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The theology and ethics of the environment

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The paper surveys the world problematic with Orthodox Christian criteria, particularly the doctrines of the dominion of man and the divine image. A social response to the world problematic needs ethics. Although the Church cannot make the state moral, the Church must suffer with society.

Keywords: world problematic, Orthodox theology, ethics, environment

Introduction

The theology of the Orthodox Church is a worldview, *ein weltanschauung.* For Christians, theology is the understanding of God and man and nature, and it is the unique status of Jesus Christ as Son of God which makes all the difference.

The interacting, converging problems of the environment are the environmental multi-problem, or problematic *(problematik, problematique)*. Thus, food supplies, health, childcare, women's rights, growing populations, and the risk of conflict converge on the problem of water scarcity. This problem is itself a problematic. Whether it is water scarcity in the Middle East or in the Indian subcontinent, it has similar features. Again, the problem of population – the excess of people to available resources of food and water – interacts with the problem of the lack of health care.

All these matters have a socio-economic, legal, political, cultural, ethical or religious component. They concern human beings with a Pleistocene biology, in a world where adaptation is necessary. They raise questions of rights, obligations, justice, and mercy. They evoke such terms as Armageddon (Apocalypse 16: 16) and Apocalypse. An apocalyptic catastrophe is probable.

To solve the environmental problematic requires changes in systems of urbanism, trade, production, consumption, resource flows, decision-making, advertising, and so much else [1 - 3][1]. Even reduced to 'six primary problems' [4], the environmental problematic is only a model of reality, but those six primary problems are comprehensive: food, energy, population, mass poverty, military expenditure, the world monetary system [2]. For 40 years, there has been little action. Yet the environmental problematic is the world problematic.

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1 Waddington [3, p. 9] refers to 'a series of major world problems – of population, food supplies, energy, natural resources, pollution, the conditions of cities, and others.'

2 At the sixth special session of the U.N. General Assembly, Plenary Meeting 2207, 9 April 1974, Kurt Waldheim, former Secretary General, U.N., defined six primary problems: food, energy, population, mass poverty, military expenditure, world monetary system. These we regard as constituting the world problematic. A problematic – *problematique (Fr); problematik (Ger)* - is a multi-problem; its interactions offer solutions. The six primary problems idea can be a frame of reference for policy-making.

It requires correcting intentions, policies, and strategies to achieve an ethical outcome which is benign to the environment. Just as natural resources are not merely raw materials, so human resources are not merely to be reduced to their economic value [5][3]. Yet there is a general political assumption that economic growth can overcome all problems.

Politicians prefer to promise growth, not to confront problems. Minamata disease was recognized in 1956; the international convention against mercury pollution was agreed in 2013: *57 years later!* The mass media encourage belief in endless economic growth. Since *Limits to Growth* appeared, governments and businesses have resisted the arguments [6 - 8][4]. It appears that the White House suppressed data on global warming during the presidency of George Bush [9]. Politicians think in terms of the next election, or the interests of the governing party. They do not understand that processes may take a generation to culminate in a new situation. This failure to think ahead exposes the human race to danger.

Yet, even elites cannot avoid suffering if certain trends are protracted to a level where, e.g., a general rise in temperature by 4 degrees prevails. In Western Siberia, there is significant evidence of global warming [10]. Global warming is modifying the self-regulating patterns which have kept Earth habitable. Gaia – to accept the proved theory of Lovelock – is threatening us because we have threatened her [11].

Christian responses

In relation to the fact of Jesus, the life of the believer is arranged by ethics. These are principles of action, criteria for choice, where the faith, hope and love of the believer should combine to produce a Christian outcome. The Orthodox Churches have said nothing important about the environment which has been reported in the media and or noticed by political leaders or by non-governmental organisations. The Church of England has produced reports on nuclear war [12][5] and on urban life [13]. An Anglican bishop, Hugh Montefiore, has written on environmental problems [14], and an Anglican zoologist, John Morton offered a worldview [15] like the philosophy of the French Jesuit Pierre Teilhard de Chardin. Teilhard's philosophy rests on his observations as a palaeontologist and on his theology, which appears to have been influenced by Russian Orthodoxy. Although Teilhard's philosophy is a theology of the environment, his ethics are like those of other Christians [16].

The Roman Catholic Church has made statements *inter al* on workers' rights [17][6], population (*qua* birth control) [18][7], and international peace [19]. The Jesuit Social Justice Secretariat has produced a statement on desertification [20]. But, the structure of the Orthodox Churches and their interrelations make it difficult for any statement to be amplified.

Although the Ecumenical Patriarch Bartholomew of Constantinople has condemned environmental pollution as a sin [21], his jurisdiction in Great Britain, largely comprising Greek Cypriots, has shown no notable concern with the environment. Yet the Ecumenical Patriarch has made a public *persona* from speaking about the environment, hosting

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[3] Since 2000, Sustainability and the Millennium Development Goals, especially Goal 7, 'Ensure Environmental Sustainability', have become normal in environmental studies.

[4] Re [8], this issue of GAiA focuses on the Limits to Growth, including a paper by Jorgen Randers.

[5] This is a product of the Church of England Board for Social Responsibility.

[6] Leo XIII's encyclical, 1891, *Rerum novarum,* began this line of thought and action.

[7] Many Roman Catholics questioned the *magisterium* of the Roman Catholic Church and rejected the teaching; which ignored the population problem.

cruises where like-minded guests can share their thoughts, and including the environment in his Christmas and Paschal encyclicals etc. When the Ecumenical Patriarch went to Brazil some years ago and blessed the waters of the Amazon, his act received almost no attention from the newspapers. There have been statements by the Greek Orthodox and Antiochian archbishops in the United States. Some Orthodox theologians have made statements about bioethics [22 - 24][8]. The Russian Orthodox Church has also made statements on bioethics and ecological problems [25][9].

Developing dilemmas

Although adaptation is producing elements of solutions, *this does not mean* that a solution is certain, or socially acceptable. We cannot save people who go on reproducing beyond the capacity of the resource base to support them. We probably cannot prevent temperature rise and rise in sea level from causing disaster with mass deaths in Bangladesh etc.

Vast numbers will suffer if there are inundations through rising sea levels, or famine in water-scarce areas, or disease related to such events as new strains of influenza or TB overcoming immunity and antibiotics. HIV in Africa, India and China is pervasive. Similar disease risks exist in Russia and Western Europe, North and South America and Australasia. The Chief Medical Officer for England has stated (January 2013) that drug resistant diseases are proliferating and now are as grave a threat to national security as a major terrorist attack or global warming. The net effect may be benign for the environment, but adverse to human beings. The ethics of triage will apply.

There are at least three moral dilemmas in consequence. Firstly, rich Muslim countries which could assist disaster-prone South Asian Muslim countries (Bangladesh, Pakistan and Afghanistan) should be made responsible by Western diplomatic means, i.e., by ‘the Christian world’. Similarly, there is no international aid from Russia or from the Orthodox majority countries of the European Union (Greece, Romania, Bulgaria, Cyprus). There is no evidence of persuasion by these countries towards rich Muslim countries to help their weaker Muslim neighbours. Why should Orthodox countries be inactive? This is hard to answer (Luke 16: 19-31). And why should Christians help Maldives, which could disappear under rising sea levels, when it is aggressively Muslim, prevents Christian literature from being imported, and has destroyed pre-Islamic Hindu and Buddhist monuments? This is easier to answer (Matthew 5: 43-48).

Secondly, the indifference of God in blessing both the righteous and the unrighteous (Matt: 5, 44-45) is to be understood in relation to the Beatitudes (Matt: 5, 2-12); which Russian Orthodox and Romanians - but not Greeks or Antiochians - encounter in every Divine Liturgy. The Biblical view of the universe (Genesis 1) is that it is good (Genesis 1: 4, 10, 12, 18, 21, 25, 31); and this is congruent with the view that nature goes on adapting, securing a balance, because that is the nature of the universe. Nature is neutral; God is neutral, in the sense of blessing both the righteous and the unrighteous. The Biblical view (Genesis 2: 15) is that man is responsible for maintaining the garden, i.e., keeping the Earth productive and orderly.

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[8] Re [24], Metropolitan Nikolaos of Mesogaia and Lavreotiki, heads the Bioethics Committee, Church of Greece, Hellenic Centre for Biomedical Ethics, G Gennimata 51, 162 31 Vyronas, Athens, Greece. 2003.

[9] This contains a long statement on the Bases of the Social Concept of the Russian Orthodox Church, from the Jubilee Bishops’ Council, August 13-16, 2000. Chs iv, Christian ethics and secular law; xii, Problems of bioethics; and xiii, The Church and ecological problems repay study.

Thirdly, the precautionary principle is an ethical response to environmental pollution. If an action carries the risk of harm, even if it is not certain that the action will be harmful, that action must be proved to be safe. This is related to the legal principle of a duty of care; where the idea is that of the neighbour in the sense of the gospel (Luke 10: 25-37): a point made in the leading case of *Donoghue v Stevenson [1932].* In the sense of the neighbour, the Christian must be responsible for helping the Muslim, although in the world community of Islam, some Muslims (e.g., those in the Gulf) can and should help other Muslims (e.g., those in Bangladesh). For the Christian, the point is that the unlikely gift of help is the right gift of help, because it shows mercy, compassion (Luke 10: 37), and it is Jesus' teaching that we should do likewise (Matthew 25: 31-46). The gospel of St Mathew says that unless we act with mercy in the world as it is, we shall be denied mercy in the life to come. Christian ethics are more shocking than convenient.

The question of risk complicates the precautionary principle and the neighbour principle. Risk is a matter of probabilities. What is improbable is a safer risk than what is probable. Events have changed this idea. Thus, the probability that two airliners would collide was once unlikely; but then two airliners collided on a runway in the Canary Islands. The idea of an airliner crashing onto a crowded football stadium was once unlikely; but then two airliners were directed by Muslim terrorists to crash into the twin towers of the World Trade Centre in New York. The safety measures for Fukushima were weakened by combined events which exceeded those for which the safety systems were designed. The improbable is now probable; the unlikely may be becoming normal.

Then, there is the scale of complexity of these improbable events. The Bhopal disaster, 30 years ago, produced a chaotic reaction. A nuclear emergency in India would also be chaotic. It is unlikely that iodine tablets would be distributed to everyone. Any fallout carried by winds to Bangladesh or Pakistan would have unpredictable consequences. The calculus of risk has changed because the unlikely has become more probable than improbable. Thus, the precautionary principle has more force; and so also has the neighbour principle of Christian faith. But Christians are not dominant in South Asia.

The potential of the Orthodox Churches

Orthodoxy does not take initiatives like those taken by Anglicans, Roman Catholics or Protestant believers in the social gospel [26]. The reasons include the centuries of persecution of Orthodox Christians in lands dominated by Islam; the structure of political systems in countries which are majority Orthodox societies; the lack of education in many quarters. Ethics require to be tested in daily life and are social. Orthodox persons have a limited range of action. In the United States the Orthodox are a significant minority; but in France they live in a secular state. Undoubtedly, Orthodox Christians can seek to do good in a secular world. But statements from Orthodox Churches on ethical questions such as those in the world problematic tend to avoid conflict or challenge [25], and so they avoid the prophetic role. The Orthodox do not use the Apocalypse in their services; but its images may provoke useful thought.

Orthodox theology is expressed by the Bible, the writings of the Fathers, the decisions of Church Councils, the canons, the icons; by prayer, by the services of the Church; and these include joyful statements of the reality of the created world. For example, the Great Blessing of Waters at Theophany; the Divine Liturgy itself, where just before the communion, the priest gives thanks that God has 'brought forth all things from nothing into being.' The prayer of the heart cultivates an accepting, joyful, penitent approach.

Holy tradition includes many components – Bible, writings of the Fathers, decisions of Councils etc - , but there is no central authority in the Orthodox Churches responsible for issuing statements on any socio-economic or political topic.

If there had not been 400 years of Ottoman rule in Greece and a similar phase in the Balkans, the areas which are now Bulgaria and Romania; if there had not been 70 years of communism in Russia and what is now her federation, in Belarus, in Ukraine, in Georgia and elsewhere in the Caucasus, the industrialising of these areas and the corresponding developments in social life would have given the Orthodox Church reason to respond to economic and social reality; without the persecution and distortion of social life which Ottoman rule and communism both produced. It is probable that as the Church had administered social welfare to those in need, whereas after 1917 in Russia this was impossible, the normal social role of the Church would have continued and she would also have taken up environmental problems. But the lack of co-ordination among the Orthodox Churches would remain the same. This is a result of the Fall of Byzantium in 1453, after which Moscow became the Third Rome; there have been tensions between Moscow and Constantinople ever since.

Genesis, the dominion of man, the divine image

The Bible states the Jewish and Christian doctrine of man's place in nature in Genesis; which attempts to explain the cosmos. Genesis contains two creation accounts: Genesis 1:1-2:3; and Genesis 2:4-25. These say that God is creator of the universe and of all that is in it including man, who is accountable to his creator. The Fathers understood this, and so the Nicene Creed states; 'I believe in one God, Father, Almighty, maker of heaven and earth, and of all things visible and invisible...' Astrophysics explains The Big Bang, the moment astronomers identify as the origin of the universe; but the first verse of Genesis says the same thing: 'In the beginning God created the heaven and the earth...' It argues that there is a first cause. It describes God as being greater than earth gods and sky gods together *(elohim);* and the limits of the human mind are just as impressive today in explaining the moments before the Big Bang.

Genesis shows man as being responsible for maintaining order and fruitfulness in the garden [27]. Blaming Christian belief for the environmental problems of the world ignores some facts. *Firstly,* the 'dominion of man' is subordinate. The man in charge of the garden is responsible to the owner – God – who is the creator. The owner has made an agent responsible for maintenance and oversight. Adam, made from earth, and Eve made from a rib of Adam, are both part of nature; and so Genesis gives us an image of man's place in nature in which man is part of nature. The Biblical dominion of man is not unaccountable dictatorship, but a subordination of man as local agent or steward of the landowner, God. Man is made in the image of God (Genesis 1: 26-28). The image can become more like the original by righteous work and God's grace: by synergy. As S. Irenaeus of Lyons says, 'The glory of God is the living man, and the life of man is the vision of God' [Adversus Haereses, IV, 20,7]. This understanding – from the second century – reflects the gospel of St John's understanding that 'the Word was made flesh and dwelt among us' [John 1: 14].

Secondly, in much of the world the Biblical understanding is absent. Ancient desert in China, Africa and Australia is natural. Other deserts of China, the Indian sub-continent, Arabia, and Africa have resulted from keeping herds of cattle, sheep and goats without adequate protection of grass, shrubs and trees. In many cases, the herdsmen are not

Christian. Iran is 85 percent desert, but Christianity in Iran was persecuted into a minor form by the coming of Islam; and was exterminated in Arabia. In the Sahel, Christians are rare. Christians in Egypt are a minority, with few possibilities to take initiatives. The Egyptian government has not reversed the desert and made it productive; yet Israel has done this, and so could Egypt. The Biblical idea of man's place in nature does not produce destruction of land and vegetation.

The first monks went from Alexandria into the desert in the 4th Century, and the use of water from below the desert to cultivate plants and trees shows adaptation, but no effort to reverse desertification. There is no evidence that monasteries in Greece attempted re-vegetation of eroded mountains. The exception is the vegetated state of Mount Athos, where monasteries have looked after the environment with great care [28]. But when the State of Israel began to reclaim the Negev, after 1948, much more science and technology were available than in the 4th century. Besides, conditions for working in cool temperate climates are more favourable than those in arid and semi-arid environments. Thus, if in the ancient world Christians did not understand the relation between keeping herds of cattle, sheep and goats and their impact on vegetation, their acceptance of marginal conditions and acceptance of suffering could have been united in the religious perspective. The writings of the Desert Fathers show a positive evaluation of the barren spaces. Although Genesis makes clear the subordination of man to God, it is not a guide to desert horticulture: it is a picture of spiritual facts.

Thirdly, the rise of science and technology in the West weakened the values of Christianity through the Renaissance, the Reformation, the Enlightenment, and the Industrial Revolution. The dominion of man was replaced by an idea of man's power over nature, which did not need the hypothesis of God. Man now manifested unaccountable dictatorship, not the subordination and accountability which Genesis describes. The world problematic results from an un-Christian view of man's place in nature, not a Christian one.

Science and technology had different effects in Russia and her empire down to 1917. In Russia there was no Renaissance or Reformation, and the Enlightenment appears not to have produced an anti-religious spirit in Russia, but a widespread interest in science. It did not abolish serfdom, nor did it lead to a political revolution (as in France), and it was reversed to some extent by Paul I. Russia's Industrial Revolution had not gone very far by 1917. The monasteries in remote forests of Russia and Siberia did not have effects like coal mining in Britain and America. Russian monasteries during the expansion into wilderness are like those of the Cistercians in mediaeval England; which made land productive, became centres of social welfare, and practised efficient farming.

To demonstrate social responsibility among the Orthodox, one could instance the fish farming of the Transfiguration Monastery at Nafpaktos; or the ministry to the poor of SS. Kosmas and Damian in Moscow; or the care of psychiatric patients at Novinki by the nuns of St. Elizabeth. But, in general, the Church is not manifesting its theology and ethics sufficiently against negative trends and destructive socio-economic habits.

The Ten Commandments

Christian ethics include the Ten Commandments (Exodus 20: 2-17). The first is not to have other gods before God; but in the 70 years of the Soviet Union, the atheism of the Party became a false god. The second is not to worship any graven image, and this applies to many idols today – power, success, money, possessions. The third is not to take the name of God in vain; yet the profaning of God's name and the freedom with which we can see promises being made and broken show that this is easily broken. The fourth is to keep the Sabbath day holy; but endless activity, 24 hours and seven days a week, breaks this commandment. The fifth is to honour one's father and mother; whereas the destruction of the family in many cases, with old people rejected and their rights ignored, breaks this law. The sixth is not to kill, but this law is widely broken; and we should see this applying to many species whose habitats man has destroyed, thus affecting posterity. The seventh is not to commit adultery, and this is broken by the vast misuse of female images to advertise consumer goods. The eighth not to steal is broken to the detriment of posterity by e.g., our destruction of habitats and species, our depletion of groundwater, our pollution of productive land which thus is taken out of use. The ninth is not to bear false witness, and this is broken by mass advertising, political propaganda, some journalism, plagiarism in science and the falsification of results. The tenth is not to covet, but promotion of products by advertising will make some envy those who have them, and thus to covet what others possess.

The ninth commandment against bearing false witness raises the question whether Lysenko lied about his genetic achievements for the greatest good of the greatest number, or whether he was just an *apparatchik* lying because he wanted more power. Certainly, in *Pravda* there was no *Trud,* and in *Trud* there was no *Pravda!* The tenth commandment against coveting is broken by the encouragement to envy the lifestyle of others and inducements to borrow money – i.e., to put oneself in debt – for pleasure, to gain what is coveted. In French the word *envie* means envy, inclination, disposition, wish, mind, longing etc.

Obedience to the commandments against bearing false witness and against stealing would have avoided Lysenkoism, and collectivization. The propaganda machinery of the Soviet Union, the Third Reich, Maoist China, and probably of the United States in regard to every other country is something which has born false witness; and just because there is not now or was not then the power to overturn the propaganda, that does not reduce the wrongness of the false witness.

The scientific criteria (falsifiability, replicablity, material constraints) seem to contradict ideas relying on assertions from 2,000 years ago and apparently opposed to evolution. But if Lysenko had been a Christian, would he have offered genetic alchemy and plunged science into fraud on such a scale? When Kapitsa and Sakharov denounced Lysenko, were they attached to the Biblical commandments; or did they make their attack because falsifying results and causing other scientists to lose opportunities and even their life was wrong by any criterion of rightness? Kapitsa's Jewish background may have caused him to uphold the commandment; but what Lysenko did was wrong according to natural justice. Whether the Church was free to denounce Lysenko or not, the natural law condemned him; and the natural law is in line with the Ten Commandments [29].

The utilitarian approach, cultural traditions, and actual policies

For some, ethics consist in doing no harm and in seeking the greatest good for the greatest number: the utilitarian approach. But the ethics of revelation supplement those of reason. Utilitarian ethics can be congruent with Christian ethics if the greatest good for the greatest number means conserving natural resources, reducing human impact on the planet, and solving the environmental problematic as far as possible. No government shows this to be its worldview. Sakharov was an atheist, but believed in a guiding principle; and Darwin did not exclude ethics from his assessments of behaviour, but noted altruism in the famous case of the little American monkey which defended his keeper. Kropotkin believed in mutual aid as a working principle in nature. Christians may find it difficult to recognize similar values to their own in the religions of India and China, and Islam, but all religious traditions have an idea of man's place in nature in which man is more than a mere animal and nature is more than an assembly of resources for use [29].

The premises beneath the premises – the fundamental axioms – condition behaviour. These axioms are the same in the principal cultural traditions of the West and the East. They include taboos (e.g., murder). They agree on even-handed justice dispensed honestly, a duty not to steal the property of others, a duty to speak the truth and so on. If society repudiates these values, the controllers of society may have vast influence, no accountability, and no values worth the name [29]. This is what Hitler, Stalin, Mao, and Pol Pot achieved. All religious systems uphold fundamental axioms. Christianity accepts the Ten Commandments, but following Jesus' words Christians emphasize two (Matt: 22, 36-40), and as a mode of behaviour in general apply the golden rule (Matt: 7, 12).

Few policies are pro-environment, anti-waste, anti-pollution, or sensitive to climate change. For example, the United States exempts itself from applying Kyoto. It has no policy on reducing petroleum dependency, although Carter began Project Independence when he was president: a project reversed by his successor, Reagan. Obama's preference for clean energy and reduction in oil imports 2012 is not a radical change and has operated only since 2012. The increase in U.S. shale oil reserves simply means more competition for markets for fossil fuels; not a trend to clean energy, smart grids, or solving of the world problematic.

This is abnormal in a country which alleges that it is Christian, because Christians in general state that they are concerned about others and about the environment. The prodigious use of hydrocarbons in the United States must have an impact on global warming; yet the United States shows no responsibility for this problem. Thus, Australia's supply of coal to India and China allows the impact of Australia on global warming to be ignored by its government, because there are economic advantages in selling coal and because America does not give an example. Since there is a military treaty between Australia, New Zealand and the U.S. (ANZUS), strategy, whether military or economic, is fused. This makes the science of global warming and the ethics of the environment difficult to recognize.

India and China ignore pollution and the risks of global warming. They argue that they need to develop. If they see the disasters committed by other countries, this only makes them content with their own experience. India and China see no need to modify behaviour. Yet India at least is developing the use of solar energy, e.g., at State level; not, however, with effective endorsement by central government. Malaysia and Indonesia destroy areas of rainforest and thus the habitats of the orang outan and a wealth of creatures including possibly some not even identified, for the profits of selling the timber and or planting oil palm. Palm oil is widely used in cooking but is not healthy. While Borneo, where Wallace discovered evolution, is being wrecked, no-one argues for conservation. Such trends cannot be modified unless there is questioning within those societies.

When ethics are ignored, there are both economic and environmental costs. For example, the Institution of Mechanical Engineers states that 30-50% of all food may be wasted [30]. The report notes ineffective land usage, unsustainable water usage, and wasteful energy usage. There has been evidence of the post-harvest waste of food since the 1960s [31][10]. No government in India, Pakistan, Bangladesh, or in Africa has acted to reduce post-harvest losses. Since the 1970s, miracle strains of rice and maize have produced large harvests; but the risks of mycotoxin formation in stored products, the losses by poor systems of storage and distribution etc have been suppressed. These miracle strains require costly inputs of artificial fertilizer, and these deepen the debt bondage of Indian farmers. So, as the merely quantitative approach is attractive to governments, they have ignored the waste and spoilage of food.

Ethics have often failed to constrain human behaviour; and religious criteria have often been used to justify the unjustifiable. That is why Dostoevsky made such powerful use of the Grand Inquisitor in *The Brothers Karamazov*. The defence of the French Revolution or of the Russian Revolution by cruel and arbitrary measures speaks against the value of justice professed by those revolutions. Yet when conduct contradicts values, the misconduct proves *the agents to be wrong,* to be sinful (to use the Christian term). Those who attack the values because of failure to uphold them may be disguising their own lack of values.

Human rights and basic needs

Today, there is a presumption of equality: all member states of the United Nations are equal; all people have equal rights; justice is equality. Yet the hegemony of the United States, the huge power of Russia, of China, and the rising power of states such as Brazil is somehow beyond moral constraint. To oblige nations to co-operate requires not only diplomacy or power, but also persuading with ethics and thus acceptance *because of* ethics. Few institutions and leaders are motivated by ethics. The world problematic needs action which is altruistic, far-sighted and beneficial to all. Otherwise, catastrophe will supervene.

Both coercion and co-operation are necessary. The laws and inducements to co-operate (the coercive elements) should be humane, respecting human freedom and human rights. Those fire fighters who died in the first phase of controlling the Chernobyl disaster sacrificed themselves with altruism. We recognize the equality of human beings and rely on the empathy, by which one will sacrifice himself so that another may live or be free. Empathy is what Christians call charity, *agape,* love, compassion: that love manifested by Jesus in his Crucifixion. Against this, there is the self-centred struggle to survive, experienced in the Nazi concentration camps [32, 33] and in the Gulag [34]. If trends in environmental degradation continue, this need for survival will threaten all ideas of coercion and co-operation, all ideas of ethics, and theology. Self-interest only will prevail. As Varlam Shalamov said, ‘The extraordinary fragility of human nature, of civilization’ was the first thing he learned in Kolyma.

The environment reflects the value systems of societies. In the Western world, and in the Russian Federation, those values are Christian. But the West exhibits moral anarchy, resulting from consumerism, the offshoot of capitalism. In Russia, this moral anarchy emerges from the injustices, persecutions, moral chaos and futility following the Russian Revolution; and then, the explosion into a new identity after the Communist Party’s role was ended – a reaction from the inhibition of the command economy and the ideology of Marxism-Leninism. Consumerism and moral anarchy may have

[10] This lists ca 2,100 publications.

different causes, but they create the same problems: a drain on resources, an unreality about consequences.

Marxism-Leninism was said to be scientific, but it did not prevent the disaster of the Virgin Lands of Kazakhstan; nor did it prevent the stupidity of the Chernobyl disaster. Those two experiments were unscientific. If Orthodox Christians had been in charge of the Kazakhstan Virgin Lands planning, or the experiment at Chernobyl would those experiments have gone ahead?

The Marxist-Leninists who applied their pseudo-science against the Russian Orthodox Church after 1917 gave many martyrs to the world, but wasted many human talents. The case of Fr Pavel Florensky is a spectacular example. The trend continued to the end of the Soviet Union. Thus, Sakharov, Kapitsa, Roy and Zhores Medvedev seen from the standpoint of Marxism-Leninism were enemies of Russia. But these researchers were raising questions about the legitimacy of nuclear bomb tests, the need for representative government, the role of cybernetics and so on. They were scientific and humane, crushed by atheism because they challenged its explanatory power. They asserted their human rights.

Those who framed the Universal Declaration of Human Rights included an American Lutheran –Otto Frederick Nolde - and an Antiochian Orthodox, Charles Malik; they aimed to express and uphold Christian principles. They appear in the idea of basic needs, and they are developed in the idea of sustainability and made part of the Millennium Development Goals of the U.N. [5].

The Christian vocation to freedom

Christian belief gives substance to human rights. When Russians consider the Gulag, they confront the innocent suffering of SS Boris and Gleb. When they consider the non-resistance to evil promulgated by Tolstoy and adapted by Gandhi from that and Indian sources, Russians see the prototype of innocent suffering, Jesus on the Cross. And so do all Christians. For the Incarnation brings into the created world a child who is revealed as the Son of God and who bears the burden of his Cross to save his people, and indeed all the world. The transforming power of the Resurrection is the sign of new life for the world. It is this point of salvation which makes the Church responsible for declaring the severity of the environmental problematic and for offering to lead in making good what is getting bad or worse. Salvation includes the environment.

The Russian Religious Renaissance of the Twentieth Century anticipated the contemporary world [35]. One figure stands out, Nikolai Berdyaev. He repudiated communism because it inhibited freedom. As the spiritual son of Fr Alexei Mechev, Berdyaev took his faith into the West. Berdyaev understood the socio-economic environment, and the Westernizing and Slavophil issues which arose in Russia's Enlightenment and still continue. Berdyaev recognized that the atom bomb had changed everything. He understood suffering and freedom as a Christian [36]. Fr Alexei Mechev was encouraged by St John of Kronstadt to live his ministry *among the people*. Righteous Alexei Mechev followed that path, and so did his son Fr Sergei: after the atheistic state began its struggle with the conscience of Russia, following that path *(Put')* implied by the name of Berdyaev's journal.

Consider the poverty of Bangladesh. Here, 17.6% of the population – i.e., 26 million people – belong to the extreme poor. They are mostly landless. With the use of a portable bamboo silage store, they can store silage for their milk cattle conveniently; and can increase their income by 110 percent, from about Taka 2,000 ($25) per family by 2,200 taka ($27.5) per month *to reach the figure of Taka 4,200 ($52.5) p.m.* This percentage increase applies during the 4 monsoon months. **But the return probably will fall in the other 8 months of the year if the silage is not stored using the portable bamboo system. A family is on average 5 persons. The 110% increase depends on having a cow, either owned outright or borrowed on terms** [37]. These are people living in the worst conditions imaginable. Christian ethics require support for such people; action to help them.

The problematic of Bangladesh merges with that of India, which will suffer if Bangladeshis need to escape from rising sea levels through global warming [38]. Towards the end of Gandhi's life, he produced his Talisman, an ethical standard:

I will give you a talisman. Whenever you are in doubt, or when the self becomes too much with you, apply the following test. Recall the face of the poorest and the weakest man [woman] whom you may have seen, and ask yourself, if the step you contemplate is going to be of any use to him [her]. Will he [she] gain anything by it? Will it restore him [her] to a control over his [her] own life and destiny? In other words, will it lead to *swaraj* [freedom] for the hungry and spiritually starving millions? Then you will find your doubts and your self melt away [39][11].

Gandhi wrote this because he probably repented for having ignored the rights of the Untouchables, the Dalits; who are the extreme poor in India, in Pakistan and Bangladesh. Gandhi prevented them from having political representation by an act of moral blackmail in 1932, when he threatened to fast unto death unless their advocate, Dr B.R. Ambedkar gave up his demand for separate electoral representation. Gandhi's repentance came late; but he recommended Ambedkar as Law Minister, the man responsible for India's Constitution after Independence in 1947. As Ambedkar said in 1956, 'I shall believe in the equality of man [40].' This joins with words from Berdyaev in 1939: 'Christians do not have the right to hold to a political current that would trample down freedom and humanness, that would be opposed to the Gospel spirit of love, mercy and the brotherhood of people. Christians ought to unite in a struggle for the freedom of man [41].'

Thus, we need a social response to the environmental problematic [42]12. Political solutions may be functional, to maintain order. Or there may be humane solutions, concerned with freedom [43]. There is no freedom without ethics; and without ethics there is only tyranny. The Church must walk in the way of the Cross, with hope for solutions, with faith in the Resurrection, and with love. The Church must be the Body of Christ in the world, seeking to reconcile all things through Jesus (Col 1: 20).

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landscape analysis of the changes in the number o f thermokarst lakes in West Siberian permafrost based on satellite images

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Changes in the number of thermokarst lakes were investigated using multitemporal satellite images. On the territory of WestSiberian permafrost, 33 test sites located in different landscape zones were selected. One hundred and thirty four (134) cloudless multitemporal images Landsat were obtained during the warmer months in the period 1973–2013, were used for remote research. Processing and interpretation of satellite images were performed using software tools of modern geographic information systems ENVI 4.7 and ArcGIS 9.3. The total number of thermokarst lakes in 33 test sites of Western Siberia exceeded 50,000. It is shown that the number of disappeared lakes during the period of research on average decreases with increasing geographical latitude, and the number of newly appeared lakes in average significantly increases with increasing latitude. A comparison of the number of disappeared and newly formed lakes showed that the tendency to form new lakes dominated in tundra, and a tendency to reduce the number of lakes was revealed in foresttundra and the northern and middle taiga. The number of the newly appeared thermokarst lakes is significantly larger than that of disappeared lakes. So we can assume that the increase in methane emissions to the atmosphere with an increasing number of small thermokarst lakes in Western Siberia will contribute to the greenhouse effect.

Keywords: Thermokarst lakes, space images, permafrost, landscape analysis, Western Siberia.

Introduction

It is now well accepted that the increase in mean annual temperature of the earth's surface observed for the last 3–4 decades results in degradation of permafrost landscapes in Northern Eurasia. Thermokarst lake landscapes are extremely sensitive to temperature changes in the permafrost territory. In connection with permafrost thawing thermokarst lakes emerge and develop in rather a short period of time – several decades, and they may disappear very quickly turning to khasyreys (ditches of drained lakes). But the lifetime of some of these lakes can be as long as hundreds or even thousands of years [1].

There were periods when thermokarst lakes appeared *en masse* and everywhere. Thus, during a starting period of climate optimum of the Holocene in the north of Western Siberia mass and progressive formation of embryonic lakes was started [2,3]. Today, formation of thermokarst water bodies and depressions in connection with permafrost degradation for the last 50 years has been observed in Alaska, Canada, and Europe [3–5].Our researches [6,7] also have shown that permafrost thawing under the conditions of global warming results in speedingup thermokarst processes and changes in lakes' areas in the permafrost zone in Western Siberia. Even so, none of the papers cited above as well as other published papers considers the issues of changes in the quantity of thermokarst lakes in the permafrost zone.

Accordingly, we attempted to determine the quantity of thermokarst lakes depending on landscape peculiarities of the territory under study, based on the analysis of the data on changes in the number of extinct and emerged lakes in the permafrost zone of Western Siberia during the period of research (1973–2013). Research into the question was conducted at long distance.

Data and object of research

Research into changes in the quantity of thermokarst lakes was done using satellite images Landsat made at different times. Thirtythree (33) test sites in Western Siberia were chosen for the research. Test sites (TS) were selected in the light of specific features of landscape and zone differentiation of the area [8]. In each landscape zone (subzone) several TS were selected, which made it possible to study the dynamics of the quantity of thermokarst lakes depending on the landscape zone of the area. Figure 1 shows the scheme map of landscape zones in Western Siberia; one can see that TS are evenly distributed all around the area under study. Table 1 gives the distribution of TS around landscape zones and subzones. This shows that there are 15 sites in the taiga zone and 13 in the tundra zone.

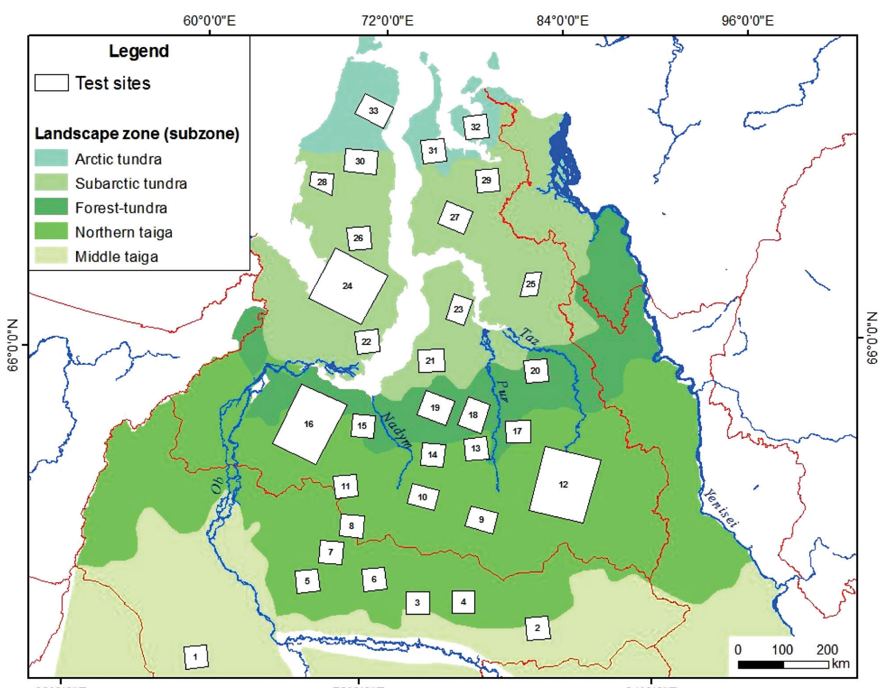


Fig. 1. Schememap of landscape zones location in Western Siberia with plotted boundaries of test sites

Table 1. Distribution of test sites in various landscape zones

Landscape zones (subzones)	Quantity of test sites (TS)	TS numbers
Arctic tundra	3	TS31 – TS33
Subarctic tundra	10	TS21 – TS30
Foresttundra	4	TS17 – TS20
Northern taiga	12	TS4 – TS16
Middle taiga	3	TS1 – TS3

For remote research 134 cloudless Landsat images of the territory under study were selected made at different times during warm months in the period 19732013. Images from Landsat collection have geographical reference to transferred projection UTM (WGS84). Table 2 contains the data about the used satellite images taken within the research period 1973–2013.

The satellite images were processed and decoded with the help of modern geo information systems (GIS) ENVI 4.7 and ArcGIS 9.3. On each TS, from several hundreds to several thousands of thermokarst lakes were detected by means of GIS. The total amount of explored lakes on 33 TS in Western Siberia exceeded 50 thousand. Decoding satellite images made at different times enabled us to form digital maps depicting the lakes' location on each TS for the year of survey.

Table 2. List of used satellite images

TS number	Starting year of the research	Final year of the research
TS1	Landsat4; 19.07.1988	Landsat8; 30.06.2013
TS2	Landsat1; 27.06.1973	Landsat8; 22.06.2013
TS3	Landsat1; 24.08.1973	Landsat8; 11.06.2013
TS4	Landsat1; 12.06.1973	Landsat8; 22.07.2013
TS5	Landsat1; 16.06.1973	Landsat8; 18.07.2013
TS6	Landsat1; 24.08.1973	Landsat8; 20.07.2013
TS7	Landsat1; 16.06.1973	Landsat8; 18.07.2013
TS8	Landsat5; 21.08.1987	Landsat8; 27.07.2013
TS9	Landsat1; 23.08.1973	Landsat8; 08.09.2013
TS10	Landsat1; 24.08.1973	Landsat8; 18.06.2013
TS11	Landsat1; 08.10.1973	Landsat8; 09.07.2013
TS12	Landsat1; 27.06.1973	Landsat8; 24.07.2013
TS13	Landsat1; 23.08.1973	Landsat8; 20.07.2013
TS14	Landsat5; 27.07.1984	Landsat8; 27.07.2013
TS15	Landsat1; 17.06.1973	Landsat8; 25.07.2013
TS16	Landsat5; 23.06.1987	Landsat8; 08.08.2013
TS17	Landsat1; 23.08.1973	Landsat8; 17.09.2013
TS18	Landsat1; 23.08.1973	Landsat8; 20.07.2013
TS19	Landsat5; 27.07.1984	Landsat8; 20.07.2013
TS20	Landsat1; 22.08.1973	Landsat8; 22.07.2013
TS21	Landsat5; 13.09.1987	Landsat8; 27.07.2013
TS22	Landsat1; 10.08.1973	Landsat8; 30.06.2013
TS23	Landsat4; 26.07.1983	Landsat8; 18.07.2013

TS24	Landsat5; 07.07.1987	Landsat8; 23.07.2013
TS25	Landsat4; 15.07.1988	Landsat8; 22.07.2013
TS26	Landsat4; 10.07.1988	Landsat8; 21.07.2013
TS27	Landsat4; 04.08.1988	Landsat8; 18.07.2013
TS28	Landsat4; 07.08.1988	Landsat8; 19.07.2013
TS29	Landsat4; 12.07.1988	Landsat8; 18.07.2013
TS30	Landsat5; 28.07.1984	Landsat8; 21.07.2013
TS31	Landsat2; 28.07.1981	Landsat8; 01.08.2013
TS32	Landsat2; 28.07.1981	Landsat8; 18.07.2013
TS33	Landsat5; 28.07.1984	Landsat8; 21.07.2013

The thermokarst lakes that disappeared and formed again within the period of study were detected by means of comparison between an initial and final maps of the lakes' location on each TS. As Table 2 shows, to make initial maps the images Landsat1 (1973), Landsat2 (1981), Landsat4 (1983 and 1988), Landsat5 (1984 and 1987) were used, and final maps were made with the help of images Landsat8, made in 2013. Images from Landsat1 (1973) were used to make similar initial maps on 16 TS.The images Landsat made in 1981–1988 were used for the rest of the TS.Consequently, using images from spacecraft Landsat8 brought into service in May 2013 makes it possible to assess changes (decrease or increase) in the quantity of thermokarst lakes on different TS within the periods of 25 to 40 years.

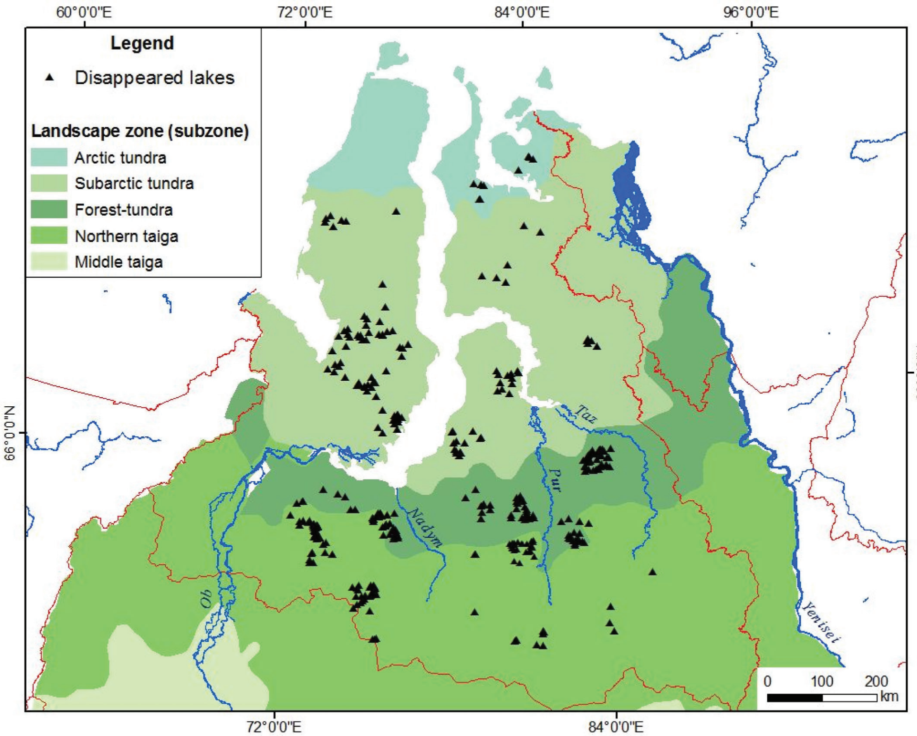
As it follows from the foregoing comparison between an initial and final map of lakes location on each TS reveals both the thermokarst lakes that disappeared and the ones that formed during the study period. As it follows from the foregoing, both the disappeared thermokarst lakes and the formed ones during the study period were determined on each TS. Further centres of disappeared and newly formed lakes were detected with ArcGIS 9.3, which is convenient for mapping these lakes.

Research results and analysis

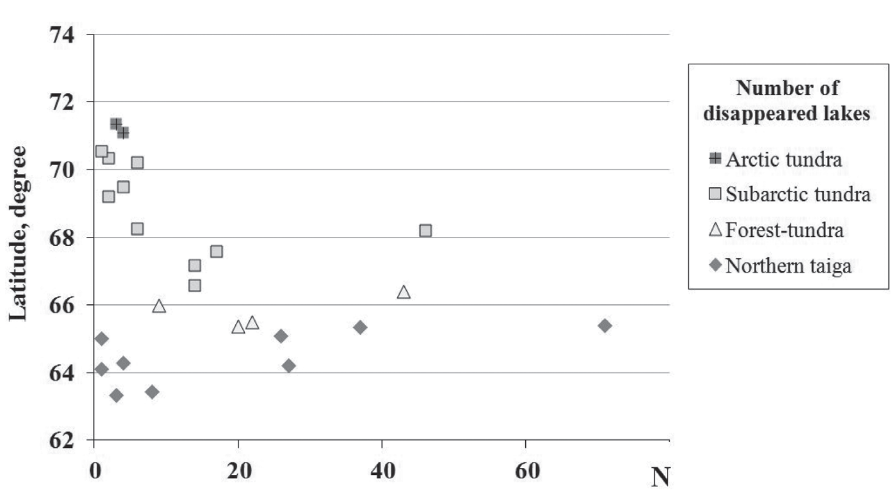
Figure 2 shows the map locating extinct lakes in Western Siberia. From this, one can see that the number of disappeared lakes during the study period differs in various landscape zones. Black triangles in Fig. 2 mark the centers of disappeared lakes. The largest of density of lakes is characteristic the subarctic tundra, foresttundra and the northern taiga.

The whole number of disappeared lakes in 33 TS representing the permafrost zone in Western Siberia was 390 for the study period. The total area of shrunk water surface caused by extinction of lakes on the territory under study was 14826 ha for this period. It is interesting to consider the changes in the number of disappeared lakes to depend on the latitude of their location and a landscape zone.

Figure 3 shows a graph of changes in the number of disappeared lakes depending on the latitude of their location and a landscape zone. A separate point on the graph plotted in the form of triangles, squares or diamonds in accordance with the landscape zone shows the number of disappeared lakes on each TS. As the graph shows (Fig. 3) the number of disappeared lakes in the arctic tundra is noticeably smaller than in landscape subzones located southward. It is of interest to analyse changes of mean values of the number of disappeared lakes calculated for different landscape zones and subzones given in Table 3.



Landscape analysis of changes in the number of thermokarst



lakes in West-Siberian permafrost based on satellite images

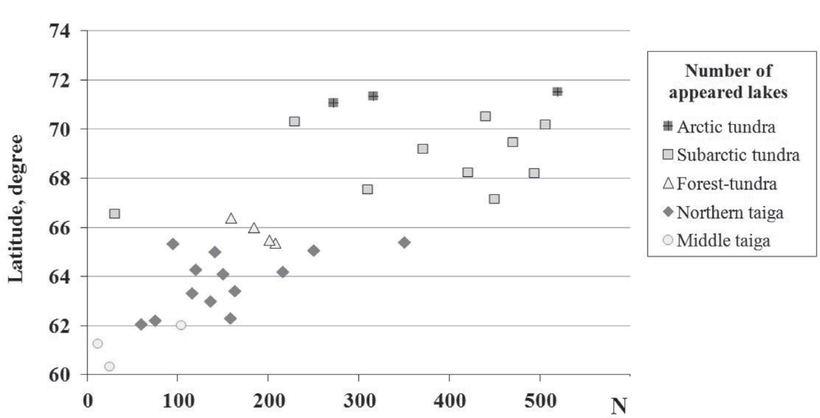
Table 3. The average number of disappeared and newly formed lakes over landscape zones (subzones)

Landscape zones (subzones)	Average number of disappeared lakes	Average number of formed lakes
Arctic tundra	3.5	369
Subarctic tundra	11.2	372
Foresttundra	23.5	188
North taiga	19.8	156.2
Middle taiga		47

The analysis of Table 3 shows that in the subzone of arctic tundra on average the number of disappeared lakes is several times smaller than in other landscape subzones. In the subarctic tundra the number of disappeared lakes is noticeably smaller as compared to the foresttundra and the north taiga located southward. Consequently, on the territory under study in the permafrost of Western Siberia the number of disappeared lakes decreases on average with increasing latitude during the period under study.

A similar analysis was done on the data concerning changes in the number of newly appeared lakes. It was stated that the number of newly formed lakes for the period under study in WestSiberian permafrost exceeded 7000 with a total water surface area of 13649 ha. Comparison of the data on the total number of disappeared and newly formed lakes and their total areas shows that in spite of practically similar total areas the number of newly formed lakes exceeds the number of disappeared lakes considerably (almost 18-fold). Consequently, newly appeared thermokarst lakes are much larger than disappeared lakes. So we can assume that the observed speedup of thermokarst processes resulting from global warming will be accompanied by an increase in a number of small thermokarst lakes in the West Siberian permafrost landscapes.

Figure 4 shows a graph of dependence of the number of newly appeared lakes for the period under study on the latitude of TS location. As in Fig. 3, each point in the graph depicts a number of appeared lakes on a separate TS. As can be seen from the graph, the number of newly appeared lakes rises on average, together with the increase in latitude. Table 3 give the mean values of the number of appeared lakes in each landscape zone (subzone).



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The analysis of the data from Table 3 shows that the mean number of appeared lakes in tundra subzones exceeds by several times a number of newly formed lakes in landscape zones (subzones) located to the south. Consequently, thermokarst processes in the arctic and subarctic tundra cause more intensive forming of new lakes there than in the forest-tundra and taiga zone in Western Siberia.

Comparing the data in Table 3 on the number of disappeared and newly formed lakes makes it possible to conclude that in the north of Western Siberia in the tundra zone the trend of forming new lakes prevails while the number of lakes in the foresttundra and northern and the middle taiga tends to decrease.

Conclusion

The results of our investigation show that in the West Siberian permafrost zone because of the thermokarst spurt under the influence of global warming two contrasting processes are taking place: thermokarst lakes' disappearing because of drainage and forming new thermokarst lakes, the latter process prevailing and accompanied by a relative increase in small lakes. As experiments in Western Siberia have shown [9–11], little thermokarst lakes can be viewed as natural sources of greenhouse gases, methane in particular. Therefore, it is possible to assume that rising emission of methane into the atmosphere caused by an increase in the number of small thermokarst lakes in Western Siberia will promote growth of the greenhouse effect.

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The regularities of biotic taxa distribution on the territory of the West Siberian Plain

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Quantitative regularities of the biotic taxa distribution on the territory of the West Siberian Plain within Tyumen and Omsk regions are analyzed in the article. The article shows their relation with the climate through dryness index, which controls heatmoisture rate on the Earth surface. The nature of distribution of species, genera, families and groups of biota by geographical zones and subzones of the specified region was observed: all ranks of taxa maximum values are observed in the taiga to steppe zone transition area, where dryness index values are 0,95–1,2 (≈1). The formula of geographical and hierarchical dependence of quantity of taxa of plants and animals of any rank were determined. The article demonstrates their selfsimilarity, integrity and common (sole) climate dependence.

Keywords: West Siberian Plain, Tyumen and Omsk region, biota, system, dryness index, climate, selfsimilarity.

Introduction (objective and methods)

The most thorough description of vegetation cover and wildlife of the West Siberian Plain (WSP) is provided in the studies [2, 3, 5] which mostly include the description of qualitative characteristics of plant and animal complexes in various natural zones and subzones. In the current article quantitative biota taxa distribution and hierarchy regulations are studied within Tyumen and Omsk region, which occupies the northern and western parts of the West Siberian Plain including ten natural and climatic regions and subzones [3, 5, 7, 9] from the northern tundra to steppe.

Spatial distribution of biota is mainly determined by climate. The objective of this research is to identify quantitative regulations of taxa and climatic indices relation as well as their distribution within geographic zones and ranking levels.

The research subject was the quantity of taxa (T), which were introduced into calculations as logarithms (W=1nT), which allowed us to considerably lessen the uneven function patterns and to easily determine the correlations between the systems and their components.

Results and discussion

Heat provision and water availability indices. All climate elements (CE) are interconnected. The quantifications of these correlations for the conditions of Tyumen and Omsk region [6–9] were found, which allowed determining all the elements based on any known CE, for instance, the dryness index. The dryness index is calculated according to the formula J = B/qU, where B is radiation balance, U stands for annual precipitation, and q is latent heat vaporization. This index is the most important integrated climate element answerable for heat and moisture distribution near the Earth surface. Its values range from 0 in the arctic desert zone to 3–5 and more in the deserts of subtropical and tropical belts [1]. To determine the heat provision and water availability of the territory in agroclimatic studies they also use Selyaninov hydrothermic index [10] which is calculated according to the following formula $K_c = U_o/\sum_o$, where U_o and $\sum_o$ represent annual precipitation (cm) and the sum of air temperatures over warm time of the year. Comparative calculations of J and Kc based on the data from meteorological observing stations showed their correlation by a formula:

$$K_c = 1.85J^{-0.98} \approx 1.85 / J. \quad (1)$$

According to J values, phytosphere can be classified as northern J_n (cool and humid) and southern J_s (hot and droughty). The border between them coincides approximately with the isoline J=1. The conditions of heat and moisture exchange defined by J in the northern and southern phytospheres are logarithmically antisymmetrical. For example, the territory of persistent vegetation existence is restricted in the north by isolines $J_n \approx$ 0.2...0.33 (northern tundra), in the south $J_s \approx$ 5... 3 (southern semidesert) [1], from which it is derived $J_n \approx 1/J_s$ or $l_n J_n \approx l_n(1/J_s) \approx l_n(J_s)$.

The other indices are also antisymmetrical since expressed in correspondence with J, in particular annual precipitation, group pollen spectra, and phytoproductivity [6, 7]. The curves of these correlations are cycloids, with their maximum (peak) at J≈1÷1.2. For example, on Diagram 1 there is the correlation of annual precipitation U (cm) and phytoproductivity or annual vegetation cover output Pr (t/ha*year) with J.

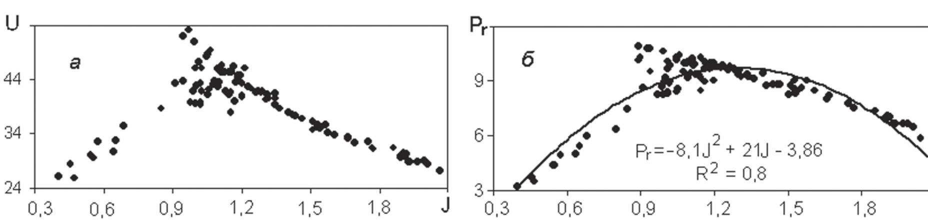

Diagram 1. Correlation of U (a) and Pr (б) with J

Geographical and hierarchical dependence of biotic taxa distribution.

Biotic taxa and J average values distribution within natural zones and subzones of the West Siberian Plain are shown in Table 1 [2, 3, 5]. The graphs in Diagram 2 show the correlation of species wealth and phytoproductivity with J (lower horizontal axis) or K_n (higher horizontal axis). Both characteristics are on a logarithmic scale: $W_i = l_n T_p$, where T_p is the quantity of plant species in subzone i (according to Table 1), and $W_{Pr} = \ln Pr$.

It can be concluded from Table 1 and Diagram 2 that the quantity of taxa under research both floristic and faunal ones change similarly: from north to south at first they increase and then decrease. The vector change happens in the subboreal forest which is the northern foreststeppe, which means that all biota habitation conditions are the most favourable in the transition zone from the taiga to foreststeppe where dryness index J vacillates in the range 1÷1.2 [6–9].

There is the same regularity observed for certain flora types, in particular for herbs and ligneous plants. Most of the herbs on the territory of the West Siberian Plain belong to the families Cyperaceae (sedge family, 297 species) and Poaceae (gramineous family, 285 species); most of ligneous plants belong to Salicaceae (willow family, 73 species), Pinaceae (coniferous family, 38 species), and Betulaceae (birch family, 30 species) [5]. In Table 2 the species quantity of herbs and ligneous plants referring to these families are summarized. As seen from Table 2, their zone distribution is subject to the same law as vegetation on the whole (Table 1).

Table 1. Quantity of animal (birds + mammals) and tracheophyte taxa and average values of J in subzones of the West Siberian Plain

№	Subzone	J	Animals				Plants		
			species	genera	families	orders	species	genera	families
1	Northern tundra	0.35	73+18	46+15	20+9	7+5	57	35	17
2	Southern tundra	0.6	148+32	79+22	30+11	11+5	126	67	31
3	Forest tundra	0.75	194+42	107+27	39+12	15+5	99	58	28
4	Northern taiga	0.87	207+51	115+33	41+15	16+6	174	86	43
5	Middle taiga	0.96	257+59	136+38	48+17	18+6	247	147	50
6	Southern taiga	1.0	246+60	130+38	47+17	16+6	380	203	73
7	Subboreal forest	1.1	271+67	141+41	54+18	18+6	493	260	74
8	Northern Forest-steppe	1.3	259+63	139+43	50+19	19+6	540	267	64
9	Southern Forest-steppe	1.5	252+67	135+42	48+18	18+6	449	226	54
10	Steppe	1.9	208+58	115+40	45+16	19+6	215	131	36

Table 2. Distribution of herbs (Tp) and ligneous plants (D) of the most widespread on the territory of the West Siberian Plain (subzones are numbered according to Table 1; numerator is species quantity; denominator is their logarithms)

i	D	Tp	i	D	Tp
1	5 / 1.61	22 / 3.09	6	27 / 3.27	68 / 4.22
2	12 / 2.48	40 / 3.5	7	28 / 3.37	95 / 4.55
3	15 / 2.71	30 / 3.4	8	16 / 2.78	101/ 4.62
4	17 / 2.83	47 / 3.85	9	4 / 1.38	85 / 4.44
5	23 / 3.14	59 / 4.08	10	–	33 / 3.6

The peculiarity of geographic subzones in Table 1 is reflected by their sequential numbers.

There was found general formula for the dependence of taxa quantity on the sequential number of the zone:

$$W_i = Ai^2 + Bi + C, \qquad (2)$$

where $W_i = \ln(T_i)$, T_i stands for the biotic taxa quantity of this rank in the range: order (o) – family (f) – genus (g) – species (s) in geographic subzone i, while A, B and C are empirical constants, which are defined in Table 3.

Table 3. Constants in the formula (2); formula fidelity (R^2) for different biota groups: I – tracheophytes, II – birds, III – mammals, IV – birds and mammals

Group	Taxa	A	B	C	R^2
I	Species	–0.042	0.57	2.27	0.87
	genera	–0.042	0.45	2.82	0.89
	Families	–0.047	0.72	3.28	0.9
II	Species	–0.024	0.393	4.01	0.97
	genera	–0.021	0.346	3.54	0.98
	Families	–0.016	0.274	2.76	0.98
	Orders	–0.014	0.25	1.81	0.93
III	Species	–0.021	0.377	2.52	0.99
	genera	–0.015	0.29	2.38	0.99
	Families	–0.012	0.222	1.88	0.96
	Orders	–0.003	0.058	1.51	0.8
IV	Species	–0.024	0.389	4.21	0.98
	genera	–0.02	0.332	3.82	0.99
	Families	–0.015	0.259	3.11	0.99
	Orders	–0.01	0.187	2.35	0.95

Using correspondence among i, J and K_n according to Table 1 and formula (1), value of i in (2) can be changed at once to climatic indices. For the example in Diagram 3 there are graphs of dependence of W_i on i and its approximation for taxa of plants (I) and birds (II). On the lower horizontal scale of the graph there are i values, while on the higher one the corresponding J values from Table 1; marks represent the quantity of plant and bird species in the subzones on a logarithmic scale.

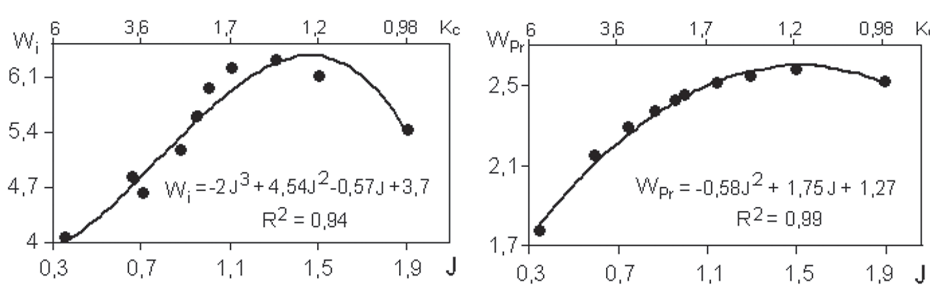

Diagram 2. Correlations of W_i and WPr on J or K_c and their formulas (signs represent the plant species quantity in the subzones)

The analysis has shown that biotic taxa of different ranks in all climatic subzones can be interconnected with W_1 (species quantity logarithm):

$$W_j = kW_1, \tag{3}$$

where j =1...4 is the sequential number of taxa logarithm ($W_{1...}$ W_4) in the series *species-genusfamilyorder*, k –empirical coefficient, which is defined according to Table 4 as function of j.

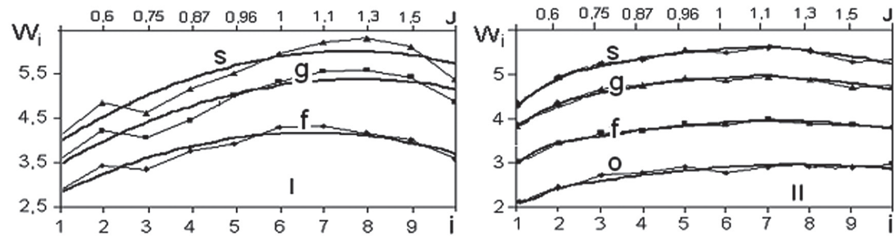

Diagram 3. Dependence of W_i on i or J and its approximation for plants (I) and birds (II) of the following ranks: species (s), genus (g), family (f), and order (o)

Table 4 as well as other introduced data indicate that there is nearly utmost unity of the biotic taxa system and their relations expressed in terms of k. Thus, the difference of the taxa ratio of floristic to faunal groups on levels speciesgenusfamily does not exceed 5%.

If we put in formula (3) $W_j = \ln T_j$ and $W_1 = \ln T_1$, then after its rearranging there is a formula which correlates the quantity of genera (T_2), families (T_3) and orders (T_4) of biota with its species (T_1) on a common (not logarithmic) scale:

$$T_j = (T_1)^k. \tag{4}$$

For example, for the southern tundra k equals 0.89; quantity of species: mammals $T_в$ = 32 (look at Table 1), mammals + birds – $T_в$ = 180; the same of genera: mammals T_p = 22, mammals + birds T_p = 101. Calculation according to formula (4) gives the following results: T_p = 23 and T_p = 106, which nearly coincides with the factual data.

Table 4. Values of W_j and k in formula (3) for plants (I) and birds (II), mammals (III) and birds + mammals (IV)

№	j	W_j	k	№	j	W_j	k
I	1	5.4	1	III	1	4	1
	2	4.7	0. 88		2	3.6	0.9
	3	3.8	0.7		3	2.8	0.69
	4				4	1.8	0.45
II	1	5.3	1	IV	1	5.7	1
	2	4.7	0.89		2	5.1	0.89
	3	3.7	0.7		3	4.2	0.73
	4	2.7	0.51		4	3.1	0.55

As known, many systems under certain mathematical representation are fractal or selfsimilar on all districts of their habitat and lifetime. B. Mandelbrot who introduced the notion of fractality for scientific use gave it quite a general definition (according to [4]): "... fractal is a structure which consists of parts similar to the whole". An example of such a structure is a tree crown, a river basin and its affluent, a hemal system, etc. System hierarchies can also be considered fractal including biotic ones: species – genus – family – order. Such hierarchies usually represent geometric progressions with approximately fixed factor, i.e. multiplier reflecting conformity of its components.

Let us consider the hierarchy of values of mn coefficient, which equals ratio of the previous component $W_j = \ln N_j$ to the following $W_j + 1 = \ln N_j + 1$ in sequence: 1) species; 2) genus; 3) family; 4) order (i.e. j = 1, 2, 3, 4):

$$W_1 / W_2 \rightarrow W_2 / W_3 \rightarrow W_3 / W_4. \qquad (5)$$

In Table 5 there are values of m_n coefficient for the taxa of the main groups of biota (according to Table 4). The analysis of Table 6 demonstrates that the ratio of hierarchy components (5) is described by the formula:

$$m_n = (m_{1,2})^n, \qquad (6)$$

where n is the sequential number of the ratio in the hierarchy (5). The correlations in (6) are denoted by one letter m with indices pointing out taxa numbers in the row: 1) species... 4) order. The first correlation is $(W_1 / W_2) = (m_{1,2})1$, the second one is $(W_2 / W_3) = (m_{1,2})2$, and the third one is $(W_3 / W_4) = (m_{1,2})3$.

Table 5. Factual and calculated values of m1.2 . m2.3 and m3.4

Groups	Values	Factual value of $m_{1,2} - m_{3,4}$	Calculated value of $m_{1,2} - m_{3,4}$
I	$m_{1,2}$	1.13	1.13
	$m_{2,3}$	1.26	1.27
II	$m_{1,2}$	1.13	1.13
	$m_{2,3}$	1.27	1.27
	$m_{3,4}$	1.37	1.44
III	$m_{1,2}$	1.11	1.11
	$m_{2,3}$	1.29	1.24
	$m_{3,4}$	1.53	1.37
IV	$m_{1,2}$	1.11	1.11
	$m_{2,3}$	1.23	1.23

It can be concluded out of formula (6) that the hierarchy components (5) are fractal, notably, the coefficient of a similitude (fractal dimension) for the all taxa of groups under study (I...IV), both animals and plants, equals $W_1 / W_2 = m_{1,2} \approx 1.12$.

Now we can approximately estimate the third hierarchy component which is missing (5), i.e. correlation between orders and families of plants m 3.4, and the quantity of orders as such: $W_3 / W_4 = m_{3,4} = (m_{1,2})3 = 1.4$; further on, according to Table 4 we find: $W_3 = \ln N_3 = 3.8$; from where we get: $W_4 = 3.8/1.4 = 2.7$, while the quantity of orders – $N_4 = \exp(2.7) \approx 15$. We can also calculate even theoretically the correlations between the following biotic hierarchy components: classes, phyla, etc. Then when n equals 4, there is $W_4 / W_5 = (m_{1,2})4 = 1.57$, from which we get $W_5 = 2.7/1.57 = 1.71$, and $N_5 = \exp(W_5) \approx 6$, etc. The value of mn in the formula (6) approximates 1, when n increases, and that corresponds to the top of biotic taxonomy, i.e. biosphere.

Conclusion

The quantity of biotic taxa depends on their hierarchal rank and geographic location. The maximal values of taxa which corresponded to ideal existence conditions are observed in the subboreal forest or northern foreststeppe. The taxa quantity decreases in the north and in the south of the region due to the lack of heat in the north and its abundance in the south. We were derived the formulas of the dependence of taxa quantity of both plants and animals of any rank on the dryness index that is a complex climatic variable showing the correlation between heat and moisture in a certain area.

We determined selfsimilarity (fractality) of biotic taxa in hierarchal system *species … order*, when on a logarithmic scale.

On the whole, the obtained results demonstrate integrity and interdependence of plants and animals existence and their shared climate dependence.

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Geosimulation approach to modelling spatial objects and its application to creating thermokarst lake model using remote sensing data

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The paper discusses various approaches to modelling complicated objects. As shown The geosimulation approach is considered to be the most useful for modelling natural objects with spatial properties. The geosimulation model of the dynamics of these fields is proposed on the basis of experimentally determined statistical properties of the thermokarst lake fields. An analysis of experimental data on the statistical properties of the fields of thermokarst lakes in the area of permafrost in Western Siberia was carried out using remote sensing for measurement of lake areas. The relationship between climatic changes and geocryological parameters was studied and a multiple regression equation to take account of temperature and precipitation changes in the model was determined. A geosimulation software package was developed. This makes it possible to model the dynamics of the thermokarst lake fields, taking into account identified thermokarst and climate changes. The validity of the model and its accuracy in use were tested by comparing model results with experimental remote data. The results can be used for prediction of the thermokarst change dynamics in permafrost.

Keywords: geosimulation modelling, climate changes, geosimulation software, thermokarst lakes, permafrost.

Introduction

The intensification of geocryological processes in the permafrost caused by climate change, accompanied by intensified impact on infrastructure and other buildings in Arctic regions, will increase geoecological risks and result in significant economic damage. Remedial measures require making valid predictions concerning changes in the state of the permafrost, taking into account global warming. The forecasting of changes in the permafrost caused by climate change is an extremely important problem. There is a need for techniques and tools of mathematical modelling which use experimental data concerning changes in the permafrost. Since it is hard to reach the West Siberian wetland, collecting data is impossible without the use of remote sensing.

Thermokarst lakes, which can be decoded easily in satellite images, are the most suitable indicators of geocryogenic surface changes in northern permafrost landscapes. Sets of lakes of different sizes characterise these landscapes. Thermokarst lake fields display noticeable changes in both space and time. Their boundaries' shape and water surface areas change, new lakes emerge, some lakes disappear, turning into khasyreis (hollows of drained lakes). It is necessary to determine statistical regularities of spatiotemporal changeability of these fields' properties, using the analysis of experimental data obtained by remote sensing, to develop techniques and tools for modelling thermokarst lake field dynamics.

Thermokarst processes can be modelled mathematically with analytical models based on theory. Matt has shown [1] that such models are efficient for studying processes in a single thermokarst lake, but unsuitable for modelling spatiotemporal changes of thermokarst lake fields. The methods of mathematical morphology developed by Victorov [2, 3]are of great importance here as they are designed to use analytical models for territory dynamics modelling. These methods enable longterm dynamics of the state of a territory to be predicted; but they are not designed for the study of the spatiotemporal changeability of fields of thermokarst lakes. At present, no models are available for studying the spatialtemporal changes of random thermokarst lake fields.

There is a need for a new approach to modelling the dynamics of thermokarst lakes' fields. This approach based on geosimulation methodology was proposed in our previous work [4]. Methodological issues were not discussed in that work, nor in works of other authors. The aim of this paper is to present the methodological issues in a geosimulation approach to modelling natural objects with spatial properties and its application via a mathematical model of the dynamics of thermokarst lakes' field.

1. Geosimulation approach to modelling complex objects with spatial properties

1.1. Mathematical models and modelling

Complexity and specific features of natural objects make experimental analysis of such objects extremely costly in time and money. As a result, researchers of complex natural systems face a lack of experimental data. This problem could be solved by using theoretical information from previous research. Propositions of such kind required development of a new approach to natural system research, on the basis that a model should be regarded not only as a means for information storage about an object under but also as an instrument for research development and forecast. Thus, mathematical modelling becomes an independent research concept. According to Trusov [5], modelling is defined as a process of model construction and use.

A model of natural systems cannot be developed using only theoretical research; the whole range of information about a researched object should be used. Thus, to design a proper model a combination of theoretical and experimental methods and data should be applied. Computer experimental work, based on models of researched objects and using computer generated means, takes place in this framework.

There are two main types of computerbased experiments: computational and simulation ones. Both types apply mathematical models as "substitutes" for a real research object. But, there are differences also. A mathematical model used in a computational experiment is realized in equations (differential, algebraic, etc.) which are impossible to be solved in analytical form (formula enclosing parameter dependency). Besides, numerical methods and effective computational algorithms are to be used. In contrast, simulation experiments, not based on general research object theory, describe behaviour of a real object, using empirical data, and are realized in a set of algorithms, reflecting changes defined by some scenarios in conditions of a modelled object [6, 7]. Simulation experiments result not in numerical solutions of some equations of a model, but in implementation of computer generated processes imitating the behaviour of a real natural object. The accuracy of the task completed, generated by mathematical modelling, depends on the degree of coincidence between the model and a real object. Thus, development of valid models for real objects is an urgent problem.

There is no single definition of a model. The most common definitions are presented below. According to Trusov [5], a model is a substitute object (analogous to the real one) which substitutes for a real object in the course of the research, preserving its typical features critical for the research. This condition allows a researcher to study original properties under question. According to Schrader [8], a mathematical model is a set of some elements in relations determined by this set. Peschel defines a model is defined as a structure to store knowledge about an object [9]. According to Fleishman *et al* [10], a mathematical model of a complex object is a sign system, the properties of which are in such proximity relation to properties of a studied object, that computer experiments can obtain all the necessary information about the object's behaviour and properties in set conditions.

We shall now consider basic approaches to complex system model construction and summarise model classification on the principle of application of *a priori* information about an object and a researcher's involvement in the construction process. An approach may be either inductive or deductive. An inductive approach uses empirical information as a source for *a priori* knowledge about an object. A deductive approach uses theoretical knowledge for the same purpose. Depending on the knowledge chosen as a basis for model construction, conventional types of models may be either empirical (inductive) or analytical (deductive).

Complex natural object research tasks have shown that neither empirical nor theoretical knowledge alone is sufficient for model construction. Thus, a new inductivedeductive model construction approach has been formulated. This urges a model researcher to use both empirical and theoretical knowledge about an object's properties and its behaviour.

Since presentation formats of empirical and theoretical knowledge are substantially different, the main difficulty in model construction is to create a structure which can organize object property information extraction procedures from empirical data and theoretically determined patterns in the most efficient way. Thus, it is necessary when designing such models to focus on special strategies and procedures, capable of applying an increase in information (empirical and theoretical) in the model. As such, the task is rather informational than mathematical. Accordingly, this task requires application of computer science methods and means as well as information technology. The importance of computer use is higher in the process of model construction in comparison with its use in model application.

Today, semiempirical models, based on inductive and deductive ones, are becoming widely used, replacing conventional types of models (analytical and empirical) applying conventional inductive and deductive approaches to model constructing. Simulation models are typical semiempirical models used to record numerical information about a modelled object. A detailed account of these model types now follows.

1.2. Basic types of mathematical models

Analytical models use theoretical knowledge as an information source about an object. When constructing these, the modeller selects what he considers to be the most substantial phenomena and objects, their elements and relations. This makes such analytical models, due to their extreme simplicity, applicable only for "rough" explanation and qualitative description of studied phenomena or an object.

The researcher's role in such modelling process is central. Analytical models can be implemented without computer technology, but in case of high model equation complexity, when obtaining of dependencies explicitly is problematic, model application results can be obtained with the help of a computational experiment. Such results have a limited character due to a simplified object model description and, as a rule, they are not efficient enough for the tasks of numerical prediction of complex object properties.

Empirical models commonly implement an inductive approach, usually being empiricstatistical models. These are based on statistical information about a modelled object. They also depend on the application of welldeveloped methods of mathematical statistics (regression and correlation analyses, statistical distribution law hypothesis check, etc.) These methods are not designed to reveal causeeffect relations but can be used to identify factors of interrelation presence between indexes of studied object conditions and hypothesis check concerning these relations.

Simulation models are mathematical. They are constructed in a condition of insufficient object description. They are thus different from any conventional models of mathematical modelling. The ability to construct simulation models without sufficient information about an object makes simulation modelling more true to life. One may expect substantial expansion of this type's application in research of complex natural objects.

A simulation model is a mathematical model [6] representing the process of a modelled object functioning within time by imitating basic phenomena and processes, and preserving their logical structure and time sequences, which allows using initial data about object state at snapshots to estimate features of a real object. Object behaviour is presented in a model as a set of algorithms which actualize conditions emerging in a real object state and changing in accordance with defined scenarios. Prediction of object properties and object behaviour forecast within simulation modelling ideology is performed by means of simulation experiment with a model. Such experiment allows the researcher to "replay" various situations changing according to some set scenarios in a real object state. The "scenarios" of simulation experiment are defined as either formalized or nonformalized descriptions of experiment objectives and procedures.

1.3. Geosimulation modelling and geosimulation models

Simulation modelling is one of the most important mathematical modelling types. According to Moiseev and Svirezhev [11], simulation modelling is a research method which can build an approximate model of a studied object; the simulation model describes a real object with accuracy sufficient for current research. Kosolapova and Kovrov [12], and Low and Kelton [13] claim that simulation modelling is used to construct models in cases where, firstly, there is no analytical solution or this solution is very complex and requires huge computer capacity and, secondly, the amount of experimental data about a modelled object is insufficient for statistical method. In such a case a mathematical model is developed in simulation modelling.

Russian scientists, Berlyant *et al* [14], have made a major contribution to methodology development of spatial objects modelling. They have named this type mathematicocartographical modelling. Tikunov [15] presents methodological issues of using this type of model for modelling spatial natural objects. Kuzmichenok [16], Kovalev [17], Serdutskaya and Yatsishin [18], Kulik and Yurofeev [19], and Timonin [20], have all studied spatiodistributed objects using methods of mathematico-cartographical modelling.

A group of authors have introduced the special terms for modelling spatial objects. Lawson and Denison [21], Wang [22], PohChin et al [23], Zhao and Murayama [24] have introduced spatial modelling.

Royle and Dorazio [25], Lawson [26], and Sang and Gelfand [27] introduced hierarchical.

Polishchuk and Tokareva [28], Zhao and Murayama [24], and Polishchuk Yu. M. and Polishchuk V. Yu. [29] have introduced geosimulation modelling.

All the above types of modelling aim to study spatial objects using spatial data, analysis of which is based on spatial analysis methods implemented with the help of modern geoinformation systems (GISanalysis). In our opinion, the most suitable general term for the mentioned types of modelling (mathematicocartographical, spatial, hierarchical, geoinformation, geosimulation) is the term 'geosimulation modelling' which is defined as a model creation and model application for objects with spatial structure. Problems of creating a geosimulation model of thermokarst lake fields will be considered further.

2. Creation of geosimulation model of thermokarst lake fields

2.1. Experimental basis for geosimulation modelling of spatial structure of thermokarst lakes' fields

Creation of a geosimulation model of thermokarst lakes' fields requires knowledge of the basic properties of these fields, which can be obtained experimentally. Because of the inaccessibility of the northern territories of Siberia, thermokarst experimental studies were carried out by remote sensing. For remote study twentynine test sites (TS) were chosen in different zones of the WestSiberian permafrost (sporadic, discontinuous and continuous). Remote study of the shape of thermokarst lakes' boundaries was carried out via satellite images in our research [30]. Research conducted in test sites in sporadic, discontinuous and continuous permafrost showed that the error in estimating lakes' areas while replacing their real lakes boundaries by a circle is comparatively small (about 5%). It may serve as a reason to choose a circle as a model for a lake in geosimulation modelling thermokarst lake fields. In addition, the formation of geosimulation model of thermokarst lakes' fields in the form of a population of random circles requires experimental knowledge about the distribution of coordinates of lakes centres and the distribution of lakes sizes (areas).

To state the regularities for distribution of random coordinates of lakes, satellite images were used. Analysis of histograms of distribution of latitude and longitude values of location of lakes' centres given in Polishchuk, Yu. and Polishchuk, V., 2011 [30] showed that experimental regularities of distribution of coordinates of lakes' centres correspond to the law of uniform density according to criterion χ^2 with a probability of 95% [31, 32].

Histograms of distribution of lakes' number in accordance with their areas were built for all the test sites, located in different permafrost zones. For example, Fig. 1 represented the histograms for three test sites located in different permafrost zones. Here K_i – the relative number of lakes in each *i*th interval of histogram, s – lake's area.

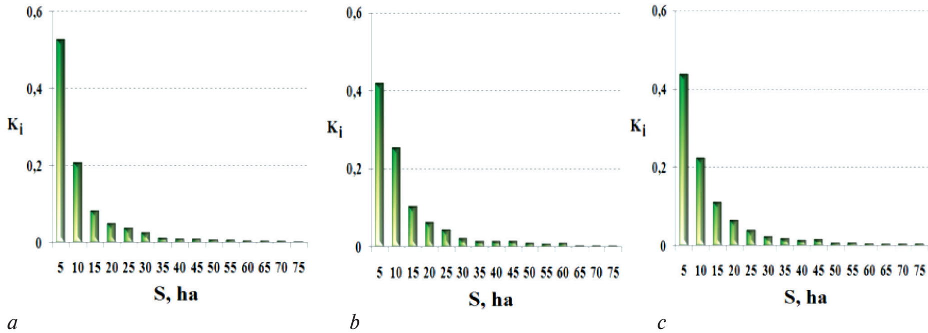

Fig. 1. Histograms of distribution of lakes in accordance with their areas: *a* – sporadic permafrost; *b* – discontinuous permafrost; *c* – continuous permafrost

Comparison of the diagrams shows that they have, in general, an exponential character by means of the experimental law of distribution, which makes it possible (for thermokarst lake fields to be modelled easily. We may choose a oneparameter exponential law to describe thermokarst lakes' distribution in accordance with areas in the following form:

$$y = \lambda \cdot e^{-\lambda s} \tag{1}$$

where λ – a parameter of distribution law.

The value of parameter λ can be determined with the help of experimental data. According to Wentzel [31], mathematical expectation of random quantity following the distribution law is determined in the form:

$$M(s) = \frac{1}{\lambda}.$$

Using as the estimate of mathematical expectation *M(s)* the value of average lake area estimated in accordance with experimental data in the following form:

$$\bar{S} = \frac{1}{n}\sum_{i=1}^{n} S_i,\ i = \overline{1,n},$$

we will find that parameter λ can be determined with the help of experimental data according to the formula:

$$\lambda = 1/\bar{S} \tag{2}$$

Testing correspondence of exponential law of lake area distribution given by Eq. (1) to experimental histograms shows that in all researched test sites this law corresponds to experimental data in accordance with criterion χ^2 with average probability 90%. Consequently, the stated law of lake distribution in form Eq. (1) according to areas does not contradict the experimental data. The analysis of the experimental distribution of lakes according to their areas shows that λ in all test sites in a continuous permafrost varies in the range of 0.037–0.071, and in a discontinuous permafrost – in the range of 0.034 – 0.086 with average values 0.054 and 0.060 respectively.

From the point of view of modelling thermokarst lakes, it is interesting to investigate the statistical relationship between changes in thermokarst lakes' areas and coordinates of their centres. Table 1 contains correlation matrices determining the degree of statistical relationship between changes in geographical coordinates of the lakes and their areas. Here we use the following agreed notations:

s – lakes' area;

x – geographical longitude;

y – geographical latitude.

Table 1. Correlation matrices of interconnection of changes in thermokarst lakes' areas (*s*) and centres' coordinates (*x,y*) in different permafrost zones

Discontinuous					Continuous			
random quantity	s	x	y		random quantity	s	x	y
s	1	–0,06	–0,09	xxxxxxx	s	1	–0,04	–0,03
x	–0,06	1	–0,06		x	–0,04	1	–0,08
y	–0,09	–0,06	1		y	–0,03	–0,08	1

Correlation analysis conducted for all test sites showed that the correlation coefficients between latitude and longitude do not exceed 0.1

These values display nearly absent correlated relationship between changing coordinates, which results in the conclusion about statistical independence of longitude and latitude changes. Correlation factors between values of areas and coordinates are within the interval –0.09 and +0.04, which also gives grounds for a conclusion about the statistical independence of changes in lakes' areas and their centres' location coordinates in different permafrost zones. Consequently, an important feature of thermokarst lakes' fields is statistical independence of changes in random quantities of centre coordinates and lakes' areas.

Accordingly, the following fundamental principles determining substantial properties of a model of spatialtemporal structure of thermokarst lakes' field can be formulated:

Lake coastline shapes can be represented by a circle equation with centres' coordinates x_i, y_i and area S_i (i – lake serial number).

Spatial changes in the position of centres of circles and their areas are statistically independent.

Random distribution of circle centres' coordinates x_i, y_i (i =,) is governed by a uniform law.

Random distribution of number of circles over their areas conforms to the exponential law of distribution as in (1) with λ as a parameter.

Time changes in statistical properties of population of random circles and their dependence on climatic changes are determined by dependency of parameter λ on time and climatic characteristics in the following equation:

$$\lambda = f\ (T, P, t) \qquad (3)$$

where T – temperature; P – level of precipitation, t – time.

2.2. Geometric interpretation of model of spatial structure of thermokarst lake fields

A model of a thermokarst lake field is a population of random circles (Fig. 2), whose statistical characteristics correspond to the above principles (1–5). Figure 2 presents a geometrical interpretation of the model of thermokarst lake fields. Using number triple (*x, y, s*), representing the value of the centre of the circle coordinates and value of its area, coordinates of the points determining borders of each circle are calculated a s follows:

$$x_k = R^* \cos\gamma + x, \quad (4)$$

$$y_k = R^* \sin\gamma + y, \quad (5)$$

where x and y – coordinates of the centre of the circle; x_k and y_k – coordinates of k – th point on the circle; γ – value of axial angle x and radius, directed from the centre of the circle into k –th point on the circle R – radius of the circle, computed using the following formula $R = \sqrt{s/\pi}$; where S – random value, distributed by exponential law and determining the area of the circle.

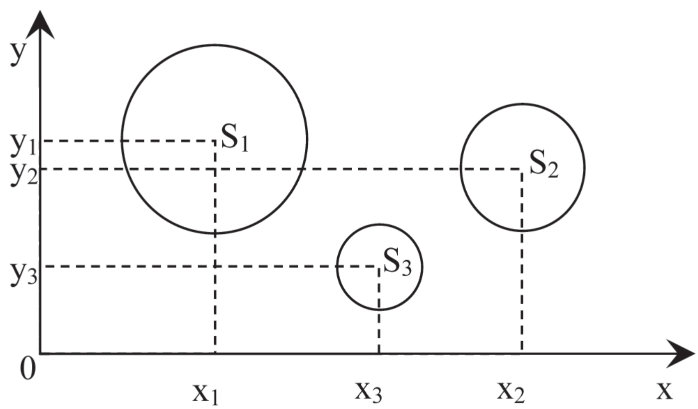

Fig. 2. Geometrical representation of thermokarst lake field model fragment as a population of random circles

Consequently, major elements in the model description are characteristics of lake shapes, parameters of their random location on surface and random distribution of lakes over their size (areas). Analysis of experimental data on number change of thermokarst lakes, presented in the previous section, shows that the relative number of reemerged lakes does not exceed 9% for the last three decades on the test site, and a relative number of disappeared lakes over the same period is a per cent share. Therefore, lake appearance and disappearance processes are not reflected in the developed geosimulation model of thermokarst lakes.

2.3. Study of interrelation of climate and geocryological changes in permafrost and its accounting in the model

To consider climate change influence on properties of thermokarst lake fields, it is necessary to use geosimulation modelling for the study of correlation of climatic and thermokast changes in the West Siberian permafrost zone. This requires the simultaneous analysis of data on area dynamics of thermokast lakes and time sequences of climatic indices provided by meteorological stations located on the geocryological changes test sites. Accordingly, location overlap (or at least close location) of test sites and meteorological stations is necessary.

The analysis of test sites and meteorological stations locations on the territory under study shows that, as a rule, they do not match. Meteorological stations are usually based on river and sea coasts or in an inhabited locality on hardtoreach territories of the permafrost zone and thus are distant from test sites. Such location divergence of test sites and meteorological stations can cause considerable inaccuracy in the results of analysis of correlation of climatic and geocryological changes on the tested territory. Therefore, to analyse correlation of area change of thermokarst lakes and climatic indices (average annual temperature and precipitation level) an alternative approach was taken to obtain data on air temperature and precipitation. The approach is based on reanalysis of meteorological data which makes it possible to estimate the value of climatic indices in test sites.

Reanalysis (repeated meteorological analysis) [33] is a method to obtain meteorological information in set points of the tested territory. Reanalysis is based on "acquisition" of historical observational data from the net of meteorological stations, covering a continuous period and using a unified scheme of consistent data "acquisition" over the whole period of analysis. The main advantage of such meteorological data is uniform cover of the territory. Various systems [34, 35] of reanalysis are available. In the present work *Reanalysis ECMWF ERA40, Reanalysis ECMWF ERAINTERIM and APHRODITE JMA* systems were used to define climatic characteristics.

A brief description of reanalysis of data use procedure in the present research now follows. Average monthly values of air temperature and annual precipitation in test sites from 1970 until 2010 were obtained with the help of reanalysis. As such data are represented in a set of graphic files in the wellknown *.png format, a template map locating test sites was developed to extract information necessary for climatic study. The template map was overlaid on the map of temperature and level of precipitation fields, obtained by reanalysis, and with the help of graphic editor MSPaint the template map was overlaid on the map of temperature and level of precipitation fields, obtained by reanalysis, a new image representing an overlap of test site location maps and temperature (or precipitation level) field was produced.

Such integrated maps helped to determine average monthly values of air temperatures and annual precipitation in the centre of each test site. The next stage was to calculate average value of air temperature for each test site monthly and annually. As a result, tables of time series of annual average value of air temperature and annual precipitation for each test site were obtained.

As shown in the previous section, features of thermokarst lake fields change under the conditions of contemporary climate warming. The most sensitive indicator of thermokarst processes influenced by temperature rise is thermokarst lakes' area, which is illustrated with the results of remote study in West Siberia [36, 37]. Bryksina *et al* [38] and Polishchuk *et al* [29] analyse the interconnection between thermokarst and climate change. This section will describe the results of analysis of interconnection between geocryological changes in thermokarst lake fields and climate features (air temperature and precipitation level) in the permafrost of West Siberia.

One can see the results of comparing time series of average lake area and average annual temperature in 29 test sites. According to the results of measuring lake areas with the help of satellite images, average lake areas were determined in each test site. The analysis of time series of total areas of thermokarst lakes made it possible to indicate trends in changing average area of the lakes. For example, in Fig. 3 there is a diagram of time dependence of average area of thermokarst lakes in TS – 13, displaying on average decrease in time in average lake area with coefficient of a linear trend $\alpha = -0{,}11$ha/year. A straight line in Fig. 3 presents the trend line.

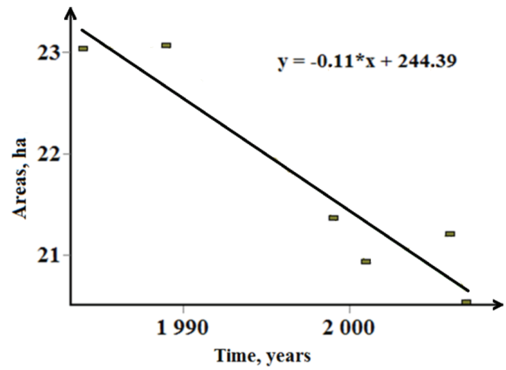

Fig. 3. Changes in the average area of thermokarst lakes in time

To study the interrelation between the changes of thermokarst lake areas and changes of air temperature and precipitation level we shall compare coefficients of a linear trend of time changes of average values of the lakes' areas and climate characteristics. It is the analysis of the data obtained for developing a model of thermokarst lake fields suitable for prediction that is of most interest. It is necessary to study temperature dependence of parameter λ, which determines the kind of law for thermokarst lakes' distribution in accordance with their areas, discussed in section 2.1. The data exist only for the years when cloudless images were taken, which made it possible to calculate the value of parameter λ.

The diagrams illustrating dependence of the value of parameter λ on average annual air temperature and precipitation level, presented in Fig. 4, show the dependence of parameter λ on climate indicators under study.

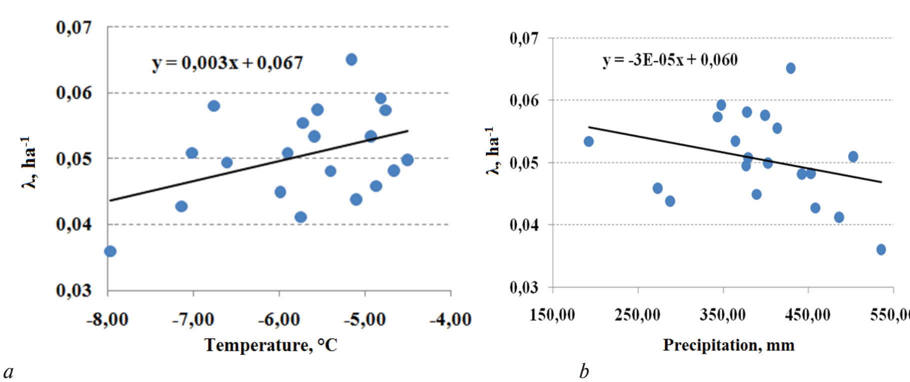

Fig. 4. Dependence of the values of parameter λ on annual rainfall and average annual air temperature

Figure 5 shows the time dependence of parameter λ. The equation of linear approximation of time dependence of λ shows the presence of dependence of parameter λ on time. This conclusion is important because taking into account time dependence of this parameter in modelling will allow the prediction of spatiotemporal changes in thermokarst lake fields under the conditions of climate change.

Previously the equation of dependence of parameter λ on time and climate features was introduced in implicit form (3). To develop a model of actual thermokarst lake dynamics it is necessary to define this dependence in explicit form. This was the reason for doing multidimensional regression analysis [32] of time series of the values of parameter λ and climate features in the West Siberian territory under study represented in Figs. 4 and 5.

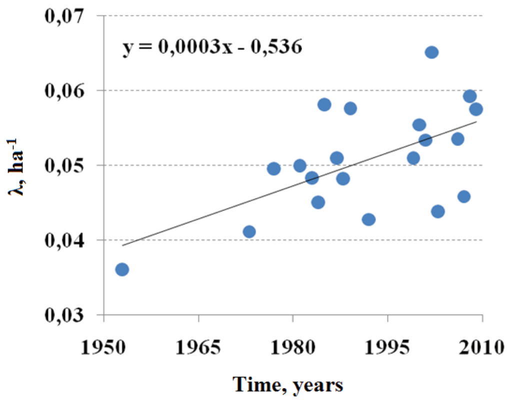

Fig. 5. Average value of parameter λ depending on time

The results of multidimensional regression analysis of the data on parameter λ and climate features can be presented as an equation of multiple regression in the form:

$$\lambda = c_0 + c_1{}^* x_1 + c_2{}^* x_2 + c_3{}^* x_3, \tag{6}$$

where x_1 – average annual air temperature; x_2 – precipitation level; x_3 – time; c_i – coefficients of regression equation; $i = 0,\ldots,3$.

In the result of the regression analysis of time series of the values of parameter λ and climate features, the following values of regression equation coefficients were obtained (6): $c_0 = -0{,}585$ ha^{-1}; $c_1 = 0{,}00062$ ha^{-1}/ºC; $c_2 = 0{,}000014$ ha^{1}/mm; $c_3 = 0{,}00032$ ha^{-1}/year.

The stated regression dependence of parameter λ on time and climate changes is a basis for developing algorithms for modelling random thermokarst lake fields, discussed in the next section.

3. Geosimulation modelling spatiotemporal structure of thermokarst lake fields

3.1. Algorithm for spatiotemporal modelling thermokarst lake fields

In a general case, mutual density of probabilities of random coordinates of centres and areas of circles imitating lakes in a mathematical model of random thermokarst lake fields can be presented in the form:

$$f(x, y, s) \tag{7}$$

where x and y – coordinates of circle centre in a model; s – area of a circle imitating a lake.

Consequently, the totality of circles in the model of lake fields will be presented as a totality of groups of three random values (x, y, s). To develop an algorithm for modelling thermokarst lake fields, it is necessary to take into consideration statistical connections between changes in lakes' coordinates and their areas. The analysis of correlation matrix done in subsection 1.3 showed that random spatial changes in areas and coordinates of lake centres, in the same way as coordinates of lake centres between each other, are statistically independent. This is the reason why, when modelling thermokarst lake fields, mutual density of probabilities (7) can be presented in the form:

$$f(x, y, s) = f(x) \cdot f(y) \cdot f(s), \tag{8}$$

where *f(x)* and *f(y)* – densities of the probability of even distribution; *f(s)* and value of model parameter λ are determined by (1) and (2) respectively.

Further to equation (7), the randomnumber sequence determining characteristics of location of circles' centres (x and y) is generated using the antenna of pseudorandom numbers distributed in accordance with the law of even distribution. And to form circles of random size whose areas are distributed according to the law conforming to equation (1) it is necessary to generate randomnumber sequences distributed in accordance with the demonstrative law conforming to equation [39]:

$$s_i = -\frac{1}{y}\ hz_j, \tag{9}$$

where Z_j – numbers with even distribution in the interval (0,1), $j = 1,\ldots, m$.

Consequently, together with using software generators for even distribution of pseudorandom numbers, the software realization of an imitation model of thermokarst lake fields includes creating a generator for pseudorandom number sequences, distributed in accordance with the demonstrative law. Then algorithms for modelling spatiotemporal structure of random thermokarst lake fields are considered.

We should consider a geosimulation model of spatial structure of a thermokarst lake field $M_П (t)$ that is a totality of circles and reflects the state of a thermokarst lake field at the moment of time t, whose geometrical representation is shown in Fig. 2. To model the dynamics of thermokarst lake fields, we should consider a general model of spatiotemporal structure of a thermokarst lake field in the form:

$$M_{ПВ} = \{M_{ПВ}(t_1),\ldots,M_П(t_j),\ldots, M_П(t_n)\}, \cdot j = 1,\ldots,n, \tag{10}$$

which is a totality (time sequence) of geosimulation models of a thermokarst lake field $M_П (t_j)$, $j = 1,\ldots,n$, where each model relates to a particular moment of time.

Figure 6 gives a visual presentation of the general model for spatiotemporal structure of thermokarst lake fields in the form of geoinformation system (GIS) layers that relate to given time moments $t_1, t_2,\ldots, t_n \in (t_1, t_n)$

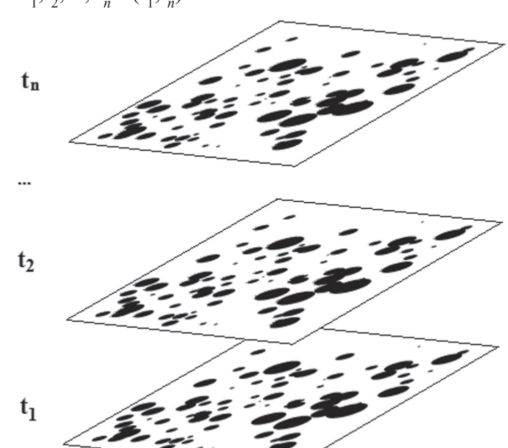

Fig. 6. Visual presentation of a general model of dynamics of thermokarst lake fields. Legend: t_i – time (year), $i = \overline{1,n}$

When modelling spatiotemporal structure of thermokarst lake fields it is important to take into consideration both time dependence and climate features (temperature, precipitation level). Accordingly, the dependence of parameter λ on time and climate features is determined by the equation of multiple regression in the form (6). This is the reason why equation (6) was used to develop an algorithm for numerical modelling dynamics of thermokarst lake fields.

The developed algorithm for modelling dynamics of thermokarst lake fields can be presented as follows:

the year of modelling is specified t_j, $j = 1,...,m$;

the areas (S_{MA}) of the model area (MA) under study are specified;

lake density (δ_{MA}) in MA is specified;

the number of circles within MA is determined in accordance with formula:

$$N_{MA} = S_{MA} \times \delta_{MA};$$

the centre of MA location in the map is specified;

parameter λ is determined in accordance with formula (6) for given values of temperature and time (year of modelling);

pseudorandom number is generated, distributed in accordance with uniform law;

using the number obtained at the previous step, a pseudorandom number is calculated according to formula (9) to characterize the value of circle area;

two pseudorandom numbers are generated, distributed in accordance with uniform law, determining the coordinates for circle centre location on the screen;

using the values of a number triple *(x, y, s)* obtained at previous steps 8 and 9, in accordance with equations (4) and (5) a circle is formed on the screen;

If the number of circles obtained is less than N_{MA}, determined at step 4, the algorithm repeats beginning with step 7, otherwise it is completed.

The given algorithm allows formation of a model of spatial structure for a given time moment $M_{\Pi}(t_j)$, where $j = 1,...,m$. To make a general model of dynamics of a thermokarst lake field by means of forming a time sequence of models $M_{\Pi}(t_j)$ for a given set of moments t_j ($i = 1,...,m$) the algorithm repeats for the number of times (m) needed.

Polishchuk (2013) presents a structural scheme of the developed software package for geosimulation modelling thermokarst lake fields [40]; and the same paper discusses the software realization of the algorithm for geosimulation modelling. Figure 7 presents an example of modelling thermokarst lakes' field.

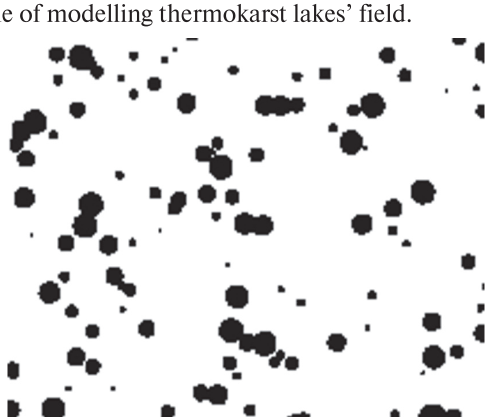

Fig. 7. Example of modelling thermokarst lakes' fields

The software package for geosimulation modelling thermokarst lake fields is registered by Russian Federal Intellectual Property Service [41].

3.2. Studying model validity and modelling accuracy

The research is based on carrying out computerbased experiments. Model validity was studied by comparing average lake areas according to experimental and modelling data. Two data arrays containing 29 values corresponding to the number of TS were compared. The first data array contains values of thermokarst lake areas for each TS, averaged for the period under study, determined in accordance with satellite images. The second one – averaged for the period under study – contains values of model lake areas calculated with the help of the developed model. The second data array, in accordance with empirical data averaged for the period under study, contains average values of lake areas with the values of parameter λ being determined, as they were used in modelling.

Comparison of two selected arrays was done in accordance with the Student test. The formula used in calculation [42] to compare two small samples i.e. samples less than is:

$$t_\beta = \frac{\left|\overline{X} - \overline{Y}\right| * \sqrt{n*(n-1)}}{\sqrt{\sum\left[(x_i - y_i) - (\overline{X} - \overline{Y})\right]^2}}$$

with the number of degrees of freedom $k = 2*(n-1)$,

where t_β – value of Student's test, used to determine confidence probability of groups' difference;

x_i and y_i –average values of lake areas in ith TS, averaged for the period under study, according to experimental and modelling data respectively for ith TS;

and – arithmetic means for average values of lake areas according to experimental and modelling data, averaged for the period under study ;

n – size of experimental and modelling data samples.

During the research it was stated that with number of degrees of freedom $k = 56$ value of Student's test $t_\beta = 0{,}62$. According to Polishchuk [40], if $t_\beta = 0{,}62 < t_{\beta\_tab} = 2{,}003$ with $k = 56$, then for confidence probability 95 % we can reach a conclusion about the reliability of the similarity of samples.

Consequently, the developed model can be regarded as appropriate to the experimental data.

Accuracy of modelling dynamics of thermokarst lake fields was studied in the form of computer experiment on the model. Values of parameter λ in this case are calculated according to the multiple regression formula (6) using the data about average annual temperature and precipitation level determined for each TS by reanalysis. Then a model field is formed in accordance with the algorithm described above. The formed model thermokarst lake field is displayed onscreen (Fig. 7), then the array of values of modelled lake areas is saved as a file for analysis.

As mentioned above, calculated values of λ were used to generate model lake fields used to determine average values of model lake areas. Figure 8 shows the graph of time dependence of model area values with a solid line. A dashed line shows time dependence of average experimental values of lake areas. Vertical dashed sections indicate intervals between maximal and minimal values of experimental average values of lake areas. Figure 8 shows that the graph for average values of model areas in general keeps within the intervals, which may serve to indicate the reliability of modelling results.

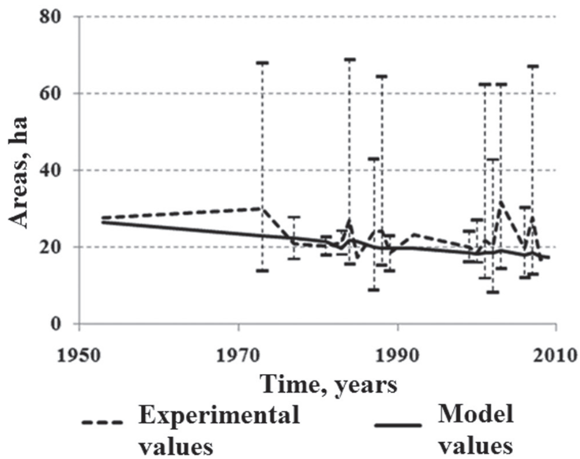

Fig. 8. Time dependences of average values of experimental and modelled average values of lakes' areas

To estimate the accuracy of modelling average thermokarst lake areas in the permafrost we shall determine rootmeansquare deviation with Wentzel's formula [31]:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (\frac{x_i - y_i}{x_i})^2}{n-1}},$$

where x_i and y_i – average values for experimental and modelled lake areas respectively; n – number of values, $i = \overline{1n}$.

Estimation showed that the error of determination of average values of lakes' areas on base of modelling with use of experimental data is 17 %. This may well be regarded as a suitable result of modelling thermokarst lake fields for predicting thermokarst lake fields' dynamics.

Acknowledgements

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