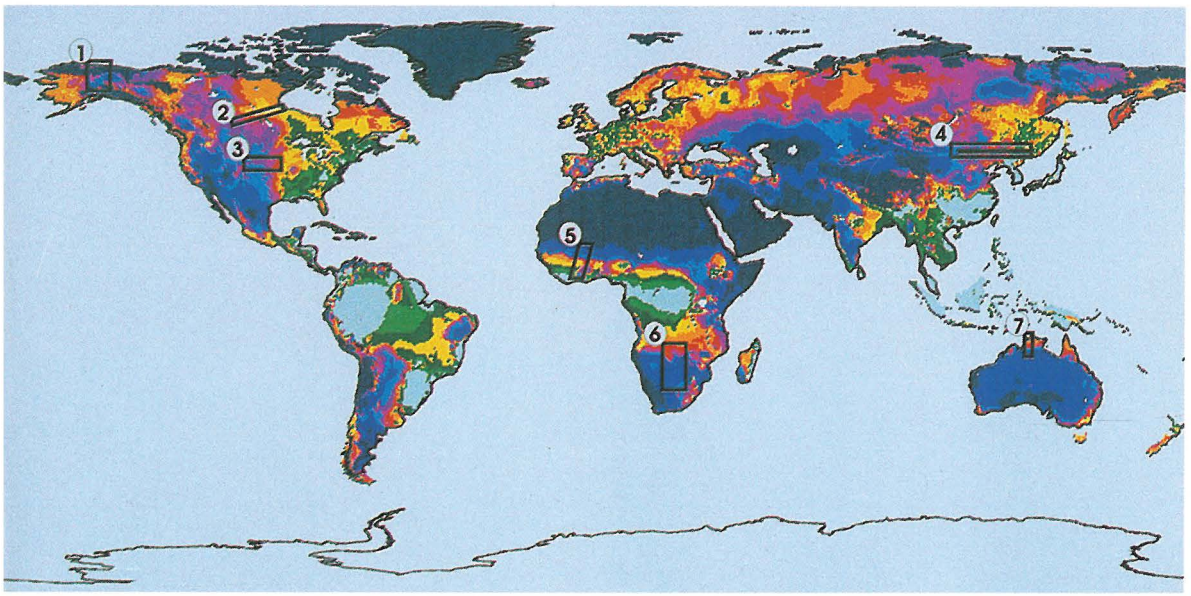
GLOBAL CHANGE

IGBP

REPORT No. 36



The IGBP Terrestrial Transects: Science Plan

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
Stockholm, 1995

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The IGBP Terrestrial Transects: Science Plan

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Cover photo illustrates the following transects:
1 = AGR (Alaskan Transect) 2 = BFTCS (Boreal Forest Transect Case Study) 3 = NAMER (Northern American Transect) 4 = NECT (North East China Transect) 5 = SALT (South African Longitudinal Transect 6 = KALA (Kalahari Transect) 7 = NATT (Northern Australia Tropical Transect)
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Contents

Executive Summary

Current or predicted changes in atmospheric composition, land use, and climate are likely to alter significantly the biogeochemistry, surface-atmosphere exchange, and composition and structure of terrestrial ecosystems, and consequently may lead to feedbacks to components of global change. The IGBP Terrestrial Transects are a set of integrated global change studies consisting of distributed observational studies and manipulative experiments coupled with modelling and synthesis activities organised along existing gradients of underlying global change parameters, such as temperature, precipitation and land use. The global change issues that can best be addressed with the gradient approach include questions where: a long period of prior equilibration is required; spatial context is essential; identification of thresholds along a continuum is important; and gradient-driven processes are important. The transect approach also promotes collaborative, interdisciplinary research and leads to an efficient use of scarce scientific resources.

The IGBP Terrestrial Transects consist of a set of study sites arranged along an underlying gradient; they are of order 1000 km in length and are wide enough to encompass the dimensions of remote sensing images. The transects can be visualised most easily where they represent a simple gradient of a single controlling factor that varies in space - for example, the gradient in precipitation from moist tropical forest to dry savanna. In addition to relatively straightforward transects in which a single environmental factor varies continuously in space, a set of IGBP Terrestrial Transects has been identified in which the underlying gradient is one of land use. These gradients are more spatially complex than the quasi-linear transects since ecosystems experiencing differing intensities of land use are rarely distributed in such a way that distance along the transect corresponds directly to intensity of land use. Nevertheless, it is useful to place study sites along a conceptual gradient based on intensity of land use.

Most IGBP Core Projects are involved, actively or potentially, in the IGBP Terrestrial Transects as many of their objectives can be addressed in this format. Biospheric Aspects of the Hydrological Cycle (BAHC) aims to determine the role of changes in the land surface in controlling the fluxes of water, energy and carbon between the land surface and the atmosphere. The International Global Atmospheric Chemistry Project (IGAC) is interested in determining the quantities and controlling factors of trace gas emissions from the biosphere, including biomes ranging from the humid tropics where land-use change is the dominant factor to the high latitudes where an increase in temperature is predicted to be important. Global Change and Terrestrial Ecosystems (GCTE) will use the transects as a major tool in its programme to (i) determine changes in terrestrial biogeochemical cycling; (ii) study the effects of global change on ecosystem composition and structure; (iii) serve as platforms for studying the impacts of global change on various aspects of terrestrial ecosystems, such as production systems (*e.g.*, managed forests, complex agroecosystems), soil processes and ecological complexity. Land-Use and Land-Cover Change (LUCC) can use the transects as a coherent set of study sites to determine how land use and associated land cover are changing globally as a result of social and environmental factors, and how they interact with biophysical factors. Some of the transects, particularly the land-use change transects in the humid tropics, will be of value to Land-Ocean Interactions in the Coastal Zone (LOICZ) in

determining how land-cover conversions affect the delivery of sediments to the coastal zone. In general, the transects will serve as a valuable tool in facilitating interaction among the Core Projects at appropriate points and in scaling the results of smaller scale process studies to the longer time and larger spatial scales required for global modelling and analysis.

Other elements of IGBP will play an important role in the transects. Past Global Changes (PAGES) has developed a system of Pole-Equator-Pole (PEP) transects that will provide the long-term temporal framework for this effort. IGBP Data and Information System (IGBP-DIS) will provide essential assistance with the organisation of a management and data information plan, with the compilation of standardised databases for the transects, and for the procurement and use of remote sensing data. As the IGBP Terrestrial Transects are regional in scope, they are ideally placed for a partnership with Global Change System for Analysis, Research and Training (START) in terms of regional- and national-scale analyses of global change impacts and feedbacks and in capacity-building activities. Finally, the integrated understanding of global change impacts on biogeochemistry, surface-atmosphere exchange, and composition and structure of terrestrial ecosystems at the regional scale will provide excellent input for the calibration and validation of the global models to be developed within Global Analysis, Interpretation and Modelling (GAIM).

The initial set of IGBP Terrestrial Transects are located in four key regions, with three or four existing, planned or proposed transects contributing to the set in each region.

Region	Land cover	Major global change gradient	Contributing transects in initial set
Humid tropics	Tropical forest (humid and dry) & its agricultural derivatives	Land use intensity	Amazon Basin/Mexico Central Africa/Miombo Southeast Asia/Thailand
Semi-arid tropics	Forest-woodland-shrubland (the savannas)	Precipitation	Savannas in the Long Term (West Africa) Kalahari (Southern Africa) Northern Australia Tropical Transect
Mid-latitude semi-arid	Forest-grassland-shrubland	Precipitation	Great Plains (USA) Argentina North East China Transect
High latitudes	Boreal forest-tundra	Temperature	Alaska Boreal Forest Transect Case Study (Canada) Scandinavia Siberia

Early coordination of the IGBP Terrestrial Transects has been provided by an interaction task team consisting of Scientific Steering Committee members and officers of BAHC, IGAC and GCTE. In addition, a number of activities, including planning and synthesis workshops, have been organised in an *ad hoc* fashion by coordinators and others associated with the individual transects. To further the development of the IGBP Terrestrial Transects in a coordinated way, there is an urgent need for the establishment of a small coordinating office within IGBP with a full-time scientific officer.

Preface

The need for transect studies was recognised early in the planning phase of the IGBP Core Project on Global Change and Terrestrial Ecosystems (GCTE) and the establishment of these transects is a central tenet of GCTE's research programme (Steffen *et al.* 1992). Much of the plan outlined here is based on a workshop organised by GCTE and supported by the Ecological Processes and Modeling Program of the U.S. National Aeronautics and Space Administration (NASA). The workshop was held at the Marconi Conference Center in California in August, 1993, and has led to subsequent developments incorporated in this report. Establishing the locations of the transects and detailing the measurements to be made is an important step in implementing the GCTE research programme. The transects described here are by no means the complete and final set; rather they are a response to a first assessment of priority needs. It is important that these transects be established so that the research can get underway in a timely and organised manner. Many groups involved in global change research have recognised the need for such transects, and a number have been established with more being planned, as described in this report. The resources are scarce, however, and it is hoped that the publication and dissemination of this document will encourage scientists to focus their efforts on a common set of transects, in a complementary and collaborative way, building on the work that (in most cases) is already under way.

Although proposed initially as a GCTE activity, it has become clear that the transects will become an important research facility for other IGBP Core Projects as well. The transects offer an excellent opportunity for studying the role of terrestrial ecosystems in controlling important land surface processes, such as trace gas emissions (IGAC) and the interchange of water and energy with the atmosphere (BAHC). They can also be useful in studying the nature of impacts of land-use change on important ecosystem functions (GCTE, IGAC, BAHC, LOICZ) and on ecosystem structure and composition (GCTE, LUCC). Given the emphasis in transect studies on scaling up from small patches to the regional level, they will be ideal test-beds for the application of remote sensing science to terrestrial global change problems (IGBP-DIS). Their regional scale also suggests that the transects be closely coordinated with other activities of the START networks. In addition, PAGES has developed a system of Pole-Equator-Pole (PEP) transects that will provide the long-term temporal framework for this effort. Thus, these transects are truly IGBP (not just GCTE) research facilities that will add significantly to our understanding of the role of the terrestrial biosphere in global change.

The transects will be implemented over a 10-15 year period, that is, over the projected lifetime of many of the contributing IGBP Core Projects. In the longer term, the transects may also provide valuable data for the Global Terrestrial Observing System (GTOS), which requires both ground data measured in a consistent way around the world and remotely sensed data.

The Rationale for Large-Scale Terrestrial Transects

Current or predicted changes in atmospheric composition, land use, and climate, collectively termed global change, are likely to alter significantly the biogeochemistry, surface-atmosphere exchange, and structure/composition of terrestrial ecosystems, and consequently may lead to feedbacks to components of global change. There are several reasons why the capacity to predict effects of global change can be gained most effectively by distributing measurements and experiments along existing gradients of each underlying controlling factor. Firstly, comparative studies have long been useful in understanding the patterns and controls on ecosystem processes; comparisons based on well-defined and continuous variation in an environmental factor yield still greater insight into how that factor controls ecosystem function. Secondly, ecosystem-level experimentation that is replicated along an environmental gradient can be used to analyse interactions among the underlying environmental factor, other environmental variables, and biotic components of ecosystems. Finally, research and associated modelling carried out along gradients enforces an integrated, extensive, regional, and realistic (in terms of human influences) perspective on global change studies.

In addition, there are two more practical reasons that the transect approach is a good one for global change research. First, the transects will promote collaborative work by scientists of various disciplines on the same sites, thus leading to both an efficient use of scarce scientific resources and to an effective strategy for tackling the complex issues associated with global change. Thus, the transects will serve as the terrestrial equivalent of oceanographic research vessels, which have facilitated collaborative research in the marine science community and have led to a regional and global picture of ocean productivity and climatology. Second, the transects will facilitate the extrapolation of smaller-scale process research to the regional and global contexts of interest to policymakers and to other researchers in Earth System science.

In addition to these general considerations there are particular global change issues that can only or best be addressed using gradient techniques. These include:

1. **Questions where a long period of prior equilibration is required.**

   If a response surface were required, for instance to rainfall and fertility, it could be obtained by conducting an irrigation x fertilisation trial at a single site. However, this would mean subjecting the ecosystem to an abrupt change, and processes which have substantial time-lags (for instance, the accumulation of soil organic matter, or a change in vegetation composition) would almost certainly not respond in the short-term in the same way as they would in the long term. Large-scale gradients in which current spatial variation is used as an analogue for expected temporal variation, in combination with patch-scale manipulative experiments, provide a powerful approach to understanding long-term responses to global change. That the vegetation at a particular point will alter under a future climate to match the vegetation currently existing at that climate at another point on a

gradient, other factors being equal, is an underlying assumption which needs to be rigorously tested. For example, in the past new combinations of species have apparently arisen with a change in climate, rather than just a simple shift in space of existing biomes (Overpeck *et al.* 1992).

2. **Questions where the spatial context is essential.**

   Processes which operate continuously in space need to be studied along continua. For instance, the process of species migration occurs from point to neighbouring point. The fact that many environmental processes are spatially autocorrelated requires that regional extrapolation of point measurements needs to be done with great care. A key uncertainty in many aspects of global change research is whether the net effect of a process at a large scale is simply the sum of the process occurring in patches at smaller scales. The indications are that it generally is not, due to interactions between adjacent patches. This question can only be answered by making measurements on contiguous patches, and at a series of nested scales. The scale to which ecological analyses will ultimately have to be related is the scale at which the global climate is simulated. For the near future, this will be in the order of a 500 x 500 km square. It is thus necessary to be able to scale up to, and down from, this order. This is the main motivation for IGBP transects to be of the order of 1000 km, or two General Circulation Model (GCM) grid cells, in length.

3. **Identification of thresholds along a continuum.**

   Ecosystem process response may not be a simple or linear function of a given global change variable. Studies along existing gradients of components of global change (*e.g.*, precipitation or land use intensity) may reveal discontinuities which can provide the basis for more focused experiments.

4. **Questions of gradient-driven processes.**

   Ecosystems everywhere occur on gradients of one type or another, but in some places the gradients are so strong and integral to the functioning of that ecosystem that to ignore them would be to misrepresent the system. An obvious example is the altitude gradient which drives hydrological processes in a catchment. Another example would be the intensity of grazing in migratory herbivore systems of African savannas, where the animals exploit the gradient to satisfy their nutritional requirements on an annual basis.

There are also organisational advantages to a transect approach. Transects will provide a high profile, multi-national, and interdisciplinary platform to encourage collaboration among researchers involved with the different Core Projects and framework activities of the IGBP. Integration of activities among different IGBP groups will be more easily achieved if research is conducted on the same or related study sites.

As will become clear in later sections, the proposed transect studies involve both extensive, coarse-grain studies and intensive, patch-scale experimental studies at selected sites along the transects. The intensive studies will be particularly important in examining fine-scale heterogeneity that is of special significance for certain processes, for example, the controls on trace-gas fluxes by local-scale soil factors.

There are a number of research areas that are common to all of the transects in the IGBP set. These are:

- hydrologic cycle
- carbon and nutrient cycles
- atmosphere-biosphere trace gas exchange
- land surface characteristics (albedo, roughness, etc.)
- ecosystem structure and composition (based on plant functional types)

In addition to these broad questions, more specific issues for various regions are presented in more detail in the sections for each type of transect.

The rationale and methodology embodied in the transect approach and described in this report has already been adopted and proven valuable in global change research in several areas. For example, the Savannas in the Long Term (SALT) transect in West Africa has been established for several years and is producing significant new ecological knowledge about the structure and function of semi-arid tropical systems (*e.g.*, Menaut *et al.* 1991). The Arctic Flux Study is a multidisciplinary study in Alaska which combines hydrological, trace gas, atmospheric chemical, and ecological research and which forms the backbone of the Alaskan high latitude transect (Weller *et al.* 1995).

Types of Transects and Selection Criteria

Definition of IGBP Transects

Each IGBP transect has been chosen to reflect the effect of variation in a major environmental factor as it influences terrestrial ecosystem structure/function/composition, biosphere-atmosphere trace gas exchange, and hydrologic cycling. Thus, each transect consists of a set of study sites distributed in a larger geographical context (of order 1000 km or larger) that encompasses existing gradients of underlying controlling factors of ecosystem structure and function (*e.g.*, climatic, edaphic or land-use gradients). The transects can be visualised most easily where they represent a simple gradient of a single controlling factor that varies in space - for example, the gradient in precipitation from moist tropical forest to dry savanna. In practice, of course, all of the IGBP transects are more or less complex; multiple factors contribute to the structure and function of any ecosystem, and interact to shape its dynamics. Nevertheless, the presence of a strong underlying gradient shapes the ecosystems along a transect and their interactions with other environmental factors, thereby helping us to understand how these systems function, and how they are likely to change.

In some cases, the environmental gradients are sufficiently orderly to support an approximately linear gradient in physical space, but this is not a necessary condition. For certain questions (particularly those involving scaling and context-dependent processes) it is important that the gradient be physically continuous. The length of the transects has been specified as of the order of 1000 km, to ensure that they overlap with the spatial realm of climate and atmosphere models and are relevant to a policy-making scale, but they do not in principle have a fixed width. Figure 1 shows the design of a generic transect study, which incorporates several field research stations (sites) and a larger number of sample plots. Although not shown in the figure, the transects can also have secondary gradients. That is, a set of sites clustered near a research station along the primary gradient can sample another global change variable such as intensity of land use (*e.g.*, grazing intensity in the semi-arid tropical transects). Studies along coupled primary and secondary gradients can be valuable in determining the relative importance of multiple variables and their interaction.

In addition to relatively straightforward transects in which a single environmental factor varies continuously in space, a set of IGBP transects has been identified in which the underlying gradient is one of intensity of land use. These gradients are more spatially complex than the quasi-linear transects, since ecosystems that experience differing intensities of land use are rarely distributed in such a way that distance along a regional transect corresponds directly to the intensity of land use. Nevertheless, often it is possible to place differing land uses along a gradient of intensity (*e.g.*, from unmanaged forest to selective forest harvesting to clearfelling followed by forest succession to conversion into pasture to conversion into permanent, high-input agriculture). Sites within a region can then be located and evaluated according to their position along such a gradient, yielding a situation analogous to a spatially-monotonic moisture or temperature gradient.

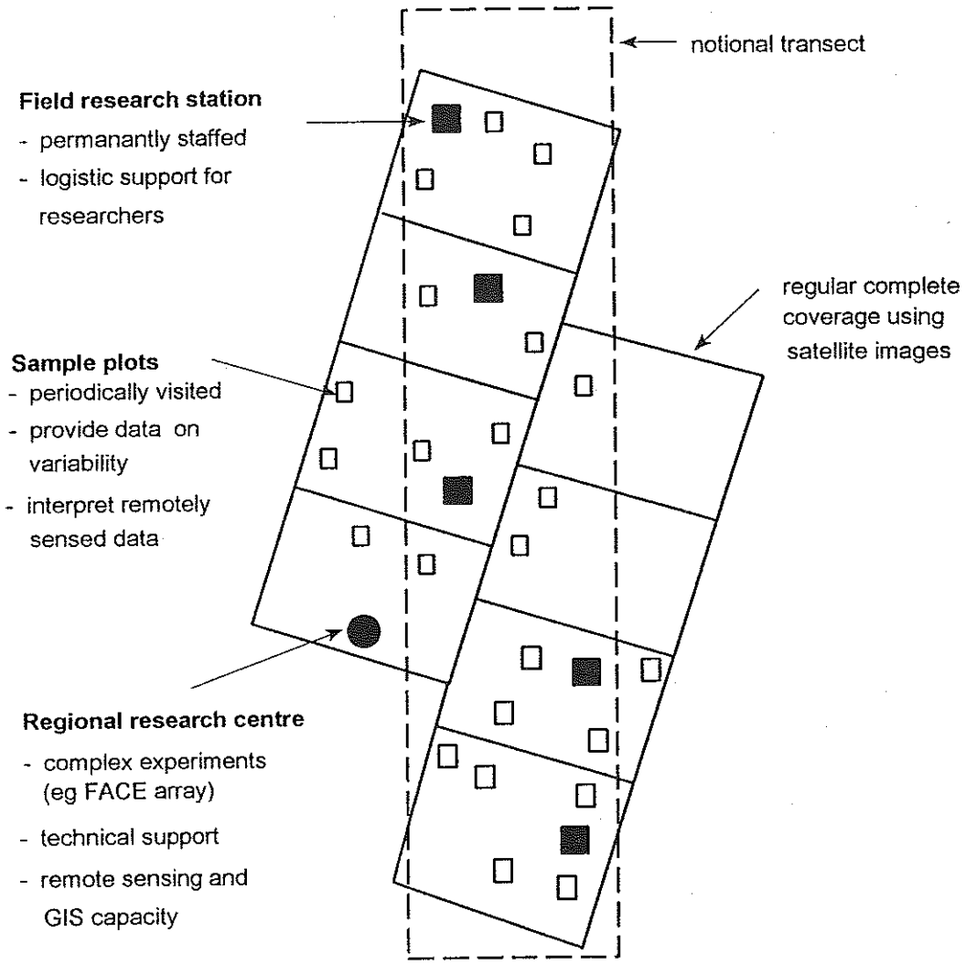


Figure 1. Design of a generic transect study. The notional transect is about 1000 km long and a few hundred km wide.

It should be pointed out that many globally significant research sites and networks do not fit our definition of transects. IGBP research sites where interdisciplinary research on the effects of elevated carbon dioxide is being carried out fall into this category, as does the U.S. Long Term Ecological Research network. They are integral to the IGBP, but in and of themselves they are not transects as defined here. In some cases transects may be located so as to include some or all of these sites. This would provide benefits for both the transects and the local studies.

Selection Criteria

The proposed initial IGBP transects were chosen according to a rather stringent set of criteria. Each transect:

1. Represents a coherent set of sites that differs more or less straightforwardly and continuously in relation to a major environmental factor that is subject to change (or has already changed) as a consequence of anthropogenic global environmental change.

2. Is located in a region that is being or is likely to be altered by forcing from components of global environmental change, where the alteration is itself likely to be globally significant, or where the alteration is likely to feed back to affect atmospheric, climatic, or hydrologic systems.

3. Spans a sufficiently broad gradient that (i) understanding gained from research on the transect can be applied beyond a narrow region; (ii) it crosses a transition between systems dominated by different major life forms (*e.g.*, forest/prairie or savanna, taiga/tundra); (iii) it requires resources that are ordinarily beyond the scope of individual research groups funded by national sources. On the other hand, transects should not be so broad as to lose focus, as would be the case for a transect from pole to pole. Finer-scale studies can, of course, make equally valuable contributions to the IGBP program, but do not require a coordinated international effort to be established.

4. Provides a useful resource for a number of IGBP activities, drawn from more than one IGBP Core Project and Framework Activity.

5. Is established or actively developing, with a number of research sites selected, much of the research team in place, and a clearly identified transect scientist who can serve as a representative and a point of contact for the transect.

It must be stressed that the transects selected to date are a proposed initial set, not a final set, of IGBP transects. Other transects will be added to this list to the extent that they (i) meet the criteria above; and, (ii) add something significant (a new environmental factor, a new transition between biomes, or representation of a globally significant region) to the set of IGBP transects.

It should also be noted that the IGBP transects will be valuable research tools for related non-IGBP research, such as the work on the origins and maintenance of biodiversity being undertaken by *DIVERSITAS* and work on ecologically sustainable development.

Spatial Extrapolation and Modelling on IGBP Transects

Given their spatial scale (1000 km) it is impractical to conduct ground-based measurements and experiments along even a small fraction of the entire extent of an IGBP Transect. Thus, many of the measurements or observations taken along the transects will be survey-oriented, such as measurements of climate, soil types, vegetation types, soil organic matter levels, above-ground biomass, net primary productivity (NPP), etc. In addition, more intensive, process studies will be undertaken at a few sites along the transects.

There is a need to extrapolate these measurements, particularly those from the intensive process studies, to the landscape and regional scales. The strategy proposed to accomplish this extrapolation involves a hierarchy of observations, such as remote sensing data and tower and aircraft measurements, and models, ranging from patch-scale process models to landscape and regional vegetation dynamic models, and their linkage to geo-referenced databases of major climatic factors as well as the distribution, structure, and biophysical properties of the soil and vegetation. Modelling studies will provide an integrating framework for the experimental and observational studies and for predicting consequences of future land-cover change. For each process of interest, models at the patch and regional scales are required, as well as methodologies for translating between the scales.

Spatial extrapolation will require extension of ecosystem biogeochemical and surface flux process models (*e.g.*, CENTURY, TEM, CASA, SVATs, BIOME-BGC) to the landscape and regional scales by linkage to geographical databases of the major driving variables, such as climate and soils. For modelling purposes, spatial extrapolation can be considered as a stepwise process, with refinement involving iteration of the steps: 1) process-level understanding of ecosystem function is acquired (*e.g.*, root distribution - functional type relationships and their interaction with respect to an environmental variable); 2) development of simulation models that represent process-level understanding; 3) application of simulation models to geo-referenced databases to develop regional response surfaces of ecosystem structure and function; 4) validation or cross-reference to regional data derived from satellite and other observations. Extrapolation in time, requiring predictions of future vegetation distribution, will utilise vegetation dynamic and succession models (*e.g.*, FORET, ZELIG, STEPPE), projections in direct, human-driven changes to land cover (from the LUCC Core Project) and models linking land cover change with biogeochemistry (*e.g.*, the IMAGE system). Ultimately, this hierarchy of models should feed in to models of atmospheric transport and chemistry to provide the basis for examining the feedbacks to the atmosphere of global change impacts on terrestrial ecosystems.

One of the central questions to be addressed by the transect studies relates to the process of scaling itself. Is the effect of a given ecosystem property or function expressed at the regional scale simply the sum of the effects measured at a local scale, weighted by the

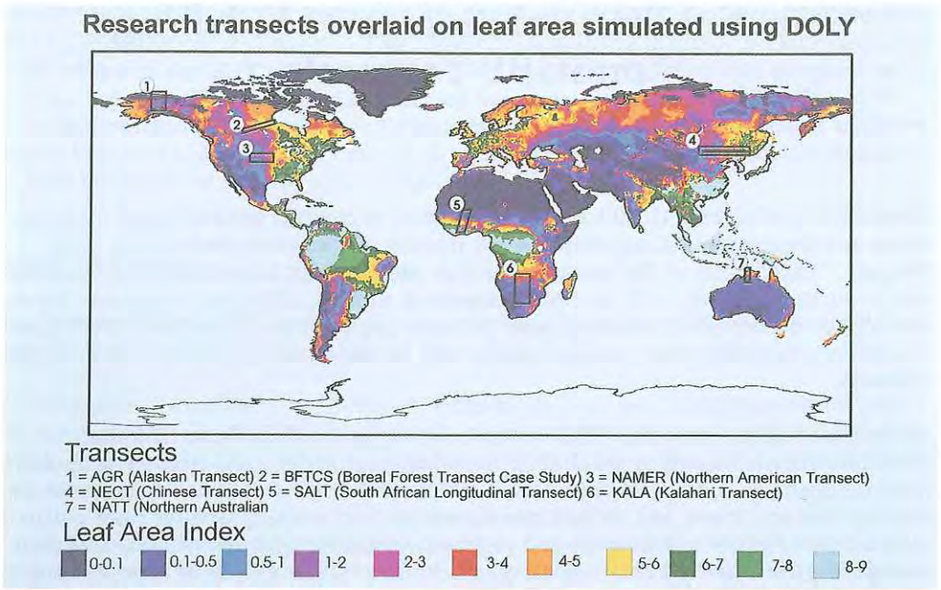


Figure 2. The global set of active IGBP Transects, including NECT (North East China Transect), No. 4. The global map depicts leaf area index (LAI) as simulated by the DOLY model (Woodward *et al.* 1995).

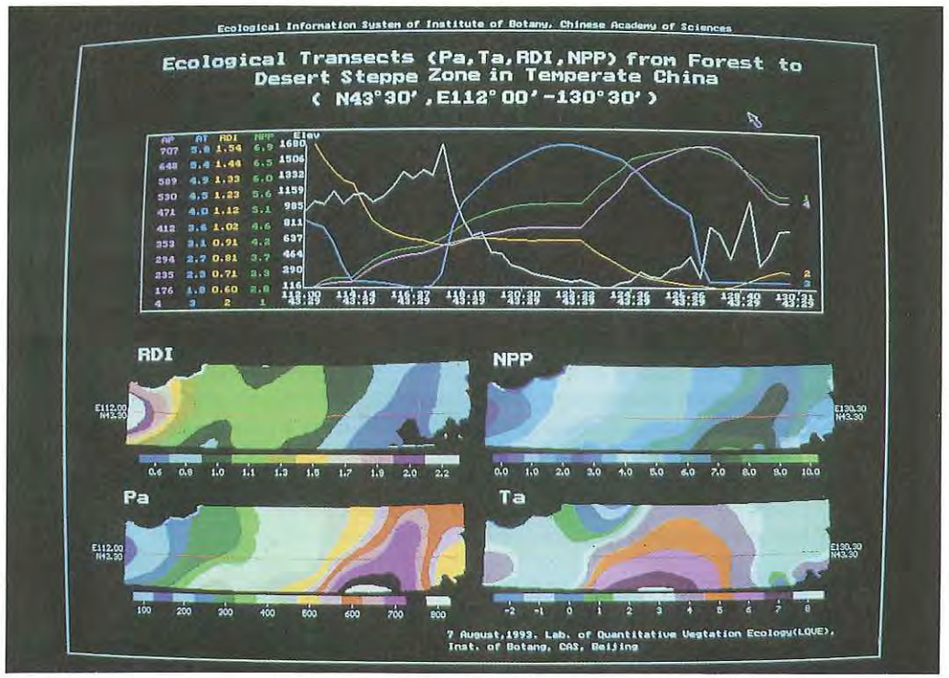


Figure 3. Maps of relative drought index, simulated NPP, precipitation and temperature along NECT.

Figure 4 and 5.

Examples of vegetation at the eastern (mixed coniferous - deciduous broad-leafed forest) and the western (steppe) ends of NECT.

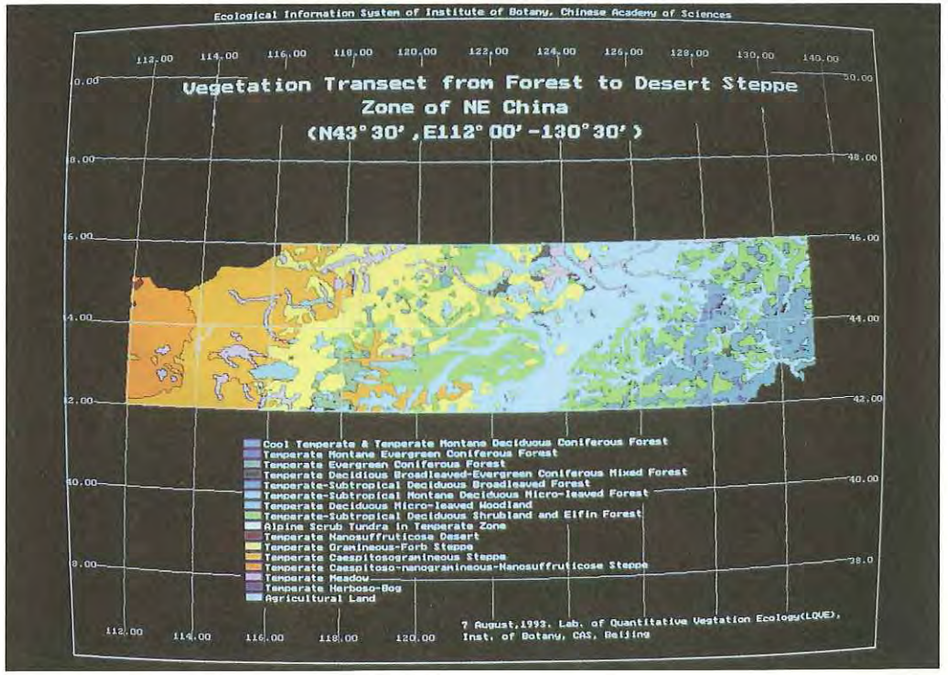


Figure 6. Vegetation types along NECT.

proportions of each ecosystem type in the region? This crucial question can only be addressed by comparing model outputs, and observations, within a nested hierarchy of scales.

Ideally patch-scale process models would be developed in conjunction with the planning of the experimental aspects of each transect study so that initial simulations could provide input to the experimental design and to data collection of key input and validation datasets. The developing network of modelling centres within GCTE's Long-term Ecological Modelling Activity (LEMA) (Steffen *et al.* 1992) may provide a mechanism for linking modelling efforts to particular transects.

Taken together, the set of IGBP Terrestrial Transects will provide valuable information on the effects of global change on land surface-atmosphere exchange, on trace gas emissions, and on ecosystem processes and structure at the global scale. Thus, they will provide data to calibrate and validate the global models under development within GAIM, and to underpin GAIM's analysis and interpretation activities. An example is the use of the transects, for which NPP and its controlling factors will be determined, as testbeds for comparison of global models which simulate NPP.

The Proposed Initial Set of IGBP Transects

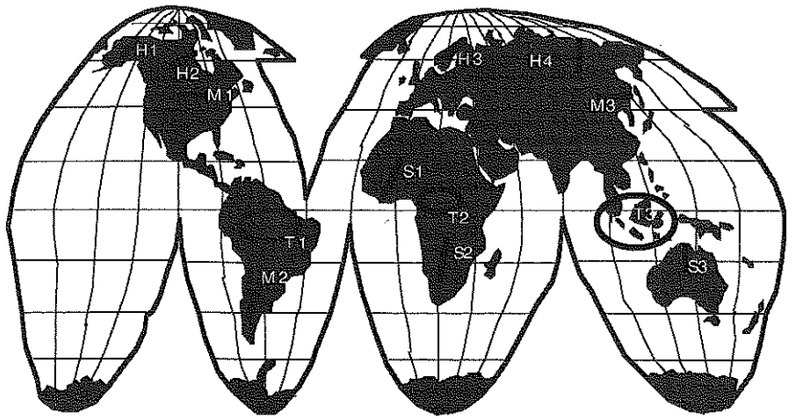
The proposed initial IGBP Terrestrial Transects are located in four key regions (Table 1), identified on the basis of their likelihood to be altered by components of global change and the strength of their potential feedbacks to global change (Steffen *et al.* 1992). These include (1) humid tropical systems undergoing land-use change, (2) high latitude regions extending from boreal forest into tundra, (3) semi-arid tropical regions from dry forest to shrublands, and, (4) mid-latitude semi-arid regions encompassing transitions from forest or shrubland to grasslands. Within each of these regions, a distribution of transects between hemispheres or continents is desirable The specific rationale and design of transect studies proposed for each of these regions are given in the following sections. Two studies in semi-arid tropical regions, the Savanna in the Long Term (SALT) and Northern Australia Terrestrial Transect (NATT) projects, are currently active and already have been accepted into the GCTE Core Research program as transect studies according to the criteria listed above. The research plans outlined for the other transects are still being developed through coordinating meetings of representatives from different IGBP Core Projects and other scientists.

Table 1. Priority regions and general characteristics of IGBP Transects.

Region	Land cover	Major global change gradient	Secondary gradients
Humid tropics	Tropical forest & its agricultural derivatives	Land use intensity	Precipitation
Semi-arid tropics	Forest-woodland-shrubland (the savannas)	Precipitation	Land use intensity Nutrient status
Mid-latitude semi-arid	Forest-grassland-shrubland	Precipitation	Land use intensity
High latitudes	Boreal forest-tundra	Temperature	Precipitation Nutrient status

The approximate geographic location of each transect discussed below is shown in Figure 2. The several transects proposed within each priority region (*e.g.*, high latitudes) are meant to encompass the major vegetation assemblages and physical characteristics found within these regions. They are clearly not replicates in the statistical sense.

The objectives of the Core Projects that can be addressed within the system of IGBP terrestrial transects are summarised in Table 2.



Humid Tropical Forests

T1 Amazon Basin

T2 Central Africa

T3 South East Asia

High Latitude

H1 Alaska

H2 BFTCS

H3 Scandinavia

H4 Siberia

Mid Latitude

M1 Great Plains

M2 Mato Grosso

M3 NECT

Semi-Arid Tropics

S1 SALT

S2 Kalahari

S3 NATT

Figure 7. The approximate locations of the proposed initial set of IGBP Terrestrial Transects. Transects along gradients of major climatic variables (temperature and precipitation) are shown by straight lines. Locations of land use intensity transects in the humid tropics are enclosed in ellipses. The individual transects are described in more detail in the text.

Table 2. Objectives of the Core Projects which can be addressed within the system of transects. The objectives have been extracted from the operational plans and have been paraphrased in the interests of brevity.

Core Project	Humid tropics	Semi-arid tropics	Mid-latitude	High latitude
BAHC	Determine the characteristics of the land surface with respect to the exchanges of water, energy and momentum at a point and regional scale; define plant functional types with respect to water and energy exchange; perform spatial and temporal integrations of water and energy fluxes, especially for data-sparse areas.			
	Determine the hydrological pathways and quantities of element fluxes associated with land cover change.			
GCTE	Effects of land clearing and agricultural intensification on quantities and pathways of carbon and nutrient loss; structure, composition and production of regrowth forest; soil erosion; and ecosystem complexity-function relationships.	Interactive effects of altered precipitation and land use (especially grazing and fire) on the biogeochemistry of semiarid tropical systems along a moisture gradient.		Interactive effects of increased temperature and changes in nutrient availability on carbon and nutrient pools and fluxes across the transition from boreal forest to tundra.
	Impacts of change in atmospheric composition and climate on agricultural systems; effects of global change on pasture and range composition and production, and consequently on livestock; effects of global change on soil organic matter.			Effects of global change on soil biology and trace gas production (with HESS)
	Quantify bulk surface conductance of major vegetation types; develop linked plant-soil models of carbon, nutrient and water interactions at patch scale; understand emissions and sequestration of CO_2 from terrestrial ecosystems; develop a general system of plant functional types; identify and quantify the mechanisms linking ecosystem structure to ecosystem function; develop landscape scale models of land cover and composition change; improve methods for predicting vegetation distribution; develop a dynamic vegetation model which can be linked to GCMs.			
IGAC	BATGE: Determine fluxes of trace gases between tropical biomes and the atmosphere; the factors that control them; and the effect of land use change on the flux.		TRAGEX: document fluxes of CO_2, CH_4, N_2O and CO from soil and determine controlling factors. MILOX: Mid-latitude oxidant study.	BIBEX[see below] HESS: Estimate trace gas emissions; the factors which control them; and their sensitivity to climate change.
	BIBEX: Characterise production of gases and aerosols from biomass burning; determine the consequences of burning for regional and global atmospheric chemistry and climate; determine the effects of fire on post-fire exchanges of trace gases; determine the biogeochemical consequences of deposition of burning products.			
LOICZ	Determine the influence of land-use change, particularly the conversion from forest to agriculture, on the delivery of sediments from land via river systems to the coastal sea.			
LUCC	Determine how land use and associated land cover are changing globally as a result of social and environmental factors.			
PAGES	Provide quantitative understanding of the Earth's past environment and definition of the envelope of natural environmental variability.			

Humid Tropical Systems Undergoing Land-Use Change

Why Transects in this Region?

The humid tropics are a high priority region for global change studies because of the significant impact of land-use change (usually the conversion of forests to agricultural use) on biogeochemical cycles, particularly the global carbon and water cycles. The impact occurs in two phases: (i) the initial clearing of the forests, the techniques of which are important in determining the short-term alterations to biogeochemical cycles, and (ii) the type and intensity of the subsequent agricultural use, which are critical in determining the longer term effects.

In addition to biogeochemistry, the conversion/intensification sequence impacts on other important, related ecosystem processes. These include the biotic control of water and energy exchange between the land surface and the atmosphere; the composition, structure and production of regrowth forests; and ecological complexity and its relationship to ecosystem function.

The use of the term "transect" here refers to a "conceptual" transect rather than a physically contiguous linear transect. The controlling parameter on which the gradient is based is intensity of land use, which is determined by social, economic and technological factors, and forms a complex spatial pattern at a regional scale.

What are the Major Questions?

In these transect studies the primary focus is on biogeochemical cycles and their alteration by different land use practices. The key questions are as follows.

- What are the effects of land clearing and subsequent land use on quantities, pathways and processes of carbon and nutrient loss (or gain)? Are fluxes of key trace gases (CO_2, CH_4, N_2O, CO, NO, VOC) differentially affected by different land use patterns? How do these processes affect the global carbon and nitrogen cycles and the oxidising capacity of the atmosphere?

- What are the land surface characteristics (albedo, roughness, bulk conductance) of vegetation types arising during different land use sequences?

- How are local, landscape, and regional hydrological cycles affected by clearing and subsequent land use?

- What are the impacts of biomass burning on regional atmospheric chemistry?

The studies will also examine the effects of land use intensity on the composition, structure and production of regrowth forests. Although studies of the impacts of clearing and subsequent land use on the complexity/function relationship are not included in the design of these transects, the transects do offer an excellent framework for their later inclusion, as well as for collaborative work on climate change impacts on tropical agriculture.

Relevance to IGBP Core Projects

Studies on land-use change in the humid tropics are important components of a number of IGBP Core Projects and framework activities. Their general objectives summarised in Table 2 are applicable in the humid tropics; in addition there are some specific interest areas. The objectives of the Core Projects with particular reference to the humid tropics are briefly summarised below.

In the case of GCTE objectives to measure nutrient fluxes, the focus is not only the gross changes associated with the conversion of forest to agriculture, but also the more subtle changes associated with changes in particular land management practices and the resultant changes in biogeochemistry. IGAC aims, on the basis of information collected in the Biomass Burning Experiment (BIBEX) and Biosphere-Atmosphere Trace Gas Exchange in the Tropics (BATGE) activities, to be able to predict impact on fluxes of changes in climate and land use, including soil physical, chemical, and microbial status, surface vegetation and atmospheric processes. BAHC's objectives are to quantify the effects of changes in the land surface on both water, energy and carbon exchange with the atmosphere and on the surface hydrological pathways and quantities of element fluxes. LOICZ is interested in how changes in land cover will affect the delivery of sediments via river systems to the coastal zone. LUCC has a role with respect to the tropical land use transects that is analogous to that of the GCMs for the environmental gradient transects; that is, LUCC will provide the scenarios for future land use patterns upon which regional extrapolation of the results from the land use intensity transects will be based. LUCC will benefit from interaction with the IGBP transects by gaining information regarding how global change may affect vegetation composition and function, and thus, suitability for and susceptibility to different land uses.

Which Transects?

Six transects are proposed, two in each of the three major humid tropical regions - Central and South America, Central Africa and Southeast Asia. In each case one study will focus on humid forests while the other will be centred on dry forests. Table 3 presents the locations of the transects, with question marks indicating locations that are only notional at this stage. The locations without question marks are areas where known existing or planned projects can form parts of a study.

Table 3. Location of proposed transects along gradients of land use intensity in the humid tropics.

Major tropical forest region	Humid forests	Dry forests
Central & South America	Amazon	Mexico
South-eastern Asia	Indonesia	Thailand (?)
Central Africa	Cameroon (?)	Miombo

Research Design

The framework for the IGBP transects in the humid tropics is based on an integration of the relevant components of the IGAC, BAHC, GCTE, and LOICZ operational plans. The transects will have five elements - (i) intensive process studies (the "budget-closing experiment") at a small number of sites in each transect; (ii) a more extensive network of observational studies along the major gradient (land-use intensity); (iii) networks of measurements and development of associated algorithms designed for scaling results to the region; (iv) remote sensing studies to determine the extent, rate and type of land conversion and subsequent land use; (v) modelling studies to synthesise and integrate the experimental results and to quantify the consequences of future land-use change scenarios.

(i) Intensive process studies

Although a number of biogeochemical studies have been carried out in the humid tropics, particularly in the Amazon Basin, there has not yet been a study which completely accounts for all the gains, losses and transformations of key chemical elements associated with the land-clearing process and subsequent management or abandonment (this is known as "closing the budget"; until the budget balances, there can be no certainty that the major processes have been addressed). Thus, the intensive process study proposed here aims to measure all major pathways of element loss and transformation, hydrologic as well as atmospheric, during and following land clearing.

The study will be based on a small watershed scale (a few km^2) and carried out over a 5-year (or longer) period to follow the biogeochemical changes associated with the conversion of primary forest to agricultural use. Both atmospheric and hydrological pathways of element loss and input will be measured, as well as changes in ecosystem pools. The pulse of initial element loss during and immediately after the clearing (which may occur with or without burning) will be measured as will the change in element fluxes with the subsequent agricultural use of the land over a 3-4 year period. In short, an intensive biogeochemical process study of the land cover conversion process itself will be undertaken.

Atmospheric measurements will include both chamber and tower-based (eddy correlation) measurements of emissions of important trace gases (*e.g.*, CO_2, CH_4, N_2O, CO), as well as measurements of atmospheric deposition (*e.g.*, N, cations, anions). Hydrological fluxes will be determined by measurement of precipitation, stream flow, sediment loads and chemistry in the watershed (Bruijnzeel 1991). Soil-plant process measurements include soil moisture and structure, litter decomposition rates, and microbial processes. The measurement regime will be carried out throughout the experimental period, before, during and after land clearing.

The land clearing technique and subsequent land use adopted for the study will be chosen to be representative of the region. The land clearing options include slash-and-burn, mechanical clearance and selective logging. For clearing techniques involving burning, measurements of fuel load and combustion coefficients will be made. Land-use type includes pasture, crop agriculture (low to high input, annual or perennial crops), plantation forestry and forest regrowth.

(ii) Extensive network

The intensive process studies will be complemented by a regional network of sites measuring element fluxes on plots of various land-use types and histories (e.g., chronosequence studies). This network will form the primary gradient for the humid tropics transects. The sites, of course, will not be physically contiguous or form a linear pattern in physical space, but will be organised by intensity of land-use to form a conceptual transect.

The network will consist of small, plot-scale sites at which a number of processes are measured. Atmospheric exchange will be monitored by standardised chamber measurements of important trace gases (NO, N_2O, CH_4, CO, CO_2). Soil measurements include soil moisture, groundwater chemistry, carbon, nitrogen and phosphorus stocks, carbon and nitrogen isotopes, microbial biomass and nitrogen mineralisation and nitrification.

At some sites, tower-based land-atmosphere energy and trace gas exchange measurements (sensible and latent heat, CO_2, HCs, O_3, CH_4, NO, NO_x, N_2O) will be made. These will be aimed at determining the biotic control on water and energy fluxes, in addition to element fluxes, from the land surface and will provide an excellent set of reliable data for the validation and improvement of land-surface models in GCMs.

At sites where agriculture has been abandoned or where the forest has been allowed to regrow directly after clearing, the species and functional type composition, structure, biomass, and leaf area index of the regrowth forest will also be determined. At some of these sites leaf-chamber measurements of NMHC, CO_2, NO_x, H_2O, CO, O_3, as well as tower-based measurements of trace gas, water and energy exchange, will be made to determine the variations with functional type in canopy exchange processes.

The following characteristics will be determined for each site: soil properties (physical, chemical, biological); land-use history; climate (precipitation (particularly seasonality), temperature, wind speed/direction, radiation); vegetation composition, structure and biomass; topography - hillslope and structure.

Considerable effort is required to coordinate and integrate the extensive site network (particularly in the Amazon Basin, where existing work may provide many of the sites needed for the network). A special effort should be made to standardise measurement techniques and data protocols so far as possible, and to identify and include those sites with long-term studies.

Modelling and Regional Extrapolation

The scaling-up of the hydrological fluxes of elements to the region will be centred on a basin-wide network of hydrological stations measuring water flow, sediment loads and water chemistry. The latter is particularly important for closing element budgets on a watershed and basin basis. Such a network already exists in the Amazon basin.

Scaling measurements of trace gas emissions from the individual sites in the transect from the patch to the landscape and regional level will be accomplished by using aircraft flights and the boundary-layer averaging technique. The latter will require some sites to include tower-based measurements of gas fluxes. The flights will include

measurements of atmospheric stability, depth of mixed layer, radiation, O_3, CO_2, H_2O, HCs, NO, N_2O, PAN, organic nitrates, NO_y, HCHO, H_2O_2, and aerosols for studying and modelling chemical transformations in the atmosphere.

Remote sensing studies will provide the extent and rate of land cover conversion in the regions. Such a study has already been completed for the Amazon Basin (Skole and Tucker 1993) and plans for similar studies in the other two humid tropical regions are well advanced. Of particular importance is the accurate determination of the type and history (if possible) of land-use for linkage to the ground-based process studies and observations. The remote sensing studies should be expanded to include estimates of canopy structure and canopy chemistry when the technology is available. Remote sensing studies may also contribute to quantifying and monitoring the regional distribution of aerosols.

Modelling studies will provide an integrating framework for the experimental and observational studies and for predicting consequences of future land-cover change. For each process, models at the patch and regional scales are required, as well as methodologies for translating between the scales. Examples of types of models that may be useful in the transect studies in general, including the humid tropics, are given in Table 4.

Table 4. Types and examples of models which could be applied within the transect studies in general. In some cases specific regional models are available.

Model capability	Example(s)	Reference(s)
Biogeochemistry of terrestrial ecosystems, particularly of C and N, but also including P, S and other elements in some cases.	CENTURY, TEM/GEM	Parton *et al.* 1993; Melillo *et al.* 1993
Water and energy exchange across the land/atmosphere interface	SVATs (such as SiB and BATS), BIOME-BGC	Xue *et al.* 1991; Dickinson *et al.* 1992; Running and Hunt 1993
Ecosystem production models	MAESTRO, BIOMASS	Jarvis 1993; McMurtrie *et al.* 1990
Succession models	FORET, ZELIG	Shugart 1984; Smith and Urban 1988
Two-dimensional atmospheric chemistry and transport models for trace gases		
Land use and biogeochemistry	IMAGE system	Alcamo 1994

Coordination and Integration

Coordination within IGBP is provided mainly by the BAHC-IGAC-GCTE Task Team; its activities are described in more detail later in the report. On the Amazonian transect the Task Team is working with NASA and various Brazilian scientific research agencies, which are playing leading roles in coordinating the various component studies planned or proposed for the Amazon to create a single, integrated project. Three large studies - LAMBADA (water and energy exchange), BATERISTA (biogeochemistry), and AMBIACE (biogeochemistry; ecology) - are now coalescing under NASA's guidance into a single framework. The integrated LBA project is expected to meet IGBP's needs in the Amazon.

Initial activities associated with the Southeast Asian transect will be coordinated jointly by GCTE, LUCC, IGAC, IGBP-DIS and the Southeast Asian Regional Committee for START (SARCS).

Links to other Programs

Alternatives to Slash and Burn - This large, pan-tropical project, under the leadership of the International Centre for Research in Agroforestry (ICRAF), aims to develop alternative strategies to slash-and-burn agriculture. One of its objectives is to determine the impacts on greenhouse gas emissions of various agricultural practices. It could provide some sites for the gradient in intensity of agricultural land use, and the products from the IGBP study will help Alternatives to Slash and Burn meet its gas emission-related objective.

Timetable

A phased approach is appropriate for the development of the IGBP humid tropics transects. Initial attention will be focused on Central/South America, particularly the Amazon Basin, as planning is most advanced for that study. The general order of implementation will be (i) Amazon, (ii) Southeast Asia, (iii) Central Africa.

1995 GCTE-IAI Symposium, Buenos Aires (session on Amazon study)

1995 LBA ecology planning meeting, Manaus, Brazil

1996 LBA final science planning meeting, Brasilia, Brazil

1996 Initial workshop for Southeast Asian study, Bogor, Indonesia

1996 Work begins on integrated Amazon study

Semi-Arid Tropical Systems

Why Transects in this Region?

The major environmental gradient determining ecosystem structure and function in the semi-arid tropics is aridity. This gradient is strong and relatively unconfounded by factors such as past glaciation (Justice, Scholes and Frost 1994). The semi-arid tropics occupy about one fifth of the global land surface, and include a large fraction of the rapidly-growing population of the developing world and a large proportion of the global domestic livestock herd. Although the carbon density is not high, the large extent of these lands makes them a significant carbon pool (about 134 Pg C) and contributor to global NPP (7.6 Pg C yr-1) (Scholes and Hall 1995).

Since the semi-arid tropics span the Intertropical Convergence Zone, small changes in global circulation systems could translate into substantial climate shifts on the ground. They also span the transition from the wooded ecosystems of the humid tropics to the grass- and shrub-based ecosystems of the subtropical deserts. This transition is associated with large differences in carbon storage, both as woody biomass and in the soil. The savannas which occupy this region have the potential to be globally significant carbon sinks or carbon sources, depending on the direction of climate change (particularly with respect to precipitation), and in response to land use changes such as alteration in the fire regime or the expansion of crop agriculture.

The proportion of trees and grasses in the savannas of the semi-arid tropics is highly dynamic, and will be strongly influenced by changes in the distribution and intensity of rainfall, atmospheric CO_2 concentration, and grazing pressure. The seasonally dry climate makes the savannas of the semi-arid tropics the major global location of biomass burning (Andreae 1991), with globally significant effects on trace gas emissions and the atmospheric aerosol composition. The frequency of fire is under both climatic and land-use control.

What are the Major Questions?

- How do changes in the water balance and land use (especially fire and herbivory), coupled with soil type, interact to determine ecosystem carbon stocks and fluxes and their stability, and vegetation composition and structure?

  How do key plant traits or functional attributes, for example, roots (physiology, symbiosis, architecture) and leaves (size, structure) change along the gradient in moisture availability?

- How do the distribution limits and biomass density of woody plants and grasses relate to climate and land use, and how might they change under increasing CO_2 and changing climate and land use?

- How do the carbon and nitrogen cycles change along the moisture gradient to determine the palatability, digestibility and decomposition rate of plant parts, and how might this interaction be altered by global change?

- What is the strength and importance of atmospheric feedbacks from savannas to the global atmosphere via pyrogenic and biogenic emissions of CH_4, CO, NO_x, non-methane hydrocarbons and aerosol particles?

- How do emissions of VOC, NO and O_3 vary along the gradient as woody to herbaceous mixtures change?

Relevance to IGBP Core Projects

BAHC objectives as outlined in Table 2 are applicable to the semi-arid tropics. Of particular importance in these water-limited systems is the partitioning of energy between latent and sensible heat. IGAC interest in the semi-arid tropics relates to the trace gas exchange and biomass burning studies described in the BATGE and BIBEX Activities (cf. Table 2). GCTE has activities in ecosystem biogeochemistry (Activity 1.2), ecosystem structure (Activities 2.1, 2.2, and 2.3) and rangeland pastoral systems (Task 3.1.3) which are directly focused on the key questions above. The semi-arid tropics are an area of increasingly rapid land-use and land-cover change, making them an area of interest to LUCC.

Which Transects?

Three transects along tropical aridity gradients have been proposed. These are the Northern Australia Tropical Transect (NATT), the Savannas in the Long Term (SALT) transect in West Africa, and the Kalahari Transect in southern Africa. Two of these, NATT and SALT, are established and have already been accepted as GCTE Core Research.

The NATT is a transect through the northern end of the Northern Territory of Australia. It is approximately 1000 km long, from the coastal Darwin region (ca. 12°S) south to the inland region north-west of Tennant Creek (ca. 19°S). Rainfall varies from ca. 1600 mm in the northern, coastal regions to less than 500 mm in the inland south. Soils are patchy, with sands, loams and clays occurring in each major biogeographic region of the transect. Vegetation varies from open forest in the humid north to open woodland and tall shrubland in the arid south. The intensity of fire and grazing is variable throughout.

The SALT transect traverses West Africa, from the coast of Côte d'Ivoire inland to Mali. It covers a rainfall gradient from 1500 mm to 200 mm per annum, and several major vegetation belts, including the Guinean and Sahelian savannas. A perpendicular axis of continentality extends from Senegal to Chad.

The Kalahari transect follows a SSW-NNE rainfall gradient, from ca. 150 mm at 27°S in South Africa to ca. 1000 mm at 13°S in Zambia. The soils are sandy, very deep and comparatively uniform over the whole transect, since it falls entirely within the Kalahari sand basin. Vegetation varies from open low shrub savanna in the south, through several types of woodland to evergreen tropical forest in the north.

Additional potential transects include the cerrado-caatinga transition in Brazil, and savannas in India and Thailand. While these regions raise some interesting and unique problems, and should not be ignored, the first priority should be to ensure that the three existing or proposed transects are functioning well.

Research Design

The proposed and existing transects are all linear and continuous in physical space, rather than being conceptual transects in environment space. The research design consists of two types of site: (i) a small number (perhaps five per transect) of permanent 'intensive' study sites, and (ii) a larger number of periodically-visited 'extensive' sites to encompass the range of variation in soils, topography, vegetation and land use which exists under a single climate. The purpose of the intensive sites is to conduct process studies leading to model development, while the extensive sites serve mostly for model validation. The transects also include a series of more-or-less temporary opportunistic sample points in between these sites. The areal interpolation of models will make use of remotely sensed data, soil and vegetation maps, and regional climatologies. The duration of the studies is initially five years, but a decade or more is desirable.

Table 5 lists the types of parameters which are proposed for collection on the semi-arid tropical transects.

Modelling and Regional Extrapolation

Mechanistic models are to be used as far as possible to integrate the data for individual sites and to provide an instrument for regional extrapolation. Where the mechanisms are not clearly understood, correlative models will also be used. Remotely sensed data can be used both as an input to the extrapolation models and for validation purposes, provided that considerations of data independence are observed. Since the major axes of variation in climate, soil and land use within tropical savanna regions are accounted for by the proposed transects in Africa and Australia, a robust platform will exist for extrapolation to the savannas of the world. Assessment of the impacts of global change on savanna ecosystems at the global scale requires the development and adoption of a system of plant functional types (PFTs), since only a small portion of the total savanna biota will have been sampled on the transects. Global model validation could be performed using data from independent sites (not necessarily in a transect configuration) in Brazil and India.

Coordination and Integration

The proposed savanna transects are similar in basic biogeography, focused on similar problems, and encompass a representative range of savanna conditions. The research group working on savannas is relatively small, and informal communication will achieve most research needs. Two priorities are the development of a catalogue of PFTs and a common modelling approach. A core set of biotic and abiotic variables must be specified. For this exercise the priorities are specification of parameters and their resolution, rather than specific methods.

Table 5. The types of parameters which are proposed for collection on the semi-arid tropical transects. Similar parameter sets are likely to be targeted on other transects, modified to reflect key features of the region.

Tropical Area	Intensive Sites	Extensive Sites	Remote sensing, regional data & modelling
Composition and structure	Biomass, LAI, basal area, cover by species, populations of marked individuals, mycorrhizal community	Cover by dominant species, landscape pattern	Vegetation maps and characteristics, high and low spatial resolution satellite data
Production	Seasonal trend of grass and fine root biomass, litterfall, stem increment, tower CO_2 fluxes	Peak standing crop, soil carbon	Regional photosynthetic efficiency models
Phenology	Weekly observations	High temporal resolution satellite data	
Water balance	Tower studies of vertical fluxes of energy, water and momentum, soil water content, depth to water table, rooting depth	Nearest weather station data interpolated	Regional climate surfaces, topographic data
Trace gases	Chamber or tower measurements of NO, N_2O, CH_4, leaf measurements of NMHC, fire emission factors	In-lab gas fluxes	Satellite fire monitoring, regional emissions, chemistry and transport models
Biogeochemistry	Soil total C, N & P and selected isotopes, mineralisation rates, leaching losses, wet and dry deposition	Soil total C, N & P and selected isotopes, in-lab mineralisation	Maps of soil attributes, topographic data
Decomposition	Litterbag mass loss, soil respiration, leaf lignin and tannins	Litter standing crop and chemistry	Regional decomposition model
Disturbance and land use	Record of herbivory (including insect outbreaks) and fires, annual-triennial TM coverage	Land cover mapping, livestock census	Satellite land cover classification and change detection, fire mapping

The requirements from IGBP relate mostly to the availability of remotely sensed data. The need is for scaled, matched series of images at appropriate (but not necessarily constant) times of the year. AVHRR data are seen as a priority for within and between transect comparison, and higher resolution data (TM, SPOT or similar) for land cover assessment on the transects.

Timetable

1996 All three transects operational

1996 Shared sample and data protocols among the transects

1997 Specifications for joint models

1998 Data intercomparison and modelling workshop

Mid Latitude Semi-Arid Systems

Why Transects in this Region?

Transects from temperate semi-arid to sub-humid areas represent gradients of water availability (precipitation and potential evapotranspiration) over a range in which ecosystems are particularly responsive. The vegetation along such transects typically changes from grasslands and shrublands at the dry end to forests at the wet end. The exception to this is in Argentina, where grasslands dominate across the range of environmental conditions even at the wet end. This lack of forests in the Pampas region has attracted comment from plant geographers and ecologists for many years without resolution. Studies of comparable transects on three continents may help resolve this problem.

An important feature of the ecosystems that occur along these mid-latitude transects is that the location and size of the major stores of carbon change over the gradient. Carbon stores increase from the dry to the wet end and the location of the largest pool changes from below-ground in grasslands to above-ground in forests. The vulnerability of these carbon pools to disturbances and to global change, and the regional and global consequences of perturbing them, will be different depending upon the specific location on the transect. Preliminary simulation studies in the U.S. have suggested that the major carbon pool in grasslands (soil organic matter) is more vulnerable to land-use modification than to climate change. Transect studies will help to evaluate the generality of this result for other continents.

Changes in temperature and precipitation as a result of climate change are likely to alter water availability, so those sites located in sensitive areas will provide a great deal of information about responses to global change. Drought is a common occurrence in these regions. Despite the importance of drought in the evolutionary history of the organisms and the developmental history of the ecosystems, droughts in this century in the U.S. have interacted strongly with land use and their deleterious effects have been magnified. Regions represented by such transects cover a large proportion of the earth's surface, and these mid-latitude regions are predicted to have significant changes in climate. If climate change increases or decreases the frequency and intensity of droughts, for example, there will likely be important changes in ecosystem structure and function.

These mid-latitude semi-arid regions have a pronounced gradient in land-use management practices, and are managed intensively for rangeland, crops, and forest products. The three transects (U.S., Argentina, and China) differ in the intensity of current land-use practices as well as in future patterns of exploitation. These transects will facilitate the study of the interactions between environment and land use under current and future conditions. They include gradients in C_3 and C_4 species composition, which may change significantly due to different responses to enhanced CO_2.

What are the Major Questions?

A general question that will guide this work, as well as the work in other regions of the globe, is "how does water availability influence the composition of plant functional types, soil organic matter, net primary production, trace gas flux, and land-use distribution?" Comparisons across transects will allow the generality of ecological relationships to be tested, both within and between climatic regions.

Specific questions to be addressed on the mid-latitude transects are:

- How does rainfall amount and distribution affect the mixture of PFTs that inhabit the three transects?
- What are the key interactions between climate, soil type, PFTs and ecosystem processes, such as trace gas emissions?
- How are equilibrium patterns in soil organic matter and nutrient dynamics influenced by patterns in PFTs?
- How do patterns in soil organic matter and nutrient dynamics change through time in response to changes in vegetation?
- Are root distributions characteristic of particular PFTs a key determinant of vegetation structure along a spatial gradient in water availability?
- Is net primary production mainly controlled by precipitation and decomposition by temperature?
- Will regions of feasibility/sustainability of crop production change under global change? Where are the most sensitive areas to changes in climate, land use, or CO_2?
- Specifically, are the grass/shrub and grass/forest boundaries the locations most susceptible to rapid change?
- What is the relative importance of demographic versus metabolic controls in determining the response of mid-latitude systems to global change?
- Will transects with a mix of C_3 and C_4 species show a larger change in species composition as a result of increases in CO_2 than those exclusively dominated by C_3 or C_4 species?

Relevance to IGBP Core Projects

The general Core Project interest areas outlined in Table 2 are relevant to the mid-latitude transects. In addition, two IGAC Activities are of special interest in the mid-latitudes:

TRAGEX is focused on the exchange of trace gases in the mid-latitudes. It has the following objectives:

- To document contemporary fluxes of CO_2, CH_4, N_2O, and CO between the soil and the atmosphere.

- To determine the factors controlling these fluxes and improve our ability to predict future fluxes.

A developing IGAC Activity on Mid-Latitude Oxidants (MILOX) has a number of objectives related to assessing the sources and sinks for, and magnitude of the impacts of, atmospheric oxidants (and related compounds) in mid-latitude ecosystems, including agricultural and forested systems. The proposed locations for IGAC studies in the mid-latitudes coincide in many cases with those of the transects described below and initial interactions between IGAC and other Core Projects have already begun.

Which Transects?

Three transects have been proposed. The Great Plains transect would build on an existing network of Long-Term Ecological Research sites and field agricultural research stations located in the U.S. and Canada. There is a strong east-west moisture gradient, and north-south temperature gradient. The natural vegetation consists of short-grass prairie in the west, through tall-grass prairie to deciduous broad-leafed forest in the east. A high proportion of the landscape is now covered with cereal crops, principally maize and wheat.

The China Ecological Research Network consists of 22 existing sites, of which a subset falls along an aridity gradient from the short-grass Mongolian steppe to the intensive agricultural systems and remnant broad-leafed forests of the coastal plain and Changbai Mountain. These sites have been linked to form the North East China Transect (NECT).

The proposed Pampas transect would extend from Patagonia northwards, within Argentina. The natural vegetation is dominated by grasses throughout, with large-scale cereal farming at the moist end of the gradient.

Research Design

Sites should be located along carefully chosen transects for the purpose of (i) characterising gradients in representative ecosystem types, *e.g.*, short-grass steppe, tall-grass prairie, deciduous forests; (ii) monitoring change in especially sensitive locations along the transect, i.e. locations in which the environmental gradients are steep or are effecting significant transitions in ecosystem structure. For these transects, such areas will be located particularly at boundaries in vegetation structure or major changes in PFT composition or land use; (iii) taking advantage of existing long-term datasets.

All sites should be monitored for a set of mutually agreed variables representing ecosystem structure and function. The first planned workshop for the transect scientists will have this as a major agenda item. These should include, but not be

limited to: soil water content, net primary production, decomposition, soil organic matter, species composition, CH_4 and N_2O fluxes, and nutrient availability.

It is suggested that these and other measurements be made using a "SWAT" team approach, in which teams of scientists move from site to site. This approach would have the advantage of ensuring consistency and expertise for comparisons within transects. Consistency among transects will be achieved by frequent exchange of information and a series of workshops each of which includes a portion of the agenda devoted to standard methods.

A minimum set of experiments should be initiated at a select set of sites on each transect. Reciprocal transplant experiments are especially appropriate for assessing interaction between PFTs, soil organic matter, and decomposition, as they vary across environmental gradients. For example, plants from one end of the environmental gradient should be transplanted to the other locations, and litter bags exchanged among a number of locations along the gradients.

Modelling and Regional Extrapolation

Sensitivity analyses of existing models should be conducted to specifically address questions of sensitivity to environmental change, land-use change, and interactions between PFTs and biogeochemistry. These modelling exercises will use data from the reciprocal transplant experiments for validation, and will simulate future effects based on global change scenarios. They will include dynamic models of plant communities, ecosystem function, and soil water dynamics. In addition to relying on existing models, development should continue on multiple life-form models that link vegetation structure and ecosystem processes. These models represent the tools required to capture the new information coming out of transect studies and to make it relevant to surrounding regions. Further, models that can take information coming out of the transects and generalise it to continental and global scales must also be developed as part of the studies.

Application of models to regional databases will be conducted to (i) test models under current conditions, and (ii) to simulate regional effects of climate change, and develop large-scale estimates of carbon budgets and PFT changes. The process of extrapolation is well tested on the Great Plains transect (U.S.). It requires four steps. First, process-level research must be conducted to develop an understanding of how ecosystems function, for example, research on root distributions of major PFTs and the interactions of those PFTs and water availability. Second, simulation models must be developed that represent our current understanding of processes. Next, those simulation models must be applied to geo-referenced databases using a geographic information system to simulate regional patterns in ecosystem structure and function. In addition, the models must be validated at each scale by comparison to experimental results or observations.

Coordination and Integration

A series of workshops is planned to develop comparable methodologies for experiments and field studies, and to discuss results and modelling outcomes. The first of the workshops will be held in the United States in 1996. This workshop will focus

mainly on organisational issues including site location, experiments, and methods. A second workshop will be held in China in 1997. This workshop will continue the discussions of experimental design and methods and take up the special issue of ecosystem restoration that is most important on the China transect. The final workshop in the initial series will be held in Argentina in 1998. It will have as its major agenda item discussion of initial results and inter-transect comparison.

Timetable

1996 Workshop on site locations, experiments and methods

1997 Ecosystem restoration workshop

1998 Inter-transect comparison workshop

High Latitude Systems

Why Transects in this Region?

High-latitude terrestrial ecosystems occupy some 25% of the Earth's land area, and according to recent estimates, harbour 800-900 Gt of carbon - perhaps 33% of the global terrestrial ecosystem total (Gorham 1991; Apps *et al.* 1993). These ecosystems generally appear to be quite sensitive to changes in climate, with responses observable at all levels of organisation, i.e. in vegetation ecophysiology, in soil and wetland processes, in community-level dynamics (seeding, competition and succession) and in the frequency and intensity of disturbances (particularly fire and insect infestations) (*e.g.*, Bonan *et al.* 1990; Clark 1990; Kurz *et al.* 1992). This sensitivity has lead biogeographers to suggest that if climate warming occurs as predicted by general circulation models, then these processes combined will tend to cause existing northern high-latitude vegetation to be replaced by vegetation similar to that currently found under warmer climates further south (*e.g.*, Prentice *et al.* 1992). Major changes in the distributions of existing vegetation would inevitably lead to significant effects on the functional characteristics of these ecosystems, both locally and regionally, and hence could be of considerable socio-economic impact.

In particular, although the circumpolar tundra and boreal biomes currently function as a major terrestrial sink for atmospheric CO_2 (*e.g.*, Apps *et al.* 1993), it is feared that anticipated global changes (i.e. climate warming and land-cover conversions, including deforestation) may result in accelerated releases of store carbon (*e.g.*, Oechel *et al.* 1993). This could cause them to become net sources of CO_2 within the next 50-100 years, hence accelerating the greenhouse warming. Conversely, recent research has suggested that elevated temperatures may increase rates of nitrogen mineralisation (as well as soil respiration) resulting in increased carbon storage in vegetation on tundra sites where nutrients are currently immobilised (Shaver *et al.* 1992). Another study indicates that large-scale disappearance of existing boreal forest would cause surface albedo and roughness to alter - possibly even causing significant cooling of the global climate (Bonan *et al.* 1992).

Given that these issues are of global importance, an integrated research programme is urgently required to enhance our understanding of the functioning of these high-latitude ecosystems - an essential first step in predicting the responses to global change, assessing possible impacts, and implementing appropriate management strategies. Both field experiments and models are essential components of such a programme. Carefully selected large-scale transects present an effective means of increasing our understanding of how carbon and energy balances of northern ecosystems vary along environmental gradients (*e.g.*, temperature, soil moisture, nutrient availability and land-use intensity). Observations of variations in biotic composition along these gradients will also provide insight into how individual species or Functional Types (FTs) respond, adapt or even contribute to environmental changes (*e.g.*, effects of insects on vegetation dynamics; interactions of tussock-forming plants with soil processes; influence of beaver populations on wetland dynamics). The objectives of such studies are both to establish the important ecological processes that govern high-latitude vegetation dynamics and to use variations along spatial gradients as analogues for possible long-term consequences of perturbations, especially global change.

What are the Major Questions?

- How do gradients of temperature, soil moisture and land use affect biotic processes, such as growth, decomposition and competition, which define biome boundaries? How stable are the boundaries of the high-latitude biomes under current and possible future climates?

- Are high-latitude ecosystems currently sinks or sources of atmospheric carbon? What gradients (temperature, soil moisture, nutrients, biota etc.) are most important in affecting the carbon balance? How does net carbon balance vary along a gradient?

- How will land-use change and/or climate-induced changes in disturbance regimes (*e.g.*, fire, insect attacks) affect ecosystem carbon balance and surface characteristics (albedo, roughness, bulk stomatal conductance)? How will such changes influence surface energy balances?

- What are the likely socio-economic effects (local, regional and global) of anticipated global change on high-latitude ecosystems?

Relevance to IGBP Core Projects

GCTE's major objectives with respect to high-latitude regions are (i) to determine the interactive effects of increased temperature and changes in nutrient availability on carbon and nutrient pools and fluxes across the transition from boreal forest to tundra, and (ii) to determine how changes in resource availability under global change affects, and is affected by, species composition. In addition to its general interest in biotic control of land surface-atmosphere exchange, BAHC will focus on the effects of changing snow cover and permafrost regime on water and energy exchange, on trace gas emissions (with IGAC), and on ecosystem structure and function (with GCTE). IGAC's HESS (High Latitude Ecosystems as Sources and Sinks of Trace Gases) Activity has as its objective the understanding of the controls of trace gas fluxes by soil, vegetation and climatic factors in high-latitude ecosystems. LUCC will also play a key role in studying and projecting land-use and -cover change, an issue of particular importance for the Siberian transect.

Which Transects?

The proposed set of high latitude transects is given in Table 6. Note that the Canadian transect, which is active, and the proposed Siberian transect can be paired as having continental climates, while the Alaskan and Scandinavian transects have more maritime climates.

The two North American transects are developing rapidly; the Arctic Flux Study, accepted as GCTE Core Research, provides the backbone for the Alaskan transect, while the Boreal Forest Transect Case Study (BFTCS) (Price and Apps 1995; Halliwell *et al.* 1995) in Canada is already active and providing valuable information on boreal forest response to global change. The latter incorporates the BOREAS land-surface

experiment (Boreal Ecosystems Atmosphere Study). Sufficient relevant research and established sites exist in Scandinavia and Northern Europe, but a concerted effort is required to coordinate them to form a transect study.

A prospectus for an IGBP Northern Eurasian Study was developed at a BAHC-IGAC-GCTE workshop in late 1994. The Study is centred on the interaction between global change and the regional carbon cycle, and is comprised of a number of components stretching across the Northern Eurasian region. One important component is a north-south transect in eastern Siberian, which will include sites in tundra, larch forest and the tundra-larch transition zone. That transect will be designed to be compatible with the Alaskan, Canadian (BFTCS) and Scandinavian transects, and will thus provide the Siberian component of the IGBP high latitude set.

Table 6. Approximate locations of the high-latitude transects.

Transect	Towns nearest transect extremities	Biomes included
Alaska	N: Prudhoe Bay S: Fairbanks	Tundra, boreal and tundra-boreal transition
Canada (BFTCS)	N: Gillam, Manitoba S: Batoche, Saskatchewan	Boreal, tundra-boreal transition, and boreal-grassland transition
Scandinavia/ N. Europe	N: Abisko, Sweden/ Kevo, Finland S: Undecided	Tundra, boreal and tundra-boreal transition
Siberia	N: Undecided S: Undecided	Tundra, boreal larch forest, tundra-boreal transition

Research Design

At individual transect sites, studies will be carried out to investigate the interacting effects of temperature, nutrient availability, soil water, elevated CO_2 concentration and land use on species composition, growth forms and ecosystem dynamics. Models of nutrient cycling and ecophysiological responses (perhaps grouped by FTs) will be developed. At the large scale, the boreal and tundra biomes appear relatively homogeneous compared to other biomes considered in the proposed IGBP set of transects. Hence extrapolation from the landscape scale upwards should be relatively straightforward. At the patch scale, however, site heterogeneity and ecosystem disturbances are important characteristics determining patch-level dynamics; hence valid scaling from patch to landscape is likely to be problematic. Innovative approaches for tackling these problems, such as those employed by the BFTCS, including the BOREAS campaign in Canada, and the Arctic Flux Study in Alaska, are under development or are being implemented. These will benefit from comparisons conducted among all transects in the high-latitude set.

Modelling and Regional Extrapolation

Several candidate ecosystem-level models are available which could be parameterised using response surfaces developed at the level of FTs or individual species (see Table 4). Models will be exchanged freely among transect research groups to allow comparisons among transect areas within the high-latitude set. Large-scale extrapolations (spatial and temporal) will make use of data derived from remote sensing studies and from GCM simulations. In particular, simulations of biome-scale dynamics will be validated against large-scale remote sensing data.

Coordination and Integration

Each transect is expected to have an informal association of researchers and support staff. Contact people will be responsible for maintaining communications with other groups. Gaps in knowledge will be identified, and attention devoted to filling these gaps as far as possible (*e.g.*, larch ecophysiology and ecosystem dynamics in Siberian larch boreal forest). Each group will take a coordinating role in some aspects of the transect studies. Based on current expertise and resources, an initial outline of these roles is suggested in Table 7.

Table 7. Provisional allocation of subject area coordination responsibilities of high-latitude transect studies.

Transect	Coordinating role
Alaska	Tundra and boreal ecosystems, succession and biogeochemistry.
Canada (BFTCS)	Boreal, boreal-tundra and boreal-grassland transition zone ecosystems. Large-scale vegetation/climate interactions. C budget assessments.
Scandinavia/ N. Europe	Ecophysiology of tree FTs (pines, spruces). Measurement techniques and fine-scale environmental responses.
Siberia	Tundra, boreal larch, and boreal-tundra transition zone ecosystems. Larch FT ecophysiology.

A centralised data and information system should be established as a repository of experimental findings and for making them easily accessible to all transect participants. The specifications for a minimum data set need to be established. Any survey data currently available for the transect areas, *e.g.*, from forest inventories, soils maps, surface hydrology studies, land classification assessments, etc., should be located, and information on availability and access included in the data and information system. Remote sensing coverage required includes coarse and high spatial resolution data as well as coverage from the emerging microwave sensors. Simulating transect-scale responses to anticipated climate change will require GCM output data, preferably

down-scaled for better spatial and temporal resolution. IGBP-DIS will be asked to help with the acquisition of large-scale data and with the establishment of an appropriate data and information system.

Timetable

1996 Publication of prospectus for IGBP Northern Eurasia Study

1996 Synthesis and integration of existing Alaskan and Canadian research of relevance to the transect approach.

1997 Preliminary sensitivity studies for IGBP Northern Eurasian Study; establishment of Siberian transect

1997 Coordination of existing Scandinavian and Northern European research into a transect

Other Transects

In addition to the proposed transects described above, it is expected that other types of transects will contribute to the overall effort to understand global change effects. In some cases, studies designed with a more limited scope may become incorporated into future IGBP transects. For example, the European study NIPHYS (Nitrogen Physiology of Forest Plants and Soils), already a part of the GCTE Core Research Programme, is examining soil nitrogen transformations, atmospheric nitrogen deposition, and their interactions and consequences for broad-leaved and coniferous trees over a broad North-South climatic range through Europe. Although not a transect in the sense of being a contiguous set of sites connected by relatively undisturbed natural landscapes, NIPHYS is nonetheless addressing questions that are very important for the overall analysis of global change effects on terrestrial ecosystems and it may form the backbone of a high latitude transect extending into Scandinavia.

A second class of studies that will complement the large-scale terrestrial transects are those along altitudinal gradients. The similarity of climatic controls on vegetation zonation with latitude and altitude has long been recognised. Altitudinal transects typically encompass steep gradients of multiple environmental factors including temperature, moisture, CO_2 and UV-B levels, and thus do not meet the criteria of an IGBP terrestrial transect in terms of being dominated by a single factor gradient. They will be very important in their own right for understanding local interactions among multiple components of global change as well as for understanding global change impacts on ecological complexity. The latter issue may be particularly important where climatic zones become compressed or expanded around high elevation "islands". The Terrestrial Ecosystems in Monsoon Asia (TEMA) project (already a GCTE Core Research contributing project in the area of vegetation modelling) includes a set of altitudinal gradients arranged along a broad latitudinal range in eastern Asia. TEMA may provide the foundation for a focused study examining global change effects among a set of local altitudinal transects which are distributed across a broad regional background of climate and potential climate change.

GCTE and BAHC are developing a collaborative project on global change and mountainous regions, focused on linked altitudinal gradient/catchment hydrology studies.

Implementation and Organisation of the IGBP Transects

An Interaction Task Team involving Scientific Steering Committee members and officers from BAHC, IGAC and GCTE was formed in January 1994 to improve coordination of studies on hydrological and biogeochemical exchanges in terrestrial ecosystems. The set of IGBP Terrestrial Transects described in this report has provided a strong basis on which to build collaboration among the three Core Projects.

As a first step, the Task Team has identified the relevant studies within each Core Project that could contribute to a more integrated effort. Table 8 shows the various terrestrial-based studies within the Core Projects and how they relate to one another. It should be noted that BAHC has other interests in the transects in addition to the land-surface experiments (LSEs) themselves. In particular, BAHC Focus 1 will benefit from longer-term studies of water and energy exchange at the individual sites along the transects.

The Task Team has noted the difficulties in collaboration among the hydrological, atmospheric chemical and ecological studies in the past due to the different time (and often spatial) scales of the studies. The LSEs, and to a certain extent the IGAC activities, have tended to be concentrated field campaigns carried out in short time spans at one or two sites. The ecological studies, on the other hand, require a number of sites distributed along an environmental gradient (of order 1,000 km) operating over multi-year or even decadal time scales. This mismatch of scales has too often vitiated collaboration in the past.

IGBP could play an important role in improving collaboration and coordination by ensuring that the LSEs are carried out at one or more sites along the IGBP transects. The LSEs would benefit from more extensive background understanding of the ecology of the system (thus extending the applicability of their results in time and space), and the ecological studies would be enhanced by detailed, fine-scale experiments of important processes at one or more of their sites. The transects also provide the framework for the scaling up of models of various types and for the linkage of remote sensing data to the ground-based studies.

Specific ways in which IGBP could facilitate collaboration on terrestrial process studies include: (i) developing transects to incorporate sites of past LSEs, or adding value to past LSEs through ecological studies on ongoing transects, (ii) assisting the development of projects in the planning phase to achieve better collaboration; and (iii) taking the lead in developing the science plans for new terrestrial process studies.
An example of each type of collaboration is given below.

Savannas in the Long Term (SALT)
SALT is an active programme based on an integrated study of the linkages between the mechanisms of energy and matter flows and of species and vegetation dynamics in the West African savannas region. Significant added value may be realised by combining

the results of this ongoing effort with those from past BAHC-relevant (HAPEX-SAHEL) and IGAC (DECAFE) field studies that have been conducted in the same region of West Africa.

Table 8. Selected established or planned process studies and land-surface experiments (LSEs) in terrestrial environments and their relationship to IGBP Core Projects. (Adapted from report of first BAHC-IGAC-GCTE Interaction Task Team meeting.)

Region	BAHC-relevant (LSE) studies (hydrology)	IGAC campaigns (trace gas emissions; biomass burning)	GCTE studies (biogeochemistry)
Humid Tropics	LBA	LBA BIBEX (STARE) BATGE (EXPRESSO)	Amazon (LBA) Southeast Asia Central Africa
Semi-arid Tropics	HAPEX-SAHEL	BATGE (DECAFE) BIBEX (SAFARI)	SALT NATT Kalahari
Mid Latitude	FIFE EFEDA	TRAGEX (TRAGNET) TRAGEX (Europe) MILOX	U.S. Great Plains Central China Argentina
High Latitude	BOREAS IGBP Northern Eurasia Study	HESS BIBEX IGBP Northern Eurasia Study	Alaska Canada Scandinavia/N Europe Siberia (IGBP Northern Eurasia Study

Amazon Transect
Planning is advancing rapidly for a coordinated land-use change study in the Amazon, incorporating water-and-energy exchange, biogeochemical and ecological components. BAHC, IGAC and GCTE have interacted individually with NASA, which is taking the lead role in coordinating the study, and with projects which may potentially contribute to the study. Further work is required to coordinate the BAHC, IGAC and GCTE components into an integrated IGBP plan for the Amazon, and to liaise closely with NASA to achieve maximum compatibility between the IGBP plans and the LBA study now under development.

Siberian Transect
Because of Siberia's size, uniqueness, importance in the global carbon cycle, and susceptibility to future land-use change, the BAHC-IGAC-GCTE Task Team recommended that IGBP take the initiative in developing a prospectus for a coordinated global change study in the boreal/tundra region of Siberia (and European Russia). Thus, IGBP would take a leading role from the inception in a Northern Eurasian

study. A workshop was held in late 1994, and the prospectus for the IGBP Study will be published in 1996. The Northern Eurasian Study includes a North-South transect in eastern Siberia which contributes to the set of four IGBP Terrestrial Transects in the high latitudes.

At present the IGBP Terrestrial Transects are being coordinated informally by the BAHC-IGAC-GCTE Interaction Task Team in a series of workshops convened by the respective Core Project executive officers. While this has been useful in establishing interaction among the three Core Projects and in the planning of a few of the individual transects (*e.g.*, the Siberian transect), it is an urgent priority that a small coordinating office be established within IGBP and a scientific officer be appointed to coordinate the development of the IGBP Terrestrial Transects on a full-time basis.

PAGES - PEP Transects

Late Quaternary geo-biological records contain information on the natural variability of the Earth's past environment and climate. These data provide the framework for understanding how physical and biospheric systems interact across multiple temporal and spatial scales, the critical palaeoenvironmental role of biogeochemical cycling, and for testing and improving our understanding of mechanisms of past and present climate changes. Because palaeoenvironmental records can be analysed at different levels of temporal and spatial resolution, the derived palaeoclimatic information provides insight into the character, rate and geographical extent of climate change. In order to advance these objectives on the global scale, regional and multi-disciplinary evidence has to be assembled and integrated. Integration of such data must be based on an understanding of both the specific responses of regional environmental systems to climate change, and the climatic linkage between the different regions and systems.

To this end, a study of palaeoclimate records on a global scale is being coordinated by the PAGES Core Project. Through a framework of three interhemispheric Pole-Equator-Pole (PEP) Transects, which encompass key sites and projects, PAGES will provide a comprehensive understanding of the characteristics of natural climatic variability and the nature of the sensitivity and interaction of the Earth's climate and biosphere to a large number of forcing factors.

The most detailed palaeoclimatic information, with annual resolution, is available for the last 2,000 years and is reconstructed from tree-rings, corals, varved marine and lacustrine sediments, ice cores, and historical records. These records provide a history of high frequency changes in the environment (PAGES "Temporal Stream 1"). Records of climate change over the last 250,000 years are needed to document glacial-interglacial variations during two complete climatic cycles which appear to have had very different characteristics (PAGES "Temporal Stream 2"). Records that span the last glacial-interglacial cycles can potentially provide a resolution of decades-to-centuries, and include: loess, peat, lacustrine sediments, lake levels, and ice cores.

Palaeoclimate records have shown that the concentration of trace gases, such as CO_2 and CH_4, has changed significantly over glacial-interglacial timescales, and at times these changes have been rapid. Changes in past atmospheric CO_2 concentrations have been reconstructed from polar ice cores and more recently from peat bog and lake cores. All these records show high-amplitude changes that are approximately synchronous with palaeoclimate changes. Many unresolved questions remain regarding the dynamic processes involved in the global carbon cycle. Some of these questions, related to the past role of vegetation for terrestrial carbon storage, characterisation of land surface properties, and climate change feedbacks from the land surface, will be addressed in projects within the PEP and IGBP transects. Changes in the extent of tropical rainforests (a source and sink of atmospheric CO_2 and terrestrial carbon storage) and of tropical wetlands as a source of CH_4 will be of particular importance. The apparent synchrony between abrupt drops in the CH_4 levels, as deduced from the Greenland ice core record, and an abrupt post-glacial return to dry conditions over the northern tropics, especially North Africa, raises the question of linkages between

changes in tropical land surface conditions and atmospheric CH_4 levels, particularly during the pre-Holocene period when the northern plains were ice-covered or frozen.

During the late Quaternary period, there were also enormous changes in the atmospheric load largely as a result of changes in aridity in continental interiors, and the production of extensive outwash plains associated with the development and decay of continental ice sheets. Periods of increased dust flux to the atmosphere, during the cold glacial periods, are clearly recorded in even very remote polar ice cores. In addition, there have been periods of cataclysmic explosive volcanism which may have played a role in triggering climatic changes. Within the PEP transects there are long terrestrial records of dust deposition, containing essential palaeoclimatic information to unravel the past history of aeolian activity and biospheric response.

There are many approaches and problems in common between the IGBP and PEP/PAGES transects. Close interaction will be maintained to provide intellectual and operational linkages. Many of the results of PEP research will provide the long term understanding for the IGBP transects. Similarly, the more focused IGBP transects will provide the proxy-calibration and process information needed to better interpret the palaeoenvironment. Research carried out by ecologists, plant physiologists, hydrologists, geomorphologists and atmospheric scientists in the IGBP transects will provide a better appreciation of climatic feedback mechanisms and the role of land surface and biospheric dynamics for the PEP transects.

Data and Information Systems for the IGBP Transects

Well coordinated and managed data and information aspects of the transect studies are critical to their success and should not be underestimated. The proposed transect studies will include the compilation and, in some cases, reworking of existing data associated with long term sites along the transects as well as the collection of new data from ground, airborne and satellite measurements. These measurements will be made by national and international scientists at different sites along the transects over a number of years, and will be both spatial and point data. Discussion is needed at the earliest possible stage in the implementation of the transect science plans concerning the overarching data protocols and policies, in keeping with IGBP and ICSU guidelines on data.

As outlined earlier in the report, the data collected at different locations on the transects will be used for a variety of process and comparative studies. The various types of data collected will need to be easily accessible to the transect scientists and to the broader IGBP community. The data will require efficient management and distribution as well as archiving. For scientists concerned with global analyses and comparative studies, there may be some advantage in having similar data management systems for the various IGBP transects.

Compilation of existing databases for sites along the transects and regional datasets will provide a useful base to identify gaps and design new data collection programmes. In some cases reanalysis of existing data may provide new insights. In most cases historical datasets will need updating. START scientists may offer a unique contribution by the identification, reanalysis and management of these existing datasets which are often held in the universities, agencies or national archives of the countries concerned. The transects may cover several countries and effort may be required to determine commonality between datasets - for example, providing a mapping between different land classification schemes or calibrating different field measurement schemes adopted by different countries.

To enable comparative studies from sites within a transect, protocols will need to be established for new ground data collection. Robust measurement techniques which can be applied in different ecosystems and environments may need to be agreed upon by the participating scientists. Measurement and laboratory standards may also need to be agreed upon. Resources and logistical support will be needed to ensure consistent and, in some cases, regular measurement. Automated measurement systems will need to be tested to cover the range of environmental conditions found within the transects.

Remote sensing data will be collected to provide the regional context of the transect studies and surface characterisation as well as providing a record of recent surface changes. Collection of data for well characterised sites enable the testing and development of new algorithms for surface and atmospheric parameterisation. Satellite data will be at both high and low spatial and temporal resolutions from a variety of sensors.

Processing the data from the various sensing systems into common formats to be easily usable by transect scientists will be an advantage. Similarly, the development of derived data products that can be incorporated into the process models will ensure more effective use of the remote sensing data. The IGBP 1 km AVHRR project is already acquiring data that could be used to place the transect measurements in a regional context (Townshend 1992; Eidenshink and Faundeen 1994). IGBP-DIS (Data and Information Systems) and CEOS (Committee on Earth Observation Satellites) could play a role in the coordination of satellite data acquisition for the transects as well as working issues associated with data access for global change research.

For example, IGBP-DIS has facilitated interaction between IGBP scientists and the remote sensing community through the CEOS/IGBP-DIS Data Exchange Pilot Project. The project recognises the need for providing essential remotely sensed data to the global change scientific community at affordable rates. The overall goal of the pilot project is to develop ways to coordinate the acquisition and dissemination of high resolution satellite data for global change research, thereby using existing technology in new ways to assist in solving fundamental questions about the Earth system.

The specific objectives of the Data Exchange Pilot Project are:

(i) To ascertain what data are available from existing high spatial resolution satellite systems, including SPOT, Landsat, MOS-1, AVHRR, and others, for global change research projects within the IGBP

(ii) To assemble datasets from existing archives for selected IGBP Core Projects

(iii) To develop and implement a data acquisition model for acquiring new high resolution datasets to support selected IGBP Core Projects

(iv) To provide to the global change research community ready access to these data at the marginal cost of reproduction.

The CEOS/IGBP-DIS Data Exchange Pilot Project has already proved beneficial to the IGBP Transects initiative. SPOT data have been supplied to both the SALT transect in West Africa and the NATT transect project in Australia and preliminary analysis of the SALT data has already been undertaken. As the IGBP Transects programme develops, the CEOS/IGBP-DIS initiative provides a framework to enable the provision of high resolution data to researchers working on these and other proposed transects. This will require close collaboration between the Core Projects and IGBP-DIS to ensure that data become available in a timely fashion as individual transects are implemented and become positioned to use the data.

The efficient management of the transect data will be critical to the success of the programme. Issues such as adequate documentation, formats and projections need to be addressed and agreed upon. GIS systems are commonly used to manage spatial data and will provide important analysis tools for transect data. There are, however, severe problems of incompatibility between the various available GIS systems. Where possible, agreements will need to be made on the GIS systems to be used for the transect data to ensure interoperability. Although often a delicate issue for scientists, the open and timely access to data collected for the transects are essential aspects to the transect programme. Distribution media need to meet the requirements of the scientists engaged in the study. Recent developments in data sharing through Internet and

the World Wide Web provide new and effective ways for scientists to share data. The availability of data to scientists without these technologies is also important. The transect community can benefit from the data management and data systems experiences developed as part of the FIFE, HAPEX and BOREAS field campaigns. CD-ROMs have been generated containing a complex variety of *in situ* and remotely sensed data (Sellers *et al.* 1992; Justice *et al.* 1995).

START and the IGBP Terrestrial Transects

By their design, the IGBP Terrestrial Transects will facilitate the transfer of information, understanding, and predictive capability across scales, from patch to region. In particular, they will be valuable tools in translating results from global models and analyses to the regional and landscape scales, which are generally of more interest to policy-makers and resource managers. The START networks are being developed around the world to support IGBP, WCRP (World Climate Research Programme) and HDP (Human Dimensions of Global Environmental Change Programme) research at the regional level, to carry out regional and national scale global change analyses, and to improve the capacity of the scientific communities in developing countries to carry out global change research. These aims are compatible with many of the activities which are being or which will be carried out on the transects. In addition, in most cases the transects fall within a single START region, which will enhance interaction in a more practical sense.

Capacity-building is an area in which the transects are already having an impact. Because the transects require a large number of researchers from various disciplines working on a few sites, they are well-suited to promote collaborative research. Further, when the transect is located in the developing world, it is well-placed to serve as a vehicle for enhancing the skills of developing country scientists and for building long-term collaboration between scientists from developed and developing countries. A good example is the SALT transect, on which French and African scientists have collaborated for a number of years.

The transects may also provide an appropriate integrating mechanism for many START activities within a region. For example, the initial set of activities now being carried out within the SARCS region includes studies of greenhouse gas emissions and of land-use change. Both are focused on specific objectives. The IGBP Transect in Southeast Asia proposed as part of the set "Humid tropics undergoing land-use change" could provide the framework required to integrate the two SARCS studies and other relevant work which is planned for that region. The result would be an improved understanding of how land use, interacting with changing climate and CO_2 concentration, will affect the carbon and nitrogen cycles in Southeast Asia over the longer term.

The IGBP Terrestrial Transects and the START networks are developing at different rates and according to different priorities around the world. Emphasis should be placed on ensuring that effective collaboration is achieved promptly in areas where both transects and START networks are in a position to interact. This is particularly important when both are in the planning phase.

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Acronyms and Abbreviations

AMBIACE	Amazon Biogeochemistry and Atmospheric Chemistry Experiment
AVHRR	Advanced Very High Resolution Radiometer
BAHC	Biospheric Aspects of the Hydrological Cycle
BATERISTA	Biosphere-Atmosphere Transfer, Ecological Research and *in situ* Studies in Amazonia
BATGE	Biosphere-Atmosphere Trace Gas Exchange in the Tropics
BATS	Biosphere-Atmosphere Transfer Scheme
BFTCS	Boreal Forest Transect Case Study
BIBEX	Biomass Burning Experiment
BIOME-BGC	Global Biome Model - Biogeochemical Cycle
BOREAS	Boreal Ecosystems Atmosphere Study
CENTURY	*Name of long-term model*
CEOS	Committee on Earth Observations Satellites
CERN	Chinese Ecological Research Network
DECAFE	Dynamique et Chimie Atmosphérique en Forêt Equatoriale
DIS	Data and Information Systems
ECHIVAL	European International Project of Climate and Hydrological Interactions between Vegetation, Atmosphere, and Land Surfaces
EFEDA	ECHIVAL Field Experiment in Desertification-threatened Area
EXPRESSO	Experiment for Regional Sources and Sinks of Oxidants
FAO	Food and Agriculture Organization
FIFE	First ISLSCP Field Experiment
FORET	Forests of East Tennessee
FT	Functional Type
GAIM	Global Analysis, Interpretation and Modelling
GCM	General Circulation Model
GCTE	Global Change and Terrestrial Ecosystems
GEM	General Ecosystem Model
GIS	Geographic Information System
GTOS	Global Terrestrial Observing System
HAPEX-SAHEL	Hydrologic and Atmospheric Pilot Experiment - Sahel
HDP	Human Dimensions of Global Environmental Change Programme
HESS	High Latitude Ecosystems as Sources and Sinks of Trace Gases
IAI	Inter-American Institute for Global Change Research
ICRAF	International Centre for Research in Agroforestry
ICSU	International Council of Scientific Unions
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Programme
IMAGE	Integrated Model for Assessment of the Greenhouse Effect
ISLSCP	International Satellite Land Surface Comparison Project
LAI	Leaf Area Index
LAMBADA	Large-scale Atmosphere Moisture Balance of Amazonia using Data Assimilation
Landsat	Land Remote-Sensing Satellite
LBA	LAMBADA-BATERISTA-AMBIACE
LEMA	Long-term Ecological Modelling Activity

LOICZ	Land-Ocean Interactions in the Coastal Zone
LSE	Land Surface Experiment
LUCC	Land-Use and Land-Cover Change
MAESTRO	Multiple-array, Assimilation, Evaporation, Stand, Tree, Radiation Orgy
MILOX	Mid-Latitude Ecosystems as Sources and Sinks for Atmospheric Oxidants
MOS-1	Marine Observation Satellite
NASA	National Aeronautics and Space Administration
NATT	Northern Australia Tropical Transect
NECT	North East China Transect
NIPHYS	Nitrogen Physiology of Forest Plants and Soils
NMHC	Non-Methane Hydrocarbon
NPP	Net Primary Productivity
PAGES	Past Global Changes
PEP	Pole-Equator-Pole transects
PFT	Plant Functional Types
SAFARI	Southern African Fire Atmosphere Research Initiative
SALT	Savannas in the Long Term
SARCS	Southeast Asian Regional Committee for START
SiB	Simple Biosphere Model
SPOT	Système pour l'Observation de la Terre
STARE	Southern Tropical Atlantic Regional Experiment
START	Global Change System for Analysis, Research and Training
STEPPE	*Name of grassland model*
SVAT	Soil-Vegetation-Atmosphere Transfer Model
TEM	Terrestrial Ecosystem Model
TEMA	Terrestrial Ecosystems in Monsoon Asia
TM	Thematic Mapper
TRAGEX	Trace Gas Exchange: Mid-Latitude Terrestrial Ecosystems and Atmosphere
TRAGNET	Trace Gas Network
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCRP	World Climate Research Programme
ZELIG	*Name of model*