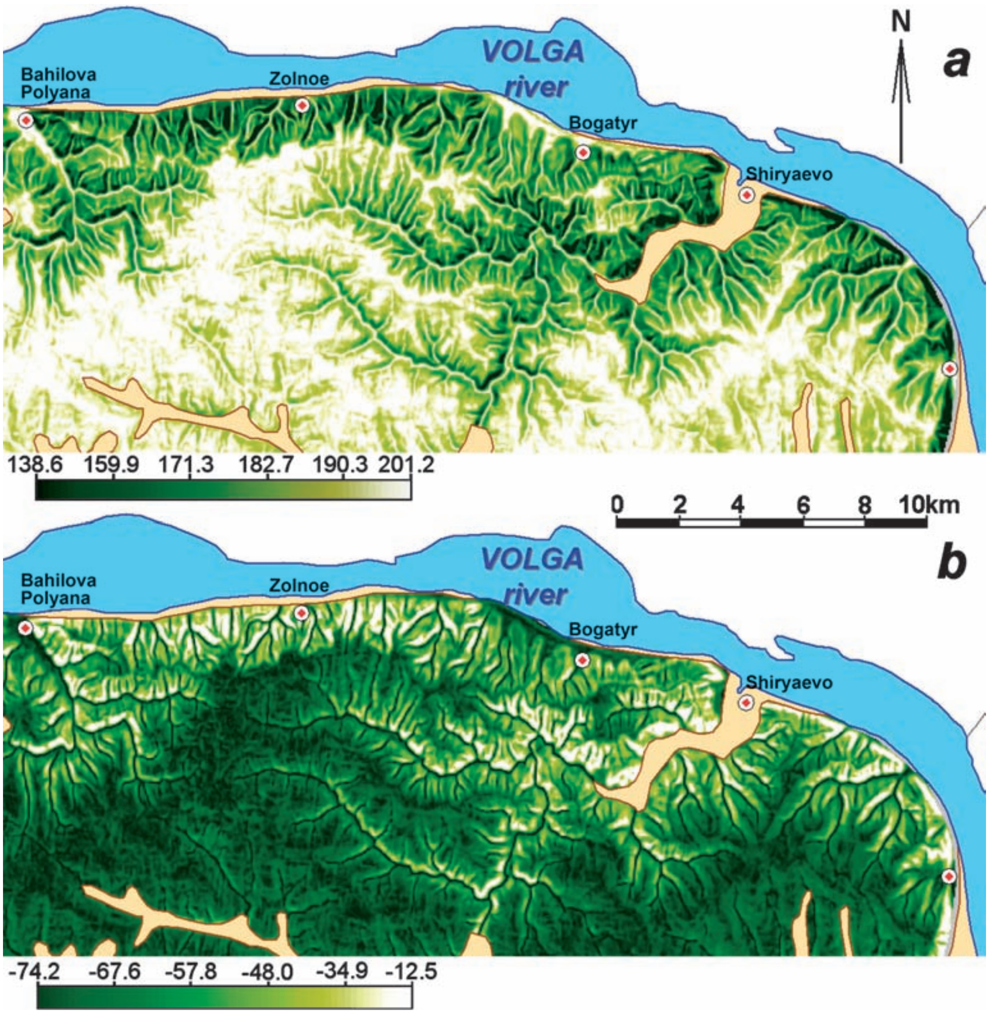


Fig. 2. The total carbon content in forest ecosystems in the territory of the Zhyguli ecoregion (*a*) and changes in the total carbon content for the predicted period of 2050 (*b*), in t/ha, according to HadCM3 model

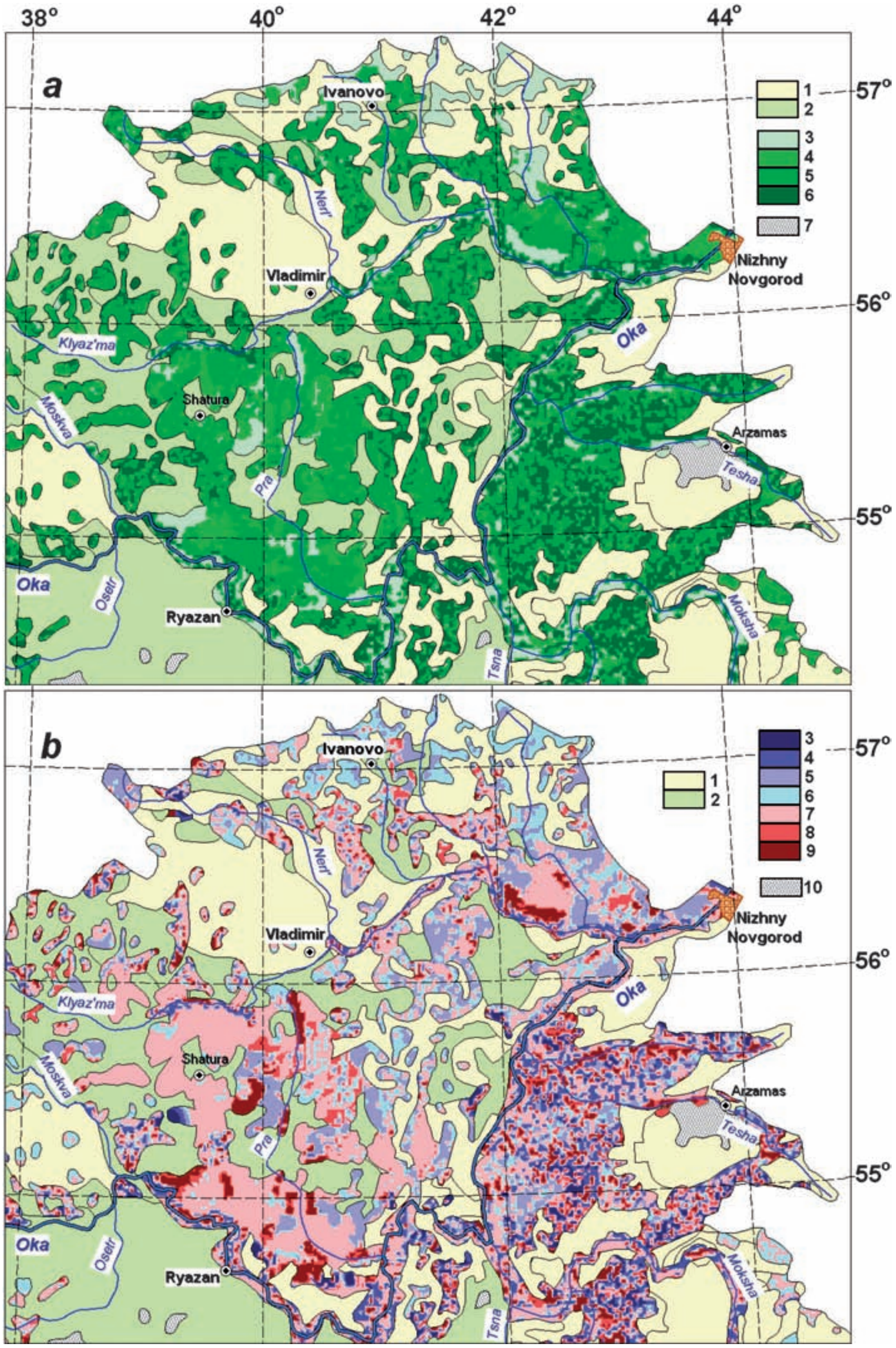


Fig. 3. The fragments of the maps on the total carbon content and its forecasted changes within the territory of the Oka river basin.

a. The distribution of the carbon content at the end of the baseline period (1985). The carbon stocks (t/ha): 1 – 10.2–15.0; 2 – 15.0–19.3; 3 – 43–130; 4 – 130–160; 5 – 160–200; 6 – 200–423; 7 – the northern area of steppes

b. The changes in the total carbon stocks for the forecast period of 2050 relative to the baseline (t/ha): 1 – (–1.3)÷0; 2 – 0÷5.5; 3 – (–115)÷(–89); 4 – (–89)÷(–38); 5 – (–38)÷(–12); 6 – (–12)÷0; 7 – 0÷38; 8 – 38÷63; 9 – 63÷115. 1; 2 – fragmentary large tracts of forest among agricultural land; 3–9 – forest areas. 10 – the northern area of steppes

Table 3. The equations of connection between carbon content changes and the most important environment factors in forest formations of the Oka river basin to the year of 2050 ($\Delta C(Fa)_{2050}$)

Groups of plant formations	Regression equations
a) Spruce and broadleaf-spruce forests	$\Delta C(Fa)_{2050} = 76.7Z + 46.7T + 24.0Q - 63.8$
b) Pine and broadleaf-pine forests	$\Delta C(Fa)_{2050} = -24.0Z + 21.0MCA - 7.1Q + 12.1$
c) Broadleaf forests	$\Delta C(Fa)_{2050} = -76.2T + 42.9MCA + 12.1GA + 5.1$
d) Secondary substituting for pine and broadleaf/pine forests	$\Delta C(Fa)_{2050} = 83.1k_{max} + 76.6MCA + 9.7T - 61.6$
e) Secondary substituting for spruce, pine, and broadleaf forests (all secondary forests of basin)	$\Delta C(Fa)_{2050} = 37.5MCA - 18.4GA - 10.9T + 12.7$
f) Primary and secondary forests of basin (all basin forests on their contemporary areas)	$\Delta C(Fa)_{2050} = 28.8MCA + 23.9k_{max} - 7.2T - 7.8$

Note: Predictors in regression equations are: *Z* – elevation; *MCA* –catchment areas; *GA* – degree of slope; k_{max} – maximal curvature that defines the "ridge" landscape forms; *Q* – insolation of slopes with the Sun position at the southern azimuth (180º), sun declination 35º; *T* – average temperature of July.

the highest total carbon stocks are typical of the gentle near-watershed shady slopes of the Zhyguli with the least catchment area. In the forecast period, these locations, as well as the bottoms of small valleys, will be characterized by the maximal CO_2 emissions. On steep slopes, the initial carbon stocks are minimal and the forecasted release of carbon will be insignificant too.

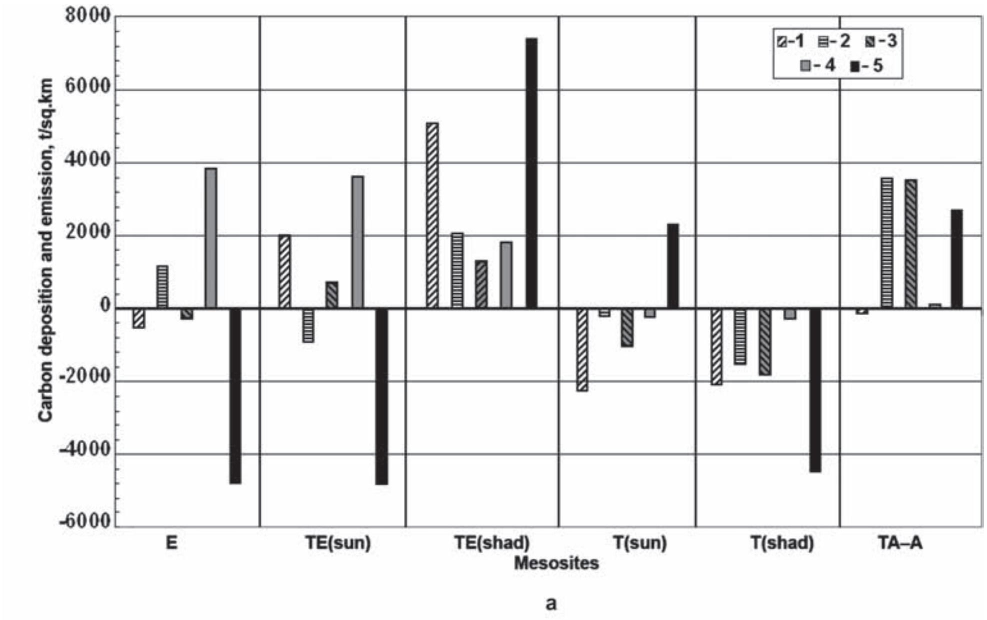
The regional level is represented, as mentioned above, by the Oka river basin (Fig. 3). Multiple regression equations used for construction of the maps are presented in Table 3. Under global warming, the modern forest cover of this territory will perform positive (as a whole) carbon cycle regulation. However, the scale of this regulation will not be of any significance due to relatively low changes in the carbon content in most of the pools, including the skeletal phytomass (see Fig. 1, E, F).

The forecast map shows also the pronounced contrast and frequent patchiness of positive and negative values of the carbon balance. A particularly patchy distribution of ($\Delta C(Fa)$ varying from +(65–100) to –(80–136) t/ha), is typical of the north-western part of the By-Volga Upland that is occupied by complex pine and small-leaved forests. The other regions of the positive biotic carbon cycle regulation are the swampy forested lowland of Ryazanskaya Meshchera and the eastern slopes of the Smolensk-Moscow ridge; there, broadleaf, spruce, and birch-aspen forests are mainly prevalent.

Weakly marked negative $\Delta C(Fa)$ values (0 to –12; occasionally, up to –38 t/ha) will be characteristic to oak-lime and birch-aspen forests of the north-west boundary of the Central Russian Upland, and to broadleaf-spruce and spruce-birch forests of the lowland-outwash left bank of the Klyazma river downstream area and the neighboring right bank of the Volga river. Fragmentary forests on the vast territories of agricultural land will exhibit a weakly marked, for the most part, positive biotic regulation of the carbon cycle.

Territorial Generalizations of Cartographic Forecast

It is necessary to assess the contribution of separate groups of forest formations of the Oka river basin to the total biotic carbon cycle regulation (Fig. 4, Table 4). Spruce and broadleaf-spruce forests will actively deposit carbon at relatively dry TE mesosites, where the temperature rise will induce an intense growth of stands (Fig. 4, ***a***). The maximum carbon deposition may be up to



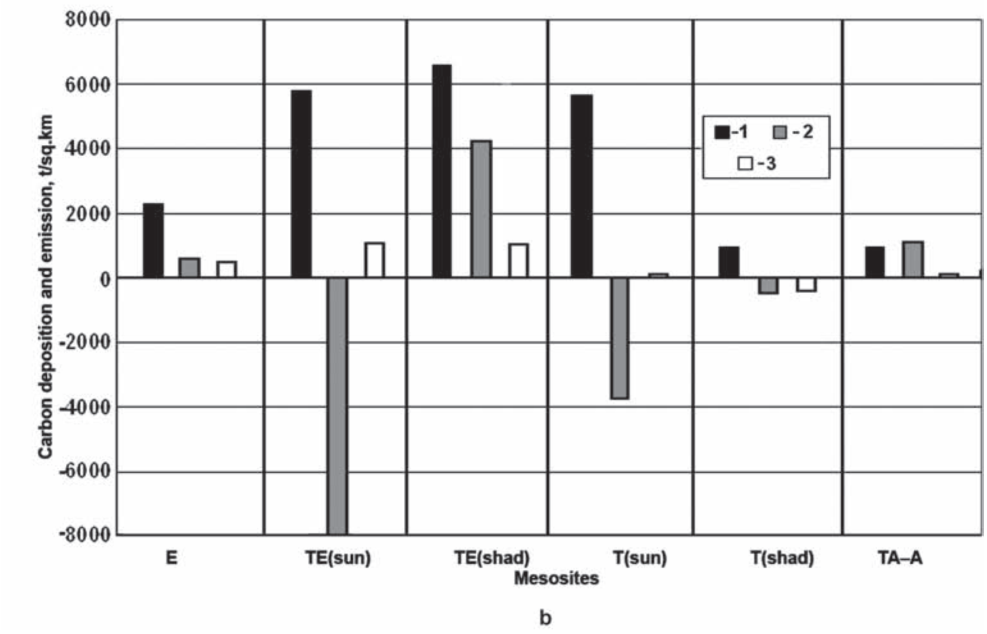


Fig. 4. The changes in the total C stocks in the groups of plant formations of the Oka river basin predicted for 2050 under different conditions of plain mesorelief

a) Aboriginal formations: 1– spruce and broadleaf-spruce; 2 – pine and broadleaf-pine; 3 – broadleaf; 4 – paludal forest; 5 – flood-plain

b) Secondary small-leaved formations in the place of forests: 1– spruce and broadleaf-spruce; 2 – pine and broadleaf-pine; 3 – broadleaf. E, TE, T, types of mesosites (see in the text); sun and shad – solar exposure (see Fig. 1)

4.6–7.5 th t/km^2. At the more hydromorphic E and T territories, carbon deposition in the skeletal phytomass will be surpassed by the carbon emissions as a result of drastic intensification of the processes of forest litter decay and humus mineralization. Overall, carbon deposition in dark-coniferous forests will exceed carbon emissions by nearly 70% (see also Fig. 4, ***a);*** however, because of an insignificant area of these formations, their contribution to changes in the regional carbon balance will be minor.

Pine and broadleaf-pine formations will also have positive effect on the carbon cycle, i.e., their contribution will be 1.5 times stronger, than that of dark-coniferous forests (see Table 4 and Fig. 4, *a)*. Occupying the greatest areas in the Oka river basin, pine forests will make a considerable positive contribution to the regulation of the carbon cycle. Carbon will accumulate mainly in pine forests on the TE and TA–A elements of the mesorelief. Negative values of the carbon balance should be expected in the light-coniferous forests of flat interfluve sites and of gentle even slopes. Broadleaf forests will serve as minor carbon sinks. The main role in carbon deposition will be played by mesohygrophytic oak-lime forests of river valleys and adjacent slopes, especially those facing north. The E and T mesorelief components will act as CO_2 emitters.

Paludal forest formations will provide for the main positive carbon cycle regulation (based on the Le Chatelier's principle) (see Fig. 4, *a*). Global warming will drastically increase their productivity. The CO_2 sequestration in the skeletal phytomass will significantly exceed its emissions from peat litter decay; therefore, 3.6–3.8 th t/km^2 of carbon will be additionally fixed within swamp watersheds by 2050.

The group of floodplain forest formations is expected to have the highest territorial contrasts of ΔC(*Fa*). On the shady and neutral slopes, soil temperature rise and groundwater level decrease will induce significant intensification of productivity. The carbon deposition values there will be maximal in relation to the entire Oka river basin, i.e., up to 7.5 th. t/km^2 (see Fig. 4, ***a***). At the same time, there will be intensification of decomposition in the communities of eluvial and sunny TE sites resulting in additional CO_2 emission of 4.4–4.8 th t/km^2. The resultant contribution of the floodplain forests to the total carbon balance of the region will be positive.

Secondary small-leaved forests will be associated with changes in the carbon content different in sign (see Fig. 4, *b*). Birch and aspen forests substituting for sub-taiga dark-coniferous forest associations grow in higher hydromorphic conditions on sabulous loamy soils. Thermo-arid trend will induce accelerated growth of stands in these communities. In the upper links of mesocatenae, an additional carbon storage in the skeletal phytomass will be 5.7–6.6 th. t/km^2 by 2050. The fact of substitution of secondary birch and aspen forests for spruce and broadleaf-spruce forests i.e., of the permanent presence of initial stages of restorative successions, must contribute to additional deposition of carbon in the growing timber. This seems to be the leading role of the boreal forest cover consisting of dark-coniferous taiga and sub-taiga types in positive carbon cycle regulation according to the Le Chatelier's principle.

On less hydromorphic sandy soils, where small-leaved associations exist in the place of pine and broadleaf-pine forests, there will be a significant negative carbon balance (see Table 4 and Fig. 4, ***b***). Birch-aspen forests growing In place of oak and lime forests will make a relatively little impact on the above described pattern of ΔC(Fa) dynamics typical of their aboriginal precursors.

CONCLUSION

Thus, the biotical carbon cycle regulation by temperate coniferous, mixed, and broadleaf forests under global warming may have both positive and negative

Table 4. Changes of the total carbon stocks (mln t) in plant formations of the Oka river basin by 2050

Forests (groups of plant formations)	Area, km^2	Total carbon (baseline)	Change of the carbon content			
			accumulation	emission	Total	
					millions of thons	%
1. Spruce and broadleaf-spruce mixed	2034	37.14	3.02	-1.8	1.22	3.28
2. Pine and broadleaf-pine mixed	26230	481.76	45.77	-23.17	22.6	4.69
3. Broadleaf	4770	84.68	6.76	–4.96	1.8	2.13
4. Secondary substituting for dark-coniferous and mixed	17770	293.26	40.77	–14.79	25.98	8.86
5. Secondary substituting for light-coniferous and mixed	16670	318.7	40.97	-51	-10.03	-3.15
6. Secondary substituting for broadleaf	4911	76.83	0.42	-1.18	-0.76	-0.99
7. Paludal	2343	35.18	1.01	-0.17	0.84	2.39
8. Flood-plain	9219	149.28	6.62	-4.45	2.17	1.45
All groups of forest formations	83947	1476.83	145.34	-101.52	43.82	2.97

effects on the state of terrestrial ecosystems and the biosphere as a whole. By 2050, the carbon balance of the forests of the main water catchment area of the Volga river basin, average weighted by area, may be from –(21÷27)% to +(11÷17)% of the baseline carbon content. These figures are quite comparable to the data of other predictive regional estimations. For coniferous, mixed, and other USA forests, changes in the net primary productivity and the carbon content were calculated by predictive biogeochemical models CEN (CENTERE) and TER [Aber et al, 2001]. It was shown that, according to the scenario of UKMO-1987 climate model (the precursor of HadCM3), doubling of atmospheric CO_2 results in relative carbon balance values in the range of –(1.5÷1.8) to +(7.8÷12.5)%.

Let us compare the obtained results with some materials on the forest cover of Russia as a whole. Based on the modern rates of the carbon sink in the Russian forests [Zalihanov et al, 2006], it may be assumed that the total C deposition in the forests during a 65-year period (1985-2050) is about 23.1 Gt. For one percent of this area (i.e., an approximate area of the Oka river basin), this parameter will be equal to 231 mln t, i.e. five times greater than forecasted for the territory by 2050 according to HadCM3 model (see Table 4, column "Deposit"). As one can see, the results of our predictive modeling of the carbon balance are quite realistic and, though HadCM3 is considered to be extreme, its calculations give much lower estimates of carbon content changes in the forest vegetation cover. ■

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SUSTAINABLE DEVELOPMENT IN THE CONTEXT OF EDUCATION: SWEDISH REALITIES AND RUSSIAN POTENTIAL

ABSTRACT

The goal of this paper is to discuss current problems of education for sustainable development, i.e. a global educational innovation that is actively growing in the new century. In Sweden, which has extensive experience in ecological education, education for sustainable development is considered a national model for the creation of the foundation for SD. In Russia, difficulties exist in defining and achieving SD objectives. It has been demonstrated that cooperation between Russia and Sweden in the field of ESD may prove to be very successful. Such cooperation is based on historical, cultural, and geographical factors. Examples of successful cooperation are joint educational projects aimed at improving the ESD framework and its practical implementation. The results of joint projects between the two countries have been analyzed in the context of mutual interests of Russia and Sweden and new goals for cooperation have been outlines.

KEY WORDS: education for sustainable development, environmental policy, greening of education, ecological culture, preservation of cultural heritage, educational practices.

INTRODUCTION

Recognition of education as a «key factor for changes» in the transition to sustainable development (SD) has promoted the emergence of the «Education for Sustainable Development" (ESD) phenomenon. As a civilizational project, ESD has a dual nature. On the one hand, ESD is based on the well-known and sufficiently studied national educational system. On the other hand, ESD is a global innovation that needs an adequate scientific foundation because of its virtue, novelty, and the important role it will play in the world's development.

In this context, the ESD phenomenon has drawn increasing attention of researchers immediately after its emergence in the global discourse in the 1990s. The period 2005-2014 has been declared the UN Decade of Education for Sustainable Development (DESD). It became an important momentum in the ESD research. The results of studies related to different ESD aspects achieved to date are impressive in their scope, breadth, and depth. Undoubtedly, this research aspect will remain relevant for many years to come.

The World Conference on ESD held in 2009 in Bonn summed the first half of the DESD and set the objectives for the second period. It is quite logical that among these objectives, was the development of SD aspects in the context of education. The Bonn Declaration calls on countries to *«encourage and enhance academic achievement, research, and new knowledge for ESD by engaging higher education institutions and research networks in ESD"* [The Bonn Declaration, 2009]. To solve this problem, it was recommended to use the «principal functions of universities, which have proved to be positive in the actual practice of modern research."

The Bonn Declaration also calls for international cooperation and for integration of the efforts of individual nations in the study of the ESD phenomenon as a means of achieving real progress in the world's SD. Responding to this call and realizing the importance of this research, a group of Russian and Swedish universities has been successfully working in this field for several years. The results of this cooperation are not only of applied but also of theoretical relevance. Among other things, its practical applicability is manifested in identification of individual features of research in the ESD field.

THE SD'S EDUCATIONAL CONTEXT IN RUSSIA AND SWEDEN

The Johannesburg Declaration on Sustainable Development tasked the nations with *«integrating sustainable development into education systems at all levels in order to promote education as a key factor for change»* (Section X, «Means of Implementation," paragraph 121). It is crucial that the assessment of the unique role of education in the destiny of mankind contained in the above quotation not only reflects the national goals, but also knowledge gained so far.

In the USSR, a valuable experience in the priority development of the national education system for modernization of the country has been accumulated. A historic breakthrough in space, which climaxed with the first flight into space on April 12, 1961, is the striking validation of this statement. The Soviet system of education was justly recognized as one of the best in the world. It was capable to respond to all major challenges of the time, including the need of its own greening. It is not surprising that the first in human history UNESCO conference on education in the field of environment protection was held in the USSR (Georgia, 1977). Unfortunately in the post-Soviet period, many achievements of the Russian education system have been lost, giving rise to numerous risks, including de-greening of development, which clearly contradicts the national interests and rises the concerns of its neighbors.

No less valuable experience to foster education has been gained in Sweden. Accepting today's realities, for many decades, its special value and attractiveness to the global community has been the insurance of high standards of environmental performance of the national development. The first global UN Conference on Environment (Stockholm, 1972) was a logical consequence of this recognition. It is also no coincidence that Sweden is one of the obvious leaders in promoting the ideas of SD at the national and international levels and in using the most modern educational technologies.

This information is well known to Russian specialists, which explains their interest in the Swedish achievements in SD and ESD. Continued DESD, suggesting broad international cooperation, resulted in new opportunities for cooperation and exchange of best practices between countries, including Sweden and Russia. Objectively, such cooperation is fully in the interests of both countries while meeting the goals of SD [Kasimov and Mazurov, 2010].

The initiative of Russian and Swedish specialists to cooperate in promoting environmental components of ESD in Russia is the logical development of the processes discussed above. The success of this initiative may truly contribute to a more predictable and prosperous future of the countries involved in the cooperation. At the same time, a critical examination of its content, form, and meaning is of general theoretical significance as a possible model for the formation of a «key factor of change» in today's ever more globalized world.

ENVIRONMENTAL POLICY AND ESD IN SWEDEN

Society's movement towards SD is seen in modern Sweden as one of the main goals for the future. In 1969, as one of the first countries in the world, Sweden introduced its first Law on Environmental Protection. Over the years, the law was amended many times and environmental legislation in Sweden became difficult to grasp by the new rules created according to the need that arose. Some environmental laws were also available elsewhere, such as the Planning and Building Act and the Radiation Protection Act. The present Environmental Code came into force on 1 January 1999 and it is a coordinated, broader, and stricter environmental legislation for SD that merges rules from sixteen previous environmental laws.

In furtherance of efforts to green the education, in March 1992, the government charged the Swedish Council for the Renewal of Higher Education with the task of developing a special program, known as MINT (The Integrated Environmental Education Studies Program). For these purposes and under the umbrella of the Council, a special working group of teachers and students from different fields of knowledge has been organized. The group was united by a common interest in promoting SD in higher education. Supporting the efforts of national universities for education greening has become the most important task for this group. More than 35 major projects at 20 universities have been implemented towards meeting this goal.

The MINT's efforts have been mostly focused on presenting the results of scientific research obtained in various SD areas in relevant published sources. A section with specific instructions about using the results by both teachers and students became mandatory in these publications. Other actions of MINT included: the annual conference «Greenspiration» (ecological inspiration) for students and university staff with representatives from the production sector that participate in shaping the employment field for future graduates; professional exchanges of groups of teachers and students with universities in countries that have achieved significant progress in development of ESD (in particular, with universities in Netherlands); support of participation of Swedish students in the National Student Environmental Network (*Svenska Ecodemiker*); special grants to Swedish teachers for the development of training courses related to SD and based on opinions of both experts and students.

Active work on the greening of higher education in Sweden is highly appreciated in Europe. This work led to the initiation and promotion of similar activities in neighboring countries. As a result, in May 2002, the countries of the Baltic Sea region have adopted an agreement on the development of education in the field of SD in the region *"Baltic 21 E"* to enhance cooperation and exchange of good practice in this field. It is significant that the signing countries call Sweden the *«regional and global leader in achieving SD environmentally,»* and acknowledge its leadership in the ESD development.

The undoubted success of Sweden in the development of ESD may be also explained, among other factors, by the active position of its government. This statement is supported by the speech of former Swedish Prime Minister G. Persson at the Global Summit on

SD in Johannesburg on 3 September 2002, *«One of the basic conditions of progress and social activity is education. We would like to see more teachers involved in the discussion of the impact of our lifestyles on the environment. Universities should include courses on global survival in the major educational programs...».*

Educational policy in Sweden is definitely focused on the active and direct involvement of its citizens in greening of the country, treated as a basic condition for its SD. The most important form of environmental policy in Sweden was the implementation of the 1998 social-democratic government's bill *"Swedish Environmental Objectives: An Environmental Policy for a Sustainable Sweden."*

As stated in this document, the goal of environmental policy is *"to hand over to the next generation a society in which Sweden's major environmental problems have been solved"* [Sweden's Environmental Objectives, 2008]. In accordance with this national program in the country, 16 priority goals (directions) of the environmental policy (Fig. 1) have been set. Under this policy, specific targets were identified, whose achievement should be secured by 2020.

It is important to note that policymakers estimated fairly precisely the cost of achieving the goals of the environmental policy. The growth of the cost of environmentally oriented projects will be about 50% relative to the base

Fig. 1. A long-term strategy on the greening of the country is presented as 16 areas of environmental policy

level of funding for this sector at the end of 1990, or 20 billion SEK a year in real terms, including no less than 8 billion SEK from the government's budget. The final cost has been set at the level of 60 billion SEK annually, which amounts to about 2% of the modern GDP [Sweden's Environmental Objectives, 2208: 338]. The structure of the expenses has also been defined in terms of both the areas for allocation and the financing sources. Bulk of spending is associated with business and municipal budgets in full accordance with the internationally accepted principle *«polluter pays.»* The total expenditures correspond to the gross value of environmental taxes and charges collected in the country.

The level of 2% of GDP is a relatively small fee for creating a lasting ecological foundation for SD. It is known that the most economically developed countries in the 1960s and 1970s paid much more for a way out of the acute stage of the ecological crisis, i.e., up to 6–8% of their GDP with Japan spending 11%. However, the following information must be considered.

First, Sweden has generally achieved the most advanced environmental infrastructure, created previously by investing predominantly during the postwar decades. These investments have already solved the basic environmental problems (environmental safety, preservation of natural heritage, and sustainable use of natural resources) and allowed achieving high environmental standards of society as a whole (Fig. 2). In essence, we are talking about financing irreversible state of the already manifested positive trend of key environmental parameters.

Second, one should bear in mind that creating a lasting ecological basis for SD in Sweden has been achieved not only through the realization of the goals stated in the document. The actual total cost of achieving these goals is higher than 2% of the environmental investments mentioned above. At the present level of economic development, it is difficult to define the total expenditures in absolute terms, as well as the value of the total economic impact of such expenditures. However, we can consider with confidence such effect as existence of positive environmental externalities in the socialization of environmental policy.

Third, the specifics of the modern environmental policy in Sweden is associated with more clear synthesis of advanced environmentally-oriented scientific technologies («new natural resource use») of the 6th technological wave and the active civil position of the overwhelming

Fig. 2. A metallurgical plant in Luleå, in December 2008. Conditions of snow cover represent one of the most obvious indicators of industrial ecological conditions

majority of the citizens in relation to the adopted public policy on SD. Specifically, it is manifested in the fact that since the late 1990s, there has been active work to achieve the 16 environmental goals well known to the public in Sweden. This work has actually become a form of systematic greening of society, the original national model for the formation of ecological basis for SD. It is crucial that during this period, education, at all levels, was considered an important condition for realization of the stated environmental policy.

In Sweden, an important prerequisite for progress in this area is the responsible attitude of the country's specialists towards incorporation of education in SD, their self-criticism, readiness for systematic evaluation of ongoing projects, and deep understanding of their social aspects. K. Sammalisto, MINT's representative, wrote, *«We must realize that most of the work we do is like planting seeds that will take years and possibly even decades to become a fruit"* [Sammalisto, 2002: 31]. These words are so characteristic of Swedish realism, but without any compromise in relation to the country's adopted standards and to the principles of development respected by the neighbors and are attractive to them for replication. It is clear that Russia is one of the most objectively interested nations.

One of the important «background» factors of Sweden's national environmental policy is to contribute to the greening of the neighboring countries and of other countries in need of this policy. Often, such assistance may be provided on a sustained basis. Thus, the strategy of cooperation with Russia states, *«The preferential direction of the Swedish-Russian cooperation in development should continue to be deepening of democracy, economic reforms, social protection, environment, collective security, as well as education and research»* (http://www.rurik.se/index.php?id=38). This implies that ESD, really integrating all of these areas, is the logical priority of bilateral cooperation.

ESD IN RUSSIA

As it is widely recognized in the world, achievements of environmental education (EE) and the greening of education in general became a launching pad of ESD. Russia has been among the world's leaders in this field. From 1995 to the present time, the number of Russian universities, where environmental specialties were launched, increased from 2 to 160. Practically all higher educational institutions associated with geographical, biological, and environmental education became involved in one way or another in promoting ESD [Education for Sustainable Development: Experience of..., 2008; Education for Sustainable Development in Higher Education of Russia..., 2008].

The following achievements can be named as the most important socio-economic consequences of EE at the national level in Russia:

- Mitigating manifestations of ecological crisis in the country;
- Developing environmental infrastructure;
- Ensuring access to environmental information;
- Increasing environmental awareness of the population;
- Establishing a network of environmental non-governmental organizations as part of civil society.

However, one must admit that the aforementioned results did not provide for a decisive turning point in trends of dynamics of the ecological situation in the country. Among other things, this situation is aggravated by the emergence of new global challenges that have significant national component relevant to Russia. These challenges include: global climate change, increasing threat of natural disasters, increasing problem of access to quality water, the problem of food quality, the collapse of the system of waste management, etc. The discrepancy factor (development gap) between the educational system (formal and informal) and the challenges of the time represents one of the reasons of worsening of the world's ecological conditions.

In Russia, continuing challenges of the "transition period" are superimposed onto the background global ecological problems. One of the challenges is the lack of proper coordination in the environmental and related areas of national policy. Here is a typical example of its manifestation: some experts [Dumnov, 2011, p. 62] suggest that the modern environmental policy costs Russia about 1-2% of its GDP. In fact, it is the same cost level as in Sweden for the modern program of ecological modernization, as noted above. If, however, in Sweden these costs provide for a consistent system of the country's greening, in Russia, they are not even sufficient for the maintenance of the existing environmental situation. In Sweden, ecological modernization is carried out with targeted support for education and culture in general, which created a powerful synergistic pressure and became, in essence, a driving force for the effective development of ESD in the country. In Russia, this is not currently possible because of the actual exclusion of the educational and cultural sectors from the environmental policy.

In recent years, researchers in the sphere of education and training have repeatedly noted that the basic ideas of ESD are inherent in the traditional Russian education established in the pre-Soviet and the Soviet periods [Kasimov and Mazurov, 2007]. It is also known that the widely recognized achievements of the Soviet education system are largely due to its intrinsic link with academic science. One would expect that a comprehensive system of ESD, for which methodological, organizational, and political conditions exist, will actively develop on a firm and sustainable foundation of EE in Russia. However, often being the driving force, EE becomes simply a substitute for ESD.

Among other problems of ESD, the slow integration of SD in the industry and the general courses, the weak interaction between secondary and higher education, and the lack of motivation of teachers, academia, governmental officials, and educational authorities should be noted. The lack of established management practices and implementation of ESD in schools undermines the success. There remains a deficit of finance and personnel for ESD. All this occurs at the background of the general low priority of SD issues in society.

However, in modern Russia there are many examples of achievements in the ESD field. Among them:

- understanding foreign experience in the formation of ESD and similar educational paradigms;
- researching the principle paths to the greening, humanization, and socialization of education, both formal and informal, from preschool to postgraduate;
- developing innovative models of ESD in the form of training programs, educational courses, teaching development, etc.;
- adapting the ESD potential to the challenges of the time and to specific nature of education.

It is quite natural that all those concerned with the success of ESD are more interested in the problems hindering its development in Russia. Most often, the following problems are named:

- weak support for ESD as a new educational paradigm from the authorities, especially at the regional and local levels;
- relatively low social status of SD ideas due to a certain imputation by society;
- overall degradation of the system of education and culture in the post-Soviet period;
- low awareness of nearly entire educational community of the advanced achievements of other countries in the field.

In this situation, one of the most effective means of changing the situation for the better that utilizes the concepts of social psychology and mentality of Russian citizens could be the appeal to the positive experience of the world's community. Obviously, this must be a compelling experience of those countries whose achievements are well known and are not doubted by the majority of the Russian population. An important fact in this case is the high moral authority of Sweden. Among not so many countries that meet the criteria mentioned, Russian people consistently refer to Sweden that in many ways embodies the principles of social justice and civic responsibility. These circumstances determine the natural interest in the Russian society to the Swedish model of SD, which serves as the basic premise of the Russian-Swedish cooperation in the field of ESD.

BACKGROUND FOR COOPERATION AND INTERESTS OF THE PARTIES

Potentially high efficiency of the Russian-Swedish cooperation in the field of ESD is granted, along with relevance, by the presence of significant, though often non-so-obvious, premisses. Geographical proximity, common historical roots, and mutual interest of the people to each other are the major factors. The magnitude and specific character of manifestations of these assumptions predetermine the interest of the parties to cooperate and to format real parameters of cooperation.

The factor of geographical proximity is manifested in the common interests with respect to different natural objects, connecting or separating the countries. The Baltic Sea and the Barents Sea region are the most important areas for our countries; their welfare is largely predetermined by the responsible treatment by Russia and Sweden.

The proximity provides for the similarities in climatic conditions in Sweden and a large part of Russia. These similarities make possible cooperation of neighbors in formulation and implementation of environmental policies, in monitoring the state of the environment, in ecological adaptation of industrial technologies, and in coordination of the efforts to format environmental frameworks of the territories and «new natural resources use» as an essential component of the 6th global technological wave as a whole.

Spatial proximity makes it possible to minimize costs in foreign trade and a wide range of international relations. However, the proximity factor is associated with inevitable risks of problems transfer from one country to the territory of its neighbors. It is known that Russian territories are under the influence of «western transfer» of air masses. For Russia, this means that up to 60% of the modern background air pollution in the western region is due to emissions of air pollutants from Western Europe. Hence, the obvious interest of Russia is to further green the production of its Western neighbors.

Obviously, the factor of «western transfer» does not guarantee the safety of Sweden in case of accidents or other significant abnormal events in Russia. The most striking example in this respect has been the situation associated with the consequences of the Chernobyl accident in 1986. Fig. 3 shows the impressive magnitude of the isotope Cs-137 affecting about 40% of Sweden as a result of rainfall immediately after the accident. To date, the concentration of this radioactive pollutant has decreased substantially, but awareness of the need to prevent such incidents has clearly grown in the Swedish society.

For most Swedish people, radiation pollution is not just an abstract concept. Effective environmental education in the country and the availability of environmental monitoring data provided for a high level of environmental awareness and culture of Swedish people. For the most part, environmental education allows one to adequately assess potential risks, including radioactive contamination of the environment and food products. In Sweden, it is a well known fact that the two major peaks of radioactive isotope Cs-137 in milk produced in its territory are related to the effects of the events in the east of its borders (Fig. 4). The first peak is associated with the consequences of nuclear weapons tests at the climax of the Cold War and the other one is due to the Chernobyl accident.

The proximity to the country that has already twice subject Sweden to unacceptable environmental risks is a permanent factor of concern to the public and the government

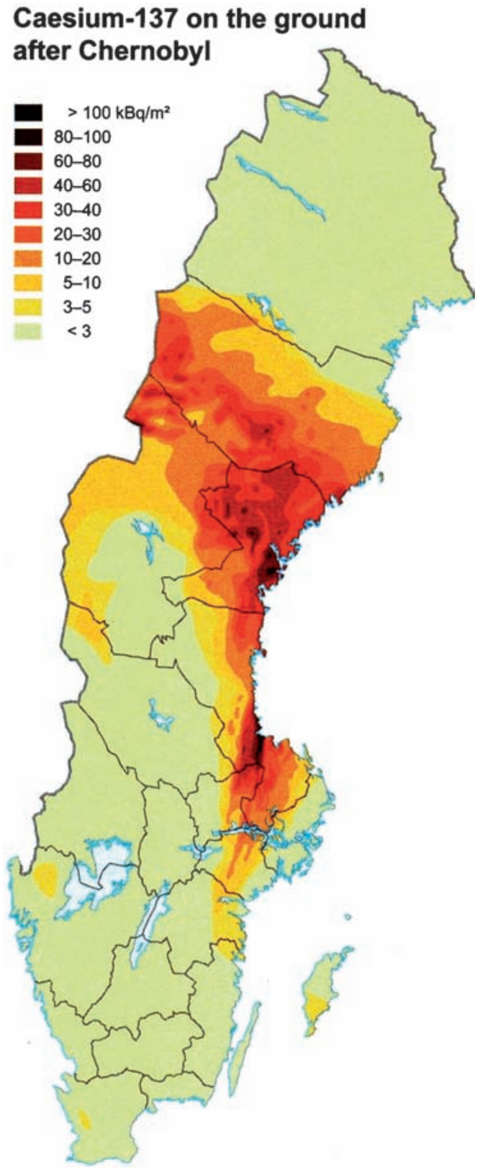

Fig. 3. Distribution of Cs-137 as a result of the Chernobyl accident (Source: [Bernes and Lundgren, 2009: 148])

of this nation. In Sweden, it is understood that the best way to minimize such risks is Russia's transition to a real model of SD, which is possible by a successful promotion of ESD. This fact plays the role of a decisive condition to the countries' cooperation in this sphere.

Existence of common historical roots is an important factor of the contemporary relations between the countries and the people. Such long-term relations have been established between the people of the two neighboring countries – .Sweden and Russia. The arena of the relationship was originally the Baltic coast, the North-Western Russia, and the historical path «from the Varangian to the Greeks" starting from the first Swedish capital Birka and extending through the lands of the eastern Slavs (Gardariki – "the kingdom of cities," in the Vikings' interpretation).

Historical information about ethnic contacts at that time is extremely scarce. But what is known often relates to territorial rivalries, i.e., contacts with the negative sign. Among them, is the famous, in Russian history, Battle of the Neva (July 15, 1240), i.e., the Battle on the Neva River between the people's militia of Novgorod, under the command of Prince Alexander Yaroslavich, and the Swedish troops. For the victory and for his personal courage, Prince Alexander was given the honorary name of «Nevsky.»

Since then, the severity of the disputes between the two neighbors only grew, reaching its apogee in the Northern War. The battle of Poltava became the principle event for these disputes. The victory over the army of Charles XII, the strongest in Europe at that time, as well as the construction of a naval fortress of St. Petersburg for protection

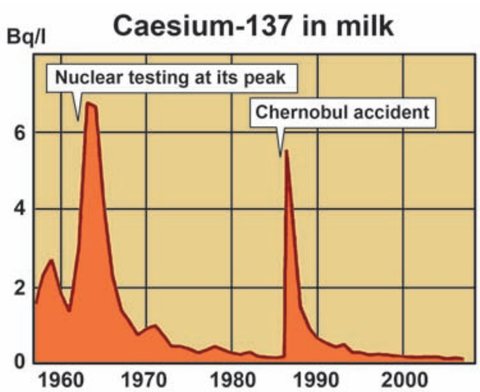

Fig. 4. Dynamics of the concentration of Cs-137 in milk produced in Sweden. According to the Swedish Radiation Safety Authority (Source: [Bernes and Lundgren, 2009: 149])

against the «*haughty neighbor*» [A.S. Pushkin, "Bronze Horseman"] came to Russia at great expense. For Russia, Sweden remained the most problematic neighbor until 1809 (the last war in the Swedish history) that could not but leave a negative trace in the historical memory of the Russian people. Something similar is probably typical, to some extent, and for the Swedish mentality. It is demonstrated by the exposition «*The Russian Outrages*» showing the destruction of the iron mines by the Russian Expeditionary Forces in 1719, in the museum on the island of Utö and by the monumental Charles XII in the central Stockholm with his hand pointing towards Russia (Fig. 5).

Fig. 6. St. Anna of Novgorod. An orthodox icon from the museum in Sigtuna, Sweden

However, not all in our shared history can be written in dark colors only. The most striking exception to this general picture is the St. Anne of Novgorod (Fig. 6), one of the most revered figures in the Russian Orthodoxy. She was the daughter of the Swedish King Olaf Sketktung, the "All-Christian King." In Sweden, she was known as Princess Indigherd and married Yaroslav the Wise, Grand Prince of Kiev, in 1016, taking the name Irene, consonant with her original Swedish name. In folk traditions of Scandinavia, Indigherd is remembered as a woman of selflessness, possessing a kind heart, intelligent, courageous, and adventurous, who always kept a significant impact on circumstances she encountered by fate.

Fig. 5. Monument to Charles XII in the center of Stockholm

After moving into her husband's homeland, the princess adhered to its interests and was guided only by them in her relations with the countries of Scandinavia rather than by her native kinship. In many ways, it is her personal influence and the family ties that contributed to the peaceful and friendly relations between Russia and Sweden, which were especially strengthened after her arrival in Russia and did not interrupt for a substantial period of time. In this respect, prominent places in the relations are also occupied by her relatives, e.g., by her brother Jacob, who served for a long time in Russia, by the husband of her sister, i.e., the Norwegian King Olaf, by her relative on the mother (Slavic) line, Earl Rognvald Ulfson, and by his three sons.

According to the marriage contract, Princess Irina was given a large parish – .the city Aldeygaborg (later Ladoga, now the village of Staraya Ladoga) with its domain. This region's boundaries appear to coincide with what later became known as Ingria (or

Ingermanland). Translated from Finnish, this place name means "*Land of Ingegerd*" and has its origin, in all probability, in the name of the wife of Yaroslav.

She was a mother of seven sons and three daughters who later became the queens of Norway, Hungary, and France. Among her grandchildren is Prince Vladimir Monomakh. Widowed, she became a nun named Anna. She died in Novgorod, having before her death the schema with the name Anna. Ingegerd Irene's tonsure was the first in the grand house that began the tonsure tradition by the Russian princes and princesses after the execution of their duties as rulers of the people.

Information presented above states the known historical facts that are, however, still underestimated as significant factors in the cultural context of the Russian-Swedish relations. This discussion is not intended to substitute the existing geographical proximity by a virtual cultural, but it reflects the pattern of some similarities in the system of cultural values, which is supported by the well-known cultural studies. Thus, on the Cultural Map of the World (Fig. 7), R. Inglehart and C. Welzel put Russia and Sweden at about the same level in the upper part of the coordinate axis *The Traditional/Secular-Rational Values*. However, in the system of *Survival/Self-Expression Values*, the authors place these two cultures in diametrically opposing positions [Inglehart, Welzel, 2005].

The map reflects the authors' interpretation of the system of ethnic cultural values. Not all elements of this map that relate to Russia and Sweden are accepted without reservations. However, this map correctly reflects the presence of not only fundamental differences, but also of similarities in the cultures, specifically, in the system of ethnic values and historical communication between the people.

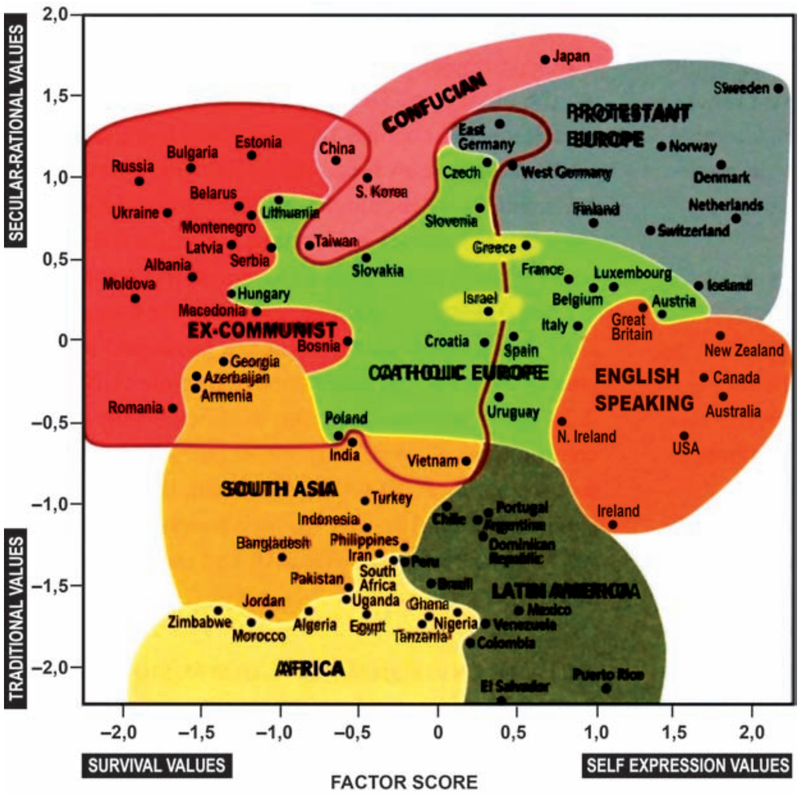

Fig. 7. Cultural Map of the World [Inglehart, Welzel, Press, 2005: p. 64]

The historical relations and features of the cultures explain the mutual interest of the people of Russia and Sweden to each other. In the most obvious form, this interest is manifested in the tourism sector whose extent and dynamics strongly support the existence of such interest.

The mutual interest of the people of the two countries as a social phenomenon has been insufficiently considered. However, it is clear that the fact of existence of this interest in itself indicates not only the differences between the two geographically close cultures, but also the similarities manifested in the mutual mental and spiritual values. This is reflected in how the Russian people perceive the works of Swedish children's writer Astrid Lindgren. Her fiction characters – *Pippi Longstocking, Lillebror, Karlsson-on-the-Roof* – .are the archetypes of modern Sweden. At the same time, these characters have been living in Russian culture for decades (in books, theater, movies, TV, life, etc.) and they have blended in with it so organically that they are largely accepted by the Russian people as a part of their culture. This situation, for all its seemingly paradoxicality, has profoundly legitimate roots and signifies the fact that common values are undoubtedly shared.

Among common, for the two people, values, their stance on fairness occupies a special place as the main category of the SD ideology. In fact, specifically this value is at the core of modern Swedish society that has the world's minimal decile coefficient. Social fairness is the basic principle of the model of «Swedish socialism,» the widely known and popular in the world and deeply rooted in this country. Social justice is a priority value of Russian mentality no less than in Sweden, which can be seen, in particular, from both classical Russian literature and the experience of social practices of the XXth century. This kind of social experiments and achievements cannot but to be attractive to the neighboring nations.

As one of the most important reasons for the similarities in the systems of values of Swedish and Russian people is the actual identity of landscape environment that contributes to the formation of ethnic groups. In essence, the natural conditions of Northwestern Russia and Central Scandinavia are very close, which means that the people of these countries had a typologically common «nourishing landscape» [Gumilev, 1990], which led to their commitment to a common, in many respects, system of spiritual values. An example of the Swedish interpretation of the image of the national cultural heritage provided below supports this statement. Fig. 8 shows a photograph of a rural estate on the cover of the Swedish national atlas of cultural heritage. The authors of the atlas used this photograph to demonstrate a typical image of the rural environment.

Thus, the archetype of the national cultural heritage in Sweden is not a royal palace, or a cathedral, or a castle, but the rural landscape with its characteristic features, i.e., birch trees, boulders, a fence around the pasture, a manor house. It is paradoxical but true: structurally, the Swedish and the

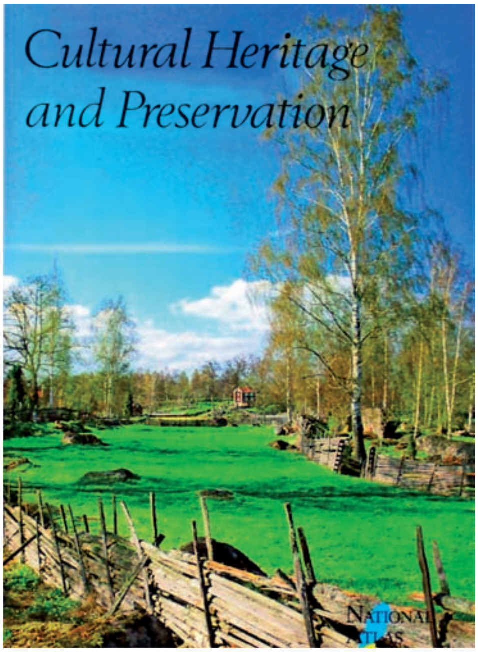

Fig. 8. The iconic rural landscape on the cover of the Swedish national atlas of cultural heritage

Russian archetypes are identical and their components are similar. For example, birch is one of the most typical symbols of the Russian landscape.

THE RUSSIAN-SWEDISH PROJECT IN THE FIELD OF ESD

Since 2008, under the framework of international cooperation, a Russian-Swedish educational project aimed at improving the conceptual principles of ESD and their implementation has been successfully implemented. The results of the project obtained represent interest not only to the participants of the project but contribute also to understanding the cooperation potential between different countries in the field of ESD.

The interest of both nations in exchange of positive experiences served as impetus to the joint ESD project. The Ministry of Natural Resources and Environment of Russia has expressed its intent to cooperate with the Swedish Agency for Environmental Protection (SEPA). Several entities within scientific-educational community became involved too: the Russian Academy of Public Administration under the President of the Russian Federation (RAPA), M.V. Lomonosov Moscow State University, and three leading universities of Sweden in the ESD area: universities of the cities of Lund and Uppsala and Luleå University of Technology.

The first phase of the project aimed at supporting the development of ESD in Russia was successfully implemented from September 2008 to January 2009. It resulted in development and successful organization of a joint Russian-Swedish seminar on ESD for public officials who determine the national environmental policy in Russia (Fig. 9). The high evaluation of the results of the first phase by both the organizers and the participants of the pilot workshop identified the need for development of activities initiated, which led to the adoption of joint decisions on a continuation of the project.

The scope of the second phase of the project, designed for 2010–2012, includes communication of experiences in ESD and identification, development, and testing of new educational methods for further education of civil servants in the field of sustainable management in Russia (Fig. 10). Particular attention in the project is focused on the key concepts of SD, i.e., environmentally efficient economy, biodiversity, sustainable cities, ecological footprint, cleaner production, sustainable consumption, renewable

Fig. 9. The final part of the training workshop for civil servants in the RAPA: Mr. A. Mikaelson (SEPA) and President of RAPA Prof. A.M. Margolin hand the certificates to the participants

Fig. 10. An educational session of the ESD project in Vladimir, in November 2010: general discussion

energy, and energy efficiency. Interaction with other projects within the Swedish-Russian cooperation in the environmental field has been also considered, especially, in the Barents Sea and the Baltic regions.

The main idea of the second phase of the project is to develop and improve approaches to the system of extended education and retraining of civil servants and decision makers by organizing and conducting educational seminars in the relevant fields. Target audience includes government officials responsible for environmental policy and decision making in the appropriate federal government bodies of Russia, as well as members of scientific and educational institutions engaged in ESD. The project involves implementation of the 12 areas combined into three main parts: 1) training session, 2) information dissemination, and 3) assessment and recommendations.

Systematic monitoring of the project includes assessment of its activities by the participants of the training seminars. Summarizing the results of their educational activities can provide the audience with the "core" of experience gained. The areas most often emphasized by the participants of the seminars include: relevance of such forms of educational practice; demand for the Sweden's experience to promote SD in Russia and to involve ESD potential in the process; high scientific and methodical level of ongoing sessions; practical benefits gained from the sessions to the members and to the areas of their occupation; and prospects for similar educational projects.

THE FIRST RESULTS OF THE PROJECT AND THEIR UNDERSTANDING

To date, the first results of the project have been obtained, including:

- the original concept of educational seminars for professionals of environmental policies on SD (goals, program, target audience, and partnership);
- algorithm for training and seminars on SD through international cooperation (action plan, logistics, program, and participation

ratio between Russian and Swedish educators);
- experience in conducting SD seminars within the Russian-Swedish project (testing the concept and the algorithm);
- assessment of the past workshops by the participants that is representative of all major components of assessment (content of seminars, their form, and results).

Other important findings include: widening and deepening the participants' knowledge about Sweden as a neighbor of Russia and as one of the world's leaders in the field of SD and ESD; deepening mutual understanding of the participants – .citizens of Russia and Sweden; strengthening good neighborly relations between Russia and Sweden; and obtaining unique international cooperation experience in education in general and in ESD specifically.

Comprehension of the results of the project is the basis for its overall positive evaluation. Such assessment is primarily based on the opinion polls of the participants of the past educational seminars most of whom regarded such seminars as extremely relevant and useful. According to the results of the pilot project, which was confirmed later by the subsequent project activities, there is a possibility of replicating the project in Russia and other countries. The partnership between the Russian and the Swedish parties established in the course of the project demonstrated its high efficiency based on close understanding, in both cultures, of such fundamental categories of SD as fairness and responsibility.

Problems that emerged during the implementation of the project can be divided into objective and subjective. The objective problems include, above all, the low status of SD ideology in Russia, its known discrediting in Russian society, and its weak support, including state financial support. In recent years, the situation in this area has been changing for the better. In particular, the support for the SD ideas has being increasingly clearly expressed by the Russian Orthodox Church. However, the problems mentioned above will continue to be significant with the existing trends. The subjective problems are associated with selection of participants, team alignment, and providing participants with relevant educational materials (literature, information, etc.).

A review of the SD issues in the educational context suggests the following key findings:

1. Ideally, ESD is a synthesis of cultural (spiritual) values and educational technologies that allow integrating these values into society;

2. The ESD subjects is the integration of a pair of basic categories of the SD ideology, i.e., fairness and accountability, in the key areas of social life at all hierarchical levels;

3. A prerequisite for effective ESD is the interest in the diffusion of educational innovations (such as in teaching and in training);

4. Swedish realities of the ESD scope make them attractive for diffusion as the innovation to all participants of potential partnerships. Russia's potential in this sphere can be greatly strengthened by adopting the achievements of Sweden, which is facilitated by territorial proximity and by similarities of values.

One of the main findings of the interpretation of the results of the project consists of the presence of real and significant potential of the Russian-Swedish cooperation in the field of ESD. Another important finding is associated with an extremely poor use of this existing potential. In the future, there may be two possible scenarios for the relationship between the stakeholders: 1) the potential as a treasure (the value that is removed from circulation), or 2) the potential as a capital (the value that creates a new value).

Critical evaluation of the progress of the project in the context of the mutual interests of Russia and Sweden raises the question about new challenges and prospects of bilateral cooperation in the field of ESD. The main task is to convert the potential of this cooperation into the real capital of our countries' development and to make it work not on a case-by-case basis, but systematically and effectively in the interests of SD of the people of Russia, Sweden, and the world in general. Speaking of the latter, undoubtedly, the idea of establishing international ESD standards has a great potential. The Russian-Swedish project has demonstrated its relevance and came very close to its formatting in a particular educational context.

CONCLUSION

The Bohn Declaration on ESD of 2009 states that, *"ESD is a new direction in education and training for everyone. It promotes quality education and applies to all people. It is based on values, principles, and methods that are necessary to respond effectively to existing and potential challenges"* [The Bonn Declaration, 2009].

It is this interpretation of ESD in Sweden and its adoption at the state level that allowed this country to make an impressive step towards a sustainable and predictable future. The same interpretation has its historical background in the Russian national education system as well. In the interest of the country, it can and must be transformed into the national policy that would incorporate into life virtually uncontested principles of SD. The formula for success on this path can be defined as a synthesis of national traditions and innovations of the advanced world and, among them, of the impressive achievements of Sweden.

Thus, the Russian-Swedish cooperation in the field of ESD is important for both countries. If successful, Russia would effectively promote the idea of SD and Sweden would obtain a more predictable and environmentally friendly neighbor and partner.

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TOURISM AND RECREATION: FUNDAMENTAL AND APPLIED RESEARCH IN RUSSIA

Starting in 2006, Moscow State University (Faculty of Geography), the Russian Academy of Sciences, National Academy of Tourism, the Russian International Academy of Tourism, and the Russian Union of Travel Industry have been conducting in Russia the annual international research and practice conference *"Tourism and recreation: fundamental and applied research."* The conference has been also supported by the Federation Council of Russia, the State Duma, the Ministry of Sports Tourism and Youth Affairs, Federal Agency for Tourism, and the Chamber of Commerce. A conference of such a high profile and the set of its members indicate the urgent need for scientific and human resources support of the rapidly developing tourism industry in Russia. Each year, the conference involves 150-200 participants from different regions of Russia, CIS, and the republics of the former Soviet Union. They are representatives of academic and university research fields, tourism industry, legislative and executive authorities of different levels, and undergraduate and graduate students. In total, the conference was attended by over 1000 people; nearly 700 reports were made at the plenary and breakout sessions and roundtables. All announced reports were published in the annual Proceedings of the International Research and Practice Conference; the conference resolutions were sent to the legislature and the executive governmental bodies for practical application.

The conference discussed the following research areas:

- theoretical and methodological foundations of studies of tourism and recreation;
- tourism and recreational potential and regional characteristics of tourism development;
- actual problems of recreation and tourism;
- crisis management of tourism;
- tourism market: state and forecast for development;
- problems and prospects of development of tourism and recreational systems (TRSs);
- safety and sustainable development of tourism and recreation;
- personnel training, continuous education, and skills development.

The development directions listed above point to a wide range of scientific issues that are important in Russia and abroad. Tourism has been declared the phenomenon of the XX century. In the beginning of the XXI century, it became actually one of the leading areas of socio-economic and cultural life of most countries. One can argue (and it has been the experience of many countries, including Russia) that tourism is becoming an essential part of the life support of human activities aimed at restoring and developing human physical, spiritual, and intellectual potential. One of the main tasks of the state and its legislative and executive bodies at all levels is the organization of recreation and tourism as the most important needs and standards of living in Russia. Tourism performs an essential preventive function associated with the human health and is one of the most steadily growing source of revenue for the state, making a significant contribution to sustainable development. In this case, we use the definition of sustainable development by N.S. Kasimov, and Yu.L. Mazurov, i.e., "the process of modernization of society based on the synthesis of traditions and environmentally friendly innovation."

Successful and sustainable tourism development is impossible without conducting basic and applied research on comprehensive investigation of recreational features of the territories. A sharply increased interest in tourism and recreational development in the regions, the transition to the path of innovation development of economy, and other factors dictate the search for new theoretical and methodological approaches to the investigation and development of recreational areas and promote growth of tourism industry. Among a variety of scientific areas, we will consider only three topics studied in detail at the conference. These are the studies of territorial TRSs, of tourist and recreational clusters (TRCs) and mechanism of their formation, and of the system of professional training.

Russia, like many other world's countries, is actively integrating into the global tourism sphere. Countries and regions of the world differ markedly from each other in terms of tourism development. Due to the multidimensional economic ties and the flow of tourists, the world tourist community is making a transition from coexisting countries to a coherent complex and dynamically evolving system of global recreational space. This space combines national recreational space of the countries with different levels of tourism development. In Russia, already established centers of tourism activity exist along with semi-peripheral and peripheral regions with different levels of development of the tourism industry.

Every region should be studied by isolating TRSs of varying complexity and consisting of the territorial integration of holidaymakers, natural and cultural environment, utility and recreational facilities, personnel, and management systems.

Tourism and recreation studies should be conducted at the federal level and within regional and municipal boundaries. Given that the system of territorial management is confined to the boundaries of territories of administrative divisions, it is feasible to isolate three levels of TRSs corresponding to three levels of administrative division: municipal, regional, and federal. Within municipal boundaries, it is more effective to develop basic TRSs, consisting of compactly located tourism sights, recreation areas, and recreational enterprises. There may be several TRSs located usually within the municipal administrative boundaries. In the case when a TRS is located within adjacent municipalities, there are often problems of its management as a single recreational entity. A combination of TRSs within the boundaries of a particular region forms its tourism and recreational specialization that, depending on the tourism potential and diversity of natural, cultural, and historical factors, can be of either a cross-sectional or of a mono-profile nature of development of different types of tourism and recreation.

Within selected boundaries, TRSs consist of interrelated tourism-recreational infrastructure elements. There are three types of infrastructure, specifically, areal, linear-nodal, and ethno-social. The areal type includes geological, geomorphological, landscape, ecological, residential, cultural, and historical elements. The linear-nodal type includes transport, energy, information, water and sewer (utility), etc. The ethno-social type consists of local residents and holidaymakers and it is the "living connective tissue" of the tourism- recreational territory. The types of specific elements of the tourism-recreation infrastructure and their combination determine the degree of difficulty of designing and developing of TRSs and the amount of required financial costs. For the design purposes, TPSs should be also categorized in terms of their development stages. As a rule, three states can be identified. The first stage is the most simple combination of tourism-recreation infrastructure elements, with the emphasis on the linear-nodal type. The final stage is characterized by the maximal saturation of TRSs with all necessary elements and their combinations, ensuring its effective functioning, and the largest influx of tourists. Creation of the TRSs would ultimately lead to employment growth, human welfare enhancement, and economic development, as well as to promotion of favorable conditions for development of tourism and recreation of Russian and foreign citizens. The ultimate goal of the recreational development is the creation of a unified *TRS* in the country, ensuring tourism and recreation needs of the population.

In thematic literature, territorial concentration within the production system have been termed a *cluster*. According to M. Porter, a cluster is a group of geographically adjacent interconnected companies and related organizations operating in a certain area, sharing a common activity, and complementing each other. Geographical extent of a cluster can vary from one city or a state to a country or to even a number of neighboring countries. A cluster is formed by a special innovative environment that enhances competitiveness of its member firms and the prosperity of the region. M. Porter states that a cluster can be defined as a system of interconnected companies and institutions whose importance as a whole exceeds the sum of its parts. As practice shows, the cluster approach plays a crucial role in the formation and operation of tourism space and functioning of tourism centers. The essence of a *tourism- recreation cluster* (TRC) becomes apparent through the relationships of its member firms, which appear in the form of a value-added chain and a value accumulating system. In a TRC, partner companies receive a number of benefits from joint activities. These are reduction in risk and uncertainty, restriction of competition, dominance of the market, technological and organizational innovation, strengthening of the image, growth of quality tourism products, enhancement of conditions for effective marketing, synergetic effect, promotion of development of regional economies, etc. Competitive clusters are a pillar of sustainable regional development of tourism and of new recreational areas through the creation of the tourism product. TRCs are an integral part of the market economy. They are formed based on the market laws. The state, together with other interested entities, may act as one of the initiators of TRCs' formation, but it does not play the major role in their organization and functioning. In many countries, practice of creation of TRCs at national and local levels has been already established, as well as practice of development of thematic clusters (sports, adventure, culture, education, wine, etc.). At present, Russia is in the process of forming a number of regional and local clusters with the support of the Federal target program.

In our understanding, a TRC is a group of geographically adjacent and interconnected companies, non governmental organizations, and related government bodies, forming and serving the tourist flows and using the recreational potential of the territory.

The evolution of scientific ideas about TRCs indicates the necessity of rethinking the theoretical foundations of recreational geography. With growing human-components of recreational activities, TRCs should be viewed in terms of their geo-socio-economic system organization. TRCs represent a set of interacting elements functioning as separate organizations and enterprises of various ownerships that influence the development of the tourism-recreational industry and related industries in the region. They serve as a progressive form of territorial organization of the productive forces of the region and they are characterized by a set of technologically and economically interconnected enterprises concentrated within territorial boundaries that use this territory's resources and its common infrastructure. Therefore, a TRC includes a set of tourism and recreational businesses operating based on such infrastructure-forming structural components as the production, technology, resource, and infrastructure subsystems that interact through shared processes of tourism and recreation sector and provide the public with quality tourism and recreational services.

TRCs are based on the key tourism and recreational resources of the region. TRCs' participants, in addition to businesses and organizations that provide production and sales of tourism products and services, may also include administrative authorities, research institutes, educational institutions, professional associations, public representatives, etc. A TRC can be configured on a local (municipal) level as well as on regional and interregional levels.

Development of TRCs within a territory must go through several stages: starting from the initiative of business representatives, and local residents through the formation of the management company, identification of the strategic development of the territory, the implementation of ongoing management, and monitoring and further development using principles of self-organization. The management company should operate as a separate legal entity using organizational principles of public-private partnership, i.e., the management company should include representatives from administrative bodies, business sector, and public organizations.

In general, successful implementation of TRC projects is only possible in the presence of coordinated and legislatively founded development strategy. It is ineffective to develop TRCs apart from the general concept of regional development, i.e., strategies of development of individual clusters and the regional development strategies should agree. Experience gained to date around the world shows that the cluster approach involves the development of various forms of public-private partnerships and implementation of program-target methods and requires efficiency of regional governance. In this case, the functioning of a cluster is ensured not only by individual areas with high tourism and recreational potential, but also by engaging the entire region in the cluster. This approach will provide for creation of multilevel system of regional clusters and for regional development of domestic and inbound tourism.

The federal target program "Development of Domestic Tourism and Inbound Tourism in the Russian Federation (2011–2016)" has been developed and adopted based on the cluster ideology. This opens up promising prospects for the tourism industry in our country. In the next five years, this sector will attract more than 300 billion rubles primarily through domestic and foreign investors and with the help of the federal and regional budgets. In Russia, there are unique situation and opportunity to create a unified TRS that would consist of TRCs of different levels and complexity and functioning on the principles of public-private partnership. This will allow addressing a wide range of important social and economic problems, including expanded reproduction of labor resources, growth of employment and prosperity, improvement of quality of life of society, and insurance of social and cultural development.

Availability of highly-qualified human resources plays a key role in addition to scientific support in the development of the tourism industry. This implies creation, based on existing resources, of training and academic institutions, educational tourism industry enterprises, and scientific and industrial complexes designed to provide comprehensive training for professionals at all levels on a "turnkey" basis. The needs of the tourism market related to human resources include:

- the need for educational, scientific, and industrial complexes, linking educational process and sectoral science and practice, that would allow, in the course of the learning process, to develop work skills immediately at the workplace, to implement innovative technologies in education, and to improve instructor training;
- improvement of continuous professional education on the basis of short training courses, internships, workshops, and modular system for building training programs, as well as increase the number of programs for advanced training of human resources with primary and secondary professional education;
- close interaction of Russian and foreign educational institutions and training centers in sharing experiences and techniques of modern training technologies;
- creation of educational clusters ecompasing all levels of education, the system of continuous education, and employers.

This is far from being a complete list of priority actions aimed at quality scientific and human resources support for a thriving tourism industry in Russia. Leading national and regional universities and academies that have skilled scientific and pedagogical resources should play a coordinating role in this process.

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