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REPORT No. 37

IGBP Northern Eurasia Study: Prospectus for an Integrated Global Change Research Project

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
Stockholm, 1996

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IGBP Northern Eurasia Study: Prospectus for an Integrated Global Change Research Project

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Siberian tundra in the Yakutia region
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Executive Summary

Northern Eurasia (European Russia, Siberia, and the Far East of Russia) is of increasing interest within global change research. It is a vast area, about which relatively little is known in the Western scientific community. The northern hemisphere high latitude belt is a region where temperature rise due to anthropogenic climate forcing is predicted to be the greatest, and where the consequent feedbacks to the atmosphere are potentially large. In addition, it is poised to undergo rapid economic development, which may lead to large and significant changes in its land cover. Much of the interest in Northern Eurasia, as in the high latitude regions in general, is centred on its role in the global carbon cycle, which is likely to alter significantly under the impact of global change.

This report was prepared by scientists representing the Biospheric Aspects of the Hydrological Cycle (BAHC), the International Global Atmospheric Chemistry (IGAC) and the Global Change and Terrestrial Ecosystems (GCTE) Core Projects of the IGBP. It is a prospectus for an integrated hydrological, atmospheric chemical, biogeochemical, and ecological global change study in the tundra/boreal region of Northern Eurasia. The Study will also involve the IGBP Programme Elements Past Global Changes (PAGES), Land-Use and Land-Cover Change (LUCC), Global Analysis, Interpretation and Modelling (GAIM) and the IGBP Data and Information System (IGBP-DIS). The unifying theme of the IGBP Northern Eurasia Study is the terrestrial carbon cycle and its controlling factors. Its most important overall objective is to determine how these will alter under the rapidly changing environmental conditions (i.e., global change). Two issues are particularly important. Firstly, it is critical to understand the interaction between ecosystem composition and ecosystem process. Secondly, a projection is required not just of net primary productivity or net ecosystem productivity, but of "biome productivity", that is, net ecosystem productivity integrated over large spatial and temporal scales to account for such processes as successional dynamics and major disturbances such as fire, timber harvesting and insect outbreaks.

The IGBP Northern Eurasia Study will consist of an integrated set of experimental and observational studies at a variety of scales, modelling and aggregation activities, and the development of supporting databases and GIS systems. The major activities will be:

- The development and operation of north-south transect(s) in eastern Siberia (East Siberia/Far East) including sites in tundra, tundra-forest transition and in larch forest. This is a critical region for study; it has a high degree of continentality, it contains a vast expanse of larch forest about which more needs to be known, and the potential for land-use change over the coming decades is high. The transect(s) will be included with others in Alaska, Canada and Scandinavia/northern Europe as part of the high latitude set of IGBP terrestrial transects. The IGBP Northern Eurasia Study Open Meeting, Tsukuba, Japan, December 1995, recommended that two north-south transects should be developed, one in the Lena River basin and the other along the Yenesei River.

- The development and operation of a network of observing sites throughout Northern Eurasia focusing on trace gas emissions and their controlling factors. The network

will be concentrated on the extensive wetlands in western Siberia but should include at least two or three other sites in wetlands in the northern areas of European Russia and in eastern Siberia (including the area of continuous permafrost), one site in the coniferous evergreen forests, and one site in the tundra. Of particular importance is an apparent "hot spot" for gas emissions in the wetlands at the southern edge of western Siberia.

- A water, energy and carbon flux study, integrated with the transect and network components. The design of this component requires further background research and modelling sensitivity studies before it is finalised, but its linkage, so far as possible, to the trace gas and ecological components will provide a powerful mechanism for integrating much of the work in the IGBP Northern Eurasia Study.

- Studies of disturbance regimes. The studies should include work on all major disturbances of Northern Eurasian ecosystems, such as timber harvesting and insect infestations, but particular emphasis will be placed on fire. They should include work on both gaseous and aerosol emissions from fires, and on the ecological role of fire in influencing the successional dynamics of the boreal forests and permafrost formation. An essential component is the development of a fire database which includes extent, frequency and controlling factors so that fire regimes and impacts of fire on terrestrial and atmospheric carbon budgets under a changing environment can be predicted.

- Scaling up, modelling, integration. A wide variety of models will be used to help design the experimental and observational studies, interpret the data, and project the impacts of global change on high latitude systems into the future. These include ecosystem physiology and dynamics models at various scales, trace gas flux models, Soil-Vegetation-Atmosphere Transfers (SVATs), landscape hydrological models, atmospheric transport models, biome-scale simulations of the carbon and hydrological cycles, and comparisons to palaeo-climate and -vegetation studies. Scaling methodologies such as nested watershed studies and the boundary-layer averaging technique will be used, as appropriate, to scale up results of the process studies carried out at individual sites. Remote sensing, data assimilation and management and GIS technology are important research tools that will be used in the study.

- Associated studies. The IGBP Northern Eurasia Study provides a framework for related global change research. Examples include global change impacts on managed forests, observational and modelling studies of land-use/land-cover change in the region, and research on global change and ecological complexity (biodiversity). The land-use/land-cover change study, in particular, is crucial to long-term projections of change in the carbon cycle in the Northern Eurasian region, and should become a central element of the IGBP study. Taken together, the IGBP Northern Eurasia Study and associated studies will provide valuable information to assist the development of sustainable management strategies for Northern Eurasia, in addition to elucidating its role in the Earth system.

The IGBP Northern Eurasia Study will be implemented in a phased manner. Where there is already general agreement that research is required in a particular area, such as a north-south transect(s) in eastern Siberia, appropriate sites can be selected and long-term

observational studies can be initiated as soon as practicable. Care should be taken, however, that sites selected are compatible with the requirements of more intensive studies that will be phased in later. This is a critical consideration, as the "whole system" approach recommended for this study requires that the various individual activities be carried out at the same sites, if at all possible.

Other components of the Study, such as the intensive measurements of water, energy, carbon and trace gas fluxes, require preparatory (sensitivity) analyses before an experimental design can be finalised and work begun. Given the overall requirement for a general understanding of the composition/structure and physiology/productivity of Northern Eurasian ecosystems at a large scale, an early task is to survey the existing research that is being carried out in the region, analyse past work, and, where appropriate, retrieve and standardise data from this existing and past work.

There are already a large number of groups interested in various aspects of global change research in Northern Eurasia. IGBP aims to collaborate so far as possible with these other groups to avoid unnecessary duplication, to enhance the scientific value of the work, and to maximise the efficiency of the use of resources. Of particular importance to the IGBP Northern Eurasia Study are GAME (GEWEX Asian Monsoon Experiment), which is planning observational and modelling studies of the hydrological cycle in eastern Siberia, and two IIASA studies, one a comprehensive study of Siberian forests and the other a project on modelling land-use and land-cover changes in Europe and Northern Asia.

The production of this prospectus is the first step in the implementation of the IGBP Northern Eurasia Study. The next steps include: (i) an awareness campaign, to introduce the Study to global change scientists around the world, and particularly in Russia; (ii) sensitivity studies to refine the design of the study; (iii) a review of existing research and data in the Northern Eurasian region; (iv) and the selection of sites for the transect(s) and the initiation of the long-term ecological studies. It will also be necessary to obtain formal approval and recognition of the Study by the Scientific Committee of the IGBP and to establish a project office to coordinate the Study.

Preface

"Burn it down to something you can achieve"

E.-D. Schulze

The prospectus presented herein for an integrated Northern Eurasia Global Change Study under the auspices of IGBP was largely the work of a small group of scientists who met during the first week of November, 1994, at the Royal Swedish Academy of Sciences in Stockholm. Their task was to pull together the various components of three Core Projects - BAHC, IGAC and GCTE - that are relevant to Northern Eurasia into a single framework for a coordinated IGBP Study. The idea was not to develop an exclusive or pre-emptive IGBP experiment, but simply to ensure that within the IGBP, a reasonable level of coordination had been achieved amongst the component parts before extensive interactions took place with the many other groups that have an interest in global change-related research in Northern Eurasia. We hope that this prospectus provides a useful framework for establishing effective collaboration among IGBP and these other groups.

The task was a daunting one, and at times it seemed that the potential enormity of the Study, the complexity of the region we were considering, and the varied interests of the individual Core Projects might render a coordinated Study impossible. But through the good will and hard work of the participants, common ground was achieved and an excellent overall outcome obtained. I believe that considerable progress has been made. An overall theme was adopted (the carbon cycle), and a defined but flexible framework was laid out that will permit work to begin very soon on some components of the study while allowing future components room to evolve and develop.

A particularly valuable contribution to the workshop was made by Detlef Schulze, who managed to keep the participants focused on their goal at several critical points during the meeting. The motto set out above symbolises the resolve of the participants to construct a well-focused, realistic, achievable plan for the IGBP Northern Eurasia Study. It coincidentally emphasises the importance of fire and successional dynamics, a theme which came out strongly during the workshop.

On behalf of the participants, I commend this IGBP prospectus to groups interested in undertaking global change research in Northern Eurasia, and offer it as useful framework around which to build a scientifically effective and efficient study.

Will Steffen
Convenor of Workshop
GCTE Core Project Officer

Background

Interest within the global change research community in Northern Eurasia has grown dramatically in the last few years. It is a vast area about which relatively little is known in the Western scientific world. It is a region where temperature rise is predicted to be the greatest, particularly in winter, and where the consequent feedbacks to the atmosphere are potentially large (Ganopolsky 1994; Budiko and Groisman 1991). In addition, on a decadal timeframe it has the potential to undergo rapid economic development, which may lead to large and significant changes to its land cover.

For the purposes of this Study, Northern Eurasia is defined as extending from the border of Russia in the west to the Pacific Ocean coast of Asia in the east, and from the Arctic Ocean coastline in the north to the ecotone between boreal forest (taiga) and the biomes to the south, usually steppe or temperate forest. Thus, it includes most of Russia's land area. Also, in this prospectus we refer to three regions of Northern Eurasia: European Russia (west of the Ural Mountains), western Siberia (between the Ural Mountains and the Yenesei River), and eastern Siberia (east of the Yenesei River, often divided into two regions - East Siberia and the Far East - see Fig. 1).

Much of the interest in Northern Eurasia, as in the high latitude regions in general, is centred on their role in the global carbon cycle. High latitude regions occupy about 25% of the Earth's land area and, according to recent estimates, contain about 800-900 Gt carbon, perhaps 33% of the global terrestrial total (*e.g.*, Gorham 1991; Apps *et al.* 1993) (see Figure 2 for an overview of the global carbon cycle). Furthermore, about two-thirds of the world's boreal forests are located in Northern Eurasia, or about 20% of the world's forests in total. Because of ice contained in permafrost (often 50% of soil volume, Tomirdiaro 1980), these ecosystems are very sensitive to changes in climate and land use, with responses observable at all levels of organisation (i.e., ecosystem physiology, soil and wetland processes, community-level dynamics, and frequency and intensity of disturbances).

In terms of ecosystem physiology and soil and wetland processes, global change will have direct effects on the carbon cycle, on water and energy exchange, and on nutrient dynamics. General Circulation Model (GCM) scenarios suggest that warming will intensify towards the poles, providing the potential for strongly enhanced CO_2 and CH_4 emissions from northern wetlands and permafrost regions, thus causing these regions to become net sources of carbon over the next 50-100 years. The high latitude regions also emit other chemically active compounds and act as significant recipients for trace gases and aerosol particles transported from mid-latitudes.

Much of the interest in tundra/boreal systems is centred on trace gas fluxes (CO_2 is defined as a trace gas for the purposes of this Study). Virtually nothing was known about these fluxes as recently as a decade ago. Large interdisciplinary campaigns and individual studies have led to rapid growth of the data base in North America and Scandinavia, but large and potentially important parts of Northern Eurasia remain relatively unstudied. Previous work has involved estimates of the source strength of high latitude environments for trace gases, and has identified factors controlling fluxes (substrate quality, temperature, moisture status), but many of these are site-specific and subject to high variability. It is still not feasible to make reliable predictions of trace gas fluxes, and there is only a small amount of information on sensitivities and feedbacks to climate change variables.

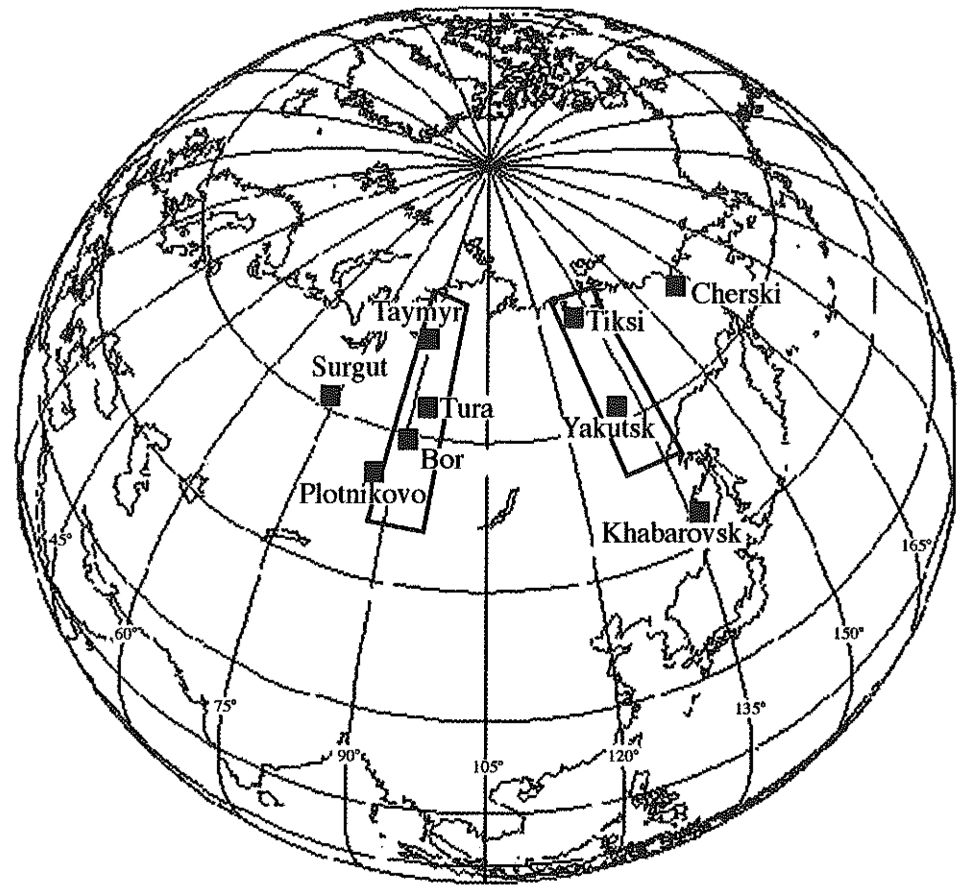


Figure 1. Map of Siberia showing the two major north-south transects proposed for the IGBP Northern Eurasia Study. The Far East Siberian transect is centred on the 135° meridian and will be a collaborative effort with the GAME project of the WCRP. The proposed West Siberian transect basically follows the 90° meridian, along the Yenesei River. The sites shown form the nucleus of a trace gas study network. Two sub-transects have been proposed in conjunction with the trace gas network: (i) a north-south variation to the Yenesei transect, from Taymyr to west of Plotnikovo, and (ii) an east-west transect crossing Plotnikovo. Further study is required before the precise locations of the transects are determined, but it is expected that the two primary north-south transects and the trace gas sites shown will all be part of the Study. Note that West Siberia is defined as the region between the Ural Mountains and the Yenesei River; East Siberia is defined as the region between the Yenesei and a line running roughly from the eastern edge of the Taimyr Peninsula to the Amur River at 120° East, and the remainder is defined as the Far East.

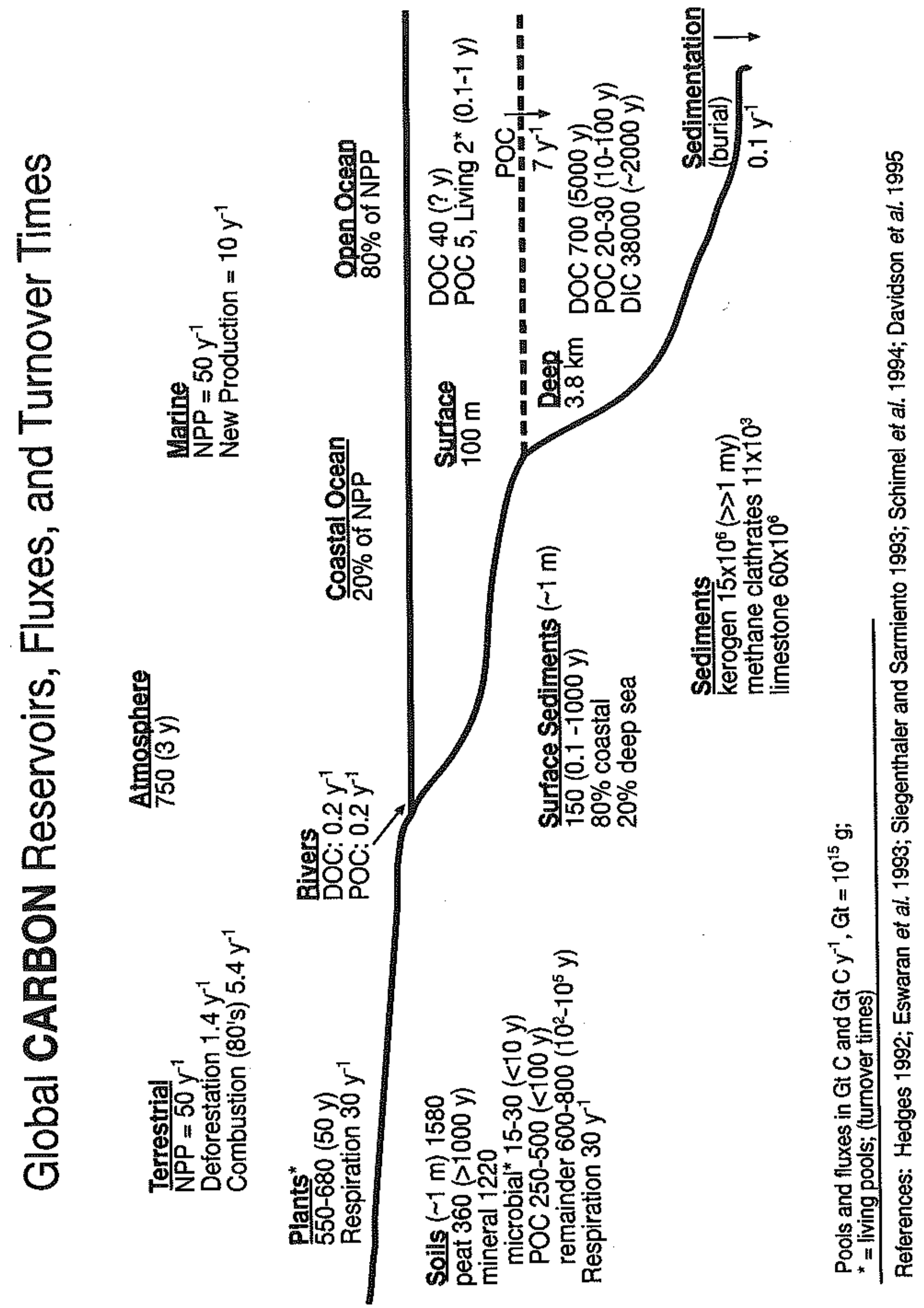


Figure 2. The global carbon cycle: Reservoirs, fluxes and turnover times. Figure courtesy of W.S. Reeburgh.

Hydrological processes play a key role in the functioning of tundra and boreal ecosystems. These systems are unique in that permafrost formation is widespread, and this together with topography play a large role in determining water flux rates and the level of the water table. These aspects of hydrology, in turn, are critical factors in determining vegetation type, carbon balance and ecosystem/atmosphere exchange. Since temperature change is predicted to be particularly large at high latitudes, understanding its impacts on permafrost and other aspects of hydrology is essential in projecting overall system response. In terms of water and energy exchange between the land surface and the atmosphere, the Northern Eurasian tundra and boreal biomes are relatively little studied. Given their large extent and the potentially significant changes in ecosystem function under global change, it is important that this lacuna be rectified.

Global change is also predicted to have pronounced effects on the composition and structure of high latitude ecosystems (Prentice *et al.* 1992), with consequent strong impacts on the carbon balance and on land surface-atmosphere interaction in the longer term. A recent modelling study has suggested that if the impacts of climatic change on ecosystem function alone are considered, high latitude systems will become a source of carbon, whereas if the longer term migration of forests northward under climatic change are considered together with changes in function, high latitude systems will become a sink for carbon (Plöchl and Cramer 1995). Analyses such as these are based on predicted changes in potential vegetation, and do not account for land-use changes and other disturbances.

Disturbances, most notably fire, insect outbreaks and direct human conversion or modification of land cover, play a critical role in the hydrology, atmospheric chemistry, biogeochemistry and ecology of many biomes around the world. Fires in forests, savannas and peatlands impact the hydrological cycle through changes in rates of evaporation and run-off, and represent a significant global source of radiatively active trace gases and aerosols to the atmosphere (Crutzen and Goldammer 1993; Levine 1991). Fires in northern Eurasia have a significant impact on the structure and composition of forests at patch and landscape levels, on formation and nutrient status of soils, on the formation of peatlands and permafrost, and on insect population dynamics (Goldammer and Furyaev 1996). Dendrochronological and lake sediment analyses suggest that boreal forests have been influenced by fire since the mid-Holocene and therefore must be considered as an important natural phenomenon.

Assessments of present pyrogenic carbon and trace gas fluxes from Northern Eurasian ecosystems are based on fire data systematically collected on protected lands of the former USSR and today's Russian Forest Fund (Shvidenko *et al.* 1995). First systematic evaluation of remotely sensed fire data indicate that these data highly underestimate the total fire activity and consequently the quantity of pyrogenic emissions (Cahoon *et al.* 1994). The emissions data collected during the 1993 phase of the Fire Research Campaign Asia-North (FIRESCAN) reveal that boreal forest fires produce higher amounts of radiatively active trace gases (*e.g.*, CO, CH_4) and ozone-depleting components like CH_3Br than fires in other vegetation types. The magnitude of pyrogenic formation of elemental carbon in boreal fire ecosystems and its role as an atmospheric carbon sink is largely unknown and should be explored as a high priority (Kuhlbusch and Crutzen 1995).

GCM-based scenarios of future fire regimes indicate that the successional state of the forest in much of Northern Eurasia may be determined by increased fire frequencies and fire severities, and will therefore strongly influence the regional carbon cycle in the longer term. Thus, there is an urgent need to understand fire behaviour in the high latitudes.

Fires in tundra, forest, and peatland biomes, especially production of trace gases and aerosols, are much less understand than burning processes in the tropics. (For more detailed information on the role of fire in Northern Eurasia ecosystems, see *e.g.*, Furyaev and Kireev 1979; Goldammer and Furyaev 1995, 1996; Sheshukov *et al.* 1992; Sofronov 1967; Telizin 1988; Valendik 1990.)

Much of the above rationale applies to high latitudes in general. However, in addition to the general lack of knowledge about Northern Eurasia, there are several features of this vast region, in contrast to North America and Scandinavia, which make it a high priority region for global change research. First, eastern Siberia includes the coldest, driest area in the high latitudes; this region has the most extremely continental climate of any circumpolar area. Second, the same area is covered by large stands of deciduous larch forests, about whose ecology little is known, at least in the international global change research community (there is considerable understanding of larch forests within the Russian scientific community). Recent studies indicate that even in mid-summer system-level carbon uptake rates by larch forests are very low (Hollinger *et al.* 1995), but more needs to be understood about their behaviour over longer time frames and in different successional states, which are fire dependent and which have significance for nutrient dynamics. Third, throughout much of the Northern Eurasian region, the transition zone between tundra and boreal forest is gradual. Fourth, Northern Eurasia contains extensive regions of permafrost, which plays a key role in the hydrological cycle and exerts a strong influence on the structure and function of ecosystems. Fifth, rivers which drain northern Siberia are the major freshwater inputs to the Arctic Ocean, which is the source of the North Atlantic deep water that has been hypothesised to strongly influence the global climate system. Finally, Northern Eurasian ecosystems were largely unglaciated during the Pleistocene, during which time they accumulated large quantities of soil carbon. Thus, they are large potential sources of carbon to the atmosphere. For example, emissions of CH_4 from Russian wetlands are currently estimated to be about 35 Tg C per year (Rozanov 1995). Also, a five-year time series in northeastern Siberia shows this area to be a consistent CO_2 source to the atmosphere of about 150 g C m^{-2} yr^{-1} (Zimov *et al.* 1993), although whether these results can be extrapolated over the entire Northern Eurasian region remains to be determined.

The potential for large-scale land-use change also differentiates Northern Eurasia from the other high latitude regions. There has been some exploitation of Northern Eurasia in the past, but with the recent political changes in Russia, there is growing interest from the West in the economic development of its high latitude regions, particularly in Siberia. The current economic situation in Russia has actually slowed development of Siberia, but this may be a short-term phenomenon. The timber and mineral wealth in this region is vast, and the long-term potential for exploitation is high. Precipitate development could lead to careless exploitation of Siberian resources, increased carbon release to the atmosphere, and destruction of fragile ecosystems. Over the coming decades Northern Eurasia could well become the next global "hot spot" of land-use change, following the humid tropical areas where much current interest is focused. Another type of socio-economic development, industrialisation, may also significantly affect Northern Eurasian ecosystems. However, industrial development may affect these systems in completely unknown directions, ranging from large-scale forest devastation to increased growth from N-deposition and other potentially favourable outcomes from global change (Felistor *et al.* 1990).

Although much of the interest in the Siberian region with respect to global change has focused on its potential role in providing feedbacks to the atmosphere and to the physical

climate system, there is also much interest in the impacts of global change on Siberian ecosystems in their own right. As noted above, the boreal forests of Siberia are a considerable economic resource for Russia, and there is concern about the impacts of global change on the future structure, biomass production and yield of these forests ("feed forward" rather than "feed back" effects). There is thus an urgent need to identify resource management strategies for sustainable forestry under changed climatic conditions.

Because of its importance in global change studies, a number of Programme Elements of IGBP have a strong interest in an IGBP study in Northern Eurasia. IGAC has an interest in trace gas emissions and uptake in high latitude systems and in the potential for increased fires and their consequences. The role of changes in hydrologic systems in modulating changes in the carbon cycle is of central interest to BAHC. In addition, BAHC, in collaboration with the Global Energy and Water Cycle Experiment (GEWEX), is interested in a tundra land surface experiment (intensive study of the exchange of water and energy between the land surface and the atmosphere and the factors which control this exchange), as well as in longer-term measurements of water and energy exchange at various sites in the Northern Eurasian region. GCTE aims to study changes in biogeochemistry (coupled carbon, nutrient and water cycles) in high latitude systems, long-term changes in ecosystem structure and composition in the tundra/boreal region, and global change impacts on boreal forests in their own right. As GCTE is interested in both ecosystem- and biome-scale biogeochemical cycling in general and in changes in ecosystem composition and structure, it is in a good position to integrate the carbon dynamics of the region over long time and space scales. As well as these three, the PAGES Core Project is interested in the past changes to vegetation, hydrology, carbon cycle and climate over this vast region, and can provide a valuable long-term perspective to the Study. Given the potential importance of land-use change in Northern Eurasia in the long term, the LUCC Core Project is also a key component of the Study. The importance of Northern Eurasia for the terrestrial carbon cycle is of obvious interest to GAIM. In addition, the Study will provide a useful testbed for the global models being developed in GAIM. Expertise in IGBP-DIS is crucial to the collection and management of data.

There is clearly a strong need, both in terms of economy and scientific effectiveness, to carry out much of this work on the same sites at the same time. This need has been recognised within the IGBP, and two initiatives have been undertaken to meet it. First, a workshop in mid-1993 launched a set of large-scale terrestrial transects for global change research. These transects were initiated by the BAHC, IGAC and GCTE Core Projects, but have quickly evolved into facilities of potential use to nearly every IGBP Programme Element. They are designed as multi-national and interdisciplinary platforms for collaboration amongst researchers in global change studies involving atmospheric chemistry, biogeochemistry, hydrology, land surface-atmosphere exchange, and the vegetation dynamics of terrestrial ecosystems. The rationale for and description of the IGBP Terrestrial Transects is given in Koch *et al.* 1995.

Second, on an initiative from IGAC, the BAHC-IGAC-GCTE Science Task Team was established to enhance inter-Core Project collaboration. The Task Team met in January 1994 and recommended, as a major theme for collaboration, process studies in terrestrial environments. The conclusions of this meeting clearly pointed to the high latitude transect studies as a high priority area for collaboration amongst the three Core Projects.

There are also two other significant factors that highlight the importance of high latitude studies, and a proposed Northern Eurasia Study in particular. These are: (i) the desire of the international land-surface experiment community to conduct an experiment on a tundra ecosystem late this century or early next; and (ii) the large number of groups proposing, planning, or carrying out global change-related research in Siberia (see section on Collaboration with International Groups) and thus the need for IGBP to have a coherent science plan for its proposed research in the region.

For these reasons, the Scientific Committee for the IGBP (SC-IGBP) decided to focus a follow-up meeting on the proposed IGBP Northern Eurasia Study. The objective of this meeting is embodied in this document - a prospectus for an integrated hydrological, atmospheric chemical, biogeochemical, and ecological global change study in the tundra/boreal region of Northern Eurasia. The prospectus outlines the overall goals of such a study; gives an overview of the general structure and design of the study, describes the individual experimental/observational components and modelling activities and their more specific objectives; addresses the general site requirements and measurement protocols; and discusses a number of issues associated with the implementation of the prospectus.

Goals of the Study

The unifying theme of the IGBP Northern Eurasia Study is the terrestrial carbon cycle and its controlling factors. The Study's most important overall objective is to determine how the carbon cycle will be affected by global change, and how the consequent alterations to the cycle will feed back to further change.

Two aspects of the Study's overall objective are particularly important. First, understanding the interaction between ecosystem composition and ecosystem process is critical. Both will be affected by global change, but not independently. Most studies to date have concentrated on one only, and assumed that the other is invariant. Linking the two in experiment, observation and modelling is thus an important challenge to this study.

Second, the overall objective demands a projection not just of net primary productivity or net ecosystem productivity but of "biome productivity". That is, net ecosystem productivity must be integrated over large spatial and temporal scales. Thus, a determination of "biome productivity" must take into account (i) the change in net ecosystem productivity caused by changes in atmospheric CO_2 and climate, both direct and via changes in nutrient and hydrological cycles; (ii) changes in the composition and structure of ecosystems caused by disturbance patterns (especially fire), direct human modification of land cover, and direct effects of climate and atmospheric composition (*e.g.*, change in composition through succession or migration of vegetation); and (iii) the integration of these changes over decades and over the entire Northern Eurasian region.

To meet the overall objective, the IGBP Northern Eurasia Study is built around four primary goals:

1. To predict the direct effects of global change on the cycling of carbon and other important elements, such as nitrogen, in Northern Eurasian tundra and boreal ecosystems, with particular emphasis on the emissions and uptake of trace gases, primarily CO_2 and CH_4, and their controlling factors.

2. To predict the effects of global change on the land-atmosphere exchange of water and energy and on groundwater hydrology in Northern Eurasian tundra/boreal systems, with an emphasis on the linkage between the hydrological and carbon cycles.

3. To predict the effects of global change on the composition and structure of Northern Eurasian tundra and boreal ecosystems, and the interaction with ecosystem function (*e.g.*, water and energy exchange, biogeochemistry).

4. To determine the interaction of direct human-driven land-use change and changes in disturbance regimes, most importantly fire, insect outbreaks and thermokarst (melting of permafrost), with biogeochemical cycles and with the function, structure and composition of Northern Eurasian tundra and boreal ecosystems.

The first two goals are aimed at improving our understanding of global change impacts on two critical ecosystem functions - biogeochemical and hydrological cycling, both essential for understanding the carbon dynamics of the region. The first directly addresses the question of major importance in high latitude regions - how will global change affect the ecophysiological aspects of the carbon balance? The second is focused on the effects of increasing temperature on the hydrology of high latitude systems, in particular its effects on the biospheric control of water and energy exchange between the land surface and the atmosphere and on the extent of permafrost. The second goal also provides the conceptual linkage to the proposed tundra land surface experiment. These two goals contribute to the important task of improving the representation of the high-latitude regions in global predictive models.

Ecosystem function, however, interacts strongly with ecosystem structure and composition; direct effects of global change on function (*e.g.*, CO_2 fertilisation effect) can be largely overridden if ecosystem structure changes (*e.g.*, tundra to boreal forest). The third goal is aimed at projecting changes in ecosystem structure and composition, and will be closely linked to the first two goals. Disturbance will play a critical role in the response of tundra/boreal ecosystem function and structure to global change. Two of these disturbances - human land-use change (including industrial development) and fire - are so important that they have been highlighted in an overall goal of their own. This last goal requires the expertise being developed in the LUCC Core Project, and its active collaboration in the IGBP Northern Eurasia Study should be established at an early stage.

The four overall goals are concerned primarily with the feedbacks of changes in tundra/boreal systems to biogeochemical cycles and to the physical climate system, and all are crucial in understanding the regional carbon cycle. However, there is much interest in the impacts of global change on other aspects of tundra/boreal systems. For example, the tundra/boreal ecotone provides an excellent opportunity to study the interaction between ecological complexity (biodiversity) and ecosystem function, and sites in the IGBP Northern Eurasia Study could provide the facilities and background information on which to base some of GCTE's Focus 4 research. In addition, there is much interest in the impacts of global change on the boreal forests of Northern Eurasia in their own right, regardless of feedbacks to climate. There is strong interest in the impacts of global change on the productivity of Northern Eurasian forests, and the implications for the sustainable development of this vast natural resource. The IGBP Northern Eurasia Study will provide a useful framework on which other groups can carry out such impact studies. In this prospectus, we explicitly highlight one such study - global change impacts on managed boreal forests - which forms part of the work of GCTE's Focus 3. The Study will provide the platform for collaborative work with other groups wishing to carry out impact studies in their own areas of interest.

Each of the four goals will be addressed by one or more studies, each with its own set of individual components that contribute to, in addition to the unifying theme of this study, various parts of the BAHC, IGAC and GCTE programmes. These individual components and their more specific objectives are described in detail in the next few sections of this document.

General Biogeography of Northern Eurasia

In designing a global change study in Northern Eurasia, based on the overall theme of the region's role in the carbon cycle, it is useful to consider the general biogeography of the region. The Northern Eurasia region is characterised, as are all the high latitude regions, by a strong temperature gradient from north to south. This is the major determinant of the general biome structure of Northern Eurasia, which is classified as tundra and four subzones of taiga (boreal forest): sparse, northern, middle and southern. Together these biomes cover 90% the total land area of Siberia (Kurnayev 1973; Shvidenko and Nilsson 1994).

In addition, the Northern Eurasian region exhibits strong continentality in an east-west direction, with large gradients in temperature and rainfall. The western region receives more than 400 mm per year in precipitation and minimum temperatures are generally above -50°C. This contrasts with the eastern region, with annual precipitation below 200 mm and minimum temperatures below -50°C; the northern hemisphere pole of cold air is situated in the central Yakutia region of eastern Siberia. Figure 3 shows examples of climatic gradients along the 62° latitude, which also shows a shorter period for temperatures above 10°C in the east.

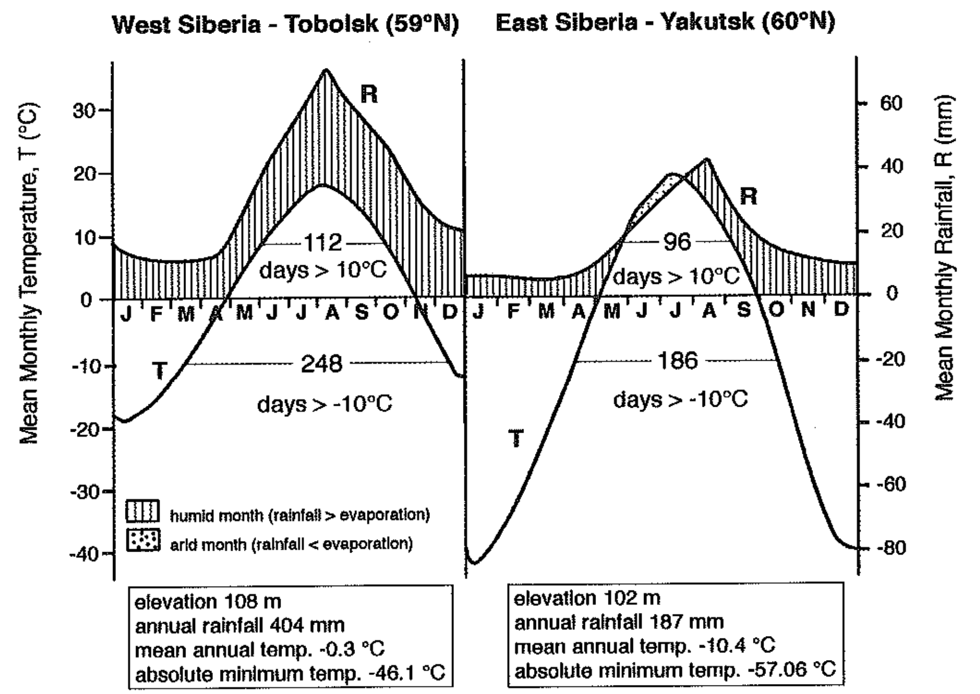
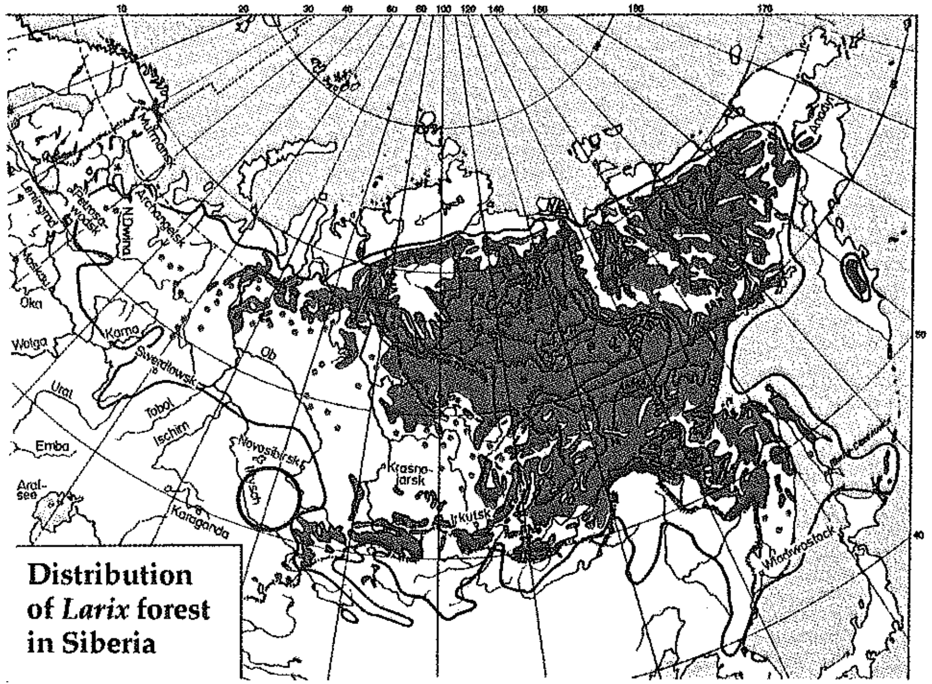


Figure 3. Examples of west and east Siberian climate at about 60°N latitude: for Tobolsk at the Irtysch River (58°N, 68°E) and for Yakutsk at the Lena River (62°N, 130°E). (Walter 1974)



= Total distribution of genus *Larix* = Distribution of closed *Larix* forest

= "Hot spot" for CH_4 emissions

Figure 4. Map of Northern Eurasia showing the distribution of *Larix* species and the southwestern Siberian region of high CH_4 emissions. (Walter 1974; Inoue 1994)

These climatic gradients result in a differentiation of vegetation which is more diverse than in either Europe or North America. The western Siberian tundra is an extremely wet region which changes to colder, but drier tundra types in eastern Siberia. Permafrost is deeper in the east than in the west. More pronounced are the differences in the tundra/boreal transition, where the western tundra grades into the evergreen conifer *Picea obovata*, while the eastern tundra borders on the deciduous conifer *Larix gmelinii*. Thus, the western "dark" taiga is dominated by evergreen conifers (mixed with extended swamps) while the eastern "light" taiga is dominated by almost monotypic stands of *Larix*. Figure 4 shows the distribution of *Larix* species in Siberia. The large extent of *Larix* forests, their unique character (being a deciduous conifer), and the relative lack of knowledge about their potential responses to global change point to the importance of eastern Siberia for global change research.

These differences in moisture regimes between east and west also have a profound effect on trace gas emissions. Initial measurements of CH_4 fluxes over long east-west and north-south transects across Siberia indicate an area of very high emissions at the southern edge of the west Siberian wetland (see Fig. 4 and Inoue 1994). These initial measurements are consistent with emission projections of a few years ago (Mathews and Fung 1987), but

much greater than measured emissions from the North American northern wetlands and estimated emissions from other wetlands in western Siberia and the northeastern part of European Russia (N. Panikov, personal communication to K. Smith).

The hydrological characteristics of the Northern Eurasia region is characterised in broad terms by the east-west gradient in precipitation. However, as far as water and energy exchange between the tundra, boreal forest and transition zone land surfaces and the atmosphere is concerned, sensitivity analyses are required to determine in more detail the characteristics and relative importances of the various sub-regions within Northern Eurasia.

One further feature should be noted: a complicated interaction between the broad, continental-scale gradients and more specific regional gradients. The latter include macrorelief (topography), intensity of land-use, and the nature of the ecotone at the southern boundary of taiga, usually steppe or temperate forest.

General Organisation of the Study

The IGBP Northern Eurasia Study will consist of an integrated set of experimental and observational studies at a number of scales, modelling and aggregation activities, and supporting databases and GIS systems. At the largest scale, there are at least two basic ways in which coordinated sets of observations can be made. One is based on a network of sites representative of important features of a large region, where measurements can be made according to standard protocols to maximise comparability. Another is to organise the sites in a transect along a gradient of an underlying environmental parameter. This is the rationale for the IGBP Terrestrial Transects, described in more detail in Koch *et al.* 1995. Within both the network and transect designs, more intensive observations and manipulative experiments can be carried out at a number of the individual sites in the overall system.

The more detailed description of the network and transect designs as well as the associated modelling and aggregation activities are given in later sections. More work, particularly preliminary modelling sensitivity studies coupled with a careful analysis of existing patterns of vegetation distribution and disturbance regimes, is required before specific sites are selected. However, here we examine the possible observational site arrangements (network and transect) in the context of the broad characteristics of the Northern Eurasian region and the present state of knowledge, and make some general recommendations for the design of the IGBP Study.

The characteristics of eastern Siberia which differentiate it so markedly from the other high latitude regions of the world (high degree of continentality, vast expanse of larch forests, relative lack of knowledge, potential for rapid development) clearly point to its importance within the IGBP Northern Eurasia Study. The general lack of wetlands and thus specific regions of intense trace gas emissions and the gradual transition from tundra to forest suggest that a transect approach is well suited for eastern Siberia. Such a transect should include, at a minimum, intensive study sites in the tundra, in the transition zone, and in the larch forest. A number of less intensively studied sites at more frequent intervals along the transect would add considerable value to the study, as would one or two more intensive sites if resources permit. The plans for GEWEX/GAME studies in eastern Siberia, and the potential for fruitful collaboration with that project, (see section on Interactions) suggest that this area should receive early priority.

In western Siberia and European Russia, where many of the trace gas emissions appear to be concentrated in regions of high emissivity associated with wetlands, a network approach appears to be the more appropriate structure for the studies. The array of sites should include, at a minimum, the area of intense emissions at the southern edge of the western Siberian wetland, at least two or three other sites in wetlands in the northern areas of European Russia and in western Siberia, one site in the coniferous evergreen forests, and one site in the tundra. The latter two sites, particularly if coupled to a third site in the tundra/forest transition zone, would offer a degree of comparability with a transect study in eastern Siberia and with the other IGBP high latitude transects. As in the eastern Siberian transect, more sites would be desirable in the western Siberian/European Russian network if sufficient resources and scientific manpower could be obtained. In addition, these sites could prove valuable in linking to the European networks of ecosystem studies.

Also, if possible, paired sites, one located in an undisturbed system and the other in a human-modified system, are desirable in areas of strong anthropogenic influence.

As mentioned earlier, the general biogeographic characteristics of the Northern Eurasia region which suggest certain areas as high priorities for atmospheric chemical and ecological studies do not point so clearly to equivalent areas of importance for water and energy exchange. More background research and sensitivity studies are required before more specific areas for study and priorities for implementation can be established. However, it is likely that areas of more pronounced relief may undergo the greatest change in the hydrologic cycle, given the importance of topography (regional scale) coupled with permafrost stability (watershed scale) in controlling hydrologic budgets.

Whatever sites are selected, since the carbon and hydrological cycles are intimately linked and water, energy, nutrient and carbon fluxes are routinely measured together, it is essential that the intensive flux studies are integrated so far as possible with the transect and network components. Indeed, it is desirable that flux measurements be made at as many sites and for as long as resources and manpower permit. The precise deployment of limited equipment and manpower will be based on the results of pre-study modelling activities and sensitivity analyses.

Thus, although the proposed tundra land surface experiment (LSE) itself is probably some years away yet, the general design of the IGBP Northern Eurasia Study already offers two significant advantages for the proposed tundra LSE as an integral part of the Study:

(i) The LSE can build on a multi-year and multi-site base of ecological observations and experiments, including eddy correlation measurements of water, energy and trace gas fluxes, that will facilitate the more reliable extrapolation of the LSE results to the "biome productivity" scale

(ii) The establishment of transect and network arrays, each with at least one intensive tundra study site, in both eastern Siberia and western Siberia/European Russia will allow considerable flexibility in the design and selection of a site or sites for the tundra LSE, whatever form it will eventually take.

The projected duration of the IGBP Northern Eurasia Study is about 10 years, with some of the more intensive campaign-style components embedded within longer term observational studies. Much of the ecological research should continue beyond the minimum of 10 years, and some of the observational components may become part of the Global Terrestrial Observing System (GTOS) (Heal *et al.* 1993). The IGBP Northern Eurasia Study will be implemented with a phased approach. As described below, some components can be initiated in the relatively near future. Others require further planning, aided by modelling pre-studies and sensitivity analyses, before the experimental design is finalised and work is actually begun.

Most importantly, the Russian scientific community must be centrally involved in the detailed planning and execution of the IGBP Northern Eurasia Study. Northern Eurasia is the only place in the world where large groups of scientists live and work in the far North for 12 months of the year. There is much previous Russian work in the region that will provide valuable background knowledge, while ongoing Russian research could provide most of the components of the IGBP Study. In particular, it will be important to consider the existence of current Russian research projects in the selection of sites, as described in the next section of this document.

Design of the Transect Component

The transect design outlined here is based on the principles described for the IGBP Terrestrial Transects (Koch *et al.* 1995). Although the participants did not recommend any specific sites for components of the IGBP Northern Eurasia Study, it does seem logical to establish a component based on a north-south transect in eastern Siberia (see previous section), and indeed the interest of GEWEX/GAME in that area suggests that the IGBP Northern Eurasia Study should give it early attention. The design outlined below would be appropriate for an eastern Siberian transect. It should also be emphasised that a north-south transect will be one of a set of four such high-latitude IGBP Terrestrial Transects, the others being located in Alaska, Canada, and Scandinavia/northern Europe. In this context, the eastern Siberian transect would add the most to the set and is thus favoured from the global perspective. However, a strong case could also be made for a transect approach to the western Siberia component of the Study.

The issue of where to locate a north-south transect(s) was discussed at length at the IGBP Northern Eurasia Open Meeting, December 1995, which had significant participation from the Russian scientific community. The recommendation of that meeting was that two such transects be established, one in the Far East in the Lena River basin in collaboration with GAME, and the other along the Yenesei River. See Appendix 6 for a report of the meeting and Figure 1 for the proposed location of the transects and the other recommended study sites.

Figure 5 shows the overall design of a transect, organised around field research stations and associated sample plots. The overall transect is based on a minimum of three intensive (Level 1) sites - one each for the tundra, the tundra/forest transition, and the forest zones. In the case of an eastern Siberian transect, the forest site would be located in a larch forest with a possible extension to the mountain cedar (*Pinus siberica*), spruce and fir forests ("dark coniferous" forests, in the Russian terminology) further to the south. A number of less intensive (Level 2) sites will be located at intermediate positions along the transect. It would be highly desirable if a fourth Level 1 site, located within the forest biome at the southern permafrost boundary, be established. This may be feasible in eastern Siberia through collaboration with GEWEX/GAME.

Each Level 1 site will consist of a "super site" where many of the intensive measurement campaigns and manipulative experiments will take place and where the major infrastructure will be located, and at least four sub-sites (for the forest and tundra/forest transition sites). The sub-sites will sample different types of successional stages in the systems, and will include logged forest, post-burning forest, and young, middle-aged, and old regrowth forests. The tundra site will be the core of the tundra LSE (see below) and will include a number of sub-sites sampling a range of vegetation types and hydrological regimes.

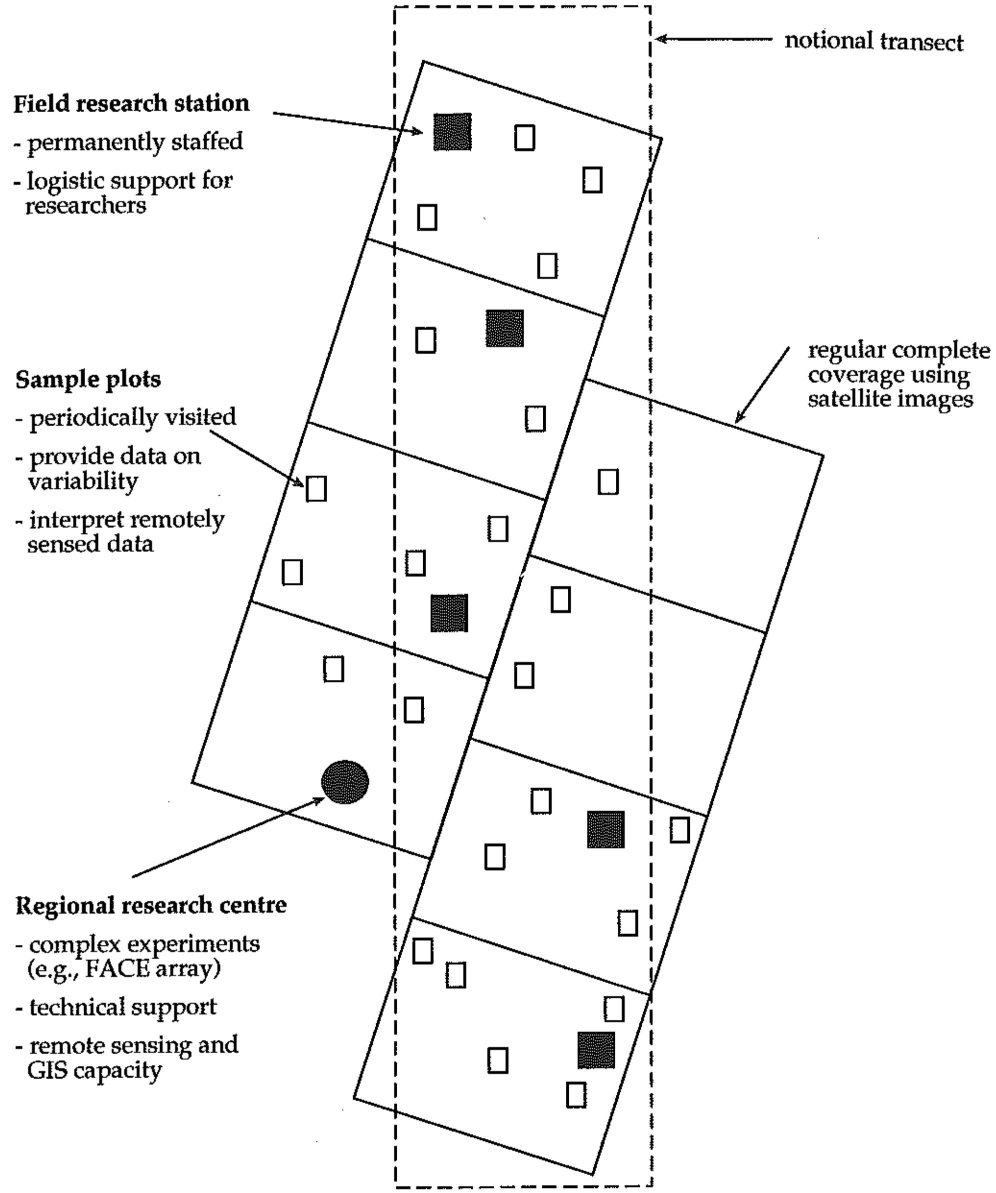


Figure 5. Idealised design for a north-south transect within the IGBP Northern Eurasia Study (from IGBP Report No. 36: IGBP Terrestrial Transects: Science Plan). The field research stations (minimum of three) should be located in the tundra, tundra/forest transition, and boreal forest zones. The sample plots should encompass the various stages in the successional dynamics of the forest.

An important objective of the suite of observations and experiments carried out at each Level 1 site will be to close the carbon, nitrogen and water budgets by measuring all components, with none left to be estimated by difference. These closure experiments will require that measurements, particularly those made in a series of campaigns over long time spans, be made with standardised methodologies and be carefully coordinated. It is also essential that these measurements be standardised with those being made along the other three IGBP high latitude transects.

A number of measurements are required at each super site and at as many of the sub-sites within the Level 1 site as possible. These include:

- Site characteristics (*e.g.*, landscape unit, soil type, vegetation composition/structure, land-use/cover history)
- Environmental variables (*e.g.*, weather, climate, soil moisture and temperature, *etc.*)
- Flux measurements, both air- and water-borne (C and N compounds, H_2O, via aircraft, eddy correlation, chambers; groundwater and stream chemistry)
- Forest growth, productivity, stand structure
- Decomposition, microbiology.

To derive the maximum possible benefit from the Study, it is important that standard methodologies for measuring these variables be used wherever possible. Protocols exist for the standardised measurement of many of them. For example, Appendix 1 gives protocols for site characteristics and environmental variables for the IGAC/TRAGEX networks, and could provide the basis of these measurements on the IGBP Northern Eurasia transect(s). They would also facilitate comparison with other sites in Northern Eurasia arranged in a network array (see next section).

In addition, there is a need to intercalibrate soil measurements made in this Study with the other high latitude transects in the IGBP set. As a basis for a common protocol, the set of methods used by the IGAC/TRAGEX (Trace Gas Exchange: Mid-Latitude Terrestrial Ecosystems and Atmosphere) and HESS (High Latitude Ecosystems as Sources and Sinks of Trace Gases) Activities may be a useful starting point. To build on this, it may be necessary to (i) run one or several workshops on methodological aspects of the soil measurements, and/or (ii) assign a person or team of persons to write a handbook on methods (cf. the Tropical Soil Biology and Fertility Programme (TSBF) Handbook used in the tropics). These activities should be given high priority because they should precede the start of the transect studies in both Scandinavia/northern Europe and Northern Eurasia.

It is of particular interest to distinguish between active and passive pools of soil C and N. Classical litter bag type studies may be of limited value, not least because of slow processes. It may instead by worthwhile to try to analyse the age of fractions of soil organic matter (*e.g.*, three humus fractions) by various radioisotope techniques. Northern Eurasia provides unique possibilities to use "bomb" ^{14}C and ^{137}Cs. Recent advances also show that $^{13}C/^{12}C$ ratios may provide useful information about decomposition and vegetation composition in the past. Retrospective studies of this kind should be coupled to modelling of vegetation and hydrology; links to PAGES studies in this area are important.

It should also be mentioned that flat sites, without major topographic or land cover perturbations for several kilometres in extent, are required for the eddy correlation measurements (see section below on Water, Energy and Carbon Flux Component).

Several suggestions to enhance the value of the measurements should be noted:

- Flux measurements should be carried out long enough to capture the seasonal and inter-annual variability of the system.
- Natural isotope studies (in addition to "bomb-isotope" studies) should be employed where possible to determine the pathways and rates of element movement through the system, particularly movement into the surface and groundwater hydrological systems.
- As part of the site characteristics, autecological characteristics (*e.g.*, temperature limits, drought tolerance) and silvics (*e.g.*, tree height, basal area, thickness, gross and net growth, leaf area per unit stemwood) of major Siberian trees species are required. Stand age structure is also an important characteristic of the forest system that should be determined. Much of this data may already be available, but some of it may need to be obtained by measurement or observation.
- Records of past land-use practices and disturbance (fire and insect) patterns, if available, will be valuable in interpreting the history of the successional stages of the sub-sites.
- Wherever possible, observations of ecosystem composition should be linked to the long-term process studies that are being carried out on the same sites. For example, studies that examine tree line shift should examine whether hydrological patterns in the landscape are associated with the transition from tundra to taiga in a causal manner.
- Measurements should be nested within an instrumented hydrological basin.

In addition to observational studies, manipulative experiments can also be carried out at one or possibly more of the supersites. The types of experiments proposed include nutrient treatments, soil warming, water level manipulation (tundra site), burning, and thinning (forest site).

Elevated CO_2 treatments, preferably over long time spans and in combinations with the other treatments, are also desirable, but are expensive and logistically demanding. Results from a three-year, ecosystem-level elevated CO_2 experiment on tussock tundra in Alaska indicate that the responses of natural ecosystems to elevated CO_2 may not always be positive, and are unlikely to be straightforward (Oechel *et al.* 1994). Further elevated CO_2 research is required to determine the generality of the results from Alaska.

Protocols for manipulative experiments in relation to global change studies are available, and should be adopted here where possible. See Appendix 2 for an example.

The Level 2 sites will support a subset of the measurements of the Level 1 sites, primarily to provide information for the development, calibration and validation of the ecosystem dynamics models. Level 2 sites may also be used for less intensive measurements associated with process studies, such as chamber measurements of trace gas emissions.

Practical considerations with respect to site selection are very important. The sites should be readily accessible to teams of Russian and international scientists, should have accommodation and power available, and should ideally be associated with a university or research institute that can provide the basic infrastructure required for a field research station on a continuing basis. Facilities for reliable and rapid communication and the capability for emergency evacuation are also important requirements. To ensure the cohesiveness of the transect study as a whole, transport between the sites along the transect should be convenient and relatively quick.

On the other hand, remote sites could also prove valuable, as only these will be truly undisturbed. Siberia is one of the few areas in the world where large areas of natural ecosystems remain. Helicopter transport may provide access to remote sites, albeit at a somewhat higher cost than those accessible by road or river.

Design of the Network Component

A key rationale for the establishment of a network of study sites in western Siberia, the Far East and European Russia is the quantification of trace gas fluxes from a variety of systems and the understanding of the putative controls of these fluxes so that their variation under global change can be predicted. As noted in the section above, trace gas flux measurements along the eastern Siberian transect, if carried out in a standardised way, would combine with the measurements outlined here to lead to a network of flux measurements spanning the entire Northern Eurasian region. As for the transect, it is highly desirable that long-term ecological studies, as well as measurements of water and energy fluxes, also be carried out at sites in the network. Many Siberian and European Russian institutions have already developed a set of long-term experiment sites which could provide an excellent base for much of the work proposed for this Study.

The questions which such an extensive network could address include:

- Is the southwestern Siberian wetland region unique with respect to biosphere-atmosphere exchange of H_2O, CO_2, CH_4 and other trace gases?
- What proportion of trace gas emissions are "fossil", viz., from carbon stored under decaying thermokarst lakes in eastern Siberia or released by exploitation of oil and gas deposits?
- What impact do trace gas emissions from forested areas have on atmospheric composition (O_3 precursors, N_2O, *etc.*)?
- What types of fire experiments and campaigns can usefully be linked to sites established for other purposes to study, for example, peat fires?
- Are the vegetation and soil factors that influence carbon, water and energy exchange in this wetter, relatively warmer region similar to those in eastern Siberia?

It is essential that a standardised dataset of site characteristics and environmental variables be measured at each site in the network to facilitate model development and allow comparison of fluxes between different sites. A trace gas flux measurement network is being established in North America and Europe as part of the TRAGEX Activity of IGAC, and the proposed protocols for measurement of site characteristics and environmental variables established there (see Appendix 1) could provide a useful basis on which to construct protocols for this Study.

For the trace gas flux measurements themselves, it is suggested that the exact measurement technique or even the instrument to be used should not be specified. Some techniques may not be available at some sites, and emerging technology (*e.g.*, eddy correlation, conditional sampling) may be employed partway through the Study. Rather, it is more important to specify the units in which the flux measurements are to be expressed and the accuracy required.

To assist with the extrapolation of the measurements made at the sites, several other types of measurements or observations will be valuable. First, it is imperative that the vertical profiles of trace gas concentrations be measured, up to a height of about 7 kilometres. Second, measurements of atmospheric composition over longer horizontal spatial scales, for example by the use of aircraft transects, will be useful in scaling up fluxes. Such aircraft transects have already proved valuable in identifying potential regions of high emissions of trace gases (Inoue 1994). Finally, remote sensing data will be crucial in scaling up estimates of fluxes based on ecosystem type and state, particularly in describing the complexity of landscape patterns and the influence of natural and anthropogenic disturbances on it.

In addition to the measurement of trace gas fluxes (other than CO_2), integrated measurements of carbon and water fluxes (by eddy correlation) should be made at several sites in the network over long periods of time. Such integrated measurements will help to determine experimentally the daily, seasonal and interannual variability of water, energy and carbon exchange from the various ecosystem types represented in the network. Again, it is essential that these measurements be carried out under similar designs and with comparable methodologies to those employed in the eastern Siberia transect.

An appropriate set of sites from the network combined with corresponding sites from the eastern Siberian transect will provide useful data for calibrating and validating patch-scale ecosystem dynamics models along an east-west gradient of climate continentality. Such models can predict forest composition along a temperature gradient rather well, but are less reliable in simulating change in forest composition along a moisture gradient.

Design of the Water, Energy, and Carbon Flux Component

There are two aspects of water, energy and carbon fluxes to consider in relation to the IGBP Northern Eurasia Study. First, as mentioned earlier, water and energy and carbon fluxes are coupled, and, increasingly, measurement campaigns aimed at determining water and energy fluxes also determine CO_2 fluxes as part of the study. Thus, any study of carbon dynamics should also consider the hydrological cycle. Second, water and energy fluxes between the land surface and the atmosphere influence climate, and therefore global change studies have a strong interest in water and energy exchange processes in their own right. In the IGBP context, the emphasis is on the biotic control of water and energy exchange.

As mentioned above, the precise configuration of the measurement sites, the types and duration of the measurements, and the nature of the aggregation strategies and tools will be refined following initial analysis of existing data and experimental work and modelling sensitivity studies. However, even at this early stage, a number of recommendations can be made concerning the design of the water, energy and carbon flux component of the Study:

- Measurements should include both eddy correlation measurements of water, energy and carbon fluxes between the land surface and the atmosphere and nested catchment studies of water and carbon fluxes along the land surface.

- So far as possible, eddy correlation measurements should be made at the intensive study sites along the eastern Siberian transect and the western Siberian/Far East/European Russian network. This requires that these intensive sites be chosen carefully to ensure compatibility with the needs of the flux measurements (*e.g.*, adequate fetch, infrastructure, representativeness of ecosystems, *etc.*). In most cases, these requirements are similar to those needed for the biogeochemical and ecological research.

- Eddy correlation and chamber measurements of trace gas fluxes should be made simultaneously at the same locations, if possible, for calibration of techniques and cross-comparison of results.

- Eddy correlation measurements of fluxes should be made, equipment and manpower permitting, at a number of locations around an intensive site (see Fig. 4) representing the major stages of forest succession. Also, the duration of the measurements should be extended beyond the usual campaigns of a few weeks during the summer to sample the four seasons as well as to attempt to capture some of the interannual variability. This will be facilitated if sites are chosen where Russian scientists are already based year-round.

- The surface hydrological studies should include catchment experiments at a variety of scales, linking with the GEWEX studies at the larger scales. The studies should include measurements with shallow groundwater wells, detailed soil moisture measurements, and precipitation measurements. Measurements of sediments and dissolved chemicals (particularly carbon compounds) should be included.

- The measurement of snow fall, lie and melt are essential measurements in the Northern Eurasia Study. These are required to understand the hydrology, the energy balance, the trace gas fluxes and the evolution of soil moisture throughout the year. At the smaller scales, snowmelt and surface runoff and their relationship to permafrost should be measured.

- Impacts of permafrost and mesoscale landscape processes need to be considered.

Previous intensive studies of water, energy and carbon fluxes in boreal forests, such as the Boreal Ecosystem Atmosphere Study (BOREAS) and the Northern Hemisphere Climate Processes Experiment (NOPEX), will provide valuable experience on which to build similar measurements in this Study. Indeed, the models and algorithms being developed in those studies could provide the basis, with appropriate parameterisation, for the sensitivity studies to be conducted in the early stages here.

Although the unifying theme of the IGBP Northern Eurasia Study is the terrestrial carbon cycle, BAHC has a strong interest in water and energy exchange, not only for its linkages with the carbon cycle, but also for its direct effects on the climate. Along with other groups interested in the issue, BAHC is involved in planning for a tundra LSE to be carried out late this century or early next century. Although planning for the tundra LSE is very much in the early stages, a brief description of the BAHC perspective for a tundra LSE is useful to place it in the context of the IGBP Northern Eurasia Study. It is also useful to note here that tundra ecosystems in eastern and western Siberia are significantly different, as are the flat tundra systems found in European Russia and the mountain tundra systems of the Far East.

The principal objectives of a tundra LSE are:

- To investigate the energy, water and trace gas exchange processes at the soil-vegetation-atmosphere interface on a local scale for tundra ecosystems

- To investigate and apply methods to aggregate fluxes and land-surface (biological and hydrological) parameters from local to continental scales

- To investigate the spatial and temporal variability of atmospheric and land-surface parameters describing the SVAT processes for tundra ecosystems

- To develop and validate methods to derive regionally distributed hydroclimatological information from GCM output ("downscaling")

- To determine the relative importance of different topographic or vegetation units in regional H_2O/energy fluxes and to predict how climate or land-use induced changes in these units will alter regional hydrologic budgets.

The tundra LSE will be an integrated study involving modelling, field observations and satellite remote sensing. There will likely be a hierarchy of observational data nets, including continental GIS, basin-wide networks for water balance studies, and imbedded 'anchor stations' and 'anchor areas' for local and/or regional energy balance studies. Important aspects of the study will be long-term observations and validation/ improvement of SVAT schemes, and the area-extended validation/development of SVAT schemes and remote sensing algorithms.

The next steps for the further design and implementation of the tundra LSE include the following: (i) a review of the state-of-the-art in hydroclimatology, palaeo-climate and -vegetation, previous observations, previous modelling studies, remote sensing studies, and data availability; (ii) development of regional GIS using existing data (vegetation/ soils and hydroclimatology); (iii) the definition of "anchor stations" (long-term/year-round covering major tundra biome types, climates, and emission situations); and (iv) preparatory modelling and remote sensing studies to develop the observational strategy.

It is highly desirable that the tundra sites of the IGBP Northern Eurasia Study should also be the anchor stations of the tundra LSE. Since some components of the Study will likely be in place several years before the tundra LSE is in the advanced planning and operational phases, it is important that the requirements for the anchor stations are considered carefully now rather than later. In general terms, the tundra LSE requires sites which are truly representative of the major tundra ecosystem types, which preferably have long-term hydrological and climatological data collection in place, and which have the logistical characteristics required to mount a large-scale, technologically sophisticated experiment. The latter suggests a site with basic infrastructure to house teams of scientists during periods of intensive study; an adequate and reliable power supply; nearby transport available for hire; and, if possible, with a workable airstrip within 50 km of the sites (perhaps a disused but still functional airbase).

Design of the Fire Component

Fire-induced successional dynamics are a critical element in determining "biome productivity", as measurements of carbon fluxes made at point locations during relatively short time steps must be scaled up over decades and over large regions containing ecosystems in various stages of succession. It is essential that the extent and frequency of fires under changing environmental conditions and management scenarios be predicted, based on data of present-day fire regimes and their relationship to climate and biomass.

The fire component of the IGBP Northern Eurasia Study will have four parts: (i) fire manipulations at individual forest sites; (ii) a series of campaigns based on air- and spaceborne research platforms; (iii) the construction of a fire database, relating the extent, frequency and intensity of fires to vegetation and climatic conditions for present-day and historic conditions; and (iv) development of aggregated models of forest fire frequency and extent, responsive to global change variables.

First, fire will be used as a treatment in the manipulative experiments at some of the intensive study sites in the transect and in the network. The experiments will measure the effects of fire on the successional dynamics of the vegetation, particularly on the composition of the regrowth forest, and will determine the effects on the nutrient dynamics of the soil and the vegetation. Special attention will be given to the consequences of fire on permafrost sites, and to emission characteristics and elemental carbon formation of peat fires and other less studied fuel types.

Second, more research campaigns in the frame of FIRESCAN are required to couple air- and spaceborne measurements of biogenic trace gas and aerosol emissions with pyrogenic sources. The newly established National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radar (AVHRR) receiving stations in Krasnoyarsk, Yakutsk and Khabarovsk will play an important role in identifying fires in real-time or post-campaign reconstructions.

Third, given the importance of fire in terms of long-term and large scale ecosystem dynamics, a comprehensive ecologically-oriented fire database for Northern Eurasia is essential. The database will build on the National Resources Geographic Information System developed by the Russian International Forestry Institute and should include, in a geographically explicit format, the timing, areal extent, frequency, and intensity (in terms of effects on vegetation as well as gas emissions) of fires, and the state of the vegetation and the climatic conditions at the place and time of the fires. Past fire regimes will be reconstructed through linkage of tree ring fire chronologies and densitrometric analyses with palynological and charcoal data in peat layers and lake sediment cores.

Fourth, the ultimate aim is to develop a model of change in fire frequencies and patterns under global change, based on an environmental response surface for fire. Such a model must also be responsive to natural disturbances such as lightning and to changes in fire patterns caused by socioeconomically driven land-use changes.

Modelling, Integration and Data

Modelling, integration and data are at the heart of the IGBP Northern Eurasia Study. As described below, modelling sensitivity studies will be undertaken before some observational and experimental work is begun to improve the designs of those components, and to identify key variables and weaknesses in understanding. Integrated models will be employed and developed at a variety of scales combining the process and compositional aspects of ecosystem response to global change to project the consequences for trace gas emissions, water and energy exchange, and, at the regional scale, biome productivity. The modelling, observational and experimental studies together will provide the basis for analysis, interpretation and synthesis activities, which will be the ultimate product of the Northern Eurasia Study. These activities will aim to answer the fundamental question of how global change will impact upon the terrestrial carbon cycle in Northern Eurasia, and will link closely to GAIM to assist in its goal of understanding, analysing and simulating the global carbon cycle.

The data requirements associated with these activities are considerable, and a coordinated strategy for the collection, archiving and dissemination of data must be established in the early planning phases of the Northern Eurasia Study. IGBP-DIS will provide valuable assistance with the development of a coherent data plan for the Study.

Models

Modelling studies will be undertaken at a variety of scales using a number of specific modelling tools, some of which already exist and others which will have to be developed as part of the Northern Eurasia Study. In general, there are three scales at which modelling will be undertaken. The "patch" scale is usually based on an internally homogeneous unit of the system under study (often tens or hundreds of metres in extent), and is usually associated with experimental or observational studies carried out at specific sites. The regional or continental scale spans the entire Northern Eurasian region, and the simulation tools used at this scale are normally regional or global models (*e.g.*, GCMs, global biogeochemical models, or global vegetation models). Processes at the scales in between patch and continent are often the most difficult to simulate. In some cases, for example, the aggregation of water and energy fluxes between the land surface and atmosphere ("up-scaling"), considerable progress has been made by taking into account the dynamics of the atmospheric boundary layer and the heterogeneity of the land surface. However, for ecosystem dynamics, phenomena such as fire and insect outbreaks operate at scales larger than a patch and smaller than a continent, and there is no clear connection between patch scale and these larger scale processes, thus vitiating the application of atmospheric-type aggregation techniques.

A major aim of the modelling component of the IGBP Northern Eurasia Study is to tackle this difficult scale of tens to hundreds of kilometres. The Study, and the transect component in particular, is well designed to address this aim (see Koch *et al.* 1995 for a description of the role of transect studies in tackling the scaling issue).

Below we list a number of existing and proposed modelling tools which could be of value in the Northern Eurasia Study. The list is not meant to be exhaustive or exclusive, but rather to give examples of the range of models which could be usefully employed.

Patch Scale

Trace gas flux models
Field measurements from a range of environments have shown that methane emission is the balance between production and oxidation. This balance is a complex function of soil temperature, moisture and water table level, substrate quality, microbial populations, and vegetation. The soil parameters and methane flux are poorly correlated and site-specific, and indicate that a single parameter capable of predicting methane flux is unlikely. Parameters that integrate conditions influencing flux appear to be the best flux predictors over the emission period. Soil climate models and process-level models, which apply to small spatial scales, are being developed from seasonal time series observations and field manipulation experiments. No general models are available for reliably predicting methane flux, but vegetation-type: integrated emission correlations applied to remotely-sensed vegetation maps and relationships between net ecosystem exchange and methane emission show promise for scaling up and application as components of GCMs.

Ecophysiological models
Well-known models of this type include SVAT (Soil-Vegetation-Atmosphere Transfer) models, patch-scale biogeochemical models such as CENTURY, and process-based models of forest growth and productivity. SVAT models are designed to simulate the exchange of water and energy between the vegetation-soil system and the atmosphere. They are often employed as components of GCMs but are increasingly being used in a variety of applications where ecophysiological models operating on small time scales (20 or 30 min) are required. Biogeochemical models emphasise below-ground processes of soil organic matter dynamics and nutrient dynamics, and can simulate the emission of trace gases from the soil. Such models, or derivatives thereof, are essential in simulating net ecosystem productivity. Forest growth models simulate the accumulation of above-ground biomass and other aspects of tree growth as a function of climate and soil parameters.

Patch models of ecosystem dynamics
Much of the predictive research on change of ecosystem composition and structure in temperate and boreal forests under global change has been carried out using "patch" models (models operating at the scale of a few mature individual trees). The development and application of these models has usually been site-specific, and the models differ widely with respect to the processes considered and the level of detail used in their formulation. Robust, generally applicable patch models are required for simulation of ecosystem dynamics in the IGBP Northern Eurasia Study. Data from the individual sites along the transect will be crucial in developing models that can be transferred from one area to another with confidence. Also, the definition of plant functional types (FTs) will circumvent the need for species-specific model parameters (Bugmann 1996). Recent studies have shown the potential for developing patch models of forest dynamics that are generalisable at continental scales (Bugmann and Solomon 1995). Cross-comparison of existing patch models at different sites, particularly along the eastern Siberia transect, will

be an important component of the Study. Finally, patch models must also be able to handle permafrost dynamics, an aspect with which BAHC may able to assist.

Since patch models of ecosystem dynamics simulate compositional change within forests over hundreds of years, records of past changes in forest composition are valuable validation tools. Thus, data on vegetation dynamics during the past centuries, as far as available, should be obtained; these can be written records as well as reconstructions based on proxy data, such as pollen records or tree-ring data. Again, collaboration with PAGES will be important for this aspect of the Study.

Site requirements and measurement protocols for patch models of ecosystem dynamics (based on a transect design) are given in Appendix 3.

Semi-empirical forest production models
These models are based on a phenomenological description of the structure and dynamics of the forest ecosystem (*e.g.*, yield tables, semi-empirical growth models, phytomass fraction dynamics, statistical models of structure, *etc.* - see Korjakin 1990; Sokolov *et al.* 1993), and are commonly used in Russian forest management. Such models can provide a useful first approximation to change in forest productivity, as well as providing cross-comparisons to other models.

Continental Scale

Ecosystem and regional biogeochemical models
There are several available models that simulate the net primary productivity (NPP) of ecosystems at the biome and global scale. Two examples of these are the Terrestrial Ecosystem Model (TEM - Melillo *et al.* 1993) and the Frankfurt Biosphere Model (FBM - Lüdeke *et al.* 1994). Such models will be useful in providing a "top-down" regional estimate of the terrestrial carbon balance, in comparison to the estimates generated from the upscaling of processes studies, patch models, and landscape models to the region. Global models that combine biogeochemistry and vegetation distribution (*e.g.*, PLAI - Potsdam Land-Atmosphere Interaction model, Plöchl and Cramer 1995) will be particularly valuable.

General Circulation Models (GCMs)
GCMs simulate the future evolution of the climate given changes to atmospheric forcing functions, such as greenhouse gas concentrations. Outputs from various GCM scenarios will provide the future climatic data which will be used to drive the various ecosystem and trace gas models. In the longer term, results from the IGBP Northern Eurasia Study will contribute towards the development of dynamic global vegetation models, which will provide a dynamic, interactive land surface for future GCMs.

Models of atmospheric chemistry
A hierarchy of atmospheric chemical models could be used to address specific aspects of the IGBP Northern Eurasia Study, for example, to help interpret some measurements; to interpolate measured concentrations of chemical compounds between sites; and to provide a general framework for the atmospheric chemical aspects of the Study. Intensive zero-

dimensional models of atmospheric chemistry will be appropriate to study the fate of chemically reactive biogenic gases (*e.g.*, isoprene, terpenes) and their contribution to the production of other chemical species (*e.g.*, oxygenated hydrocarbons, carbon monoxide, aerosols, tropospheric ozone). Regional three-dimensional models driven by analysed or assimilated dynamical fields (winds, temperature, *etc.*) will provide useful information about the transport of chemical compounds (including boundary layer exchanges and advection in the free troposphere). These models, especially if nested in global chemical transport models, will be essential to analyse temporal and spatial variability in the concentration of trace constituents measured at different sites. Finally, global chemical transport models will be appropriate tools to assess the possible impacts of trace gas emissions in Northern Eurasia on remote regions, and ultimately on the entire Northern Hemisphere.

Landscape-scale Models and Aggregation Tools

As landscape-scale models are often useful in making the linkages between patch and continental scales, we consider them together with aggregation tools.

Hydroclimatological aggregation techniques

Considerable progress has been made over the last decade or so in developing techniques for upscaling water, energy and trace gas fluxes from small patches to landscape and larger scales. More recently, advances have been made in scaling up fluxes in areas of pronounced surface heterogeneity (*e.g.*, irrigated patches in an arid landscape) and in hilly topography.

Meso-scale meteorological models

These operate with a grid cell of 1 to 20 km and run for short time periods (typically 24 hours) forced by the global forecast models. They provide a valuable tool for aggregating patch scale processes up to the GCM grid size and for the integration and assimilation of surface, aircraft and satellite measurements. Increasingly they are coupled to hydrological models and, within the time scale of this Study, will have the capability to include carbon and trace gas fluxes.

Landscape models of ecosystem dynamics

Processes that operate at larger scales and lead to distinctive spatial patterns in boreal forests, such as fires, windthrow and insect infestation, must also be included in models of ecosystem dynamics. A number of such models already exist; appropriate ones must be selected and refined for Siberian conditions. An important objective here is to link the landscape models of ecosystem dynamics with landscape models of processes, such as hydrology and biogeochemistry. The use of the same FT classification in both types of landscape model should facilitate this linkage. Another potentially useful tool is the ecoregion approach, as proposed in the Siberian Forest Study (see Interactions section, below).

Landscape hydrological models

These semi-distributed hydrological models can be used to describe the carbon balance and ecosystem/atmosphere exchange processes at catchment scales. They also predict vegetation type as a function of hydrology and topography, with a high degree of success in tundra systems. By imposing a "top-down" perspective on the variability of processes at individual sites in a landscape, such models will be instrumental in the scaling up of processes from patch to landscape.

Fire models

A number of models related to fire are required: (i) models of the gaseous and particulate emissions of biomass burning and their transport, with particular emphasis on their vertical transport into the troposphere and stratosphere; (ii) probability-type fire ignition models based on climatic conditions and the amount and condition of the biomass; and (iii) rule based models of fire pattern and extent, derived from databases of the spatial distribution and frequency of fires in the tundra/boreal region.

One other type of model must be considered if realistic projections of change in the terrestrial carbon cycle of Northern Eurasia can be made.

Land-use change projections

It is likely that even with the best process and compositional models of ecosystem change and with the best simulations of trace gas emissions, the projections of changes in the terrestrial carbon cycle of Northern Eurasia will be very inaccurate. None of these models takes into account human-driven land use, which may have a profound effect on biome productivity over the next several decades.

The LUCC Core Project of the IGBP and the International Human Dimensions Programme on Global Environmental Change (IHDP) has been established to understand and project changes in land use and land cover driven by a suite of human-related forces, such as demography, socio-economics, and politics. The understanding and tools being developed in LUCC should be employed in the IGBP Northern Eurasia Study as soon as they are ready for testing, given the long-term potential for land-use/cover change in Siberia. The combination of LUCC's land-use and cover change projections and the biophysical predictions of change being developed in the Study should lead to the most realistic projections of changes in the regional carbon cycle over decadal time scales. The International Institute of Applied Systems Analysis (IIASA) project on modelling land-use and land-cover change in Europe and Northern Asia (see section on Interactions, below) will play a key role in providing such projections.

Data

Data will be generated at small scales as part of the intensive studies undertaken at individual sites within networks or transects, and at network- and transect-scale. Here we consider the data requirements of the Northern Eurasia Study as a whole, that is, for the entire Northern Eurasian region.

A georeferenced baseline dataset will be required for the Northern Eurasia Study. This will include the following information:

- Landform classification
- Digital elevation model
- Vegetation (by structural and functional types) distribution. Major vegetation types should be classified and analysed in terms of structure and its relation to function. Thus, the vegetation classification should not be species based, but be oriented toward a typology based on key functions (i.e., FTs)
- Soil type (functional classification), related to the role of soils in regulating key processes, such as CO_2 exchange, CH_4 generation or consumption, and decomposition (*e.g.*, organic matter content, chemical fractionation of organic matter, temperature, pH); distribution, depth and C content of Pleistocene sediments
- Water table levels, permafrost distribution and thaw depth
- Climatic data (temperature, precipitation, radiation, snow cover on a monthly basis (with variability) for a minimum of 30 years)
- Frequencies and extents of disturbances, including timber harvesting and other direct anthropogenic disturbances.

The IIASA Siberian Forest Study is the most extensive international study ever undertaken of Siberia's forest resources, and is amassing an comprehensive database on Siberia's environment, forest resources and related factors. Many components of this database will be very useful for the IGBP Northern Eurasia Study.

In addition, remotely sensed data will contribute to many of the above datasets. In addition, we note two initiatives of IGBP-DIS that will be valuable for the IGBP Northern Eurasia Study.

AVHRR 1-km database. This ongoing database will give estimates of changes in net primary productivity (NPP) (derived from Normalised Difference Vegetation Index, NDVI), which can be used to validate components of the various carbon flux models. In addition, the 1-km database can detect interannual variability in NPP and, at longer time-scales, can monitor changes in land cover.

CEOS/IGBP-DIS High Resolution Data Project. This project is currently in a pilot phase. If successful and extended, it could provide high resolution data (Système pour l'Observation de la Terre - SPOT and Land Remote-Sensing Satellite - Landsat) at the intensive sites and along the transect for the calibration and validation of landscape and meso-scale models. Combining the AVHRR data with the higher resolution data for the same sites will be a valuable tool in facilitating extrapolation of understanding to larger scales.

In addition, there are other remote sensing systems which will provide valuable information for the Northern Eurasia Study, for example, on fire frequencies and extents. SAR (Synthetic Aperture Radar) will also be useful in providing an estimate for surface soil moisture and for lake fraction of landcover, which can be as high as 30% in parts of Northern Eurasia.

Global Change Impacts on Managed Forests

Although the central theme of the IGBP Northern Eurasia Study is the carbon cycle, and the coordinated set of components described above is focused on that issue, the Study provides an excellent platform for related research within the various IGBP Core Projects and other groups interested in studying aspects of global change. Many such potential related projects could be described. In this section we highlight one of them - global change impacts on managed forests - as an example of how such projects could be linked to the Study, to the benefit of each through the sharing of resources and scientific expertise.

There is much interest in the impacts of global change on the forests of Northern Eurasia in their own right, regardless of their role in the global carbon cycle. One of the primary aims of the research in GCTE's Activity 3.5 "Global Change Impacts on Managed Forests" is to identify resource management strategies for sustainable forestry and ecosystem management under global change. The research strategy underlying this Activity is to sample a representative range of forest types, growing under various conditions in different parts of the world. Within these, establishment of identical, or very similar, experiments will allow evaluation of the variation of, and constraints on, the productivity and biological diversity of forests. Boreal forests have been identified as a high priority forest type.

Within the context of the IGBP Northern Eurasia Study, the forest sites in both the eastern Siberian transect and the western Siberian/European Russian network may be useful as part of the global networks to be established by GCTE Activity 3.5. The eastern Siberian transect in its entirety (apart from the tundra site) may also be directly relevant in helping to determine the influence of temperature on boreal forest productivity.

The observation strategy outlined for GCTE Activity 3.5 is based on a nested approach with three levels: 1 - extensive level, baseline measurements; 2 - medium level, community dynamics; and 3 - intensive level, process measurements. Many of these measurements and observations are identical or very similar to those outlined earlier for the IGBP Northern Eurasia Study. The manipulative experiments called for in the managed forests research of GCTE are identical to those described above in the transect component of the IGBP Northern Eurasia Study, with the possible addition of elevated CO_2 experiments. It is also important to note that landscape scale phenomena, which often interact with the physiologically based processes at patch scale, are critical for forest management.

The larch forest site in the eastern Siberian transect is a particularly important one. There is an urgent need to understand the potential responses of larch forests to global change variables to support their sustainable use over the next decades. As mentioned above, the larch forests are a potential large source of timber, and there is much concern that ill-considered forestry practices could permanently scar the regional environment.

GCTE's research on managed forests, which is focused on the impacts of global change, could make an important contribution to the IIASA Siberian Forest Study, which aims to develop strategies for the sustainable development of Siberian forests. Such applications-oriented work is an important output of the Study from the perspective of Russian agencies charged with the management of Northern Eurasia's vast natural resources.

Interactions

Scientists from the Northern Eurasian Region

This prospectus describes the framework for an integrated IGBP Study for Northern Eurasia, in the context of the global IGBP research programme. Much of the research itself will be carried out by scientists from Northern Eurasia, often in collaboration with international colleagues. Thus, regional scientists must be closely involved with the detailed planning and implementation of the Northern Eurasia Study at all phases.

The first step is to undertake wide consultations with regional scientists about the further development of this prospectus. The participants considered a number of strategies, such as a visit by a small group of IGBP scientists throughout the Northern Eurasian region or a symposium at an appropriate venue in the region, where the prospectus will be outlined and discussed and ongoing relevant Russian research will be presented. Further work is required to develop a coherent and appropriate strategy for consultation with the regional scientific community.

In the longer term, strategies are required for ensuring effective interaction between regional scientists and the international scientific research community in the implementation of the IGBP Northern Eurasia Study. Research appointments and post-doctoral positions for Russian scientists in collaborating institutions in North America, Europe, Japan and elsewhere are one approach for achieving this interaction. Others should be identified as detailed planning progresses.

A list of Russian scientific institutions with a potential interest in the IGBP Northern Eurasia Study is given in Appendix 4.

Other International Groups

There are a large number of other international groups with an interest in scientific research in Northern Eurasia. Many of these planned or current projects have a global change aspect. The IGBP Northern Eurasia Study is designed to build on this other work by incorporating appropriate components of it, if mutually agreed, within the overall framework of this prospectus. As in its other studies, IGBP's role is to coordinate existing research of a global change nature and identify and fill gaps to create a coherent overall global change study.

The list below is not meant to be complete or exclusive, but rather a sample of the existing or planned research which could contribute to or collaborate with the IGBP Northern Eurasia Study. Groups or projects not listed here can certainly become involved as collaborators in the IGBP Study as and when appropriate.

GAME (GEWEX Asian Monsoon Experiment)
The objective of this large, multidisciplinary study is to determine the role of the Asian monsoon as a major part of the energy transport and water cycle in the global climate system, and to understand the feedback processes involved in the monsoon system, particularly in radiation, clouds and land surface hydrology, associated with its intra-seasonal, seasonal and interannual variability. The study will have six components: (i) observation of energy and water cycles of Asian monsoon system; (ii) observation of the atmospheric and surface radiation budget over monsoon Asia; (iii) field-based process study of large-scale atmospheric/land surface interactions; (iv) modelling and field-based process study of meso-scale convective systems and regional hydrological cycle; (v) modelling studies of the monsoon and land/atmosphere/ocean system coupling; (vi) four-dimensional data assimilation. One component proposed in GAME is a series of small-scale observation studies in the tundra/taiga region of Siberia. These studies, which are based on measurements of one-dimensional (vertical) heat and water flux between the forest and atmosphere, of moisture movement through the forest trees, and of soil moisture flux, offer an excellent opportunity for collaboration with the IGBP Northern Eurasia Study. GAME has tentatively decided to carry out its Siberian research in the Lena River basin, which suggests that this area might be a good location for the eastern Siberian IGBP transect and that development of this component of the Northern Eurasia Study should be initiated as a high priority, in collaboration with GAME.

MAGS (Mackenzie GEWEX Study)
This study is the Canadian contribution to GEWEX and is a coordinated hydrological and atmospheric study in an area where snow, ice and permafrost are important.

IIASA Siberian Forest Study
The Siberian Forest Study of the International Institute for Applied Systems Analysis (IIASA) is the most extensive international study ever undertaken on Siberian forests. The goals of the study are to assess Siberia's forest resources, forest industries, and infrastructure; to examine the forest's economic, social, and biospheric functions; with these functions in mind, to identify possible pathways for their sustainable development; and to translate these pathways into policy options for Russian and international agencies. Nine different areas of analysis are identified in the overall policy framework of the study: Siberian study databases, biodiversity and landscapes, greenhouse gas balances, environmental status, non-wood products and functions, forest resources and forest utilisation, transportation infrastructure, forest industry and markets, and socio-economics. The first phase of the study was to establish a Russian network of 25 collaborating institutions and to assemble a database on five major themes: forest resources, ecology and global change, markets, industry and infrastructure, and socio-economics.

IIASA Project on Modelling Land-Use and Land-Cover Changes in Europe and Northern Asia
The three-year multinational, multidisciplinary research project was established in 1995 by the International Institute for Applied Systems Analysis (IIASA). A major objective is to analyse and understand the spatial characteristics, temporal dynamics and environmental consequences of land-use and land-cover changes that have occurred in Europe and Northern Asia over the period 1900 to 1990 as a result of a range of socio-economic and biophysical driving forces. The analysis will then be used to define plausible future

changes in land use and land cover for the period 1990 to 2050 under different assumptions of future demographic, economic, technological, social and political conditions.

IASC (International Arctic Science Committee)
The Working Group on Global Change of the International Arctic Science Committee has decided to focus its efforts on implementing regional impact assessments across the circumpolar Arctic. Such assessments were considered highly desirable since they would fill a void in present global change research efforts. These assessments should include studies on basic natural processes, natural variability, biogeochemical and physical impacts, and socio-economic aspects. Because of the high degree of complexity of these comprehensive studies, it was agreed that they should have a regional focus, although the ultimate goal is that a number of such regional studies would provide the basis for a circumpolar perspective on global change impacts in the Arctic. Two regional projects are presently being planned, BASIS (the Barents Sea Impact Study) and BESIS (the Bering Sea Impact Study).

ARCSS (Arctic System Science)
This project focuses on the Arctic as a coupled system of land, ocean and atmosphere. Studies of trace gas fluxes, water/energy balance and hydrologic transport are linked to a regional climate model. The program is currently centred in Alaska but plans to expand to the Russian Arctic in 1997. As currently envisioned, it has no forest component.

BFTCS (Boreal Forest Transect Case Study)
The BFTCS is a multidisciplinary ecological study organised around a 1000 km transect located in central Canada. The transect is oriented along an ecoclimatic gradient in a region likely to undergo significant environmental change within the next few decades, and crosses the climate-sensitive boreal forest biome, including the transitions north and south into tundra and grassland respectively. The BFTCS provides the capability to extend the results and understanding from the BOREAS project, which is located along the transect, by addressing the effects of larger scale, longer term processes such as vegetation succession and ecosystem disturbances.

BOREAS (Boreal Ecosystems Atmosphere Study)
This is a joint Canada-USA study based on satellite, aircraft and ground observations, aimed at detailed understanding of canopy level processes governing boreal forest function at two different locations (environmental regimes) in Canadian boreal forests. There are two main components to the study: intensive measurements of physical and ecophysiological processes and development of models to extend this understanding to the landscape scale, where aircraft and satellite remote sensing measurements are used for validation.

IBFRA (International Boreal Forest Research Association)
IBFRA coordinates research between member countries in the following areas:
(i) inventory, monitoring and classification; (ii) ecosystem function, anthropogenic impacts, and global change; and (iii) forest management and biodiversity. A major ongoing cooperative effort is between IBFRA Stand Replacement Fire Working Group and the Fire Research Campaign Asia-North (FIRESCAN).

FIRESCAN (Fire Research Campaign Asia-North)
This multi-year campaign was initiated in 1991 as a regional fire research campaign under the framework of the IGAC Biomass Burning Experiment (BIBEX) and as a joint effort with the IBFRA Stand Replacement Fire Working Group. FIRESCAN aims to explore the historic, contemporary and future role of fire on ecosystems of boreal Eurasia and the atmospheric chemical and climatic implications.

ITEX (International Tundra Experiment)
This study is a coordinated international effort to assess the effects of temperature warming on arctic and alpine plant populations by using a network of northern, circumpolar sites which are beyond altitudinal and latitudinal treeline. At each ITEX site, a basic, common experiment is performed, which entails a standard warming study using a small greenhouse and the measurement of standard climatic variables. Other experiments, such as enhancement of atmospheric CO_2, increasing soil temperature, fertiliser treatments, and transplant gardens, may be undertaken at a few sites. Taken together, these experiments seek to quantify the potential ecological and evolutionary responses of representative tundra plant populations to the increased growing temperatures predicted for northern regions.

ISF (International Science Foundation)
The International Science Foundation provides funding for Russian research projects, and already has supported an ecophysiological experiment in a larch forest in Eastern Siberia, of relevance to this Study.

Resource Requirements and Priorities

The participants did not address resource requirements for the Northern Eurasia Study at this stage. However, to implement the entire suite of contributing components described above would require a very large injection of resources in terms of equipment, operating funds and scientific manpower over a 10-15 year period. On the other hand, the prospectus is not unrealistically large or complex, if sufficient coordination is achieved amongst the many groups that are already interested in global change related research in Northern Eurasia.

As noted in the Section above, a wide variety of agencies is interested in the research outlined in this prospectus; some such work is already under way and much more is in various stages of planning. Each agency will fund and support components in which it is interested. To maximise the economy of scientific resource usage and to maximise the effectiveness of scientific output, the global change aspects of these various studies should be coordinated. IGBP is in an ideal position to do this.

However, coordination of such a complex study is beyond the resources of the any of the individual Core Projects. The participants recommend that a small, dedicated IGBP coordinating office be established in the near future as a high priority. The coordinating office should be staffed by a project scientist(s) whose job is to coordinate the study and to help contributing groups obtain resources and carry out synthesis and integrating activities.

In addition to the establishment of a coordinating office for the IGBP Northern Eurasia Study, several other actions to progress the Study in the near term were identified at the workshop. These are outlined in the next section.

Next Steps

The development of this prospectus, although an important first step, is only the beginning of a long process required to achieve the objectives of the Study. The participants identified a number of steps which can be taken in the near future (1-2 years) to bring the Study closer to reality. These are: (i) a campaign to increase awareness of the prospectus within Northern Eurasia and within the international global change research community; (ii) a number of pre-study activities designed to refine and improve the initial, general experimental and observational design; and (iii) the establishment of an IGBP Northern Eurasia Study project office, as mentioned above.

Awareness Campaign

A number of activities designed to increase awareness of the prospectus were considered. A visit by IGBP scientists, as outlined in the section on Interactions above, was one such activity. Several others were based on events already scheduled that would have an intrinsic interest in the Study. Examples include:

- International Union of Forest Research Organizations (IUFRO) Congress.
  The IUFRO-95 Congress, which was held in Tampere, Finland, brought together forest researchers from around the world. A session at the Congress, chaired by Sune Linder and Paul Jarvis, introduced the prospectus to the forest research community. A series of sessions of the FIRESCAN Science Team, chaired by Johann G. Goldammer, evaluated the first part of the joint Northern Eurasia fire research programme.

- START/IGU (International Geographical Union) Congress - Moscow,
  START TEACOM (Temperate East Asia Committee) Meeting - Novosibirsk.
  The International Geographical Union's Congress in Moscow in August 1995 and the START TEACOM meeting in Novosibirsk immediately after provided platforms for the presentation of the prospectus to the Russian scientific community and to other global change researchers interested in Northern Eurasia. It should be emphasised again that the early involvement of the Russian scientific community in the detailed planning of the study is essential for its success. The START meeting was an appropriate opportunity to develop the strong links to the START networks required for the Study to reach its full potential.

- Russian Arctic Disturbance Symposium, September 1995.

- A visit by Will Steffen and Anatoly Shvidenko to Moscow, Kharbarovsk and Krasnoyarsk in September 1995 was a first step in introducing the IGBP Study to the broader Russian scientific community.

- Open Science Meeting on the IGBP Northern Eurasia Study, Tsukuba, Japan, December 1995. The objectives of this meeting were (i) to introduce this prospectus to the broader scientific community to involve them in the further planning and execution of the Study, and (ii) to obtain input from the broader community to improve and refine the science plan as outlined in this prospectus. The meeting was based on presentations on the main scientific issues associated with the Study, concentrating on four themes: water, energy and carbon exchanges; trace gas emissions; ecosystem studies (impacts and feedbacks); and land-use/cover change. The results of the Open Science Meeting, including refinements to this Science Plan, are presented in Appendix 6.

- A monograph "Fire in Ecosystems of Boreal Eurasia" (Goldammer, J.G. and Furyaev, V.V., eds., 1996) has recently been published by Kluwer Academic Publishers (mid 1996). The work is based on an international Volkswagen symposium which was held at the beginning of the first phase of FIRESCAN, Krasnoyarsk, July 1993. The book contains 31 chapters by Russian authors and 15 chapters by non-Russians, and will provide a state-of-knowledge review of the historical, ecological, and atmospheric chemical role of fire in Northern Eurasia. The book will serve as an initial base for future joint research in the IGBP Northern Eurasia Study. More information on East-West cooperation in fire research can be found in Goldammer and Furyaev (1995).

Pre-Study Activities

The participants recommend a number of pre-study activities that could begin in the very near future. These include:

- Liaison group with GEWEX/GAME. GAME is already planning intensive field studies of vertical water and energy fluxes in the tundra and taiga regions of eastern Siberia, and have begun investigations of sites in the Lena River basin. Given the complementarity between GAME and the IGBP Northern Eurasia Study and the potential for sharing of resources, it is critical that consultations between the two groups begin as soon as possible. The participants recommended that an IGBP liaison group be formed to interact with GAME. Since BAHC is the IGBP Core Project with the closest relationship with GEWEX, it was recommended that the liaison group be led by the BAHC representative and include representatives of IGAC and GCTE. Pavel Kabat was nominated at the BAHC representative, Terry Chapin as the GCTE representative, and Bill Reeburgh as the IGAC representative.

- Review of modelling results. A number of modelling studies, primarily in the areas of ecophysiology, water and energy exchange, land-use change and climatic feedbacks, and ecosystem dynamics, have been carried out on various aspects of the Study. Before plans for the Study are finalised, a review of previous work would be valuable input to the design of the observational networks and transects. It was suggested that one of Prof. Paul Jarvis' post-doctoral researchers at Edinburgh University might be available to undertake such a review.

- Catalogue of existing data. There exists now a large body of environmental data for Northern Eurasia, much of which would be relevant to the Study. However, the data exist in various forms, in various locations, and have been collected with different techniques to different levels of accuracy. Much work is required to bring it together and standardise it into a single meta database oriented towards global change research. Fortunately, this issue has already been recognised and several groups are tackling this difficult problem. An excellent example is the comprehensive forest database being assembled as part of the IIASA Siberian Forest Study. The IGBP Study could benefit from this current activity. In addition, the participants recommended that IGBP-DIS be invited to assist with the retrieval of existing data in Russia and with the data gathering, archiving and transfer activities associated with the Study itself.

- Modelling sensitivity studies. Building on the existing background of modelling studies, a set of modelling sensitivity studies specifically designed to assist in the further design of the Study was strongly recommended. The current ARCSS, BFTCS and BOREAS studies being undertaken in the Alaskan tundra and in the Canadian boreal forests, respectively, will provide a good starting point for such studies. Models developed in those programmes for their systems can be run with parameters for Northern Eurasia as a first stage in the sensitivity studies. A series of synthesis workshops on the North American work, convened by Terry Chapin and supported by the US National Science Foundation (NSF), will provide a framework for such sensitivity studies.

Project Office

This prospectus provides a general base on which to build the Northern Eurasia Study, and the awareness campaign and pre-study activities will increase the momentum begun at the workshop. However, to implement the Study itself will require the establishment of a small coordinating office. The participants thus recommend to the Scientific Committee of the IGBP and to the Scientific Steering Committees of the BAHC, IGAC and GCTE Core Projects that resources for the establishment and operation of a small coordinating office for the IGBP Northern Eurasia Study be obtained; the Scientific Steering Committees of IGAC, GCTE and BAHC have all endorsed this recommendation.

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Glossary

biome productivity - net ecosystem productivity integrated over large spatial and temporal scales to account for such processes as successional dynamics and major disturbances such as fire.

boreal forest - the band of high latitude forests located between the tundra biome to the north and either steppe/grassland or temperate forest to the south. Boreal forests are found in Alaska, Canada, Scandinavia and Russia, and are often dominated by coniferous trees or consist of mixed coniferous/deciduous stands.

boundary-layer - the lowest layer of the atmosphere, usually between 100 m and 1 km in depth, which interacts with the land surface and provides the links between it and other layers in the troposphere.

disturbance - a specific event occurring over a short period of time that has a significant impact on ecosystem structure, composition and functions. Examples of disturbances are fires, timber harvesting, storms and insect outbreaks. Disturbance regime refers to a sequence of disturbances, often occurring in a pattern, which can exert a strong control on the successional dynamics of ecosystems.

Earth system - the interacting global physical climate, biogeochemical, and biological systems which together provide the conditions for life. There is concern that anthropogenic activity is now significantly affecting the Earth system.

ecological complexity - biological diversity or biodiversity but in a broader sense, including not only species diversity but diversity of ecosystems and landscapes, as well as genetic diversity within species. In addition, ecological complexity involves the diversity of tropic pathways and interactions, that is, the connectivity of ecosystems.

ecosystem physiology - refers to the ways in which ecosystems function, usually focusing on primary ecosystem processes such as the exchange of energy, water and trace gases with the atmosphere, element cycling and storage, and biomass accumulation or loss.

eddy correlation - a technique for measuring fluxes of energy and mass exchange between the land surface and the atmosphere, based on the simultaneous measurement of scalar concentration and the vertical component of wind velocity.

forest fund, forest land, forested areas - official Russian terms which identify, respectively, all lands belonging to forest authorities; lands designated for forest growth, including areas covered by plantation forests; and unforested areas which are not presently covered by forests but which potentially could be covered by forests (*e.g.*, burned areas, ungenerated cuts, sparse forests and grassy glades).

global change - changes in atmospheric composition, climate and land-use/cover, and the interaction among them.

landscape scale - a unit of terrain consisting of a number of contiguous patches. The dimensions of a landscape are generally of order 1-10 km, or 1-100 km^2. This is the scale at which many disturbance regimes operate, and is often the scale of relevance for resource management authorities.

land-use and land-cover change - land use refers to the ways in which humans use the vegetation/soil complex, while land cover refers to a particular state of the vegetation/soil complex. The two are often related. For example, a temperate forest is a type of land over, while timber production from that forest is a land use. Land uses may or may not lead to modification or conversion of land cover. Changes in land use and land cover are currently the dominant component of global change.

land-surface experiment - an intensive process study focusing on the exchange of water, energy and trace gases between the land surface and the atmosphere. Land-surface experiments normally include a nested set of measurements, from leaf-scale to regional, using a number of techniques, from leaf cuvettes to remotely sensed images.

Northern Eurasia - defined as extending from the border of Russia in the west to the Pacific Ocean coast of Asia in the east, and from the Arctic Ocean coastline in the north to the ecotone between boreal forest (taiga) and the biomes to the south, usually steppe or temperate forest. Thus, it includes most of Russia's land area. Also, in this prospectus we refer to three regions of Northern Eurasia: European Russia (west of the Ural Mountains), western Siberia (between the Ural Mountains and the Yenesei River), and eastern Siberia (east of the Yenesei River, often divided into two regions - East Siberia and the Far East - see Fig. 1).

patch scale - a land unit treated as homogeneous for the purpose at hand, and integrated for the ecological property in question. Patches are normally of order 10-100 m, or 100-10,000 m^2 in area.

permafrost - frozen soil water, occurring from within a few centimetres of the soil surface to depths of many metres. Permafrost occurs in the tundra and northern parts of the boreal forest zones, as well as in high mountainous regions, such as the Tibetan Plateau and the mountain ridges in the Lake Baikal region. Permafrost plays an important role in the hydrological and ecological processes of areas where it is extensive.

regional/continental scale - a land unit consisting of a number of contiguous landscapes, and is generally at least 100 km in dimension and often larger. It is the scale of most relevance for global modelling.

soil-vegetation-atmosphere transfer model - a simulation of the processes which transfer water, energy and trace gases (*e.g.*, CO_2) between the soil/vegetation system and the atmosphere.

stand structure - the combination of tree species and their age classes (sizes) within a small patch of forest. Stand structure can include vertical canopy closure, distribution by area (*e.g.*, regular, or various types of irregular patterns), types of age stand structure (distribution of trees by age in separate stands, *etc*.)

successional dynamics - the long-term change in ecosystem composition which occurs naturally as a function of different growth and mortality rates of the constituent species of the system. If allowed to proceed long enough, successional dynamics leads to a "climax" state dominated by slow-growing, long-lived species. Disturbances, such as fire, "re-set" the process of successional dynamics, in which fast-growing, short-lived species again dominate the system during the early stages of succession.

taiga - the Russian term for boreal (usually coniferous) forest. Taiga generally refers to the belt of high latitude forests across Northern Eurasia, between the tundra ecosystems to the north and the steppe and temperate forest biomes to the south.

transect - an integrated global change study consisting of distributed observational studies and manipulative experiments coupled with modelling and synthesis activities organized along existing gradients of underlying global change parameters, such as temperature, precipitation and land use.

Appendix 1

Site Characterisation: Required Data on Vegetation, Soil, Land Use and Climate for Trace Gas Flux Measurements

From TRAGEX Activity of IGAC
(courtesy of K.A. Smith)

Variable	Intensive sites	Extensive sites	Frequency
Site characterisation - vegetation			
Vegetation description and classification	x	x	One time
Land use and disturbance history	x	x	One time
Leaf area index (seasonal)	x	x	Periodic depending on variability
Above and below ground biomass	x	-	Annually
Litterfall	x	-	Annually
Root decay	?	?	Annually
Litter residue chemistry (C, N, lignin contents	x	x	One time or more frequent depending on disturbance
Above ground Net Primary Production (direct or simulated)	x	x	Annually

Variable	Intensive sites	Extensive sites	Frequency
Site characterisation - agricultural crops			
Land use and disturbance history	x	x	One time
Leaf area index (seasonal)	x	x	Periodic
Plant biomass and N-uptake	x	x	Periodic during growing season
Yield and composition	x	x	Annually
Crop residues and composition	x	x	Annually
N-addition: - N-form - application mode - timing - source (mineral fertiliser, animal manure, N-deposition, biological N-fixation	x	x	Annually
Irrigation scheme (supply and timing)	x	x	Annually during growing season
Crop sequence / crop rotation	x	x	Annually during growing season
Tillage and other management techniques	x	x	Annually
Livestock management system (number of animals / ha; period of grazing)	x	x	Annually

Variable	Intensive sites	Extensive sites	Frequency
Site characterisation - supporting soil data			
Soil description and classification	x	x	One time
Local soil map, preferably digital	x	x	One time
Topography (slope and aspect)	x	x	One time
Rooting profile and rooting depth	x	x	One time (root development for crops)
Moisture release profiles	x	-	One time
Bulk density	Soil profile	Surface soil A-horizon / plow layer)	One time
Texture	Soil profile	Surface soil A-horizon / plow layer)	One time
Description of soil structure	Soil profile	Surface soil A-horizon / plow layer)	One time
Soil diffusivity	x	-	One time
Saturated and unsaturated hydraulic conductivity	x	-	One time
Total organic C and N	Soil profile	Surface soil A-horizon / plow layer)	Frequency depends on temporal variability and/or disturbance
Total P and available P	Soil profile	Surface soil A-horizon / plow layer)	Annually
Soil pH (H_2O, KCl), Cation Exchange Capacity (CEC), Base Saturation	Soil profile	Surface soil A-horizon / plow layer)	One time
NH_4^+, NO_3^-	Soil profile	Surface soil A-horizon / plow layer)	Time of flux measurement
N-mineralisation (*in situ* undisturbed)	x	x	Time of flux measurement
Nitrification (potential)	x	-	Monthly
Depth to ground water	x	x	Annual variability on time; exact depth at time of flux
Depth to permafrost	x	x	Annual variability on time; exact depth at time of flux

Variable	Intensive sites	Extensive sites	Frequency
Site characterisation - driving variables			
Climate (daily mean, maximum and minimum temperature; daily precipitation)	x	x	daily
Surface soil temperature	-	x	Time of flux measurement
Surface soil moisture	-	x	Time of flux measurement
Soil temperature profile	x	-	daily
Soil moisture profile	x	-	daily
Evapotranspiration	?	?	Estimate based on temperature
Interception	?	?	Seasonal differences in interception and interception storage capacity
Solar radiation	x	x	daily / during growing season
Windspeed	x	x	daily / during growing season

Appendix 2

Protocols for Manipulative Experiments at Forest Sites

(courtesy of S. Linder)

CO_2

At sites where detailed physiological studies can be carried out it is recommended that manipulation experiments should be done to determine forest responses to temperature and CO_2 as well as water and nutrition. Elevated CO_2 can be achieved in open-topped chambers, open branch chambers (Branch bags) or, as a future possibility, by "Free Air CO_2 Enrichment" (FACE). Branch bags are the simplest to use, although even these involve considerable technology to control and monitor the CO_2, air humidity and temperature in the bags. The effects of such treatments and the extent to which the results reflect the response of trees to increased CO_2 are not yet clear; considerable experimental work is necessary in this area. It is recommended that elevated CO_2 treatments should be ambient + 350 ppm, applied in a step change. This level is sufficiently high to detect a response in susceptible systems, but is not outside the range of predictions for future CO_2 concentrations. CO_2 should be applied day and night, but may be discontinued during certain periods of the year when tree activity is minimal due to low temperatures or deciduous habit.

Temperature

Air temperature may be varied in enclosures and soil temperature by heating. (Controlled soil cooling is technically possible but will almost always be prohibitively expensive.) Guidelines for temperature treatments should be based on the current consensus prediction of General Circulation Models (GCMs). Elevated temperature treatments should be the GCM prediction for a greenhouse forcing equivalent to a doubling of CO_2; this will range from relatively large (4 - 8°C) increases at higher latitudes to minor temperature changes at low latitudes. The temperature treatments should also attempt to match the predicted seasonality of a 2 x CO_2 climate because changes in seasonality may be of equal or greater biological importance as changes in means.

Nutrition

Whenever possible nutrient x CO_2 interactions should be included in the experimental design. Nutrient treatments should include all essential nutrient elements and repeated fertilisation to maintain "non-limited" nutrient conditions. Wherever possible current understanding of optimal nutritional requirements should be utilised both to minimise nutrient excesses and to target tree requirements accurately. Untreated stands will generally be used as the nutrient-limited condition for comparison.

Water

Supplementation to maintain field capacity should be imposed at all water-limited sites to provide a base-line for comparison of other water related treatments. Natural (rainfall supplied) water levels will generally provide the other treatment conditions. For forests in regions where GCM estimates of temperature and precipitation predict reductions in soil water, treatments might include reductions in water availability by means of throughfall diversion.

Wherever possible, experiments should be planned to run for many years. It is becoming clear that the value of carefully monitored long-term experiments, in which consistent data collection and recording procedures are used, increases steadily with time. The data from such experiments should if possible be made widely available.

Appendix 3

Site Requirements and Measurement Protocols for Patch Models of Ecosystem Dynamics, Based on Transect Design

(courtesy of H.K.M. Bugmann)

Site requirements

The selection of study sites for the Siberian transect component necessarily will reflect a compromise among many, often mutually exclusive requirements. The following criteria are important for the patch-scale modelling activities:

1. The study sites should cover the tundra-boreal forest ecotone; it would be desirable to include also the ecotone between boreal and temperate forest and/or between boreal forest and steppe. In these cases the transect would cover a wide range of climatic conditions, which could impose strong limits on the density of study sites along the gradient (see item 2).

2. The number of sites should provide a dense coverage of the underlying climate gradient. It would be insufficient if only a small number of sites, say 2 or 3, were chosen for the study. Instead, it is suggested that a larger number of sites (more than 6) is chosen: At about three study sites, intensive measurement and modelling campaigns should take place, whereas at the other sites only a subset of the variables would be measured.

3. Two measurement protocols should be developed: A full protocol ("Level 1") for the intensively studied sites, and a reduced protocol ("Level 2"), which is a subset of the Level 1 protocol, for the other sites. Such a design ensures that for a number of variables consistent data are available from a comparatively dense set of study sites.

4. For patch modelling purposes, it is important that a "site" is conceived as an excerpt of the local vegetation that covers the various successional phases. All these phases and their spatial extent need to be considered to assess the carbon balance of larger areas. Consequently, the area of a site is likely to be about 5-20 hectares; it should be noted that it is not a single stand.

5. For model validation purposes, it would be highly desirable if the sites coincided with locations where the vegetation history through the last 100 years or even further into the past (proxy data) is known. If there were palaeoecologists interested in cooperating in the study, perhaps through the PAGES Core Project of the IGBP, these data sets could be compiled as a part of the measurements.

6. Essentially, the sites should be chosen along a temperature gradient. Most probably it will be inevitable that precipitation will also change along the transect. In this case, the sites should be chosen so that precipitation changes in a systematic way (*e.g.*, monotonically) along the transect.

Measurement protocols

For patch modelling purposes, the following information should be available along the transect (it is indicated in parentheses at which sites these data should be collected, cf. the Level 1 and Level 2 protocols mentioned above):

- Autecological characteristics and silvics of the Siberian tree species. A considerable amount of data can be found in the literature (*e.g.*, Nikolov and Helmisaari 1992). It may have to be complemented by measurements, depending on the requirements of the patch models (Level 1).

  Long (30 yr.) time series of climatic data. At least the means of temperature, precipitation sum and incident radiation should be available at a monthly or higher resolution. While the long-term means may readily be obtained (*e.g.*, Leemans and Cramer 1991), it will also be necessary to quantify the variability (distribution) of these data (Level 1 & Level 2).

- Data on disturbances such as insect infestations, forest fires, and wind throw, both as statistical distributions under current climatic conditions and as indices related to vegetation structure and functioning (Level 1).

These items will provide the input data that is required for running patch models along the transect. The data listed below shall be used to validate the models:

- Information on the species composition in present forests together with records on land-use practices (including forest management regime) in the past and the present. These data should also comprise information about the various successional phases that can be observed within one site (Level 1 & Level 2).

- Records of vegetation dynamics during the past centuries, as far as available and accessible; these can be written records as well as reconstructions based on proxy data, *e.g.*, pollen records or tree-ring data (Level 1).

- Information about the height-, size- and age-structure of the forest stands within the sites. This information is important because many models succeed in predicting the correct species composition, but the simulated stand structure may deviate strongly from reality (cf. Leemans 1992) (Level 1 & Level 2).

It is likely that a number of these data requirements can not be fulfilled by *in situ* measurements along the transect. For the IGBP Northern Eurasia Study it may be vital to access existing data sources and, where necessary, to adapt mechanisms for extrapolating the data to the study sites along the transect (*e.g.*, climatic data).

Appendix 4

Russian Scientific Institutions with a Potential Interest in the IGBP Northern Eurasia Study

Institute of Geography, Russian Academy of Sciences (RAS), Staromonetny lane 29, Moscow, 109017, Russia. Tel 7-095-238-8610; Fax: 7-095-230-2090; E-mail: climat@glas.apc.org. Contact persons: Director, Academician V.M. Kotlyakov; Head of the Laboratory, Prof. A.N. Krenke.

A.N. Severtsov Institute of Ecology and Evolution, RAS, Leninsky prospect 33, Moscow, 117071, Russia. Tel: 7-095-954-7553; Fax: 7-095-954-5534. Contact persons: Director, Academician V.E. Sokolov; Head of the Ecological Lab, Dr N.N. Vygodskaya; Prof. Yu.G. Puzachenko.

Institute of Microbiology, RAS, Prospect 60-letija Oktjabrja, 7, build. 2, GSP-7, Moscow, 117811, Russia. Tel: 7-095-135-2139; Fax: 7-095-135-6530. Contact persons: Director, Academician M.V. Ivanov; Head of the Lab, Prof. G.A. Zavarzin.

Centre of Problems of Forest Ecology and Productivity, RAS, Novocheremushkinskaja str., 69, Moscow, 117418, Russia. Tel: 7-095-332-8652; Fax: 7-095-332-2917; E-mail: postmaster@spepl.msk.su. Contact person: Academician A.S. Isaev.

Institute of the Global Climate and Ecology, Russian Hydrome-Teorological Committee, Glebovskaja, 20b, Moscow, 107258, Russia. Tel: 7-095-169-2411; Fax: 7-095-160-0831. Contact person: Director, Academician Ju.A. Israel.

Faculty of Geography, Moscow State University. Moscow, 119899 GSP-3, Russia. Tel: 7-095-939-3962; Fax: 7-095-932-8836. Contact persons: Dean Prof. N.S. Kasimov, Prof. G.N. Golubev (Holder of the Chair).

Russian Research Institute "Nature", Ministry of Ecology Znamenskoe-Sadki, Moscow, 113628, Russia. Tel: 7-095-423-0322; Fax: 7-095-423-2322. Contact person: Director, Dr A.S. Peshkov.

Federal Service of Forest Management of the Russian Federation, 59/19 Pyatnitskaya str., Moscow, 113184, Russia. Tel: 7-095-231-8720; Fax: 7-095-233-0950. Contact person: Deputy Chief, Academician A.I. Pisarenko.

All-Russian Scientific Research & Information Center for Forest Resources, Russian Forest Federal Service, Novocheriomushkinskaja str., 69, Moscow 117877, Russia . Tel. 7-095-332-53-38. Fax 7-095-331-05-33. Contact person: Director Dr. V.V. Strakov

V.V. Dokuchaev Soil Institute, Russian Academy of Agricultural Science, Pyshevsky per., 7, Moscow 109017, Russia. Tel. 7-095-231-09-25. Fax 7-095-231-50-38, E-mail rojkov@boruga.msk.ru. Contact person: Vice-Director Academician V.A. Rojkov

Institute of Pedology and Photosynthesis, RAS, Pushchino, Moscow Province, 142292, Russia. Tel: 7-095-923-3558. Contact persons: Director, Prof. V.I. Kereli, Prof. Gilichinsky (Head of the Kolyma Expedition).

Institute of Forest Research, Russian Academy of Sciences, Uspenskoye 143 030, Moscow region, Russia. Tel. 7-095-561-65-90. Contact persons: Director Professor S.E. Vompersky; Prof. A.I. Utkin.

State Institute of Geology - GINGEO, Noginsk region of Moscow 142452, Russia. Contact person: Prof. A. Pavlov.

V.L. Komarov Botanical Institute, RAS, Prof. Popov str. 2, St Petersburg, 197376, Russia. Tel: 7-812-234-1237; Fax: 7-812-234-4512. Contact persons: Director, Prof. L.Ju. Budantsev, Prof. V.I. Vasilevich.

Faculty of Chemistry, St Petersburg University, Universitetskiji prospect, Petrodvorets, St Petersburg, 198904, Russia. Tel: 7-812-428-4089; Fax: 7-812-428-6939. Contact person: Prof. V.A. Isidorov.

State Hydrological Institute, Russian Hydrometeorological Committee, 2nd line, 23, Vasilievskiji ostrov, St Petersburg, 199053, Russia. Tel: 7-812-213-0128; Fax: 7-812-213-0128. Contact person: Director, Prof. I.A. Shiklomanov.

Arkhangelsk Forest and Forest Chemistry Institute, 13, Nikitova str., Arkhangelsk, 163 062, Russia, Tel. 7-8182-412-583. Contact person: Director Professor G.A. Chibisov

Institute of Biology, Komi Scientific Center, RAS, Kommunis-ticheskaja str., 28, Syktyvkar GSP 167610, Komi Republik, Russia. Tel: 7-821-222-0163. Contact persons: Director, Dr A.I. Taskaev, Prof. M.S. Gessen (Head of Vorcuta Biological Station belonging to the Institute).

Presidium of Komi Scientific Center, RAS, Kommunisticheskaja str. 24, Syktyvkar 167610, Komi Republik, Russia. Tel: 7-821-222-1608. Contact person: President, Prof. M.P. Roshchevskiji.

Arkhangelsk Institute of Ecology, Urals Scientific Center, RAS, Vyuchijiskaja str. 59, Arkhangelsk 163040, Russia. Tel: 7-818-009-1367. Contact person: Dr N.P. Zalyvskiji, Head of the Laboratory.

Narjan-Mar Experimental Agricultural Station, Russian Ministry of Agriculture, Rybnikov str., 1a, Narjan-Mar, 164700, Nenetskji Autonomous District, Arkhangelsk Province, Russia. Tel: 77-67 (No automatic connection, only through operator in Arkhangelsk - 7-818-003-0000). Contact person: Director, Dr V.T. Teslenko.

Institute of Ecology of Plants and Animals, Urals Scientific Center. 8th Marta str. 202, GSP-511, Ecatherinburg, 620219, Russia. Tel: 7-343-222-8570. Contact person: Director, Academician V.N. Bolshakov.

Institute of Forest of Karelian Department of RAS, Pushkinskaya str 11, Petrazavodsk 185610, Russia. Tel: 7-81400-795-00. Contact persons: Prof. L. Kaibiyaynen; Dr T. Sazonova.

Institute of the Earth's Kryosphere, Siberian Division of RAS (SO RAS), Tjumen 3, abonent box 1230, Tjumen, 625003, Russia. Tel: 7-345-224-3649; Fax: 7-345-229-9293; Contact person: Director, Prof. V.P. Melnikov.

Institute of the North Development Problems, SO RAS, Tjumen 3 abonent box 2774, Tjumen, 625003, Russia. Tel: 7-345-221-3441; Fax: 7-345-221-3441. Contact person: Director, Dr V.R. Tsybulskiji.

Presidium of Siberian Division of RAS, Academician Lavrentjev prospect, 17, Novosibirsk-90, 630090, Russia. Tel: 7-383-235-7418. Contact person: President SO RAS, Academician V.A. Koptjug.

Central Siberian Botanical Garden, SO RAS, Zolotorechenskaya Str., 101, Novosibirsk-30, 630030, Russia. Tel: 7-383-235-4101; Fax: 7-383-235-4986. Contact person: Director, Academician I.Yu. Korapachinskiyi.

Novosibirsk Department of Forest Dynamic, Zhukovskogo str., 100/1, Novosibirsk 630 082, Russia. Tel. 7-3832-25-37-83. Contact person: Head, Professor V.N. Sedykh

Institute of Ecology and Zoology (former Institute of Biological Ecology), SO RAS, Novosibirsk 690030, Russia. Contact person: Dr Yu. Rafkin.

Institute of Soil Science and Agrochemistry, Zolotodolinskaya str 31, ap. 44, Novosibirsk 690072, Russia. Contact person: Prof. A. Titlyanova

V.N. Sukachev Institute of Forest, SO RAS, Akademgorodok, Krasnoyarsk, 660036, Russia. Tel: 7-391-245-2269; Fax: 7-391-245-2484. Contact person: Director, Prof. E.A. Vaganov.

Institute of Biophysics of SO RAS, Akademgorodok, Krasnoyarsk 660036, Russia. Contact person: Prof. F. Sidko.

Institute of the Far North Agriculture, Russian Ministry of Agriculture, Komsomolskaya str. 1, Norilsk, 663305, Krasnoyarski region, Russia. Tel: 7-381-524-1034. Contact person: Director, Dr V.G. Shchelopov.

Siberian Institute of Plant Physiology and Biochemistry, SO RAS, Irkutsk, Russia. Tel: 7-3952-460-721; 7-3952-460-621. Contact persons: Director, Prof. R. Salyaev; Dr. A. Scherbatuk.

Institute of Geography of SO RAS, Box 4A, Irkutsk-33, Russia. Tel: 7-3952-461-928. Contact persons: Prof. V. Snutko; Dr A. Belov; Dr G. Martyanova; Dr Grigoryiev.

Tajimyr State Nature Reserve, Khatanga, abonent box 31, Tajimyr National Autonomous District, 663260, Krasnojarskiji region, Russia. Tel: 21097 (No automatic connection, only through operator in Krasnojarsk - 7-391-227-5959). Contact person: Director, Mr Ju.M. Karbainov.

Yakutsk Institute of Biology, SO RAS, Lenin str. 41, Yakutsk-891, 677891, Sakha Republik, Russia. Tel.: 7-411-222-4132. Contact person: Director, Prof. N.G. Solomonov.

Institute of Permafrost, SO RAS, Yakutsk-18, Yakutsk, 677018, Sakha Republik, Russia. Tel.: 7-411-224-4634. Contact person: Director, Dr R.M. Kamenskiji.

Northeast Scientific Station, Pacific Institute for Geography, Far-East Branch, Russian Academy of Sciences, Republic of Sakha, Yakutia, Cherskii 678830, Russia. Contact person: Dr Sergei Zimov.

Far East Forestry Research Institute, Volochaevskaya str, 71, Khabarovsk, 680020, Russia. Tel: 7-4212-218-548; Fax: 7-4212-216-798; E-mail: efremov@niilkh.khabarovsk.su. Contact person: Director, Dr Dmitry F. Efremov.

Economic Research Institute, 153, Tikhookeanskaya, Khabarovsk 680020, Russia. Tel: 7-4212-358-422; Fax: 7-4212-358-110; E-mail: alexsh@ecrin.khabarovsk.su. Contact person: Vice Director, Dr Alexander S. Sheingauz.

Ministry of Environmental Protection and Natural Resources of Russia, Committee on Environmental Protection and Natural Resources of Khabarovsk Territory, 6a, Kadrovyi s-st, Khabarovsk 680013, Russia. Tel: 7-4212-212-084; Fax: 7-4212-335-270. Contact person: Vice-Chairman, Dr Victor B. Skachkov.

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Institute for Ecology of Natural Complexes, SD, RAS, Academichesky pr., 2, Academgorodok, Tomsk, 634055, Russia. Tel: 7-3822-25-88-55; Fax: 7-3822-25-88-55. Contact person: Director Prof. V.N. Vorobjev.

Appendix 5

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Appendix 6

Summary of Northern Eurasia Study Open Meeting, Tsukuba, Japan
28 November - 1 December 1995

Introduction

An Open Meeting for the IGBP Northern Eurasia Study was held in Tsukuba, Japan, 28 November-1 December 1995, hosted by the National Institute for Environmental Studies, Tsukuba, and supported by the Environment Agency, Japan. The meeting was attended by 84 scientists from 12 countries; 12 Russian scientists participated in the meeting.

The objectives were:

- To survey the current level of global change research in Northern Eurasia, with an emphasis on Russian and Japanese research
- To get additional input from the Russian scientific community into the prospectus
- To refine the prospectus developed in Stockholm, adding specific details to both the science plan and the location/organisation of the integrated study.

This report updates the progress made at the Stockholm meeting in developing a science plan for the Study. In particular, it refines the scientific plans for several of the components and it recommends general locations in Northern Eurasia for the conduct of the Study.

Working groups addressed these two types of issues; their reports are given below. In general, the four working groups on the various aspects of the science plan organised their reports around (i) a set of guiding scientific questions, (ii) the types of research required to address these questions; and (iii) in some cases, comments on the timeframe of the work and the initial set of contributing groups or projects.

The two working groups on the location of research in the IGBP Northern Eurasia Study focused on (i) the Far East, and (ii) the Yenesei/West Siberia/European Russia areas. They recommended the adoption of the transect approach, with a north-south transect along the Lena River basin with an extension to the south along the 135° meridian to Khabarovsk, and a second north-south transect along the east bank of the Yenesei River. The latter should be complemented by two intensive study areas, one in the wetlands in the southwest region of West Siberia (i.e., the "hot spot" for methane emissions, as determined by earlier research) and the other in the wet tundra region in the northern part of West Siberia.

Working Group Reports

Water, energy, and carbon fluxes / surface hydrology

Chairman: J. Tenhunen; Rapporteur: R. Harding

Participants: F. Chapin, H. Dolman, J. Kim, A. Krenke, W. Oechel, W. Steffen, R. Weisburd

Goals

The goals of research related to assessing water, energy, and carbon fluxes in the IGBP Northern Eurasia Study include:

- Development of methods for flux assessment at a relevant scales, such that estimates are representative for the major vegetation zones, including the effects of typical heterogeneity in landscape structure and landscape distribution of water, thus providing a basis for simple one-dimensional SVAT Parameterisation at the study locations
- Definition of biological, topographic, and physical climate controls on flux rates
- Development of methods for simultaneous assessment of CO_2, CH_4, H_2O fluxes in Northern Eurasian landscapes as well as the transport of substances from terrestrial to aquatic ecosystems
- Use of methods described above to close carbon and nutrient balances
- Development of better methods for assessing carbon and trace gas fluxes and carbon storage at the continental scale.

To accomplish these goals, it is critical that the design of experimental studies at the level 1 sites, the acquisition of experimental data at these sites, and the synthesis of these data in simulation models be coordinated and that the extensive experience on up- and down-scaling of information gained in recent years from GEWEX and BAHC Land Surface Experiments (LSEs), from the Alaskan R4D study (Reynolds and Tenhunen 1996), and the Alaskan ARCSS study be utilised (Weller *et al.* 1995).

The working group discussion focused on two major points of planning that determine the way in which measurements will be carried out as well as our ability to synthesise data in the form of models which provide new insight and up-scaling capabilities. These two points consider (i) the structure and size of level 1 sites and (ii) the definition of a "target" scale at which synthesis and modelling will be conducted.

Definition of level 1 sites

Site structure and size

The idealised concept of the area to be studied is from north to south 1) a tundra region characterised by east/west bands of vegetation that change in the sequence a) moist coastal lowland tundra, b) drained hillslope tundra, and c) upland shrub tundra; 2) a tundra/taiga transition zone with trees (*Larix*) invading shrub tundra on the uplands and moist meadows in the lowlands; and 3) a forest belt with closed stands on the uplands and moist meadows in the lowlands. Level 1 sites (field research stations) should be established within the three vegetation zones indicated along this north/south transect and as described in Fig. 5 of this report. The geographic extent of each level 1 site will differ to accommodate spatial integration of landscape elements found at these locations. In order to characterise heterogeneity in fluxes and determine the effects of hydrological transport within each vegetation zone, the size of level 1 sites should be large (approximately 5 000 to 10 000 km^2 and comparable to the area under study in Alaskan tundra by ARCSS). This choice of large areas over which to quantify hydrological components of the water cycle and water flux partitioning at the landscape to regional scale provides the basis for interaction and cooperation with GAME.

As described here, the level 1 sites are larger units than those identified in Appendix 3 of this report. However, nested within the large areas are intensive research sites. At least two intensive research sites should be identified at each level 1 site at upland and lowland locations where ecosystem process studies will be carried out. In the case of tundra where 3 tundra types are encountered, a total of six intensive sites are visualised to satisfy hydrological concerns. Thus, 10 landscape elements are identified for intensive study and would be used for the modelling. These elements may, however, have additional attributes that alter their function, *e.g.*, Leaf Area Index (LAI) differences derived from NDVI observations or differing species composition derived from multi-band remote sensing, *etc.* The sites should otherwise meet the requirements laid out in Appendix 3.

The level 1 sites should encompass river systems that are a repeating unit within each respective vegetation zone. The inclusion of strong orographic gradients at level 1 sites that influence atmospheric circulation, water fluxes and water resource distribution is seen as an advantage, since the general understanding of these effects is of high priority to BAHC. A nesting of experiments will be required at each level 1 site in order to sort out the differing needs in scaling-up of information related to ecosystem processes, hydrology, and vegetation/atmosphere exchanges.

Initial activities at the sites

Remote sensing data acquisition, the development of digital elevation models (DEMs - a DEM of 50 m resolution will be required for the smaller catchments -see below), and modelling activities should commence as soon as specific sites have been established. Remote sensing should be used to obtain land surface classifications and to examine hydrological variables, i.e., snow distribution, surface freeze/thaw patterns, and surface temperature patterns during different seasons. If possible, meteorological and hydrological stations should be immediately installed. These stations are essential if we are to achieve spatial integration of flux data and a closure of budgets. Modelling should include the modification of existing models to realise new potentials in line with the goals described in section 1. Sensitivity analyses should be carried out to identify major areas of

Working Group Reports

Water, energy, and carbon fluxes / surface hydrology

Chairman: J. Tenhunen; Rapporteur: R. Harding

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The level 1 sites should encompass river systems that are a repeating unit within each respective vegetation zone. The inclusion of strong orographic gradients at level 1 sites that influence atmospheric circulation, water fluxes and water resource distribution is seen as an advantage, since the general understanding of these effects is of high priority to BAHC. A nesting of experiments will be required at each level 1 site in order to sort out the differing needs in scaling-up of information related to ecosystem processes, hydrology, and vegetation/atmosphere exchanges.

Initial activities at the sites

Remote sensing data acquisition, the development of digital elevation models (DEMs - a DEM of 50 m resolution will be required for the smaller catchments -see below), and modelling activities should commence as soon as specific sites have been established. Remote sensing should be used to obtain land surface classifications and to examine hydrological variables, i.e., snow distribution, surface freeze/thaw patterns, and surface temperature patterns during different seasons. If possible, meteorological and hydrological stations should be immediately installed. These stations are essential if we are to achieve spatial integration of flux data and a closure of budgets. Modelling should include the modification of existing models to realise new potentials in line with the goals described in section 1. Sensitivity analyses should be carried out to identify major areas of uncertainty. The early stage modelling should be oriented to all scales of interest, ranging from patch scale to mesoscale, and to all disciplines of concern in BAHC, IGAC, and GCTE tundra experiments. A review of tundra models is provided in Reynolds and Tenhunen (1996).

Hydrology issues

The objectives of hydrological studies at level 1 sites must be:

- To define the surface runoff and, thus, establish transport capacities, to define time dependent changes in active layer depths, and to describe and predict ponding and soil water storage
- To identify the lateral movements of water, carbon and nutrients
- To identify the spatial variability of water logging
- To check the estimates of the water and carbon balances at the catchment scale.

These hydrological objectives require a catchment study of maximum area 10,000 km^2, with smaller, nested subcatchments of the order of 100 km^2. Flow and areal precipitation measurements are required to support work at both of these scales. Within the smaller catchments distributed measurements of permafrost depth, soil moisture and surface ponding will be required. It is also envisaged that the smaller catchments will contain a wider variety of functional landscape elements. Flux towers will be operated over these vegetation covers to define biological controls on flux rates and strategies will be developed to up-scale this biological information. Detailed surveys of vegetation and soils will be carried out at this scale.

Microwave satellite measurements (such as SAR) provide a powerful tool for identifying the extent of waterlogged, frozen and snow covered areas. Such spatial resolution of data, when used in conjunction with hydrological models, provide a powerful tool to estimate time dependent spatial fields of soil conditions (essential to the estimation of the fluxes of water and carbon).

Distributed hydrological models (such as TOPMODEL, a topographically based model of surface hydrology at the landscape scale) will be used to provide physically based methods to distribute water (and dissolved carbon) across the catchments. Methodologies will have to be developed to scale these from the smaller to the larger catchments (level 1 site).

Snow

Snow is a vital component of the hydrology and carbon cycle in these areas. Measurements of fluxes through the winter are essential if the full annual water and carbon fluxes are to be quantified (although this can be accomplished with just a single flux station at each level 1 site). A discussion of snow distribution as related to hydrology and tundra ecosystem function is found in Hinzman *et al.* 1996. The spring snow storage and melt is

important to the eventual summer soil moisture patterns. The interaction between snow and forest cover is both scientifically interesting and practically important, particularly in the transition zone. Snow chemistry should also be addressed (see Everett *et al.* 1996).

Integrated mobile measurement systems

In order to scale-up the information gathered from level 1 flux sites, it is desirable to deploy mobile eddy correlation systems (F.S. Chapin III, personal communication). Such systems may be moved to determine local heterogeneity in fluxes and identify key patches that may disproportionately affect fluxes within the footprint of large tower measurements or aircraft observations. Such systems also provide data for intercomparisons between long-term tower flux stations. Process-level measurements (leaf level photosynthesis and stomatal conductance, soil CO_2 efflux, dark respiration of branches and stems, other supporting data related to canopy height, canopy structure, water table and thaw depth, leaf area index, or general descriptions of microtopography, *etc.*) should be conducted in conjunction with operation of these mobile systems (Schulze *et al.* 1995). The emphasis in these studies must be on identifying suites of characteristics that are key variables in determining flux rates and ecosystem process rates. These variables are of particular value when observed simultaneously and at different scales rather than in isolation and only at small scales.

Scaling issues: Patch scale experimentation, level 1 site landscape processes, and regional and transect integration

Our attempts to resolve ecosystem function at all spatial scales are hampered by natural heterogeneity. In addition, our tools to assess ecosystem processes impose scales on our measurements which may or may not conveniently coincide with the actual scales at which landscape units function. Therefore, field measurements confront the issue of appropriate scaling for each environment examined and with the constraints imposed by the analytical approaches employed. Flexibility in the methods used and the timing and spatial location of sampling are necessary because the relevant natural and analytical scales vary in different environments and at different times. Appropriate scaling choices are essential for closure of the mass and energy balances which are necessary for reliable assessments of fluxes.

The extrapolation of data from a range of studies (each with different scaling) from small and medium scales up to larger scales, is extremely difficult. As far as possible, all participants in the Northern Eurasia Study must be encouraged to work towards a uniform intermediate pixel size in their measurement strategies to facilitate scaling-up from process studies and down from remote sensing studies.

For reasons listed below, we suggest a target pixel size of 1 km^2. What this means is that all groups working on patch level processes, the GCM community interested in parameterising land surface characteristics, and those attempting to provide regional driver variables ("weather generator output" in BAHC terminology) must identify their work in relation to this scale and attempt to build an interface that allows information exchange at this scale.

Advantages of the 1 km² pixel as a "hand-shaking" tool

There are several advantages to adopting 1 km² as the target pixel size:

- Remote sensing data for large areas is available from AVHRR and SAR
- AVHRR data will allow landscape description in terms of the 10 landscape elements identified in section 1.2; multi-band information of AVHRR may further allow direct identification of further functional characteristics within a landscape category
- Aggregation of patch-scale and SPOT data from 30 m pixel size to 1 km² is easily accomplished and reasonably acceptable to ecosystem scientists
- Patch-scale SVATs that assume homogeneity over a surface of 1 km² seem to provide a reasonable idealisation of the landscape; techniques can be devised at this level to weight remotely sensed or ground-based studies in such a manner that the information may be captured by such SVATs
- Down-scaling of weather data will soon be achievable at this resolution (1.5 km grid as highest resolution is now used with MM5 in Southern Bavaria with boundary conditions given for Bavaria - we can expect improvement in these models during the next years)
- Level 1 sites defined above and having a sub-structure at this resolution can feasibly be characterised by landscape oriented ecosystem studies (*e.g.*, flux measurements from permanent and portable towers) while enough spatial resolution exists to consider lateral hydrological transport of materials
- Application of TOPMODEL and hydrological modelling of ARCSS at this scale is feasible which provides a framework for extrapolation of belowground effects over large areas and takes both monitored and non-monitored tributaries of the river system into consideration
- Hydrological studies with greater resolution may be easily nested within this grid size and may be viewed at two scales, i.e., hydrological effects driving ecosystem processes (Ostendorf *et al.* 1996) at very fine scale (30 m pixel size) may be translated or up-scaled
- The hydrological modelling mentioned provides a framework that has already been used successfully to quantify material transports from terrestrial to aquatic systems; this is essential for quantifying dissolved and particulate organic carbon fluxes; the 1 km² resolution appears adequate to recognise the specific fluxes of CO_2 from lakes and major rivers to the atmosphere (Oechel *et al.* 1994)
- The footprint of flux determinations by aircraft in ARCSS summarise the collective response of 9 pixels and provide an effective up-scaling tool that can still be related to observed heterogeneity on the ground.

Trace Gas Fluxes

Chairman: Nikolai S. Panikov; Rapporteur: Neil B.A. Trivett.

Participants: V.U. Khattatov; J. Kim, G. Inoue, T. Machida, W.C. Oechel, Y. Harazono, M. Sorokin, B.K. Sitaula, Y. Takahashi.

Questions

- What is the contribution of the major biomes in the Siberian region to the concentration of radiatively active trace gases in the atmosphere?
- What changes to the source/sink strength of these gases will result from the expected changes in climate?

Objectives

The major objectives are to understand the factors controlling the flux of radiatively active trace gases into and out of the Siberian ecosystems by measuring these fluxes from the major ecosystem elements and to scale the results from the micro (patch) through the regional to the global scale.

Discussion

Increase of the concentration of greenhouse gases (CO_2, CH_4, N_2O) is believed to be one of the major causes and outcomes of anticipated climatic changes. Northern terrestrial ecosystems should play a significant role in the emission of such greenhouse gases as methane and in the uptake of CO_2. Evidence for this come primarily from the data on latitudinal distribution of CH_4 and ^{13}C-CH_4 in atmosphere with maxima of total methane concentration and its light biogenic isotope at high latitudes, and the data showing a large seasonal variation of CO_2 concentration. However, most of the data on gas emission was obtained for Northern America, vast wetland territories of Russia still not involved in intensive long-term studies. There are preliminary data indicating considerable contribution of West Siberian wetlands to global budget of atmospheric methane (Panikov 1994).

In addition, the group recognised that fires will have a major impact on the measurements and are a key component of the trace gas exchange. A strong link with the fire research group should be maintained throughout the planning and operational aspects of the trace gas program.

The group recognised that there would be many researchers working on various components of interest, including those trying to interpret the trace gas measurements, and that a major problem would be one of scaling. In addition, the group recognised that the technical limitations of the trace gas measurements precluded the design of an all inclusive experiment. Rather, the discussion focused on what trace gases to measure, what scales were practical for the flux and concentration measurements, what specific intensive experiments might be done and where and how to supplement the aircraft program with ground based measurements. These are summarised in Table 1.

Mechanistic understanding of the observed dynamic patterns and temporal variation of trace gas emission call for careful studies of ecosystem physiology. First, there is the need for obtaining precise data on the carbon cycle (biomass of soil microbes, plant and animals, respiration and photosynthesis, decomposition and accumulation of dead organic matter) as well as the effects of N, P, and other biogenic elements on the rates of C-transformation (*e.g.*, one hypothesis to be tested in experimental studies is attributing the observed increase in CH_4 emission to the atmosphere to inhibitory effects of airborne N-compounds on methane-oxidising microorganisms). It is especially important to fill the gap in our knowledge of major Siberian soils in the rates of N deposition, hydrological regime, soil texture and aeration, pH, ionic composition, and buffer capacity. Another important issue is interaction of microbial populations responsible for trace gas production and consumption with the plant community (vascular gas transfer, root effects on composition and performance of microbial community, *etc.*).

Measurements

The measurement program should address both the spatial (through the use of aircraft) and the temporal (through the use of tall towers) variations of the greenhouse gas fluxes. Where the technology exists to do so, fluxes should be measured from both tower and aircraft platforms. Flux and concentration measurements on the tall towers should be made at a number of levels appropriate to the scale of vegetation changes in the study area. Intensive field campaigns for the measurement of the fluxes of CO_2, CH_4, and N_2O should be supplemented by long term measurements of the trace gases and isotopes listed in Table 1. Some promising new developments in "pilotless" aircraft would allow more measurements of the spatial variability to be made at a reasonable cost. Air sampling into very large containers at a low flow rate would allow time-integrated concentration and isotope measurements to be made at a number of locations in addition to the main sites (a subsample would be sent to the main site for analysis). The monitoring of nitrogen deposition was also considered to be important.

Where

The group considered that intensive ground-based measurements should be established at several sites representative of the major biomes along the transect (to be established in collaboration with other groups). Very tall towers would be established at these sites. However, the group also recognised that the specialised nature of the flux measurements and the infrastructure requirements limited the choice of sites. These ground based measurement would be the anchor for the aircraft measurements. Several transects were suggested: Surgat-Tomsk, Krasnoyarsk-Tura, and Yakutsk- Tiksi.

Table 1. Long-term measurement of trace gas emissions: techniques and locations.

1. Trace gases

CO_2, CH_4, N_2O, CO, hydrocarbons including terpenes and isoprene, H_2, CH_3Br. Stable isotopes ($^{13}CO_2$, $^{13}CH_4$, ^{13}C), ^{14}C, ^{222}Rn (as a tracer to estimate flux intensity from the ground).

2. Methods and scale

Patch scale:	Chambers
Landscape scale:	Micrometeorological techniques (Tower-gradient, eddy correlation, tethered balloon)
Regional scale:	Aircraft (inversion trap, eddy correlation, vertical and horizontal distribution of gas concentration)
Global scale:	Monitoring network, satellite remote sensing

3. Experiments

- Ecosystem physiology (microcosms, field plots)
- Perturbation and manipulation experiments with modified temperature and water regimes, CO_2 fertilisation, simulation of enhanced N deposition
- Assessment of ecosystem diversity, i.e., different types of plant communities and soils

4. Who and Where

- National Institute of Environmental Studies, Japan (G. Inoue); Tomsk - Surgut - Krasnoyarsk - Yakutsk
- Institute of Microbiology, Russia (N. Panikov); Tomsk
- Institute of Pedology and Photosynthesis, Russia (Gilichinsky); Chersky
- Institute of Geography, Russia (Zimov); Chersky
- San Diego State University (Oechel), International Forest Institute (Zamolodchikov); Taymyr
- Central Aerological Observatory, Russia (Khattatov); Surgut - Yakutsk

Terrestrial Ecology

Chairman: E.-D. Schulze; Rapporteur: F.S. Chapin III

Participants: D. Efremov, J.G. Goldammer, T. Hara, L.G. Kondrashov, P. Kuhry, A. Osawa, Y. Oshima, L.V. Pomazkina, T. Sato, N.N. Vygodskaya

Questions

- How will biogeochemical cycles, hydrological regimes, and the long-term carbon budget respond to changes in (i) climate, (ii) disturbance regimes (fire, thermokarst, logging, other land-use changes), and (iii) community composition?
- How will changes in environment and biogeochemical cycles alter community structure and dynamics and their feedbacks to carbons sequestration and surface energy budgets?
- How will changes in herbivore and disease populations alter community structure and dynamics and their links to biogeochemical cycles?
- How does plant community structure link to historic trends (tree ring chronologies, pollen and charcoal analysis, *etc.*)?

Type of Research Needed

The mutual feedbacks between biogeochemical cycles and community structure need to be studied by:

- Observations of biogeochemical cycles in chronosequences of widespread (dominant) communities. Emphasis should be given to understanding the decomposition part of the nutrient cycle (N,P), which determines nutrient availability and C-assimilation capacity of the plant cover. Also, a quantification is needed of C loss by dissolved organic carbon (DOS) and formation of elemental carbon (humus, charcoal).
- Studies of a range of edaphic situations of soil water supply (dry, moist, wet habitats) in conjunction with soil pH on a chronosequence of stands. These should give insights into biogeochemical effects on plant succession and/or abrupt switches (*e.g.*, thermokarst) in community development.
- Long-term experimental plots of silvicultural experiments (*e.g.*, by Utkin in *Larix* forest) can be evaluated in terms of their effect on biogeochemistry.
- Studies of chronosequences of existing stands, with an emphasis on understanding the distribution of dominant species along a pH/soil moisture continuum. In this analysis, the biogeochemical cycles will be a function of the plant species, but will affect the way in which the population biology of the system changes over time, and the population biology in turn will, via community structure (dimensions such as forest height, leaf area index, *etc.*), feedback to biogeochemistry.

Where

The group recommended the establishment of studies along:

- An eastern Siberia N/S transect
- A western Siberia N/S transect

Russian participants suggested placing the eastern transect along the 135° meridian, across the Yakutia Mountains east of the Lena basin, because of the high biodiversity and for institutional considerations. The non-Russian participants argued that cutting a transect across a major mountain range will complicate the investigations, with the species diversity only of minor importance on the larger scale.

The western transect may need to be split at its southern end into studies in typical forest systems and in wetland systems. A network approach is not favoured because it would not focus manpower and equipment resources as well as a transect would.

Approach

The transects should contain a GIS database of a few critical parameters (NDVI, permafrost and snow cover, temperature, precipitation, vegetation cover, recent fire events, *etc.*). Intensive study sites are needed at the northern and southern ends of this thermocline, each of which should include:

- A major study site (watershed) with flux measurements and general meteorological measurements
- Subsites which include: (i) forests of different stand ages on uniform soil types, (ii) different edaphic conditions of the same community (*e.g.*, wet/dry, poor to rich nutrient supply, low to high pH), (iii) sites with natural and manipulated disturbances (fire, wind, insects, diseases), and (iv) sites with anthropogenic impact of logging, agroforestry (grazing, haymaking), and agriculture.

When

The timeframes of the various groups interested in undertaking terrestrial ecological research in Northern Eurasia suggest that 1997-2000 will be an initial period of intensive work:

- The Japanese GAME community will start site selection in the eastern transect in 1996
- The Japanese ecological community is seeking funding for the 1997-1999 period
- The European ecological community will likely obtain support for the 1996-2000 period
- The USA arctic community is seeking a renewal of support, for work in Northern Eurasia as well as Alaska, for the 1997-1999 period.

Who

The Japanese community, through GAME and the ecological community, in collaboration with Russian scientists working the Far East, will likely take the lead in the eastern transect. Germany will continue work in the Yenesei forest region in 1996 and 1998, in collaboration with Russian forest scientists and ecologists from Moscow and central Siberia.

Data, Integration, Scaling and Modelling

Chairman/Rapporteur: A.Z. Shvidenko

Participants: D. Deering, M. Fukuda, A. Isaev, G. Korovin, S. Maksytov, W. Steffen

The group first discussed general questions dealing with the organisation of the proposed transects in the region. It was recommended that two transects - along the 90° meridian (Yenesei River) and 135° meridian (Lena River) - be established. Simultaneously, it was stressed that the large diversity of Northern Eurasian vegetation and soil types, as well as topography, requires a well developed network, of which the transect sites are a very important part.

To facilitate the organisation of the IGBP Northern Eurasia Study, all existing databases should be analysed and relevant information should be made available to prospective participants in the Study and other interested scientists. The databases that some Russian institutions maintain (primarily those of the IIASA Siberian Forest Study; the Center of Ecology and Productivity of Forests, Russian Academy of Sciences, Moscow; Dokuchaev Soil Institute, Moscow; Russian Academy of Agricultural Sciences, Moscow; *etc.*) will be useful.

Far East Transect

Chairman/Rapporteur: G. Inoue

Participants: F.S. Chapin III, H. Dolman, D. Efremov, Y. Harasono, L. Kondrashov, P. Kuhry, T. Ohata, T. Sato, T. Yasunari

Scientific Rationale

- The transect is underlain by an extensive area of permafrost; there is significant erosion of edoma structures in the north.
- The climate along the transect is strongly continental, contrasting with the Alaskan and Scandinavian transect.
- Vegetation types from tundra through taiga are found on the transect.

- There is a strong anthropogenic effect on forest structure and composition in the south. This is captured by included the mixed forests to the northwest of Khabarovsk as a southern extension of the transect.
- The Far East Transects provides an excellent opportunity for collaboration with GAME.

Location

The overall location of the transect is shown in Fig. 1. The northernmost site is at Tiksi, on the Lena River delta, with a major forest site (*Larix* forests) near Yakutsk. Additional forest sites, sampling mixed forest types and various anthropogenic influences, are located to the south, in the region between Khabarovsk and Yakutsk. Additional tundra-based research may be undertaken at Chersky, to the east of the main axis of the transect; the Chersky site may offer a good opportunity to study the tundra-forest transition zone.

Organisation / Logistics

A number of issues need to be resolved to establish the transect as a coherent, integrated research effort:

- Identification of coordinating institution. Possibilities include: Far East Forestry Research Institute, Khabarovsk; Institute of Biology, Yakutsk; Permafrost Institute, Yakutsk; Institute of Cosmophysical Research and Aeronomy, Tiksi; National Institute of Polar Research, Tokyo, Japan.
- Establish reliable communication links between transect institutions and scientific groups and the broader research community. It was noted that reliable electronic mail communication is already established at the Far East Forestry Research Institute, Khabarovsk.
- Establishment of reliable supply lines along the transect, and resolution of associated logistical problems.
- Resolution of political issues, such as potential duties on imported scientific equipment.

Next Steps

The working group identified several activities which should be undertaken in the near future:

- Review of current activities and research groups working along the transect

- Collation and analysis of data generating by past and existing global change-related research at transect sites
- Evaluation of research stations of the Far East Forestry Research Institute, Khabarovsk, to identify a main southern site for the transect.

Yenesei/West Siberia Studies

Chairman: E-D. Schulze; Rapporteur: R. Harding

Participants: D.W. Deering, F. Fukuda, J.G. Goldammer, A.S. Isaev, V.U. Khattatov, G. Korovin, A.N. Krenke, P. Kuhry, S. Maksyutov, F. Nakagawa, N. Panikov, L.V. Pomazkina, A.Z. Shvidenko, N.N. Vygodskaya

Scientific Rationale

- There is a possibility of a continuous and extended tundra/forest transition not complicated by topography (as in the Far East Siberian transect).
- The tundra regions on the west bank of the Yenesei are significantly different from those on the east (*e.g.*, no edoma ice).
- There appear to be considerable methane emissions from the wetlands in the southern part of the transect region.
- There is much interest in the transition between wetlands and pine forest and the interactions between these land cover types.
- In the southern part of the proposed transect, the east and west banks of the Yenesei carry very different forest types, with nutrient limited pine on the west bank and relatively nutrient rich, tall forest on the east bank.

Objectives / Questions

The following scientific questions for the Study were proposed:

- For wetlands: (i) How will global change, especially disturbances such as climatic extremes, fire, permafrost collapse, mining, drainage, affect peat deposits? (ii) How will climatic change affect bog extent?
- For wetland/forest transition zone: (i) How will global change affect fire frequency and permafrost extent? (ii) How will peat fires affect trace gas emissions? (iii) What are the interactions between the pools of carbon in forests and those in wetlands (fluxes of dissolved organic carbon)?
- For forests: (i) How will natural and anthropogenic disturbances (fire, logging, windfall, insects) affect the status and dynamics of humus? (ii) How is the carbon sink capacity of forests linked to soil nutrition?

Recommendations for the Transect Study

The group made the following recommendations on the design and organisation of the transect study.

- The main transect should be aligned in a north-south direction and based on the east side of the Yenesei River because of the extensive plateau regions on that side, suitable for the study of the tundra/forest transition. The pine forests at the southern end of the transect also have considerable interest, for their commercial importance as well as for their interaction with wetlands. In the north, the effect of industry around Norilsk must be considered.
- A tundra site on the west side of the Yenesei delta would be interesting (no edoma ice), particularly in comparison to peat areas further south.
- In the southern wetlands, an associated east-west transect would be useful (between the Yenesie and the Ob Rivers, about 60° N) to study forest-wetlands interactions and also include the gas production areas. This associated transect would connect the FIRESCAN site with the Japanese sites at Surgut and Tomsk. The exact trace of this transect will have to be explored by airborne sampling.
- A total of six intensive sites are likely to be required: (i) tundra, (ii) tundra/forest transition, (iii) pine forest (west bank), (iv) mixed conifer forest (east bank, paired with pine forest site), (v), (vi) southern wetlands, close and distant from gas fields, including studies on peat fires. In addition, a larger number of less intensive sites along the east bank transect are required.

Current and Planned Activities

The group listed the following activities, which are of relevance to the proposed transect study. It should be emphasised that this list is still incomplete representing the workshop participation.

- Measurement of carbon fluxes and pools in pine/wetland area on the west bank of the Yenesei (FIRESCAN site, 60°N); tower measurements (eddy correlation) supplemented with aircraft measurements; 1996. Similar studies on birch/Picea fire successional sequence on east bank at 60°N, 1998. (Schulze)
- Peat studies of fire histories in the south Yenesei basin, 1997. Study of permafrost collapse in the north Yenesei basin, 1998. (Kuhry)
- Measurement of CH_4, CO_2, CO and H_2 fluxes in wetlands in the Tomsk region; chamber and eddy correlation techniques; scaling up to 100 km scale using wetland classification from SPOT and SAR images; flux measurements at 100 km scale using aircraft, 1996-1998. (Inoue, Maksyutov, Panikov, Tamura)

- Regular (monthly) atmospheric profile sampling over Surgut for CH_4, CO_2, N_2O, CO, d13C and twice-yearly sampling of d14C, 1996-long term. (Inoue, Maksyutov, Panikov)

- Monthly atmospheric profiles of CH_4 and CO_2 at a tundra site in the Taimyr region, 1997-98. (Korovin, Panikov)

- Measurements of biomass, net primary productivity and fire chronosequences at a forest site in the Tura region. (Osawa)

- Estimation of disturbance frequencies and extents (both natural and anthropogenic) in Russian state forests by use of remote sensing. (Isaev, Korovin)

- Mapping of UV-B fluences. (Khattatov)

- Mapping of gross primary productivity, net primary productivity and ecosystem structure in unprotected Russian forest areas. (Shvidenko)

- Feasibility study for tundra experiment, 1996-97. Water and energy flux measurements, hydrological studies in tundra, 1998-99. (Harding)

- Measurement of carbon pools in forest steppe/agricultural systems in the Baikal region. (Pomazkina)

- Hydrological studies in European Russia. Maps of changes in snow cover. Regional climate models. (Krenke)

- Temperature profiles in permafrost to 40 m depths in Tienshan and Magadan alpine tundra, 1996-98. Palaeoclimate reconstructions from peat sediments in the Tomsk region. (Fukuda)

- Isotope measurements of rainfall chemistry and of CH_4 in the atmosphere over a large network. (Nakagawa)

- Ground truth measurements for remote sensing of vegetation structure and landscape mapping, 1996-97. (Dearing)

Next Steps

The meeting concluded with a discussion of the next steps to be taken in promoting and coordinating work in the IGBP Northern Eurasia Study. The recommendations were organised with respect to the Far East Transect, studies in the Yenesei/West Siberia region, and data and integration issues.

Far East Transect

A number of activities were recommended:

- Catalogue existing data, research groups and facilities, and relevant expertise in the Far East region. This will be undertaken by the Far East Forest Research Institute, Khabarovsk, and GAME

- Visits to potential study sites and selection of sites, to be coordinated by GAME

- Sensitivity/modelling studies. A proposal for EU support will be prepared by BAHC, GAME and the Far East Forest Research Institute.

Coordination for the Far East Transect will initially be provided by a contact group consisting of:

- Far East Forest Research Institute, Khabarovsk, Russia (D. Efremov, L. Kondrashov)

- GAME, Japan (T. Yasunari, T. Ohata); NIES, Japan (G. Inoue)

- Data Coordinating Group (see below)

- IGBP, through the BAHC, IGAC and GCTE Core Project Offices and through BIBEX (J.G. Goldammer).

Yenesei/West Siberia Studies

A series of pre-study activities, including a catalogue of existing data, research groups, and facilities, was also recommended here. Two other data needs were identified for early action:

- Wetlands maps and classification, digitised into a GIS system

- Baseline data on vegetation and soils for the East Yenesei transect.

In addition, a meeting to develop coordination for the Yenesei/West Siberia Study Area was proposed, to be held in association with the IBFRA conference to be held in St Petersburg in August 1996.

Coordination for the Yenesei/West Siberia Study Area will initially be provided by a contact group consisting of:

- International Forestry Institute, Moscow (A.S. Isaev, G. Korovin); Institute of Forest, Krasnoyarsk (E. Vaganov); Institute of Microbiology, Moscow (N.S. Panikov); Novosibirsk Institute of Soil Science, Russia

- National Institute for Environmental Studies (NIES), Japan (G. Inoue)

- Data Coordinating Group (see below)
- IGBP, through the BAHC, IGAC and GCTE Core Project Offices and through BIBEX (J.G. Goldammer).

Data and Integration

The base for the Northern Eurasia Study data and information system will be provided by the existing, excellent forests database of the International Forestry Institute, Moscow; International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria; and the Dokuchaev Soil Institute, Moscow. Several additions to this database were recommended, as an initial priority:

- Tundra, permafrost, wetlands
- Land-use/cover change
- Disturbances, especially fire. It was noted that a fire database for much of Northern Eurasia, relevant to both studies, will soon be available (to be provided by J.G. Goldammer)
- Suite of atmospheric data, especially trace gas concentrations where available
- Classifications and definitions, to be standardised with international usage.

Further suggestions was that a CD-ROM, with the initial data sets, be produced for use by modelling groups with an interest in Northern Eurasia; and that information on the IGBP Northern Eurasia Study be provided to the broader scientific community through a World Wide Web homepage.

Coordination for the Data and Information Activities of the Northern Eurasia Study will initially be provided by a contact group consisting of:

- International Forestry Institute, Moscow, Russia (A.S. Isaev, G. Korovin)
- IIASA, Laxenburg, Austria (A.Z. Shvidenko)
- National Aeronautics and Space Administration (NASA), USA (D.W. Deering)
- National Space Development Agency (NASDA), Japan
- IGBP-DIS.

Overall Coordination

The following recommendations were made:

- The three contact groups listed above should communicate frequently to ensure overall coordination of the next phases of the Study
- The Russian scientific community, acting through the Russian National IGBP Committee and through the Russian scientific groups represented at this meeting and other Russian groups interested in the IGBP Northern Eurasia Study, should establish a coordinating committee and a leader for the Study
- The IGBP, at the IGBP Congress to be held in Germany in April 1996, should establish an advisory committee to assist the Russian coordinating committee in the further planning and execution of the Study
- The IGBP should obtain resources for a scientific officer, to assist the Chairmen of the Russian coordinating committee and the IGBP advisory committee, and for further, more detailed workshops and meetings to focus on scientific coordination and integration of the Study.

List of Participants

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Appendix 7
IGBP Reports

*Reports marked with an * are no longer available.*

No. 12 The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). The Initial Core Projects. (1990)

No. 13 Terrestrial Biosphere Perspective of the IGAC Project: Companion to the Dookie Report. Edited by P.A. Matson and D.S. Ojima. (1990)

No. 14 Coast Ocean Fluxes and Resources. Edited by P.M. Holligan. (1990)

No. 15 Global Change System for Analysis, Research and Training (START). Report of the Bellagio Meeting. Edited by J.A. Eddy, T.F. Malone, J.J. McCarthy and T. Rosswall. (1991)

No. 16 Report of the IGBP Regional Workshop for South America. (1991)

No. 17 Plant-Water Interactions in Large-Scale Hydrological Modelling. (1991)

No. 18.1 Recommendations of the Asian Workshop. Edited by R.R. Daniel. (1991)

No. 18.2 Proceedings of the Asian Workshop. Edited by R.R. Daniel and B. Babuji. (1992)

No. 19 * The PAGES Project: Proposed Implementation Plans for Research Activities. Edited by J.A. Eddy. (1992)

No. 20 * Improved Global Data for Land Applications: A Proposal for a New High Resolution Data Set. Report of the Land Cover Working Group of IGBP-DIS. Edited by J.R.G. Townshend. (1992)

No. 21 * Global Change and Terrestrial Ecosystems: The Operational Plan. Edited by W.L. Steffen, B.H. Walker, J.S.I. Ingram and G.W. Koch. (1992)

No. 22 Report from the START Regional Meeting for Southeast Asia. (1992)

No. 23 Joint Global Ocean Flux Study: Implementation Plan. Published jointly with SCOR. (1992)

No. 24 Relating Land Use and Global Land Cover Change. Edited by B.L. Turner II, R.H. Moss and D.L. Skole. Also HDP/Report No. 5. (1993)

No. 25 Land-Ocean Interactions in the Coastal Zone: Science Plan. Edited by P.M. Holligan and H. de Boois. (1993)

No. 26 Towards a Global Terrestrial Observing System (GTOS): detecting and monitoring change in terrestrial ecosystems. (Report of Fontainbleau Workshop). Edited by O.W. Heal, J.-C. Menaut and W.L. Steffen. Also UNESCO/MAB Digest. (1993)

No. 27 * Biospheric Aspects of the Hydrological Cycle: The Operational Plan. (1993)

No. 28 * IGBP In Action: Work Plan 1994 - 1998. (1994)

No. 29 Africa and Global Change. Report from a Meeting at Niamey, Niger, 23-27 November, 1992. (1994)

No. 30 IGBP Global Modelling and Data Activities 1994 - 1998. (1994)

No. 31 African Savannas and the Global Atmosphere: Research Agenda. Edited by C. Justice, R.J. Scholes and P.G.H. Frost. (1994)

No. 32 International Global Atmospheric Chemistry (IGAC) Project: The Operational Plan. (1994)

No. 33 Land-Ocean Interactions in the Coastal Zone: Implementation Plan. Edited by J.C. Pernetta and J.D. Milliman. (1995)

No. 34 BAHC-IGAC-GCTE Science Task Team: Report of First Meeting. (1995)

No. 35 Land-Use and Land-Cover Change (LUCC): Science/Research Plan. Edited by B.L. Turner II, D. Skole, S. Sanderson, G. Fischer, L. Fresco and R. Leemans. (1995)

No. 36 The IGBP Terrestrial Transects: Science Plan. Edited by G.W. Koch, R.J. Scholes, W.L. Steffen, P.M. Vitousek and B.H. Walker. (1995)

No. 37 IGBP Northern Eurasia Study: Prospectus for an Integrated Global Change Research Project. Edited by W.L. Steffen and A.Z. Shvidenko. (1996)

Appendix 8

Acronyms and Abbreviations

ARCSS	Arctic System Science
AVHRR	Advanced Very High Resolution Radar
BAHC	Biospheric Aspects of the Hydrological Cycle
BASIS	the Barents Sea Impact Study
BESIS	the Bering Sea Impact Study
BFTCS	Boreal Forest Transect Case Study
BIBEX	Biomass Burning Experiment
BOREAS	Boreal Ecosystems Atmosphere Study
CD-ROM	Compact Disk - Read Only Memory
CEC	Cation Exchange Capacity
CENTURY	*Name of long-term model*
CEOS	Committee on Earth Observations Satellites
DEM	Digital Elevation Model
DIS	Data and Information System
DOS	Dissolved Organic Carbon
EU	European Union
FACE	Free Air CO_2 Enrichment
FBM	Frankfurt Biosphere Model
FIRESCAN	Fire Research Campaign Asia-North
FT	Functional Type
GAIM	Global Analysis, Interpretation and Modelling
GAME	GEWEX Asian Monsoon Experiment
GCM	General Circulation Model
GCTE	Global Change and Terrestrial Ecosystems
GEWEX	Global Energy and Water Cycle Experiment
GIS	Geographic Information System
GTOS	Global Terrestrial Observing System
HESS	High Latitude Ecosystems as Sources and Sinks of Trace Gases
IASC	International Arctic Science Committee
IBFRA	International Boreal Forest Research Association
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Programme
IGU	International Geographical Union
IHDP	International Human Dimensions Programme on Global Environmental Change
IIASA	International Institute of Applied Systems Analysis
ISF	International Science Foundation
ITEX	International Tundra Experiment
IUFRO	International Union of Forest Research Organizations
LAI	Leaf Area Index
Landsat	Land Remote-Sensing Satellite
LSE	Land Surface Experiment
LUCC	Land-Use and Land-Cover Change

MAGS	Mackenzie GEWEX Study
NASA	National Aeronautics and Space Administration (USA)
NASDA	National Space Development Agency of Japan
NDVI	Normalised Difference Vegetation Index
NIES	National Institute for Environmental Studies
NOAA	National Oceanic and Atmospheric Administration (USA)
NOPEX	Northern Hemisphere Climate Processes Experiment
NPP	Net Primary Productivity
NSF	National Science Foundation (USA)
PAGES	Past Global Changes
PLAI	Potsdam Land-Atmosphere Interaction Model
R4D	Response, Resistance, Resilience and Recovery of arctic ecosystems to Disturbance (USA)
SAR	Synthetic Aperture Radar
SC-IGBP	Scientific Committee for the IGBP
SPOT	Système pour l'Observation de la Terre
START	Global Change System for Analysis, Research and Training
SVAT	Soil-Vegetation-Atmosphere Transfer
TEACOM	Temperate East Asia Committee for START
TEM	Terrestrial Ecosystem Model
TOPMODEL	Topographic Model
TRAGEX	Trace Gas Exchange: Mid-Latitude Terrestrial Ecosystems and Atmosphere
TSBF	Tropical Soil Biology and Fertility Programme