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Enviro-RISKS:

Man-induced Environmental Risks: Monitoring, Management and Remediation of Man-made Changes in Siberia

Alexander Baklanov and Evgeny Gordov, Editors

Volume 1:

Enviro-RISKS Project and its Major Outputs

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Contributing Authors: M. Heimann, M. Kabanov, V. Lykosov, A. Onuchin, V. Penenko, P. Pushistov, A. Shvidenko, E. Zakarin

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Enviro-RISKS Report Content:

Executive Summary

The Project Description *(in this Volume)*

Major Outputs and Recommendations *(in this Volume)*

Thematic Focus 1: Atmospheric Pollution and Risk *(in a separate Volume 2:* www.dmi.dk/dmi/sr08-05-2.pdf*)*

Thematic Focus 2: Climate/Global Change and Risks *(in a separate Volume 3:* www.dmi.dk/dmi/sr08-05-3.pdf*)*

Thematic Focus 3: Terrestrial Ecosystems and Hydrology and Risks *(in a separate Volume 4:* www.dmi.dk/dmi/sr08-05-4.pdf*)*

Thematic Focus 4: Information Systems, Integration and Synthesis *(in a separate Volume 5:* www.dmi.dk/dmi/sr08-05-5.pdf*)*

EXECUTIVE SUMMARY

Siberia environment has been subjected to serious man-made transformations during last 50 years. Current regional level environmental risks are: direct damages to environment caused by accidents in process of petroleum/gas production and transporting including their influence on water, soil, vegetation and animals; caused by deforestation (legal and illegal cutting and forest fires) variations in Siberian rivers runoffs and wetland regimes; direct and indirect influence of forest fires, flambeau lights and losses of gas and petroleum during their transportation on regional atmosphere composition; deposition of hazardous species leading to risks to soil, water and consequently to risks in the food chain.

In this Final Report, published in five separate Volumes, the major Enviro-RISKS project (http://project.risks.scert.ru/) outcomes are summarized. They include the state of the art of environmental RTD activity in Siberia, suggested methodology and recommendations on future environmental research in Siberia. These outcomes are based on results obtained by the four Thematic Expert Groups in process of preparation of Thematic Focuses Reports.
Three Thematic Focuses/Groups consider major risks inherent to Siberia environment. These groups (with their leaders) are the following:

1. **Atmospheric Pollution and Risks** (Alexander Baklanov (DMI) and Vladimir Penenko (ICMMG)),
2. **Climate/Global Change and Risks** (Martin Heimann (MPI for Biogeochemistry) and Vasily Lykosov (INM)), and
3. **Terrestrial Ecosystems and Hydrology and Risks** (Michael Kabanov (IMCES) and Anatoly Shvidenko (IIASA)).

The forth Focus has a generic nature and is devoted to:

4. **Information Systems for Environmental Sciences, Integration and Synthesis** (Evgeny Gordov (SCERT) and Edige Zakarin (KGC)).

The groups analyzed relevant RTD projects (lists of those are mentioned in the Introduction and attached to respective Focus Groups Reports) and summarized the state of the art, existing methodology and applications in the considered area. Additional contributions of all Project Partners also have been used in this Report.
On this basis also practical recommendation to international research community and regional environmental decision makers were formulated (see in Volume 1). These recommendations are translated into Russian and disseminated to targeted community via direct mailing and the Project web site.

Content of Volume 1: Enviro-RISKS Project and its Major Outputs

INTRODUCTION

Siberia environment has been subjected to serious man-made transformations during last 50 years. Current regional level environmental risks, which directly are man-made, include: direct damages to environment caused by accidents in process of petroleum/gas production and transporting including their influence on water, soil, vegetation and animals; caused by deforestation and other impacts on forests (legal and illegal harvest; forest fires; unregulated anthropogenic pressure); variations in Siberian rivers runoffs and wetland regimes; direct and indirect influence of forest fires, flambeau lights and losses of gas and petroleum during their transportation on regional atmosphere composition; deposition of hazardous species leading to risks to soil, water and consequently to risks in the food chain as well as directly to population health. All these risks became more pronounced now under influence of global climate change. Additionally, global warming might lead to increase of weather extremes number in the region (heavy rains, strong winds, floods, etc.), which can lead to direct risks as well as cause relevant accidents. Last but not least are risks associated with possible permafrost thawing and shift of its border to North.

It should be mentioned that neither basic nor applied environmental RTD activity related to man-made environmental risks are not within direct objectives of this Co-ordination action. The Project strategic objective is to facilitate elaboration of solid scientific background and understanding of man-made associated environmental risks, their influence on all aspects of regional environment and optimal ways for it remediation by means of coordinated initiatives of a range of relevant RTD projects as well as to achieve improved integration of the European research giving the projects additional synergy in current and future activities and potential for practical applications.

In this Report major project outcomes, which form Memorandum on the state of the art of environmental RTD activity in Siberia, Recommendations on future environmental RTD activity in Siberia and Roadmap for environmental research and development activity in the region are summarized. These outcomes are based on results obtained by the four Thematic Expert Groups in process of preparation of Thematic Focuses Reports.
Three Thematic Focuses/Groups consider major risks inherent to Siberia environment. These groups (with their leaders) are the following:

- **Atmospheric Pollution and Risks** (Alexander Baklanov (DMI) and Vladimir Penenko (ICMMG)),
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The forth Focus has a generic nature and is devoted to:

- **Information Systems for Environmental Sciences, Integration and Synthesis , Integration and Synthesis** (Evgeny Gordov (SCERT) and Edige Zakarin (KGC)).

Scientific background used is formed by a number of different levels RTD projects devoted to near all aspects of the theme but in virtue of synergy lack yet not resulting in improvement of regional environmental situation. The set comprise EC funded thematic international projects performed within FP5, FP6 and liquidating now INTAS, national projects supported by Siberian Branch of RAS, RAS and Russian Foundation for Basic Research and projects performed by research institutions and SME under contracts with regional/local administrations and petroleum/gas producing and transporting enterprises/companies. In spite of the fact that numbers of results obtained in these projects make significant progress in understanding mechanisms of formation of man-made environmental risks, including monitoring and management of environmental crisis situations and suggest reliable ways to their mitigation and remediation of damaged territories, none of the projects is aimed at the whole pallet of monitoring, management and remediation of man-made environmental risks in Siberia.

Below in the Memorandum on the state of the art of environmental RTD activity in Siberia, Recommendations on future environmental RTD activity in Siberia and Roadmap for environmental research and development activity in the region relevant Focus Expert Groups finding will be summarized.

It should be noted that due to improved recently RTD oriented funding in Russia and under direct influence of key Enviro-RISKS Project performers in some cases situation in Siberia are changing now. In more details these recent developments will be described in Conclusions.

The Project Description

The very idea of this project appeared as result of authors concern with current situation in the Siberia environment itself and in basic and applied research activity devoted to it. It is well known that the Siberia environment has been influenced by serious man-made transformations during the last 50 years. Major contemporary regional level environmental risks include the following. At first, these are direct damages to environment caused by accidents during petroleum/gas production and transporting. It is also risks caused by deforestation variations in Siberian rivers runoffs and wetland regimes. Moreover, it includes influence of forest fires, flambeau lights and losses of gas and petroleum during their transportation on regional atmosphere composition as well as atmospheric transport and deposition of hazardous species leading to risks for soil, water and consequently for food-chains. Near all of the risks might be significantly enforced by regional manifestations of global change, which evolves dramatically in the Northern territories [1]. Regional consequences of global warming (e.g. anomalous increase of winter temperatures [2]) are strongly pronounced in Siberia. This tendency is supported by the results of climate modeling for XX-XXII centuries [3].
This process not only threatens Siberia with destruction of the most part of extractive and transport infrastructure caused by the shift of permafrost borders northwards but also can change the dynamics of the natural climatic system as a whole as a result of extrication of a large mass of greenhouse gases. Similar regional problems occur in a number of Northern countries. However, Siberia is actually a place where the synergy between natural and man-induced impacts on the environment might lead to heavier environmental damage and consequences, then their separate consequences. It also includes possible strong variations of regional feedbacks to the global system, which makes relevant study important on the global scale as well.
In spite of significant research efforts of recent years the deep understanding of the dynamics of regional environment main components is not gained yet. Although many projects supported by national (SB RAS, RAS) and international (EC, IGBP-2, NEESPI, etc.) organizations are devoted to study of modern dynamics of Siberian environment, we still know little about the behavior of main components of the regional climatic system. A review on state-of-the-art in Siberian environmental research is published in the dedicated to Siberia issue of the Bulletin of Russian National Committee on IGBP [4] and available in Internet (http://www.scert.ru/files/igbp/EngBul.pdf). Many institutes of SB RAS also work in this direction in the frameworks of their budgets and initiative themes. But taking into account their fragmentation, these studies will not lead to the emerging of the full picture of modern natural-climatic changes in Siberia.
Siberia is one of the promising regions for the development of such basic and applied regional study of environmental dynamics [4]. In spite of significant resources used, the effectiveness of the work is not high because of insufficient funding and coordination between projects. To overcome these weaknesses a special activity is necessary. In order to gather up for now scattered regional, national and international efforts in these investigations, a sort of regional concentrated activity aimed at the both basic and applied studies is required. That is why we decided to initiate relevant project namely as FP6 co-ordination action. According to the FP6 definition the Co-ordination actions (CA) are intended to promote and support the co-ordinated initiatives of a range of research and innovation operators, in order to achieve improved integration of the European research. The coordination action is an instrument to network or co-ordinate research organizations, initiatives or projects for a specific purpose. It provides organizational support to achieve the networking or coordination of the research and innovation activities of the operators involved. Namely, co-ordination activities could address tasks such as establishing a roadmap for research in specific topics and performance of required preparatory work like studies, analysis and report writing, establishment of specifications for common information systems, development of such systems and the use of common information systems to facilitate exchange and dissemination of good practices and manage common activities.

Additional positives of co-ordination actions are in the fact that they may contain training activities as well.

Enviro-RISKS project description

The three years FP6 CA Project "Man-induced Environmental Risks: Monitoring, Management and Remediation of Man-made Changes in Siberia" (Enviro-RISKS) has been started on 1 November 2005. Its strategic objective is to facilitate elaboration of solid scientific background and understanding of man-made associated environmental risks, their influence on all aspects of regional environment and optimal ways for it remediation by means of coordinated initiatives of a range of relevant RTD projects as well as to achieve improved integration of the EU research giving the projects additional synergy in current activities and potential for practical applications.

Scientific background and foundation for the project performance is formed by a number of different levels RTD projects devoted to near all aspects of the theme but in virtue of synergy lack not resulting in improvement of regional environmental situation. The set comprise coordinated/performed by partners EC funded thematic international projects, Russian national projects and other projects performed by NIS partners. List of partners includes 3 leading European research organizations: Danish Meteorological Institute (Co-ordinator; Copenhagen, Denmark), Max-Planck-Institute for Biogeochemistry (Jena, Germany) and International Institute for Applied Systems Analysis (Laxenburg, Austria); 6 leading Russian research organizations (5 - located in Siberia): Siberian Center for Environmental Research and Training (NIS Co-ordinator) and Institute of Monitoring of Climatic and Ecological Systems SB RAS, (both in Tomsk), Institute for Numerical Mathematics RAS (Moscow), SB RAS Institutes Forest SB RAS (Krasnoyarsk), Institute of Computational Mathematics and Mathematical Geophysics (Novosibirsk), Ugra Research Institute of Information Technologies (Khanty-Mansiisk) as well as the KazGeoCosmos enterprise (Almaty, Republic of Kazakhstan). Additionally to the listed above partners several research organizations joined to the Project as Associated Partners. Among those are the MEDIAS-France (Toulouse, France; http://mediasfrance.org/), and several Russian organizations - Institute of Computational Modeling SB RAS (Krasnoyarsk), Institute of Northern Environmental Problems of Kola Science Center RAS (Apatity, http://inep.ksc.ru/), Tomsk State University (http://www.tsu.ru/), and Ural Division of RAS (Ekaterinburg).

List of performed projects, whose results will be included into dedicated studies in course of CA, comprises the following:

FUMAPEX (Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure, http://fumapex.dmi.dk/) Project, co-ordinated by DMI, which was aimed at improvement of meteorological forecasts for urban areas, integration and link Numerical Weather Prediction (NWP) models to Urban Air Pollution and Population Exposure models leading to an improved Urban Air Quality Information and Forecast System for application in cities in various European climates;

SIBERIA 2 (Multi-sensor concept for Greenhouse Gases Accounting in Northern Eurasia, http://www.siberia2.uni-jena.de/index.php), aimed at understanding the greenhouse gas budget and its interactions with climate change in the Eurosiberian region (**IIASA** and **IF** were its key performers);

TCOS-Siberia (Terrestrial Carbon Observing System – Siberia, http://www.bgc.mpg.de/public/carboeur/web_TCOS/), coordinated by MPI for Bio-geochemistry (Jena) and aimed at implementation of the first components of a continental scale observing system to help determine the net carbon balance of Siberia and its variation from year to year;

ISIREMM (Integrated System for Intelligent Regional Environmental Monitoring & Management), SCERT coordinated NIS Partners activity, which addressed the problem of industrial pollution, and in particular, air pollution, and its effects on the human and natural environment.

It also includes FP6 Special Support Action **ENVIROMIS-SSA** (Environmental Observations, Modelling and Information Systems, http://project.enviromis.scert.ru/enviromis2/) coordinated by **SCERT**, which formed coherent set of coordination, dissemination and education actions directly aimed at environment protection and stabilization of research and development potential in Russia and other NIS countries, as well as INTAS supported projects **ATMOS** (Web Portal on Atmospheric Environment, http://atmos.iao.ru; http://atmos.scert.ru) aimed at development a bilingual Internet portal for the domain of Atmospheric Physics and Chemistry, and the related application domain of air quality assessment and management (among key participants were **SCERT, INM and IMCES)** and "Modelling and parameterization of the 'air-vegetation-snow-soil' system, including special aspects of the permafrost degradation" aimed at evaluation and understanding effects of the active layer of the cryosphere on climate and studying potential effects of the global climate change on the permafrost degradation (**INM** played the key role in it). Important part of the set is formed by the SB RAS Interdisciplinary Integrated Projects devoted to actual issues of Siberia environment. Among those are co-ordinated by **IMCES** projects **SGBP** ("Siberian Geosphere – Biosphere Program: integrated regional study of contemporary natural and climatic changes", http://sgbp.scert.ru/en/about/), in which efforts of 14 Institutes of SB RAS and RAS as well as 5 Universities were coherently joined to initiate relevant study of the region and **GVB** («Complex Monitoring of Great Vasyugan Bog: study of modern state and development processes», http://www.scert.ru/en/projects/current/bvb/) aimed at study of development of the unique natural-climatic complex Great Vasyugan Bog (GVB) as the natural formation of planetary importance under global and regional environmental and climate change and elaboration of remediation methods for damaged by oil producing activity parts of it territory; as well as co-ordinated by **ICMMG** project «Ecological Problems of Siberian Cities», which goal was to conduct multidisciplinary scientific research to answer the basic questions: how do cities change hydrothermodynamic behavior and composition of atmosphere and how do these changes affect the quality of life, public health and quality of environment. Complete list of the projects also comprise the Kazakhstan Ministry of Industry and Trade projects, performed by **KGC** and set of projects performed by **URIIT** for regional petroleum and gas producing companies. More detailed description of the performed by partners' projects as well as those, recently started, can be found at the Enviro-RISKS web portal (http://risks.scert.ru/).

One of the project tasks is facilitation to development of Siberia Integrated Regional Study (**SIRS**, http://sirs.scert.ru/). Accordingly to present knowledge, Siberia is the region where the most pronounced consequences of climate changes already happen and will happen. Various models have been developed to address different dimensions of this issue. Variability in space and time as well as regions of critical importance ("hotspots") have been evidenced through in situ and remote sensing measurement techniques and were forecasted by advanced climatic models. Siberia environment has been subjected to serious man-made transformations during last 50 years, whose negative consequences might be amplified by regional manifestations of global change. Say caused by deforestation (cutting and forest fires) variations in Siberian rivers runoffs and wetland regimes might interfere with change of atmospheric circulation in the region, which varies forest fires frequency, flambeau lights and losses of gas and petroleum during their transportation vary regional atmosphere composition and its radiation properties, etc. These regional problems are typical for number of NIS and for near all Northern countries.

Elaboration of solid scientific background and understanding of man-made associated environmental risks, their influence on all aspects of regional environment and optimal ways for it remediation is required to get practical results in enhancing of environment and diminish environmental risks. The region requires a new research paradigm. An overarching vision of regional aspects and its various connections to global aspects is now needed in line with the defined by the Earth System Science Partnership Integrated Regional Studies (IRS) approach, which could lead to Siberia IRS (SIRS) program. This requires bringing together scientists from several disciplines and sub-regions into a

much wider approach and setting up the relevant structures (institutions, regional and transregional and international networks, funding) to lead such integrative studies. Results of such studies should be bridged with and acknowledged by relevant decision policy makers in order to implement proper mitigation and remediation actions at managerial and political decision levels.
The main activities, aimed at realization of the Enviro-RISKS objective and coordination of the basic and applied environmentally oriented projects comprise:
• Development and support of the Project web portal and environmental information distributed database;
• Gathering and systematization of information resources obtained;
• Gathering, analysis and synergy search in different level projects on Siberian environment;
• Organization of conferences and experts meetings;
• Search for synergy between the different projects on Siberian environment and elaboration of recommendation for new Projects;
• Exchange of research personnel and postgraduates.

Presentation of results
The major result of the Coordination Action and involved projects are presented in this Report in four separate Volumes by four **Thematic Focuses** and in established relevant **Working Groups**.
Three Thematic Focuses/Groups consider major risks inherent to Siberia environment. These groups (with their leaders) are the following:
1. **Atmospheric Pollution and Risks** (Alexander Baklanov and Vladimir Penenko),
2. **Climate/Global Change and Risks** (Martin Heimann and Vasily Lykosov), and
3. **Terrestrial Ecosystems and Hydrology and Risks** (Michael Kabanov and Anatoly Shvidenko).
The forth Focus has a generic nature and is devoted to:
4. **Information Systems, Integration and Synthesis** (Evgeny Gordov and Edige Zakarin).
The working groups also formed a basis for organization of the thematic Expert Groups, which elaborated practical recommendations for coordination of new projects on Siberia environment initiated by Partners (see the Concluding Chapter in the Volume 4 of this Report and also Enviro-RISKS Deliverable 8.2 Report: 'Memorandum and Recommendations on future RTD environmental activity in Siberia' on the project web-site: http://project.risks.scert.ru/).
Several previous studies and applications were also published in separate scientific reports of the Enviro-RISKS project (see e.g. [6, 7]).

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Memorandum on the state of the art of environmental RTD activity in Siberia

Atmospheric Pollution and Risks

Analyzed projects results show that major atmospheric pollution risks are related with the health of population, which in Siberia is residing mainly in cities. Essential dependence of air quality from climatic conditions is typical for Siberian cities. A stable atmospheric stratification and temperature inversions are predominant weather patterns for more than half a year. This contributes to accumulation of pollutants of different nature in the low layers of the atmosphere namely where ecosystems function and people live. In addition to the severe climatic conditions, man-made impacts on environment in industrial cities strengthen more and more. The impacts manifest themselves in pollution of environment, change of the Earth surface, of hydrological and hydrodynamic regimes of the atmosphere, etc.

In the cities, original mesoclimates promote pollution accumulation. For instance, Novosibirsk, Krasnoyarsk, Irkutsk, Ulan-Ude are in the influence zones of the mesoclimates provided by the interplay of the city heat island and the water objects. This increases vulnerability of the atmospheric quality to the pollution. These aspects demand additional studies while planning the economical activity. One more important fact is that the cities of West Siberia are situated in the influence regions of the vast wetland (bog) territories of the gas-oil provinces where methane is naturally emitted into the atmosphere. We know methane as a greenhouse gas. Hence, the problems of climate change are directly concerned with Siberia. Moreover, the emission resulted from mining and processing hydrocarbons is added to increase the concentrations. It is known that series of toxic secondary products such as formaldehyde, formic acid, etc. is generated when methane transforms. It is not quite clear till now to what extent does this neighborhood be dangerous for Siberian people.

Urban cenosis develop there in the extreme and evolutionary non-providing conditions. Therefore they are peculiar and weakly studied ecosystem types. Here the natural and industrial (energy, transport) complexes are closely connected. There are severe contradictions between the growing chemistry components in all branches of industry and the low level of general chemistry competence even at a level of decision-making of high responsibility. For example, the unfinished technologies without of final stages of the wastes use are often used. That is why a potential risk of man-made catastrophes is high. The latter may in their turn provoke ecological disasters by atmospheric emission of heat, humidity, and toxic pollutants.

It should be noted that cities are not isolated systems. They may as distribute pollution over surroundings as get it from the outside. Thus the problem of mutual risk assessment for the cities should not be underestimated in the specific Siberian conditions, too. The influence of the transboundary transport between Russia, China, Kazakhstan, Mongolia should not be ignored as well. All these problems are connected with ecological safety and life quality.

Now the close connection between environment quality and man's health, working capacity and life time is beyond any doubt. A general worsening of ecological situation in Siberian cities causes its input to the accumulation of the toxic products in the organs and tissues of men. This reflects in the functioning of the organism as a whole and leads to the metabolic imbalance.

Environmental problems are under study of Siberian scientists. As our thematic group in the project concerns with atmospheric pollution and risk, we concentrate on numerical modelling in these fields giving the proper attention to the close connection between climatic and environmental problems.

There are some leading groups of environmental modelers in Novosibirsk, Tomsk, Irkutsk, Krasnoyarsk, Tumen, Barnaul, Kemerovo, Yakutsk, Ulan-Ude, Chita, Omsk, and Khanti-Mansiisk. These groups belong mainly to the institutes of the Siberian Branch of the Russian Academy of Sciences.

There are three approaches to model pollution transport and transformation in Siberia
• using simplified regulatory models (Gaussian type, one/two dimensions, a few parameters, etc.), (about 50-60 %);
• adopting well-known internet-available models, like MM5, WRF, HYSPLIT, etc. (20-30 %, increasing);
• developing original comprehensive models of different complexity from local to global scale (10-15%, decreasing).

As for our focus group, the participants have been developing all types of the models.

A system for modelling dynamics and pollution in Tomsk region is developed by Tomsk State University, IAO and IMCES SB RAS. The models MM5, WRF and an original version of non-hydrostatic meso-scale hydrodynamic model as well as the model of transport and transformation of substances are used. Photochemical reactions are also considered in the air quality models for urban and suburban areas. Special attention is given to the parallel realisation of the models and high performance numerical schemes.

In KazGeoCosmos, a geo-informative system for simulation of a city and industrial region pollution is elaborated. A 2D model of pollutant transport is included into it. The model is adapted to the Alma-Ata city conditions. A special version of the model is developed for assessment of the atmospheric quality in Kazakhstan's sector of Caspian region. The main part of emission is the products of burning at processing hydrocarbons. The emergency cases are considered too.

In ICMMG, a set of atmospheric models of environmental orientation (CARMEN) has been developed. The model set is hierarchically constructed in such a way that the basic models of some vertical and horizontal scales participate in it. The models are of local, meso, hemispheric and global scales. The adjustment of the models is fulfilled by variational principles. A methodology has been developed to build the combined methods of forward and inverse modeling for the problems of the higher system level connected with the problems of ecological safety and environment control. The methodology includes the basic elements for calculation of sensitivity functions to the variations of input data, parameters, and sources. Mathematical aspects of methodology, statements of the problems, and modeling technology are based on an original concept of environment modeling using variational principles and solution of the forward, inverse, and adjoint problems.

Following the concept, the constructions in the form of functionals describing the generalized characteristics of the processes, data, and models are considered together with the basic model components. Ecological restrictions on the environment quality, the results of measurements of different kinds, control and design criteria, model quality criteria, etc. are presented by the functionals. The restriction functionals are introduced for solving the problems of optimization of environment protection activity, management of environment quality, and ecological design. The content of the restrictions results from the conditions of environmentally sustainable development and ecological safety of the industrial regions. The typical restrictions are the mathematical formulations of the demand of fulfillment of the atmospheric quality standards. The characteristics and restrictions might be global, distributed, and local. Adjoint problems, methods of inverse modeling , sensitivity and optimization methods are generated with the help of such functionals.

The structure and the principles for construction of the model set for the system of the atmosphere of an industrial region are developed for practical implementation of the proposed concept. In the concept, a region is considered as an element of the climatic system which is both a source and a receptor of pollutants. To combine the models of processes, observational data, and a set of the functionals in the frames of forward and back relations, it is supposed that each element may contain uncertainty. In this case, it is naturally to formulate a variational principle for construction of such relations based on minimum conditions for a total measure of all uncertainties. The proposed variational principle ensures the agreed description of all models and processes in physical sense and the construction of the appropriate structure of numerical schemes and algorithms.

Assessment of environmental risk and vulnerability of territories with respect to anthropogenic effects is one of the typical problems of environmental prognosis and design which can be solved on this basis. From ecological point of view, each industrial source, even in normal conditions, has an influence on the environment. The fact itself that a source falls into the sensitivity region for the goal or restriction functional, already says about the risk to obtain the pollution from it in the receptor zone. Therefore the sensitivity relations which are a measure of direct influence of the source variations and transformation mechanisms on the value of functional variation (the influence of the source itself, in the linear case), give the algorithms for quantitative estimates of the risk/vulnerability domains and for revealing the sources of this risk.

Risk control also can be formalized within the approach framework. The main objectives are development of a concept and a methodology of optimization of risk control in accordance with the given criteria and restrictions as well as elaboration of express-methods for assessment of tendencies of increasing or decreasing risks for chosen region-receptors undergone the influence of different factors. Here all functionals and restrictions containing the state functions are described by the integral form which is dictated by the chosen variational principle for construction of the adjoint problems and sensitivity functions . The control algorithms are realised by the combination of the forward and inverse modeling techniques. The main stages of analysis are given as:

- the set of goal functionals and restrictions is prescribed;
- the set of receptors is prescribed and the structure of the functionals for their description are defined;
- sensitivity relations are constructed and calculate (to this moment, we need the solutions of the forward and adjoint problems for chosen system of functionals);
- the regions of risk/vulnerability are revealed from the sensitivity analysis for given set of receptors and functionals;
- the sources being in the region of risk/vulnerability are defined;
- the sources are ranged with respect to the potential danger and the SFs' significance levels in the zones of sources localisation;
- the sources are separated into two groups: accessible to control or not (eg., if the source is abroad);
- the control strategies are designed by means of the feedback equations;
- examination of criteria and restrictions after the strategy was applied;
- in case of need, the parameters are corrected and the process is repeated beginning with the third item.

The processes of interest are described by the models of hydrodynamics in the climatic system, the models of transport and transformation of humidity, chemically and optically active pollutants in gaseous state and aerosols. In general sense the main components of environment models usually are:

1. a hydrodynamics component that calculates pressure, three components of wind velocity vector and components of the hydrological cycle;

2. a transport and diffusion component that calculates the three-dimensional motion of gases and aerosols in a gridded model domain;
3. a gas-phase chemistry component that calculates the change in gaseous concentrations due to chemical transformations;
4. an aerosol component that calculates the size distribution and chemical composition of aerosols due to chemical and physical transformations;
5. a cloud/fog component that calculates the physical characteristics of clouds and fog based on information from the meteorological model (or from observation);
6. a cloud/fog chemistry component that calculates the change in chemical concentrations in clouds and fog;
7. a wet deposition component that calculates the rates of deposition due to precipitation (and, possibly, cloud impaction and fog settling) and the corresponding change in chemical concentrations;
8. a dry deposition component that calculates the rates of dry deposition for gases and aerosols and the corresponding changes in their concentrations.

Urban air quality Forecasting systems are becoming quite reliable tools nowadays. Integration of all developed tools will greatly benefit the development of urban air quality information and forecasting systems (UAQIFS) for a variety of applications and end-users. Modern numerical weather prediction (NWP) and meso-meteorological models (MetM) able to resolve urban-scale processes are considered to be the main tools in future urban air pollution (UAP) forecasting and assessments because they allow for sufficiently high spatial and temporal resolution and can trace back the linkages between sources and impacts.

In particular, major aspects of urban effects were considered by the FUMAPEX project in improved urban-scale NWP and meteorological models: higher spatial grid resolution and model downscaling, improved physiographic data and land-use classification, calculation of effective urban roughness and urban heat fluxes, urban canopy and soil submodels, MH in urban areas. On-line chemical modeling should be the next step. Quantification of the combined effect of bio-meteorological factors together with the effects of air pollution is also a major issue. In this context two levels of the integration strategy are suggested:
1. Off-line integration of Urban Meteorology, Air Pollution and Population Exposure models for urban air pollution forecast and emergency preparedness, which is the main issue e.g. in the EC FUMAPEX project;
2. On-line integration of meso-scale meteorological models and atmospheric aerosol & chemical transport models with consideration of the feedbacks of air pollution (e.g. urban aerosols) on meteorological processes and urban climate. This will lead to a new generation of models for "chemical weather forecasting", a goal that is being investigated via the COST action ES0602.

The Danish Emergency Response Model for Atmosphere (DERMA), developed by DMI originally in the direct mode, is also tested in the inverse (adjoint) mode for different resolutions and grid domains for forecast and for long-term simulation of source-receptor relationship for various pollutants including nuclear, chemical, biological etc. danger. Among 28 models from most of European countries, USA, Canada and Japan, which contributed to model validations based on the European Tracer EXperiment (ETEX), the DMI's DERMA model was emphasized as performing excellently. The methodology was tested on examples of the risk sites located in Arctic, Sub-Arctic, and Northern Europe. The sites included the nuclear power plants' reactors, nuclear reprocessing plant, nuclear submarine, decommissioning site, and former nuclear weapons testing site.

To illustrate the state in the art in this theme in more details below some specific results obtained by the Project participants are presented.

The problems of the long-term environmental forecasting demand to reveal the dynamical active zones and the areas of increased sensitivity to the variations of parameters (forcings). The methodology of accounting the climatic data into environmental studies developed by ICMMG is suitable for studying such kind of problems. Analysis of the long-term behavior of the global climatic system and decomposition of the long-term series of meteorological data with respect to the scales of processes allows one to identify activity centers and to use this information to formulate the problems of risk/vulnerability for sources/receptors. The Siberian regions are of special interest for us from the viewpoint of decomposition of the phase spaces describing the global climatic circulation mechanisms and their manifestation in the formation of environmental dynamics. Joint analysis of basic subspaces, the fragments of which are presented in Fig. 1, shows that Siberia and especially the Lake Baikal region are situated in the places which separate the circulation systems of high energy activity. In winter season they are between the Pacific and Atlantic energy-active zones whereas they separate the Arctic and South-Asian zones in summer seasons. This fact directs onto interpretation of manifestation of the climatic instability in the region. In the autumn-winter season, the instability expresses as sharp alteration of weather cycles. The formation of Altai-Sayan cyclogenesis which is of the same intensity as the Mediterranean one, is specific for warm seasons. In climatological works it is referred as lee-type cyclogenesis. This is the large scale phenomenon in the climatic system of the central part of Eurasia.

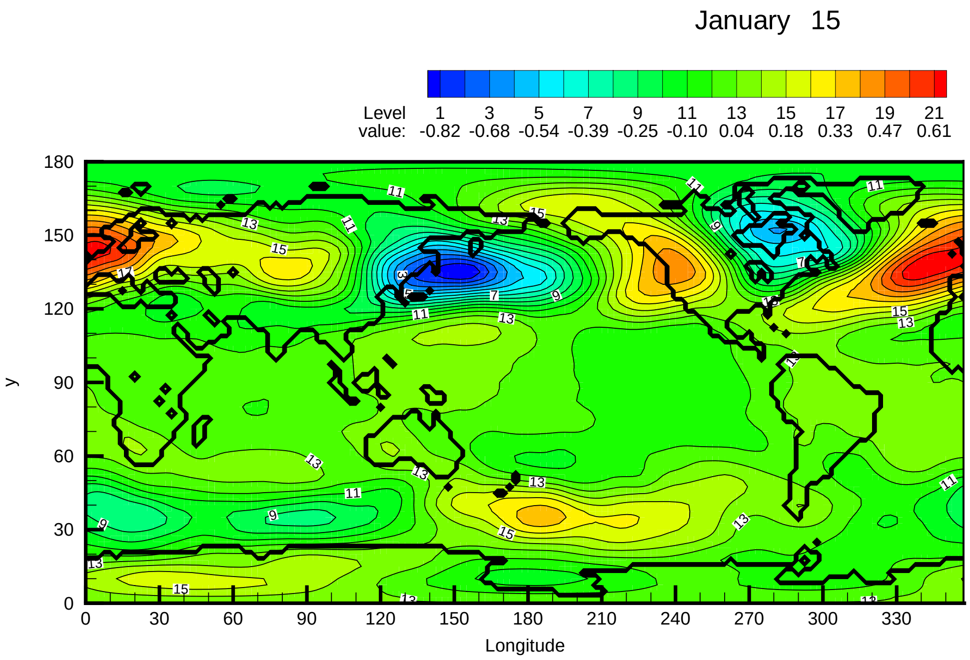

Fig.1. One of the 62 fragments of the leading orthogonal basis vector (OBV-1). The basis is constructed on NCEP reanalysis data of the 500-hPa geopotential height for 56 years. The fragment corresponds to 00:00 UTC 15 January.

The region of Lake Baikal ($45^\circ - 60^\circ$ N , $95^\circ - 115^\circ$ E) falls into the zone which is characterized by the high degree of cyclone activity and therefore is situated on the cross-roads of air pollution transport. Even imperfect observing system which are in Siberia shows that man-made emission leads to the worsening the air quality. The typical sources of emission having an a influence on ecological situation are the following: industrial objects on mining and making of mineral resources and energy production, vast forest fires, etc. In the recent years the emission of aerosols stimulated by military conflict in Afghanistan and Iraq, dusty storms in the Central and South-East Asia was increased. Due to the climate change in Western Siberia the methane emission from the wet soils and wetlands became stronger. As a result of photochemical reactions, the increased concentrations of formaldehydes and other active products are produced. This creates the pre-conditions for arising the situations of ecological risks and demands of particular attention to the planning of economic activity and environmentally protected strategies in the region. From the point of view of system analysis, the methods of orthogonal decomposition along with the methods of sensitivity theory and risk assessment offer a tool which allows one **to move the results of the global atmospheric and climatic studies onto the regional level**. Namely this level puts the concrete questions on the environmental quality and its changes.

In Fig. 2 an example of the long-term risk forecast for Lake Baikal region is given. Monthly mean estimates of the relative input in the quality functional for the receptor-zone from emission of the acting and potentially possible sources in the region ($45^\circ - 60^\circ$ N, $95^\circ - 115^\circ$ E) are shown. For this scenario the atmosphere over the Lake Baikal surface is taken as the evaluated receptor zone. The fragment is 2D section of the 3D risk-function field at the upper boundary of the surface layer. The forecast is made for the typical climatic October (with respect to decomposition analysis of NCEP reanalysis data for 56 years).

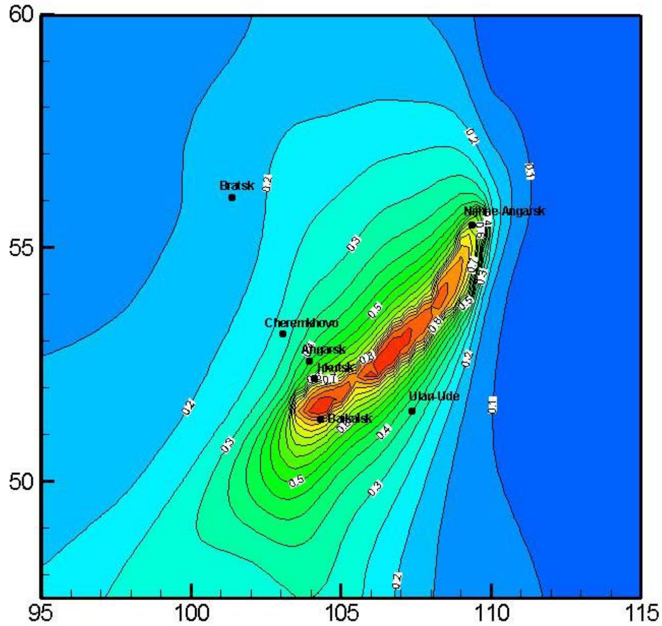

Fig. 2. A forecast of the risks for Lake Baikal region. Monthly mean estimates of the relative input in the quality functional from emission of the acting and potentially possible sources in the region.

It should be noted that cities are not isolated systems. They may as distribute pollution over surroundings as get it from the outside. Thus the problem of mutual risk assessment for the cities should not be underestimated in the specific Siberian conditions, too. The influence of the transboundary transport between Russia, China, Kazakhstan, Mongolia should not be ignored as well. All these problems are connected with ecological safety and life quality.

Further one more example of numerical scenarios for Siberian Federal District (SFD) calculated by the ICMMG team is given. The methodology of environmental modeling described above is essentially used in them. The ecological risks connected with an exchange of pollution between the large cities are given in Fig 3. In this scenario, calculated forward in time, the cities are considered as aggregated sources. It should be noted that we need the emission data to calculate the fields of concentrations and risk assessment.

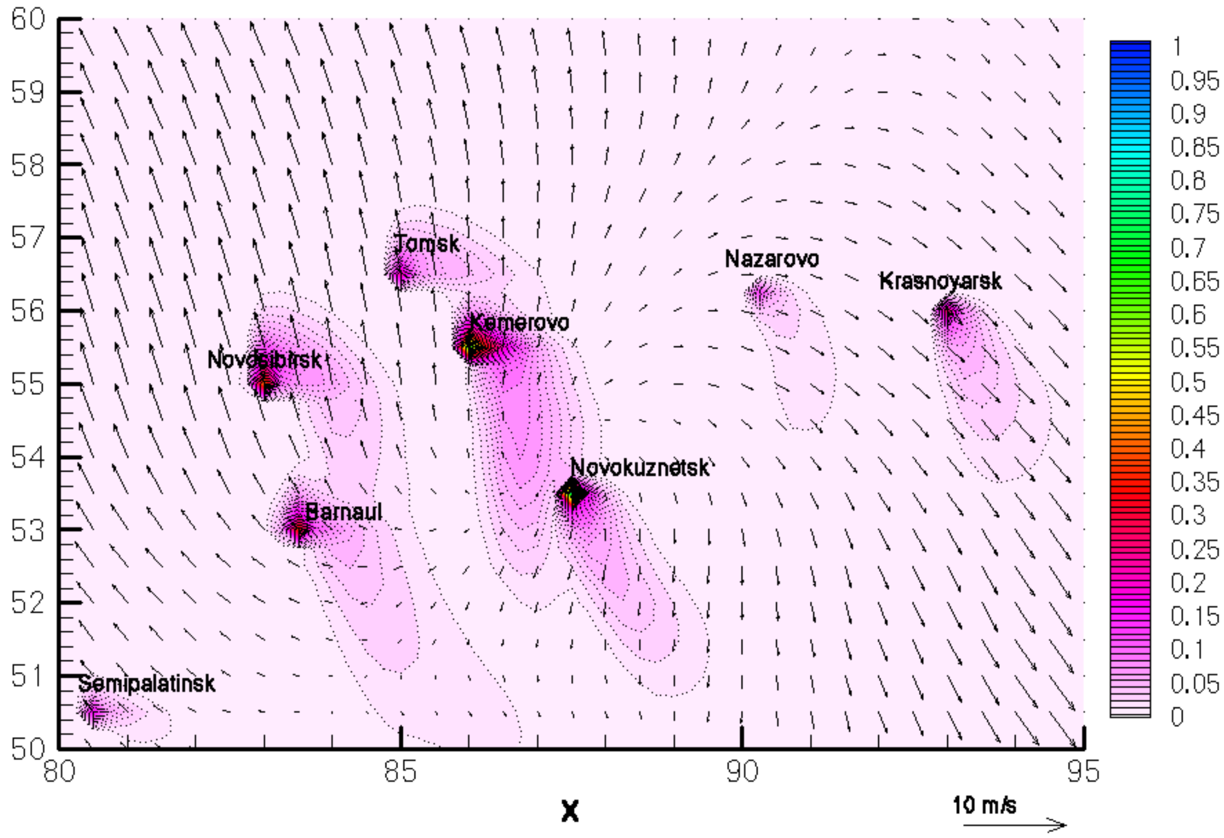

Fig. 3. Pollution of the surface layer of atmosphere in Sibirean Federal District. Big cities are considered as aggregated sources of pollution. Fragment of the forward scenario. Hydrodynamics is reconstructed by means of the regional model taking into account the global circulation. The arrows show the wind field (m/s).

The risk scenarios calculated by means of regional numerical models in the inverse mode do not demand such data for realization of scenarios and risk assessment. Here the cities are considered as receptors and the goal functionals of atmospheric quality in receptors are introduced. In Fig. 4 the risk functions for the cites to get pollution from the acting and potentially possible sources, placed at the surface layer, are presented. The instant snapshot of the risk functions show configuration and relative input of the regions, the emission from which can influence on the atmospheric quality in the receptors. Such data are more informal then those of forward scenarios for the decision-makers, because the role of each source (separately) are seen whereas the forward scenarios give the summarized effect of all sources. A decision-maker should organize the control strategy in each receptor to minimize the product of the values of risk functions (shown in Figs. 2 and 4) on emission amount of the concrete sources in the risk domain for this receptor.

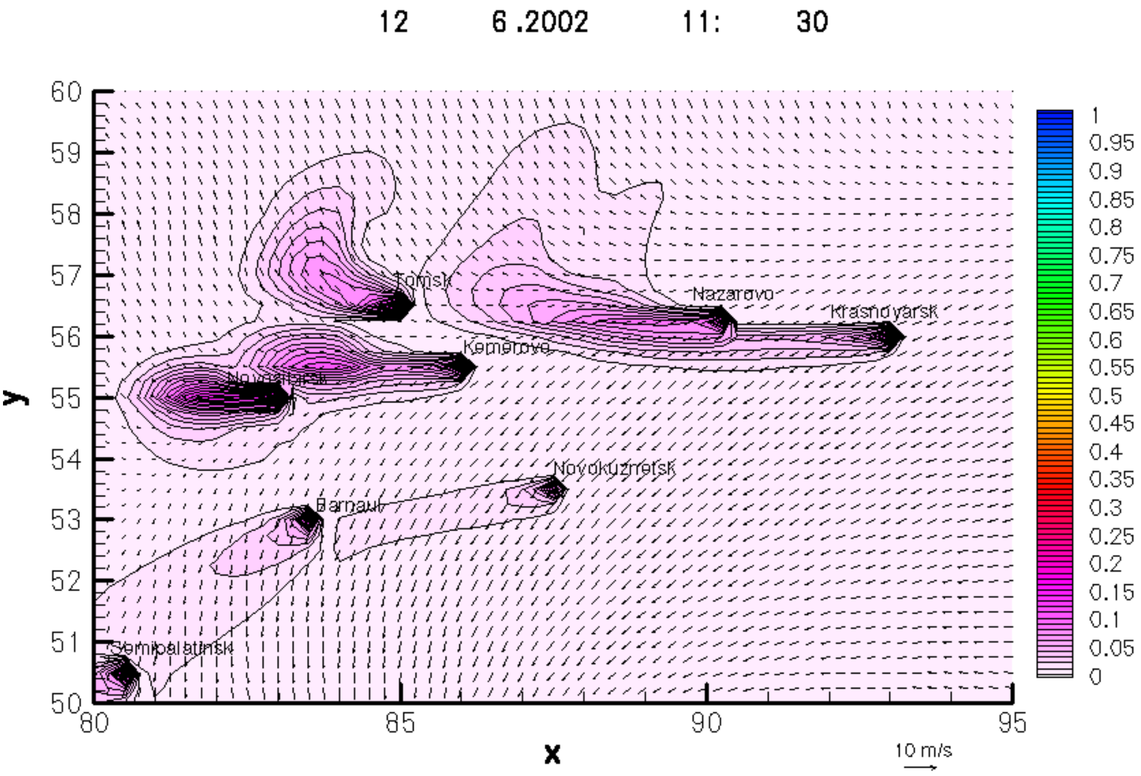

Fig. 4. Fragment of the 4D risk function (relative units) and velocity vector (m/s) for the moment 11:30 12/06/2002 for the cities of Siberian Federal district (surface level).

Climate/Global Change and Risks

The state-of-the-art climate models are based on a combined atmosphere–ocean general circulation model. A central direction of their development is associated with an increasingly accurate description of all physical processes participating in climate formation. This direction appears to be reasonable because, in order to correctly describe the climate system's response (even its first moment) to small external forcing, it is necessary to adequately reproduce not only climate itself but also the dynamics on the attractor of the climate system (the probability of transition of the climate system from one state to another).

In modeling global climate, it is necessary to reconstruct the latitudinal spectrum of its characteristics: seasonal and monthly mean values, seasonal variability (monsoon cycle, parameters of storm-tracks, etc.), climatic variability (its dominating modes, such as El Niño or Arctic Oscillation), etc. At the same time, it is quite urgent now to use modern mathematical models in studying regional climate and ecological peculiarities, in particular, that of Siberia. It is related with the fact that, according to modern ideas, natural environment in mid- and high latitudes of the Northern hemisphere is most sensitive to the observed global climate changes. One should consider such tasks of modeling regional climate as detailed reconstruction of its characteristics, investigation of the peculiarities of hydrological cycle, estimation of the possibility of extreme phenomena to occur, and investigation of the consequences of the regional climate changes for the environment and socio-economic relations as its basic tasks.

Changes in nature and climate in Siberia are of special interest in view of the global change in the Earth system. This special interest has been initiated by some facts. First, the vast continental territory of Siberia (about 10 million km^2) is undoubtedly a ponderable natural territorial region of Eurasian continent, which is characterized by the various combinations of climate-forming factors. Second, forests, water, and wetland areas are situated on a significant part of Siberia, which play planetary important climate regulating role due to the processes of emission and accumulation of the main greenhouse gases (CO_2, CH_4, etc.). Third, the variety of climatic zones in Siberia and the presence of mesoscale regions with extremely high or absolutely absent industrial load create globally unprecedented conditions for scientific investigations of the changes in nature and climate, as well as for revealing the weights of natural and anthropogenic factors in the observed changes. The aforementioned and some other regional peculiarities of Siberia are undoubtedly important reason for integrated regional investigations in this region of the planet. But more important reasons for such investigations are the facts that evidence of the enhanced rates of the warming observed in the region and the consequences of such warming for natural environment. The Institute for monitoring of climatic and ecological systems, Siberian Branch of the Russian Academy of Sciences, is actively participating in such investigations.

Experimental investigations of the real climatic system (monitoring) and theoretical investigations of the global climate system (mathematical modeling) came to a new turning point of combined investigations. To develop such investigations, it is necessary to construct the relevant hierarchy of interacting subsystems in the comprising the global climate system and to improve the description of the physical processes occurring in them. Industrial systems, the role of which, on the quantitative level, has not yet reliably been revealed, occupy special place among similar subsystems with different scales of spatiotemporal variations.

The **A**tmospheric **M**odel **I**ntercomparison **P**roject (AMIP), the first standard experimental protocol for testing the performance of global atmospheric general circulation models (AGCMs) under common specifications of observed ocean boundary conditions, provided a community-based infrastructure in support of climate model diagnosis, validation, intercomparison, documentation and data access (see http://www-pcmdi.llnl.gov/amip). The **C**oupled **M**odel **I**ntercomparison **P**roject (CMIP), which is the analog of AMIP for global coupled ocean-atmosphere general circulation models, emphasises on the reproduction of the sea surface temperature and sea ice distribution (see http://www-pcmdi.llnl.gov/projects/cmip/index.php). The Institute for Numerical Mathematics (INM), Russian Academy of Sciences, participates in both (AMIP and CMIP) programs and some modelling results for Siberia characterize possible evolution of its climate and related risks.

Firstly, it was shown in AMIP that different land surface schemes partition precipitation between evaporation and runoff differently and that this is also responsible for different predictions of basin-scale water budgets. This means that the selection of a land surface scheme for an atmospheric model has significant impacts on the predicted continental and basin-scale surface hydrology. An important output of the AMIP program has been the solution of the following problems: (i) description of the present-day climate (1979–1995), (ii) study of the nature of monsoon circulation, (iii) investigation of the response of atmospheric circulation to an El Niño event, (iv) study of the role of soil processes in the formation of atmospheric dynamics, and (v) investigation of the interaction of radiation with cloudiness related to superabsorption in clouds. Among other interesting problems, one can note the modeling of (i) the stratosphere and mesosphere, (ii) the negative trend of temperature near the mesopause during the past three decades, and (iii) the role (in this process) of increasing carbon dioxide concentration and decreasing ozone concentration in the stratosphere. The recent intercomparison of atmospheric general circulation models made within the framework of AMIP II has shown that the best of these models are presently capable of reproducing the main features of the observed atmospheric circulation with good accuracy. Errors in reproducing many climatic quantities with such models are only slightly greater in value than the uncertainties with which these quantities are determined from observations. At the same time, there are also systematic errors in climate reproduction, which are inherent in virtually all of these models. The most complete analysis of climate reproduction with the models participating in AMIP II can be found at http://www-pcmdi.llnl.gov/amip.

At present, CMIP is being performed to compare the climate-change predictions obtained with different climate models under the scenarios proposed by IPCC (2001) for possible future variations in the atmospheric concentrations of greenhouse gases, aerosols, and other pollutants. This program is a step forward as compared to a similar comparison that was carried out in 2001 and whose results were reflected in the third IPCC report (IPCC, 2001). The results obtained in the course of this program are reflected in the fourth IPCC report (IPCC, 2007). Results of numerical experiments with the INM climate model on reproduction of climate changes in the 20th century and estimation of possible climate changes in the 21st and 22nd centuries in accordance with three scenarios of changes in the contents of greenhouse and other gases (IPCC, 2001) have been used in AR4 (IPCC, 2007).

The IPCC scenarios for future concentration of greenhouse gases were used to estimate possible both global and regional (in particular, for Siberia) consequences. Accordingly to the INM climate model results, the global warming to the end of 21st century will be, depending on scenario, of value from 2.0^{o}C to 3.5^{o}C. The most pronounced warming is expected in Arctic and in middle latitudes, especially, in Russia. For example, under scenario A1B the global warming is expected to be about 3.3^{o}C, while the winter warming in Russia is estimated from 4-6^{o}C in southern part to 8-10^{o}C in northern regions. In summer, the warming in Russia is estimated from 5-6^{o}C in south to 3-4^{o}C in north. Thus, one can expect essential consequences of this warming to the Siberia environment. In Fig. 5 possible catastrophic shortage of the permafrost area in Siberia to the end of 21st century are shown. It might lead to serious risks to infrastructure in Northern Siberia.

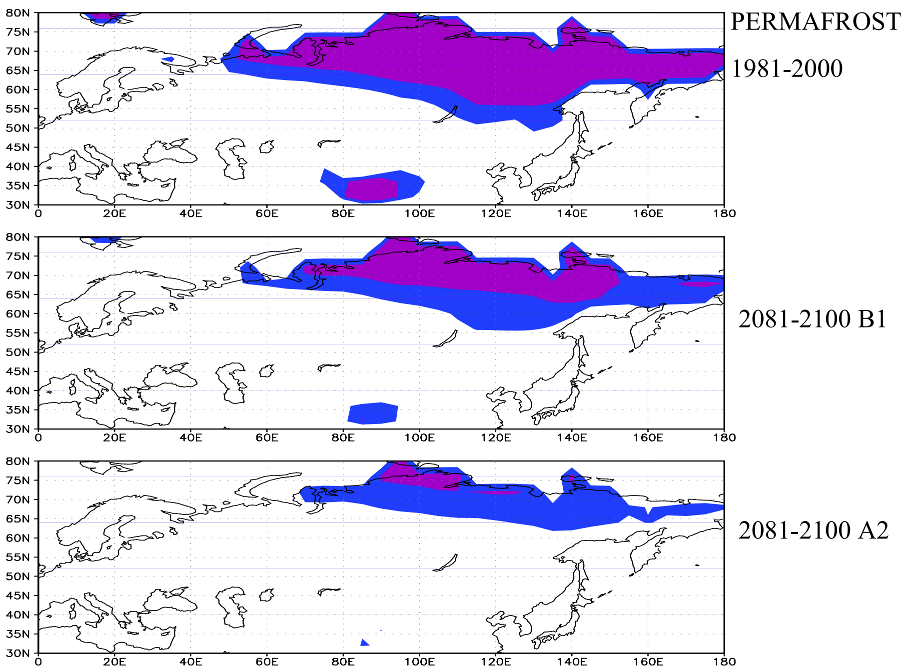

Fig. 5. Spatial distribution of continuous (violet) and sporadic (blue) permafrost as follows from INM climate model experiments: in 1981-2000 (top), 2081 - 2100 under scenario B1 (middle) and in 2081 - 2100 under scenario A2 (bottom).

Results of numerical experiments with the INM climate model show that the possible changes in the snow water equivalent depth (Fig. 6) may be comparable with the present-day quantities, which might increase risks of floods in Siberia.

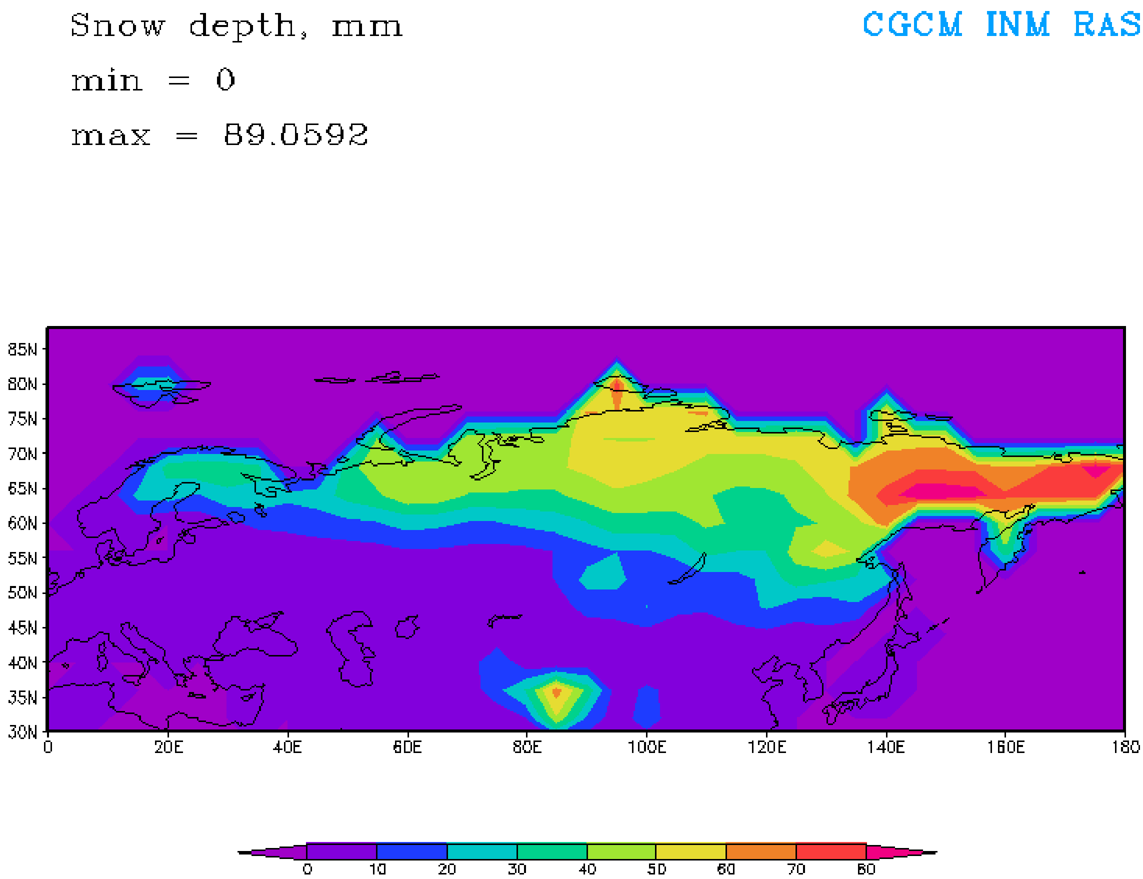

Fig. 6. Spatial distribution of the snow water equivalent depth difference between the IPCC scenario A1B experiment and present-day climate experiment with the INM model.

Cryospheric processes play very important role in the surface energy and water balance under the cold climate conditions. To represent land surface processes in atmospheric models different schemes have been developed, including soil–vegetation–atmosphere transfer schemes (SVATs) that incorporate snow models of the different complexity. At the moment many time series of different meteorological and hydrological characteristics have been accumulated from different field experiments and regular observations. It makes possible thorough evaluation and intercomparison of snow models to understand what snow processes must be represented in the coupled SVAT and atmospheric models.

Developed in INM one-dimensional model of the atmosphere-soil interaction was used to perform a series of experiments with a one-dimensional model of heat and moisture transfer in the snow – permafrost system on the base of routine observations made at the Franklin Bluffs research station (Alaska) and four meteorological stations located in northern and central Siberia. The model is shown to be capable of reproducing qualitative and quantitative features of the thermal conditions in permafrost. The ground temperature and the depth of seasonal thaw are shown to be highly sensitive to processes that affect snow densification. It is also shown that the thickness of the active layer is highly sensitive to variations in the moss – lichen – peat cover depth, which is relatively small in nature.

Implications of global climatic change to Siberia and Siberian contributions to global climate change are two sides of one medal. Globally effective anthropogenic influences are of relevance on local scales, while local response to these implications on the global scale. Linked with this anticipated changes are potential risks or unknowns, which are related for example with changes in land cover/land use (fires, forest logging, transition steppe ⇆ agriculture), changing permafrost conditions (deepening of active layer, destruction of frozen soil C stores) or changes in snow cover, sea ice extension, etc. which might provoke alterations in atmospheric circulation schemes. One aim of scientists is therefore the qualification and the quantification of the occurring processes and their effects on ecosystems and the atmospheric composition and circulation patterns. This goal needs at least a description the previous conditions, the acquisition of the actual status and predictions regarding the future development.

The Siberian boreal forest is a significant component of the global carbon cycle, since it stores about 10% of the global terrestrial carbon in vegetation and soils, whereby about 65% of the Siberian forests contain permafrost with a carbon storage assumed to be in the order of roughly 400 PgC. Environmental risks, i.e. affections by anthropogenic influences via global climate change, as well as direct impacts on the local/regional scale will provoke changes and adaptations of the present ecosystems. Recent research on the impacts of climate change in high latitudes has mostly assessed the “equilibrium” response of ecosystems. An example is the question what the “potential” location of the Arctic tree-line or the southern limit of permafrost would be under conditions of global warming. However, of much greater importance, not least from a political perspective, are transient responses of the climate system. Examples of such questions are: How quickly will the Arctic tree-line migrate? How quickly will permafrost thaw? How quickly will enhanced soil organic matter decay result in increased greenhouse gas emissions? Different time lags in these processes will cause significant deviations from the equilibrium response.

To answer some of these questions, a carbon cycle block is included into the INM climate model. This block includes description of the plant, soil, ocean and atmospheric carbon evolution. The model was run from 1860 to 2100 with prescribed scenario of CO_2 emission due to the fuel burning and land use. It was found that the simulated spatial distribution of carbon in plants, soil and ocean agrees with present estimations. The model is capable to reproduce observed increase of CO_2 in 20-th century as well as the absorbing of additional carbon by terrestrial and marine ecosystems in 80-th and 90-th years of 20th century. The feedback between climate change and carbon cycle in the model is found to be positive with the feedback coefficient close to the value obtained by averaging over all present-day climate models with the carbon cycle. The global warming in 2081-2100 with respect to 1981-2000 is found to be equal 2.3 degrees.

By using global climate change scenarios as driving fields, one can obtain permafrost dynamics in high temporal resolution on the order of years. For the 21st century under the IPCC SRES scenarios A2 and B2, an increase of mean annual ground temperature by up to 6 K (Fig. 7) and of active layer depth by up to 2 m within the East Siberian transect are found. According to these simulations, a significant part of the transect will suffer from permafrost degradation by the end of the century.

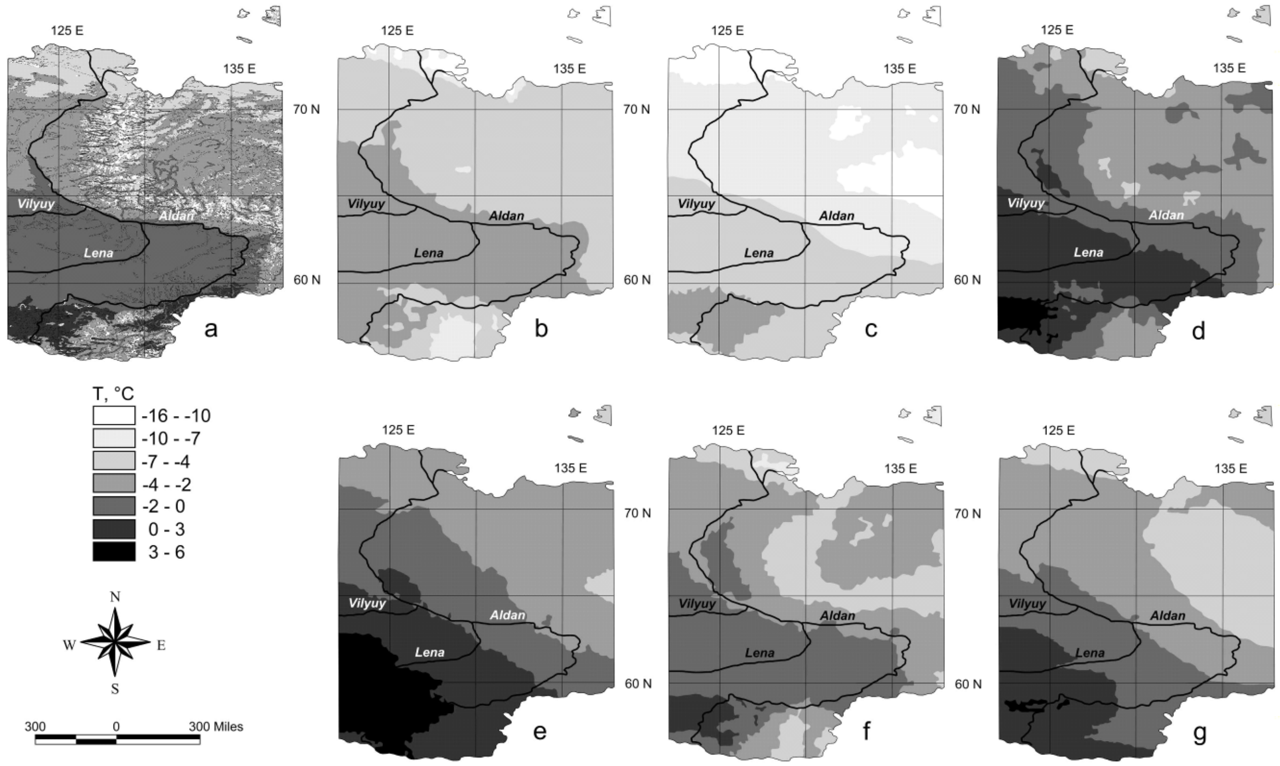

Fig. 7**.** Temporal change of mean annual ground temperature [°C] (a) derived from the Map of Landscapes and Permafrost Conditions in Yakutia (scale 1:2,500,000) (Melnikov, 1988) , GIPL model forced with (b) HIRHAM control run, (c) ECHAM control run, (d) HIRHAM, scenario A2, average 2071-2100, (e) ECHAM, scenario A2, average 2071-2100, (f) as (d) and (g) as (e), for scenario B2.

Large amounts of soil carbon deposited in permafrost may be released due to deeper seasonal thawing under the climatic conditions projected for the future. An increase in the volume of the available organic material together with the higher ground temperatures may lead to enhanced emission of greenhouse gasses, in particular, of methane, which has a much stronger greenhouse effect than an equal amount of CO_2. Production of methane is favoured in the wetlands, which occupy up to 0.7 million km^2 in Russian permafrost regions and have accumulated about 50 Gt of carbon (Gt C). In the abovementioned paper, a permafrost model and several climatic scenarios are used to construct projections of the soil temperature and the depth of seasonal thawing. To evaluate the effect of such changes on the volume of the seasonally thawing organic material, the permafrost projections were overlaid on the digitized geographically referenced contours of 59 846 wetlands in the Russian Arctic. Results for the mid-21st century climate indicated up to 50% increase in the volume of organic substrate in the northernmost locations along the Arctic coast and in East Siberia, where wetlands are sparse, and a relatively small increase by 10%–15% in West Siberia, where wetlands occupy 50%–80% of the land (see Fig. 8). A soil carbon model was developed to estimate the changes in the methane fluxes due to higher soil temperature and increased substrate availability. It was found that by mid-21st century the annual net flux of methane from Russian permafrost regions may increase by 6–8 Mt, depending on climatic scenario. If other sinks and sources of methane remain unchanged, this may increase the overall content of methane in the atmosphere by approximately 100 Mt, or 0.04 ppm, and lead to 0.012 °C global temperature rise.

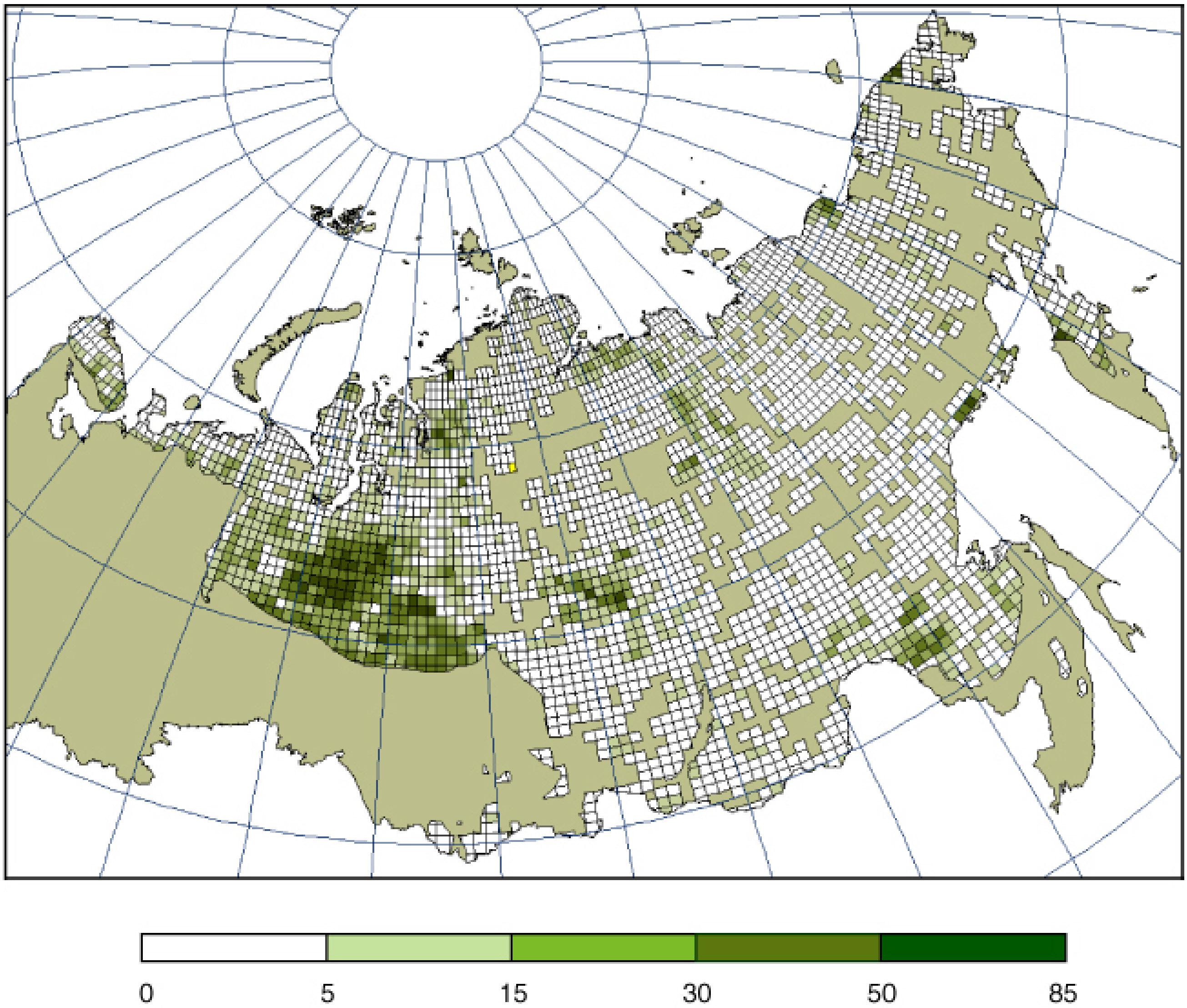

Fig. 8. Fraction of land area occupied by wetlands in Russian permafrost region (Anisimov, 2007).

It should be noted that current development of mathematical models of climate is characterized by a permanent increase of its spatial resolution and by the rejection the hydrostatic approximation (at least in regional models). These tendencies cause new problems in the parameterization of subgrid-scale processes. Among those problems one of crucial importance is the interaction of the atmosphere with hydrologically heterogeneous land – the territory, occupied by a dense network of water bodies (lakes, rivers, wetlands, etc.), covering a significant fraction of the total area. A good example of hydrological heterogeneity is the territory of Western Siberia (where water bodies occupy up to 50% of the area), Karalee, and North America. Due to the difference in the vertical heat exchange mechanisms between water bodies and soil, the distribution of surface temperature in such a territory in warm season is very heterogeneous: during daytime water bodies (for example, lakes) act as cold patches, and at night as 'heat islands', initiating in both cases breeze like circulations. Under conditions of strong synoptic flow, the breeze circulation is almost negligible, but even in this case lakes still considerably affect the structure of the boundary layer. Thus, it is possible to suggest that the further improvement of land-surface schemes might be done by taking into account effects of the land surface heterogeneity.

Analysis of results of reproduction by the INM climate model of regional features of the atmosphere and land interaction has shown that there are systematic errors in characteristics of heat- and moisture exchange in the Western Siberia region in warm season. It is important to stress out that widely used NCAR/NCEP reanalysis data and ECMWF reanalysis data are significantly differ in this region. The possible reason of this inconsistency could be non-adequate accounting of hydrological processes. In many forecast models and land data assimilation systems inland waters are considered as land surface elements. In reality, lakes in middle and high latitudes are vertically stratified on density.

Moreover, the current development of climate models is characterized by a permanent increase of spatial resolution. This tendency causes new problems in the parameterization of subgrid-scale processes. Among those problems one of crucial importance is the interaction of the atmosphere with hydrologically heterogeneous land – the territory, occupied by a dense network of inland waters, covering a significant fraction of the total area (for example, the territory of Western Siberia). Two-way approach might be employed to solve this problem: an aggregation of subgrid-scale turbulent fluxes and the use of a physically sound and computationally efficient lake model capable of predicting the lake vertical temperature structure, as well as the evolution of the ice and snow cover. It is especially important to reveal the climatic characteristics (as well as the accuracy of their determination) necessary to simulate hydrologic processes (with consideration for the response of the latter to variations in the corresponding climatic characteristics). With the aim to study processes of interaction of the atmosphere and underlying surface, covered by a dense net of hydrological objects the one-dimensional model of lake was included into nonhydrostatic mesoscale atmospheric model.

Basic processes, which form the annual cycle of climate, are connected with seasonal changes in the thermal regime of the atmosphere over continents, in the large-scale atmosphere – ocean interaction and in the latitudinal heat and mass exchange. The consideration of four seasons, two of which one can call as extreme seasons (winter and summer) and two others as transition seasons (spring and autumn), is connected with changes in the annual cycle of the solar radiation, which achieves extreme values in winter and summer and is sharply changing in transitional seasons. As it is stated in (IPCC, 2007), many regional climate changes can be described in terms of preferred patterns of climate variability. For example, the North Atlantic Oscillation (NAO) is a measure of the strength of the Icelandic Low and the Azores High, and of the westerly winds between them. When the atmospheric pressure over the central Atlantic is higher than normal, strong westerly winds transport heat and precipitation toward Northern Eurasia more intensively.

Hydrologic consequences of climate changes are of importance for the region as well. The problems under consideration now were mainly related to the following lines of investigations: (1) identification of variations in water balance and river runoff under conditions of changing climate according to multiyear hydrological and meteorological observations; (2) analysis of variations in hydrological and meteorological characteristics on the basis of modeling global processes (with the use of atmospheric circulation models); (3) estimation of the response of important hydrologic systems to possible climate changes; (4) analysis of the influence of climate changes on the recurrence and characteristics of extreme hydrologic phenomena; (5) consideration for uncertainty in determining (modeling) hypothetical climate changes in estimating their hydrologic consequences; and (6) consideration for possible climate changes and their hydrologic consequences in the planning and development of water-related activities. Much attention is given to the indicated problems as applied to water bodies and hydrologic processes under the natural conditions of Siberia and the northern region. In particular, it is noted that a characteristic feature of the formation of river runoff in northern Siberia under permafrost conditions is the influence of the hydrologic conditions of the preceding year. Under these conditions, when the air temperature becomes negative, a certain portion of the water reaching watersheds is conserved in the overwetted soil and only next year does it take an active part in the water cycle and in the formation of runoff.

From the data obtained from the **T**errestrial **C**arbon **O**bservation **S**ystem Siberia (TCOS-Siberia) project the expected high inter-annual variability of terrestrial carbon fluxes became clearly obvious, that is driven by the large variability of climate and fire occurrence. A very interesting finding was that Siberia seems to be a smaller sink than generally assumed: the amount of the carbon sequestration of Siberia is only less than 20% of the fossil fuel emissions from the Russian Federation. Thus, the question if Siberia acts on a long-term scale as source or sink for carbon is still unsolved. In consequence, the continuation of measurements is mandatory, with broadening the focus on additional effects due to climate change for example on permafrost and ecosystem migration, and on effects of local and regional anthropogenic impacts. Globally effective anthropogenic influences are affecting directly the local scale, while local contamination and exhaustive cultivation are responsible vice versa for global impacts. Max-Planck-Institute for Biogeochemistry (MPI-BGC) has a great experience in ecological and atmospheric scientific research and conducts several projects focusing on Siberian key ecosystems and atmospheric research with respect to climate change (Sabine et al., 2003, Canadell et al., 2004). From these studies status information of environmental conditions and their response to global and local impacts can be provided, information will become available also from on-going activities. As an example, Fig. 9 presents CO_2 data from the lowest flight level at Zotino profile site (~60°N / ~90°E).

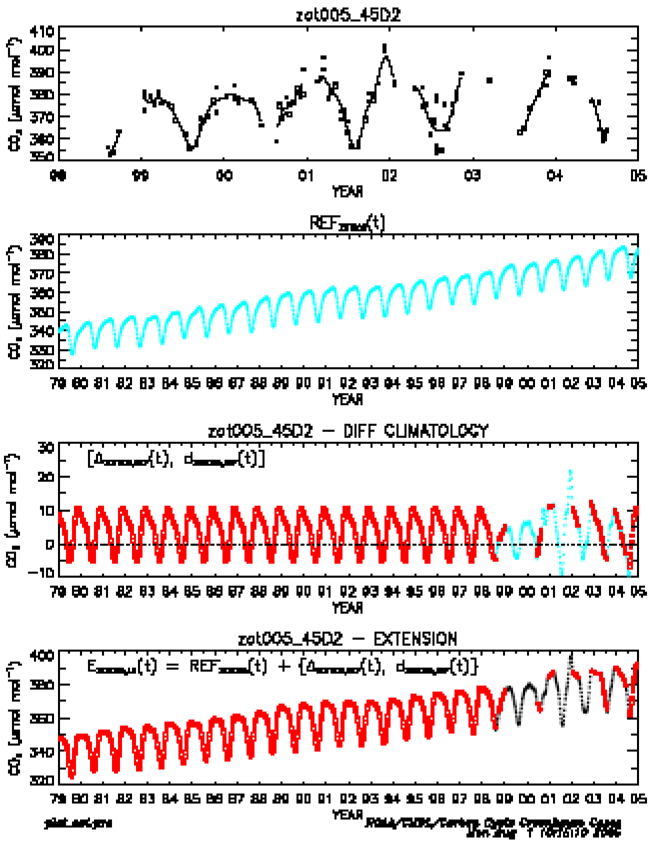

Fig. 9. CO_2 data from the lowest flight level at Zotino profile site (implemented in NOAA/CMDL GLOBALVIEW-CO_2 database). [Panels from top to bottom : top - Time series of CO_2 mixing ratios; middle - Reference marine boundary layer time series; bottom - Difference between measurement and reference (blue circles; interpolated *red circles* and extrapolated *red squares* differences) and extended record including smoothed measurement data and interpolated and extrapolated values derived from data extension procedure].

Terrestrial Ecosystems and Hydrology and Risks

A list of the most substantial ecological and landscape-ecosystem consequences of expected climatic change includes, *inter alia*:
(1) permafrost degradation (decreasing the total area of permafrost is predicted to be 10-18%; 15-30% and 25-35% by 2030, 2050 and 2080, respectively; the area of continuous permafrost will likely decrease by 25-50% by 2080; intensive development of thermocarst, paludification (or aridity depending on geographical distribution and landscape peculiarities, with following processes of northern steppization and "green desertification" there);
(2) increasing sea level and flooding coastal areas, change of salinity regime of low reaches of rivers, change of ecological processes in deltas, substantial intensification of processes of coastal erosion;
(3) acceleration of rates of decreasing sea ice, shrinking ice cover of Arctic seas, and – in future – change to the global cycle of fresh water;
(4) shifting of all types of vegetation to the north; this process will result in a substantial (in some assessments – two-fold by the end of the century) decrease of forested area, increase of steppes and, specifically, a substantial increase in the area of desertified steppes; this will impact biodiversity, standard of life of local population and conditions for wild animals;
(5) acceleration of natural disturbances, such as fire and insects' outbreaks; wild fires in Asian Russia in 2003 (the satellite estimate of areas enveloped by vegetation fires comprised about 23 million ha) and the outbreak of Siberian moth in Larch forests of middle taiga in 2001-2002 (an area more than 10 million ha) clearly demonstrated the scale of expected natural disturbances in the "catastrophic" weather conditions years;
(6) transformation of the hydrological cycle including a change of runoff of large Siberian rivers, the condition and dynamics of vast wetland territories of West Siberia and north of the region;
(7) dangerous acceleration of major biogeochemical cycles, basically at the expense of a thermal increase of carbon emissions (as CO_2, CO and CH_4) because the majority of carbon is accumulated in organogenic soils, permafrost and hydrates of northern seas; and
(8) steady deficit of water resources and losses of yield of agricultural crops and pastures in southern regions.

It is very likely that climatic changes will directly impact human health and living conditions in a clearly negative way due to increasing severity and frequency of extreme climatic phenomena, such as flooding, increasing wind, and – in southern parts of the region – increased number of hot days, heat waves, and longer and more intensive dry periods. Additionally, warming increases the danger of infectious diseases, particularly those which are distributed by insect-carriers or by water. Sharp intensification of epidemic processes caused by intestinal infection in the south (sometimes – up to a unprecedented level), increasing parasitic and non-infection pathology, and evident northward shifting of the areas of carriers of infection, are already observed in different regions of Siberia.

Current peculiarities of social and economic development of Siberia which are accompanied by the destructive anthropogenic impacts on the environment and natural landscapes may substantially accelerate the negative consequences of climatic change. Methods existing today of industrial exploitation of northern territories do not provide for any optimistic estimate of future interactions of the industry and environment in Siberia. The level of atmospheric pollution and soil contamination in major regions of intensive oil and gas extraction has exceeded all acceptable limits. The rate of contamination has been increasing. The quality of river water, specifically in southern regions with maximal density of population does not correspond to the norms of water use for drinking and fisheries. The governance of natural resources (in particular, forests) and the control of the use of natural resources are below a critical level. The impacts of toxic anthropogenic water contamination, the decline of the human immune system, increasing stresses, impacts of many negative social phenomena connected, among others, to intensification of migration processes, with a high probability will accelerate the negative impacts of climatic change on standards of life and health of the population, as well as enforce undesirable feedbacks.

Land use – land cover change (LULCC) in the region during the last decades was mostly driven by economic processes and inherited specifics of wrecking systems of natural resources used. It revealed in impoverishment of forests and decreasing their quality over large areas (decreasing areas of valuable coniferous forests; restoration of forests through change of species; increasing areas of burnt areas and dead stands etc.), particularly in densely populated areas. From other side, the restoration potential of boreal forests remains very high that results in restoration of disturbed areas and encroachment of forests and shrubs in previously non-forest areas. The second typical feature of LUCC is abandonment of agricultural land in the forest steppe and steppe zones of the region. Such lands are out of any management activities now that transforms these territories in weed- and disease-breeder. These lands require a special program of reforestation taking into account expected climatic conditions in the ecotone forest-steppe.

During the last decade, there were substantial findings of research on the topic received by a number of institutes of Siberian Branch of RAS; regional and central universities; such Western and international institutions like Max Plank Institute of Biogeochemistry (Jena, Germany); Friedrich-Shiller University (Jena, Germany); National Institute of Environmental Studies (Tsukuba, Japan); International Institute for Applied Systems Analysis (Laxenburg, Austria); some others. Results of these studies help much in development of information base, methodologies and models of integrated approach.

We present only one example. Detailed estimates of gross and net growth, mortality, phytomass, and NPP of the terrestrial vegetation at the regional and country scale attempting at estimating of uncertainties of the results were done by IIASA together with Siberian institutions. All indicators were estimated in a consistent way using information of the State Forest Account (SFA) -2003 by each forest enterprises (of the total amount of ~ 2000) by a definite data based on a specially developed modeling system. The system includes: (1) regionally distributed models of growth of stands of major forest forming species; (2) multi-dimensional models of live biomass (phytomass) and (3) models of biological production of forest ecosystems. Uncertainties of the results were analyzed with an approach developed by the International Institute for Applied Systems Analysis for large-scale complicated ecological tasks which do not allow direct formal verification. This approach takes into account the fuzzy character of the ecological problem considered and is based on system integration of available results received by methods of a different nature. It allows (1) providing reliable and comprehensive assessment of uncertainties at level which is sufficient to be used in other tasks and by policy makers; (2) to use these results as empirical validation information in modeling approaches of different nature.

At the same time, current knowledge of specifics and consequences of global change is limited; levels of uncertainties of estimates and predictions are high and often unknown. Many questions that are vital for future generations require in-depth consideration and analysis. These questions include such fundamental problems as thresholds of acceptable (not destructing) impacts on ecosystems taking into account non-linear and multi-variant responses of ecosystems to long-term accumulation of stresses; system (holistic) analysis of complicated systems which contain components of different nature – biophysical, ecological, social and economic; theory and practice of decision making under uncertainties; development of integrated observing systems; and many others.

In spite of numerous projects in the region on the topic, there are many gaps and weaknesses in information background, organizing and coordinating research of changing environment, ecosystems and use of natural resources. These gaps are mostly dealt with needs of empirical data which would be complete with respect to major parameters of ecosystem functioning, spatial and temporal coverage of data. The Siberian Branch of the Russian Academy of Sciences which is main coordinator and driver of science in the region does not have enough resources to cover all scientific needs of huge, fragile and dynamic territories. Under such conditions, existing science Programs are not able to completely carry out their coordinated role. International efforts implemented in the region are fragmented and – by definition – cannot serve as an overall organizing base, although such integrated activities as Global Carbon Project of IGBP and NEESPI (Northern Eurasia Earth System Partnership Initiative) play an evident important role.

System combination and coordination of research of the abovementioned type require a new systems approach, which would be able to provide a real interdisciplinary integration of different problems and methods; would involve all relevant scientific institutions of the region; accumulates available resources; involves all major stakeholders, local authorities and business; and finally would bridge of science –policy – implementation. Such an approach could be realized within the ***Siberia Integrated Regional Study***. The Enviro-RISKS project substantially contributed to understanding of science plan and institutional decisions of SIRS.

Problems connected to global change still are not considered as a basis for important social, economic and management decisions in many countries of the world including Russia. The country as a whole, and Siberia particularly, require urgent development of a long-term strategic program of adaptation of natural landscapes and all parts of the regional economy to climatic change, and the mitigation of negative consequences of climatic change. The Siberian program should have a clear regional character in all ramifications – in assessment of predictions, by priorities and objectives, and by ways of practical implementation. The program should have a solid legislative, economic and social basis. Without such a program, all speculations on the transition to sustainable development of Siberia would remain only words and far from reality.

Information Systems for Environmental Sciences, Integration and Synthesis

It is clear nowadays that a very beneficial synergy effect could be achieved by closely coupling the areas of Environmental Sciences (ES) and Information-Computational Technologies (ICT) that is for an interdisciplinary field concerned with the interaction of processes that shape our natural environment (ecology, geosciences, hydrology, and atmospheric sciences), and the way that these processes are "mapped" into an information system architecture and are dealt with, via relevant software tools. This fact is acknowledged by managing bodies of SB RAS and forms the mainstream of this domain current development in Siberia. Major efforts here are undertaken either in attempt to provide GIS platforms with required web accessibility, computing power and data interoperability or to exploit completely huge potential of web bases technologies.

Recent development of Earth and Space Sciences Informatics resulted in appearance in the region a set of powerful information-computational web systems organized as scientific web portals devoted to different areas of Earth Sciences. The first step in this direction was done in course of development of the bilingual (Russian and English) scientific web portal ATMOS (http://atmos.iao.ru/). ATMOS is designed as an integrated set of distributed but coordinated topical web sites, combining standard multimedia information with research databases, models and analytical tools for on-line use and visualization. The main topics addressed are from Atmospheric Physics and Chemistry domain. It should be noted that in spite of the fact that the portal middleware employs PHP scripting language (http://www.php.net/), it has quite flexible and generic nature, which allows one to use it for different applications. Currently on this basis are developed and launched web portals, providing distributed collaborative information-computational environment to organizations/researchers participating in execution of EC FP6 projects "Environmental Observations, Modelling and Information Systems " (http://enviromis.scert.ru/) and "Enviro–RISKS - Man-induced Environmental Risks: Monitoring, Management and Remediation of Man-made Changes in Siberia" (http://risks.scert.ru/). The portals are also powerful instruments for dissemination of the projects results and open a free access to collections of regional environmental data and education resources. Namely these portals provide an infrastructure for integration and synthesis of environmental RTD activity in the region.

The bilingual ATMOS web portal comprises information resources on physics and chemistry of atmosphere (http://atmos.iao.ru) as well as those on air quality issues and two Siberian territorial objects, which are West Siberia and Lake Baikal (http://atmos.scert.ru). It provides a qualified user with opportunity to get relevant information on all levels of relevant physical and chemical processes descriptions. To provide the portal with such functionality, a special middleware was designed. Based on it, portal operates as an Internet accessible multi-user system oriented on applied problems solving. In it user can solve typical problems from the thematic domains, save intermediate of final results on the server side, compare results with stored in the system experimental or computational data (this functionality is supported for molecular spectroscopy only), etc. An apparatus part comprises three components, which are database server, applications server and computational cluster oriented to atmospheric chemistry and climate problems solving. The middleware consists of a set of services and a transaction processing monitor, which performs function of a dispatcher of each user request and of some services. Each thematic site of Atmospheric Physics and Chemistry group is based on databases or data sets inherent to its thematic domain. Computational models accessible in the portal after registration include in particular three scale models: global GCM model of the RAS Institute for Numerical Mathematics (INM), regional scale models Mesoscale Model 5 (MM5) and Weather Research and Forecasting Model, and models of city level. The INM climate model is equipped with a comprehensive physical package that includes advanced parameterizations of the boundary-layer turbulence and air-sea/air-land interaction, solar radiation transfer, land surface and soil hydrology, and other climatic processes (http://climate.atmos.iao.ru/).

The bilingual (Russian and English) Enviro-RISKS web-portal (http://risks.scert.ru/) is aimed at dissemination of information on general environment issues adjusted also for usage in education process and giving an access to regional environmental data and instruments to process them on-line. The portal is organized as a set of interrelated scientific sites, which are opened for external access. The Portal engine employs ATMOS portal software. The portal opens easy access to structured information resources on Siberia environment and to results of project expert groups studies devoted to regional environment management under anthropogenic environmental risks. A built-in Intranet is used as an instrument for project management as well as for exchange and dissemination of information between the project partners. The portal gives also an access to gathered and analyzed detailed information on all coordinated projects, gathered and systemized results and findings obtained including relevant observation data and information resources, distributed database, which will provide an access to data on characteristics of Siberian environment to the project partners and an access to relevant metadata to all interested professional community. The basic thematic sites currently integrated into the Enviro-RISKS web-portal are the Climate site aimed at an access to specially designed analytical tools allowing to get spatial pattern of selected Siberia climatic characteristics from measured or simulated data sets and the Air Quality Assessment site, which compiles basic and applied aspects of air pollution and environmental impact assessment. Special site is devoted to dissemination of information about the Enviro-RISKS project and its outcomes.

The Climate site of the portal (http://climate.risks.scert.ru/) upon a qualified user request gives an access to interactive web-system for regional climate change assessment on the base of standard meteorological data archives. The system is a specialized web-application aimed at mathematical and statistical processing of huge arrays of meteorological and climatic data as well as on the visualization of results. The data of the first and second NCAR/NCEP Reanalysis editions, European and Japanese Reanalyzes are currently used for processing and analysis. Grid Analysis and Display System (GrADS, http://www.iges.org/grads/) and Interactive Data Language (IDL, http://www.ittvis.com/idl/) are employed for visualization of the results obtained. The system graphic user interface is a dynamic web form to choose parameters for calculation and visualization and designed using HTML, PHP and JavaScript languages. Currently system allows performing for chosen spatial and time ranges the following mathematical and statistical operations, key for the climate assessment: calculation of maximum, minimum, average, variance and standard deviation values, number of days with the value of the chosen meteorological parameter within given range, as well as time smoothing of parameter values using moving averaging window. It is also possible to calculate correlation coefficient for an arbitrary pair of parameters, linear regression coefficients between some pair of characteristics and to determine first (last) cold (warm) period (such as day, week, month) of the year. The user interface allows one to choose geographic domain, time interval, characteristic of interest and visualization parameters. User can choose a geographical domain of interest, type of statistical characteristic, interval for averaging, altitude level, and so on. While calculating averages with moving window, which width can be specified as week, month, three months, half of the year and year, one gets the smoothed sequence of spatial distributions for the characteristic of interest. This set is represented as an animation, which can be viewed either in automatic or in controlled regime. Below several shots from such sequence are shown including the control bar specifying the viewing mode. The system allows to perform different mathematical and statistical operation, including calculations of mean values, standard deviations, determination of the first (last) warm (cold) day (week, month) of the selected year, amount of days with precipitation from the given interval etc. Comparison of characteristics retrieved from different data sets is also possible. Possibility to calculate time trends is also realized in the system.

The web-system for Tomsk air quality assessment (http://air.risks.scert.ru/tomsk-mkg/) deployed at the portal is based on mathematical modeling of the pollution transport and transformations. It is aimed at effective air chemical composition assessment and forecast in the conditions of the industrial city area and its suburbs. The technique applied is based on the meteorological observations, taking into account atmospheric emissions of industrial enterprises and traffic, measurements of the concentration of the atmospheric pollutants as well as on the numerical modeling of the gaseous substances transformation and transport processes in the atmosphere. Currently air quality data sets for assessment of Tomsk area air pollution used by the system are obtained with the help of the pollution transport mathematical model employing meteorological characteristics fields calculated with prognostic meteorological models for selected periods within 2000 – 2006. The model takes into account transport, dispersion and dry deposition of the pollutants as well as their photochemical transformations. The system allows a registered user to get visualized results of such characteristics as average monthly and seasonal pollutions along with their annual dynamics as well as daily dynamics for various pollutants. User can select “Air pollutant” with such options as airborne particulate matter, sulfur dioxide, nitrogen dioxide, carbon oxide and ozone, “Atmospheric layer altitude” ranging from 10 to180 meters, “Characteristic to compute” (it is possible to calculate such characteristics as average pollution for month, season and their dynamics within the time interval, and hourly dynamics during the selected day), Date range, graphical output type and picture size. There is also a possibility to choose animation frame rate to see dynamics of the concentrations. It should be added that the system has generic character and being provided with characteristics of industrial and transport pollution sources, local meteorology data, surface properties and generated by the photochemical transport and transformations model pollution data sets it can be easily adjusted for conditions of another Siberian city.

The system for web-presentation of climate modeling results (http://83.149.207.89/GCM_DATA_PLOTTING/GCM_INM_DATA_en.html) developed at the Institute for Numerical Mathematics contains description of the INM climate model and results of numerical experiments with this model and launched it at the INM site (http://kvs.inm.ras.ru/index.html). These numerical experiments were devoted to reproduction of climate change in the 20th century and estimation of possible climate change in the 21st and 22nd centuries. At the moment, there are 3 options: 1) the description of the model and experiments, and some selected publications, 2) tools to calculate and plot one-dimensional data, and 3) tools for two-dimensional data post-processing and plotting. An user of this database has a possibility to learn on the present-day state of climate and climate change mathematical modeling, to extract the digital information related to modeled climate, to calculate and plot geographical distributions of climate characteristics for selected regions. Additionally to the coupled atmosphere–ocean general circulation model, an atmosphere model coupled with a simple balance model of the heat content of a homogeneous 50-m ocean layer is used. This model also involves the calculation of sea ice and uses the correction of heat fluxes at the ocean surface. Such a simplified coupled model allows prompt obtainment of an equilibrium response to a prescribed external forcing, for example, to an increase in the CO_2 concentration. Results from a number of numerical experiments with this model are available at the site.

GIS technology is well adapted to the important for region tasks of monitoring and modeling of atmospheric pollution as well as of oil pollution of bogs or flooded territories. KazGeoCosmos developed GIS systems solving the both problems. Here are used space survey data to detect air or oil pollution and results of forecast modeling of pollution spreading in atmosphere or along the flooded/ bog areas, respectively. In particular, the system developed covers all stages of computation of air pollution from multiple oil/gas industry sources, from the location of well head flares to prognostic calculation of combustion materials distribution. Relevant mathematical models are plunged into GIS developed in ArcGIS environment customized to the conditions of region and all the modeling and analysis phases are accomplished in the informational sphere, based on the real data. Such approach known as geoinformation modeling is quite promising to practical applications.

For the purpose of unification of the methods of information systems development intended for the in-depth analysis of satellite survey data, a prototype was developed for the system of geoinformation modeling of territorial processes SysGISM (System of GIS - Modeling). Solutions implemented in SysGISM are quite universal and can be used for the region of Siberia as well. UML (Unified Modeling Language) was chosen as a project tool. Preliminary analysis showed that UML suited the modeling of any system: from enterprise level information systems to distributed Web-applications to even built-in real time systems. According to this method SysGISM project was done with UML stage by stage: (1) target setting, (2) analysis, (3) designing, (4) system programming. SysGISM supports operation of different GIS-technology applications; allows its usage as an analyzing subsystem; and provide possibility of complex analysis of remote survey data, surface survey data and results of scientific researches of certain territorial processes. The system developed supports the communication between the users and designers of different territorial tasks, stores all related data on the territory and processes and provides advanced GIS service for storing and processing of data through respective interfaces.

Significant step to integration of web and GIS resources was done in process of the SB RAS GIS-portal development (http://gis.sbras.ru/). Here two web-accessible Geo-Informational Systems were created and supported at the information sites of ICT SB RAS (http://gis.ict.nsc.ru/) and ICM SB RAS (http://gis.krasn.ru/). These systems consolidate several GIS-servers containing various databases. Among those are Remote sensing data server and Atmosphere aerosols of Siberia server. Remote sensing data server gives access to web-tools for selection and visualization of satellite data obtained from AVHRR, HRV, MSS, TM, ETM+ and SPOT instruments. Atmosphere aerosol server contains database of surface atmosphere aerosols observation results collected in Western Siberia, and gives web-access to processing and visualization of them.

Integration and synthesis of the developed in the region IT tools occurs in process of development of the Siberia Integrated Regional Study (SIRS), which also forms a test bed and major users community for those. SIRS (http://sirs.scert.ru/) is one of realizations of suggested IGBP few years ago development of integrated regional studies of environment in selected regions, which may function as choke or switch points (in both biophysical and socio-economic senses) and small changes in relevant regional systems may lead to profound changes in the ways in which the Earth System operates. Siberia is one of the promising regions for the development of such basic and applied regional study of environmental dynamics, since regional consequences of global warming (e.g. anomalous increase of winter temperatures) are strongly pronounced here. This tendency is supported by the results of climate modeling for XX-XXII centuries The climate warming not only threatens Siberia with destruction of the most part of extractive and traffic infrastructure caused by the shift of permafrost borders northwards but also can change the dynamics of the natural-climatic system as a whole. Change of climatic characteristics creates the prerequisites for large and significant biological, climatic and socioeconomically coupled land use variations throughout this region. Science issues for region are growing in global importance not only in relation to climate change and carbon, but also for condition and stability of aquatic, arid, and agricultural systems, snow and ice dynamics. IGBP reported recently that the circumboreal region including Northern Eurasia is one of the critical "Switch and Choke" points in the Earth system, which may generate small changes in regional systems potentially leading to profound changes in the ways in which the Earth System operates.

The SIRS approach adopted was examined and endorsed by the Russian National Committee for IGBP in 2005. SIRS is managed by the Siberian Branch of which has decided that during the first stage of SIRS development it is necessary to focus on four lines of investigation:
- Quantification of the terrestrial biota full greenhouse gas budget, in particular exchange of major biophilic elements between biota and atmosphere;
- Monitoring and modeling of regional climate change impact;
- Development of SIRS information-computational infrastructure; and
- Development of an anticipatory regional strategy of adaptation to and mitigation of the negative consequences of global change.

At the same time, appeared few years ago as a joint program of RAS and NASA “Northern Eurasia Earth Science Partnership Initiative” (NEESPI, http://www.neespi.org/) now has transformed into the international Program and quite recently it was adopted as one of external projects of IGBP. Nowadays SIRS is a NEESPI mega project co-ordinating national and international activity in the region in line with ESSP approach.

SIRS activity has four basic components:

- Scientific: Clustering national (SB RAS, RAS, RFBR) and international projects on Siberia environment in line with SIRS objectives;
- Infrastructural: Development of informational-computational infrastructure of integrated regional study of Siberia environment;

- Organizational: Siberian Branch of Russian National Committee for IGBP is responsible for SIRS development;
- Educational (capacity building): ENVIROMIS Multidisciplinary Conference with elements of YSS (invited lectures embedded as well as thematic workshops) & CITES (Computational and Information Technologies for Environmental Sciences) YSS and Conference (lecture courses, training sessions as well as invited lectures).

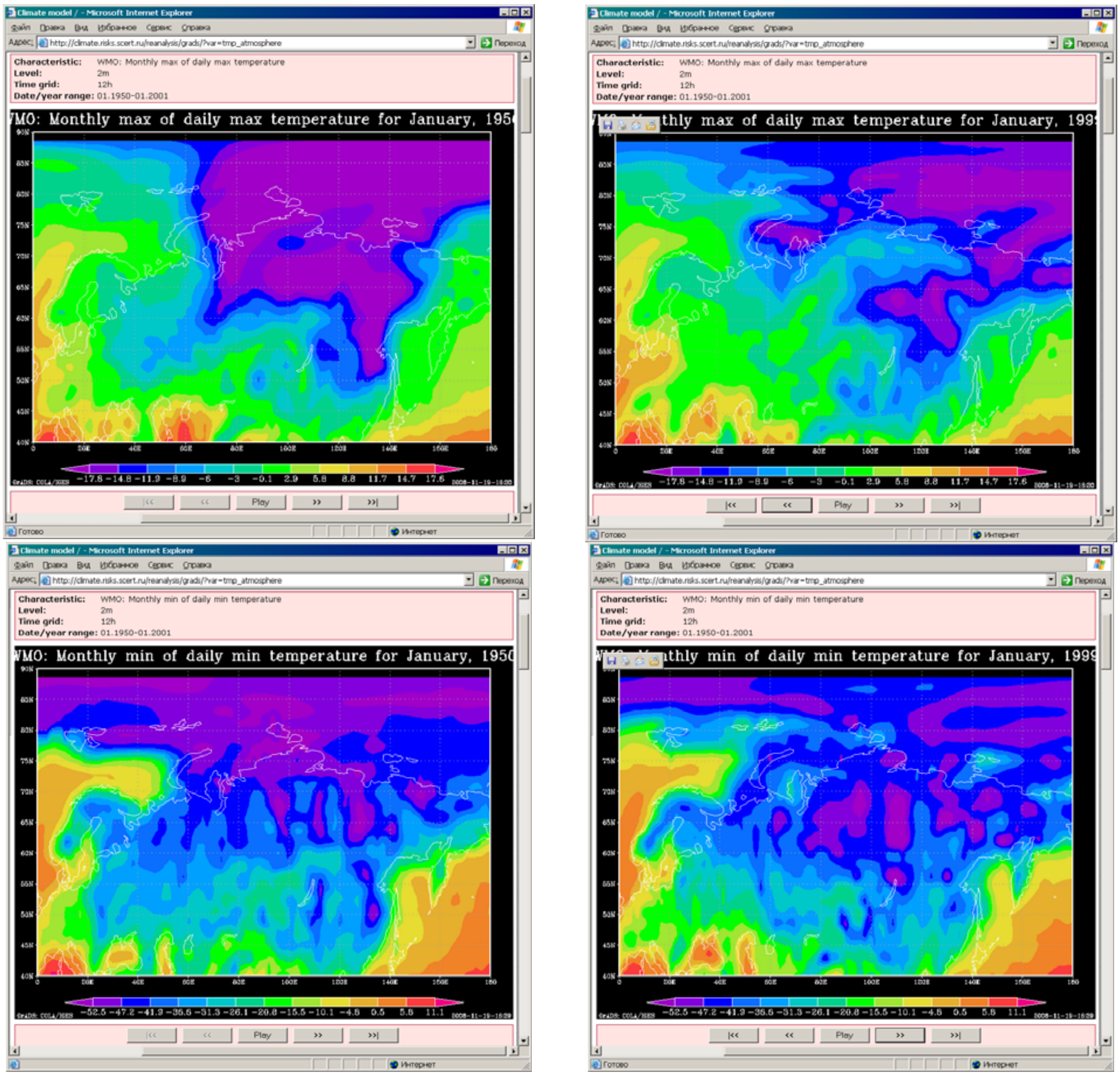

Fig. 10. Comparison of monthly maxima of maximal daily air temperature (above) and minima of minimal daily air temperature (below) for January 1950 (left panel) and January 1999 (right panel).

All SIRS components heavily rely upon the information-computational infrastructure under development. It takes advantage of the SB RAS IT structure and includes the key elements listed above (ATMOS, RISKS, ENVIROMIS). In spite of the fact that only few elements of the SIRS information-computational infrastructure has been elaborated by this time it has proved its efficiency yet. For example, using the Climate system one can easily analyze dynamics of winters in Eurasia (Fig. 10 below) and see that in results of global warming in the region occurred significant winter warming, zero temperature can occur in any place of Northern Eurasia (compare two upper panels), while well known ”severe Siberian January frosts” became significantly less severe (see lower panels).

Methodology of evaluation of natural and man-induced risk on a territory was developed in Institute of Computational Modeling SB RAS (Krasnoyarsk, the Project Associated Partner) and applied to the Krasnoyarsk region. The analysis of the sources of danger and risk shows that within the Krasnoyarsk region a number of natural, man-induced and natural-man-induced emergencies may occur, which requires developing a consistent calculation model allowing quantifying area risks. In a general case, the dynamics of emergency situations in the areas under consideration can be presented as the Poisson stream of events with given frequencies depending on the type of emergency situation. Taking into account the above given problem the emergency statistics has been considered and individual, collective, social and complex risks of man-induced, natural and natural-man-induced emergency situations risk components have been evaluated within the Krasnoyarsk region during 2001-2006. GIS technology of mapping risk-prone areas has been developed and the areas of the region have been subdivided according to the risks (see Fig. 11).

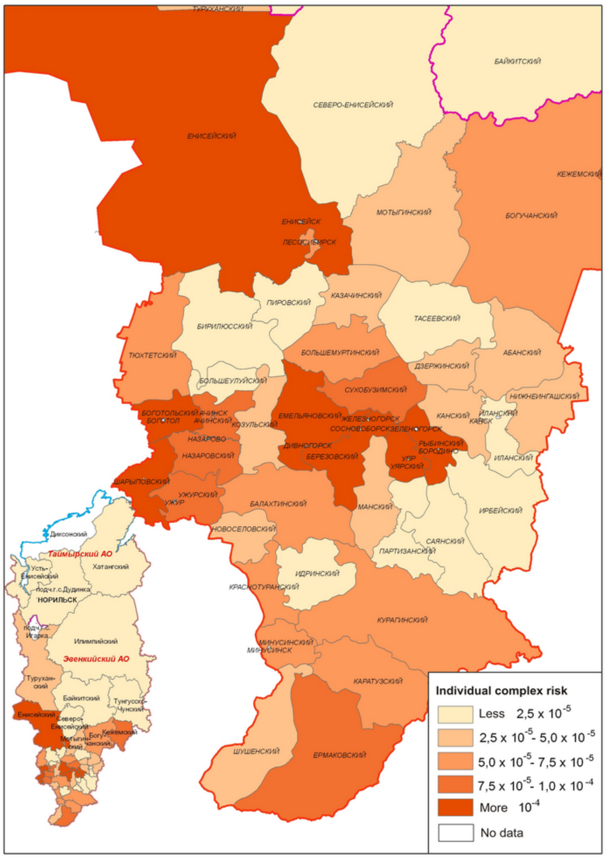

Fig. 11. Complex risk (population-normalized).

Complex risk values obtained indicates areas in which it is necessary to primarily pay attention to developing regional goal-oriented programs of monitoring danger and decreasing risks of natural and man-induced emergency situations. Risk danger in these regions has to be taken into account when developing goal-oriented programs of long-term economical and social development of the areas of the region. The results obtained reveal the possibility to solve the problem of evaluating and subdividing regions according to the risks of natural and man-induced emergencies with creating maps and atlases of risks both for certain regions and for the whole Siberian federal district.

Recommendations on future environmental RTD activity in Siberia

Due to wide international cooperation and, in particular, due to the possibilities to participate in international projects like Enviro-RISKS, the mutual exchange of ideas, plans and modelling technologies increases the synergy effect in understanding of key elements of the theoretical and applied studies. We are working on the same problems, but the specificity of the objects under study demands special adaptive strategies. The continuation of the cooperation is the most important point in recommendation on future development. The listed below problems are intensively attacked in the world and the project partners as well as other colleagues from Siberian and European teams are taking part in relevant theoretical and applied studies.

Atmospheric Pollution and Risks

The specific character of Siberian region consists in the fact that it is necessary to study the processes on the vast territories under their insufficient lighting by the data needed for the model initialisation and scenario construction. Taking into account these circumstances, we would recommend the following:

- To solve environmental problems on a modern level, we suggest elaborating the concept of environmental modelling based on application of variational approach and solution of inverse problems as fully as possible. With the help of variational principles one can generate almost all necessary computational algorithms, sensitivity theory methods for models and functionals, control theory methods and methods of direct and inverse modelling.
- To assimilate observational data, the models of observations (the models presenting the results of measurement in terms of the state functions) should be **consistently** designed with the models of processes.
- Till now, the problem of sources revealing and identifying is a weak spot in the algorithm of risk control. As the problem is nonlinear and high dimensioned, a methodology guarantying the **unique** solution (if it exists) in the case of many sources, is not designed yet. This part of work needs to be theoretically studied further.
- Specific models for **emergency** situations, when adequate quantitative assessments and optimal solutions are necessary, should be developed. The most important point here is an immediate assessment of situation when the input data are incomplete.
- Scenario approach is an important part of environmental modelling. To construct long-term forecasts and risk estimates one needs an appropriate methodology which is able to obtain the results taking the possible climate changes into account. Here the advanced approach is the use of informative bases and the methods of orthogonal decomposition of multi-dimensional phase spaces that describe the different characteristics of the phenomena under study.
- Since the methodology of analysis and prognosis is based on the joint use of models and data, it is naturally to make efforts to include as many admissible types of observational data as possible while solving environmental problems. The synergy effects of mutual co-ordination are pronounced in the construction of the thematic data bases and data processing, in the development of the methodology of data assimilation and targeting observational programs. Such co-operation should be continued in future.

It is necessary to underline that the risk assessment problems as well as the problems of estimation of changes in climate-ecology system belong to the problems of the higher system level than the ordinary problems of transport and transformation of pollutants. The former are essentially dependent on the results of the latter. Therefore we need to improve the basic models and algorithms to cope with the following tasks:

- To assess uncertainty in the models and input data for increasing the intervals of predictability under the incomplete information supply;
- To enhance the skill of atmospheric chemistry models and models of the system “gases + aerosols”. To these aims one needs to improve the algorithms for stiff systems in forward and adjoint modes, to use adaptive monotonic algorithms, and to overcome the problems of non-consistency such as monotonizators, self-limiting diffusion for divers components, etc.
- To develop a targeting data assimilation including chemical data assimilation for reconstruction of the current state and emission assessment;
- To construct the cost-effective methods for solving the optimal problems for design of sustainable strategy of environment development;
- To develop the technology for analysis and synthesis of the scenarios and their results;
- Some modifications are necessary to the numerical models, designed on the traditional approaches of forward modelling and developed earlier by different scientific teams, to be used in the context of inverse modelling. Their immediate use for the goals of adjoint sensitivity analysis and risk assessment, inverse modelling and data assimilation gives rise to definite difficulties due to the inconsistency of numerical models in forward and adjoint modes. One of the constructive ways to overcome such problems is the immersion of the forward model codes to the specific version of a variational principle, in which the appropriate procedures of generalised differentiation of the functionals and operators with respect to the state functions and parameters provide obtaining the exact gradients of evaluated cost functionals.

Climate/Global Change and Risks

Climate models based on the global coupled atmosphere-ocean-land-cryosphere system modeling exhibit a wide range of dynamical, physical, biological and chemical interactions. The traditional boundaries between weather and climate are conditional. At present, the challenge facing the weather and climate scientists is to improve the prediction of interactions between weather/climate and Earth system. The World Modelling Summit for Climate Prediction was held at the European Centre for Medium-Range Weather Forecasts on 6 – 9 May 2008 with the aim to develop a strategy to revolutionize prediction of the climate in the 21st century, in particular, at the regional level (http://wcrp.ipsl.jussieu.fr/Workshops/ModellingSummit/). It was recognized that considerably improved predictions of the changes in the statistics of regional climate (especially, of extreme events) are required to assess the impacts of climate change and to develop adaptive strategies to ameliorate their effects on environment and society. Despite progress in climate modelling (e.g., within the frame of AMIP and CMIP), the present time ability to provide robust estimates of the risk to society, in particular, from possible catastrophic changes in regional climate, is still constrained by limitations in computer power and scientific understanding. Neither the necessary scientific expertise nor the computational capability is available now in any single nation.

Thus, the Summit suggested to initiate a Climate Prediction Project coordinated by the World Climate Research Programme, in collaboration with the World Weather Research Programme and the International Geosphere – Biosphere Programme. This climate initiative will be a world climate research facility for climate prediction that will enable the national centres to accelerate progress in improving operational climate prediction in wide diapason of time scales, especially, at decadal to multi-decadal lead times. The world’s fastest computers run at hundreds of teraflops, but today’s climate models rarely run on machines that can manage more than a few tens of teraflops. This corresponds to spatial resolution of climate models of about a hundred kilometres. There is a general agreement in scientific community that more realistic models will require resolutions in the tens kilometres and even higher (a kilometre or less). Thus, the central component of the above mentioned facility should be dedicated high-end computing facilities (managing hundreds of petaflops) that will permit scientists to employ kilometre-scale modelling of the global climate system.

Access to significantly increased computing capacity will enable scientists to advance understanding and representation of the physical and biogeochemical processes responsible for climate variability and predictability. The Climate Prediction Project will enable the climate research community to make better estimates of model uncertainties and assess how they limit the skill of climate predictions. Climate models should be tested in sub-seasonal and multi-seasonal prediction mode, including use of data assimilation and ensemble systems. Such synergy between the weather and climate prediction efforts will motivate the development of seamless prediction systems. This project will help sustain the excitement of the young generation to better prepare humanity to adapt to and mitigate the consequences of climate change.

In summary, it is possible to emphasize that the strategy of modeling climate and its global changes should be based on the following four main propositions: (i) construction of an original climate model, (ii) model implementation on computational system of parallel architecture, (iii) development of the mathematical theory of climate, and (iv) study of regional problems of climatic variability and its impact on environment, in particular, in Siberia. The main directions, in which the development of the mathematical theory of climate and the improvement of modeling of climate and climate change will be possible in the coming years, can be formulated as follows (Dymnikov et al., 2006):

(1) Mathematical theory of climate: (a) elaboration of stability theory for the attractors of climate models, (b) study of the structure of the attractors of climate models, (c) development of sensitivity theory for climate models (theorems on the linear approximation for different moments, numerical study of the linear theory of response to small perturbations, optimal perturbations, and algorithms for constructing the response operator), and (d) control theory for dissipative systems (climate control).

(2) Climate models: (a) development of parameterizations for physical processes (stochastic parameterizations), (b) improvement of coupled atmosphere – ocean models, (c) development of regional climate models and methods to assess the consequences of climate changes for the natural medium, and (d) elaboration of models of the middle and upper atmosphere for solving the problems related to “space weather.”

(3) Numerical methods and parallel computations: (a) development of the theory of approximation of hydrothermodynamic equations on attractors (approximation of an attractor as a set and approximation of the measure on it), (b) approximation of the dynamics of the climate system on attractors, (c) elaboration of schemes with a specified symmetry group, (d) construction and use of spatiotemporal adaptive grids, and (e) design of computing technologies oriented toward massively parallel computing systems.

The aforementioned makes it possible to hope for the elaboration of an expert system used to obtain estimates and substantiated predictions of climate oscillations and changes on both a regional and global scales.

Terrestrial Ecosystems and Hydrology and Risks

To initiate development of new types and new generations of environmental models of different types. System organization of such models should explicitly correspond to preliminary formulated criteria. It seems relevant to regularly provide special scientific discussions on priorities, mathematical backgrounds, mechanism, and structural composition of such models. One of important types of models which are currently absent (in global science), are regional dynamic vegetation models.

To initiate development of regional integrated observing systems which are understood as self-educated goal-oriented integrated information structures, combining in optimal way different information sources (remote sensing, in-situ measurements), models of different nature (ecological, economic, social) and relevant computational technologies.

To investigate the most substantial ecological and landscape-ecosystem consequences of expected climatic change. In particular, to pay special attention to following important for the region issues: permafrost degradation; increasing sea level and flooding coastal areas, change of salinity regime of low reaches of rivers, change of ecological processes in deltas, substantial intensification of processes of coastal erosion; acceleration of rates of decreasing sea ice, shrinking ice cover of Arctic seas; shifting of all types of vegetation to the north; acceleration of natural disturbances, such as fire and insects' outbreaks; transformation of the hydrological cycle including a change of runoff of large Siberian rivers, the condition and dynamics of vast wetland territories of West Siberia and north of the region; dangerous acceleration of major biogeochemical cycles, basically at the expense of a thermal increase of carbon emissions (as CO_2, CO and CH_4); and (8) steady deficit of water resources and losses of yield of agricultural crops and pastures in southern regions.

To initiate detailed study of climatic changes (especially warming) indirect impact on human health and living conditions via possible increases the danger of infectious diseases, particularly those which are distributed by insect-carriers or by water.

To initiate detailed study of Land use – land cover change (LULCC) in the region driven by economic processes and inherited specifics of wrecking systems of natural resources used during the last decades and elaborate scientific basis for a special program of reforestation taking into account expected climatic conditions in the ecotone forest-steppe.

To initiate study of such fundamental problems as thresholds of acceptable (not destructing) impacts on ecosystems taking into account non-linear and multi-variant responses of ecosystems to long-term accumulation of stresses; system (holistic) analysis of complicated systems which contain components of different nature – biophysical, ecological, social and economic; theory and practice of decision making under uncertainties; development of integrated observing systems; and many others.

To implement a new systems approach to coordination of environmental research in the region, which would be able to provide a real interdisciplinary integration of different problems and methods; would involve all relevant scientific institutions of the region; accumulates available resources; involves all major stakeholders, local authorities and business; and finally would bridge of science –policy – implementation. Such an approach could be realized within the ***Siberian Integrated Regional Study*** in close coordination with IGBP and NEESPI (Northern Eurasia Earth System Partnership Initiative).

To develop a long-term strategic program of adaptation of Siberian natural landscapes and all parts of the regional economy to climatic change, and to mitigate of negative consequences of climatic change. The program should have a clear regional character in all ramifications – in assessment of predictions, by priorities and objectives, and by ways of practical implementation. The program should have a solid legislative, economic and social basis.

Information Systems for Environmental Sciences, Integration and Synthesis

To continue development of a set of powerful information-computational distributed web systems organized as scientific web portals devoted to different areas of Earth and Space Sciences with emphasis towards environmental problems of the region.

To develop and incorporate into climate oriented information-computational systems decision support system tools which will allow regional decision makers to perform climate dynamics assessment including negative consequences of climate change for relevant territory thus providing them with solid foundation for elaboration of relevant mitigation approaches.

To develop and incorporate into air quality monitoring oriented information-computational systems decision support system tools which will allow regional decision makers to perform assessment of environmental situation in Siberian cities and industrial centers thus providing them with reliable instrument for relevant territory development planning as well as for elaboration of relevant mitigation strategies.

To adapt to regional specifics GIS technology capable to solve important for region tasks of monitoring and modeling of atmospheric pollution as well as of oil pollution of bogs or flooded territories.

To continue efforts to integration of web and GIS resources, which were done in process of the SB RAS GIS-portal development (http://gis.sbras.ru/) thus making GIS-web portals major components of the information-computational infrastructure under development in the region.

SIRS should continue to play role a ground for ICT implementation and usage as integration and synthesis instrument. To this end SIRS itself should be more developed. Its perspectives and associated hypotheses should be as follows.
The main ecosystems under study are forests (Krasnoyarsk), wetlands (Tomsk), and permafrost (Tyumen). The structure is distributed between

- an Instrumental center (Krasnoyarsk - Tomsk participating for services),
- a data and services Center (Tomsk offering internet access to data and services for all participants)
- data and modeling Centers (Jena, Krasnoyarsk, Tomsk, Novosibirsk, Moscow).

The analysis is decentralized and involves all partners.

The creation of NEESPI/SIRS data bases and mirroring relevant NEESPI data bases in Siberia should be started, which will provide regional researchers with easy and inexpensive access to environmental data collections. SB RAS would be able to cover hardware, operational and internal traffic costs, if other funding agencies cover relevant software and external traffic cost.

The Organization of distributed SIRS/NEESPI Siberia Focus Research Center (SFRC) should be initiated by interested parties. At the initial stage the following structure is foreseen:

- Krasnoyarsk (SB RAS Institute of Forest and Siberian Federal University) is in charge of boreal forests study and GHG measurements and associated capacity building/education,

- Tomsk (SB RAS Institute of Monitoring of Climatic and Ecological Systems and Siberian Center for Environmental Research and Training) is in charge databases and modeling and capacity building/education

  SB RAS and SFU together with abroad partners would be able to co-fund SFRC, thus providing stability for its operations.

Relying upon gained experience in Krasnoyarsk region the problem of evaluating the whole Siberian federal district territory according to the risks of natural and man-induced emergencies with creating relevant maps and atlases of risks and determination of unprivileged regions should be solved.

Roadmap for environmental research and development activity in the region

Below optimistic timetable for foreseen and recommended environmental research and development activity in the region is suggested by relevant Thematic Focus Group leaders. Only few items from listed below are currently fixed in time and supported some funding. In spite of the fact that mainly this Roadmap is based on their personal opinions, some issues from the mentioned below have been yet formulated as proposals and submitted to Russian funding agencies including SB RAS and are in process of consideration right now. One can hope that they might be included into relevant official RTD activity plans rather soon.

Atmospheric Pollution and Risks

It is necessary to underline that the risk assessment problems as well as the problems of estimation of changes in climate-ecology system belong to the problems of the higher system level than the ordinary problems of transport and transformation of pollutants. The former are essentially dependent on the results of the latter. Therefore we need to improve the basic models and algorithms to cope with the following tasks:

- To assess uncertainty in the models and input data for increasing the intervals of predictability under the incomplete information supply;
- To enhance the skill of atmospheric chemistry models and models of the system "gases + aerosols". To these aims one needs to improve the algorithms for stiff systems in forward and adjoint modes, to use adaptive monotonic algorithms, and to overcome the problems of non-consistency such as monotonizators, self-limiting diffusion for divers components, etc.
- To develop a targeting data assimilation including chemical data assimilation for reconstruction of the current state and emission assessment;
- To construct the cost-effective methods for solving the optimal problems for design of sustainable strategy of environment development;
- To develop the technology for analysis and synthesis of the scenarios and their results;
- Some modifications are necessary to the numerical models, designed on the traditional approaches of forward modelling and developed earlier by different scientific teams, to be used in the context of inverse modelling. Their immediate use for the goals of adjoint sensitivity analysis and risk assessment, inverse modelling and data assimilation gives rise to definite difficulties due to the inconsistency of numerical models in forward and adjoint modes. One of the constructive ways to overcome such problems is the immersion of the forward model codes to the specific version of a variational principle, in which the appropriate procedures of generalised differentiation of the functionals and operators with respect to the state functions and parameters provide obtaining the exact gradients of evaluated cost functionals.

We hope that this set will be solved in three years. However in the conditions of the world financial crisis and diminution of industry production we hardly can expect the refinement of ecological conditions in Siberia because of primarily orientation of our economy on mining mineral resources and limited finances for monitoring and environment protection. That is why the priorities in environmental modelling we see as follows:

- development of the concept and methodology for long-term environmental quality prediction based on the combination of forward and inverse modelling technologies;
- development of new models for emergency situations with initialisation in the conditions of incomplete input data;
- design of comprehensive tools including chemical data assimilation for estimation of the dangerous secondary products of pollution specific for Siberian regions;

- further improvement of the algorithms for revealing unknown multi-point sources of pollution and assessment of their emission parameters on the base of measured concentrations (in collaboration with DMI).

We also suppose to continue some works in international co-operation, such as:

- assessment of the trans-boundary risks (Kazakhstan, Uzbekistan, Mongolia, China);
- assessment of environment quality in big (mega) cities (with European colleagues).

Some of these planned developments have been supported yet by RFBR, Presidium RAS and RAS Mathematical department Programs.

Climate/Global Change and Risks

It is foreseen that the next generation INM Climate model based on the global coupled atmosphere-ocean-land-cryosphere system modeling will be tested in control runs in two years.

High resolution regional climate model taking into account specifics of Siberia land cover will be prepared in two years and study of regional problems of climatic variability and its impact on environment in Siberia will start then.
Some of these planned developments have been supported yet by RFBR, Presidium RAS and RAS Mathematical department Programs.

Terrestrial Ecosystems and Hydrology and Risks

We expect appearance of new types and new generations of environmental models of different types in two year period. In particular, it will be regional vegetation dynamic model, permafrost dynamic model and bogs dynamic model. After that we expect their usage in solving specific problems of Siberia environment.

Under optimistic situation we hope to get the first stage of regional integrated observing systems, which are understood as self-educated goal-oriented integrated information structures, combining in optimal way different information sources (remote sensing, in-situ measurements), models of different nature (ecological, economic, social) and relevant computational technologies, in three years.

We hope that a new systems approach to coordination of environmental research in the region (the ***Siberia Integrated Regional Study)*** will be implemented in two years. It should be able to provide a real interdisciplinary integration of different problems and methods; would involve all relevant scientific institutions of the region; accumulates available resources; involves all major stakeholders, local authorities and business; and finally would bridge of science –policy – implementation.

The long-term strategic program of adaptation of Siberian natural landscapes and all parts of the regional economy to climatic change, and to mitigation of negative consequences of climatic change might be elaborated in three years.

Only few from the above issues have secured funding yet.

Information Systems for Environmental Sciences, Integration and Synthesis

We expect development of three powerful information-computational distributed web systems organized as scientific web portals devoted to different areas of Earth and Space Sciences with emphasis towards environmental problems of the region in three year.

We expect development of specialized decision support system tools and their implementation into regional climate oriented information-computational system in four years.

Develop and implementation of decision support system tools into city-level air quality monitoring oriented information-computational systems might take place in one year.

We expect that integration of web and GIS resources and development of prototype of GIS-web portal as an environmental information-computational system with GIS functionality in two years.

Creation of NEESPI/SIRS data bases and mirroring relevant NEESPI data bases in Siberia Might occur in one year.

To secure funding for the above issues several proposals were submitted to national and international funding agencies.

Conclusions

Due to increased international cooperation and, in particular, due to the possibilities to participate in international projects like Enviro-RISKS, the mutual exchange of ideas, plans and modelling technologies increases the synergy effect of scientific and applied studies. Thus we hope that formulated above objectives will be reached. It should be stressed that the Enviro-RISKS project substantially contributed to understanding of science plan and institutional decisions of Siberia Integrated Regional Study (SIRS), which is coordination of environmental research activity in Siberia and able to provide a real interdisciplinary integration of different scientific institutions of the region and problems and methods.

It should be noted that enhanced understanding of man-made risks in Siberia gained by the Partners in course of Project carrying out yet have resulted in several important environmental initiatives in the region. Important role in appearance and endorsement of these initiatives played the Project Partners and we hope that they will continue their input in course of implementation as well. Most important of those are following.

Firstly, the Workshop on " Integrated system for the meteorological elements and air quality forecasting and assessment of emission in the atmosphere of megalopolis, transport nodal points and other objects of infrastructure" (October, 2008) was organized in Novosibirsk. Specialists from academic institutes (INM, ICMMG, IMCES), from Siberian Research Institute of Hydrometeorology of Roshydromet and the end-users' representative from the Novosibirsk region administration (Vice-governor G.A.Sapozhnikov) discussed the current state of studies and future plans of innovations to the environmental policy in Novosibirsk region (see http://sibnigmi.lvs.ru/). The Workshop was aimed at planning development of such system and diminishing barriers between owners of routine data of observations on weather, atmosphere-water-soil quality, sources of emission, etc. (Hydrometeorological and Natural Resource State Services) and researchers from Academy of Sciences. As result relevant project preparation was endorsed.

Second prepared and recently endorsed by the Siberian Federal District Administration and SB RAS Presidium project is aimed at informational support of the monitoring of socio-economic and environmental observations in Siberian region on the base of remote sensed data. This distributed informational system will provide end users with processed data and will take care of their delivery. Among organizations to be involved into this system development and support of operation are ICM, IMCES and SCERT. As result of this project in Siberia Federal District the Center of socio-economic processes and environment will be organized on the base of the RAS Siberian Branch.

The last but not least initiative is a Proposal prepared by IMCES for 6 year SB RAS Project (first stage: 2009-2011) "Instrumental and methodical support of monitoring of natural and climatic processes in Siberia", which is aimed at creation of Siberian network of facilities for monitoring of natural and climatic processes. Siberian Branch will provide these facilities with funding required to buy relevant equipment.

Realization of these initiatives would be significant step to better environmental situation in Siberia and improve well being of its population.

Appendix 1. Practical recommendation to regional environmental decision makers

Listed below practical recommendation to regional environmental decision makers are based on results of analysis performed by four Thematic Expert Groups in course of the EC FP6 ENVIRO-RISKS Project (http://project.risks.scert.ru/). They are based upon the state of the art of environmental RTD activity in Siberia and summarized major outcomes of a number of different scale RTD projects devoted investigations of Siberia environment. Three Thematic Focuses/Groups consider major risks inherent to Siberia environment. These groups (with their leaders) are the following:

1. **Atmospheric Pollution and Risks** (Alexander Baklanov (DMI) and Vladimir Penenko (ICMMG)),
2. **Climate/Global Change and Risks** (Martin Heimann (MPI for Biogeochemistry) and Vasily Lykosov (INM)), and
3. **Terrestrial Ecosystems and Hydrology and Risks** (Michael Kabanov (IMCES) and Anatoly Shvidenko (IIASA)).

The forth Focus has a generic nature and is devoted to:

4. **Information Systems for Environmental Sciences, Integration and Synthesis** (Evgeny Gordov (SCERT) and Edige Zakarin (KGC)).

Relevant organizations are indicated at the end of each item in the list. Translation of these Recommendations into Russian can be found at the Project site as well after switching language button (http://project.risks.scert.ru/project_results/). Contact details of organizations/persons to be contacted for discussion of possible format of their applied RTD activity required for implementation of selected from the list solution/development are given at the end of these Recommendations and can be found at the Project site (http://project.risks.scert.ru/participants/).

1. Implementation of the prognostic modelling system for transport and transformation of pollution in city/region atmosphere taking into account photochemical reactions the air quality models for urban and suburban areas (Tomsk State University).

2. Implementation of the model set for the system of the industrial region atmosphere taking into account ecological restrictions on the environment quality, results of measurements of different kinds, control and design criteria and oriented to optimization of environment protection activity, management of environment quality, ecological design, and finally to reaching conditions of environmentally sustainable development and ecological safety of the industrial regions (ICMMG).

3. Assessment of environmental risk and vulnerability of territories with respect to anthropogenic effects and determination of quantitative estimates of the risk/vulnerability domains and for revealing the sources of this risk; organization of environmental risk control for the territory (ICMMG).

4. Implementation of the Danish Emergency Response Model for Atmosphere (DERMA) for forecast and for long-term simulation of source-receptor relationship for various pollutants including nuclear, chemical, biological, etc., danger for potentially dangerous industry enterprises and vulnerable territories (DMI).

5. Selected region climate dynamics monitoring, assessment and modeling to determine regional changes in nature and climate and associated risks (IMCES, INM).

6. Assessment of changes of the environmental conditions and ecosystems development in cryolithozone as result of nature and human disturbances of cryolithozone (solifluction, fire, felling, atmospheric and soil pollution) and determination of structure and functioning of ecosystems disturbances (IF).

7. Development and implementation of information-computational hydrodynamics and water quality system to natural and man-made emergency situations on a river (USU).

8. Implementation of space monitoring system to detect and monitor dangerous for the pipelines and objects in the buffer zone changes, including surface soil erosion in the pipeline area, swamping areas and underflooding of pipelines, displacement of natural landscapes, karst and thermokarst areas and early detection of forest, flood and tundra fires (URRIT).

9. Adaptation and implementation of the web-system for city/region air quality assessment taking into account meteorological observations, atmospheric emissions of industrial enterprises and traffic, measurements of the concentration of the atmospheric pollutants as well as results of gaseous substances transformation and transport processes modeling (SCERT, IMCES)

10. Development and implementation of GIS systems for region level tasks of monitoring and modeling of atmospheric pollution and of oil pollution of bogs or flooded territories. KazGeoCosmos developed solving the both problems. The system covers all stages of computation of air pollution from multiple oil/gas industry sources, from the location of well head flares to prognostic calculation of combustion materials distribution. Relevant mathematical models are plunged into GIS developed in ArcGIS environment customized to the conditions of region and all the modeling and analysis phases are accomplished in the informational sphere, based on the real data (KazGeoCosmos).

11. Development and implementation of the system of geoinformation modeling of territorial processes SysGISM (System of GIS - Modeling). SysGISM supports operation of different GIS-technology applications; allows its usage as an analyzing subsystem; and provide possibility of complex analysis of remote survey data, surface survey data and results of scientific researches of certain territorial processes. The system developed supports the communication between the users and designers of different territorial tasks, stores all related data on the territory and processes and provides advanced GIS service for storing and processing of data through respective interfaces (KazGeoCosmos).

12. Performing evaluation of natural and man-induced risk on a territory including individual, collective, social and complex risks; analysis of the sources of danger and risk from natural, man-induced and natural-man-induced emergencies; creating maps and atlases of risks both for certain regions and for the territory. (Institute of Computational Modeling SB RAS, Krasnoyarsk)

Appendix 2. Contact details of organizations/persons to be contacted for discussion of possible format of their applied RTD activity required for implementation of selected from the list solutions/developments

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