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VLADIMIR IVANOVICH VERNADSKY (ON THE 150TH ANNIVERSARY OF HIS BIRTH)

The geological history of the biosphere
opens to the man a huge future
if he understands it and does not use his mind
and his work on self-destruction.

V.I. Vernadsky

In 2013, the global scientific community celebrates the 150th anniversary of the birth of our great compatriot Academician Vladimir Ivanovich Vernadsky – scientist, thinker, humanist, science theorist, historian and organizer, as well as a social and political activist who has had and continues to exert an enormous influence on the development of modern science, our scientific thought, our scientific world, and our understandings.

Vladimir Vernadsky, in the words of his student Academician A.Ye. Fersman, is the "largest and original researcher of living and inanimate nature, a creator of new scientific trends, and a reformer and a founder of Russian mineralogy and the world geochemistry", whose way of life is "the way of hard work and bright creative thinking, a way that opens up new fields of science and outlines new directions of science in our country". With his scientific activity, V.I. Vernadsky – wrote his close friend, Professor B.L. Lichkov – "plowed the fields of many sciences: chemistry, mineralogy, geology, soil science, and biology; at the same time, he created new sciences – geochemistry and biogeochemistry. This fact is striking ... At our time of deep scientific expertise ... Vernadsky, as a type of scholar, throughout his work, is a rare exception. Amazing knowledge of the facts of the broad areas of nature and no less striking understanding of scientific methods and techniques, no matter where they are applied, are his characteristic features. He perceived science not as a system, like the dogmatized provisions of the present, but in a much wider sense: he perceived it deeply both dynamically and historically, as a living evolving entity, and he brilliantly knew its past... The range of his factual exact knowledge was striking ... He was a chemist, a geochemist, a biologist, and a soil scientist. But the most remarkable thing ... is that in all these branches of science, he was the *creator*, the creator of a large scale".

Indeed, now, in the second decade of the XXIth century, it is safe to say that Vladimir Ivanovich Vernadsky is an outstanding scholar and encyclopaedist, who, for a variety of fields where he left a deep impression, cannot be matched. Vernadsky made an invaluable contribution to the creation, formation, and development of many scientific disciplines and fields: crystallography, genetics, chemical mineralogy, crystal chemistry, geochemistry, biogeochemistry, radiogeology, radio-chemistry, cosmochemistry, meteoritics, geochemistry of natural waters, geochemical environmental science, landscape geo-chemistry, environmental geochemistry, hydrogeology, soil science, chemistry, biology, biogeocenology, ecology, geography, theory of science, history of science, terminology, museum studies, philosophy and logic, theory of the biosphere, living matter and its geochemical role of geochemical activity of man, minerals, dissymmetry of geological object, and optical activity of protoplasm; he developed the original concept of noosphere and a concept of space and time that is no less original. V.I. Vernadsky is the founder of a huge school of mineralogists, geochemists, biogeochemists, and representatives of other scientific fields that produced the world-renowned scientists: V.V. Arshinov, A.P. Vinogradov, K.A. Vlasov, A.A. Polkanov, A.A. Saukov, A.A. Tvalchrelidze, A.Ye. Fersman, V.G. Khlopin, D. Shcherbakov, and many others.

Scientific, organizational, and socio-political work of Vernadsky is striking in its ebullience, diversity, productivity, and originality. He is the author of more than 400 published scientific papers in his lifetime, not including impressive and fundamental works that were published after his death, numerous notes and references to various ministries, departments, and organizations (they have not lost their significance in our day), and a huge number of letters (as observed by one of his contemporary biographers, "Vernadsky could and loved to write letters"; their scientific, historical, cultural, and social significance is very high). Vernadsky's diary, which he kept throughout his adult life (the first record was made in 1877 and the last – on 24 December, 1944) has particular historical, cultural, and scientific importance.

In 1884, still a young man, V.I. Vernadsky has formulated his life credo: "The man's task is to bring the best possible benefit to others". Later, in 1866, in his letters to N.Ye. Vernadskaya he clearly pointed out his future activities and his understanding of the world: "Now I found out the way, the conditions, which will be my life. This will be the scientific, public, and journalistic activities... I ... am convinced that one of the necessary conditions for further development of human existence itself is that everyone lives according to his beliefs and works as hard as possible for the general benefit; I consider "personal sanctity" one of the important conditions of such life... It's such a life where the words are where the conviction is, where I help, as I am able to, my brothers, all people, so I contribute, as much as possible of good, honest, and spiritual, so I inflict as little as possible of distress, suffering, illness, and death. This is such a life that at my death-bed, I could say: I did everything I could. I didn't make anyone miserable, I tried that after my death my goal would be pursued and my place would be taken by the same, no, by better workers than I." Vladimir Vernadsky followed firmly these beliefs all his life – long and full with creativity and events; he remembered, until the end of his days, his ideals; the program of "Brotherhood" (a coterie of the university youth founded in 1886) – to devote life to science and education of and assistance to people, to other practical work for the benefit of society

In 1885, after graduating from the Natural History Department of Physics and Mathematics Faculty of St. Petersburg University, Vernadsky was a keeper of the Mineralogical Cabinet of St. Petersburg University (1885–1890), then Privatdocent, and (since 1898), Professor of Moscow University (until 1911), Professor at the Higher Courses for Women (1897–1906), Head of the Mineralogical Museum of the Geological Department of the Academy of Sciences (1906–1914), Director of the Geological and Mineralogical Museum of the Academy of Sciences (since 1914, and since 1921 also directed its Meteorite Department), Chairman of the Commission for the Study of the Natural Productive Forces of Russia (KEPS) (1915–1930), the first President of the Ukrainian Academy of Sciences (1918–1919), Professor and President of Tauride University (1920–1921), Director of the Radium Institute (1922–1939), Director of the Library of Geological Sciences of the USSR (1926–1929); he headed the Department on Living Matter of KEPS, Laboratory of Biogeochemistry (BIOGEL), and the Laboratory of Geochemical Problems of the USSR Academy of Sciences named after him (1921–1944).

Vernadsky conducted incredibly extensive work at the Academy of Sciences, leading many of its scientific and organizational commissions and committees (on meteorites, heavy water, history of knowledge, definition of geological age using atomic decay, isotopes of radium, mineral waters, underground water, etc.) and participating in other committees (Polar, on the study of Lake Baikal, on the library studies; on the study of the ethnic population of Russia, Caucasus, standard of radium, stratosphere, spectra of rare elements, permafrost, uranium, viruses, history of the USSR, history of biology, etc.). The total number of academic boards and committees in which, at various times, Vernadsky worked exceeded 60 (this does not include academic and institutional commissions and committees of other ministries and agencies where he was involved). Vernadsky was also a member of the Scientific Council of the Moscow Research Institute, of the Scientific Council of the Ministry of Agriculture, of the Statistical Council of the Ministry of Internal Affairs, of the Council of Dokuchaev Soil Committee of the General Directorate of Agriculture and Land Management, of the Board of Floating Marine Institute, of the Council of V.V. Dokuchaev Soil Science Institute, of the Council of the Special Research Committee of the Union and Autonomous republics, of the Academic Council of the Institute of the History of Science and Technology, of the Academic Council of the Institute of the History of Science; he was the Chairman of the scientific committee of the Agricultural Department of the Ministry of Agriculture; he was Vice-President of the International Commission for the Determination of Age of the Earth by radioactive methods; he represented the USSR Academy of Sciences in the Scientific Council of the Geological Committee of the Supreme Council of National Economy; he was a USSR member at the administrative committee of the magazine "Zeitschrift für Krystallographie und Mineralogie", which, since 1927, has become an international publication.

V.I. Vernadsky possessed outstanding, we may say unique, abilities of a science organizer. As noted by A.Ye. Fersman, "we cannot even fully count all the brilliant initiatives put forward by Vladimir Ivanovich". On the direct initiative or with the participation of Vernadsky, there were created: the Ukrainian Academy of Sciences, A.L. Shanyavsky Moscow Peoples' University, Platinum Institute, Institute of Physical and Chemical Analysis, Hydrogeological Institute, Sand and Desert Institute, Soil Science Institute, Institute of History of Science and Technology, Radium Institute, Biogeochemical Laboratory and Laboratory for Geochemical Problems (later, V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry), Laboratory of Oceanology (based on which, P.P. Shirshov Institute of Oceanology was created in 1946), Chemical Association, the Academy of Sciences of the USSR, various scientific committees of the Academy of Sciences (some of which later became scientific institutes), Commission for the Study of the Natural Productive Forces of Russia (1930), Sapropel Laboratory, and others; he participated, as a consultant of the USSR Academy of Sciences, in the organization of the Academy of Sciences of the Georgian SSR. According to A.Ye. Fersman, he "dreamed and wrote about the necessity of the Soviet Antarctic Expedition, considering that Russian science has to cover also southern countries of the Earth's hemisphere". Vernadsky was also a member of the Editorial Committee of the USSR Academy of Sciences for the publication of a series of "Scientific Legacy" and the Commission for the preparation of the publication of the Soviet review journal in chemistry. At his suggestion, since 1930, "Proceedings of the Biogeochemical Laboratory" was published, which had articles on biogeochemistry, environmental geochemistry, geochemistry, and related fields of knowledge and which played an important role in the development of scientific fields in our country (in 2003, the 24th volume of the "Proceedings" was the last volume published) In 1945, A.Ye. Fersman, remembering his teacher, wrote that "in all cases, Vladimir Ivanovich was at the launch of the most daring endeavors of the Academy", and Academician L.S. Berg said figuratively that Vernadsky "in himself, represents the entire Academy".

Of particular note is the outstanding role and work of Vernadsky in the Commission for the Study of the Natural Productive Forces of Russia (KEPS) – at that time the largest institution of the Academy of Sciences, whose main purpose was to organize a nationwide, as accurate as possible, complete and systematic accounting of its natural resources. The Commission consisted of the greatest Russian scientists D.N. Anuchin, P.I. Walden, K.D. Glinka, B.B. Golitsyn, I.A. Kablukov, N.S. Kurnakov, F.Yu. Levinson-Lessing, V.A. Obruchev, D.N. Pryanishnikov, V.Ye.Tishchenko, A.S. Famintsyn, Ye.S. Fedorov, A.Ye. Fersman, N.A. Kholodkovsky, A.Ye. Chichibabin, L.A. Chugai, and many others. From the first days of the KEPS, Vernadsky was Chairman of its Interim Bureau, and, then (11 October, 1915) was elected by secret ballot Chairman of the KEPS Board and of most of its sub-committees (on bitumens, clay, fire-resistant materials, microscopy, platinum, soils, study of the North, salt, "white coal", i.e. hydro-power, and zoology). He also served at other sub-committees: on botany, artesian waters, and use of wind power; he was Chairman of the Editorial Board for the publication of the "Natural Productive Forces of Russia", a member of the Editorial Board for the publication of "Materials for the Study of the Productive Forces of Russia". The KEPS was a truly democratic institution, whose governing bodies were elected by secret ballot. The most fundamental questions concerning the work of the Commission were discussed at the General Meeting and by the Board and Sub-Committees. The KEPS leaders sought to consider all views of scientists on various aspects of its work. The Commission's work has played a prominent role in the development of scientific and organizational approaches to the study of resource capacity and development of mineral resources of the country, including the integration of the natural productive forces, search for new sources of strategic raw materials, meeting demands of defense organizations, and publishing literature about the natural resources of the country. In November 1916, Vernadsky made a presentation at the KEPS Council with a program of the creation of a wide network of research institutions, some of which located in different climatic zones for an integrated and comprehensive study of the nature, while others, particularly in the existing research centers, focused on particular problems. It is important to note that a number of the KEPS sub-committees transformed later into independent research institutions (Platinum, Ceramic, Physical-Chemical Analysis, etc.). In 1930, on the base of the KEPS, the KIPS (Permanent Commission for the Study of the Ethnic Structure of the Population of Russia and Neighboring Countries) and the KYaR (Committee for the Study of the Yakut Republic) the SOPS (Council for the Study of Productive Forces) was established. The activities of the SOPS were focused on studying the country's natural resource potential for a radical transformation of its economy and were reflected in the prewar five-year plans. Vernadsky strongly supported this institution and wrote a note on "The Tasks of SOPS".

Vernadsky was by no means an armchair scientist. His numerous publications were the result of his research, expeditions, and experimental work carried out during the whole life. He was a participant of the famous territorial (Nizhny Novgorod and Poltava) "soil" expeditions of V.V. Dokuchaev; in different years, he conducted field research in the

Volyn, Vyatka, Ekaterinburg, Ekaterinoslav, Irkutsk, Moscow, Perm, Poltava, Saratov, Smolensk, Tauride, and Tambov oblasts; in Transbaikal, Orenburg, Perm, Tomsk, and Ferghana regions; in Finland, Caucasus, and Altai. He traveled along the Volga and the Dnieper rivers, made geological and mineralogical research trips to many countries in Europe (Austria, France, Germany, Holland, Greece, Denmark, Italy, Norway, Poland, France, Czech Republic, Switzerland, and Sweden); visited Canada and the U.S., the Balkan countries (Bulgaria, Bosnia, and Serbia) and the old mining areas of Central Europe and Scandinavia. He worked at the Pierre Curie Radium Institute in Paris, at the Murmansk and Staroselskaya Biological Stations; he lectured on the geochemistry at Charles University in Prague and at Paris University.

Vernadsky took part in the sessions of the International Geological Congresses (London in 1888, St. Petersburg in 1897; Paris in 1900, Vienna in 1903, Ottawa in 1913, and Moscow in 1937), Congress of the British Academy of Sciences (Dublin, 1908), Meeting of the International Union of Academies (1913), 2nd Congress of Practical Geology (Moscow, 1911), Special Meeting on the Development of the Background of the Draft Law on the All-Russian National Museum (1915), Conference on Weather Service convened at the Main Geophysical Observatory (1927, as a representative of the USSR Academy of Sciences), meetings on accounting of the livestock abundance of the USSR (1927, Chair), meetings of the GOSPLAN of the USSR on the problem of coordination of the geological and exploration work of the Academy of Sciences and the Geological Committee of the Supreme Council of National Economy (1927, by the order of the Presidium of the USSR), 1st International Congress for the Study of Radioactivity (Münster, Germany, 1932), XII Congress of Russian Naturalists and Physicians (Moscow, December 28, 1909 – January 6, 1910), Mendeleev Congresses (at the 2nd Congress in 1911 Vernadsky made a report on "The Gas Exchange of the Crust"), All-Union Geological Congress (Kiev, 1926, Chair), 1st All-Union Conference on Radioactivity (Leningrad, 1932, Chair), Conference on the Genesis of Ores of Iron, Manganese, and Aluminum (Moscow, 1935), 2nd Conference on Experimental Mineralogy and Petrology (Moscow, 1936), Conference on Comparative Physiology (Kiev, 1940), Conference on Pegmatites (Kyiv, 1940); he participated in many sessions of the USSR Academy of Sciences and in the meetings of its departments. He was the official agent of V.V. Dokuchaev at the World Expo (Paris, 1889) where the Department of Russian Soils received a gold medal and Dokuchaev, as the organizer, was awarded the Order "For Services to Agriculture" and the title "Chevalier du mèrite agricole."

Being an extraordinary person, a humanist, and a citizen of his country, Vernadsky productively combined his titanic scientific, organizational, and educational work with social and political activities. "The main strength of Vladimir Ivanovich in life" – wrote A.Ye. Fersman – "was his love for people, the ability to walk up to a person, to understand him". It is true to say that humanity, as a whole, was unthinkable to Vernadsky without due attention to an individual elevated to the status of "the greatest value." These human qualities of Vernadsky, a strong opponent of the death penalty, in many ways determined the directions of his social and political activities. In 1892, he was elected a member of the Territorial Council of the Morshansk Territory, Tambov Province; he became a member of the Audit and the Budget Committees of the Territorial Council. In the same year, he was elected Justice of the Peace for the Morshansk Territory for three years (1893–1895). A few miles away from the station Vernadovka (now, Pichaevsky Rayon, Tambov Oblast), at his own expense, he built a school, which, until 1917, he financed himself providing educational aids and taking care of the selection and training of teachers (some of them received teaching training with his funds). In 1891–1892, when drought covered almost the entire Black Belt region and a terrible famine began in most grain provinces, Vernadsky participated in the organization of assistance to the starving farmers of the Morshansk and Kirsanov Territories of the Tambov Province. Since 1892, V.I. Vernadsky was periodically re-elected a member of the Territorial Council of the Tambov Province and was elected Honorary Justice of the Peace for the next period (1896–1898); he took part in work of the Budget, Agricultural, and other Province Commissions. In 1904, he was a delegate to the Territory Congress that demanded the introduction of the Constitution, civil liberties, and election of the State Duma; in 1905, he participated in the All-Territorial Congresses and became a member of the Bureau of the Territorial Congress formed in Moscow. In 1903, he was among the founders of the "Union of Liberation" and, in 1905, of the Constitutional Democratic Party, whose Central Committee member he remained until 1918. In October 1918, immediately after his election the first President of the Ukrainian Academy of Sciences, he publicly announced his withdrawal from the Constitutional Democratic Party with the motivation that the head of the Academy and organizer of science must be non-partisan and should abandon political activity. In the end of 1920 Vernadsky completely ceased political activity. In 1914–1915, Vernadsky worked in various guardianships where a network of institutions for the care of children was formed.

Three times (1906, 1908–1911, and 1916–1917) Vernadsky was elected to the State Council (the upper house of the legislative institutions of the Russian Empire in 1906–1917) from the academic curia (i.e., from the Academy of Sciences and universities). In 1908, he was a member of its Agrarian Commission; in 1916, the Economic Commission, the Russian Parliamentary Economic Committee, and various Conciliation commissions for the discussion that arose between the Duma and the Council of State on disagreements on a number of bills. In 1917, Vernadsky headed the Commission on Reform of Higher Education Institutions under the Ministry of Education (from March 21 through June 10, 1917, 20 meetings of the Commission were held, where, in particular, there was a discussion on the creation of new institutions of higher education: Tbilisi Polytechnic Institute, Universities of Perm and Rostov-on-Don, and Women's Pedagogical Institute in St. Petersburg). By the Decree of the Provisional Government from August 11, 1917, Vernadsky was appointed the Deputy Minister of National Education. "In the short time when I had to work there" – he later recalled – "Perm State University was opened, ...the discussion on the establishment of new academies started, ... the question was raised on the Georgian Academy of Sciences and the Academy of Sciences of Ukraine and in Siberia ... ". In 1933–1935, Vernadsky was a member of the Karel-Murmansk Committee of the Presidium of the Executive Committee of the Leningrad People's Deputies Council.

In his socio-political and public activities, Vernadsky was largely guided by the need to solve two problems. First, one of the most important public policy goals, in his view, was "the task of preserving the unity of the Russian State – reduction of the centrifugal forces in its organization". Second, science and education, in his opinion, should be a sort of "state religion", and the main task of the state is "not a government organization of science, but the state aid to scientific work of the nation ... We should not regulate scientific work in some scientific discipline ... but need to regulate the implementation of a specific *scientific task*, necessary to the nation". He was convinced that "scientific work of society is one of the most important elements of its vitality and the most solid basis for its future because the future belongs to the nation and to society that will be the owner of the source of power, and this power, in our time and for our nearest generation, ... is in effective knowledge of nature and the active development of mathematical thinking. The nation where there is creative work in sciences, where a genius of invention, application of science to life, the conscious use of natural energy, and coordinating the strength to society or human labor are alive, can easily look into the future".

Over 20 years (1890 to 1911), academic and social activities of Vernadsky were associated with the Moscow University. In fact, it was in this period when his formation as a scholar, teacher, organizer, historian of science, and public figure happened. He defended (1891) his Master's thesis "On the Group of Sillimanite and the Role of Alumina in Silicates" where he developed the concept of the structure of silicates that was named the Theory of the Kaolin Ring (the famous French chemist Le Chatelier called the Vernadsky's ideas on the chemical constitution of alumosilicates the "ingenious hypothesis"); in 1897, he defended his Doctoral thesis "The Crystalline Substance Slip". In 1906, he was elected an adjunct member of the Physics and Mathematics Faculty (mineralogy) of the St. Petersburg Academy of Sciences; in 1912, he became Full Academician of the St. Petersburg Academy of Sciences. He published the books "Fundamentals of Crystallography", "Physical-Crystal Studies", "Practice of Descriptive Mineralogy"; he delivered a famous speech at the XII Congress of Russian Naturalists and Physicians "The Paragenesis of the Chemical Elements in the Earth's Crust" (thus founding a new science – geochemistry); he wrote extensively on the history and methodology of science and genetic mineralogy. He began to develop radio-geological, biosphere, and biogeochemical problems (he wrote in his diary: "I ran into biogeochemical problems in 1891 when I began to teach the course in mineralogy at Moscow University ... "); he wrote a series of feature articles and notes on higher education, the state system, and social movement. At the same time, Vernadsky, in his words, "clearly separated mineralogy from crystallography, shifting the center of gravity towards chemistry as a natural geological process .... In 1897, I began to move away from crystallography and became more and more deeply involved into the chemical mineralogy in the geological aspect".

In 1890, Vernadsky became Assistant Professor of mineralogy and crystallography, and Acting Guardian of the Mineralogical Cabinet of Moscow University; in 1892, he became a member of the Physics and Mathematics Faculty with a deliberative and casting vote in cases involving the Mineralogical Museum, and Guardian of the Mineralogical Museum (by 1911, the Museum has become one of the largest in Europe); in 1898 and 1902, he became an Extraordinary and Ordinary Professor, respectively; he lectured at Moscow University, simultaneously at two Faculties: in 1891–1911, at the Physics and Mathematics Faculty (crystallography in the first half of the year and mineralogy in the second, with practical sessions on both courses) and, in 1891–1898, at the Faculty of Medicine (a short course of mineralogy and elective practical sessions); in 1902–1903, he taught an elective course on the history of science; in 1905–1906, he was Assistant to the President of the Moscow University.

In 1896, Vernadsky was the first in Russia to introduce into the curriculum systematic mineralogical excursions (or, in modern terms, field practice) for students. The staff that worked with Vernadsky in the Mineralogical Cabinet also participated in the excursions. The first tour took place in May 1896 to the Urals (Zlatoust–Yekaterinburg–Tagil). Then, the mineralogical excursions were held regularly in the Moscow region and other regions of Russia. By the way, V.I. Vernadsky was a strict and fair teacher who did not tolerate a "formal" attitude of students to any course or exam. Thus, he recalled in 1943, the situation at the Faculty of Medicine during an exam on mineralogy: "... it was a custom that a student said that he was "without a fight" and he received a satisfactory grade without being tested. I disagreed firmly. ... As a result, ... I gave 42 unsatisfactory grades and caused a terrible racket. I gave them all the re-examination. The next, day I was called to the Dean, but I asked him not to interfere ...The course took my side; the students tightened up, and almost all passed, except for two or three people".

In November 1901, at the Mineralogical Cabinet, Vernadsky organized a mineralogical study group, consisting of his students and staff. This club, which lasted until December 1910, was instrumental in the development of genetic mineralogy and geochemistry in

Russia and was, according to A.Ye. Fersman, a "great generator of new ideas and new initiatives ... it was there where the great science was created". During the ten years of the club's existence, 77 reports were made at its meetings, of which almost half presented the results of original investigations of the speakers. Among the reports' authors, besides Vernadsky himself, were subsequently recognized scientists A.D. Archangelsky, A.Ye. Fersman, Yu.V. Wolf, A.V. Shubnikov, and Ya.V. Samoilov. As A.Ye. Fersman recalled later, in Moscow Vernadsky "developed the breadth of the world understanding and created, around him, a great academic school, bringing together university youth. This school became a powerful source of new ideas and new initiatives ... In the walls of the old university building, he gradually expanded the premises of the Mineralogical Cabinet; he also expanded and improved the Mineralogical Museum by appending the famous Rumyantsev's collection of minerals to it and making this modest laboratory the center of national importance".

In 1911, Vernadsky (along with a group of other faculty members – a total of over 130 people) left Moscow University (in protest against the reactionary policies of the Minister of Education L.A. Kasso and oppression of students.) In 1917, Vernadsky was elected again Ordinary Professor of the Faculty of Geology and Mineralogy of Moscow University and continued in his position at the Academy of Sciences.

You can hardly find a natural scientist, whose work in the history of science, history of knowledge, and history of human thought would occupy such a large place, as in the work of Vernadsky, and whose legacy in this area would have been as great. In his view, "the history of human thought and creativity ... is not only an area of knowledge that is the key to revealing the truth; it is necessary for so needed, especially in our country, continuity of scientific creativity and awareness and continuity of research work and for an individual field rooted in the scientific life of society." A modern science historian A.P. Ogurtsov, having examined the scientific and historical ideas of Vernadsky, identified the following trends in his historical and scientific work: 1) history of science as the development of the scientific world outlook, 2) history of science as the development of forms of organization of scientific work, 3) history of science as the development of individual disciplines, 4) history of science from the perspective of scientific problems, 5) history of Russian science, 6) biographies and assessment of contributions of different individual scientists of the past, and 7) historiographical work. We must add to this the numerous Vernadsky's notes about the research work of his contemporaries and reviews of work and activity of his colleagues and students. To Vernadsky, the study of the history of scientific ideas was a means of thorough analysis of their current status and helped formulating the task of further development. He always started the study of a particular issue or problem with an accurate historical analysis because he considered that "a naturalist ... must always know the past of the science to understand its present. Only in this way there can be a correct and complete assessment of what is produced by modern science and what is treated by it as important, true, or correct". Moreover, Vernadsky was convinced that "the scientific study of the past, including scientific thought, always leads to the introduction of a new human consciousness ... The way forward is the result of a long, invisible, and unconscious preparatory work of generations. Having reached a new and unknown, we are always surprised to find predecessors in the past". Reality often proved the correctness of Vernadsky. Among other things, at his own expense, he worked extensively for the collection of the manuscripts of M.V. Lomonosov and he gave the collected material to the Academy.

V.I. Vernadsky was a supporter of unity and internationality of science. He believed that science "is a complex social creation of mankind, the only and incomparable, because, more than literature and art, it is global in nature, weakly linked to the forms of government or public life. This is a universal panhuman creation because it is based on the same *universally equal binding scientific facts and generalizations*. Nothing like this exists in any other field of human spiritual life". Freedom of thought, for Vernadsky, was the basis of all creative activities, especially scientific. "In scientific work, personal creative work, free and fetterless, besides personal preferences and understanding of science, is its main characteristic feature. Scientific work, along with artistic creativity, is one of the most striking manifestations of a human person and personality ... Science ... is a cultural organization with little dependency on the state or tribal framework. Science is indivisible. Its goal is to search for the truth for the sake of truth; and the truth which is found, after an effort of a century of scientific work, is far from the historical situation in the moment, it is universal and is indivisible for all, without distinction". He rightly argued that "from year to year, the value of independent research as a key element of culture becomes more and more important and inevitable. Because gradually and rapidly the globe becomes the arena of public interest, because technology is being penetrated with scientific thought more deeply and the results of scientific work, with every moment, are penetrating increasingly deeper into all areas of human consciousness". One cannot fail to recall the wonderful thought of Vernadsky that "a characteristic feature of scientific work of our time is that it is determined not by the logical boundaries of science, but by the logic of the challenges".

Vernadsky recognized all learning ways for the sake of true knowledge: scientific, philosophical, religious, artistic, etc., but it is scientific knowledge (based, he stated, on "mental hygiene") that is a completely new force in the history of the biosphere and he assigned the crucial importance to it. He considered scientific work a part of the national culture. Perhaps for the first time ever, Vernadsky has declared loudly that in science, "the principal and alive content is ... scientific work of live people. Specifically these real people – scientists – comprise science in its public manifestation: their mood, their skills, their understanding and satisfaction with the accomplished, their will, the world's scientific public opinion – is one of the main factors of the historical progress of scientific knowledge ... Scientific thought itself does not exist, it is created by a human living person and is his manifestation. In the real world, there really exist persons who create and express scientific ideas and are engaged in scientific creative work exerting spiritual energy. Created by them, weightlessness value – scientific thought and scientific discovery – subsequently change the course of the processes in the biosphere and the nature around us".

Vernadsky, as a scholar, teacher, organizer of science, and social activist, acquired an exceptional reputation and great respect, both in Russia and abroad. He spoke French, German, English, Scandinavian languages and languages of the Slavic peoples; he read in some other European languages; he was familiar, was a friend, or was in close contact with many prominent Russian and foreign representatives of different branches of science and culture, community and state leaders, whose listing only would take many pages. Vigorous, diverse, and incredibly productive scientific and public activity of Vernadsky amazed even his contemporaries. The well-known geologist, mineralogist, and soil scientist Professor V.K. Agafonov asked Vernadsky: "Where do you draw your ability to give time the duration and to turn a day into a few days?" Russian historian, teacher, regional ethnographer, and social activist I.M. Grevs recalled Vernadsky-student: "Even then he was a clearly defined very talented future research scientist, naturalist-experimentalist, but with a philosophical mind fold. His erudition was amazing"; and a historian, social activist, Professor of St. Petersburg Polytechnic Institute A.A. Kornilov said about Vernadsky that "... his mind is prone to generalization and constantly sought to embrace science as a whole, and therefore there was not a branch of human knowledge, which would not interest Vernadsky". Prominent geologist, Professor of the University of Lausanne N.A. Ulyanov in 1925, noted that the book by Vernadsky "Geochemistry" "is a synthesis, a bold, original generalization that defines many new ways for work, puts the final points on the completion of the phases, and points to the areas where our knowledge is still weak".

Academician Vernadsky was elected and (or) was Honorary Member of many (more than 35) Russian scientific societies and public organizations; he was Professor of Mineralogy of the University of Paris (Sorbonne); Member of the Czech and Yugoslav Academies of Sciences; Corresponding Member of the French Academy of Sciences; Fellow of the Royal Society of Great Britain, French Mineralogical Society, German Chemical Society, Geological Society of France, Mineralogical Society of the USA, and Mineralogical Society of Germany; Honorary Member of the Indian Society of Biological Chemistry; Corresponding Member of the British Association for the Advancement of Science, Natural History Club in Prague, Czechoslovak Mineralogical and Geological Society, and Geological Society of Belgium. Among other things, since 1911 Academician Vernadsky was Actual State Councillor (civil rank of the 4th grade, which belonged to the 1st of the four groups of officials and unified those who determined the course of government policy; the persons who had that title usually held positions such as Director of Department, Governor, or Mayor). He had awards of the Russian Empire; in 1942, he was awarded the Order of Red Banner of Labor for "the outstanding contributions to the development of genetic mineralogy and geochemistry"; in 1943, for "the long-term outstanding work in Science and Technology" he was awarded the 1st degree Stalin (State) Award, half of which (100 thousand rubles) he gave to the war effort. Judging by the records in the diaries, Vernadsky treated the "non-scientific" awards rather indifferently.

The life and work of Vernadsky fell on the years of great events in the history of the world and Russian society: Russian-Turkish War (1877–1878), Russian-Japanese War (1904–1905), World War I (1914–1918), February and October revolutions (1917), Civil War (1918–1922), first decades of the Soviet regime, and Second World War (1939–1945). In November 1917, after the October Revolution, Academician Vernadsky, Permanent Member of the Kadet Central Committee, Deputy Minister of Public Education in the Provisional Government, became a member of the Small Council of Ministers that declared Soviet government illegal. Hiding from arrest, Vernadsky went from Petersburg to the south of Russia, where he endured the horrors of multiple power shifts. Only in March 1921, he returned from Crimea to Moscow and, then, to Petrograd, where in July 1921, he was arrested by the Cheka and was set free only because N.N. Kuzmin, N.A. Semashko, and A.V. Lunacharsky interfered.

In subsequent years, scientific, philosophical, and ideological ideas and views of Vernadsky were often subjected to harsh criticism; he was accused of "vitalism"; that his views were just "one of the innumerable, unoriginal, and reactionary" attempts in a "crusade against science and the protection of religion under the guise of the natural science itself"; that his work and the world outlook "are an instructive example of the pitiful state to which falls the science in captivity of bourgeois ideology". However, in the words of Vernadsky, "the vitality and importance of ideas are only recognized by long experience. The value of the creative work of a scientist is determined by time". Time and experience have shown and proved the vitality and importance of the ideas and views of Vernadsky and the value of his creative work. And words of A.Ye. Fersman are still just; in 1946, he spoke of his great teacher Academician Vladimir Ivanovich Vernadsky: "For decades and for whole centuries, his brilliant ideas and his writings will be studied and deepened – new pages will be opened, they will be the source of new quests; many researchers will have to learn his acute, persistent and minted creative thought, always brilliant but difficult to comprehend; for the younger generations, he will always be a teacher in science and a shining example of a life lived productively".

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NEW FRONTIERS OF ANTARCTIC SUBGLACIAL LAKES EXPLORATION

ABSTRACT. Antarctic subglacial aquatic environment have become of great interest to the science community because they may provide unique information about microbial evolution, the past climate of the Earth, and the formation of the Antarctic ice sheet. Nowadays it is generally recognized that a vast network of lakes, rivers, and streams exists thousands of meters beneath Antarctic Ice Sheets. Up to date only four boreholes accessed subglacial aquatic system but three of them were filled with high-toxic drilling fluid, and the subglacial water was contaminated. Two recent exploration programs proposed by UK and USA science communities anticipate direct access down to the lakes Ellsworth and Whillans, respectively, in the 2012/2013 Antarctic season. A team of British scientists and engineers engage in the first attempt to drill into Lake Ellsworth but failed. US research team has successfully drilled through 800 m of Antarctic ice to reach a subglacial lake Whillans and retrieve water and sediment samples. Both activities used hot-water drilling technology to access lakes. The main troublesome of the implemented and planned projects for accessing of Antarctic subglacial lakes is connected with the hydrostatic unbalance resulted in the upwelling of water into the hole with subsequent difficulties. The proposed RECoverable Autonomous Sonde 'RECAS' would measure and sample subglacial water while subglacial lake is reliably isolated from surface environment, and at the same time the sonde is able to measure geochemical signals *in situ* throughout the depth of ice sheet on the way to the bed. All process is going on in semi-automatic mode, and the estimated duration of subglacial lake exploration at the depth of 3500 m is 8–9 months. The general concept of the sonde as well as proposed power-supply and performance are given.

KEY WORDS: subglacial aquatic environment, environmental-friendly access technology, autonomous sonde

INTRODUCTION

Antarctica is the coldest, driest, and windiest continent, and has the highest average elevation of all the continents. About 98% of Antarctica is covered by the sheet of ice averaging at least 1,6 km thick; yet surprisingly, there is liquid water at the base of the Antarctic ice sheet. Russian scientist Peter Kropotkin first proposed the idea of fresh water under Antarctic ice sheets at the end of the 19th century. He theorized that the tremendous pressure exerted by the cumulative mass of thousands of vertical meters of ice could increase the temperature at the lowest portions of the ice sheet to the point where the ice would melt [Kropotkin, 1876]. 80 years later N.N. Zubov theoretically proved that there is a critical ice thickness, corresponding to the bottom temperature of ice sheet, equal to an ice melting point [Zubov, 1959]. In 1961, A.P. Kapitsa used Zubov's approach to suggest existence of liquid water lenses below the ice in central parts of East Antarctic Ice Sheet [Kapitsa, 1961]. The subglacial melting theory was further developed by soviet glaciologist I.A. Zotikov, who concluded that the water below the ice remains liquid since geothermal heating balances the heat loss at the ice surface (Fig. 1). According to his estimations the permanent rate of melting at the bottom of ice sheet is 1–4 mm/year [Zotikov, 1963].

Even though radar and seismic measurements have revealed water layer beneath the Antarctic ice sheet in 1970s [e.g., Oswald and Robin, 1973; Robin et al., 1977], these features had gone largely unnoticed by the broader scientific community for more than two decades. In 1996 an article in Nature written by Russian and British scientists reported that a huge lake existed beneath ~4 km of ice in East Antarctica in the region of Russian Vostok Station [Kapitsa et al., 1996]. It was concluded that the mean age of the water in the lake is about one million years. This article marked the beginning of modern Antarctic subglacial aquatic environment research.

Nowadays it is generally recognized that a vast network of lakes, rivers, and streams exists thousands of meters beneath Antarctic Ice Sheets. As of 2010, 387 subglacial lakes have been identified; this will increase as surveys improve spatial coverage [Wright and Siegert, 2011]. Estimates indicate that the total surface area of the subglacial lakes is nearly 10% of the ice sheet's base, and the volume of Antarctic subglacial lakes alone exceeds 10 000 km^3 [Dowdeswell and Siegert, 1999], with Lake Vostok (6100 km^3; Popov et al., 2011) and Lake 90°E (1800 km^3; Bell et al., 2006) being the largest.

Sealed from the Earth's atmosphere for millions of years, subglacial aquatic environment may provide unique information about microbial evolution, the past climate of the Earth, and the formation of the Antarctic ice sheet. The discovery of subglacial aquatic environments has opened an entirely new area of science in a short period of time. The next stage of exploration requires direct sampling of these aquatic systems [Talalay,

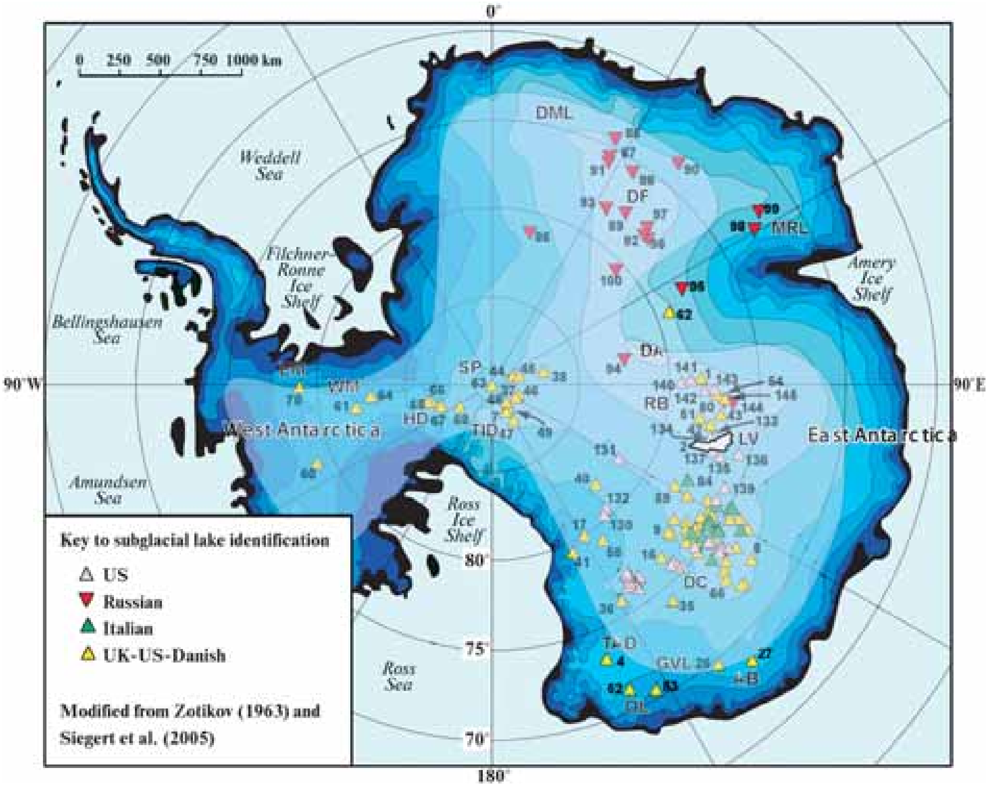

Fig. 1. Location of Antarctic subglacial lakes [Siegert et al., 2005] and bright spot area of bed melting accounting Earth geothermal flux 2,5× 10–6 kal×sm–2×sec–1[Zotikov, 1963]

2006]. The subglacial water most likely contains life, which must adapt to total darkness, low nutrient levels, high water pressures and isolation from atmosphere. It is obvious that *in situ* investigations should not contaminate these subglacial aquatic systems. This criterion makes sustainability of subglacial environment of chief importance.

BACKGROUND

The first project for penetration the Antarctic Ice Sheet to study the aqueous subglacial environment was proposed by A.P. Kapitsa and I.A. Zotikov in 1963 [Zotikov, 2006]. The project was based on a small nuclear power plant that would be lowered, as a part of hermetically sealed container, which would contain appropriate instruments and equipment. The nuclear power plant had to produce enough energy to melt ice down to the bottom of the ice sheet, and the resulting water would refreeze above the probe. Communication with the ice sheet surface is maintained by wireless means. This project was supported by the Atomic Energy Institute of the USSR Academy of Sciences which was ready to provide a small nuclear energy reactor of 100 kW, small enough to be installed in the 0,9 m diameter container. Fortunately, this project was never realized because Antarctic Treaty prohibits the disposal of radioactive wastes or nuclear plants in Antarctica.

In the following years dozen of deep drilling projects were completed in Antarctica in order to reach the ice sheet bed and to get opportunities for examining processes acting at the subglacial environment [Talalay, 2012b]. Even most of them have been succeeded at various sites of Antarctica, only three boreholes accessed subglacial aquatic system (Fig. 2).

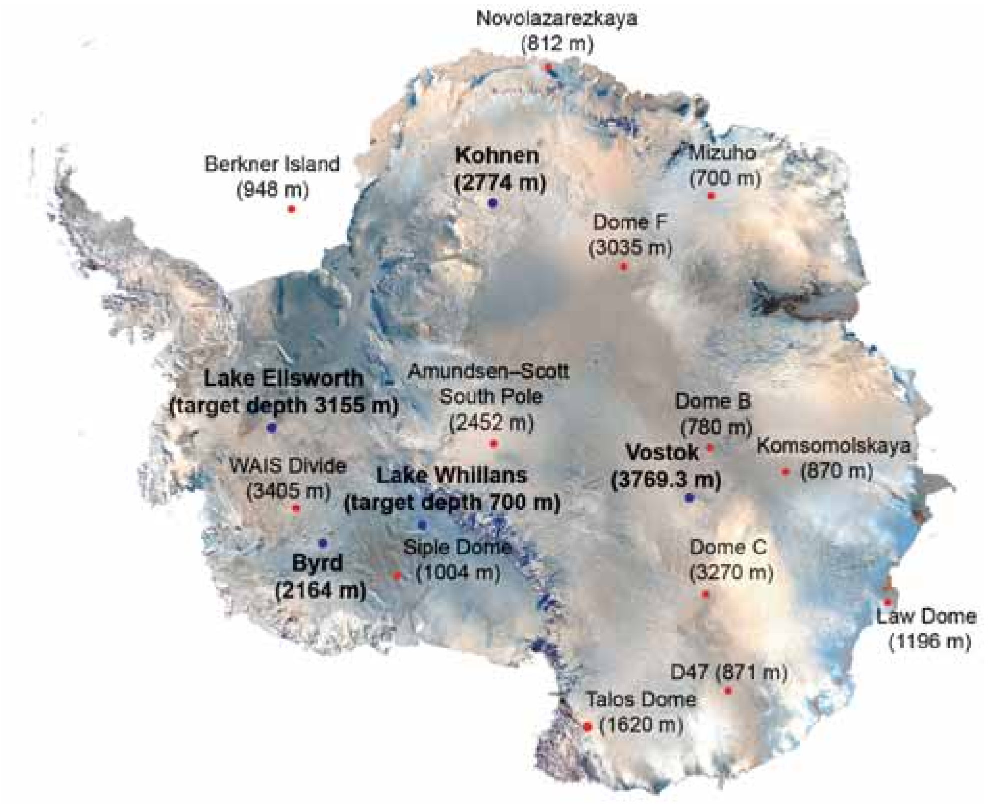

Fig. 2. Deep ice drilling sites in Antarctica (blue points mark boreholes that already reached or planned to reach subglacial aquatic systems)

Byrd Station. In 1967 and 1968 the USA CRREL electromechanical drill was used for coring at Byrd Station (80°01′S, 119°32′W, 1530 m a.s.l.), West Antarctica. At a depth of 2164,4 ma sudden decrease in power and a corresponding increase in cable tension indicated an abrupt change in material had been encountered by the cutting bit [Ueda and Garfield, 1970]. This was later concluded to be a layer of water estimated to be less than 0,3 m thick. During the time spent attempting to obtain a subglacial bedrock sample, the water which welded the hole mixed with the glycol solution used as drilling fluid in the lower part of the hole. Freezing out of the water created a heavy slush in the bottom 460 m of the hole. Within a few days, the slush became difficult to penetrate the drill, and further attempts to obtain a subglacial sample were terminated because of the possible loss of the drill. For the first time in the history of Antarctic exploration the existence of a water layer at the bottom of an ice sheet was proved experimentally. The near-bottom temperature gradient was estimated as 0,0325°C/m that gives the temperature at the ice sheet bed to be at pressure melting point of –1,5°C. No subglacial water samples were obtained at this time.

Kohnen Station. In 2001 within the framework of the European Project for Ice Coring in Antarctica (EPICA) the Kohnen station (75°00′S, 00°04′E, 2892 m a.s.l.) was established by Alfred-Wegener-Institute (Germany) in northwestern Dronning Maud Land as a logistic base for deep ice drilling activities. The estimate from radar soundings for bedrock depth was about 2780 ± 5 m [F. Wilhelms, personal communication].The near-bottom temperature log determined the temperature gradient as 0,0281°C/m that was extrapolated to the pressure melting point in 2790 m depth at 1,915°C, beyond ice thickness estimated by radar survey. Finally it was concluded that there is no melting at the bottom. In fact, in summer season 2006–2007 at the approach to the bed at the depth of 2774 m water started coming into the under-pressured hole with the flow rate of more than 1 l/min [Wilhelms, 2007]. The sample of refrozen water was recovered by special down-hole bailer (Fig. 3). Upon reducing the level of the drilling fluid, the water rose to 173m above the base. Unfortunately samples taken from the top of the column at the water-drill-fluid-interface were contaminated by the drill fluid (mixture of petroleum solvent Exxsol D40 with hydrochlorofluorocarbon HCFC-141b). It was decided not to re-drill the refrozen

Fig. 3. The first frozen samples of Antarctic subglacial water recovered at Kohnen Station, January 2007 [http://www.awi.de]

water column because of impossibility to get uncontaminated samples out of any deep ice coring hole that is stabilized by petroleum-based drill fluid.

Vostok Station. Deep drilling of a deep Hole 5G was started at Vostok Station (78°28′S, 106°48′E, 3488 m a.s.l.) in February 1990 [Vasiliev et al., 2011], six years before the large subglacial lake under the station was officially recognized [Kapitsa et al., 1996]. Twenty-two years later, in yearly February 2012, Russian researchers made contact with Lake Vostok water at a depth of 3769,3 m [Vasiliev et al., 2012; Talalay, 2012a]. The drill was rescued from rapidly rising lake water, but upon reaching the surface the whole drill was filled and coated with refrozen water ice (Fig. 4).Researchers predicted that the water would rise in the near-bottom part of the borehole, up to 30–40 m from the water table, but the first drill deployment in January 2013 found the top of frozen subglacial water at the depth of 3383 m [Press Relations Service of Arctic and Antarctic Research Institute, 10 January 2013] indicating that the water rose from the lake by 386 m. So, the pressure in Lake Vostok was much higher than expected that will need to be taken into consideration for future exploration.

A first analysis of the ice that froze onto the drill bit shows no native microbes came up with the lake water [Bulatet al., 2012]. It was preliminary concluded that the very uppermost layer of Lake Vostok appears to be "lifeless" so far but that does not mean the rest of it is. The microbes presented in the ice sample were fewer than 10 microbes/ml – about the same magnitude that would expect to find in the ultraclean room. Three of the four identified phylotypes was matched as contaminants from the drilling fluid, with the fourth unknown but also most likely from the surface.

The next stage of Lake Vostok sampling is planned for the 2012–2013 summer season by re-drilling of the frozen lake ice. It is likely that it will only be possible to re-drill upper 10–15 m of the frozen water because the main hole is inclined from the vertical by several degrees, and the re-drilled hole will deviate rapidly from the previous direction. Unfortunately, the technology used for the Lake Vostok access did not comply with the Comprehensive Environmental Evaluation [Water Sampling of the Subglacial Lake Vostok, 2002], and Lake Vostok was accessed using highly-toxic drilling fluid (mixture of kerosene with hydrochlorofluorocarbon HCFC-141b).When the subglacial water first entered the borehole, it contacted and mixed

Fig. 4. The refrozen Lake Vostok water recovered from the last run, February 5, 2012 [Credit: N.I. Vasiliev]

with the toxic drilling fluid. The subglacial water was almost certainly contaminated by the drilling fluid, and it is likely that it will be of no use for the investigation and identification of new forms of life within it.

LAST EVENTS AND NEAR FUTURE

During last decade researchers from all over the world suggested employing new methods to access Antarctic subglacial lakes and underlying sediments without undue contamination, obtain a variety of in situ physical, chemical and biological measurements and retrieve water and sediment samples [e.g. Blake and Price, 2002; Fleckenstein and Eustes, 2007; and others]. Most of them cannot be qualified as absolutely "clean" methods, and that is why they were not completed and/or financially supported. For example, autonomous cryobot designed by Jet Propulsion Laboratory (California Institute of Technology, USA) planned not to be retrieved after completing of the mission, and after certain time the probe would likely be destroyed by corrosion and contaminate the subglacial lake [Bentley et al., 2009].

Significant progress in the study of subglacial aquatic environments is now at hand with the initiation of two exploration programs likely to advance understanding of Antarctic subglacial environments over the next few years. Lake Ellsworth and Lake Whillan sprograms proposed by UK and USA science communities, respectively, anticipate direct access down to the lakes in the coming Antarctic seasons. Both activities have similar concepts, limits and performance.

Lake Ellsworth.UK consortium chose Lake Ellsworth (78°58′34″S, 90°31′04″W) as the best candidate to determine the presence, origin, evolution and maintenance of life in an Antarctic subglacial lakes. Lake Ellsworth is located in the center of the West Antarctic Ice Sheet, and the ice surface above the lake lies at approximately 1900–1925 m elevation [Proposed Exploration of Subglacial Lake Ellsworth Antarctica, 2012]. Due to radar survey the thickness of ice sheet in the region of proposed drilling site is 3155 m and the lake depth is 143 m. Minimal ice temperature is –32°C.

Hot water drilling system, designed by British Antarctic Survey, has been identified as the most effective means of obtaining rapid, clean access to Lake Ellsworth. The drilling concept is rather simple (Fig. 5): water is filtered then heated via a heat exchanger and pumped, at high pressure, through the drill hose to a nozzle that jets hot water to melt the ice. The hose and nozzle are lowered with the speed 0,5–1,0 m/s to form a straight

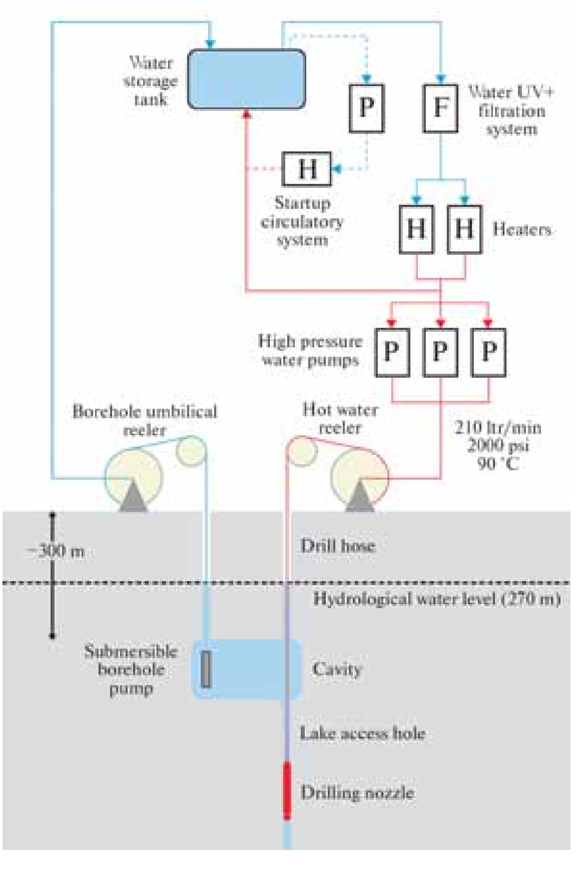

Fig. 5. Schematic diagram of the Lake Ellsworth hot water drill system (H – heaters, P – pumps, F – filters)[Proposed Exploration of Subglacial Lake Ellsworth Antarctica, 2012]

hole that will have a uniform diameter of 360 mm at the end of the drilling process. The water from the nozzle uses the melted hole as the return conduit. A submersible borehole pump installed near the surface, but below the lake's hydrological level (270 m below the ice surface), returns water to a number of large surface storage tanks, which are maintained at several degrees above freezing. The water is then reused by the hot water drill. A filtration and UV system will be used to treat drill water to remove suspended solid particles, including bacteria and viruses. The water will pass through a five staged filtration system utilizing spun bonded, pleated, and membrane filter elements with absolute micron ratings of 20, 5, 1 and 0,2, before being UV treated. This water is then heated to between 85°C and 90°C, and pumped down a single 3,4 km length of drill hose to a drill nozzle.

Creating the lake access hole into the lake will take around 3 days. Before reaching the lake, the water level in the hole will be drawn down a few meters below the hydrological lake level. This drawdown will prevent water from entering the lake. The refreezing time of 360 mm diameter borehole is estimated to be approximately 6 mm/h [Siegert et al., 2006] resulting in useable diameter of ~200 mm after a day from first access. Before the hole reduces to this size, both the water probe and a sediment corer will be deployed and retrieved.

In December 2012 a team of British scientists and engineers engage in the first attempt to drill through more than 3 km of Antarctic Ice Sheet into Lake Ellsworth but failed[1]. The first borehole was drilled to a depth of 300m and then the drill head left at that depth for 12 hours to create the cavity. The second, main borehole (located 2 m away from the first) was then drilled to 300 m depth and should have immediately connected with this cavity. This main borehole would then continue through the cavity and down to the lake while the first borehole would be used to recirculate water back to the surface using a submersible pump. For reasons that are yet to be determined the team could not establish a link between the two boreholes at 300 m depth, despite trying for over 20 hours. During this process, around 75,000 litres of hot water seeped into the porous surface layers of ice and was lost. The team attempted to replenish this water loss by digging and melting more snow but their efforts could not match the flow rate of the drill. The additional time taken to attempt to establish the cavity link significantly depleted the fuel stocks to such a level as to render the remaining operation unviable. On 25 December 2012 Martin Siegert, Principal Investigator of the Subglacial Lake Ellsworth experiment, confirmed that the mission to drill into the lake has been called off for Antarctic season 2012/2013.

Lake Whillans. The Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) project is a 6-year (2009–2015) integrative study of ice sheet stability and subglacial geobiology in West Antarctica, funded by the US National Science Foundation. Lake Whillans belongs to active subglacial lakes, which ice-surface is changed due to water volume fluctuations in subglacial basins [Fricker et al., 2011]. Subsequent studies with satellite altimetry have demonstrated that there are more than 120 such subglacial lakes in Antarctica. The ice-penetrating radar surveys showed that ice thickness above subglacial Lake Whillans is only 700 m and suggest that the depth of water in the lakes is less than 8 m even after lake drainage events.

In the same manner as Lake Ellsworth, WISSARD will use a hot water drill to clean access Lake Whillans with minimal chemical and microbial contamination to the pristine subglacial environment. The filtration and UV treatment system allows reducing microbial numbers to ~100 cell/ml within pumped into the hole hot water. The final filter size will be 0,2 mm. The drilling water will also be maintained at a temperature >90°C, which has been shown to significantly reduce the number of viable cells.

[1] http://www.ellsworth.org.uk/

The hot water drill, designed in University of Nebraska-Lincoln, will produce a borehole of at least 200 mm diameter (with future update to 800 mm diameter) that will remain open for ~8 days by periodical reaming. A variety specialized scientific instrumentation such as sub-ice robotically operated vehicle, modular oceanographic instruments, sediment samplers will be used in various combinations, depending on the mission and objective of each deployment.

In December 2012 the first testing of the hot water drilling system was carried out at a location Windless Bight near McMurdo. Then all equipment was moved 1010 km away by track-traverse across the Ross Ice Shelfto Lake Whillans[2]. On January 27, 2013 US research team has successfully drilled through 800 meters of Antarctic ice to reach a subglacial lake. Both water and sediment samples were collected from the lake. Water sampling tools deployed included a Niskin water sampler, which allows you to collect water samples at designated depths, an in situ McLane water sampler that concentrates water particulates on filters, and a CTD which measures Conductivity, Temperature and water Depth. Three different sediment sampling tools were used including a multi-corer, which collected three ~0,4 m cores each time it was deployed, a piston corer, and a larger percussion corer.

The main advantages of lakes Ellsworth and Whillans exploration methodologies are that equipment can provide samples of sub-glacial water and sediments as clean as possible from the present point of view, and the lake is accessed very fast. From the other hand there are numerous disadvantages of proposed technologies: (i) equipment is very expensive and heavy (<120 t); (ii) drilling access hole needs extremely high power consumption (2500 kW, ~25 l of gasoline per meter); (iii) access hole cannot be kept open more than 1–2 days without intensive reaming; (iv) the value of differential pressure while the lake is accessing is not predictable and is not regulated.

[2] http://www.wissard.org/

RECOVERABLE AUTONOMOUS SONDE RECAS

In 2012, Polar Research Center at Jilin University (China) undertook the development of RECoverable Autonomous Sonde 'RECAS', the design of which would measure and sample subglacial water while subglacial lake is reliably isolated from surface environment. At the same time the sonde is able to measure geochemical signals *in situ* throughout the depth of ice sheet on the way to the bed using embedded laser spectrometer. Generally, idea of RECAS design is based on the Philberth thermal probe that was used to measure temperature inside of an ice sheet [Philbert, 1976]. The outstanding characteristic of this probe was that the wire for the transmission of electric power to it and signals from it was twisted on the coil inside the probe, paid out of the advancing probe and became fixed in the refreezing melt-water above it. In 1968 two sets of the Philbert thermal probe were launched at Station Jarl-Joset, Greenland. The first probe drilled to the depth of 218 m, and the second one to the depth of 1005 m before the main heater broke down. Unlike the Philbert thermal probe, that was designed not to be recovered from the ice, the RECAS is able to move upwards.

General concept. The sonde is equipped by two hot-points with parabolic heating elements located on the bottom and top sides of the sonde (Fig. 6). The hot-point diameter is 150 mm, and diameter of the sonde body is 140 mm. The upper hot-point has a small central hole for cable sliding in it. The power of the each hot-point is ~5 kW, and the expected speed of penetration would be 1,7 m/h in pure ice at temperature –30°C accounting the efficiency of 0,75. To protect against re-freezing, the exterior cylindrical surface of the sonde is heated by special wired-in heating element with average power density 0,1 W/cm^2, and for the 4-m long sonde the side heating power is 1,8 kW.

The ~10%-portion of the melted water is pumped into the sonde through the small

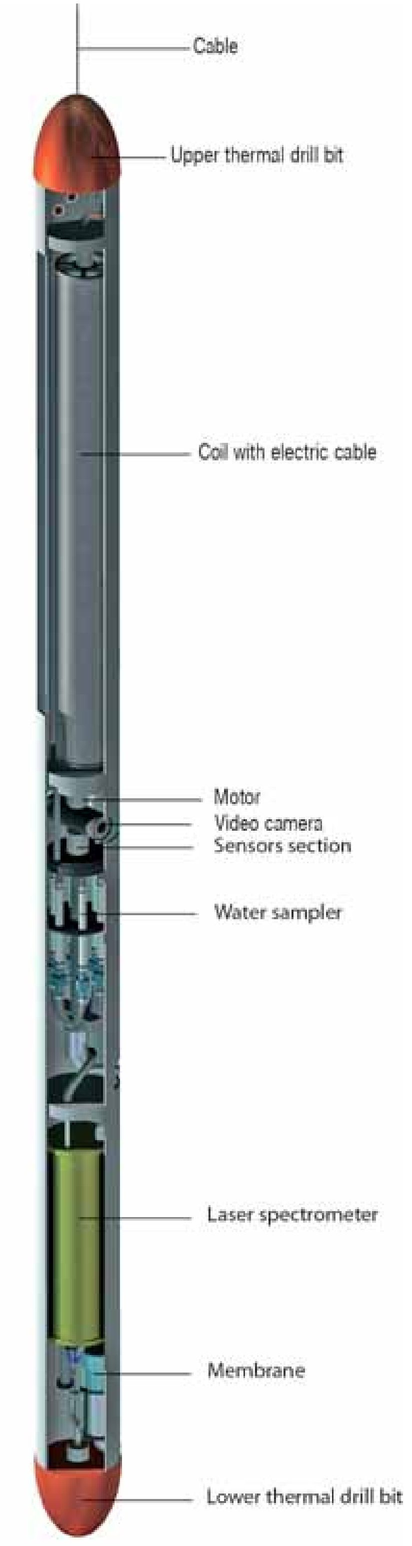

Fig. 6. Conceptual 3D-model of RECoverable Autonomous Sonde ,"RECAS"

hole located just above the lower hot-point. The gas dissolved in this water is separated in the membrane, and analyzed by embedded laser spectrometer. For this purpose, OF-CEAS spectrometer system patented by Interdisciplinary Laboratory of Physics (LIPhy), Grenoble, France can be used [Alemany et al., 2012]. This spectrometer is based on optical feedback cavity enhanced absorption spectroscopy technique, where a diode laser at 2,4 µm is injected into high-finesse (V-shape) optical cavity. Methane and water isotopes can be simultaneously analyzed with sensitivity of 1 ppm (for CH_4) and less than 1 ‰ (for δD of H_2O) over ~1 min integration time.

In the middle part of the RECAS twelve 120 ml titanium water sample bottles are installed. The bottle valves are actuated using magnetically-coupled electric motors enabling them to be opened and closed on the demand. Samples are maintained at pressure, enabling quantitative analysis of dissolved gases. The sonde is equipped by instrument chamber to measure inclination and azimuth of the borehole, pressure, temperature, pH, sound velocity, conductivity and other parameters. Video cameras and sonar provide additional information on the subglacial environment.

The coil with driven gear-motor section occupies the upper part of the sonde. The electric line for power supply and communication with down-hole sensors is twisted on the coil inside the sonde. It was proposed to design two modifications of the RECAS: one with the coil contains 1200 m of cable, and another one contains 4000 m of cable. To minimize size of the cable, the power is supplied at operating voltage of 3000–4000V DC, and then in the sonde it is transformed by voltage transformer. The cable consists from two signal lines 0,2 mm^2 and two coaxial power lines 2 mm^2. The outer diameter of the cable is in the range of 3–4 mm. The expected length of the coil with 1200 m cable is 1,3 m, and the length of coil with 4000 m cable is 4,3 m.

Pre-processed data from RECAS is transmitted to the surface computer system which transfers data to/from the internet using the Iridium modems via PPP to the Iridium ground-station, and with Short Burst Data messages. Data is automatically uploaded to webpages for human inspection, and SMS messages can be automatically sent to mobile phones to inform a human that manual intervention is required. It is possible to establish an SSH link to RECAS at any time within a few minutes.

Power supply. During moving down the RECAS highest power consumption is summarized from lower hot-point 5 kW, side heating 1,8 kW, upper hot-point 0,5 kW, coil motor 0,2 kW, sensors, down-hole computer, spectrometer, etc. 1 kW, electric losses in cable 1,5 kW; totally ~10 kW. During moving up the RECAS highest power consumption is summarized from lower hot-point 0,5 kW, side heating 1,8 kW, upper hot-point 5 kW, coil motor 0,5 kW, sensors and down-hole computer 0,4 kW, electric losses in cable 1,5 kW; totally ~9,7 kW.

The RECAS power supply should be able to provide electrical power for a full year without refueling or other intervention. The ideal power system will therefore be one that uses combination of (i) solar power during the summer, short-term electrical storage in the form of batteries, (ii) autonomous wind generators depending from site and capacity of wind, and (iii) automatically controlled diesel engines during the dark winter months.

Despite the extreme weather in Antarctica, the sun shines for extended periods through summer. Solar radiation vertical flux depends from the latitudes and as highest possible achieves 350 W/m^{2}and even more at the warmest December period. Roughly, the solar power can be converted by photovoltaic panels into electricity with an average efficiency of ~25% for polycrystalline silicon sells. At low temperatures the silicon solar cells are significantly more efficient, producing 5% more power for every 10°C drop in temperature. To put this into practical perspective, in order to meet the 10 kW electrical power supply, it would require something of 50–60 m^2 of photovoltaic panels. For example, the ConergyC167P panel with area 1,2 m^2 and nominal power output of 167 W at 25°C can be used as power supply [Lawrence et al., 2008]. Tests in Central Antarctica showed that each panel of this type produced a maximum of over 200 W and an average of ~2 kW×hr/day when the sun is above the horizon for greater than ~12 hours.

The autonomous wind generators could be a good alternative of renewable power supply, but their efficiency strongly depends from wind velocity. Tests with 1 kW wind generators (Raum, Hummer, and Bergey types) showed that turbine output power is in the 2,8-power-law relation with wind velocity, and 5 m/s wind speed gives only ~90 W of power [Allison et al., 2012]. If the site location is rather high on the Antarctic plateau that the katabatic winds will be relatively mild, this assumes low wind generator efficiency and implies large battery buffering.

The most reliable power supply is automatically controlled diesel engines, e.g. set of Hatz 1B30 diesel engines used by PLATO Antarctic site testing observatory [Lawrence et al., 2008]. The Hatz 1B30 is a compact, high efficiency, single-cylinder air-cooled diesel engine of 350 cc displacement with a maximum power output of greater than 1,5 kW at atmospheric pressure corresponding to the altitude of Antarctic Plateau. The engines are run on Jet-A1 aviation fuel. A bank of large fuel filters ensures a clean fuel supply for a minimum of one year between servicing. The fuel tank contains enough capacity for greater than nine months of continuous running and is also used to store heat from the engines to help regulate the internal temperature of the module. In addition, each engine is installed with its own bulk oil filtration and recirculation system in order to extend the required servicing interval.

Performance. All down-hole RECAS components will be sterilized by combination of chemical wash, HPV and UV sterilization

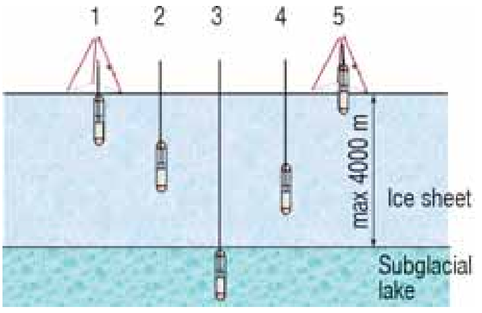

Fig. 7. RECAS subglacial access strategy (explanations are given in the text)

prior using. The working procedure is as follows (Fig. 7):

1. At the beginning of the summer season sonde is installed vertically on the surface of the Antarctic ice sheet above subglacial lake. All equipment is got into working trim, the bottom hot-point is powered, and the sonde starts to melt down to the ice sheet bed. The personnel leave the site, and all further operations are going on in semi-automatic mode.

2. The melted water does not recover from the hole and refreezes behind the sonde. Electric line for power supply and communication with down-hole sensors is released from the coil installed inside the sonde. Some of the melted water is pumped into the sonde. The gas dissolved in this water is separated through membrane and analyzed by embedded laser spectrometer. The penetration down to subglacial reservoir up to the depth of 3500 m should take about more 3–4 months.

3. Since the sonde enters into the subglacial lake, it samples the water and examines subglacial conditions (P, T, pH, sound velocity, and conductivity).

4. After sampling the motor connected with coil is switched on, and the top hot-point is put into action. The sonde begins to recover itself to the surface by spooling the cable and melting overlying ice with the help of the upper hot-point. The way to surface should take a bit longer time than the way down (~4–5 months).

5. Since 8–9 months from starting the sonde reaches the surface and waits the personnel for servicing and moving to the next site.

The RECAS is relatively cheap (10–20 times cheaper than penetration with hot-water drilling system), and small staff of 4–5 people can easily operate the sonde. The first laboratory tests of the RECAS units are planned for 2013, but the schedule of the field tests in Antarctica is open as the project did not get financial and logistical support in full.

CONCLUSIONS

As far as subglacial lakes and rivers were isolated from the exterior for thousands and millions years, they have to be extremely sensitive system. Currently, no clear protocols or standards for minimizing contamination have been established, although few initiatives to protect subglacial aquatic environments were formulated (e.g., Doran and Vincent, 2011).

The main troublesome of the implemented and planned projects for accessing of Antarctic subglacial lakes is connected with the hydrostatic unbalance resulted in the upwelling of water into the hole with subsequent difficulties. As the lake is connected with the surface via the borehole, there is no iron-clad guarantee that the modern microbiota do not get there. Moreover, open accessing of the isolated Antarctic subglacial water systems disturbs their thermobaric equilibrium state, thus changing the conditions of ice-water phase transition on the entire boundary between ice sheet and reservoir [Talalay and Markov, 2012]. This leads to formation of a new additional layer of accretion ice on the lower ice sheet surface.

Using of the recoverable autonomous sonde RECAS opens the new stage of Antarctic subglacial exploration because in this case subglacial water is reliably isolated from surface, and pressure in the lake does not influence the access technology. The sonde is able not only to measure and to sample subglacial water, but also to measure geochemical signals *in situ* using embedded laser spectrometer. The big advantage is that the RECAS is recoverable and can be used for many times. The potential drawback of the RECAR using is the impossibility of its recovery in the case of fail.

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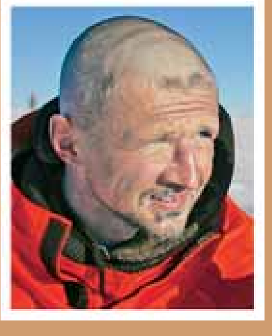

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RECOVERY FROM THE LITTLE ICE AGE: GEOTHERMAL EVIDENCES

ABSTRACT. We applied geothermal method for paleoclimatic reconstruction of the ground surface temperature history during the Little Ice Age and contemporary warming. We analyzed 83 borehole temperature profiles and estimated warming amplitudes and warming start dates after the Little Ice Age. The studied boreholes are situated in the Urals and Eastern Europe (Finland, Ukraine, and Belarus). Our investigation shows high degree of spatial variability of climatic changes in 18–19 centuries. Spatial distribution of amplitudes of paleoclimatic changes and warming start date testifies that warming following after the Little Ice Age was in progress in several steps and for different regions it started at different times.

KEYWORDS: paleoclimate, ground surface temperature history (GSTH), Little Ice Age (LIA), Urals, Eastern Europe, borehole temperature-depth profile, geothermal method, spatial distribution of paleoclimatic changes.

INTRODUCTION

Scientific interest to climatic changes, taking place in the 18^{th}–20^{th} centuries, is staying constantly high within a few recent decades. The Little Ice Age (LIA) and contemporary warming are the latest significant climatic events on the Earth. Geothermal method for reconstruction of the ground surface temperature history (GSTH) allows estimating past climatic changes occurred during this period [Lachenbruch and Marshall, 1986; Beltrami and Mareshal, 1991; Cermak et al., 1992]. Significant differences of individual borehole GSTHs are linked not so much to non-climatic factors as to spatial-temporal heterogeneities of global climatic changes for many Earth's regions [Majorowicz, 2010; Beltrami et al., 2003]. These heterogeneities may be caused both by natural reasons and non-climatic noise, and may be suppressed by data averaging over a large region [Demezhko, Golovanova, 2007]. In this case, a reliable average estimation of climatic changes for a given territory is appropriate. However, this approach loses a great deal of useful information about spatial paleoclimate features.

In this paper, having a large database of shallow boreholes, we attempted to estimate spatial-temporal features of ground surface temperature and receive useful information which could be lost in the process of GSTH averaging. We compared spatial distribution characteristics of climatic data in the Urals and Eastern Europe (Ukraine, Belarus and Finland) where geothermal reconstructions density is much lower than in the Urals.

MATHEMATICAL MODEL

Heat transfer in a homogeneous rock medium without vertical ground water flow can be described in terms of a one-dimensional heat equation [Carslaw and Jaeger, 1959]:

$$\frac{\partial^2 T}{\partial z^2} - \frac{1}{a}\frac{\partial T}{\partial t} = 0\,, \tag{1}$$

where T is temperature, z is depth, t is time and a is thermal diffusivity (thermal diffusivity a, thermal conductivity λ, density ρ and specific heat capacity c can be combined in the form $\lambda = \rho c a$). The solution of Eq. (1) can be expressed as a sum:

$$T(z, t) = T_0 + G_0 z + \Theta(z, t), \quad (2)$$

where the original surface temperature T_0 and geothermal gradient G_0 corresponding to the undisturbed part of the temperature field, and Θ is a non-stationary temperature anomaly that appears at the moment $t = 0$ and satisfies the condition at infinity:

$$\Theta(z, t) = 0, z \to \infty. \quad (3)$$

The surface boundary condition T_s can be taken as a surface temperature history approximation in the form of a series of m instantaneous surface temperature changes:

$$T_s(0,t) = \begin{cases} T_0, & t \leqslant 0 \\ T_k, t_{k-1} \leqslant t \leqslant t_k, & k = 1,2, ..., m-1 \\ T_m, & t \geqslant t_m \end{cases}. \quad (4)$$

For the conditions given and $t = t^*$ (moment of measurement) temperature anomaly has the form:

$$\theta(z, t^*) = \sum_{k=1}^{m} D_k erfc \frac{z}{2\sqrt{a(t^* - t_k)}}, \quad (5)$$

where $erfcU$ is the complementary error function, $D_k = T_k - T_{k-1}$ and $t^* - t_k$ is the time interval from the kth instantaneous temperature change till the moment of measurement. To determine the ground surface temperature history $T_s(0, t)$, we 1) evaluated unknown parameters G_0 and T_0 from the base interval of the temperature-depth

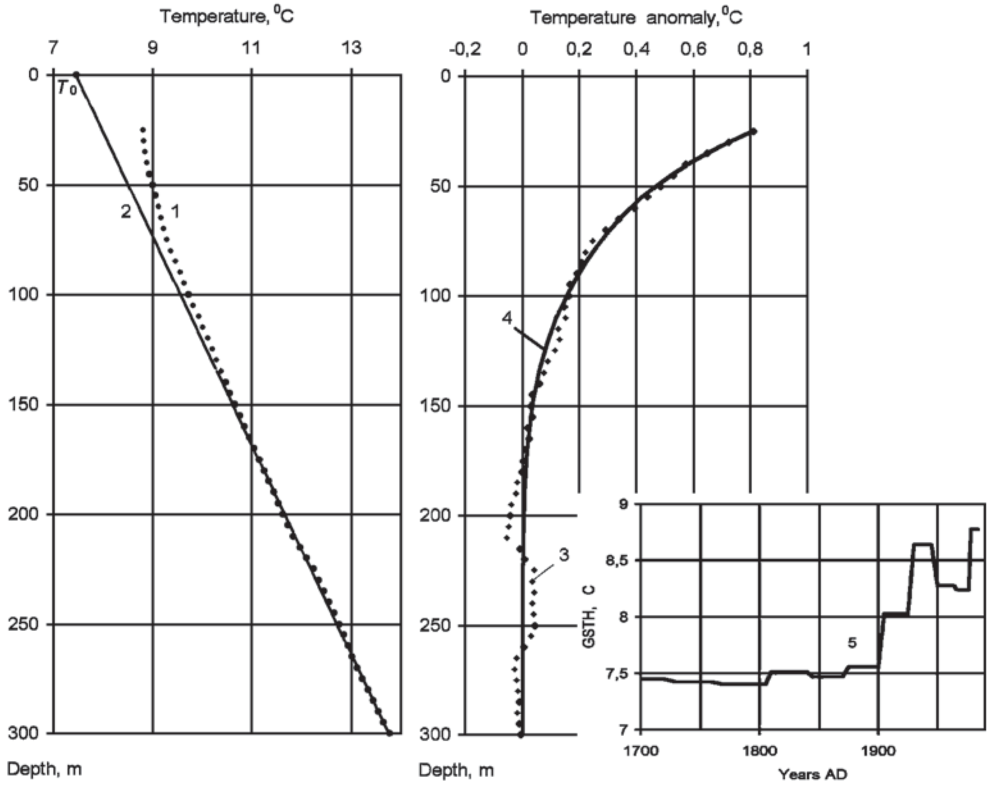

Fig. 1. An example of inversion technique utilization:

1 – measured temperature-depth profile GViZD214 (http://www.geo.lsa.umich.edu/climate/); 2 – undisturbed temperatures T(z) = T0 + G0z estimated from the deepest part of temperature-depth profile (200–300 m); 3 – temperature anomaly; 4 – calculated temperature anomaly corresponding to GSTH profile, 2) estimated temperature anomaly as the difference between measured and undisturbed temperatures, and 3) minimized the mean square error between measured temperature change and calculated anomaly (according to equations 4 and 5) by means of variation of surface temperatures T_k in the given time intervals. [D.Yu. Demezhko and V. A. Shchapov, 2001]. An example of inversion technique utilization is shown in Fig. 1.

DATA AND ANALYSES

We used the temperature-depth profiles recorded in the Urals [Demezhko and Golovanova, 2007] and European boreholes [Huang and Pollack, 1998] as the initial data for analysis of climatic changes. Location of boreholes is introduced in Fig. 2. It is noteworthy that the density of the temperature-depth profiles in the Urals is well over the density in the territory of Eastern Europe.

83 temperature profiles at least 300-meters deep were studied. Only high 300-meters intervals were used for the reconstruction. Temperature anomalies obtained by the above mentioned technique (200–300 m sections were used as the base interval for each temperature record) are shown in Fig. 3. Most of anomalies both

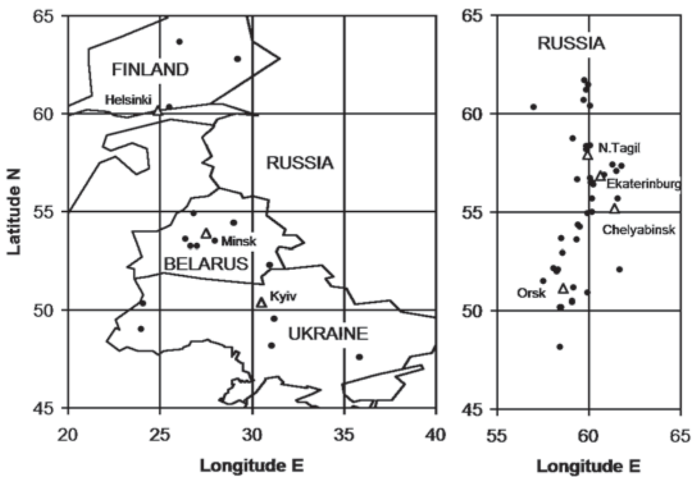

Fig. 2. Location of the boreholes in the Urals and Eastern Europe

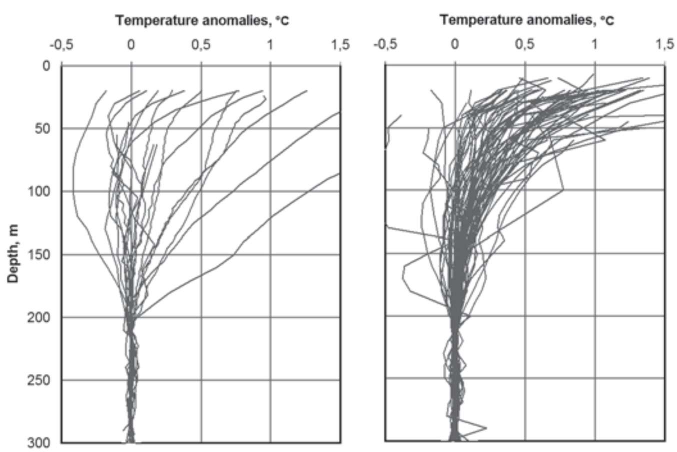

Fig. 3. Temperature anomalies for the Urals and Eastern Europe

in the Urals and Eastern Europe reflect the warming process after the LIA.

Spatial analysis of paleoclimatic reconstructions requires that all investigated boreholes are identical in depth and that the reconstruction of GSTH is made by the same parameters with application the same method for all temperature logs [Beltrami, 2003]. We used an equal thermal diffusivity of rocks = $=10^{-6}$ m^2/sec in all cases. The reconstructed GSTH from the 18th to 20th centuries compared with the long time series of meteorological records (annual surface air temperatures) are presented in Fig. 4. We can see that GSTHs and meteorological trends have a similar form reflecting warming process.

The data for the 20th century were excluded from further consideration. Firstly, the temperature histories have different duration in the 20th century because of different

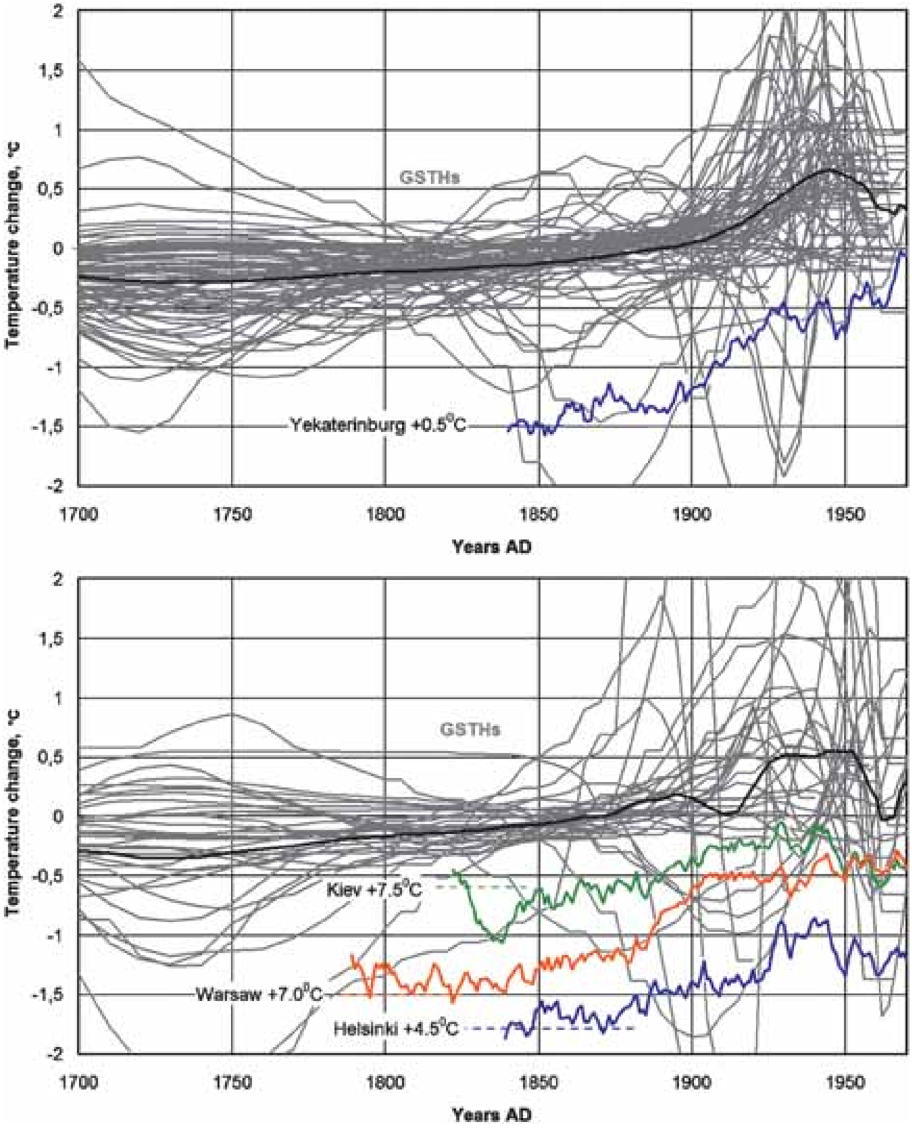

Fig. 4. Spaghetti diagram of the reconstructed GSTHs for the Urals (upper panel) and Eastern Europe (bottom panel). Each history is centered by its average temperature over the period from 1700 to 1960 (grey curves). Colour curves - long time series of air temperature records in the nearest cites averaged by 11-years running windows

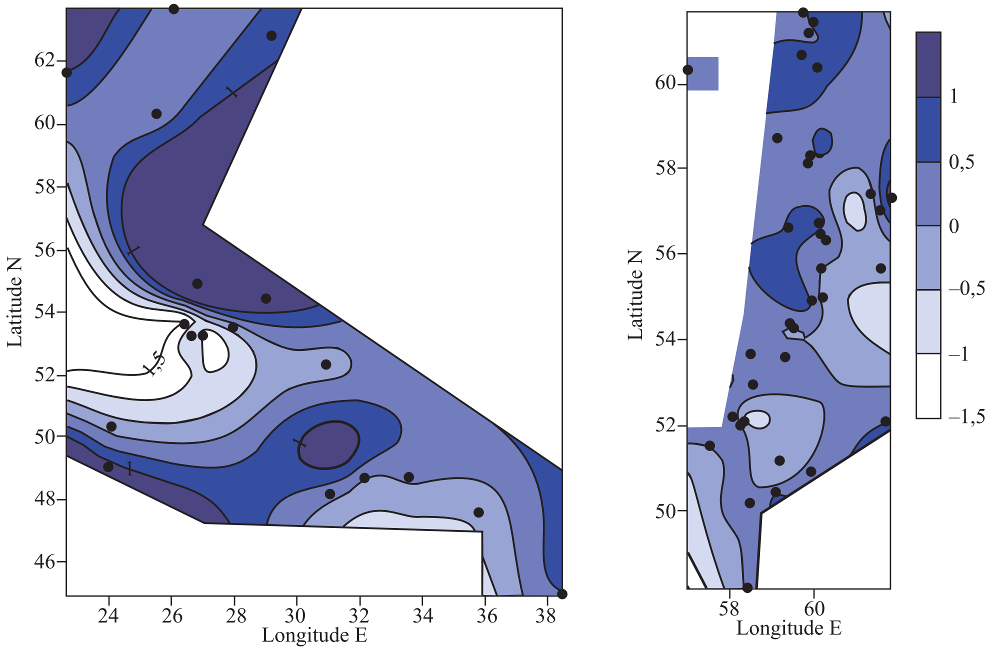

Fig. 5. Spatial distribution of the amplitudes of ground surface temperature changes (°C) in the Urals and Eastern Europe from 1700 to 1900

positions of the temperature profiles' high points. Also, Fig. 4 displays extremely large variability of the reconstructing temperatures in 20th century which is, probably, due to natural reasons as well as to the influence of non-climatic factors. Spatial analysis of such data doesn't reveal any spatial regularities, whose detection is our main investigative objective. The second reason for the exclusion of the 20th century data from consideration is that the influence of thermal effusivities contrast in the uppermost active layer is most significant for the data of such recent period [Kotlovanova, 2011]. The research results related to the period from 1700 to 1900 are presented below.

Spatial distribution of the amplitudes of ground surface temperature changes in the Urals and Eastern Europe from 1700 to 1900 is shown in Fig. 5.

As follows from Fig. 5, the amplitudes of temperature changes vary considerably for different regions. Positive values of the amplitudes correspond to climate warming in north and northwest Urals as well as to north, south, and all eastern area of Eastern Europe. The negative amplitudes trail along the south-west – northeast lines along the Urals and they are common to the central part of the European territory. Such spatial heterogeneity of the amplitudes may be due to the air masses motion transferring large masses of warm and cold air. Primary warming in the northern territory may be associated with the influence of the North Atlantic region. The role of local events for the climatic system is essential. These local phenomena may be connected with a land human invasion, landscape changes, and other anthropogenic activity. Atmospheric precipitation may be another factor that determines such distribution of the amplitudes. Snow cover increases soil temperature and summer precipitation decreases it. Spatial heterogeneity of precipitation is well above spatial heterogeneity of air temperature. These local phenomena of climatic system of the regions under study may be caused by the effect of precipitation quantity adjustment. Therefore, the positive amplitudes may be due to the snow cover height increase in these regions.

To compare the GSTHs shapes, we standardized them. Each GSTH was centered by its average value over the period from

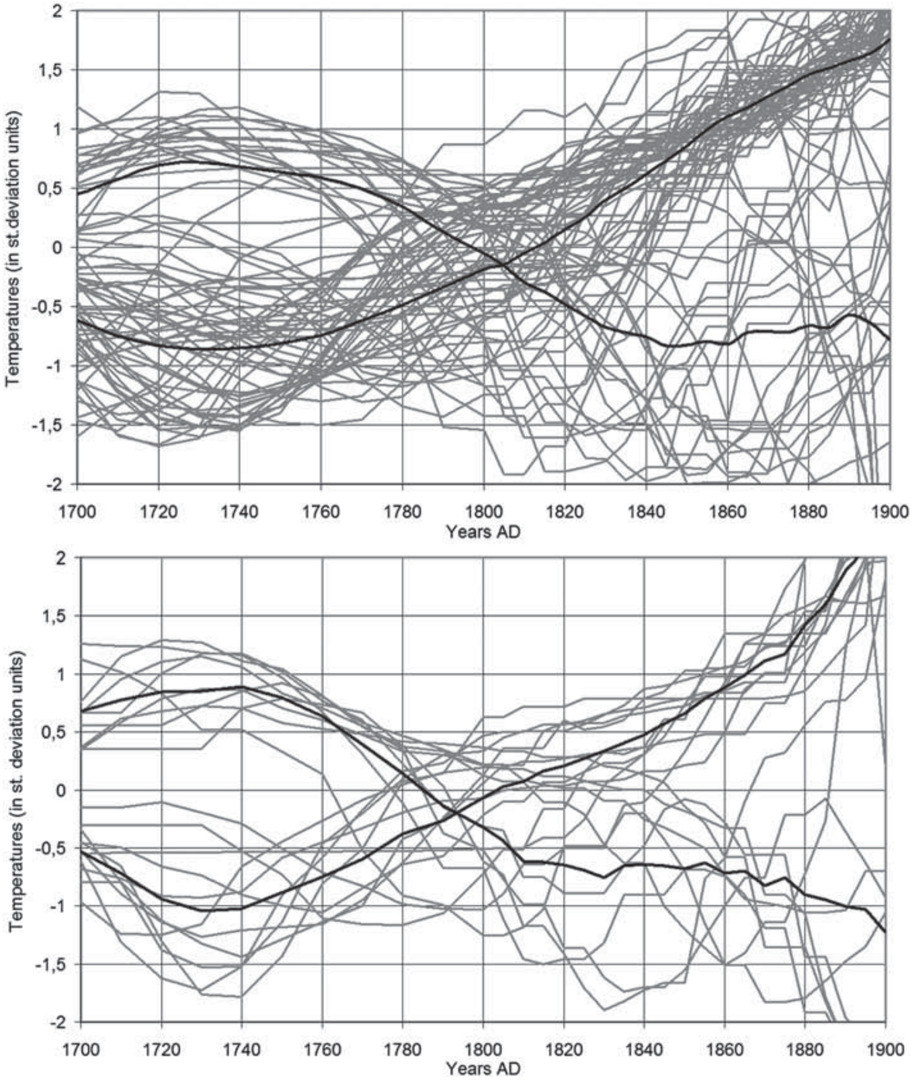

Fig. 6. Spaghetti diagram of the standardized temperature curves for the Urals (upper panel) and Eastern Europe (bottom panel). Black curves – mean GSTHs for two clusters

1700 to 1900 and was divided by the standard deviation. The standardized temperature curves are presented in Fig. 6.

Cluster analysis of the standardized temperature curves reveals at least two types of histories: with early (1720–1760) and late (after 1820) warming start date both in the Urals and Europe.

The spatial distribution of a warming start date is shown in Fig. 7. The earliest warming start is typical for the north-western part of the Urals and the northern regions of Europe. Later, climatic changes occurred in the central European area.

CONCLUSION

Investigation of the spatial feature of climatic changes helps understanding the origin of the Earth's climatic cycles, the latest of which was the LIA. There is some evidence of these changes. A proxy paleoclimate evidence (tree-ring data, pollen evidences) is based on the assumption that correlations between measured quantities and estimated climate elements in the past are close to their present-

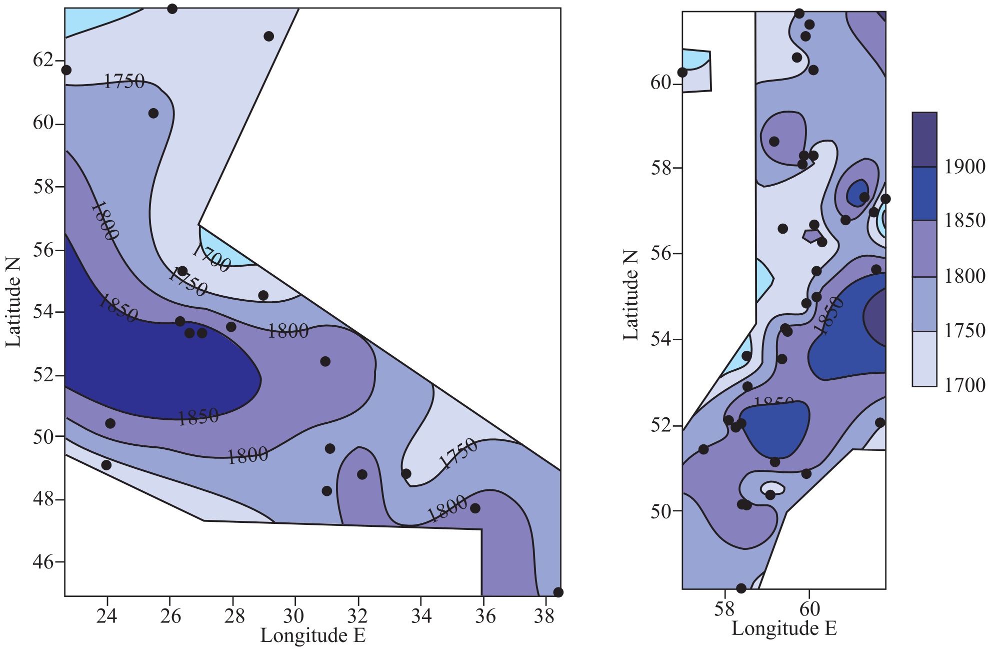

Fig. 7. Spatial distributions of a warming start date (year AD) in the Urals and Eastern Europe from the 18th to 20th centuries

day means. The geothermal method doesn't require establishing correlation links between measured and reconstructed temperatures.

Our investigation reveals distinct spatial patterns of ground surface temperature changes in the Urals and Eastern Europe in the 18th–19th centuries. There were two trends of temperature changes (warming and cooling), as manifested in both regions. The spatial distribution of the warming start dates in Eastern Europe agrees, in general, with GSTH reconstructions of Majorowicz (2010). An early warming start in the 18th century in the northern parts of the Urals and Europe was recently found by Ljungqvist et al (2012) from multiproxy data analysis (excluding borehole). Nevertheless, the influence of non-climatic factors on the geothermal reconstruction is obvious. Deforestation and land use may change ground surface temperature by several degrees while air temperature remains stable. Deviation of the real geological structure from the model of homogeneous medium also disturbs the underground temperature field. However, most of these factors have a low spatial correlation and appear as a mosaic component of the spatial pattern. The most effective way to suppress a non-climatic influence on the regional reconstructions is integration of the geothermal method with other proxies.

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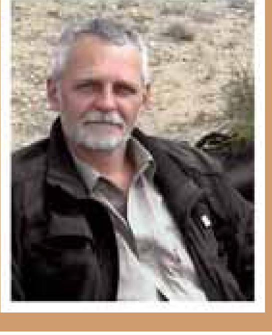

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MAKOCI: A WEB PORTAL FOR INTEGRATING AND SHARING GEOGRAPHIC INFORMATION SERVICES

ABSTRACT. The lack of integration and communication of various geographic information services (GI services) has resulted in many duplication collection of earth observation data, and challenges of semantic interoperability. This paper proposes an ontology-based multi-agents platform, called MAKOCI (multi-agent knowledge oriented cyberinfrastructure), which acts as GI service one stop to manage, publish, share, and discover GI services semantically. By ontologies, formal meanings of concepts are defined to annotate and discover GI services on a conceptual level for semantic interoperability. With the assistance of multi-agents, the processes in MAKOCI can be divided into various modules and be communicated based on the same semantics in ontologies. A prototype was implemented to test MAKOCI. Finally, we conclude the advantages and disadvantages of MAKOCI and point out several future works.

KEYWORDS: Geographic Information Service, Ontologies, Multi-agent System, Cyberinfrastructure

INTRODUCTION

The explosive growth of the Internet in recent years has led to significant advances in the use of Web services, instead of conventional software tools, for processing data and exchanging information [Kvaløy et al., 2005]. In earth observations, observed data (e.g., satellite images or phenomenon measured by in-situ sensors) can be encoded into Web services for sharing and communication. The Open Geospatial Consortium (OGC) recently has built a unique and revolutionary framework of open standards, called sensor Web enablement (SWE), for exploiting Web-connected sensors and sensor systems of all types: flood gauges, air pollution monitors, stress gauges on bridges, mobile heart monitors, Webcams, satellite-borne earth imaging devices and countless other sensors and sensor systems via Web services [Jaeger et al., 2005]. The observed data by these sensors are often accompanied with geographical information, such as place names or coordinates, and can be considered as one type of geographic information services (GI services). With the assistance of OGC, there are more standard formats for GI services, such as geography markup language (GML), Web mapping service (WMS), Web feature service (WFS), and Web processing service (WPS), have dominated the Web to perform geospatial data acquisition and processes as well as information integration and exchange [Peng and Tsou, 2003]. Nevertheless, while sharing and integrating heterogeneous GI services, a central platform for search required GI services and semantically interoperate these GI services [Egenhofer, 2002; Kuhn, 2003] appear more critical.

Semantic interoperability of geospatial data has been recognized as the main hamper for integrating GI services [Fonseca and Sheth, 2002]. It is because that different terminology may be used to describe the same phenomenon by different domains and it lacks a common and shared understanding across the domains to interoperate and communicate [Kuhn, 2003]. For example, one may use *AirTemperature* to describe an observation of air temperature in a GI service, whereas the other one may use *ATemp* to express the same observation. It will be difficult to integrate those two GI services without a shared understanding on the terminologies.

In the other hand, a central platform, such as Geospatial One-Stop[1], is lack for GI services to be registered, discovered, and managed. Data providers can easily use GIS-Server software, such as GeoServer[2], to publish their observation data into standard Web services over the Web. However, it may challenges for other users to use the Web services if they do not know where they are. In addition, semantic heterogeneity described above hampered among users as well, especially when they use different keywords to search GI services in the platform.

Therefore, this study aims to develop an ontology-enabled multi-agent platform, which facilitates ontologies to define common understandings for semantic interoperability, and uses multi agents to assist Web service providers and consumers to register and discovery GI services in the platform. The platform is called multi-agent knowledge oriented cyberinfrastructure (MAKOCI). We divide GI services into two categories: data-accessing services (Web services that provide GIS data) and geoprocessing services (Web services that analyze GIS data) [Lutz et al., 2007]. The metadata of each GI service is aimed to be registered into MAKOCI and use defined formal meanings in ontologies to annotate the registered metadata for semantic interoperability. The registered metadata is encoded in the resource description framework (RDF) [Klyne and Carroll, 2004] so that Web service consumers can search appropriate GI services not only by browsing categories or using keywords but also by using SPARQL, a query language for RDF [Prud'Hommeaux and Seaborne, 2008], on the semantic level.

This paper is organized as follows. Section 2 briefly introduces the background about ontologies, RDF, and multi agents. Section 3 presents the proposed framework of MAKOCI. Section 4 shows an implemented prototype. Section 5 concludes the advantages and disadvantages of the platform and points out some future works.

BACKGROUND

Ontologies

In information science, an ontology is defined as "an explicit specification of a conceptualization" [Gruber, 1993], where a conceptualization is a way of "thinking about a domain" [Uschold, 1998] whereas the formal meanings of both the types of concepts and their relationships in a domain are

[1] http://geo.data.gov
[2] http://geoserver.org/display/GEOS/Welcome

delineated in a machine-readable language by the explicit specifications for semantic interoperability and knowledge inference [Benjamins et al., 1998]. By Ontologies, shared and common understandings (i.e., semantics) can be communicated among people and machines [Crubézy and Musen, 2003]. The formal meanings in an ontology can be incorporated into data integration processing [Peachavanish and Karimi, 2007], search algorithms [Bernard et al., 2003; Purves et al., 2007; Stock, 2008], and analytical methods [Di et al., 2006; Lutz et al., 2007].

The Web ontology language (OWL) is the standard language of ontologies and is recommended by W3C [McGuinness and Van Harmelen, 2004]. Basic elements of OWL include individuals, classes, and properties (i.e., relationships) [Knublauch et al., 2004]. Individuals represent real instances in a domain, whereas classes represent concepts that can be seen as collections of individuals of the same type. Properties are binary and directional links that connect individuals from one class (called the domain of the property) to another (called the range of the property). Properties can be classified on the basis of this range into object and datatype properties [McGuinness and Van Harmelen, 2004]. Object properties link individuals, whereas datatype properties link an individual to an XML schema datatype (e.g., an integer or string) [Knublauch et al., 2004].

A solution to the semantic interoperability for GI services is to develop ontologies in geospatial domains to identify semantic distinctions and relations between geospatial concepts based on ontological specifications, which is a key factor suggested by Egenhofer [2002] for a geospatial semantic Web. Geospatial ontologies can be the foundation for achieving geospatial semantic interoperability [Bishr, 1998; Harvey et al., 1999; Egenhofer, 2002; Fonseca and Sheth, 2002; Kuhn, 2003; Lemmens, 2006], improving geospatial data searches [Purves et al., 2007], and discovering GI services in an SDI [Bernard et al., 2003; Lutz, 2005, 2006; Zhang and Tsou, 2009].

RDF

The RDF is one of standard frameworks for semantic Web recommended by World Wide Web Consortium (W3C) [Klyne and Carroll, 2004]. The RDF aims to represent information in the Web by formal semantics, which can be readable and accessible by machines to query and infer implicit information. The RDF encodes the information in of *subject, predicate,* and *object* triplets [Klyne and Carroll, 2004; Bizer et al., 2009]. The subject and object of a triple are uniform resource identifiers (URIs) to identify resources (e.g., concepts and individuals in ontologies) or XML schema datatype, whereas the predicate specifies the relationships between the subject and object, and is also represented by URIs [Bizer et al., 2009]. URI is similar to a uniform resource locator (URL), which use the *http://* scheme to describe an address of a website. However, URI provide a more generic means to identify resources over the Web by the HTTP protocol [Klyne and Carroll, 2004].

For example, an RDF triple can state that a GI service, *Taiwan_River,* has the *polyline* geometry, as shown in Fig. 1. The subject and object of the triple are *Taiwan_River* and the *polyline* geometry which is related by the predicate, *hasGeometry*. URIs are used to identify each resource in the RDF triple, such as *http://www.tgic.org.tw/GISData.owl#Taiwan_River* for the subject, *http://www.tgic.org.tw/GIS.owl#hasGeometry* for the predicate, and *http://www.tgic.org.tw/Geometry.owl# Polyline* for the object.

Moreover, machines not only can understand the relationship between the subject and object in an RDF triple but also can access further information via URIs. For instance, in Fig. 1, machines can use the URI of the subject, *http://www.tgic.org.tw/GISData.owl#Taiwan_ River,* which is referred to GIS Data ontology (i.e., *GISData.owl*) to access more specifications about the subject.

Multi-agent system

Agents are computer programs capable of autonomous behavior which can sense its environment, communicate with other

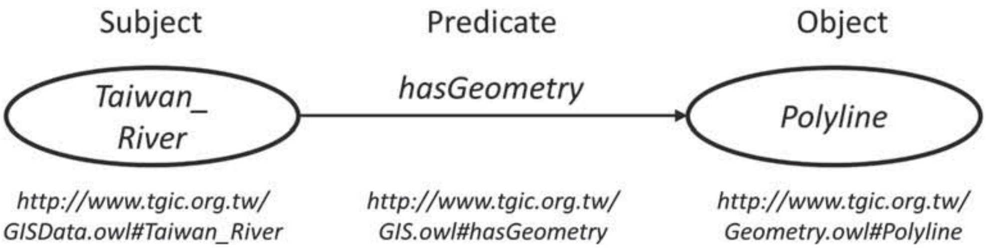

Fig. 1. An RDF triple states that a GI service, Taiwan_River, has the polyline geometry

agents, and possess rational behavior to react [Wooldridge and Jennings, 1995; Wooldridge, 1999]. Multi-agent system are referred to a system that support interactions from multiple agents with an infrastructure [Moodley and Simonis, 2006]. For the purpose of agents, two types of agents can be classified: 1) simulating the perceived or measure behaviors of people response to external stimuli using computational models of rational behaviors, and 2) assisting people to collect information and making decision in hardware and software environments [Sengupta and Sieber, 2007]. In this study, agents are acted the latter one in a software environment to detect and analyze users' behaviors, and automatically collect related information for the users.

However, agents are only computer programs and cannot automatically handle semantic heterogeneous of information without rational behaviors or rules. Without ontologies supports, agents are challenged

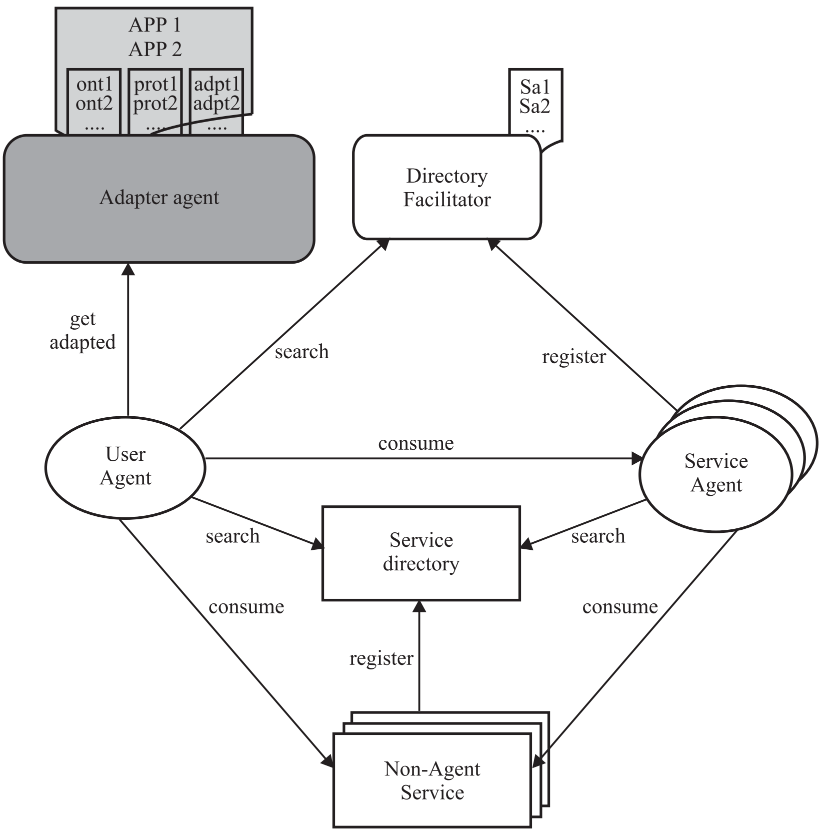

Fig. 2. MASII architecture [Moodley and Kinyua, 2006]

to exchange information based on a common and shared understanding [Hadzic *et al.,* 2009]. For instances, Rauble [Rauble, 2001] has used ontologies to model common knowledge for the communication of agents while perceiving, cognizing, and acting for the way finding; and Moodley and Simonis [Moodley and Simonis, 2006] proposed a platform, which is based on the multi-agent infrastructure for distributed Internet applications (MASII) by Moodley [Moodley and Kinyua, 2006], aimed to integrate heterogeneous sensor data with ontologies that facilitate developing applications for multiple domains.

The MASII architecture contains several agents to communicate information under the shared semantic in ontologies, as shown in Fig. 2. The agents includes 1) user agent which represent an end-user to communicate with other agents 2) service agent is a service provider which can be searched in the directory facilitator and be consumed by the user agent, 3) non-agent service which expresses conventional web services to be consumed by the user agent and the service agent, 4) adapter agent which maintains common knowledge and semantic in ontologies for semantic interoperability among agents.

Nevertheless, how to register and semantic infer sensor web services is not presented in [Moodley and Kinyua, 2006; Moodley and Simonis, 2006]. Thus, in this paper, we based on the MASII architecture and proposed an ontology-enabled multi-agents platform with a practical application for complement. Please refer to Section 3 for more detail about the proposed platform.

AN ONTOLOGY-ENABLED MULTI-AGENTS PLATFORM (MAKOCI)

The framework of MAKOCI

MAKOCI aims to develop a platform for geospatial cyberinfrastructure, an Web-based environment for the integration of geospatial knowledge, data, and technologies [Yang *et al.,* 2010]. MAKOCI adopts multi-agents and ontologies to entail GI services (as geospatial data) with geospatial knowledge for the collaboration of domain experts to contribute their domain knowledge, Web service providers to publish and semantically annotate their GI services, and Web service consumers to semantically search and use their required GI services. Ontologies are used for semantic interoperability and knowledge sharing while registering or searching GI services. And multi-agents can be intelligent to assist users to automatically discover GI services in ontologies in response of users' queries, and can be autonomously communicated each agents for exchanging information. The MAKOCI framework contains the following two levels, as shown in Fig. 3:

(1) The application level includes (a) ONTOCAT (ontology catalog) application, which provides a registry for Web service providers and consumers to register and discover GI services assisted by ontologies and multi-agents; (b) ONTOEDIT (ontologies editor), which offers an environment for domain experts to construct domain knowledge into ontologies; and (c) iSDSS (intelligent spatial decision support system), which supplies an integrated application for Web service consumers to use discovered GI services in ONTOCAT.

(2) The agent level involves Safeguard agent, User agent, Ontology agent, Service agent, and a Directory Facilitator. The Directory Facilities is an agent's registry where agents register their capabilities so that agents can be discoverable [Moodley and Simonis, 2006]. While users log into the applications in MAKOCI, a Safeguard will be initialized to examine the authorities of the users and search an available User agent in the Directory Facilitator. Once a available User agent is found, the User agent will serve the users by analyzing users' activities and searching available Ontology agents (for the references of formal concepts in ontologies) and Service agents (to translate requests into service-specific standards and call the services). In addition, the users' activities will be recorded and stored for the analysis

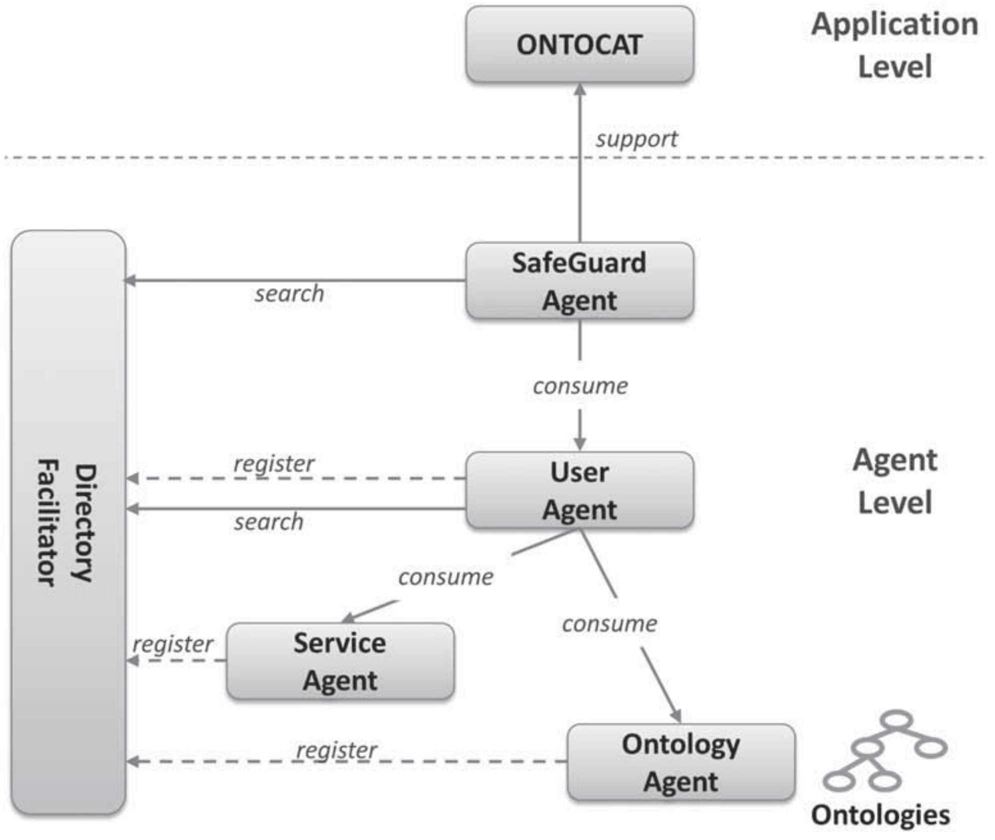

Fig. 3. The framework of MAKOCI

of users' behaviors and for the automatic recommendations of relevant GI services.

Developed Ontologies
The communication among these agents is based on the ontologies to control vocabularies and refer to the formal meaning of concepts and their relationships for semantic interoperability. Ontologies are located at the center of the framework and are developed in the 7 related geospatial domains, which are based on the suggestions of Kolas [2005].

GIS ontology
The GIS ontology delineates the relationships and definitions of geospatial features, which are abstractions of real-world phenomena with types of geometries (e.g., points, polylines, and polygons) and attributes [Moodley and Kinyua, 2006]. Three OGC specifications can be followed to develop the GIS ontology.

The "OGC Abstract Specification Topic 5: Feature" stipulates that a geospatial feature should contain a geometry (e.g., point, polyline, or polygon) with a spatial reference system and attributes [Moodley and Kinyua, 2006]. For example, in Fig. 4, *Feature, Attribute, Geometry, Spatial Reference System,* and *Feature Collection* (i.e., a set of features with the same attributes, geometries, and spatial references) are created as classes in the GIS ontology, whereas *hasGeometry, hasAttribute, and hasSpatialReference* are set as object properties to describe the relationships between these classes.

The "OGC Abstract Specification Topic 2: Spatial Referencing by Coordinates" extends the classes under the *Spatial Reference*

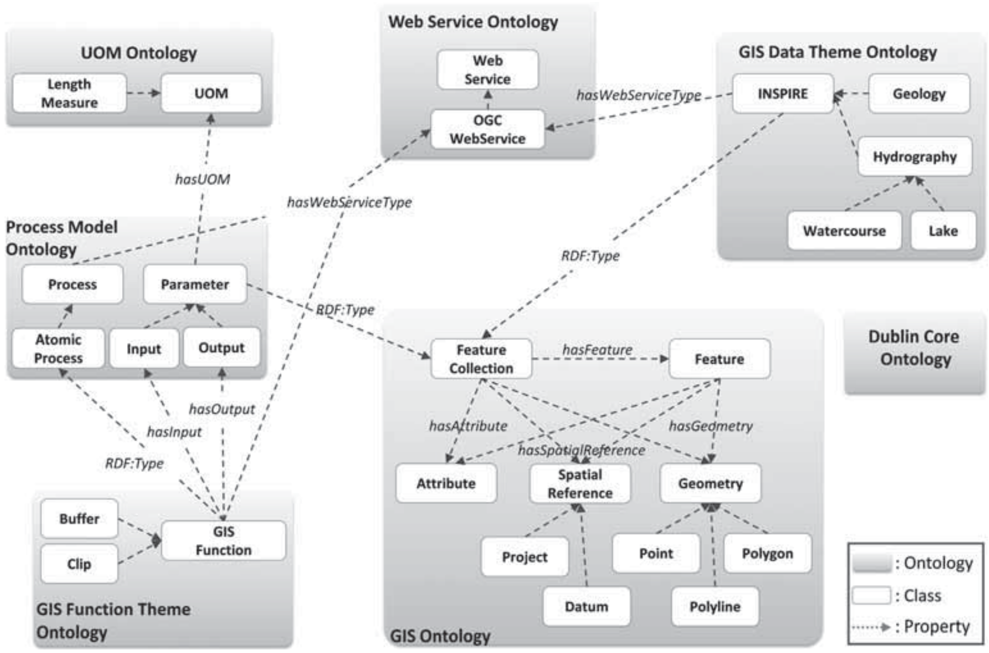

Fig. 4. The developed ontologies

Systems, such as for *Datum* and *Project* in Fig. 4 [Babitski *et al.,* 2009].

The "OGC Simple Feature Access Part 1: Common Architecture" provides categorization of common geospatial geometries, which can be expanded as classes under the *OGCGeometry* class [OGC, 2006a]. However, we here consider only vector-type geometries such as points, polylines, and polygons, leaving raster geometry for future work.

Web Service ontology

The Web Service ontology specified standards for GI services. Here, we focus only on the OGC Web Service standards, e.g., WFS [OGC, 2005], WMS [OGC, 2006b], and WPS [Goodwin and Russomanno, 2006], which are created as individuals belonging to the *OGC Web Service* class.

GIS Data Theme ontology

The GIS Data Theme ontology manages the classification of GIS data. This study follows the classification from Infrastructure for Spatial Information in the European Community (INSPIRE) to establish this ontology. The classification contains 34 spatial data themes, which are grouped in 3 annexes. For each data theme, we can further customize spatial data components and spatial data sets. For example, *Lake* and *Watercourse* can be added as subcategories of the *Hydrography*.

GIS Function Theme ontology

The GIS Function Theme ontology describes the 6 main categories and 20 universal operations proposed by Albrecht [1998] to structure GIS function classification. Universal operations are GIS operations, which are independent of data structures, and are classified from 144 GIS functions into 20 categories (e.g., spatial search, thematic search, and reclassification) [Albrecht, 1998]. Under the classification, other structure-independent GIS functions can be created as classes to customize the GIS Function Theme ontology. For example, in Fig. 5, *Overlay* is a universal GIS operation categorized by *Locational Analysis*. Under the *Overlay* operation, we can add *Clip* as a new class to extend the classification. Alternatively, *Measurement* is a universal GIS operation classified under the *Measurements* category, and *Sum* can be added as a structure-independent GIS function under the *Measurement* operation.

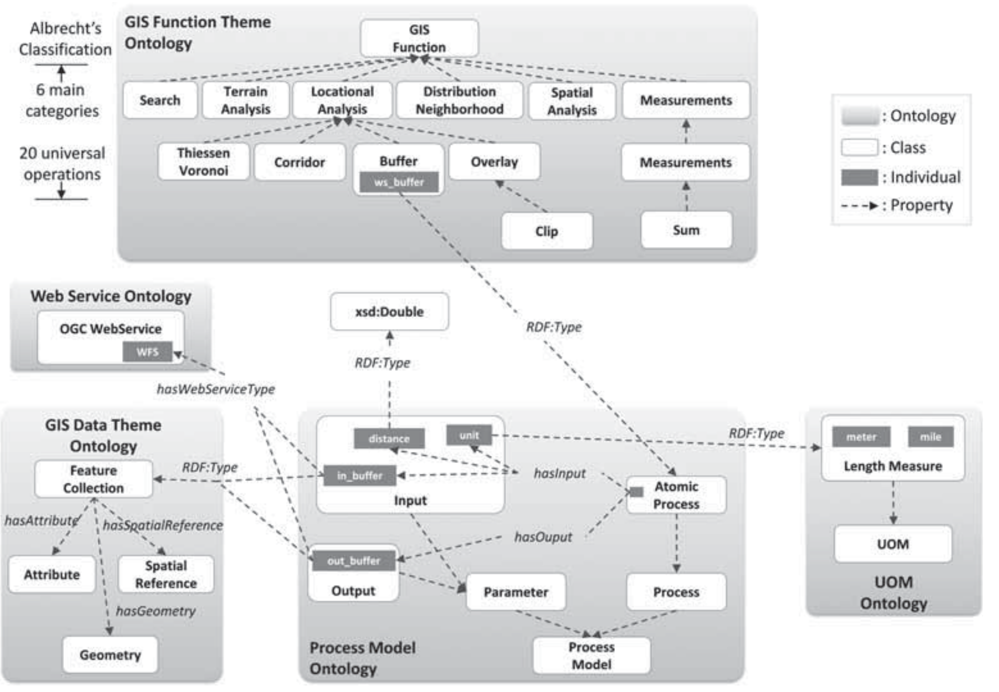

Fig. 5. The relationships between GIS Function Theme, Process Model, Units of Measure, Web Service, and GIS ontologies

Besides the categories, geoprocessing services are considered as individuals (e.g., *ws_buffer* in Fig. 5) in the GIS Function Theme ontology to state the type of geoprocessing services (e.g., the *Buffer* class). Furthermore, the inputs, outputs, preconditions, and results (the IOPR) of geoprocessing services can also be referred to formal classes in the following Process Model ontology for semantic annotations.

Process Model ontology

The Process Model ontology is one of the OWL Web service (OWL-S) ontologies which is recommended by the W3C [Martin et al., 2004]. It aims to impose meanings and relationships on the IOPR of geoprocessing services by using the controlled classes (e.g., *Atomic Process, Input,* or *Output*) and properties (e.g., *hasInput, hasOutput, hasPrecondtion, or hasResult*).

Each geoprocessing service can be specified as a type of *Atomic Process* (i.e., a one-step process) class [Janowicz et al., 2011]. It can not only semantically annotate the inputs and outputs of a geoprocessing service to the *Input* and *Output* classes by the predefined properties *hasInput* and *hasOutput* but also express their type by the *RDF:Type* property. For example, in Fig. 5, the *ws_buffer* service can first be referred to the *Atomic Process* class by using the *RDF:Type* property, so the individuals in the *input* class (e.g., *in_buffer, unit*, and *distance*) can be annotated as the inputs of the *ws_buffer* service by the *hasInput* property, where *out_buffer* can be stated as an output of the *hasOutput* property. The additional classes of these individuals, such as the *Feature Collection* class for *in_buffer* and *out_buffer,* the *Length Measure* class for *units*, and the XML schema datatype (e.g., xsd:Double) for *distance*, can be also stated using the *RDF:Type* property. Consequently, these individuals have to follow the definitions and restrictions of the additional classes. For instance, the *out_buffer* must have a geometry type (e.g., polygon) and attributes, because it has been declared as an instance of *Feature Collection* class and has to satisfy the restrictions on the *FeatureCollection* class, as shown in Fig. 5.

Moreover, the preconditions and results of a geoprocessing service can be annotated by the *hasPrecondition* and *hasResult* properties using specific expressions [Janowicz *et al.*, 2010]. A precondition is a logical formula stating that a condition should be satisfied before execution, whereas a result is a logical formula expressing what will be true upon successful execution. For example, the *distance* individual must have values before execution (precondition), whereas polygon geometry may be generated after successful execution (result). However, for simplicity, we focus only on the inputs and outputs of a geoprocessing service in this study. Further annotations of preconditions and results are listed as part of our future work.

Units of Measure ontology

The Units of Measure ontology is adopted from the suggested upper merge ontology (SUMO), an upper-level ontology providing definitions of general-purpose terms [Niles and Pease, 2001]. This ontology is used to define the units of measurement, such as *meters* and *miles* in the *Length Measurement* class (Fig. 5).

Dublin Core ontology

We followed the Dublin core metadata element set version 1.1[3], to develop the Dublin Core ontology to annotate generic metadata of GI services, such as title, descriptions, and keywords, with formal meanings.

In the following section, a prototype of MAKOCI is implemented, and the developed ontologies are used for semantic interoperability of GI services.

PROTOTYPE

We used the following techniques to implement a prototype for the proposed framework. 1) For the ontologies, Protégé software[4] was used as an ontology editor to standardize the domain knowledge. 2) For the ONTOCAT, the Protégé OWL JAVA API[5] was used as a programming interface, and the Google Maps JavaScript API[6] was used as a base map. 3) For the agents, Java agent developed framework (JADE)[7] was followed to build a multi-agent system. We used two aspects (i.e. how to register GI services and how to search GI services) to demonstrate the prototype and illustrate the processes in MAKOCI.

Registering GI services in MAKOCI

Web service providers can publish GI services, including data accessing and geoprocessing services, in the ONTOCAT. The formal meanings in ontologies can be given to the published GI services for semantic management and discovery by Web service consumers. Three steps are designed for the providers to publish their GI services.

First, the providers submit the metadata of the services (e.g., title, URL, coordinate systems, or geometry) into ONTOCAT, as shown in Fig. 6. While submitting, formal knowledge (e.g., classes, individuals, and properties defined in ontologies) can be selected to annotate semantics of the metadata via the user interface, such as drop-down lists to ensure that correct selection of individuals and classes from ontologies. For example, the values in the coordinate system and geometry drop-down lists are from the individuals of *Spatial Reference* class and *Geometry* class in the GIS ontology. The *hasSpatialReference* and *hasGeometry* properties will be used to annotate the relationship between the GI service and selected values.

Nevertheless, for geoprocessing services, the inputs and outputs of geoprocessing services are critical to be annotated with formal meanings in ontologies. ONTOCAT also provides several drop-down lists for providers to select corresponding values from the ontologies, as shown in Fig. 7. For instance, *in_buffer* is an input parameter of

[3] http://dublincore.org/documents/dces/
[4] http://protege.stanford.edu/
[5] http://protege.stanford.edu/plugins/owl/api/
[6] http://code.google.com/apis/maps/
[7] http://jade.tilab.com/

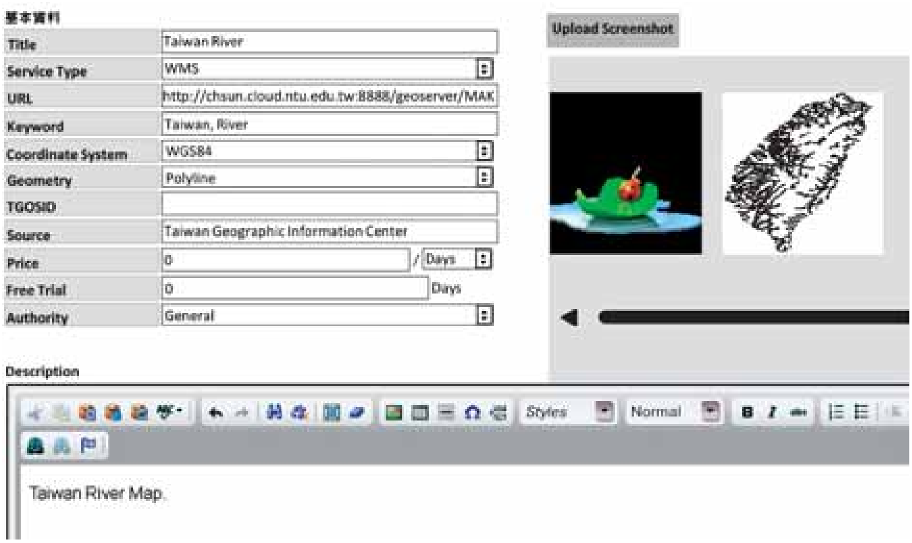

Fig. 6. Screenshots of register data accessing service in ONTOCAT

ws_buffer which have to be implemented in the *WFS* standard with the *Point* geometry and the latitude and longitude coordinate system (i.e., *WGS84*). Moreover, these metadata of the parameter will be described by corresponding properties, such as *hasWebServiceType*, *hasGeometry*, and *hasSpatialReference*, in the ontologies.

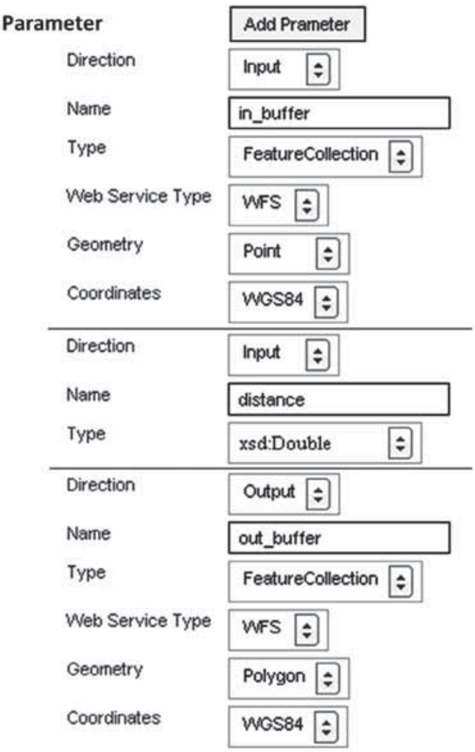

Fig. 7. A screenshot of annotating the inputs (i.e., in_buffer and distance) and an output (i.e., out_buffer) of ws_buffer geoprocessing service in ONTOCAT

Second, providers have to select at least one class from two ontologies, GIS Data Theme ontology for data accessing services and GIS Function Theme ontology for geoprocessing services, to classify GI services. Classes in these

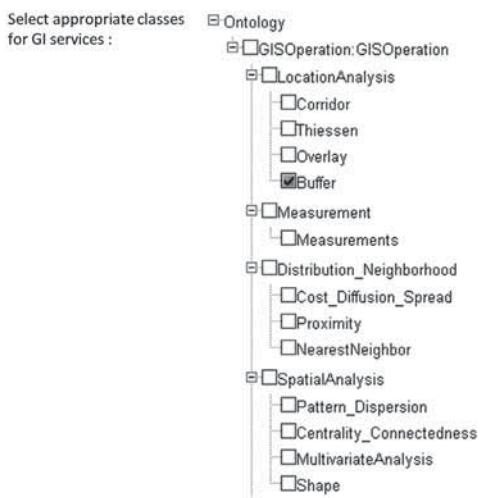

Fig. 8. Select appropriate classes from GIS Function Theme ontology for classifying a geoprocessing service, ws_buffer

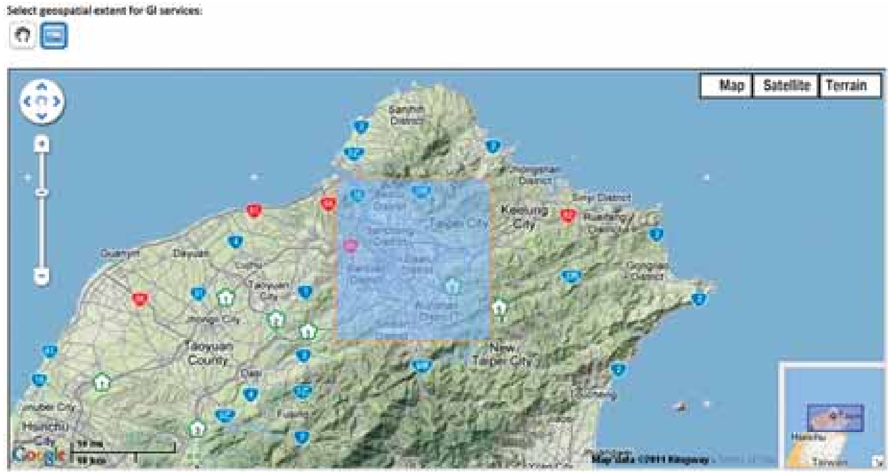

Fig. 9. A rectangular area in Taipei city, Taiwan, is given to express the geospatial extent of ws_buffer

ontologies will be listed in the ONTOCAT for selection, as shown in Fig. 8. For example, *Flood* class in the GIS Data Theme ontology can be selected for *Taiwan River*, a data accessing service; or *Buffer* class in GIS Function Theme ontology can be also chosen for *ws_buffer*, a geoprocessing service.

Third, a geospatial extent can be given for GI services to express the geographical area which GI services can be served. Providers can delimit a rectangular area in ONTOCAT as a service area for a GI service, as shown in Fig. 9.

Once registered, the metadata of the GI service will be encoded in RDF, as shown in Fig. 10 for *Taiwan_River* and Fig. 11 for *ws_buffer*. The registered metadata of GI services will be semantically formalized and presented in RDF triplets so that machines can infer more external resources via these triplets.

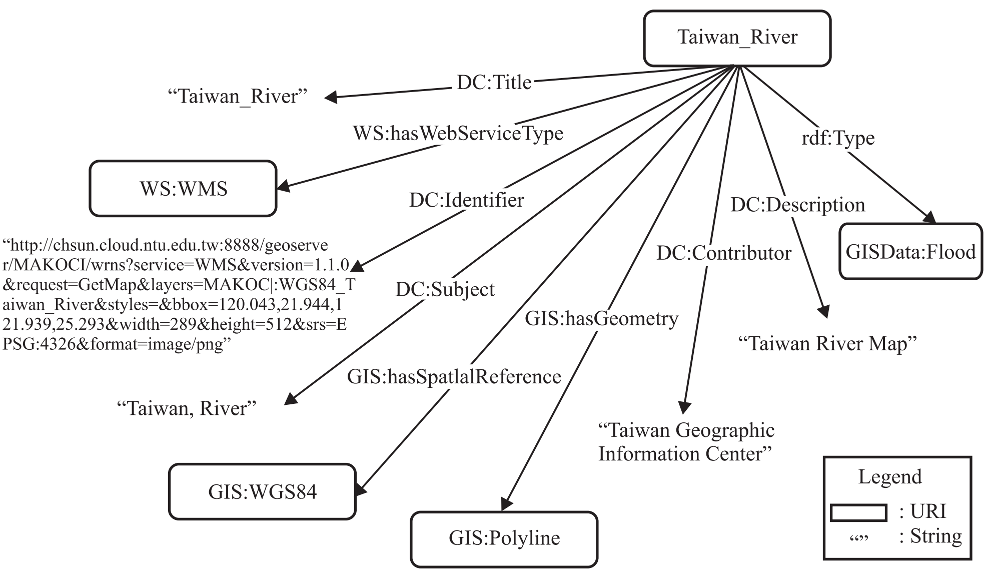

Fig. 10. The registered metadata of Taiwan_River is encoded in RDF, where DC, WS, GIS, and GISData are namespaces of corresponding ontologies, such as Dublin Core, Web Service, GIS, and GIS Data Theme ontologies, respectively

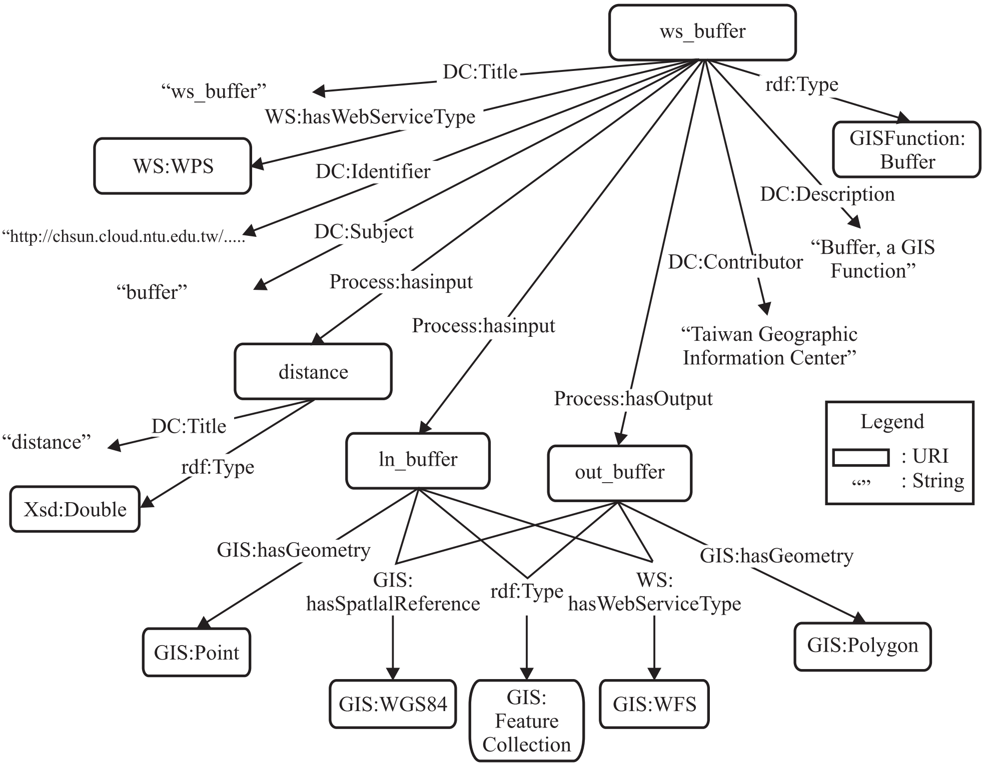

Fig. 11. The registered metadata of ws_buffer is encoded in RDF, where DC, WS, GIS, Process, and GISFunction are namespaces for corresponding ontologies, such as Dublin Core, Web Service, GIS, Process, and GIS Function Theme ontologies, respectively

Searching GI services in MAKOCI

Web service consumers can search GI services by browsing their classified classes from the two ontologies (i.e., GIS Data Theme and GIS Function Theme ontologies). Alternatively, the consumers can search GI services on the conceptual level by using SPARQL, a query language for RDF [Prud'Hommeaux and Seaborne, 2008]. The syntax of SPARQL is similar to the one of structured query language (SQL), which uses *select-from-where* syntax to query databases. However, SPARQL aims to query RDF [Yu, 2011].

```
Prefix GIS: <http://www.tgic.org.tw/gis.owl>
        GISData: <http://www.tgic.org.tw/gisdata.owl>

Select *
From  <http://www.tgic.org.tw/makoci.rdf>
Where
        ?x    rdf:Type                      GISData:Flood
        ?x    GIS:hasSpatialReference       GIS:WGS84
        ?x    GIS:hasGeometry               GIS:Polyline
```

Fig. 12. A SPARQL to query GI services (?x) which are under the Flood class in the GIS Data Theme ontology with WGS84 coordinate system and Polyline geometry

In ONTOCAT, a SPARQL endpoint is provided for the consumers to query the registered GI services in RDF. For example, if the consumers want to search all GI services which are under the *Flood* class with *WGS84* coordinate system and *Polyline* geometry, a SPARQL can be given in the endpoint, as shown in Fig. 12. Therefore, the consumers can use formal meanings of concepts and vocabularies to semantically query the RDF in the MAKOCI, which stores all registered GI services, and to search required GI services.

CONCLUSION AND FUTURE WORK

GI services in the earth observation have the potential to provide real time monitoring and historical data about our environment. How to integrate and share all these tremendous volume of GI services is a major challenge ahead of us. This study presents an initial research effort (i.e., MAKOCI) to this challenge. MAKOCI facilitates ontologies and multi-agents to develop a platform for integrating and sharing GI services. Ontologies are used for knowledge management and semantic interoperability of GI services, whereas multi-agents are adopted for intelligently assistances to search and query the GI services and ontologies. By MAKOCI, users do not need to consider the semantic heterogeneous in each GI service, but they can use formal meanings of concepts in ontologies to register, manage, and search GI services. For earth observations, MAKOCI could be a solution for sharing and integrating GI services.

However, there are several areas of MAKOCI that need to be improved in the future, as shown in the following issues.

More comprehensive ontologies
This study designs only six ontologies (as shown in Fig. 4) to describe formal meanings for GI services, and only use main classification to build hierarchical relations of classes in the ontologies, such as the 34 categories of INSPIRE are used for the GIS Data Theme ontology. More comprehensive ontologies should be developed in the future to describe completely concepts and relationships for GI services

Friendly ontologies editor
In the prototype, the concepts, individuals, and relationships of ontologies are encoded by using Protégé software. Nevertheless, using Protégé to encode the knowledge is a challenge for many domain experts. Therefore, a Web and Wiki-styled ontology editor would be a significant enhancement, allowing domain experts to directly encode and share domain knowledge in ontologies [Iorio *et al.,* 2006].

Connection with Linked Open Data
Linked Open Data aims to publish machine-readable data on the Web (i.e., RDF) to make the data inter-linkable to other external data sets [Bizer et al., 2009]. Several websites, such as Wikipedia and GeoNames, have joined into the Linked Open Data and converted their data into the RDF format and linked to external relevant data sets to make the meanings of the data explicitly defined. MAKOCI should join into the Linked Open Data and act as a GI service one-stop for external data sets to establish links. In addition, ONTOCAT should be expanded for Web service providers to input links from external data sets to make all relevant information of GI services can be interlinked. ■

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SUMMER DROUGHT 2010 IN THE EUROPEAN RUSSIA

ABSTRACT. In this paper, we investigate the spatial and temporal characteristics of the spring-summer atmospheric drought using various indicators from the meteorological station observations in the European Russia in May – August 2010.

Drought indicators suggest that the drought 2010 was not the most extensive. Weather conditions in the winter and spring of 2010 contributed to the occurrence of dry conditions in the central part of European Russia in May. It has been found that the most impact of the severe drought was on the territory of the Volga region. Drought began in May and lasted for 4 months. The intensity of severe and extreme drought increased from May to August. In the south of European Russia, severe and extreme drought was observed.

Analysis of the macrocirculation conditions of the drought formation has shown the likelihood of its occurrence in the European Russia in the near future.

KEY WORDS: drought, Selyaninov hydrothermal coefficient, Palmer Drought Severity Index, Soil Water Index, European Russia

INTRODUCTION

Drought as a hazardous natural phenomenon is determined primarily by meteorological factors. Although there have been many regional Russian drought studies, the researchers continue to examine drought conditions, frequency, and duration of climate-caused drought periods, especially in the grain-producing regions of Russia [Drozdov, 1980; Zoidze & Khomyakova, 2000; Zolotokrylin et al., 2007; Loginov, 2002; Meshcherskaya et al., 2011; Semenov, 2012; Rauner, 1981; Ulanova& Strashnaya, 2000]. Severe drought of 2010 in European Russia was the cause of new scientific studies [Volodin, 2011; Ivanova et al., 2011; Mokhov, 2011; Frolov & Strashnaya, 2011; Barriopedro et al., 2011; Blunden et al., 2011; Grumm, 2011; Lau & Kim, 2012; Schubert et al., 2011]. Research interest is caused by a negative influence of drought on agricultural productivity and instability of characteristics of the dry periods in a changing climate.

Meteorologically connected record-breaking extreme events were observed during the summer of 2010: a heat wave and wildfires in European Russia and the severe flood in Pakistan. Drought was caused by an extraordinarily strong and prolonged extratropical atmospheric blocking event in association with a large-scale atmospheric Rossby wave spanning over European Russia, Kazakhstan, and the northwestern China–Tibetan Plateau region. The heat wave was amplified by a positive feedback through changes in the surface energy fluxes between the atmospheric blocking pattern and land with below-normal soil moisture [Lau and Kim, 2012]. Anomalously heavy rain events over northern Pakistan occurred due to the southward penetration of extratropical potential vorticity in the deep trough east of the European blocking [Galarneau et al., 2012; Hong et al., 2011]. The discussion about the connection between the events of summer 2010 with the anthropogenous climate change is not complete. On the one hand, the natural variability of climate was the main cause of the heat wave in European Russia [Dole et al., 2011]. On the other hand, the record heat in July 2010 would not have happened without the large-scale climate warming [Rahmstorf & Coumou, 2011].

The authors investigated the genesis and dynamics of hazardous atmospheric drought (criteria recommended by the Hydrometeorological Research Center of Russia) and its conjunction with the macrocirculation processes in the 20 – early 21 century over the European Russia in their previous studies [Cherenkova, 2007; Cherenkova, 2012; Cherenkova & Kononova, 2012].

Some papers claimed that: 1) severe and extreme drought in 2010 was manifested in the south of European Russia and 2) drought like the drought in 2010 was not observed in the European part of Russia for 75 years of instrumental meteorological observations [Meshcherskaya et al, 2011; Frolov & Strashnaya, 2011].

The goal of this study is to identify the spatial and temporal characteristics of the spring-summer atmospheric drought in May – August 2010 over the European part of Russia using quantitative indices of drought. We also sought to answer the question, what was the area of extreme drought in 2010, compared with similar droughts in European Russia in the XX – early XXI-st century. This paper is focused on the investigation of regional peculiarities of spring and summer atmospheric drought with the emphasis on the study of severe and extreme drought and macrocirculation conditions of its formation as an event with the greatest negative impact on agricultural production.

DATA AND METHODOLOGY

The identification of atmospheric drought on the plains of European Russia from May to August, 2010, is based on the well-known, in Russian Federation, Selyaninov Hydrothermal Coefficient (HTC) and the most widely used, in the USA, the Palmer Drought Severity Index (PDSI).

The Hydrothermal Coefficient is calculated as

$$HTC = P/0{,}1 \cdot T_{>10°C}, \qquad (1)$$

where $T_{>10°C}$ is the sum of daily mean air temperature in the period with daily temperature above 10°C, P is the daily precipitation sum over the same period [Selyaninov, 1928]. For a more consistent zonal comparison of the results, we considered the normalized standard deviation anomalies of HTC [Zolotokrylin & Titkova, 2012].

In this work, we used the data set VNIIGMI MTsD on observations of air temperature and the daily total precipitation for 1936–2010 (www.meteo.ru) for calculation of the Hydrothermal Coefficient. Results were obtained from the data of 44 weather stations located in European Russia. Anomalies and the standard deviation of the normalized HTC anomalies were evaluated in comparison with the average for the period 1936, 2010. The monthly gridded global PDSI values (2,5°×2,5° resolution) are taken from the global dataset [Dai et al., 2004]. The Palmer Drought Severity Index is based on the use of empirical coefficients for calculating the regional water resources, standardized to the local climate. The index is the sum of the current moisture anomaly and combined with weighting factors of previous values of the index. Moisture anomaly is defined as:

$$d = P - \hat{P}, \qquad (2)$$

where P – the monthly amount of precipitation, $\hat{P}$ – potential values climatically appropriate for existing conditions (CAFEC) [Palmer, 1965]. The definition of $\hat{P}$ is a simple analog of the water balance equation:

$$\hat{P} = \alpha_i PE + \beta_i PR + \gamma_i PRO - \delta_i PL. \qquad (3)$$

The weighting factors are called the water-balance coefficients and are found in the following manner:

$$\alpha_i = \frac{\overline{ET_i}}{\overline{PE_i}} \qquad \beta_i = \frac{\overline{R_i}}{\overline{PR_i}}$$

$$\gamma_i = \frac{\overline{RO_i}}{\overline{PRO_i}} \qquad \gamma_i = \frac{\overline{RO_i}}{\overline{PRO_i}}$$

where i ranges over the months of the year, $\overline{ET}$ – evapotranspiration, $\overline{R}$ – recharge, $\overline{RO}$ – runoff, $\overline{L}$ – loss, $\overline{PE}$ – potential evapotranspiration, $\overline{PR}$ – potential recharge, $\overline{PRO}$ – potential runoff, $\overline{PL}$ – potential loss. The bar over a term indicates an average value, which depend on the available water holding capacity (AWC).

The moisture departure is weighted using K for comparability of the index values in the different months of the year in different locations. K is called the climatic characteristic and defined as:

$$K_i' = 1.5\log_{10}\left(\frac{\frac{\overline{PE_i}+\overline{R_i}+\overline{RO_i}}{\overline{P_i}+\overline{L_i}}+2.8}{\overline{D_i}}\right)+0.5, \qquad (4)$$

$$K_i = \frac{17.67}{\sum_{j=1}^{12}\overline{D_j}K_j'}K_i', \qquad (5)$$

where $\overline{D_j}$ is the average of the moisture anomaly for month j.

As a result, we obtain the Palmer moisture anomaly index (Z index):

$$Z = Kd \qquad (6)$$

Z index can indicate wet or dry conditions during a single month without regard to a recent trend of the ratio of heat and moisture.

Monthly values of the Palmer Drought Severity Index are calculated as:

$$PDSI_i = 0{,}897 \cdot PDSI_{i-1} + Z_i/3. \qquad (7)$$

The advantages of this methodology are demonstrated in the comparability of the values in any place and at any time of year, as well as in the ability to take into account the moisture conditions in previous months. The inability to account for evapotranspiration of frozen ground and snow accumulation limits the index usage [Alley, 1984].

The area was calculated as the percentage area of the drought from the area of research territory (%). The intensity of the drought or its severity is reflected in an identified type of drought (Table 1). Analysis of the area and intensity of drought in European Russia showed that the area and intensity correlate with a coefficient of 0,98 for the normalized HTC anomalies and 0,96 for the Palmer Drought Severity Index.

To analyze the long-term fluctuations of global atmospheric circulation we applied the classification of elementary circulation mechanisms (ECMs) for the Northern Hemisphere developed by B.L. Dzerdzeevskii [Dzerdzeevskii, 1962; Dzerdzeevskii, et al., 1946]. The results obtained using this classification (the long-term series of alternations of ECM, patterns of circulation, most recent publications, list of all publication where this classification was used) during the period from 1899 to present are placed on the website www.atmosphertccirculation.ru [Kononova, 2009].

Table 1. Classification of the drought intensity

Severity classes	Normalized HTC anomaly	Palmer Drought Severity Index
Mild drought	–1.00 to –1.24	–1.00 to –1.99
Moderate drought	–1.25 to –1.49	–2.00 to –2.99
Severe drought	–1.5 to –1.74	–3.00 to –3.99
Extreme drought	Below –1.75	Below –4.00

Table 2. The distribution of drought -related ECMs in the circulation groups for European Russia

Western zonal	Northern meridional	Southern meridional	Stationary position
2a, 2v, 6, 7al, 7bl	4b, 4v, 8bl, 8gl, 8gz, 10a, 10b, 12a, 12bl, 12vl	2b, 8bl	3,8a, 9a, 9b, 13l
The propagating edge of the Azores anticyclone	The Arctic air intrusions	The outputs of the Mediterranean cyclone tracking	Persisting anticyclone in the region

1. Zonal ECMs for the Northern Hemisphere without blocking events with three outputs of the Mediterranean cyclone tracking: 2a – towards Central and Western Europe, along the Pacific coast, across North America; 2b – from the Mediterranean via the Black Sea and Caspian Sea basins in the direction of the Volga and Ural basins along the Pacific coast and across North America; 2v – across the Caspian and Aral Sea in the direction of the Ob and Yenisei River basins, along the Pacific coast, across North America. 2) Disturbance of zonal circulation ECMs for the Northern Hemisphere: 3 – blocking anticyclone over the Atlantic; 4b – blocking event over European Russia; 4v – blocking event over the Urals and Western Siberia; 6 – blocking anticyclone in the Pacific sector; 7al – blocking event over the east of North America; 7bl – blocking event over the west of North America. 3) Northern meridional ECMs for the Northern Hemisphere. Two blocking events: 8a – over the east of North America and Western Europe; 8bl – over European Russia and Eastern Siberia; 8vl – over Eastern Siberia and the Pacific Ocean; 8gl – over the Atlantic and Western Siberia; 8gz – over the Atlantic and Eastern Siberia; 9a – over the Atlantic and Pacific Ocean; 10a – over European Russia and the east of North America; 10b – over the east of European Russia and west of North America. 12a – four blocking events, one of them over European Russia. Three blocking events: 12bl – one of them over the sector from 40°E to 100°E.; 12 vl – one of them over the basin of the Volga and Ob. 4) Southern meridional ECMs for the Northern Hemisphere: 13l – four outputs of the Mediterranean cyclone tracking.

There is an elementary circulation mechanism classification of cyclone and anticyclone finding and tracking scheme for six sectors – Atlantic, European, Siberian, Far East, Pacific and American sector [Dzerdzeevskii, 1968]. According to the cyclogenesis in the European sector (0 °–60 ° E), the elementary circulation mechanisms (ECM) are grouped into: Western zonal group, Northern meridional group, Southern meridional group and Stationary position group (Table 2).

We also used the Soil Water Index (SWI) data set from satellite observations of the Institute of Photogrammetry and Remote Sensing (Vienna University of Technology) for evaluation of soil moisture anomalies in May–August 2010. The data with a resolution of 12,5 km are available for the period from 1992 without the gap period in 2001–2003 [Naeimi et al., 2009]. The Soil Water Index can be interpreted as the soil moisture content (%) in the first 1 meter of the soil ranging between wilting level and field capacity. Soil moisture anomalies were calculated over the period 1992–2010.

RESULTS AND DISCUSSION

According to the normalized anomalies of the Selyaninov Hydrothermal Coefficient (as shown in Figure 1) large-scale drought covered 19% of the territory of European Russia in 1936, 22% in 1938, 18% in 1939, 38% in 1972, and 25% in 2010. According to the Palmer Drought Severity Index, a group of dry years was observed from 1936 to 1939 when the severe drought area increased from 35% (in 1936) to 42% (in 1939). Extensive severe droughts in the European Russia were observed in 1972 (36% of the territory), 1975 (20%), 2002 (25%) and 2010 (31%). Extreme drought occupied less area, but was also extensive.

So, the greatest area of spring and summer strong drought in European Russia in the period 1936–2010 was in 1972 (according to the HTC normalized anomalies). The priority of the largest area of similar drought according to the Palmer Drought Severity Index was in 1939. This can be explained by the cumulative effect of several years of drought in the PDSI calculation.

Let's consider weather conditions in the European part of Russia in 2010. Winter was cold over large areas of European Russia. The highest mean monthly air temperature anomaly was observed in January over the central part of the territory (on average, 5 degrees lower than the historical average). In the south and west of the territory, the

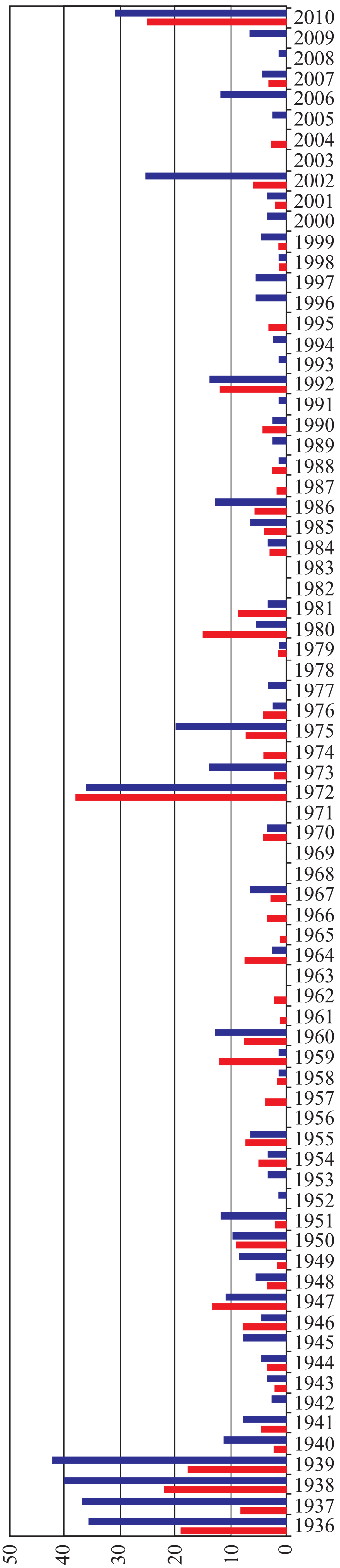

Fig. 1. The dynamics of the severe drought area (%) in European Russia in May-August in the period of 1936–2010 according to HTC normalized anomalies (red line) and the Palmer index (blue line)

winter amount of precipitation almost twice exceeded the long-term average values (Table 3). On the contrary, spring was warm. A shortage of precipitation was in the center of European Russia (in April, 40% of the historical averages). Part of the winter precipitation decreased due to the abnormally cold winter and the deep soil freezing.

The genesis of the drought in May–August 2010, in the European Russia, is shown in Figures 2 and 3. It should be noted that although the intensity and extent of drought, according to both indexes, demonstrate small differences, the results based on the analysis of the PDSI values largely repeat those based on the normalized HTC anomaly variations due to a high correlation between them (correlation coefficients: 0,81 for the mild drought, 0,83 for the moderate drought, and 0,76 for the severe drought). This difference may reflect the contribution of moisture conditions of the previous periods into the PDSI calculation.

A persistent anticyclone formed over European Russia in early May due to the penetration of Arctic air. Recurring invasion of the Arctic cold air rapidly warmed over the continent and supplemented anticyclone throughout the month. As shown in Fig. 2a, the severe and extreme drought in 2010 occurred in May in a small area in the Volga region according to the PDSI values, and the severe drought began in June according to the normalized anomalies of the HTC (Fig. 3a). A severe drought spread in all directions during June–August, but the furthest to the south-east, covering 11% of the territory in June, 21% in July, and 31% in August. There was an alternation of the processes in June and July that characterizes circulation groups “Stationary position” and “Northern meridional.” In addition, the territory was under the influence of the air of the eastern periphery of the Azores anticyclone during 25–28 June and 21–22 July. The average monthly temperature in July and August in central and south-eastern European Russia exceeded the long-term average by 5–7 degrees. There was almost

Table 3. Average deviation of temperature (°C) (1) and precipitation (%) (2) over European Russia in comparison with the period 1961–1990

December		January		February		March		April		May	
1	2	1	2	1	2	1	2	1	2	1	2
–1.2	120	–3.6	104	–0.9	123	0.3	135	1.7	77	3.0	115

no rainfall (Table 4). On July 28, Mediterranean cyclone, which arrived to the southern borders of the European Russia, was unable to break the anticyclonic regime. The next Mediterranean cyclone arrived only on August 27, during the end of drought. The maximal area of extreme drought was in July (14% of the territory) and August (12% of the territory) (Fig. 2b). The drought in the Volga region was observed in four months. Severe drought in western European Russia appeared only in July. In the south of the European Russia, there was only mild and moderate drought, which began in July. The intensity of severe drought increased from May to August. The boundary of drought extended in August in northern regions of European Russia, where it has been never observed.

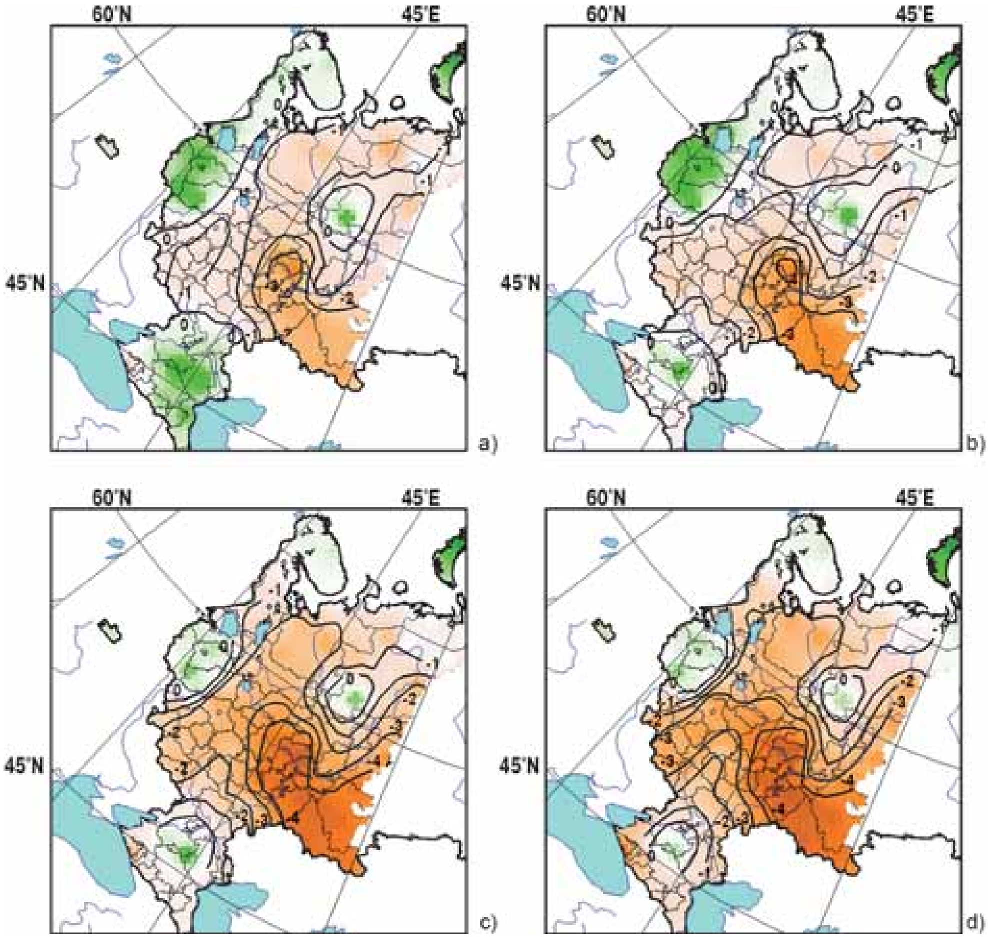

Fig. 2. Atmospheric drought in European Russia in: a) May b) June c) July and d) August, 2010 according to the Palmer Drought Severity Index. The contours show the intensity of drought

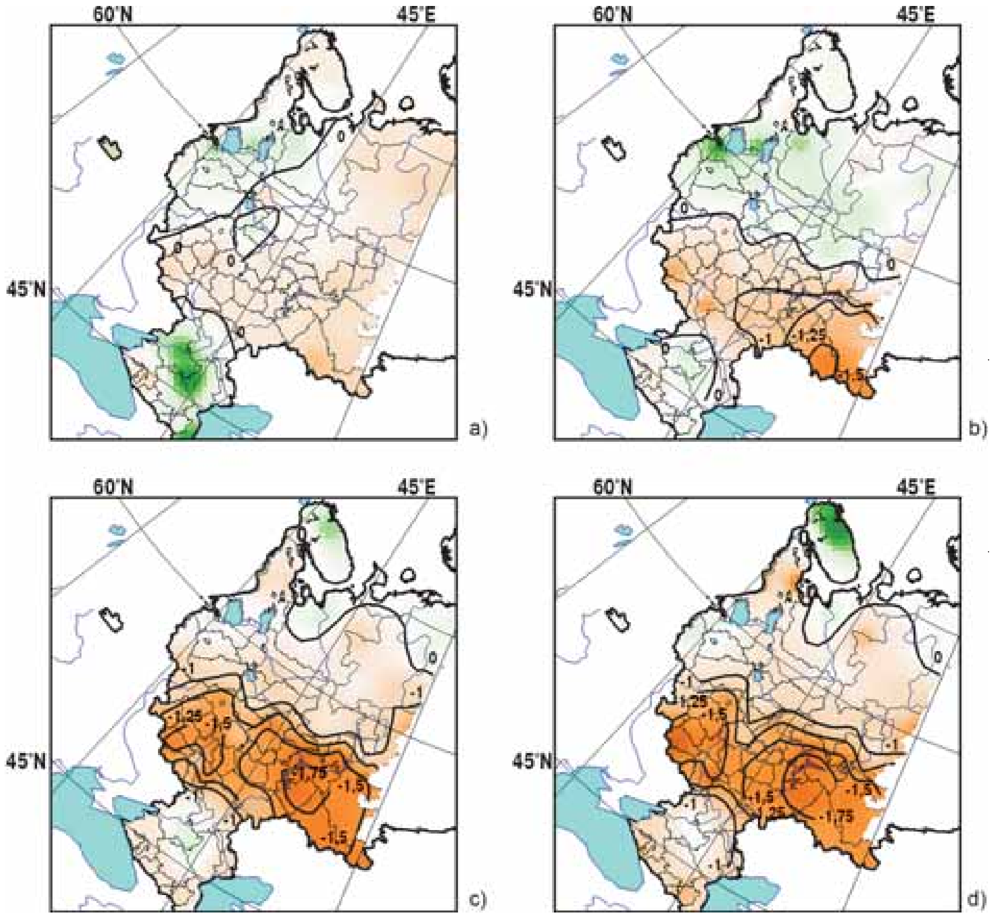

Fig. 3. Atmospheric drought in European Russia in: a) May b) May–June c) May–July and d) May–August, 2010 according to the normalized anomalies of HTC. The contours show the intensity of drought

Table 4. Mean monthly air temperature and precipitation anomalies in the summer of 2010 on the territory of European Russia compared with the period 1961–1990

Station	Air temperature, °C			Precipitation, %		
	June	July	August	June	July	August
Astrakhan	3.4	3.9	4.0	24	0	5
Elista	3.3	4.5	5.3	19	166	7
Primorsko-Akhtarsk	2.7	3.0	4.7	82	52	55
Rostov-on-Don	4.5	5.8	7.7	17	132	9
Tsimlyansk	3.6	4.1	5.4	100	104	10
Aleksandrov Gay	4.9	5.6	5.9	0	33	26
Oktyabr'skij Gorodok	4.7	6.4	6.3	1	33	20
Voronezh	4.2	6.8	7.1	52	46	52
Kamennaya Steppe	5.0	7.0	7.3	4	35	55
Samara	4.9	6.6	6.8	9	2	51
Tambov	4.0	7.3	6.5	48	15	100
Makhachkala	2.4	2.4	2.8	27	15	7

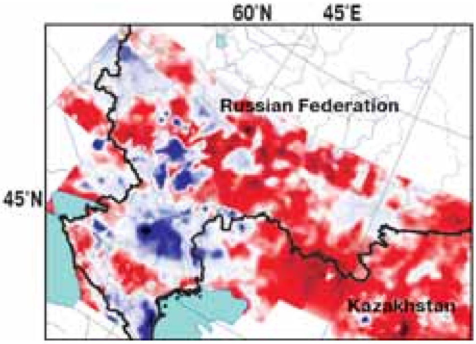

Fig. 4. Soil moisture anomaly in May 2010 (negative anomaly in red)

prevailing easterly and southeasterly winds in May and June contributed to the transfer of warm air from North Kazakhstan in the Volga region.

Based on the analysis of fluctuations of the European sector atmospheric circulation in the period from 1899, we assume that drought can be expected in European Russia in the near future due to the increasing duration of the blocking events in the recent years (Fig. 5).

The abnormally hot weather over European Russia in 2010 has beaten the previous temperature record of a hot season in Western Europe in the summer 2003 due to its intensity, duration, and spatial extent. The temperature maxima of the historical records for 500 years have been exceeded on more than 50% of the territory of European Russia. The ensemble calculations show that, over the next 40 years, the probability of such abnormalities may increase 5–10 times. However, despite these estimates, the probability of this phenomenon occurrence in the same region is very small until the middle of this century [Barriopedro et al., 2011].

CONCLUSIONS

It can be argued that the area of drought depends on the method of detection. According to the normalized anomalies of the Selyaninov Hydrothermal Coefficient and the Palmer index, the largest area of severe drought in European Russia was in 1972 and 1939.

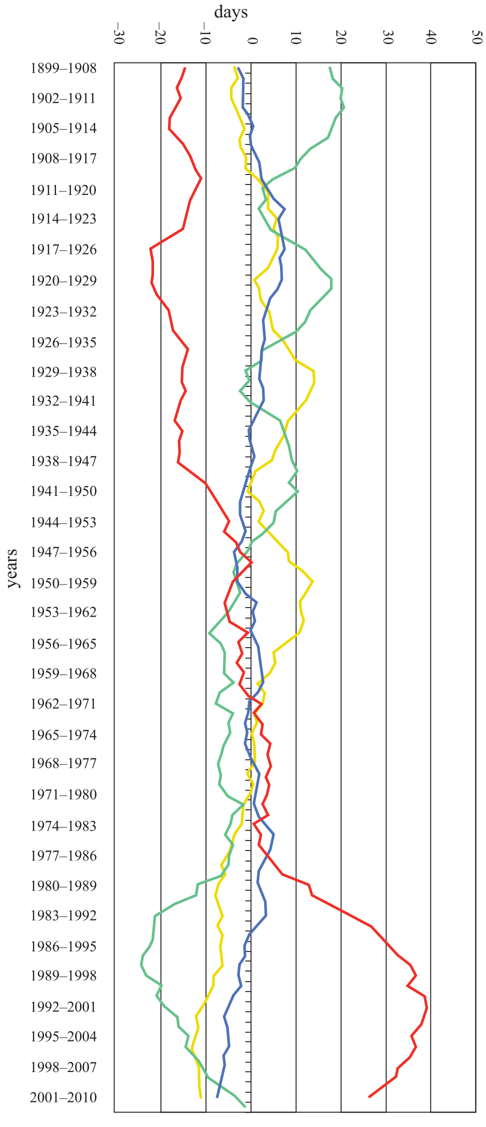

Fig. 5. 10-year moving averages of the circulation groups anomalies duration in European Russia. Western zonal group is denoted by yellow line, Northern meridional group – by green line, Southern meridional group – by blue line, and Stationary position group – by red line

The cold winter of 2010, which prevented the recharge of soil moisture due to snow melting and spring moisture deficits, had an impact on the occurrence of drought conditions in the central part of European Russia in May.

Based on the above results, we argued that the drought in 2010 began in May in the Volga region and was observed here for four months. During June–August, a severe drought spread in all directions. The intensity of drought has increased from May to August. The drought boundary extended in August to the northern regions of European Russia, where it has been never seen. The greatest impact of summer drought of 2010 happened in the south-eastern regions of European Russia. In the south of European Russia, a strong and extreme drought was not observed.

According to the circulation conditions dynamics in the period from 1899, we can expect droughts in European Russia in the near future due to the increasing duration of the blocking process in the recent years.

ACKNOWLEDGEMENT

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WHY WAS THE AUGUST 2010 ZHOUQU LANDSLIDE SO POWERFUL?

ABSTRACT. On August 8, 2010 in the northwestern Chinese province of Gansu, rainstorm-triggered debris flow devastated the small county of Zhouqu. A modeling study, using a new multiple-phase scalable and extensible geo-fluid model, suggests that the cause is the result of an intersection of several events. These were a heavy rainstorm, not necessarily the result of global warming, which triggered the landslide and followed a drought that created surface cracks and crevasses; the geology of the region, notably the loess covering heavily weathered surface rock; and the bedrock damage, which deepened the surface crevasses, inflicted by the 7,9 magnitude Wenchuan earthquake of May 12, 2008. Deforestation and topsoil erosion also contribute. The modeling results underscore the urgency for a high priority program of re-vegetation of Zhouqu county, without which the region will remain exposed to future disastrous, 'progressive bulking' type landslides.

KEY WORDS: progressive bulking, graded sloping, extreme precipitation, vegetation effects on storm-triggered landslides

INTRODUCTION

Landslides occur irregularly and future research is concerned with developing more accurate predictions about their timing (when), location (where) and size (how big they will be), and in developing procedures that convey risk and warnings to the public to mitigate loss of life and damage to infrastructure and ecosystems [van Asch et al., 2007; Casadei, Dietrich & Miller, 2003]. The storm season of 2010 saw landslides in Zhouqu China (August 8, 2010), Sikkim, India (August 27), and Guatemala (September 3). The question is if these events are a bellwether of an intensified water cycle as a consequence of climate warming [blogs.nature.com/news/thegreatbeyond/2010/08/mudychinafacingmorelandsl.html]? Or does the cause lie elsewhere?

A version of the SEGMENT modeling system, SEGMENT-Landslide [Ren, Leslie & Karoly, 2008; Ren et al., 2009; Ren et al., 2001], is used to investigate the Zhouqu debris flow of August 08, 2010, particularly the cause and possible future preventative actions.

The Zhouqu landslides were preceded by an extreme precipitation event which occurred around midnight of August 7, 2010 (Fig. 1). Both the precipitation intensity of 77,3 mm/hr near 104,42E, 33,78N, and total rainfall amount of 96,3 mm in 24 hours are the highest recorded for the period since the May 2008 Wenchuan magnitude 7,9 earthquake. From a longer perspective, the Zhouqu rainfall event had a 20-year probability of occurrence under the present climatology, considering ongoing, significant climate change. The hills around Zhouqu have been well-known for their long history of landslides [http://news.sciencenet.cn/htmlnews/2010/8/235921-1.shtm; Ma & Qi, 1997; p. 187 of Bolt, Horn, Macdonald & Scott, 1975]. However, this event is unique in its unprecedented magnitude, involving ~ 2,05×10^6 m^3 of sliding material. Because the landslide produced significant loss of life and great economic cost, it has generated intense discussion about the possible cause of the slide: 1. Previous drought conditions caused surface crevasses; 2. Unprecedented intense precipitation; 3. Wenchuan earthquake loosened slopes; 4. Historical earthquakes (century ago) and debris leftover; and 5. environmental consequences as population increases (living to previously un-occupied places). Climate warming often is seen as the major cause, by contributing to the severity

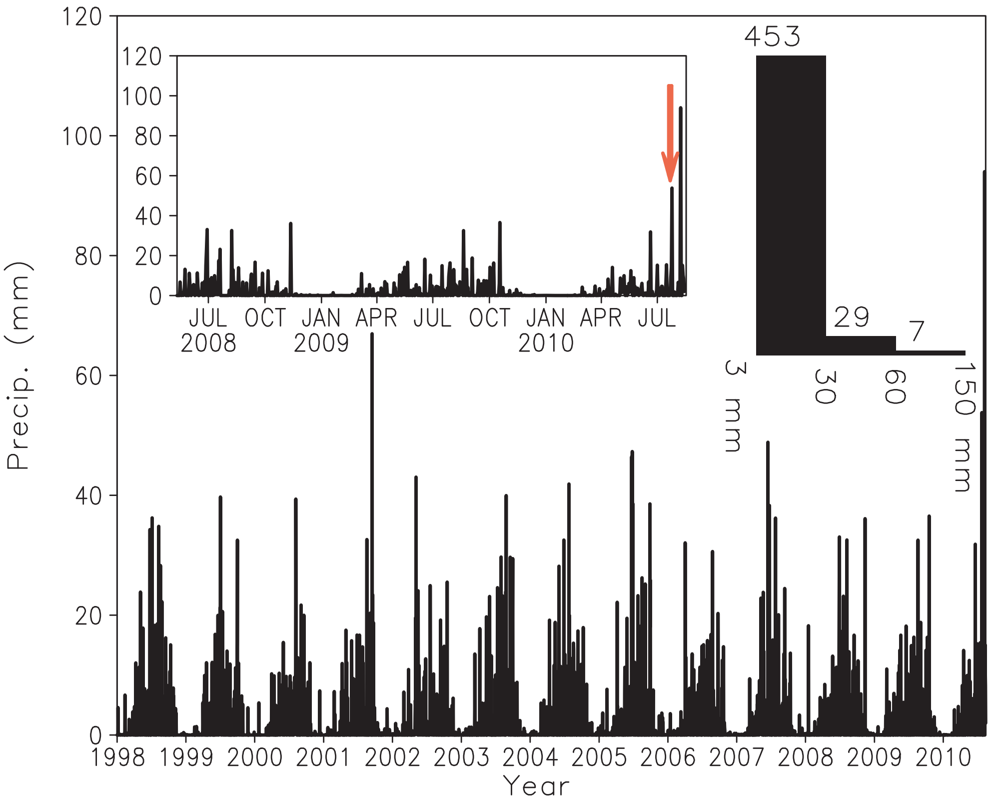

Fig. 1. The daily precipitation time series for Zhouqu (33.875N; 104.375E), for the period January 01, 1998 to August 20, 2010. These are estimated from TRMM (3B42V6, microwave-IR mixed products) 3-hourly precipitation. The last two months are from rain gauge measurements. The left inset is a zoomed-in of the period after the 2008 Wenchuan earthquake. The right inset shows the rainfall histogram based on the landslide triggering rain event analyses proposed by Ren et al. [2010]. Rain events with rainfall totals > 30 mm can trigger significant landslides in the Zhouqu region (see inset histogram). Moreover, in that period, there are 7 events with rainfall totals > 60 mm, which therefore are rainstorms as intense as that which preceded the August 7, 2010 Zhouqu mudslides (the event indicated by the red arrow in the left inset). Thus, extreme precipitation alone does not explain the magnitude of the Zhouqu mudslide

of the rainstorm; others argue that it was the recent drought, which produced cracks in the soil mantle. In addition to its geological uniqueness, because it occurred so soon after the 2008 Wenchuan earthquake, the presence of earthquake-broken bedrock also is cited as a factor contributing to the size of the landslide. A number of factors other than extreme precipitation therefore have been suggested as responsible for magnifying the Zhouqu landslide to its unexpected great size [Ma & Qi, 1997; Yu, Yang & Su, 2010].

To investigate quantitatively the relative importance of the possible causal factors, above-mentioned SEGMENT-Landslides model was applied to the event. SEGMENT-Landslide is a fully three-dimensional dynamical landslide model that incorporates not only soil/rock mechanical properties but also the hydrological and mechanical effects of vegetation on storm-triggered landslides. The model requires a wide variety of input variables, such as land cover, land use and geological data, which were provided by a research group of Beijing Normal University. The digital elevation data were from the Shuttle Radar Topography Mission, SRTM [http://srtm.mgs.gov/], at 90 m resolution. To reproduce historical landslides, we used precipitation forcing from the satellite-based National Aeronautic and Space Administration (NASA) Tropical Rainfall Measuring Mission (TRMM) which has 3-hourly data on a 0,25 by 0,25 degree resolution grid. For surface biomass loading, we used the Moderate Resolution Imaging Spectroradiometer (MODIS) products [Zhao & Running, 2010; Zhang & Kondragunta, 2006]. A team survey of the area also provided a 300 m resolution vegetation mask. To investigate possible mechanisms, we performed several sensitivity experiments with assumed vegetation conditions. Our selected region is 33,66–34,06°N; 104,26–104,66°E. The hilly terrain of this area is composed mainly of metamorphosed limestones, interspersed with altered clay layers. The ground surface rocks range from highly- to completely-weathered. The weathered rocks date from the Paleozoic (primarily the Permian period) and Mesozoic eras, the yellowish inter-bedded sandstone and siltstone date from the Silurian period, and the grey limestones dates from the Triassic period. The infiltration of rainfall through macro-pores, which are well-developed in the soil and rock mass of the Zhouqu region, plays a critical role in slope stability. The hills intersect with canyons in which increased erosion occurs during the highly regular rainy season.

METHODS

Landslides occur irregularly and future research is concerned with more accurate predictions about their timing (when), location (where) and size (how big they will be), and in developing procedures that convey risk and warnings to the public to mitigate damages to infrastructure and ecosystems. Such an effort is critical, particularly in anticipating the effects of climate change on areas prone to instability. Our study is a bellwether in this research direction as it uses a sound physically based predictive technique to assist understanding and informed decision-making. For mudslides, our model will help answer the following key questions. How and when will a particular landslide be initiated? How large will it be? How fast will it move? How far will it travel?

SEGMENT-landslides has been extensively documented by Ren et al. [Ren, Leslie & Karoly, 2008; Ren et al., 2011]. Here we present the governing equations to provide context for the above discussion. For the sliding material, we solved a coupled system for conservation of mass

$$\nabla \vec{V} = 0 \qquad (1)$$

and momentum

$$\begin{cases} \dfrac{\partial \sigma_{xx}}{\partial x} + \dfrac{\partial \sigma_{xy}}{\partial y} + \dfrac{\partial \sigma_{xz}}{\partial z} = \rho \dfrac{du}{dt} \\ \dfrac{\partial \sigma_{xy}}{\partial x} + \dfrac{\partial \sigma_{yy}}{\partial y} + \dfrac{\partial \sigma_{yz}}{\partial z} = \rho \dfrac{dv}{dt} \\ \dfrac{\partial \sigma_{xz}}{\partial x} + \dfrac{\partial \sigma_{yz}}{\partial y} + \dfrac{\partial \sigma_{zz}}{\partial z} - \rho g = \rho \dfrac{dw}{dt} \end{cases} \qquad (2)$$

under the granular rheological relationship, with viscosity parameterized as

$$v = \left(\mu_0 + \frac{\mu_1 - \mu_0}{I_0 / I + 1} \right) \frac{S}{|\dot{\varepsilon}_e|}, \quad (3)$$

where ρ is bulk density, $\vec{V}$ is velocity vector (*u, v* and *w* are the three components), σ is internal stress tensor, and *g* is gravity acceleration. Here ν is viscosity, *S* is the spherical part of the stress tensor σ, μ_0 and μ_1 are the limiting values for the friction coefficient μ, $|\dot{\varepsilon}_e|$ is the effective strain rate and $|\dot{\varepsilon}_e| = (0.5\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij})^{0.5}$, I_0 is a constant depending on the local slope of the footing bed as well as the material properties, and *I* is inertial number defined as $I = |\dot{\varepsilon}_e| d/(S/\rho_s)^{0.5}$, where *d* is particle diameter and ρ_s is the particle density. Soil moisture enhancement factor on viscosity is assumed varying according a sigmoid curve formally as Eq. (9) of Sidle [1992] but with the time decay term replaced by relative saturation.

For considered granular material resting on vegetated slopes, the cohesion provided by the roots are implemented in the full internal stress σ's. The root mechanical properties are prescribed according to the vegetation types of the Zhouqu area. There are different ways to decompose the full stress into spherical and deviatoric components. Only the deviatoric part is assumed to proportional to the strain rate through viscosity, which unfortunately depends also on normal pressure.

As a derivative from Eq. (1), the prognostic equation for surface elevation (*h*(*x, y*)) is

$$\frac{\partial h}{\partial t} + (\vec{V}\nabla_H)|_{top} h - w|_{top} = 0 \quad (4)$$

where $X|_{top}$ indicates evaluated at the free surface elevation. In the case with slope movements, Eq. (4) is solved regularly to update the sliding material geometry. It is also from this equation that we estimated the sliding material involved in the simulated landslides (e.g., Fig. 4).

The viscous term in Eq. (2) implies an energy conversion from kinetic energy to heat. To make a full closure of energy, we need the following thermal equation:

$$\rho c \left(\frac{\partial T}{\partial t} + (\vec{V}\nabla)T \right) = k\Delta T + \frac{2}{\nu}\sigma_e^2 \quad (5)$$

where ***c*** is heat capacity (J/kg/K), ***T*** is temperature (K), κ is thermal conductivity (W/K/m), and σ_e is effective stress (Pa). The last term is 'strain heating', converting of work done by gravity into heat affecting the sliding material by changing viscosity or causing a phase change.

For quantitative predictions of storm triggered landslides, a numerical modeling system like SEGMENT is needed. However, some of the requirements of SEGMENT, especially the input and verification data, generally are not available even in modern geological maps. These parameters include vegetation loading and root distributions in soils and weathered rocks. The extension of the SEGMENT landslide model to other regions is limited primarily by the lack of these high resolution input datasets. The landslide features implemented in SEGMENT, if adopted by the relevant community, hopefully will encourage the collection of such vital information in future surveys.

RESULTS

Figure 2a shows the SEGMENT-Landslide simulated unstable areas, as indicated by the maximum obtainable surface sliding speed. Under the current vegetation regime, the most significant scar is that near the Sanyanyu Valley (33,81–33,87N; 104,36–104,42E). The particular sliding is a characteristic "progressive bulking" [Iverson, 1997] type (Fig. 3). The accumulation area spreads up to 3500 m elevation, in a fan shape with the fan "handle" extending down to the Bailongjian River. The surface runoff essentially is clear water above the 3500 m elevation contour, but at lower elevations gradually becomes turbid and entrains small stones and coarse granular material into the slide streams. These creeks are usually dry except during rainy periods. Figure 4 is an enlargement of the Sanyanyu gully, showing

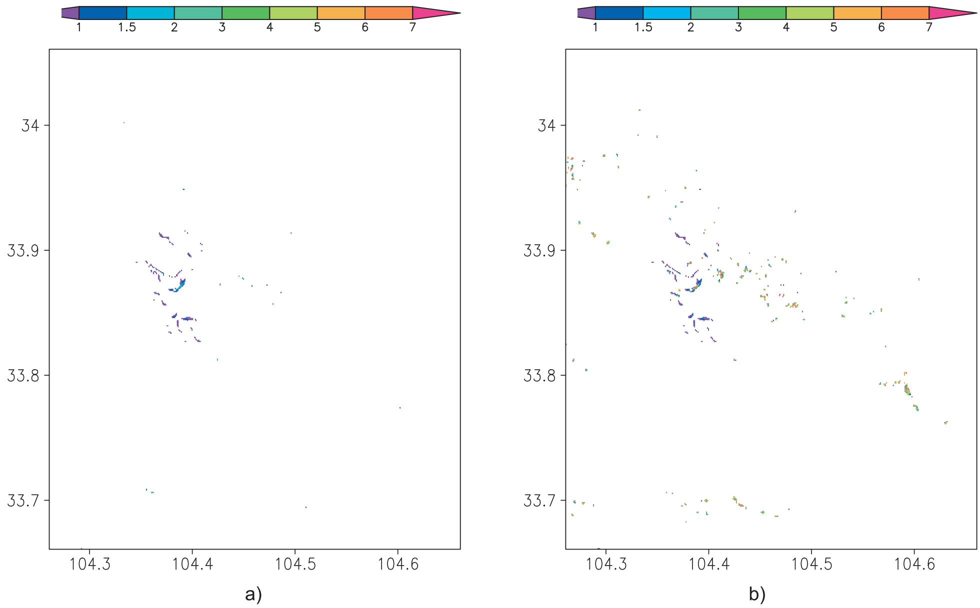

Fig. 2. A detailed comparison of the unstable areas identified by the landslide model. These are areas for which model sliding speeds (m/s) exceeded the threshold value. Panel (a) is with current vegetation. Panel (b) is with vegetation removed. Under current vegetation conditions, only the Sanyanyu area is unstable. When the vegetation is removed, there are many other unstable areas. Moreover, the landslide flow magnitudes are larger than for the vegetated case

the surface elevation changes at two times in the sliding process: the beginning (Fig. 4a) and the cessation (Fig. 4b). At the cessation, the areas indicated by the two red arrows have little elevation change, despite the massive total mass in the slide. They acted like a pathway for the sliding materials at higher elevations. For example, at point A there is a break in the slope where some of the sliding material originated. Over 70% of the sliding material came from the gully banks. Below 2300 m, the solid form of sliding material is continuous in nature and the entrainment effects are so significant that boulders (>50 cm

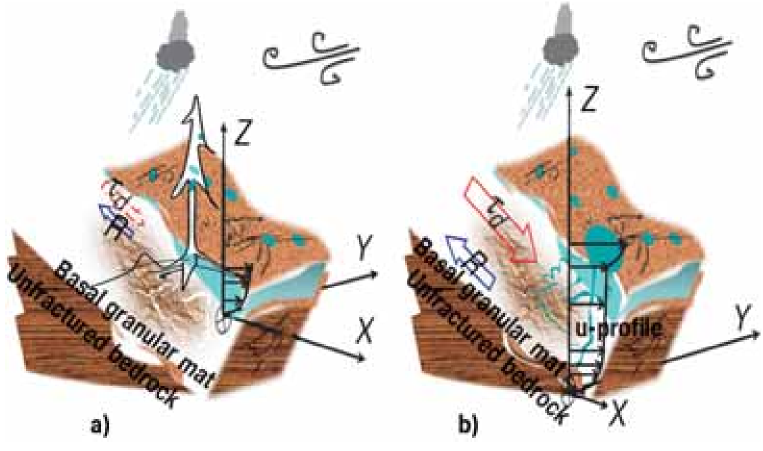

Fig. 3. A characteristic storm-triggered landslide (debris flow). This is a plane view of the entire (solid material) collection basin. The elevation divisions are only for reference. The section with concentrated solid material creeping is only a small portion of the entire area. This means of mass redistribution is referred to as "progressive bulking"

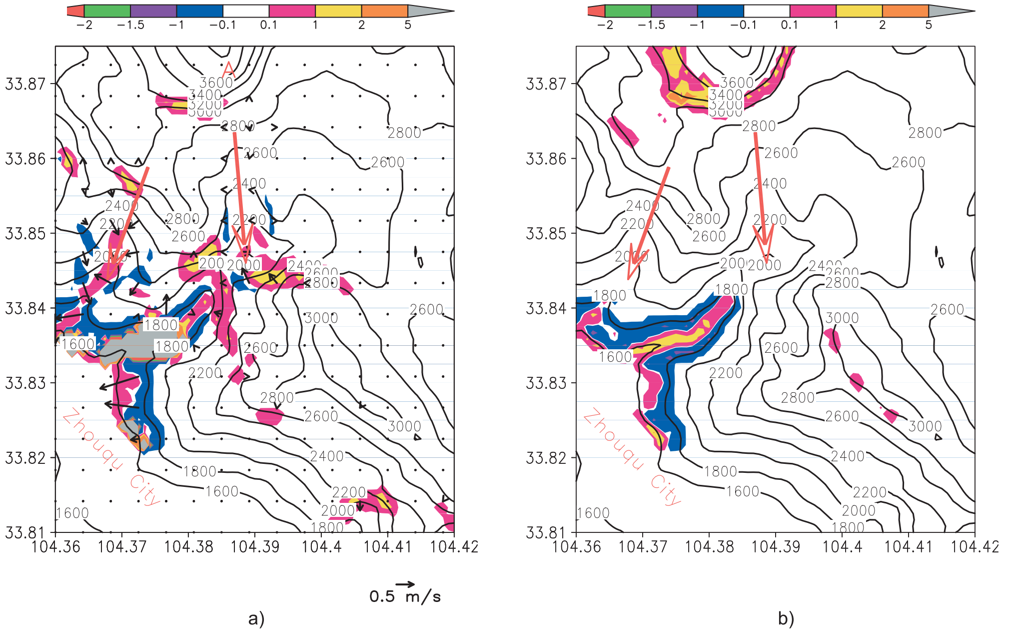

Fig. 4. The Sanyanyu gully area. Panel (a) shows the elevation changes (m) in color, at 9 minutes after the August 7th heavy rainfall event. Mud sources are clearly shown in the left panel. Its final deposition is shown in Panel (b) approximately an hour later. The flow has ceased and the deposition is in the Zhouqu city area, via the two parallel gullies. Elevation changes of the creeks (two red arrows) are small and act primarily as pathways for the sliding material. Note the break/failure of the 3400 m elevation contour, indicating the provision of sliding material for the next sliding cycle

in diameter) are relocated down the slope. The thick mud has a viscosity of about 100 Pa・s and the peak sliding speed reaches as high as 2 m/s. A total of 2,05×10^6 m^3 of solid sliding material was involved in this slide and was spread over an area of about 3,2×10^6 m^2.

Figure 4 uses the actual vegetation coverage of the area. If we assume the entire region is bare of vegetation, SEGMENT-Landslide identifies the following "hot-spots" as unstable (Fig. 2b): (33,773N, 104,375E); (33,347N, 104,412E); (33,77, 104,35), (33,79, 104,38) and (33,965, 104,105). In reality, only the Sanyanyu Valley slid significantly. The model makes it clear that the light vegetation cover over Sanyanyu is the main reason for such a large scale outbreak of debris flows. In turn, the light vegetation cover may have arisen from a positive feedback inherent in successive historical landslide deforestation [e.g., Bolt, Horn, Macdonald & Scott, 1975].

Repeated landslides, usually of smaller scale, were investigated in SEGMENT-Landslide simulations using historical TRMM archived precipitation. They show that the rainy seasons of 1998, 2001, 2008 and 2009 all produced landslides capable of destroying the existing vegetation cover. Lighter vegetation cover lowers the criteria for subsequent landslides. This self-propagating mechanism has no lower limit before leveling the slope to below the granular material repose angle.

In the Zhouqu area, the shear zone depth is variable and depends on the quantity of water penetrating into the crevasses. For bare ground (e.g., covered by previous landslide deposits or rockfalls caused by historical earthquakes), runoff readily drains into the crevasses, moistens the granular material and forms a shear zone at the bottom (the lowest reaches of the crevasses). Vegetation cover reduces surface runoff through canopy

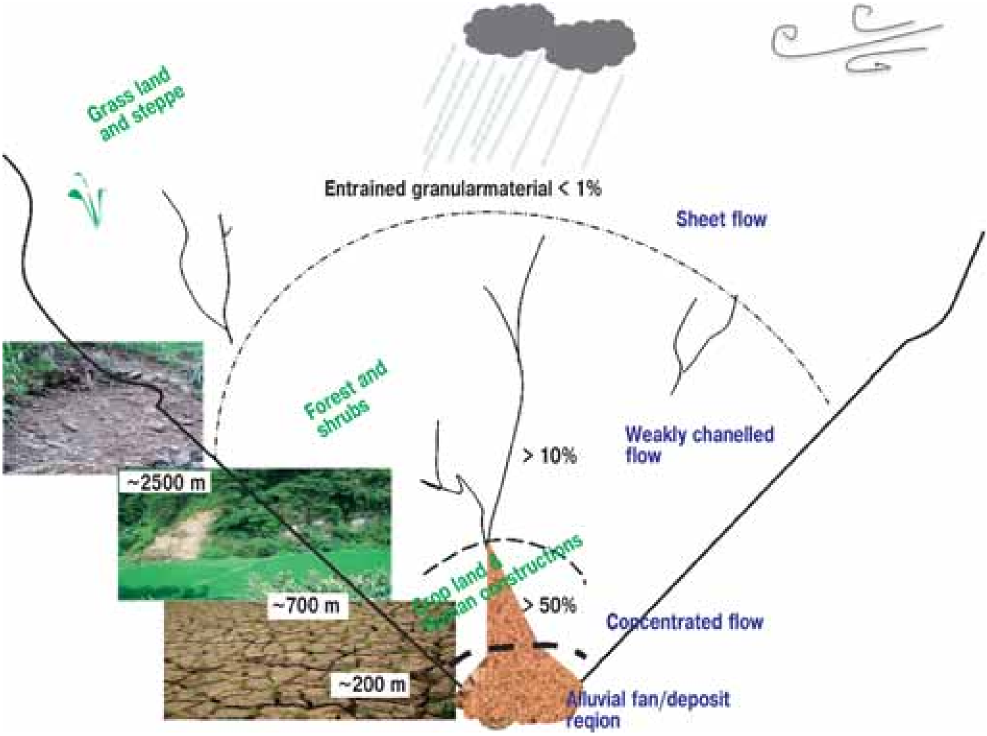

Fig. 5. Diagram showing vegetation effects on storm-triggered landslides. Panel (a) is the case with vegetation and panel (b) is the case void of vegetation. All else being equal, with vegetation, a proportion of rainfall goes into canopy interception (canopy runoff) and runoff and surface ponding are reduced as a consequence. Vegetation also effectively prevents water infiltration into deeper depth. Thus less sliding mass is involved in the vegetated case (the blank arrows show the magnitude of bulk resistive and driving stresses). In the illustration, *R* means resistive stress and τ_d means driving stress

interception. Roots also assist in the retention of water within the rhizosphere. Thus, with vegetation cover, runoff water cannot be effectively channeled into the crevasses and much less sliding material will be involved in the landslide (Fig. 5). The cohesion of the granular particles (loam soil, pebbles from fractured grey lime-stones, and sands) are of the order of 0,1 Kpa, far less than the root strength (~10 Kpa).

The presence of aboveground vegetation introduces the following effects: aboveground biomass loading (gravitational), growing season soil moisture extraction by live roots (hydrological), fortification of the soil within its extension range (mechanical), changing chemical environment of the soils through life processes (e.g., respiration, absorption of minerals selectively and secretion of organic substances) and therefore the bond strength among unit cells (chemical), and wind stress loading (meteorological). The overall effects are the interaction of the above factors and it is difficult to generalize before a detailed analysis is carried out that is specific to a certain situation. For example, the fortifying roots have yield strength larger than dry soils and the existence of roots is commonly thought to increase the resistance of soils. However, the presence of roots, especially when there is precipitation, also facilitates water channelling into deeper depths. After the soil is moistened, the cohesion between soil and the root surface is reduced greatly (to negligible strengths <0,001Mpa, [Lawrence et al., 1996]) and the root strength cannot be effectively exerted. Also, the effect of roots is to 'unify' the soil particles within root distribution range. Once the entire rhyzosphere soil layer is saturated, the fortifying effects will be totally lost.

Table 1. Root strengths of two plants growing in similar environmental conditions [Cartina, personal communication 2012]. Samples are taken at Duron Valley (46° 29'37'' N, 11° 39'25'' E) of Italy

	Root type	Diameter (mm)	Failure tensile force (kg)	Deformation ratio (%)	Tensile strength (MPa)
Juniper	Ephe. Absorb	2.9	1.9	3.9	2.87
	Woody trans.	8.6	140	3.7	24
	Structural	12.1	130	2.8	11.3
Swiss Stone Pine	Ephe. Absorb	5.1	21.6	3.6	10.5
	Woody trans.	9.3	120	6.8	17.6
	Structural	12.6	169	2.8	13.5
	Structural	13.9	195	8.8	12.9

Thus, a more accurate statement would be "the reinforcement effects from roots are an effective mitigating factor for shallow storm-triggered debris flows". It is known that shallow interlocking root networks can contribute to mechanical reinforcement to soils [Sidle et al., 1985; Selby, 1993; Lawrence et al., 1996]. For a pasture species, Selby [1993] estimated the 'additional' cohesion ranging from 0,1 to 9,8 kPa, with changes in soil moisture. There are also experimental tests on root strength for a variety of species (Table 1).

In SEGMENT-Landslide, because roots occupy a small fraction of the soil volume, the root reinforcement can be factored in as an added stress over the case of no root presence. As not only tensile strength but also the cross-sectional areas (thickness of roots) are critical, we propose the following 'allometric' approach that uses 'root weight density' and vegetation type to characterize the added tensile strength to the soil medium shear strength and elevated yielding criterion.

$$\sigma^{+} = C_{smc} \sum_{i=1}^{3} \sigma_i F_i(NPP, I_{veg}, Pa, T_{air}) \quad (6)$$

where σ^{+} is the root mechanical reinforcement (kPa), C_{smc} is soil moisture control (0–1), index i differentiates woody transport roots, woody supporting roots and ephemeral absorbing roots, σ_i (kPa) is a root species-dependent reference value (i.e., tensile strength of xylem of roots, varies from 10 to 30 MPa for most plants), *NPP* is net primary production ($kg/m^2/yr$), P_a is annual precipitation, T_{air} is annual mean air temperature, and I_{veg} is species-dependent reference *NPP* value. *F* varies from 0 to 1 represents the weight fraction of roots in a unit volume of soil (within range of influence of the roots). Value of *F* usually is close to 0,2%. The functional form of C_{smc} can be tabulated according to soil type. The modifications from climate conditions are necessary because same plants have very different strategy in allocating biomass when living in different clime zone.

Thus the mechanical effects of the roots also contribute to slope stability. We performed an additional set of sensitivity experiments to further investigate the importance of vegetation in reducing the magnitude of landslides. If the Sanyanyu Basin had been covered 70% by shrub of negligible biomass loading, with root strength of 0,1 Mpa, and coarse root (diameter >1 mm) density of 2 m^{-2} all residing within the top 2 m of soil, the amount of sliding material would be only $1{,}1\times10^6$ m^3, or about half the actual volume involved. If there is a closed cover (that is, 1,0 vegetation fraction), the sliding material can be further reduced to 10^4 m^3, and primarily involves only pebbles and protruding boulders at lower elevations. These experiments underline the critical role of vegetation in reducing the magnitude of the "progressive bulking" types of storm-triggered landslides.

Importantly, loss of vegetation has occurred not in recent 10 years and there actually

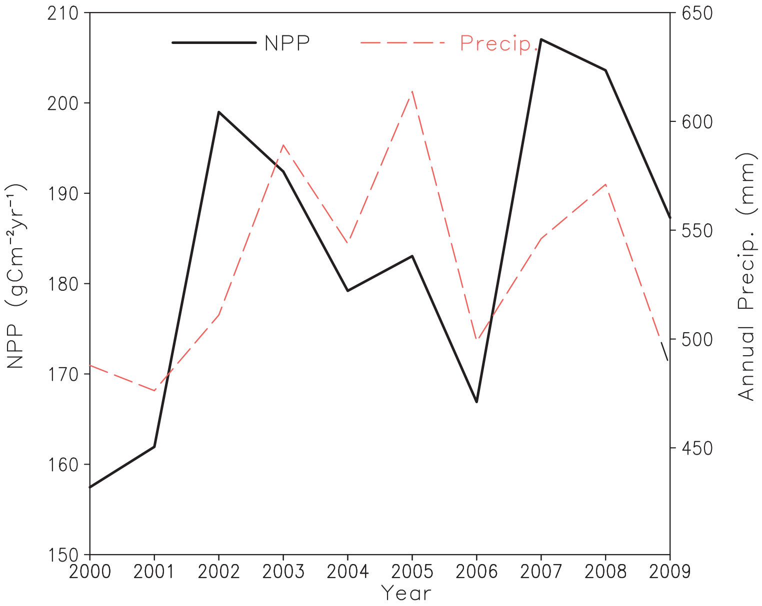

Fig. 6. The annual Net Primary Production (NPP) and precipitation over the past decade for the region of interest (33.66-34.06N; 104.26-104.66E). The 1 km resolution MODIS NPP products are obtained from M. Zhao. Precipitation data is from gauge station near Zhouqu (data obtained from Beijing Normal University). NPP quantifies the amount of atmospheric carbon fixed by plants and accumulated into ecosystem as biomass. Upward trend in NPP indicates a healthy ecosystem (vegetation is getting denser or in growing stage) or climate constraints getting relaxed. As expected, NPP match closely with annual precipitation. Discordances in 2002 and 2008 may correspond to landslide disturbance of the vegetation. The 2008 perturbation possibly is related to the Wenchuan earthquake. In the past decade, the NPP has a rising trend, indicating the vegetation cover is gradually becoming denser

are clear signs that local vegetation cover has been increasing (Fig. 6, also in [Zhao & Running, 2010]). Because the 2008 Wenchuan earthquake has deepened the crevasses within the soil mantle and the bedrock, the criteria for storm-triggered landslides are significantly lowered. Large landslides did not occur before 2008 because, previous storms, although can be equally intense and have even larger total amount (e.g., Sept. 4, 2001), could not infiltrate into deeper shear zone, without the help of the earthquake's tearing of the bedrocks. Large landslides did not occur during the past two years because the threshold precipitation intensity and total was not reached (the past two years are relatively dry as indicated by total annual precipitations: 500 for 2008 and 480 mm for 2009 respectively, see Fig. 6). The landcover in August 2010 therefore was unable to prevent landslides caused by an intense rainstorm, owing to the legacy of the 2008 Wenchuan earthquake. The sealing of the cracks caused and/or deepened, by the Wenchuan earthquake is slow process occurring on a timescale of several decades. Thus, a program of rapid restoration of the vegetation cover over the Zhouqu area is urgently required for re-building that region. The climate of that region, with an annual precipitation over the last 40 years is only 435 mm/yr, suggests the priorities are the restoration of forest on the north facing slope and of a seamless grass cover for the south facing slopes.

The Sanyanyu deep valley has much coarse granular sliding material, particularly stones and boulders, because of a self-accumulation mechanism originating from its specific topographical features and because its loamy soil mantle is more easily dissected by running water. Topographically, the creeks in the valley have 'graded river beds' because the upper parts (near peaks) are steeper than the lower parts (close to the toes).

Thus the upper river bed slopes are larger than the lower river bed slopes. For lighter precipitation events, the stones and pebbles cannot roll directly to the toe, stopping at mid-slope and creating natural barriers to the sliding material that follows (see the red blobs in Fig. 4). These accumulations apply to small slides, typically caused by low to moderate precipitation events. They have occurred at least five times during the past two years: in August, 2008; May, 2009; June, 2009; July, 2009; and September, 2009. However, when intense precipitation occurs, as in August 2010, all accumulated material will be activated and a disastrous event will be generated. Recent studies (Ma & Qi, 1997; Yu, Yang & Su, 2010) indicates that granular material accumulated after the 1879 Wenxian earthquake [Bolt, Horn, Macdonald & Scott, 1975] was involved as the major debris. This supports the progressive bulking mechanism. Because previous landslides, lacked the unfortunate combination of the rainfall intensity, earthquake and poor vegetation coverage, they fail to move the solid material of the Wenxian earthquake to the Bailongjian River.

DISCUSSIONS

On August 8, 2010 in the northwestern Chinese province of Gansu, 1765 people died or lost when a debris flow devastated the small county of Zhouqu. Our modeling study suggests that the cause is the result of an intersection of natural and human-induced events. The natural events include a heavy rainstorm, not necessarily the result of global warming, which triggered the landslide and followed a drought that created surface cracks and crevasses; the geology of the region; and the bedrock damage, which deepened the surface crevasses, inflicted by the 7,9 magnitude Wenchuan earthquake of May 12, 2008. The human contribution was historical (before 1990) deforestation and topsoil erosion. Consequently, Zhouqu became vulnerable to a devastating rainstorm-triggered landslide. The model confirmed the cause of the landslide by producing a rain-triggered mudslide far larger than historical landslides. The landslide was magnified by prior vegetation loss and by water penetration deep into the cracks and crevasses created by the Wenchuan earthquake. The recent findings [Ma & Qi, 1997; Yu, Yang & Su, 2010] that solid granular material from a historical earth quake 130 years ago was involved in the debris flows further confirm our hypothesis. It is not that the rainfall intensity is of 100 year recurrence frequency (it actually is only of 20 year recurrence frequency, according Generalized Extreme Value analysis, a likelihood of 42% occurrence in the upcoming 10 years), but because the combination of strong precipitation with poor vegetation and recent earthquake enhancement of the crevasses is lacking in the past century. Previous debris flows, of smaller scale, fail to transport the granular deposits to stable locations. It also reflects the difficulty in re-vegetating the landslide scarps and even the granular deposits for the region, due to the climate.

The massive Zhouqu landslide of August 2010 was caused by an extreme precipitation event, but was magnified by the Wenchuan earthquake of May 2008 which greatly deepened the pre-existing cracks (either from historical earthquake or more gradual erosion processes) in the ground surface. For such surfaces, intense precipitation events favor the channeling of runoff water to greater depths than usual, creating sliding surfaces at those depths. Thus, more sliding material was involved than for a less intense rainstorm. Vegetation is very effective at holding drainage water in the rhizosphere and reducing drainage into deeper levels, but the severe vegetation loss in the Zhouqu region prevented the vegetation cover from playing a protective role in reducing the critical impact of the hydrological process of deep level drainage.

The modeling results underscore the urgency for a high priority program of re-vegetation of Zhouqu county, without which the region will remain exposed to future disastrous, 'progressive bulking' type landslides. A direct cause of the large magnitude of the 2010 debris flow is the loss of historical deposits and the undercutting of loose gully bed. Re-vegetation of the areas with historical deposits is a priority. Thus, engineering approaches, such as installing check dams, slope protectors, and leveling gullies, should be followed by re-vegetation, because, restoring the current vegetation cover to its natural, much denser state is the most effective long-term approach to landslide mitigation.

CONCLUSION

The Earth's climate currently is in an interglacial period that possibly will continue for another 50 kyr [Berger & Loutre, 2002] without human alteration. Since the 1970s, however, the Earth's climate has steadily warmed and shows no signs of slowing. With the enhanced hydrological cycle [Ren et al., 2011], more extreme weather conditions are expected. The precipitation has a 20-year recurrence frequency, as calculated from projected climate change. A disaster of the same magnitude as 2010 is expected within ~20 years if no effective counter measures are taken.

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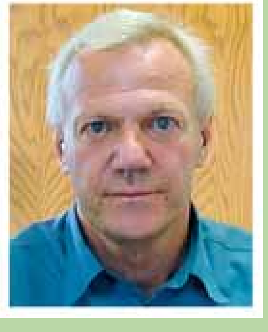

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A CONCEPTUAL VIEW ON ECOTOURISM DEVELOPMENT IN CRIMEA

ABSTRACT. A potential of Crimea for ecotourism development is discussed and the key stakeholders are defined. The main obstacles for the implementation of the ecotourism concept are analyzed and recommendations are provided based on integration of institutional, infrastructural, marketing, and educational components. Prospective regions for pilot projects on ecotourism development are outlined and priority actions defined.

KEY WORDS: ecotourism, sustainable tourism, Crimea.

INTRODUCTION

Crimean peninsula possesses a unique combination of natural and cultural heritage represented by more than 160 natural protected areas of different categories, around 11,5 thousand cultural and historical sites, and ethno-cultural mosaics of nearly 130 ethnic groups [Bagrov, Rudenko, 2003; Council of Ministers..., 2011]. Mountainous Crimea has been recognized by Ukrainian and international experts as a hotspot of biodiversity and landscape diversity of international significance [Biodiversity Support Program, 1999]. Being located for centuries on the crossroads of trade routes, Crimea inherited a unique system of antique and medieval trade pathways and mountain roads which could be considered as a special category of cultural heritage. The combination of natural and cultural heritage provides for potential for ecotourism development, especially in Mountainous and Pre-Mountainous Crimea. South-western Crimea is among the most prospective regions of Crimean peninsula for ecotourism development in the administrative boundaries of the city-region of Sevastopol that has an area of 900 sq. km with 32% of its territory covered by natural protected areas, where *zakazniks* (IUCN category IV) dominates.

THE ECOTORISM DEFINITION AND ITS MAIN COMPONENTS

Ecotourism belongs to a broader concept of sustainable tourism and has been recommended as an appropriate form of tourism activities in valuable natural sites, including protected areas, by leading international organizations such as IUCN, UNEP, UNWTO [Eagles et al., 2002; Rasin Yu. et al., 2004]. A clear definition of ecotourism has been proposed in the 1990s by the International Ecotourism Society that defined ecotourism as a *"responsible travel to natural areas that conserves the environment and improves the well-being of local people"* [The International Ecotourism Society]. Other definitions that exist in the literature follow the general concept of ecotourism which is based on

- ✓ Responsibility of travelers due to education and awareness raising component (interpretive materials, visitor centers, education on the trails, etc.), when "the prime motivation is the observation and appreciation of natural features and related cultural assets..." [UNEP, 2002].
- ✓ Establishment of the mechanism of partial redirection of the generated by ecotourism profit towards sustainable

management and protection of the natural protected areas which serve as a primary destination for ecotourists (including biodiversity and landscape diversity conservation campaigns).

✓ Contribution to sustainable development of the local communities and conservation of local and regional cultural diversity (including tangible and intangible cultural heritage).

These components combined together define the essence of ecotourism; compromising any of the components can lead to a misuse of the term "ecotourism," mislead the customers, and ultimately undermine the successful ecotourism development [Eagles et al., 2002; UNEP, 2002].

EXPECTED BENEFITS FROM ECOTOURISM DEVELOPMENT IN CRIMEA

The development of ecotourism in Crimea in a careful and corresponding to its definition and concept way can bring such benefits as:

- Diversification of tourism activities and development of brand new tour products in the region.
- Extension of the tourism season in Crimea due to attraction of ecotourists in the autumn, winter and spring seasons, out of the summer peak of tourist loads.
- Development of system of visitor management and redirection of the tourist flows both spatially and temporally in coastal and mountainous regions; balancing the increasing tourism flows with goals of protection of natural and cultural heritage.
- Optimization of the tourism activities in the mountainous forest areas via involving the "left aside" mountainous forest and pre-mountainous regions.
- Support and optimization of management of the Crimean protected areas including a mechanism of co-financing and obtaining additional resources (informational, volunteers, etc.) for sustainable management of the protected areas.
- Promotion of sustainable social-economic development in the rural territories adjusted to the areas.
- Rehabilitation of the existing trails network and development of the interconnected and sustainably managed system of ecotrails and visitor-centers as essential elements of the ecotourism infrastructure.
- Raising awareness of the local Crimean population on values of the regional natural protected areas and natural and cultural heritage.
- Raising level of knowledge and awareness among tourists and visitors on Crimean natural and cultural heritage.
- Creation of a unique image of Crimea for potential investments into "green" spheres: the niche forms of tourism such as ecotourism, heritage tourism, ethno-tourism, vine tourism, etc., into renewable energy sector and other green businesses.

A HISTORICAL OUTLINE OF ECOTOUIRMS IDEAS DEVELOPMENT IN CRIMEA

In Crimea, scientifically-based proposals similar to the modern ecotourism concept were developed at the end of the 1980s. One of them is the creation of Tavrida National Park in Mountainous Crimea covering the area from the Sevastopol region in the south-west to Kara-Dag region in the south-east [Tavrida Natural National Park]. The loop "Big Crimean Ecotrail" on the edge of the National Park was proposed; it would be nearly 500 km long and would have radial trails based on a well-developed, during the Soviet period, hiking trails network. However, due to political and economic instability of the 1990s, the National Park concept was not

Table 1. Key stakeholders for ecotourism development in the Autonomous Republic of Crimea (ARC)/Sevastopol city-region

Organization	Sector	Relevance to ecotourism development
The Republican Committee of the ARC on Forest and Hunting Service / Sevastopol State Forest and Hunting Service	GO	Management of the forested areas in Mountainous and Pre-Mountainous regions of the Autonomous Republic of Crimea / Sevastopol region and management of recreation in the forests, including trails marking and visitor management
The Ministry of Resorts and Tourism of the ARC / Sevastopol Department on Culture and Tourism	GO	Development and implementation of governmental policy on tourism in the Autonomous Republic of Crimea / Sevastopol region
The Republican Committee of the ARC on Environmental Protection / Sevastopol State Department of Environment and Nature Resources	GO	Monitoring of the state of environment in the Autonomous Republic of Crimea / Sevastopol region, particularly, control over the protected areas management and limits for visitors and tourists in protected areas
The Ministry of Emergency of Ukraine Branch in ARC/Sevastopol (Mountain Rescue Department) and Crimean/Sevastopol Rescue Service	GO	Safety control for visitors and tourists and rescue operations, particularly in Crimean Mountain area and coastal areas
Crimean Association of Tourism Agencies	NGO	These associations connect leading Crimean tour-operators, tour-agencies, tourism oriented businesses, and non-governmental organizations that are focused on marketing of Crimea as a destination
Association of Tour-Operators of Crimea and Sevastopol	NGO	
V.I. Vernadsky Tavrida National University	S	Education in the sphere of tourism and environmental management with the focus on sustainable practices. Research and practical recommendations on sustainable tourism development in Mountainous and Pre-Mountainous Crimea
M.V. Lomonosov Moscow State University Branch in Sevastopol	S	
Tour-Operator SNP-Crimea	B	One of the leading Crimean tour-operators that promotes hiking tours in Mountainous and Pre-Mountainous Crimea. Since 2005, has been initiating conferences, meetings, and partnerships on nature-based active tourism in Crimea
Tour-Operator Comandor	B	One of the leading Crimean tour-operators that promotes innovative nature-based tours in Mountainous and Pre-Mountainous Crimea
Tour-Operator Priklyuchenie	B	One of the leading Crimean tour-operators that promotes a wide spectrum of active tours in Crimea
Crimean Mountain Club	B	Historically, one of the oldest associations developing nature-based active (and currently extreme) tours in Crimea
USAID LINK	IO	Conducted a series of workshops on active and heritage tourism as well as other types of tourism development in Crimea; established a network of Tourism Information Centers
US Forest Service, Office of International Programs	IO	Conducted several workshops on ecotourism, recreational site planning, visitor management, and sustainable forest management in July, 2012
EU Crimean Diversification and Support Projects	IO	Focused on institutional, educational, and marketing support of tourism development in Crimea, including ecotourism

B – Business, GO – Governmental Organization, IO – International Organizations,
NGO – Non-Governmental Organization, S - Science

realized. In the Sevastopol region, the "Project on the Concept of Ecotourism Development in the Sevastopol Region up to 2020" was developed in 2004 [Rasin Yu. et al., 2004], but political controversies of 2005–2006 did not allow the project to become a reality. Currently, there is an environment in Crimea when ideas of ecotourism development got sound support among key governmental stakeholders, NGOs, scientists, interested tour-operators, private sector representatives, and international organizations (Table 1).

MAIN OBSTACLES ON THE WAY OF ECTOURISM DEVELOPMENT IN CRIMEA

Analysis of the current state of ecotourism development in Crimea demonstrates that there are obstacles that significantly slow down the process. These obstacles could be divided into three categories: Institutional, Infrastructural and Marketing, and Educational.

Institutional

- Unclear definition of ecotourism in the Ukrainian Law on Tourism and the regional (Crimean and Sevastopol) programs on tourism development: its definition or meaning does not correspond to the internationally recognized understanding of the ecotourism concept or the definition is blurry.

- Absence of an up-to-date concept and programs on ecotourism development in the Autonomous Republic of Crimea and the city-region of Sevastopol.

- Unsettled and unclear process with defining of carrying capacities (limits of number of visitors per season) and getting permits for recreational use in the protected areas.

Infrastructural and Marketing

- Underdeveloped ecotourism infrastructure: lack of ecotrails signage, lack of visitor-centers and criteria/standards on visitor centers functions; lack of places of accommodation (eco-lodges, green mini-hotels) and food services (organic product markets, organic cafes, and organic ethnic restaurants).

- Absence of long-term recreational site planning and visitor management plans.

- Existing hiking trails network inherited from the Soviet time needs renovation and categorization with conversion of selected trails into the system of ecotrails.

- No carefully developed ecotourism packages and weak marketing of Crimea as an ecotourism destination on the Ukrainian, Russian, and international tour markets as a separate or combined (heritage, active, wellness, etc. tours) ecotourism tour-product.

Educational

- Lack of qualified specialists in the sphere of ecotourism.

- Lack/absence of professional and certified ecotour guides.

  Cause:

  - Few programs and special courses on ecotourism offered by Crimean and Sevastopol universities, and educational and training centers.

- Lack of understanding of ecotourism perspectives among tour-operators and knowledge on ecotourism capacities among protected areas management agencies that lead to conflicts between tourists and foresters in the mountain forest areas; lack of understanding how ecotrails and visitors center should looks like and how they can help manage visitor/tourists flows.

- Unclear understanding/misunderstanding of the ecotourism concept by responsible governmental officials and tour-operators, misleading tourists by mixing ecotourism with rural, green, active, nature, geo, etc., types of tourism.

Cause:

- Few/if any trainings and workshops on ecotourism exist for governmental officials, protected areas managers, NGOs leaders, tour-operators, and tourism business sector representatives.

- Lack of international experience on eco-tourism development among tourism professionals in Crimea and Sevastopol.

- Lack of developed environmental education mechanisms for visitors/ tourists.

- No integrated electronic resource (portal) on ecotourism exists in Crimea. Available electronic resources on nature-based tourism (including ecotourism and active tourism) are at a different stage of development.

- Lack of coordination between existing courses, trainings, and workshops with the nature tourism component.

RECOMMENDATIONS

A set of recommendations has been proposed to overcome the obstacles.

Institutional

- Development of the integrated concept and strategy on ecotourism in the Autonomous Republic of Crimea and the city-region of Sevastopol:

  – conducting expert group meetings with invitation of regional experts and international experts from the regions that are successfully developing ecotourism products (e.g. Republic of Cyprus, Slovenia, etc.)

  – setting guidelines for the concept and strategy.

- Development of the Law on Ecotourism and amendments on ecotourism to the current Law of Ukraine on Tourism.

- Development of regional programs for ecotourism development in selected pilot regions with a potential for ecotourism development.

Infrastructure & Marketing

- Marking of several pilot ecotrails and development of a brand new trail marking (signage) according to both Ukrainian and international standards.

- Creation of several visitor centers in selected regions with a potential for ecotourism development in partnership with the Crimean and Sevastopol Forest Service and protected areas administrations. The visitor centers could serve, in the future, as model examples for proliferation in Crimea.

- Sharing the best international practices on places of accommodation (eco-lodges, mini-hotels, etc.) and food services (organic food markets, organic cafes, etc.) as elements of an ecotourism product.

- Development and marketing of ecotourism packages on Ukrainian, Russian, and international tour markets:

  – for the Sevastopol region: combined ecotours with inclusion of hiking, horseback riding, biking, sea kayaking, elements of heritage tourism, rural tourism, and wellness tourism

  – for the Autonomous Republic of Crimea: combined ecotour-packages specific for selected destinations.

- Defining the target audience and finding the best ways of marketing the created ecotour-packages.

Educational

- Conducting a project on education of a team of certified ecotour-guides (education for trainers with the focus on gaining practical experience) who will be able to educate new teams of ecotour-guides with the involvement of Ukrainian and international ecotourism experts and practitioners.

- Initiation and assistance in development of the focused short-term trainings based on the blended education principles (on-site education combined with innovative on-line education) for such target audience as:
  - educators from Crimean and Sevastopol universities, colleges, and educational centers
  - managers of the Crimean and Sevastopol tourism enterprises
  - protected areas managers, forest service managers, and representatives from organizations involved into management of protected areas in Crimea and Sevastopol.
- Preparation and conduct of a series of trainings and workshops on different components of ecotourism and natural tourism for focused groups, for example:
  - planning of ecotourism activities
  - risk management in ecotourism
  - best practices on ecotourism development in the EU countries.
- Development of several connected visitor centers and training the visitor centers personnel.
- Organization of educational tours for target groups of Crimean and Sevastopol tourism professionals who are interested in ecotourism development in Crimea, to the countries and regions with similar to Crimea landscapes that are successfully

Table 2. Key regions selected for the pilot projects on ecotourism development in Crimea

Region	Priorities defined for ecotourism development
Sevastopol region	• development of the regional ecotourism concept • development of a visitor center based on the Sevastopol Forest Service facilities in Laspi Valley) • marking of the proposed 5 loops and 1 radial ecotrails • training of team of ecotour guides in the autumn-winter of 2012–2013 • trainings for foresters on ecotourism aspects • marketing of planned ecotourism packages for Ukrainian, Russian and EU tour markets • development of a thematic web-site on ecotourism • promotion of south-western Crimea as a brand new ecotourism destination.
Kara-Dag Reserve area	• creation of a new visitor center in Kara-Dag Reserve • establishment of boundaries for the Reserve buffer zones and development of plans for buffer zones sustainable management • redirection of the tourism flows via new ecotrails marking in adjacent Echki-Dag and Meganom areas • marketing of scientific ecotours on EU tour market
Opuk Reserve area	• development of the concept of "ecotourism triangle" in south-eastern Crimea: Kara-Dag Reserve area – Opuk Reserve area – Kazantip Reseve and Karalarskay steppe area • marketing of thematic tours with the focus on birds-watching and heritage tours • development of a new visitor center • modernization of the Reserve web-site.
Stary Krym-Sudak-Novy Svet area	• development and marketing of a new destination for ecotourism and heritage tourism • development of combined eco/heritage/rural tourism tours and their marketing • marking of ecotrails (Tarak Tash, Baka Tash, and nearby areas) • development of a visitor center in Dachnoe village • development of innovative camping sites for motor-homes
Chatyr Dag-Demerdji area	• development of a Salgir Valley ecotourism destination • development and marketing of combined tour-packages that would include hiking, horseback riding, mountain biking, and speleo-tours in Marble Cave and Kizil Koba Cave • development of a visitor center in Dobroe village

developing ecotourism, e.g. Cyprus, Slovenia, Italy, and France.

- Development of an interactive on-line platform on ecotourism focused on education and awareness growth, information dissemination, best practices sharing in Crimea and Sevastopol, with the use of existing web-sites/portals, e.g. web-sites of the Crimean/Sevastopol Forest Service, Ministry of Tourism and Resorts, Ministry of Emergency, interested universities: Tavrida National University, Moscow State University Branch in Sevastopol, and tour-operators.

SELECTION OF SITES PROSPECTIVE FOR ECOTOURISM DEVELOPMENT IN CRIMEA

According to the proposed recommendations, a set of criteria has been developed for the selection of sites prospective for pilot projects on ecotourism (Annex 1). Based on the criteria, five regions have been selected and visited in the summer of 2012 by a team of experts to evaluate the potential of the territories for ecotourism development; a set of priorities has been defined (Table 2).

EXPECTED OUTCOMES OF THE PILOT PROJECTS ON ECOTORUISM DEVELOPMENT IN THE KEY REGIONS

- The combined concept on ecotourism development for Crimea and Sevastopol[1] will be established forming the optimal Integrated Crimean Ecotourism Model (ICEM). Regional strategies and programs will be developed for selected regions[2].

- New packages will be created for different categories of ecotourists with the focus on benefits of coming in the spring and autumn seasons and marketed for Crimean, Ukrainian, and international tour markets using existing institutional basis, created elements of infrastructure, and trained staff.

- Pilot ecotrails will be marked and equipped with signs and information placed along the ecotrails in innovative and understandable format and in an environmentally friendly way.

- Recreational site plans will be developed with the strategic vision of visitor management and protected areas sustainable management for the areas of proposed ecotrails.

- Pilot visitor centers will be established as trailheads and/or nodes of the ecotrails, equipped with interpretive information and resources (guidebooks, interpretive maps, information stands, etc.), provided with a trained staff.

- Special medium-term practical and regional specific training course on ecotour-guides education will be developed based on blended on-site and on-line education by the Educational and Training Consortia.

  – potential participants from Sevastopol: Sevastopol Forest Service, Moscow State University Branch in Sevastopol, Sevastopol Tourist Club, Sevastopol Rescue Service

  – potential participants from the Autonomous Republic of Crimea: Crimean Forest Service, Tavrida National University, Crimean Mountain Club, Ministry of Emergency

  – other educational, business, governmental and non-governmental bodies interested in ecotourism development in the region.

- Teams of selected trainers educated as ecotour-guides will start activities including guiding groups of visitors/

[1] The combined concept will allow putting together ideas of Sevastopol and Crimean experts and the contribution of international experts and avoiding further miscommunication on the functioning of the ecotourism components, and will integrate the existing interconnected trails into a manageable trail system for the benefit of the ecotourists and protected areas management.

[2] The criteria for selected regions are described in the Annex 1.

tourists on the proposed ecotrails, conducting trainings, assisting Forest Service managers in recreational flows management, and participating in educational campaigns in the region

- Special integrated on-line platform on ecotourism education, information dissemination and capacity building will be developed and start operating.

- Thematic programs will be developed for trainings and workshops to be conducted regularly on-site and on-line on recreational site planning, visitor management, and different aspects of ecotourism development for the target audiences.

- Partnership (Ecotourism Cluster) will be formed among Crimean tour-operators promoting ecotour-packages, existing and planned places of accommodation, and food services with involved governmental and non-governmental structures in the framework of a public-private partnership concept.

- A series of multilingual guidebooks on ecotourism with ecotrails routes schemes, sites of natural and cultural heritage, scenic places, information on natural areas values, and places of accommodation will be published as hard copies and also available in electronic format for distribution via visitor centers, tourist information centers, and on-line platform on ecotourism.

CONCLUSION

Ecotourism, while supporting environmental education, sustainable management of natural protected areas, conservation of natural and cultural heritage, and sustainable development of local communities, can be considered as an alternative to conventional tourism development patterns in Crimea. The recommended integrated approach to ecotourism development in Crimea based on institutional, infrastructural, marketing, and educational changes is focused on overcoming the existing obstacles and developing a framework for an innovative ecotourism tour product. The proposed combination of ecotourism and heritage tourism provides a balance between the needs of tourism development and conservation of the natural and cultural heritage of Crimean peninsula and leads to the creation of a new image of Crimea as an ecotourism – heritage tourism destination. ■

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ANNEX 1

A general set of criteria for site selection to evaluate a potential of the territories for ecotourism development in Crimea.

- Presence of natural and cultural heritage sites of local, regional, and national significance and/or places of high recreational and/or aesthetic values.
- Existing established and/or planned protected areas (IUCN category Ib-V).
- Management objectives of the existing and/or planned protected areas do not confront ecotourism activities and ecotourism infrastructure development.
- Presence of a network of user trails or tourism routes which combine relatively undisturbed nature, attracting natural and cultural components (biological and physical), picturesque views, and a potential for ecotourism infrastructure development.
- Ability of a site to provide for safety issues for ecotourists.
- Capacity of the territory in development of ecotourism and management of recreational and tourists' flows.
- Existing flows of visitors and tourists have already created a demand for a site but cause risk of damage for the natural complexes in case of conventional tourism development.
- Willingness of local and regional agencies responsible for the area management to contribute to ecotourism development.
- Sound potential of the area to contribute to local or adjacent territories sustainable development and improvement of protected area management in ecotourism development.
- Potential of a site to serve as a regional model area for ecotourism development activities (education-for-trainers places and centers of excellence that will share best practices on ecotourism in the future).

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THE ROLE OF ENVIRONMENT IN SUSTAINABLE DEVELOPMENT OF SAMARKAND

ABSTRACT. The emergence, formation, and development of the city are largely connected with its landscape position. The first stage of Samarkand's existence may be referred to as "river civilization". Over the course of development of the city, the nature and intensity of interaction of the population and economy with its landscape have undergone changes; there is a distinct general pattern: dependence on the landscape. This was largely the reason for its sustainable development for many centuries. This fact should be considered in future activities in landscape and spatial planning.

KEY WORDS: natural landscapes, landscape pattern, living conditions, sustainable development, historical environment.

INTRODUCTION

By the Decision of the General Conference of UNESCO at its 33rd session on October 20, 2005, and the Decree of the President of the Republic of Uzbekistan on July 25, 2006, Samarkand celebrated its 2750th anniversary on August 25–30, 2007. The celebration of the anniversary was internationally recognized. In May 2007, Samarkand hosted the International Conference "The Value and Place of Samarkand in History of Universal Cultural Development". In this paper, we demonstrate the importance of geographical factors in sustainable development of the city of Samarkand.

THE OBJECT OF RESEARCH

The oldest state formations in Central Asia were Bactria, Khorezm, and Sogdiana. Sogdiana occupied the Zaravshan valley and adjacent Kashka-Darya basin. The main city of Sogdiana was Samarkand.

In the Zaravshan valley, irrigation based agriculture continued to evolve and improve. Horticulture and viticulture were very sophisticated.

Edward Schaefer, the largest orientalist (researcher of Chinese culture of the Tang epoch), University of California, in his famous book with the exotic name of "The Colden peaches of Samarkand" [Schaefer, 1981], wrote: "The title of this book – "The Golden Peaches of Samarkand" – was chosen because it resembles may things at the same time: the golden apples of the Hesperides, the peaches of immortality, Chinese legend places far to the West, the "Golden journey to Samarkand" by James Elroy Flecker, and the melodies of Frederick Delius "The Road to Samarkand" for Flecker's play "Hassan." But if you leave out these vague associations with the myths and music, the golden peaches existed in reality. Twice in the VIIth century, the Samarkand kingdom sent these unusual yellow peaches as a gift to the Chinese court. "They were as big as goose eggs, and because the color was like gold, they were called: the golden peaches. A few young trees, which produced these regal fruits were brought by the embassy convoy through the desert Serinda and planted in the palace gardens of Chanani. Now we can only guess what sort of a peach it was and what was it taste. Attractive, due to their inaccessibility, the golden peaches of Samarkand symbolized, in the Heavenly Empire Tang, all exotic and desirable, all unknown, and appealing" (p. 14). Further, Edward Schaefer wrote: "Although the fruits once existed as a "reality", they have become mythic subjects, whose life went on in the form of a literary image, metaphor. In the word format, they belonged to a much greater extent to the world of representations, imaginary, than to the world real, physical" (p. 15).

Handicrafts, especially ceramics, as well as the art of building, became increasingly important. In nearby mountain ranges Karatau, Nurata, Gobduntau, and others, gold, copper, iron, and precious stones, including turquoise, were mined. In Sogdiana, there flourished urban settlements, among which Samarkand was, undoubtedly, the largest and busiest commercial and cultural center. In Samarkand, a great "lead channel" was built, which was similar to the famous aqueducts of Rome.

Extremely favorable geographical position, the relatively cool climate, abundant natural sources with excellent water, which is not without reason called Samarkand "Obi-Rahmat" – "mercy water", the proximity of the mountains with abundant game, the large Zaravshan River running nearby that served, from time immemorial, for timber rafting from the mountains – all this provided favorable conditions for human settlements in the area where a few centuries before our era, fortifications, castles, stately buildings, and Samarkand mosques emerged.

Sogdiana and its metropolitan center – Samarkand, in all phases of their history, played a crucial role in the relations between people of East and West and in establishment of trade and cultural contacts between them. Of particular significance was the fact that Samarkand had a favorable geographical position at the crossroads of caravan routes on their way from north to south and from west to east, which defined it as the dominant center, accumulating relaying cultural achievements of the great civilizations of antiquity and the Middle Ages. But Sogdians themselves, in turn, were spreading the achievements of their civilization to the West – to Europe, and to the East – to Japan and China. This was made possible by the creation of the great transcontinental road that, in science, received the name of the Great Silk Road.

THE NATURAL ENVIRONMENT OF SAMARKAND AND ITS ADJACENT TERRITORIES

The geographical location and natural environment played an important role in the formation, establishment, and sustainable development of Samarkand. Samarkand has a variety of natural conditions. Within its territory, very different landscapes of Central Asia are in direct contact. The Zaravshan River basin and especially its middle part – the Zaravshan valley, where Samarkand is located, has been one of the centers of the world's civilization; from ancient time it was considered one of the best areas for settlement. The territory of the city, which lies in the center of the Zaravshan basin, is at the junction of the two landscapes: the northern part is in the terraced alluvial plain of the Zaravshan River valley, the southern part is in the proluvial inclined plain. From the south, the city borders (15–20 km) with the powerful mountains of the Zaravshan Range; from the north and north-east – the Turkestan Range and its continuation, i.e., the Gobduntou and Karagchitou.

The middle part of the Zaravshan valley is generally flat and reaches, at the meridian of Samarkand, 40–50 km in width. The mountains and their ridges, as well as the basin itself, are gradually declining in the direction from east to west reaching, at the meridian of Samarkand – the Zaravshanskiy Ridge, 1,680 m above sea level (The Ottoman-Karachi Pass).

All these above-mentioned geographical features of Samarkand determine the specificity of the natural conditions of the city. The natural conditions and geographical environment of these different landscapes, which has long been used by man in his productive activity, have promoted concentration, in the middle of the Zaravshan valley, of economy and population. At the connection of mountains and plains, orographic, climatic, and hydrological, (the presence of numerous permanent springs) conditions create the best environment for the development of a diversified economy and for living. The development and expansion of Samarkand occurred at the contact of mountainous-plain middle part of the Zaravshan basin, within a vast piedmont plain, suitable for the development of gravity irrigation that carried many tributaries of the Zaravshan River (Agalyksay, Amankutansay, etc) to it.

The mountain ridges that surround the Zaravshan valley, affecting the circulation of the atmosphere, contribute to a year-around prevalence of east (26–43%) and south-east (32–35%) winds that "air" the Zaravshan valley and fill it with clean mountain air. Therefore, Samarkand and the surrounding areas have a relatively cool climate.

HISTORICO-GEOGRAPHICAL ANALYSIS

The book "Samaria" written in the XIXth [Abu Tahir Hodja, 1889] states: "The city's climate is fine and temperate – it is absolutely not the cause of predisposition to disease and death. For this reason, Samarkand is called "firdaus monand" – *like the paradise*. Summer time in Samarkand is relatively hot and cold times are considered moderate. Blowing from all directions, a nice, quiet breeze and the air multiplying the joy, bring peace of mind".

The natural conditions of the Zaravshan River basin (especially in the middle of its course) during the Quaternary have been favorable for the life of primitive people, as evidenced by the abundance of archaeological monuments of different eras. At present, a few hundred of them have been found – cities, castles, villages, and sites. Abundance of the Stone Age artifacts and their nature leave no doubt that the Zaravshan River basin was one of the most habitable areas of Central Asia.

In prehistoric times, and at the dawn of civilization, people usually lived in caves that were formed in the limestone due to the slow but continuous dissolution of calcium carbonate in natural waters. The northern slopes of the Zaravshan Ridge are composed of Zaravshan karst-forming Devonian limestones. Therefore, the Zaravshanskiy mountains have abundance of ancient karst caves. It is these simple natural factors (the cave in the limestone and the presence of water in small canyons, forested mountain slopes, etc.) that have determined the location of some of the earliest settlements that have arisen in those ancient times when our ancestors had to find shelter. For this reason, the northern slopes of the Zaravshan mountains bordering the Samarkand territory were populated from ancient time and there were discovered a number of Paleolithic sites: Aman-Kutan, Takaliksay, Kuturbulak, Zirabulak, etc. Among them, the world-renowned man-site – Aman-Kutan cave (south of Samarkand, 40 km). It is located on the northern slope of the Zaravshan Range at 1,400 m. About 100 thousand years ago, the cave was inhabited by primitive hunters of the Old Stone Age. Another monument dating back to the middle Paleolithic period – Takaliksay cave, located 50 km southeast of Samarkand, at an altitude of 2000 meters above sea level was also inhabited by primitive hunters.

In the caves of Aman-Kutan, Takaliksay, and others, a handful of Neanderthals huddled; they spent most of their time in the foothills to the south of Samarkand and hid in caves from the weather and predators. In the Zaravshan valley, as elsewhere, the first dwellings of primitive man were mainly caves. Later prehistoric man "came out of the cave" and began exploring new territory not only in the mountains, but in the foothills also.

An example is the Neolithic (New Stone Age) man-sites in the foothills of the northern slope of the Zaravshan Ridge in the villages of Tym and Sazagan, located 27 km south-west of Samarkand on the Sazagansai bank, who hunted, fished, and gathered edible wild plants.

In 1939, in the heart of the city of Samarkand on the right side of the Chashma-Siab valley, the Samarkand Upper Paleolithic man site was discovered. The site is a long-term settlement on the bank of a small stream gully; it was the primary location of activities of the primitive man. The Samarkand site relates to a much older, than Aman-Kutan and Takaliksay, time and is dated with the second half of the Old Stone Age.

In the Bronze Age (second millennium BC), the main sectors of the economy, characteristic of previous eras, lost their role; in the foothills, there emerged new industries – agriculture and animal husbandry, dramatically increasing productivity. The Bronze Age monuments have been studied in the villages Muminobad and Jans near Katakurgana and other places.

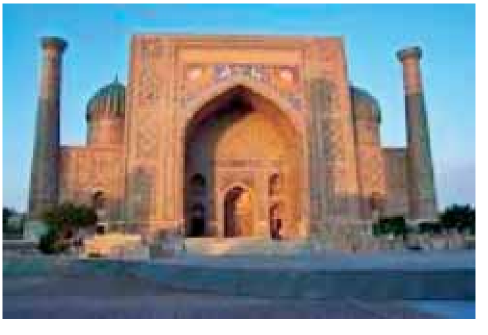
Samarkand originated in a place inhabited in the prehistoric era. Abundant mountain streams (now called Aman-Kutan, Agalyksay, Sazagan etc.), formed on the northern slopes of the Zaravshan Ridge, flew toward the Zaravshan valley. Wild bushes in the lower reaches of the streams and the Zaravshan valley had abundant supplies of water, fuel, game, and fruit. The Zaravshan River valley, almost within its entire length, was covered with dense riparian thickets and was an ideal habitat for many species of animals. These natural geographical conditions were favorable to the settlement of the region of Samarkand by tribes of hunters and gatherers of the Upper Paleolithic and Neolithic and by farmers and herdsmen of the Bronze Age.

Specifically the nature of the topography determined the location of the first settlements that eventually turned into a great city of Samarkand.

The town was founded in the heart of Sogdiana as a stronghold of the Sogdiana alliance of tribes and always remained an important location in the Middle Zaravshan. This was due to the geographic, strategic, and economic advantages of the location of the city.

Natural factors have always been essential elements of the city, identifying its location and territorial structure. It is known that the most favorable sites in choosing a place to lay-out a future city, is an elevated place, so farming and stock-raising tribes chose the hilly Afrosiab upland, located north of modern Samarkand, the ancient part of town, and "a long frozen" Afrosiab settlement – this is the territory of ancient and medieval Samarkand. The geographical location of Afrosiab was advantageous for defensive purposes: it was surrounded on three sides by the natural channels with deep ravines. The urban settlement on Afrasiab emerged in the IX–VIIIth centuries BC.

Samarkand, like all cities of the world, was formed and developed as a city on the common objective laws of historical development of human society – the development of crafts, trade, centralization of power, and the emergence of large public entities, etc. The inhabitants of the valley were able to create amazing material and cultural values.



The natural environment had a strong influence on the emergence and growth of Samarkand, on the originality of this great city. The influence of environment on the development of Samarkand was versatile;

it depended on the social system and the level of development of productive forces. At different time, different environmental conditions and natural resources were the primary factor.

In the beginning, the spatial factor had great importance in the formation of Samarkand. The spatial factor was manifested in the emergence and development of Samarkand in the form of a combination of several elements of nature: its location, proximity to the rivers of the Zaravshan and Zaravshan Ridge, and other opportunities for communicating with other localities. When all the elements harmonize with each other, a structure, called by geographers the junction area, is formed. There, large cities usually emerge.

The Zaravshan River is the natural junction structure formed by natural elements. In ancient time, before railroads and highways, the Zaravshan River was one of the main ways by which people and goods were moved (e.g., timber rafting down from the mountains). Foot and horseback routes stretched along the Zaravshan River valley. People fished in the river; the valley was used as hayfields, vegetable gardens, etc.

The territory of Samarkand is extremely rich in groundwater at a depth of 1 to 20 m. As the distance from the Zaravshan mountains increases, groundwater comes closer to the ancient surface; at low sites of the valley, there are active springs with substantial flow rate (see Fig. 1). In ancient time, the springs were the main water resources of Samarkand, which is supported by a fact that there is an Upper Paleolithic man-site found on the right bank of the Chashma-Siab creek feeding from springs. Undoubtedly,

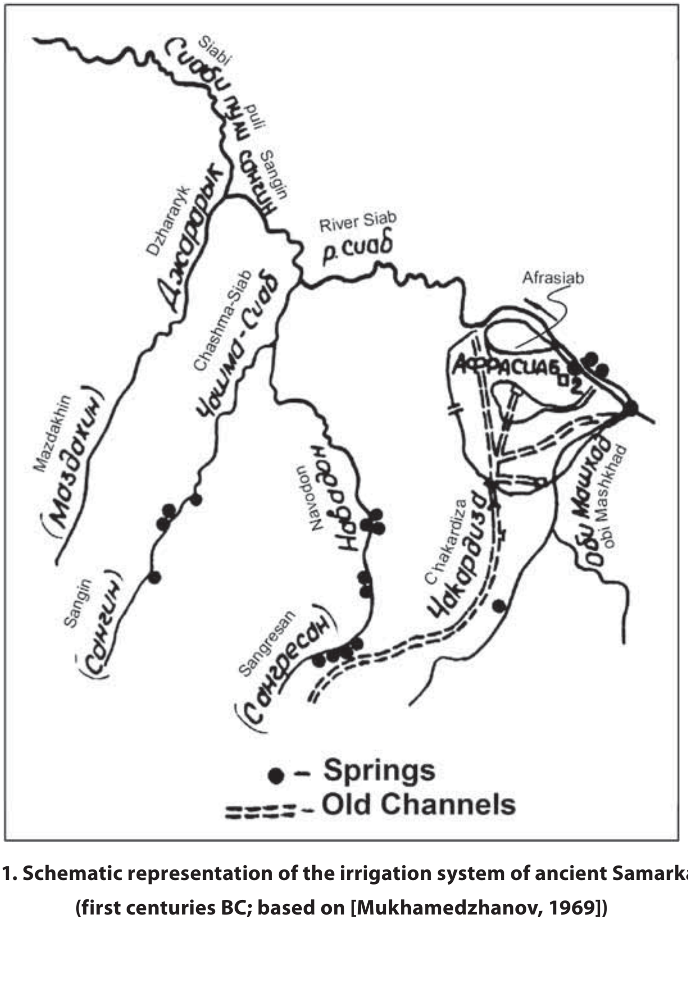


Fig. 1. Schematic representation of the irrigation system of ancient Samarkand (first centuries BC; based on [Mukhamedzhanov, 1969])

the springs located in the areas of planned construction of the city, could not but attract the attention of the ancient city planners [Mukhamedzhanov, 1969].

Probably, in ancient time, the springs made their way and opened in several places within the territory of the modern Samarkand along its merideian. Forming, on their way, small puddles and swamps covered with bushes and reeds, waterways of springs flew into the Siab River and into the Zaravshan River through it. Urban channels Obi-Mashhad, Navodon, Chashma-Siab, etc, may be considered natural creeks of spring feeding. The configuration of the river network has had a noticeable effect on the layout of the city in the past and at present.

Navodon was the largest of the streams of Samarkand with the total production rate equal to 0,072 m^3/sec (or 72 l/sec, which is more than 6 mln. l/day) [Butov, 1932]. This volume of water could meet the everyday needs of not only ancient Afrasiab, but densely populated Samarkand of the Timur and the Timurid epoch [Mukhamedzhanov, 1969].

In addition to a very advantageous location of the old Samarkand, many of its aspects of life and its appearance were influenced by the dense forest cover of the Zaravshan mountains. An expert on Central Asia, Professor M.E. Masson believed that in ancient time, the mountains between Shahrisabz and Samarkand were covered with thick forests [Masson, 1966]. Most likely, it was a juniper forest. The life of all peoples inhabiting places where the juniper grows has long been associated with this tree. Specifically the juniper beams still retain many of the arches of the ancient buildings of Samarkand. When people learned how to smelt metal, juniper still played an important role: juniper charcoal was used in smelting. With the development of civilization, juniper continuously found new applications. There can be a number of historical examples, like those presented above. They convince us that the fate of ancient Samarkand largely evolved depending on the local environmental conditions and the surrounding Zaravshan mountains.

It should be noted that a variety of environmental conditions of the mountains and foothills of Central Asia, contrasting sharply with poor and monotone surrounding arid plains, contributed to the formation in the foothills of the ancient civilizations of Central Asia. The proximity of the desert plains created continuing threat for the population and the economy, both climatic (drought, dust storms, etc.) and military (from the nomadic tribes). This forced the residents of foothill plains to tie their fate to the mountains, especially in the early stages of development. The proximity to the mountain areas predetermined emergence of transhuman grazing and dry farming. The latter ensures the stability of yields. Later, the residents learned how to use the waters of mountain streams. The pockets of ancient cultures found in the foothill plains of Central Asia point to the fact that favorable conditions of the surrounding mountains and plains have long been strategically and purposefully used by people.

In general, the mountains were a powerful stabilizing factor in economic activity for the early civilizations of Central Asia. The foothills of Central Asian are populated especially densely. They are associated with rich oases and last settlements. Almost all of the numerous cities and all of the capitals of the republics of Central Asian countries (Ashgabat, Dushanbe, Tashkent, Bishkek, Alma-Ata) are located in the foothills and have had a long and active life.

However, it should be noted that the analysis of the history of the ancient cities and their growth and decline clearly reflects the rise and fall of the ancient civilizations in the Zaravshan valley.

Professor V.M. Masson [1966] called Central Asia a "country of thousand cities". Indeed, in this region in the historical period, there were thousands of cities. Only in the Zaravshan valley, there were hundreds of cities, such as

Vardanzi, Varakhsha, Paikend, etc. Many towns and villages have disappeared. The remains of ancient settlements are under the aeolian sands or became undistinguishable small hills.

However, in existing urban areas, primarily in Samarkand, there are magnificent medieval monuments that remain the object of universal admiration.

What is the cause of prosperity of the ancient Samarkand? Here, again, we must emphasize the role of the environment and geographical location. The territory of Samarkand is located between the mountain ranges (Zaravshan and Turkestan) and the Zaravshan River valley, i.e., in the foothills (piedmont plain). Indeed, almost all major cities of Central Asia emerged in the foothills. Foothills (the piedmont plains) of Central Asia are the contact zone between highland and lowland areas; it is the band of emergence and zenith of ancient civilizations and the modern world [Alibekov, 1992].

The major cities found at the junction of mountains and plains prove to be practically immortal. Apparently, there is some critical size at which a city as a phenomenon of political, economic, and cultural life becomes indestructible. The fully functional structure of the territory where it is founded is also important.

In Central Asia, functional connections are oriented along the foothills, i.e., they represent "longitudinal" links. The fact that in Central Asia and Kazakhstan, the main transport axis goes along a strip at the joint of the mountain and lowland areas is no accident; it has only enhanced, in this belt, the conditions for concentration of households and population, caused primarily by the natural-geographical situation itself.

In fact, the railway, high-voltage line, oil, gas, and other product pipelines, and irrigation and dry channels here are aligned, in general, in parallel along the mountains or along the ridges interwoven into a powerful infrastructure.

Foothills, because of the diversity and mobility of environmental factors, react in a more versatile way and are generally more elastic. The natural links in the landscapes may be deformed but do not break, and it is encouraging. Therefore, due to these natural features, the foothills of Central Asia have always been an arena of civilization.

Thus, the foothills exhibit more stable conditions. Thus, for example, the flow of the Zaravshan River is considered relatively stable: 34% of its flow is fed by ground waters, 31% – glacier water, 34% – snow water, and only 1% – rainfall. For this reason, the seasonal regime of the Zaravshan River depends little on weather conditions and rainfall. In a drastically dry year (1917), the Zaravshan flow was only 9% lower than the multi-year average; the flow of other rivers dropped 40%. Stability of flow could not but promote sustainable prosperity of Samarkand.

The city can neither be studied nor designed separately from its natural and geographical environment. However to date, very little attention is given to the environmental conditions in cities and existing urban landscapes, as well as to the impact of the urban economy on the interaction of individual components of the landscape. However, in urban areas, specifically these factors determine the territorial division into individual districts and even city zones with different layout and different degrees of development.

It is known that the natural landscape conditions of a city have a great impact on its inner and outer appearance – the character of the buildings, architecture, structures, and squares. Despite a very strong effect of humans on nature within the city, the city just changes and adapts to the city's improvement; but it still preserves the main features of the natural (native) landscape.

The territory of Samarkand and its adjacent areas are not uniform physico-geographically;

they are located at the junction of three natural systems that divide the city and the surrounnding areas in three sharply distinct parts: 1) sloping piedmont-flat proluvial natural system, 2) hilly-ridge Paleozoic natural system with residual hills, and 3) terraced alluvial-plain natural complex.

In Samarkand, until the second half of the XXth, century there remained relatively favorable living conditions for the population and for preservation of historical monuments in their original form. However, due to the anthropogenic load, i.e., increase in population, transport, and industry, a relative balance in the system "city-nature-man" within Samarkand and its surrounding areas was broken. Now, most of the Samarkand territory and its suburbs are associated with adverse environmental conditions. This has led to an increase in the overall disease incidence, the rapid destruction of the exteriors of the buildings, and other negative phenomena. Adverse geotechnical processes and phenomena are developing; they can have a profound impact on the preservation of historical monuments.

CONCLUSIONS

The history of Samarkand reflects centuries of experience of the people, reflecting the climatic conditions of the city and its surrounding landscape. The traditional type of Samarkand buildings helped creating a favorable living environment. Samarkand of the Timur era represented a model of an environmentally friendly city. The city was surrounded by thirteen gardens – a broad green ring.

Ambassador from distant Spain Ruy González de Clavijo who visited Samarkand in 1404, wrote: "Samarkand lies on the plain. It is surrounded by orchards and vineyards. There are so many of these orchards and vineyards that when approaching the city, you see the forest of high trees and, in the middle, the city itself. The city and the gardens have many aqueducts" [In: Aleskerov, 1973].

The modern territory of Samarkand is a special and unique type of ecosystem (landscape); it is an anthropologic-environmental system that includes the natural base, urban population, and urban environment not only with its material substrate, but with specific socio-cultural space, i.e., intellectual, language, and communicative, as well.

Residents of Samarkand and the surrounding areas came from different cultures and have different historical experience of inhabiting different landscape niches; they have developed their own and often unique form of social adaptation to the environment, their distinctive "genetic code", and original way of life; to some extent, all that allowed maintaining stability in specific historical and geographical environment. All that is the guarantee and imperative of sustainable development, as far as it possible, in today's ever more globalized world.

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THE NATIONAL COMMITTEE OF RUSSIAN GEOGRAPHERS AND ITS ASSOCIATION WITH THE INTERNATIONAL GEOGRAPHICAL UNION

When in the mid-1950s, the "Iron Curtain" was lifted somewhat, the Soviet Union, through the Academy of Sciences (AS), has joined a series of scientific associations, including the International Geographical Union (IGU). In January 1957 at the Department of Geology and Geography of the USSR AS, the National Committee of Soviet Geographers was formed. The objectives of the National Committee included representation of Soviet geographers in the IGU and other international geographic organizations, development of relations with national committees of other countries, promotion of participation of Soviet geographers in the IGU and other international organizations related to geographical science, and development of scientific ties with foreign geographical institutions.

The National Committee performed its information function through publishing books and magazine reviews of international geographical congresses and of other activities of the IGU. The journal "Proceedings of the USSR AS – Geographical Series" had publications on the activities of the National Committee and translations of the IGU Bulletins and circulars of the geographical congresses and conferences. From 1984 to 1992, there was work on the annotations of new geographical books, translated into the IGU languages, and these materials were regularly forwarded for the inclusion in the International Geographical Bibliography published in Paris.

An important place in the activities of the National Committee in the 1970s was occupied by bilateral seminars with geographers of Poland, Bulgaria, France, and USA. But most important were the contacts of Soviet and foreign geographers at the IGU meetings in the USSR. These were primarily the 23rd International Geographical Congress in 1976 that gathered 3000 geographers from many countries in Moscow and symposia of the IGU Commissions on: national atlases (Moscow, 1958), the arid zone (Tashkent, 1962), the periglacial morphology (Moscow – Yakutsk, 1969), the coastal morphology (the Black Sea coast of the Caucasus, 1974), etc.

The National Committee of Russia's Geographers created by the Russian AS in 1992 became the successor of the National Committee of Soviet Geographers. In the 1990s, besides Russia, Armenia, Azerbaijan, Belarus, Georgia, Latvia, Lithuania, Ukraine, and Estonia were accepted as the IGU members and they formed their own national committees. Relations with these committees have replaced almost ceased cooperation with the countries of Eastern Europe.

At the General Assembly of the IGU in Sydney in 1988, Chairman of the National Committee of Russian Geographers V.M. Kotlyakov was elected Vice-President of the IGU and he worked in that capacity for two terms, until 1996. Among 30 commissions and study groups in 1992–1996, two were headed by Russian geographers: Historical Monitoring Committee chaired by V. Annenkov and the research team on Environmental Management and Environmental Mapping chaired by N.F. Glazovskyi.

In 1995, Moscow hosted a large conference of the IGU, which brought together several hundred Russian and foreign geographers. This conference was the first major meeting of the IGU and was the beginning of not only regional, but also of thematic conferences of the IGU. In subsequent years, the participation of Russian geographers in the IGU life has become more active. For the International Geographical Congress in The Hague, a review of the Russian geography in English was published (Geography in Russia, 1992–1995. V.M. Kotlyakov and V.S. Preobrazhensky (Eds.). Moscow, 1996. 123 p.). Russian geographers assumed the lead on Commissions and groups of the IGU: V.A. Kolosov – Commission of the World Political Map, N.F. Glazovskyi – Special Committee on the Development of the Environmental Map.

Opportunities for regular collaboration with the geographers of the CIS countries increased with the creation of the Joint Scientific Council on Fundamental Geographical Problems of the International Association of Academies of Sciences (IAAS). In 2005 in Russia (Moscow and Barnaul), the IGU organized its major conference that brought together hundreds of geographers interested in geography in Siberia.

In 2009, the Russian Geographical Society (RGS) has significantly transformed. The widely known in Russia politician Sergei Shoigu was elected President of the RGS; the RGS Board of Trustees headed by the V.V. Putin was formed. The National Committee of Russian Geographers began active collaboration with the RGS and both entities co-sponsored participation of Russian geographers in the 32nd International Geographical Congress held in August 2012 in Cologne (Germany).

During the Congress, at the meeting of the supreme body of the IGU – the General Assembly, for the first time ever, a representative of Russia – Professor V.A. Kolosov, Head of the Laboratory of Geopolitical Studies, the Institute of Geography of Russian AS, was elected the IGU President. Previously, he was Senior Vice-President of the IGU. Over the years, several Soviet geographers, namely, F.F. Davitaya, I.P. Gerasimov, V.M. Kotlyakov, and N.F. Glazovskyi, held positions of the IGU Vice-Presidents. The General Assembly of the IGU confirmed its earlier decision to hold a regional conference in 2015 in Moscow. Preparations for the conference have started in Russia.

On 22–24 October in Amsterdam, the IGU EC held its first session after the Congress in Cologne. This meeting confirmed the consensus in the EC on the IGU priorities. They may be summarized as follows.

1) We should not forget that the IGU is a truly global organization, and its objective is to connect geographers belonging to different national schools and traditions, from the North and the South, in contributing to the development of our discipline and to the increase of its role in society. We need to involve in the IGU activity geographers from the countries with low incomes, re-establish the contacts with national geographical communities that did not really participate in it in the last years, and invite new members. At the same time, we have to make the IGU more attractive for geographers from the "North", in particular, from the US and the UK, and especially for young geographers, by demonstrating the value of participation in its activities, promoting special sessions, and establishing grants and awards for beginning scholars and publishing their results in international journals. It can be reached through a better dissemination of information on the IGU and its Commissions, sharing of mailing lists, providing cross-references on different web-sites, and creation of a global data base on geographical departments and institutions similar to the global data base and search system on geographical journals already available on the IGU site (it will be regularly updated).

2) The Commissions and the Task Forces are the core of the IGU: each of them represents an autonomous international network community. Their number has recently significantly increased, which makes communication between them and coordination and integration of their work, particularly important. Our priority is to develop interdisciplinary research

through promotion of problem- and region-oriented programs, cooperation of natural and social branches of geography in studying future environmental conditions and their consequences for people, and implementation of institutional, economic, and behavioral changes enabling effective steps toward global sustainability. The Commissions have to provide connections between established and young geographers. The participation in their activity should be a step in their professional career through publications, special awards, etc.

3) The IGU Congresses and Regional Conferences remain an important link between the Commissions and between geography and other disciplines. In the period between the Congresses in Cologne and Beijing, the IGU has scheduled three annual Regional Conferences (Kyoto, 2013; Krakow, 2014; Moscow, 2015). One of its priorities is close cooperation with the local organizing committees to keep high standards established by the Congress in Cologne, to ensure the interdisciplinary character of their scientific programs, to make these meetings more accessible for scholars with limited travel budget, and to look for new flexible formats. The IGU Congress or Regional Conferences should become a platform for dialogue and the development of collaborative research programs on contemporary thematic areas and critical regions by bridging gaps between geographers, policy makers, and community leaders.

4) The cohesion of geography and its better international visibility may be achieved also through cooperation with the leading international coordinating organizations – the International Council for Science (ICSU) and the International Social Science Council (ISSC) and with other international scientific unions (International Cartographic Association, International Union of Geological Sciences, etc.) Using new opportunities for geography and the IGU, opened by a rising concern about global environmental change manifested in a number of recent important international documents, participation of the IGU in global research programs and networks should increase.

5) The IGU will continue to support its initiative to promote the declaration of the International Year on Global Understanding (IYGU) by the UN General Assembly. This ambitious and promising project is in the focus of the IGU attention. We will also strongly support the project of making a site on cities' sustainable development created on the initiative of Dutch and Chinese geographers – the world center of information and certification working under the sponsorship of the IGU.

6) Geographical education is one of the major ***raisons d'etre*** of the geographical community. The IGU has to continuously show the value of geographical education in various international and national academic and policy contexts. We will pay more attention to the role of geography at school and to geographical education, trying to cooperate with UNESCO and other international organizations in keeping and modernizing geographical curricula. The final objective may be an IGU Manual on Curriculum Development which will include recommendations on a regular curriculum revision incorporating fundamental and modern techniques and contemporary paradigms such as climate change and millennium development goals.

7) The IGU should transform its web site as an important resource of geographic information and contacts for the global geographic community, filling it with information about the activities of national geographical communities, the IGU Commissions and Task Forces, geographical journals and sites, etc. We should also explore the opportunities to use new means of communication, such as Facebook or an on-line journal.

Vladimir M. Kotlyakov
Vladimir A. Kolosov

ABOUT THE PUBLICATION OF THE JOINT RUSSIAN-CHINESE MONOGRAPH "SUSTAINABLE DEVELOPMENT AND CYCLIC ECONOMY INFORMATIZATION"[1]

In 2009, the state publishing house "Science and Technology of China" published (in Chinese) a joint Chinese-Russian monograph "Sustainable Development and Cyclic Economy Informatization", which is the one of the first systematic assessments of cyclic economy in the world. The monograph was written by a large group of Chinese scientists and specialists from the Institute of Remote Sensing Methods of the Academy of Sciences of the People's Republic of China (PRC) and the National Geomatics Research and Engineering Center of PRC, under the direction of the well-known Chinese scientist Professor Cui Wehong. Academician P.Ya. Baklanov was the co-editor of the Russian side. A number of chapters in the book were written by the faculty members of the Pacific Institute of Geography (PIG) of the Far-Eastern Branch of Russian Academy of Sciences (FEB RAS): P.Ya. Baklanov, S.S. Ganzey, and V.V. Ermoshin. This monograph is the result of a long and fruitful cooperation under the Russian-Chinese project for the transboundary areas, 2004–2005, funded by the Russian Foundation for Basic Research and the National Natural Science Foundation of PRC.

The monograph consists of 42 chapters arranged in three main sections.

The first section of the monograph "The Infrastructure of the Regional Spatial Information" begins with a definition of the basic concepts of the regional spatial information system, the main components of which are remote sensing, GIS, systems of global positioning and georeferencing of geodata, and systems of decision-making support. One of the types of such system, adapted for the goals of sustainable development, according to the authors, are distributed information systems based on the use of the Internet networks (web) as the underlying service and client-server applications. The monograph reviews the modern standards for collection, storage, and processing of metadata (International – ISO/TC 211; within China – NREDIS), which are the basic element content of these systems. The latter were used as an example for the description of the format of the body of elementary metadata in the public information network used in applications for sustainable development.

The authors outlined the available current models and data structures (vector, tessellation, hybrid, etc.) and methods of spatial analysis (overlay, analysis of spatial queries). Theoretical positions of the hierarchical spatial analysis and object-oriented spatial analysis are briefly discussed. A separate chapter is devoted to the structure of the data based on hypergraphs. The concept of geographic (attributive) feature is introduced and the distinction between the traditional and the attribute data models (space, time, qualitative, position, thematic) is discussed.

Considerable attention is given to modern problems of analysis and compilation of searches of the space-time information and to new methods of extracting information

[1] Sustainable development and cyclic economy informatization /ed. Cui Wehong, P.Ya. Baklanov (in Chinese) – Beijing, 2009. – 512 c. ISBN 978-7-5046-5467-0.

from existing heterogeneous databases (data mining)., The monograph provides a summary, as background information, of the basic mathematical approaches and tools for data mining, traditional and developed in the last decades in the world: spatial, statistical, inductive learning, spatial association, cluster, classification, neural networks, decision trees, fuzzy sets, rough sets, cloud computing, pattern recognition, genetic algorithms, data visualization, GIS graphics, and computer geometry.

To solve the problem of comparison of information obtained from different sources and regions, the authors conducted a comparative analysis of modern standards of classification and coding. V.V. Ermoshin, a faculty member of the PIG of FEB RAS reviewed Russian standards and classifications of mapping metadata for digital mapping. The first section culminates with a review of approaches to assessment of the vegetation cover index, terrestrial biomass, and productivity, and of applications used in remote sensing of vegetation, land-use, and water and soil resources.

The second section of the monograph, "Informatization of Regional Sustainable Development", begins with an overview of the main theoretical approaches to the analysis of regional sustainable development. The section provides a detailed review of: applications and approaches to informatization of regional sustainable development; the review covers decision-making support systems for sustainable development, quantitative assessment of resources and land-use analysis, construction of models on optimization of water resources use and their maintenance through integrated management, dynamic modeling of underground water, GIS for modeling of changes in the shoreline, investigation of the sea-water interaction zone and of sea abrasion, forecast of population growth and analysis of the maximal environmental load on arable land, analysis of transportation conditions from the point of view of sustainable development, etc. An example of analysis of soil erosion in the arid zone of Central Burma for optimization of the agricultural structure is also given.

The section also analyses the systems of indices of sustainable development suggested by the UN (NUCED), sustainable development indices accepted in the US, etc. The results of a model experiment on a comprehensive assessment and analysis of the dynamics of sustainable development in Zhengding County, Hebei Province, are presented. Special attention is given to research on sustainable development and its achievement in the near boarder and transboundary areas. The Russian colleagues, i.e. P.Ya. Baklanov, S.S. Ganzey, and V.V. Yermoshin, made a substantial contribution to the section. P.Ya. Baklanov presented a method, that he developed, on the assessment of dynamics of the natural resource potential of the territory and his view on the criteria and characteristics of sustainable development. V.V. Yarmoshyn wrote a chapter on the creation of GIS for land-use in the south of the Russian Far-East. The results of land-use zoning of the physiographic boundary region Border-Taypinlin on the Russian-Chinese border are presented (P.Ya. Baklanov, S.S. Ganzey); natural-economic zoning of the border areas are given (P.Ya. Baklanov, S.S. Gansey, and V.V. Yermoshin). As an example, trends in land-use in the southern part of the Russian Far East and Northeast China (P.Ya. Baklanov, S.S. Ganzey) are analyzed. The chapter ends with a comparative analysis of the main indicators of land-use in the Russian and Chinese parts of the Amur River basin (S.S. Ganzey, V.V. Ermoshin).

The third section of the monograph "Informatization of Cyclic Economy"[2] is specifically devoted to the aspects of creation of the basis of cyclic economy and to its informational support. The concept of cyclic economy and its main components are

[2] The term "cyclic economy" assumes the creation of combinations of different interconnected types of activities based on low waste closed technologies and industrial cycles analogues to the natural zero-waste cycles and circulations.

discussed. The section reviews the current state of development of cyclic economy in the world and the key provisions of the law to promote cyclic economy in China (2007). The Chinese authors analyzed the scientific basis for the construction of cyclic economy, including the relevant physical principles, environmental friendliness, system science, regional science, etc. A comparative analysis of the approaches to cyclic economy in China and the developed countries is given. Recycling technologies are the basis of cyclic economy; such technologies include minimization (energy saving and emission reduction), industrial chain, substitution, reuse, resource conservation, zero emissions, and information classification.

A special place in this section is occupied by a discussion of the information component of cyclic economy. It describes the main types of information support of cyclic economy in relation to different scales of facilities: a single enterprise, an industrial park, or a region. Methods of obtaining and processing of data, remote sensing and GIS, and digital environmental models of territories are reviewed. Progressive developments in this area are discussed, particularly, the positive experience of the China-Singapore eco-city in Tianjin; this discussion includes the description of its key components; a system of index assessment developed on the demonstration projects in the eco-city is given. The application of cyclic economy in the new urban area and the system used for environmental monitoring are described. Technical applications for a typical industrial sector are examined. On the example of the crab fisheries, water recycling is assessed. The section reviews a number of concrete examples of recycling projects in various industries: ferrous and non-ferrous metallurgy, coal industry, power industry, chemical industry, building materials, and consumer good industry. The main key areas of focus are: the use of renewable resources, recycling of metals, and recycling of household waste. The section contains a summary analysis of the basic schemes, structures, and patterns of cyclic economy for different natural and economic conditions, the types of development territories, the experience, technology, etc., in China today.

The current level of theoretical and applied research on the creation of cyclic economy (no-waste industry, sustainable management of multipurpose uses of natural resources and recycled materials) and of its informatization in China, presented in the book, was achieved by the active government support. Already established experimental closed cycles (livestock enterprises, agricultural production) in this country have a high profit margin in contrast to similar projects in the West, which makes such work very attractive worldwide. Despite the fact that the natural resources development in the Russian Far East is still occurring following the extensive pattern, the issues of geoinformation support of multipurpose use of resources, reduction of the impact on the environment, reduction of cost, and increase of profitability are of great interest for our conditions.

The authors of the monograph hope that such models of economic development will be actively implemented in Russia, in China, and in other countries. The joint monograph contributes to this cause.

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