THE CARBON CHALLENGE

An IGBP - IHDP - WCRP Joint Project

International Human Dimensions Programme

International Geosphere/ Biosphere Programme

World Climate Research Programme

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This document is a synthesis of the reports and discussions from several international planning meetings held over the past two years. Over 150 carbon-cycle researchers from 26 countries were involved (Appendix A). This Prospectus paves the way for, and is the forerunner of, a detailed scientific framework defining an integrated carbon-cycle research project jointly sponsored by IGBP, IHDP and WCRP.

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"Greenhouse gases", especially carbon dioxide (CO_2), are intimately connected to climate change. Their rapid increase is challenging the scientific community, policy makers and the public. To predict future climate change accurately and find ways to manage the concentration of atmospheric carbon dioxide, the processes and feedbacks that drive the carbon cycle must first be understood. Only then can we project its behaviour into the future.

Comparison of contemporary measurements of atmospheric CO_2 concentration with long-term ice-core records shows that we have left the regular domain of glacial–interglacial cycling in which atmospheric composition and global mean temperature have varied within well-defined limits. The global atmospheric CO_2 concentration is now nearly 100 ppmv higher than the interglacial maximum; this recent rise is equal to the entire range of CO_2 concentrations between glacial minima and interglacial maxima. Atmospheric concentrations of carbon dioxide have risen to current levels at least ten—possibly a hundred—times faster than at any other time in the last 420,000 years, and continues to rise sharply (**Figure 1**, and Falkowski et al. 2000).

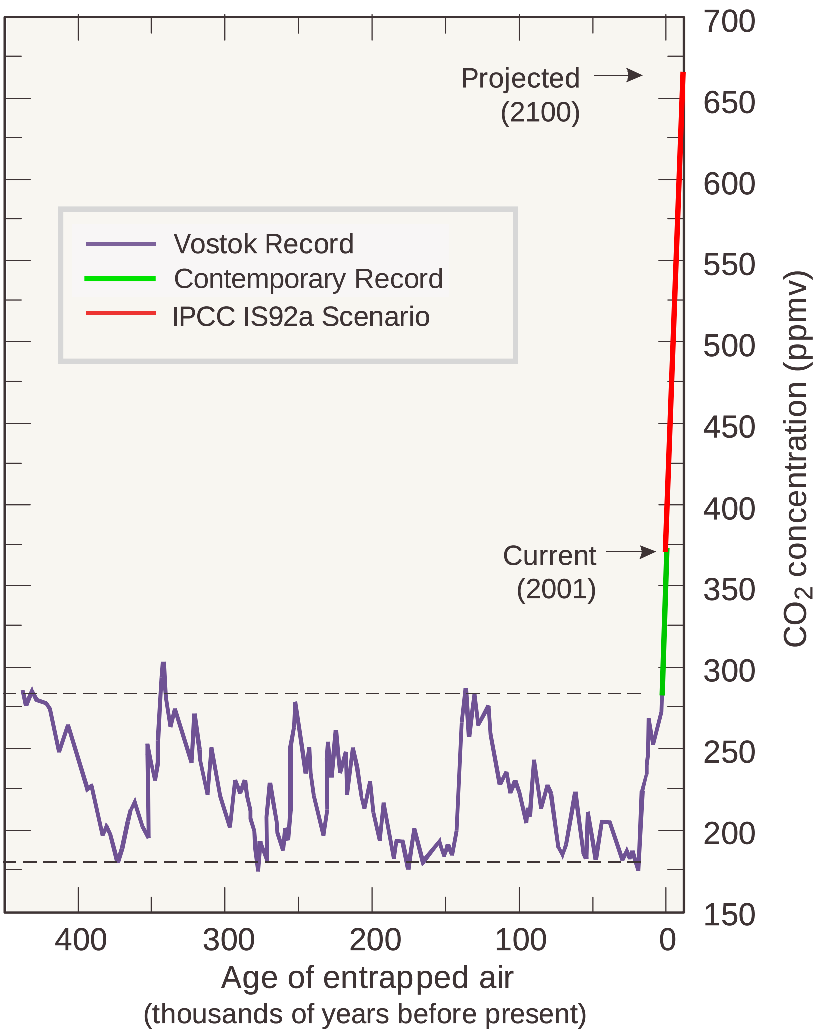


Figure 1. The Vostok ice-core record for atmospheric CO_2 concentration from Petit et al. (1999) and the "business as usual" prediction used in the IPCC Third Assessment (Prentice et al. 2001). The current concentration of atmospheric CO_2 is also indicated.

The recent dramatic increase in atmospheric CO_2 is unquestionably the result of human activities. It is highly likely the observed changes toward a warmer climate over the last century are a consequence of this increase (**Figure 2**, and Prentice et al. 2001).

However, the role of human activities in the carbon cycle is complex. Over the past two centuries, human activities—industrial production, trade and transport, agriculture, forestry and energy use—have grown to a magnitude sometimes equaling or even exceeding global-scale natural forces in their influence on the carbon cycle. Human societies are not just uni-directional drivers of change: they are impacted by changes in the carbon cycle and climate, and they respond to these impacts in ways that feed back to carbon-cycle dynamics. The Earth's social, cultural, political and economic systems provide the context in which this complex human–environment system evolves, and in which attempts by human societies to change the future direction of the carbon cycle will be made.

The international scientific community has responded to this unprecedented carbon challenge by developing the ten-year Global Carbon Cycle Joint Project. The project's framework provides an integrated perspective across disciplines as well as national boundaries. The approach is to accept that humans and their activities are an integral part of the carbon cycle, and that the human–environment system is a single, highly linked and interactive system that drives the dynamics of the carbon cycle (**Figure 3**). The goal is to understand the

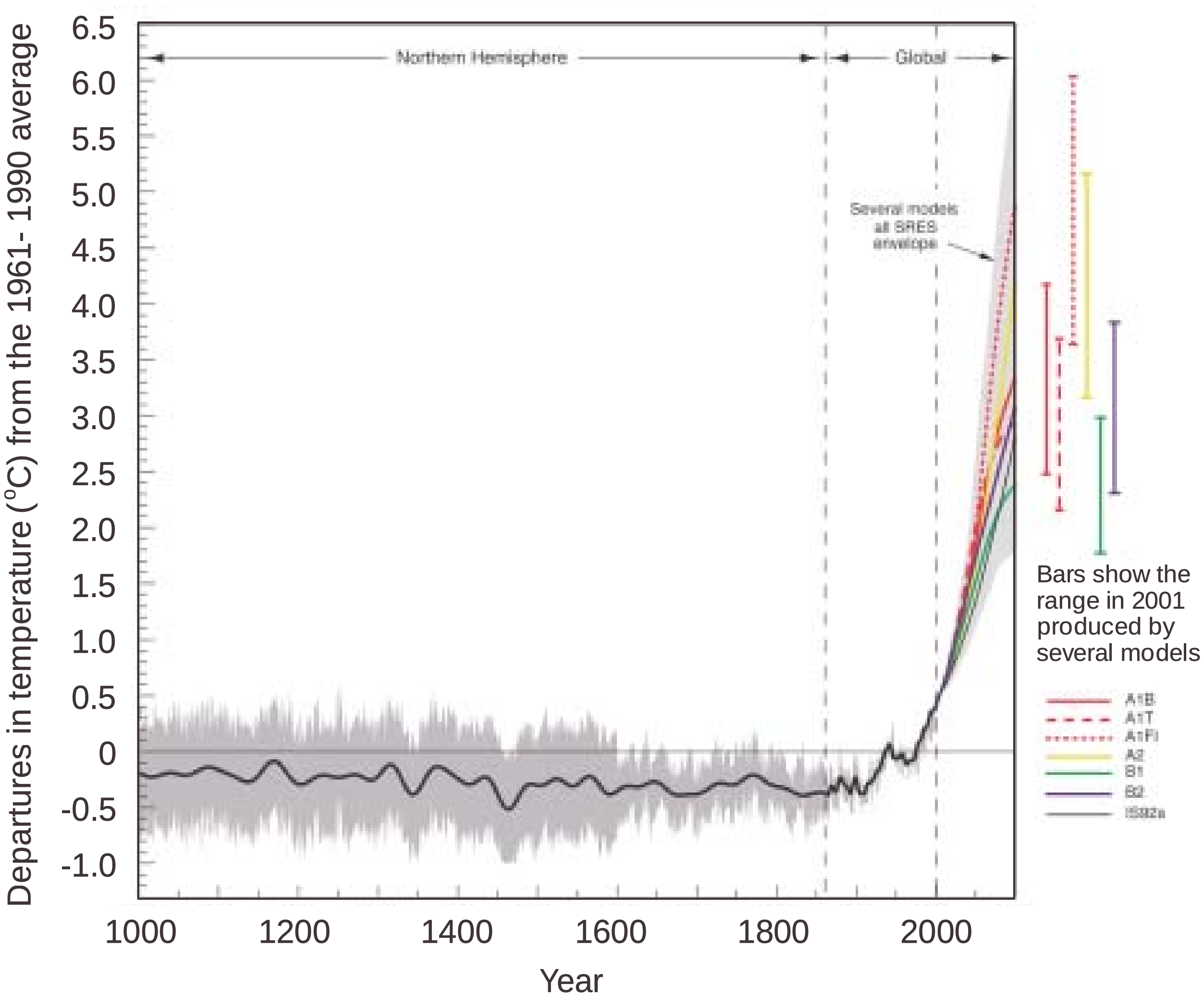


Figure 2. Variations of the Earth's surface temperature (1000 to 2100 AD). Data from IPCC TAR ((Prentice et al. 2001). Sources of data from 1000–1861 AD—northern hemisphere, proxy data (tree rings, sediment cores, etc.); 1861–2000 AD—global instrumental data; 2000–2100 AD—Special Report on Emissions Scenarios projections.

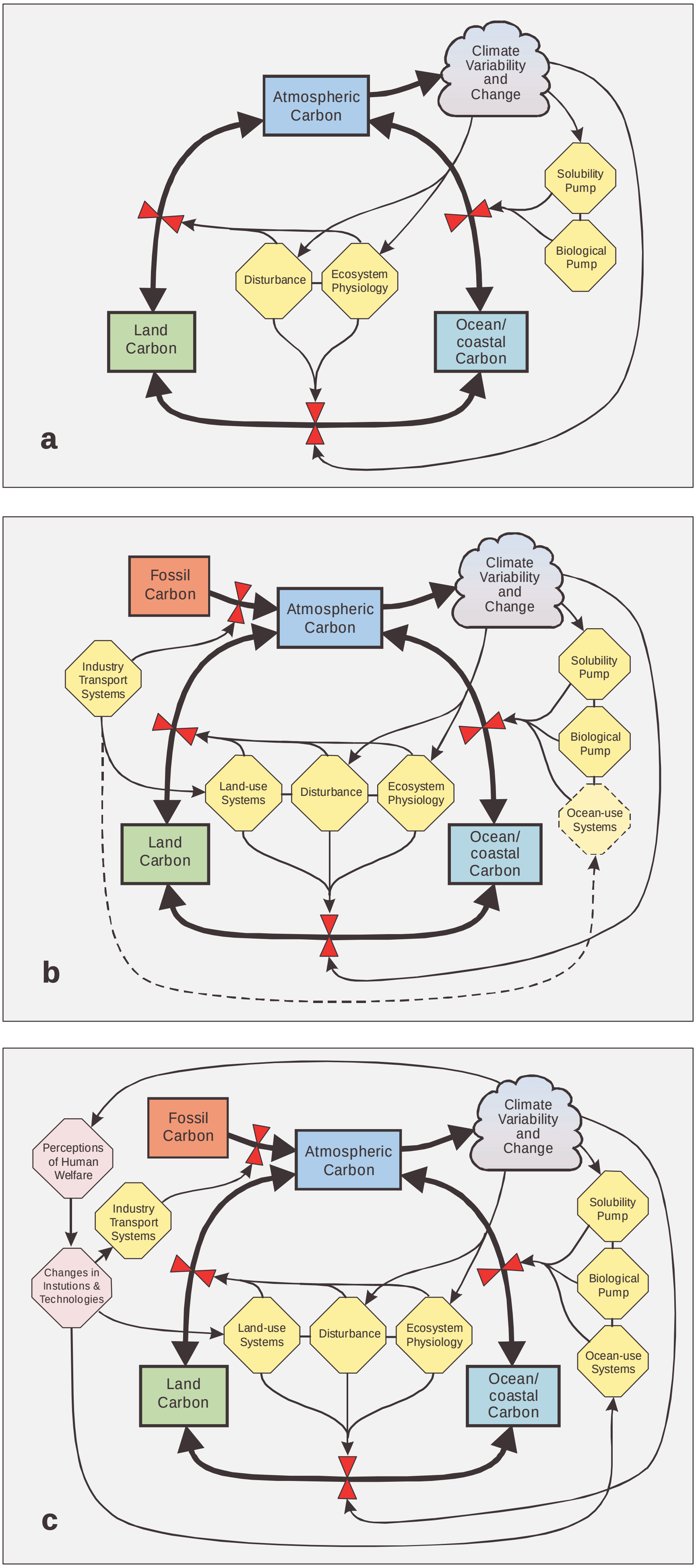
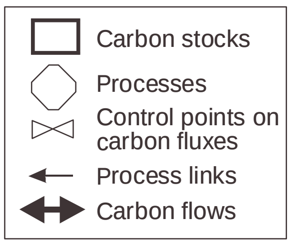


Figure 3. The global carbon cycle from three perspectives over time. **(a)** During glacial–interglacial periods and before significant human activities, the global carbon cycle was a linked system encompassing stocks in the land, oceans and atmosphere only. The system was (and still is) controlled or driven through climate variability as well as its own internal dynamics. For instance, the ocean carbon system was tightly coupled to air–sea gas exchange as well as physical and biological "pumps" that transport carbon. Interactions of the land surface and atmosphere were driven by land and ecosystem physiology as well as disturbance. **(b)** Starting about 200 years ago, industrialization and accelerating land-use change complicated the global carbon cycle by adding a new stock—fossil carbon. However, humans did not initially perceive that their welfare might be endangered. Regardless of how society responds to increased fossil fuel inputs to the atmosphere, or the consequences of intensification of current land-use practices, the global carbon cycle has been seriously impacted. **(c)** Over recent decades, humans have begun to realize that changes in climate variability and the Earth System may significantly affect their welfare as well as the functionality of the global carbon cycle. The development and implementation of institutions and regimes to manage the global carbon cycle coherently provides a new set of feedbacks in the contemporary era.



underlying mechanisms and feedbacks that control the carbon cycle, explain the current patterns of sources and sinks, and develop plausible trajectories of the behaviour of the carbon cycle into the future. The project's target is to provide societies with significantly enhanced scientific knowledge of the global carbon cycle on which to base policy debate and action.

The Global Carbon Cycle Joint Project is co-sponsored by the International Geosphere–Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP). It is organized around three fundamental scientific themes that require cooperation and collaboration from international and interdisciplinary communities:

1. Patterns and Variability

2. Processes, Controls and Interactions

3. Carbon Futures

A fundamental question and a set of supporting questions guide the work under each theme. Together, the themes provide the framework to tackle the critical issues in global carbon-cycle research.

Atmosphere

Ocean

Land

Disturbance

1. Patterns and Variability:

What are the geographical and temporal patterns of carbon sources and sinks?

1.1. How do patterns of carbon sources and sinks vary over time?

1.2. What are the continental and basin-scale spatial patterns of carbon sources and sinks and how do these relate to carbon storage?

1.3. What is the contribution of human actions, including fossil-fuel burning and land-use practices, to patterns of carbon sources and sinks?

1.4. How do regional and subregional patterns in carbon flows influence the global carbon budget?

Understanding the spatial patterns of carbon fluxes on land and ocean and in the atmosphere is essential to inform the policy process. However, our current knowledge of spatial patterns is uncertain (Peylin et al. submitted). Fossil-fuel emissions have traditionally been concentrated in the industrialized nations of the north, but the pattern is beginning to shift as developing countries begin to exploit carbon reserves. There is good evidence of a northern hemisphere terrestrial sink, although its longitudinal distribution is unknown. The behaviour of the tropical land surface, affected by both land-use changes and ecological processes, is also poorly understood.

Broad-scale patterns of ocean storage and fluxes are emerging (**Figure 4**); however, large

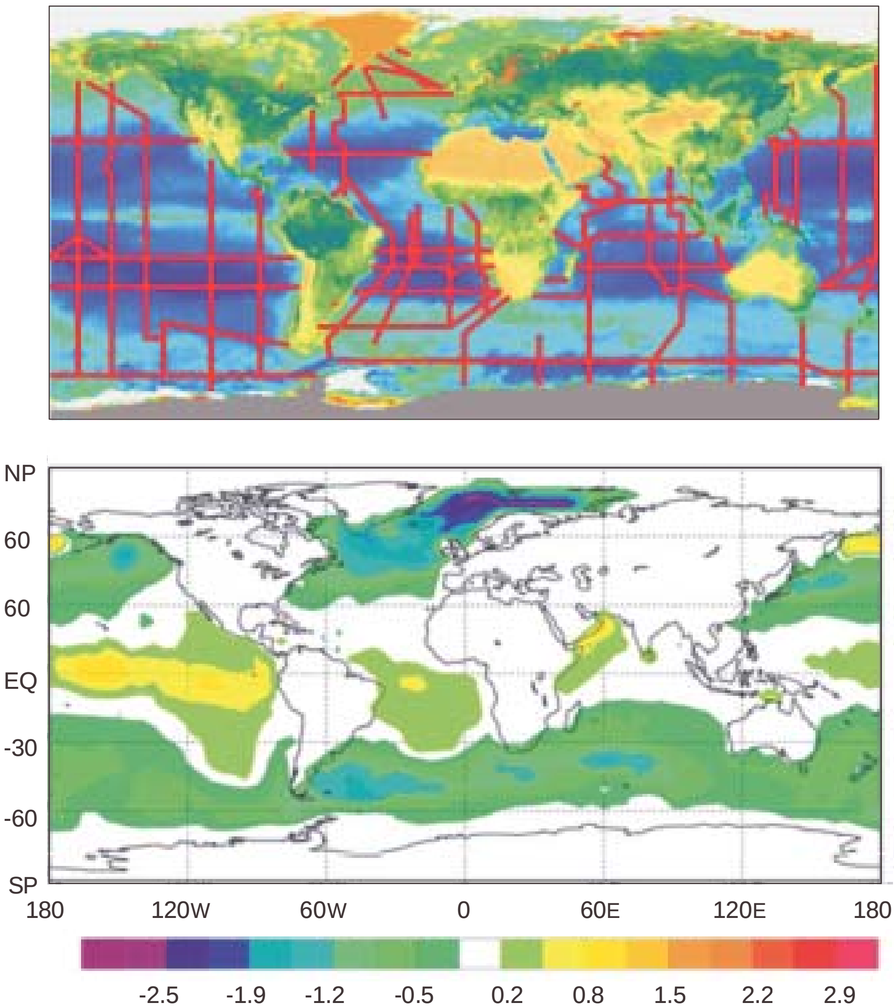


Figure 4 (Upper) Cruise tracks of oceanographic research ships in the 1990s making a global ocean survey of carbon tracers for the Joint Global Ocean Flux Study (JGOFS) and the World Ocean Circulation Experiment (WOCE). The carbon-tracer data have been used to determine the patterns and amounts of anthropogenic carbon stored in the ocean. These tracer data also provide a baseline for determining changes in the ocean's carbon inventories, which will help to close the global carbon budget on a scale of decades. (Lower) Surface measurements of the partial pressure of carbon dioxide (pCO_2) made on the cruises shown above were combined with other data collected since 1960 to estimate annual mean ocean–atmosphere fluxes for 1995 (kgC m^{-2} s^{-1} x 10^{-9}) (Takahashi et al. 1999).

uncertainties remain in many regions, including the Southern Ocean and coastal zones. Recent patterns of interannual variability in growth rates of atmospheric CO_2 point towards changes in terrestrial metabolism, possibly driven by climate variability (**Figure 5**).

The patterns of temporal variability on longer time scales (e.g. decades, centuries) give insights to the processes that control fluxes and ultimately determine carbon storage in the ocean, land and atmosphere reservoirs. Decade-scale changes in the ocean's carbon storage can now be measured. Together with atmospheric inventories, these measurements will help to close the global budget on long time scales. The spatial and temporal patterns across ocean, land and atmosphere are interlinked and mutually constrained overall by a single global budget; as patterns in one part of the world become better known, they help improve knowledge in others.

Source/sink patterns can be estimated by two approaches: top-down (e.g. inverse methods, satellite observations), and bottom-up (e.g. forest inventories and surface ocean observations of the partial pressure of carbon dioxide or pCO_2).

Top-down methods largely depend on understanding and simulating global and continental atmospheric and oceanic transport as well as carbon distribution in the atmosphere and oceans. Our understanding of large-scale transport, however, is incomplete and limits an accurate assessment of the patterns of global carbon stocks and flows.

Bottom-up methods also have large uncertainties; for example, the drivers for human decisions on land-use practices and energy systems, measurement of changes in soil carbon over time and, in oceans, the aggregation of hundreds of thousands of point measurements taken over

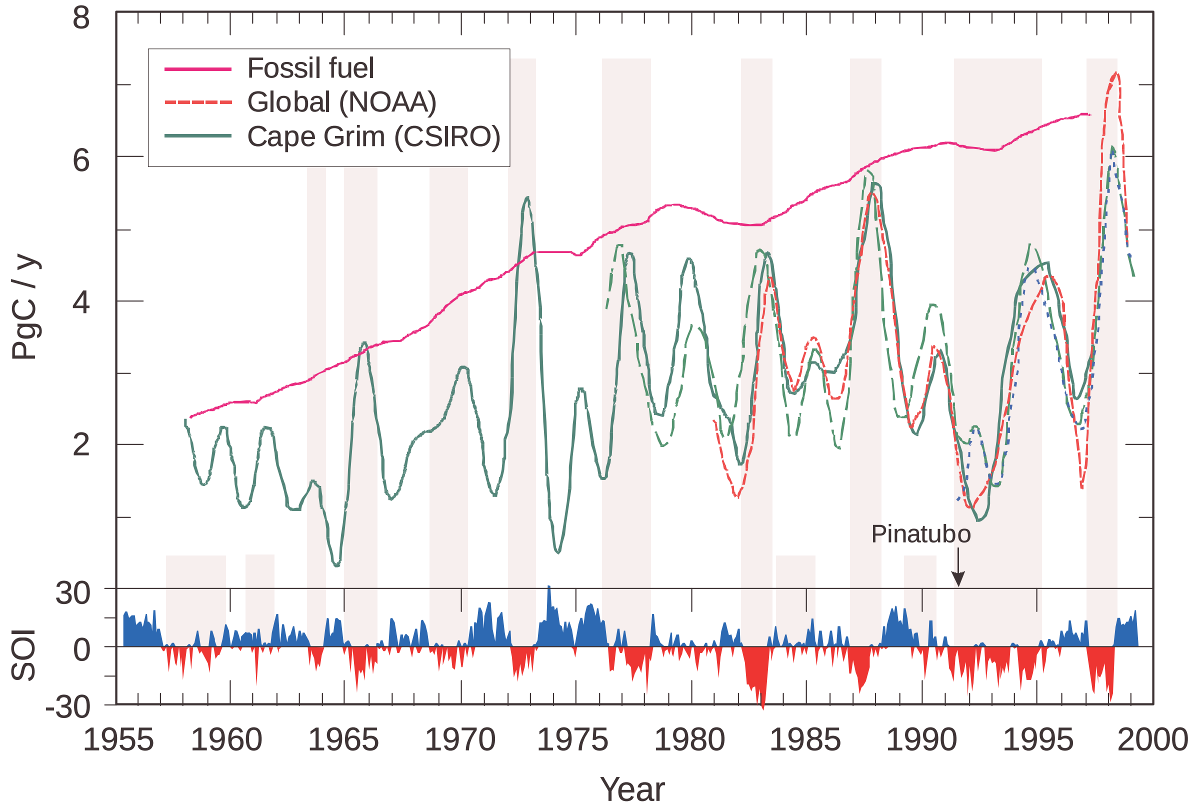


Figure 5. Annual changes in the growth rate of atmospheric CO_2 from the Mauna Loa Observatory (Scripps — solid blue line, 1957 to present; and National Oceanic/Atmospheric Administration (NOAA) — dotted blue line, 1977 to present), Cape Grim (solid green line, 1991 to present), annual fossil fuel emissions (solid red line) and global average from NOAA (dotted orange line). Note the large peaks in the interannual growth rate coinciding with El Niño events (bars), highlighting the influence of variable climate modes on the Earth's metabolism.

several years under varying conditions. Discrepancies among source/sink distributions estimated by direct human, ocean and land observations and inferred from atmospheric inverse calculations must be resolved before global and regional carbon budgets can be robust.

Sample Research Priorities:

- To resolve the longitudinal distribution of the northern hemisphere land-sink and elucidate the role of the terrestrial tropics in the global carbon cycle.

- To quantify variability in ocean sources and sinks, and determine the role of the Southern Ocean and coastal zones in the carbon cycle.

- To quantify the current distribution of anthropogenic carbon in the ocean and the relationship to air–sea flux

- To distinguish between the roles of natural disturbance and land-use and their legacies in determining the current spatial patterns of terrestrial sinks.

- To quantify the differences in patterns of fossil-fuel use among industrial sectors and among distinct regions within individual countries.

- To resolve the role of climate variability in driving the observed pattern of interannual variability in the increase of atmospheric CO_2 .

2. Processes, Controls and Interactions:

What are the control and feedback mechanisms—both anthropogenic and non-anthropogenic— that determine the dynamics of the carbon cycle on scales of years to millennia?

2.1. What mechanisms controlled paleo- and pre-industrial concentrations of atmospheric CO_2?

2.2. What mechanisms control current terrestrial and oceanic carbon fluxes?

2.3. What mechanisms control anthropogenic carbon fluxes and storage?

2.4. How do feedback mechanisms operate to magnify or dampen both anthropogenic and non-anthropogenic carbon fluxes?

To explain the current distribution of carbon sources and sinks (Theme 1) and to develop plausible trajectories of future carbon dynamics (Theme 3), a clearer understanding of critical processes and control points is required (Theme 2).

The mechanisms and feedbacks that control the long-term cyclical pattern of atmospheric CO_2 variation shown in the ice-core records are still largely unknown. The need to understand these is becoming increasingly urgent as we move rapidly out of this previously tightly bounded domain (Falkowski et al. 2000, Figure 1).

In the contemporary carbon cycle, an adequate understanding of the mechanisms behind a number of critical processes still eludes us: the proximate and ultimate drivers of changes in industrial systems and institutional regimes; the interplay between land-use, ecosystem physiology and disturbance that controls carbon flows in and out of land systems; the lateral flows and storage of carbon across landscapes and into the coastal–open ocean zones; and the biological, chemical and physical interactions that move carbon through the atmosphere/upper-ocean/deep-ocean systems.

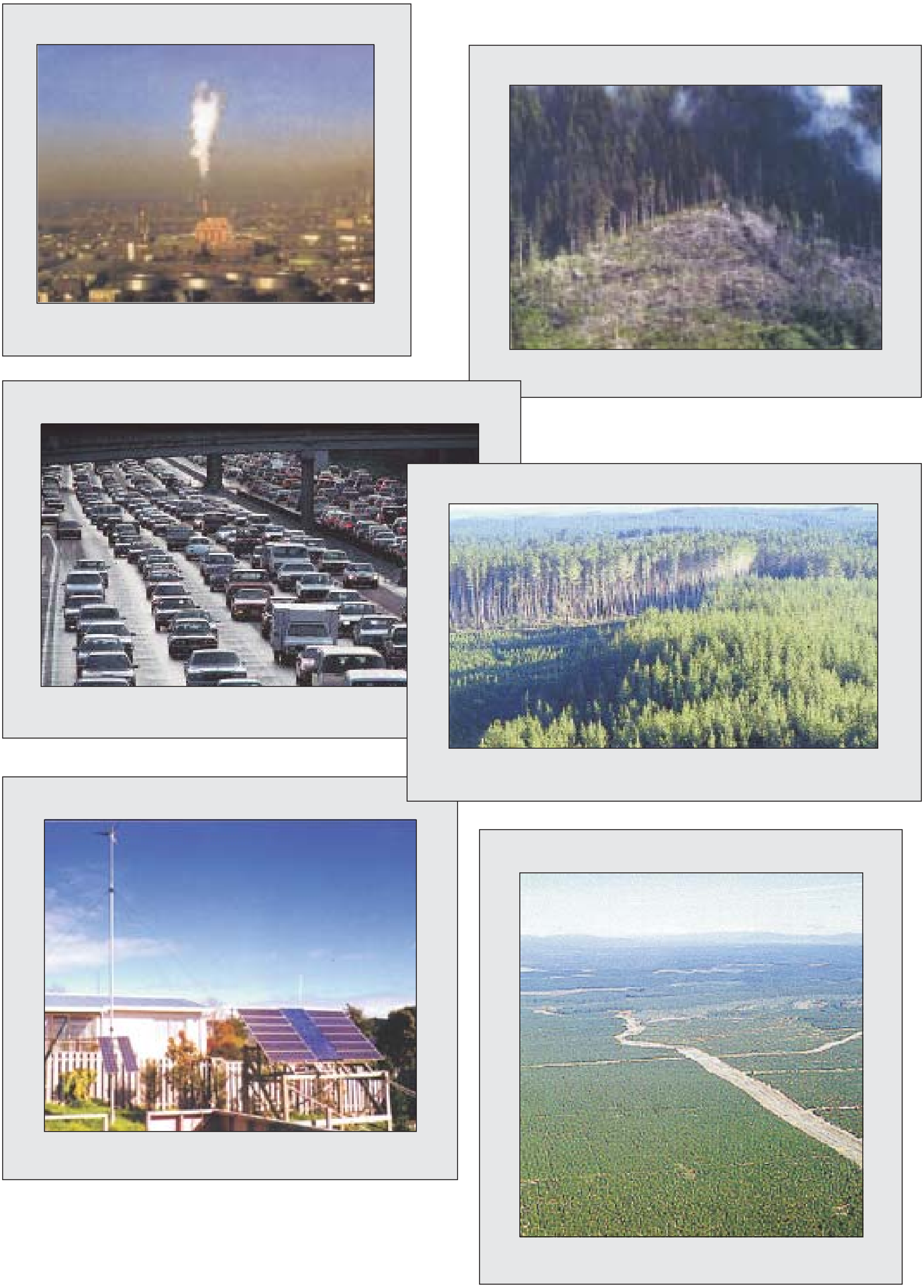


Figure 6. Collage depicting anthropogenic mechanisms that affect atmospheric carbon fluxes. The main human inputs to carbon emissions are industry, deforestation and transport. Human activities that sequester carbon or reduce emissions include forest plantations and alternative energy sources such as wind and solar power.

Elucidating how carbon-cycle processes interact with each other and with climate is an even larger challenge. Since human activities have become important processes in carbon-cycle dynamics (**Figure 6**), any likely responses of human systems to changing stocks of carbon must be incorporated into the characterization of the overall system dynamics. Especially important is the sequence of processes that link the perception of climate change and its impacts to changes in institutional regimes and eventual changes in industrial systems and land-use practices (Figure 3b,c).

Two other critical issues are: (i) the response of the terrestrial carbon cycle to changing temperature and precipitation through changes in growth, respiration, and disturbances such as fires; and (ii) the response of the ocean carbon cycle to changes in CO_2 solubility associated with changing temperature and increases in atmospheric/surface ocean CO_2, and its response to climate-related changes in ocean circulation and ecosystem dynamics.

Sample research priorities:

- To understand the controlling features and simulate the temporal dynamics of the glacial–interglacial carbon-climate system
- To understand the mechanisms that control flows of carbon between (i) land and atmospheric stocks; (ii) ocean and atmospheric stocks; and (iii) land and ocean stocks (coastal zones).
- To determine the role of oceanic and atmospheric transport in carbon-cycle dynamics.
- To explain and explore the relative importance of the drivers in the spatial and temporal variations in the intensity of humans' energy use.
- To determine how public and private activities and their interactions drive rates of deforestation and influence land-use practices.

3. Carbon Futures:

What are the likely dynamics of the global carbon cycle into the future?

3.1. Are current terrestrial carbon-sinks permanent features of the biosphere or are they likely to disappear or even become sources in the future?

3.2. How will the physical and biological drivers of carbon uptake in the ocean evolve over the next century and influence ocean storage?

3.3. What are plausible trajectories of carbon fluxes associated with industrial, commercial, transport and residential systems, as well as land-use practices and land-cover changes?

3.4. How are humans responding, and how will humans respond in the future, to the challenge of managing the carbon cycle?

The ultimate goal of carbon-cycle research is to understand the system well enough to make reliable projections of carbon-cycle dynamics into the future. This requires an integration of more focused work on processes and mechanisms and on patterns and variability to develop system-level tools that can simulate overall carbon-cycle behaviour over decades and centuries.

Several aspects of the system's behaviour are critical. The "industrial transformations–institutional challenges" complex is the dominant subsystem at present. How this complex develops over the next several decades will largely determine the concentration of atmospheric CO_2. The long-term atmospheric concentration of CO_2 also depends on the continued operation of two large biophysical subsystems—the ocean and land sinks. Some projections suggest that in this century the land sink may saturate or even turn into a source (**Figure 7**), and the ocean's capacity to take up atmospheric CO_2 may also weaken significantly.

Because the carbon cycle operates as a single interlinked system, the timing and interactions of these large subsystems are crucial. The carbon cycle, and the Earth System as a whole, could exhibit instabilities and/or multiple equilibrium states on scales of decades to centuries. If we are close to critical thresholds in the cycle, the

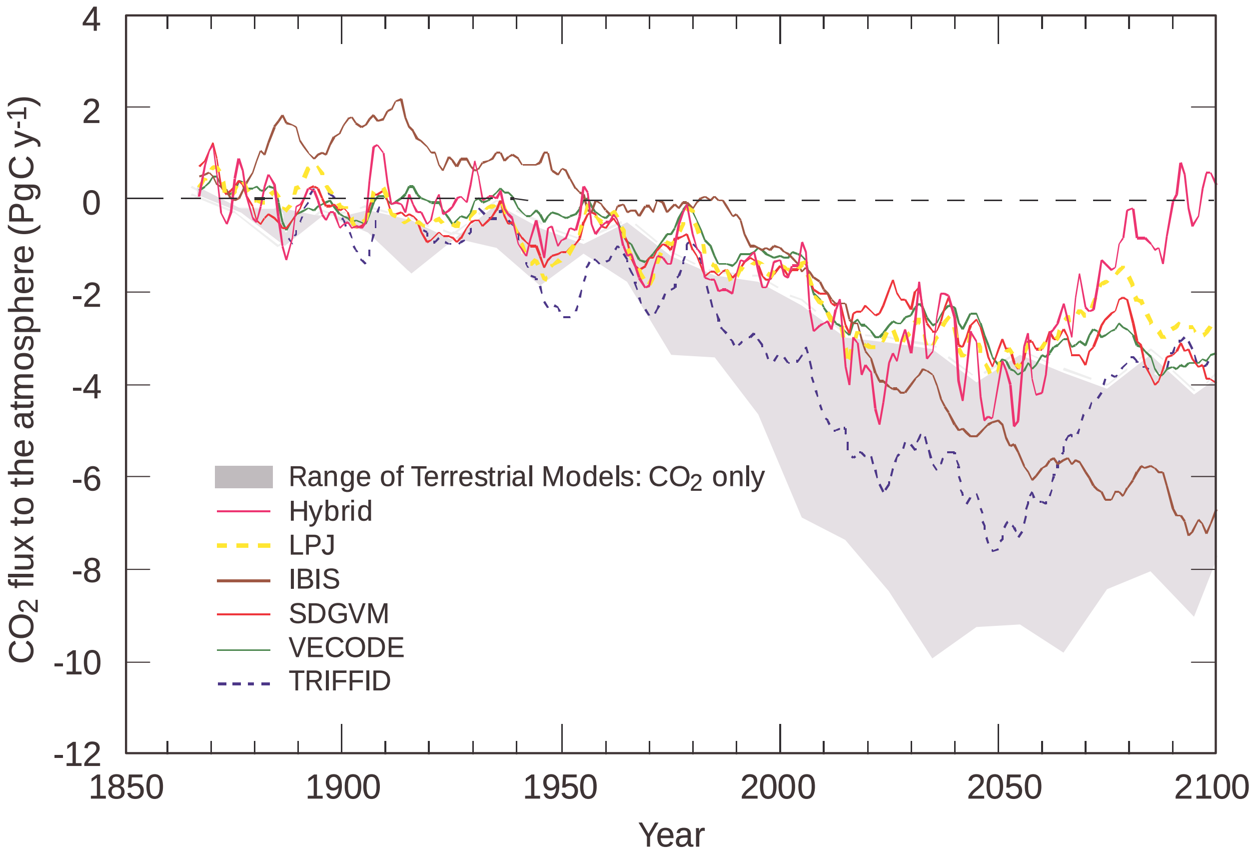


Figure 7. Results from six Dynamic Global Vegetation Models predicting Net Terrestrial Ecosystem Productivity from 1860 through to 2100 with elevated atmospheric CO_2 and climate change. Shaded area in grey represents the models' results for elevated CO_2 only. Note the general agreement between the terrestrial models from the late 1800s to 2050, suggesting that the land surface increasingly acts as an sink. After 2050, the models diverge. However, all suggest that over time the terrestrial biosphere loses its capacity to absorb carbon. The carbon sink becomes saturated.

timing—not just the magnitude—of changes in subsystems can be the determining factor. For example, if the ocean's uptake capacity is changed and land sinks weaken significantly or saturate later this century, heavy cuts in fossil-fuel emissions at that time may be too late to avoid a change in the state of the Earth System. Earlier cuts in emissions might, on the other hand, prevent the Earth Systems' crossing a critical threshold. The only way to know whether we are approaching such a threshold is to develop a sound prognostic capability based on an integrated system-level understanding of the carbon cycle.

Sample research priorities:

- To simulate the transition from the pre-industrial to the current state of the carbon cycle as a basis for predicting future mechanisms and environmental trajectories.

- To develop regional scenarios of the carbon cycle that can also be used to develop and constrain the global carbon budget.

- To identify the forces that will control the prospects for decarbonization of industrial economies over the next 10 to 50 years.

- To determine the prospects for success of a global-climate regime and analyze alternative institutional arrangements that might more effectively reduce anthropogenic emissions of CO_2.

- To determine whether the strength and patterns of terrestrial and ocean sinks will be changed and if so, when and why.

To make significant progress in answering these fundamental questions over the next decade is a formidable challenge. Much research on the global carbon cycle is already under way or planned; the strategy of the Global Carbon Cycle Joint Project is to build on this work. However, this research is largely not integrated or coordinated, which results in large gaps in some areas and duplication in others. By developing a single, unified, mutually agreed framework and the mechanisms for exchanging information, the Project aims to identify research gaps and lessen redundancy of effort and inefficiency in the use of research resources.

The Project's strategy is thus to coordinate national and disciplinary efforts within the international and multidisciplinary joint framework to tackle global-scale carbon-cycle questions that cannot be answered otherwise. In turn, analytic planning that takes a global view of the carbon system will assist national and regional efforts to constrain their budgets and identify feedbacks and teleconnections that extend beyond their geographical boundaries. In addition, the Joint Project will explore new emerging properties and pathways of the carbon cycle under future combinations of environmental factors and human behaviour.

The first element of the Project's implementation strategy is to build integration and synthesis into the framework from the outset, rather than to attempt it after the field work and case studies are complete. It will bring pieces of research together to explore the major questions rather than splitting them into finer-scale fragmented research projects.

The second element of the strategy is to contribute to the coordination and development of carbon-cycle science programmes at the international, regional and national levels, with the goal of answering the three fundamental questions.

Integration and Synthesis

A central challenge in carbon-cycle research is to synthesize the massive array of different measurements and results of case and process studies into a single, internally consistent framework. The Global Carbon Cycle Joint Project proposes to use the "multiple-constraint" synthesis approach, which combines measurements and models. In essence, it integrates observations (remotely sensed and *in situ)*, models (diagnostic and predictive), process and manipulative experiments and case studies to constrain the global carbon balance, together with regional and local budgets. It does so by using data streams from both the human and natural sciences to constrain model parameters to optimal values, and thus to infer complete space–time distributions of carbon stocks and flows, or other desired parameters (**Figure 8**).

Other integration and synthesis tools needed to work towards answering the fundamental questions include interdisciplinary workshops tackling focused questions; linking of models from the human and natural sciences and integrating their associated data sets; constructing global carbon budgets at regular intervals; modelling comparisons and tests against data; and assimilating and synthesizing international observational data sets.

Extending Observations

Observations of carbon-cycle dynamics are a fundamental component of attempts to understand the carbon cycle. Our first awareness of the seriousness of the "carbon challenge" came from the careful, long-term measurement of atmospheric CO_2 at the Mauna Loa Observatory in Hawaii. The Global Carbon Cycle Joint Project will need an expanded and improved global network of carbon and related tracer observations. To achieve this will require comparisons and calibration of observations from different instruments and techniques; the rational extension of atmospheric CO_2, carbon isotope and oxygen measurements; the continuation and extension of surface ocean

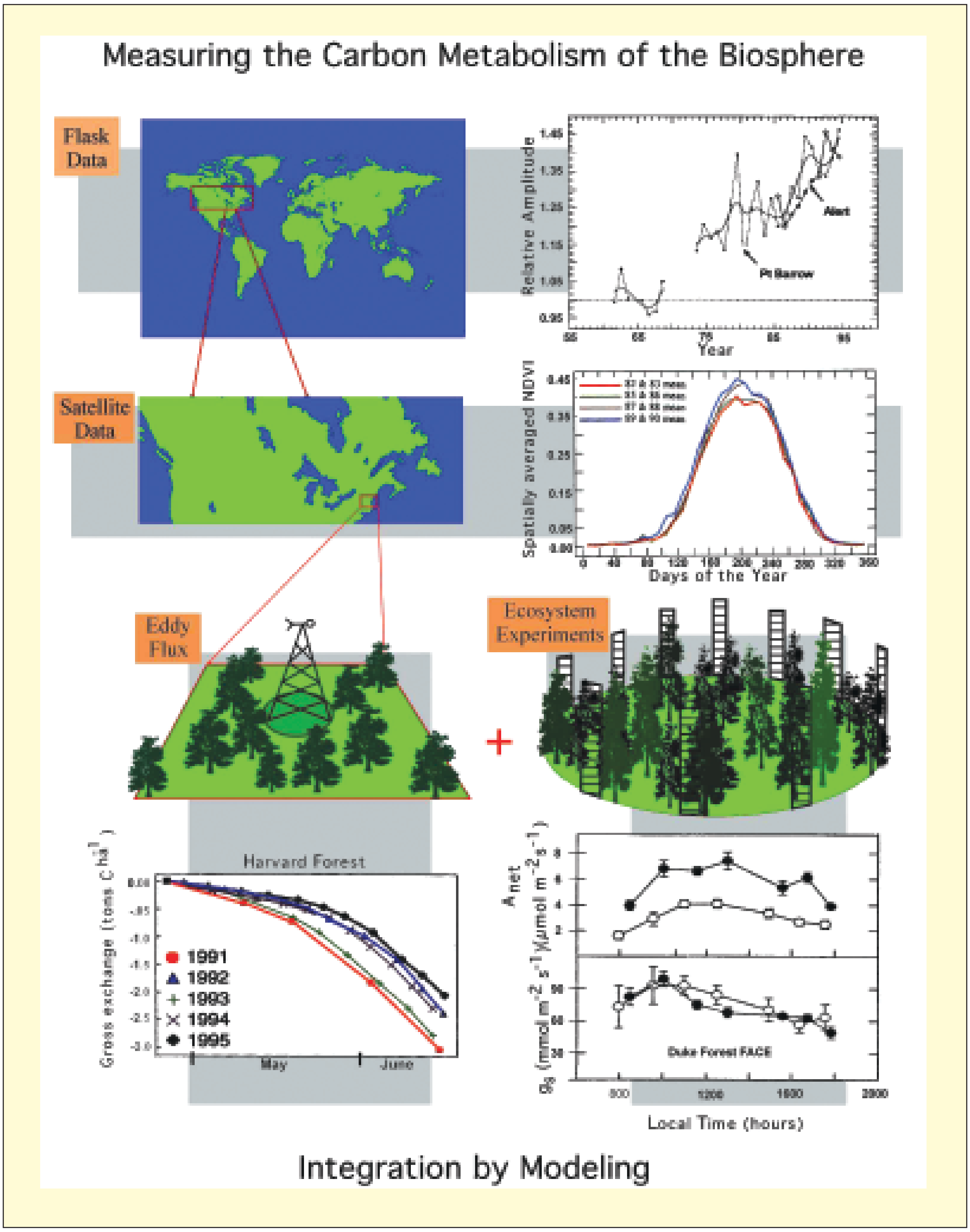


Figure 8. Measuring the carbon metabolism of the terrestrial biosphere: techniques and results (Canadell et al. 2000).

pCO_2 and time-series measurements; the enhancement of carbon-tracer measurements along repeat ocean sections; the development of satellite measurements of CO_2; the construction of spatially explicit human dimensions data sets and their integration with biophysical data; the description and quantification of land-cover change; and the scaling of data from process studies through regions to the globe.

Extending Case and Process Studies

Case and process studies provide the fundamental building blocks of mechanistic knowledge essential for system-level understanding. For example, a major challenge is to build upon and move beyond case studies and test hypotheses about the interactions of land-use, demographic change and economic development. The mechanisms by which industrial systems are transformed will provide insights into whether, and when, energy systems can be "decarbonized" (**Figure 9**). Case studies on institutional development and evolution will provide essential understanding of how human societies are responding to the carbon challenge (**Figure 10**).

On the biophysical side, a variety of process studies is needed to tackle specific questions, from the ways in which ocean circulation and nutrient availability constrain ocean-carbon uptake, to the response of soil carbon to changing temperature and moisture.

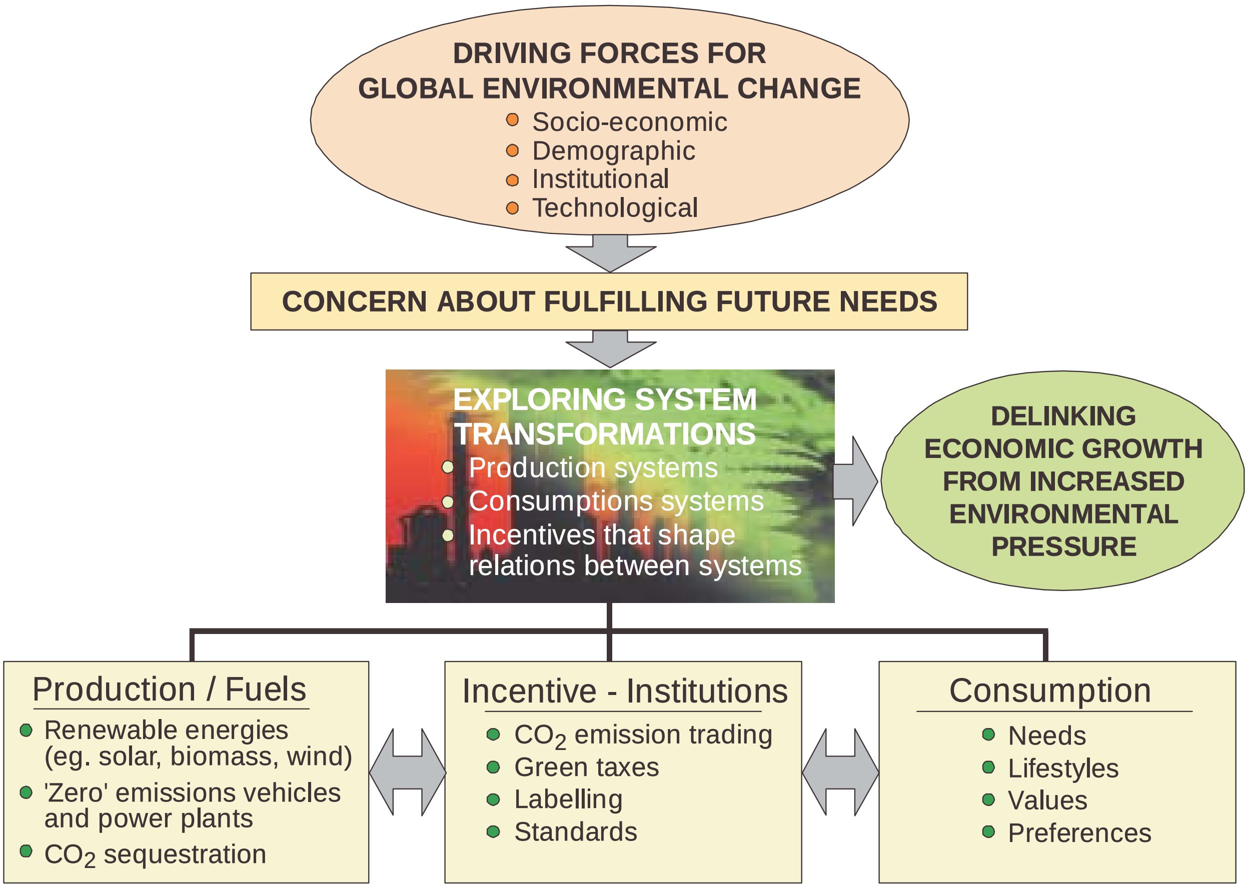


Figure 9. Decarbonising the energy system. Global environmental changes that are driven primarily by socio–economic, demographic, institutional and technological systems compel societies to satisfy human needs. However, changes in these systems are initiated only when the perceptions of current or future needs are threatened. Meeting current and future energy demands while minimizing global environmental impacts is a challenge for a global society. It requires major transformations of energy systems in both production and consumption, and the incentive structures that shape the interaction of the two. Possible options for transformations include a shift to renewable energies, introduction of CO_2 emissions trading, and changes in lifestyle and values. (Figure adapted from Vellinga and Wieczorek, 2000).

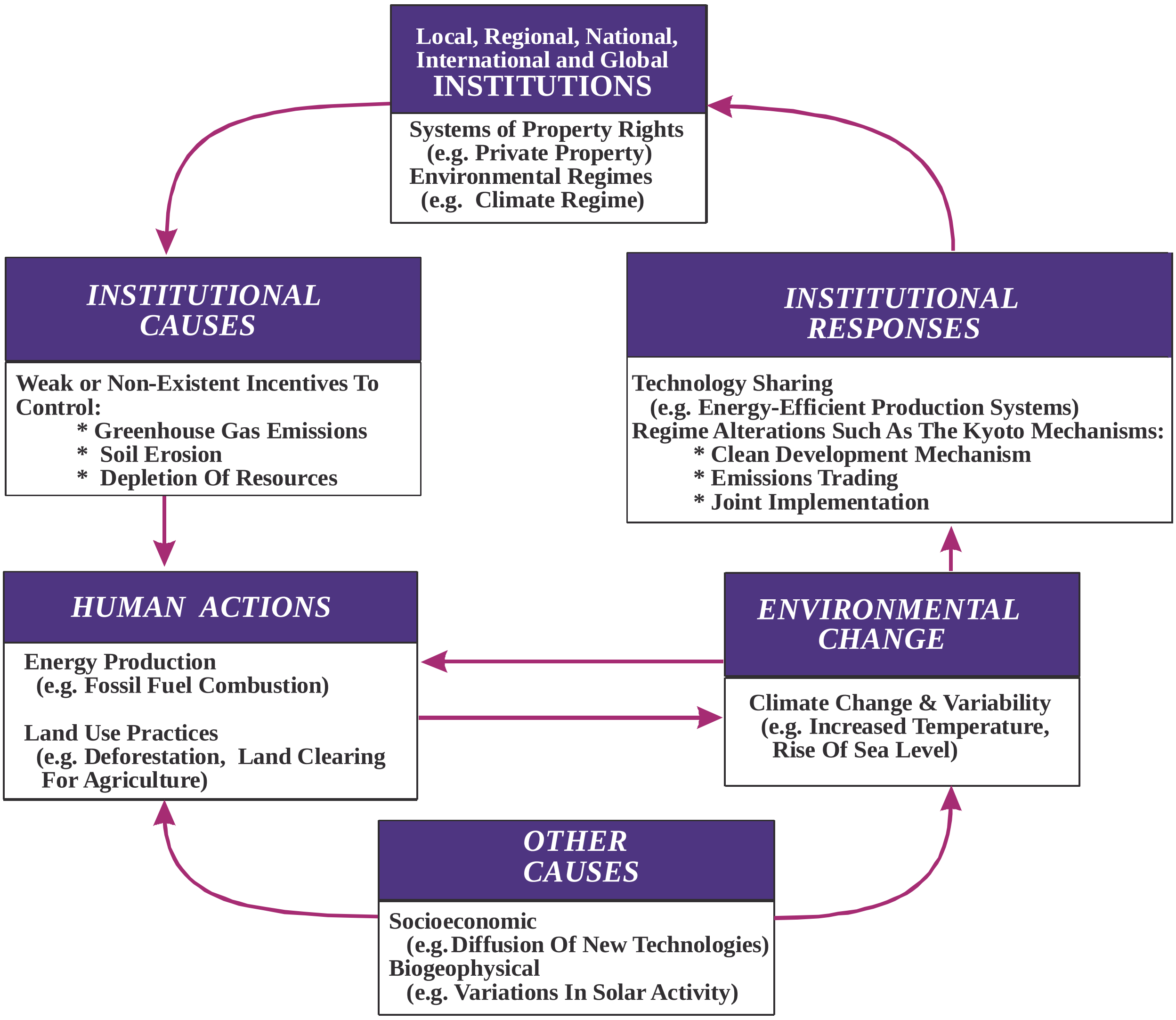


Figure 10. Institutions and their effects on the carbon cycle. (Adapted from Young et al. 1999).

Putting the Pieces Together

The three co-sponsors of the Global Carbon Cycle Joint Project are already carrying out or starting up a wealth of carbon-cycle research, providing many of the pieces required for the framework. The examples given below are representative rather than exhaustive:

IGBP has a long-standing suite of carbon-research activities. They range from iron fertilization experiments in the ocean; experimental studies of terrestrial ecosystem response to warming and elevated CO_2; budget approaches to coastal-zone carbon fluxes; and comparisons of a wide range of models related to the carbon cycle.

IHDP has initiated a suite of key carbon-related activities, including a flagship project on institutional approaches to managing the carbon cycle; research on industrial transformations and the decarbonization of energy systems; and the implications for human security of changes in carbon-cycle dynamics.

WCRP provides the modelling tools for climate variability and change essential for understanding interannual to intercentury variability in the carbon cycle; the strong control of oceanic and atmospheric circulation over carbon transport and storage; and links between the carbon and hydrological cycles.

The three programmes already work together on some areas of carbon-cycle research. For example, WCRP and IGBP work closely together on climate variability and have established a programme of ocean-carbon measurements. The IHDP and IGBP jointly sponsor a project on land-use and land-cover change, including its implications for the carbon cycle.

National and regional carbon research programmes will also contribute strongly to the Project. Conversely, the enhanced global understanding from the Project has considerable potential to feed into national and regional programmes by providing a common global context within which to study particular aspects of the carbon cycle.

National projects:
The United States and Australia are examples of countries with well-developed science plans for national-level carbon-cycle projects and are beginning to implement them. Other national-level projects are being developed around the world, from Japan to the Ukraine, Sweden and China.

Regional projects:
CarboEurope is an extensive cluster of projects in Western Europe with a regional-scale approach to carbon research. The Large-Scale Biosphere–Atmosphere Experiment in Amazonia, although not focused solely on the carbon cycle, provides complementary regional-scale information on the carbon dynamics in a developing country.

Key International Linkages
Global observations are an important component to understanding the carbon cycle. Linking global observations with models and experiments are key to interpreting and predicting the past, current and future dynamics of the global carbon cycle. The challenge of obtaining and disseminating global carbon-cycle observations has been taken up by the Integrated Global Observing Strategy Partnership (IGOS-P). IGOS-P is a consortium of space agencies, *in situ* observation organisations, and international research programmes. Building on a first phase of terrestrial-carbon observations, IGOS-P is now working on a flexible and robust strategy for acquiring international, integrated, global carbon observations over the next decade. The aim is to build a globally consistent network of observations from both space and Earth platforms. The partnership is being coordinated in synchrony with the development of the Global Carbon Cycle Joint Project. The challenge of developing an integrated global system of both remotely sensed and *in situ* observations will undoubtedly accelerate the development of new observation technologies and data-handling systems within the context of Earth System Science and the global carbon cycle.

Each of the activities or projects mentioned above, and many others, provides essential pieces of the puzzle needed to understand the global carbon cycle. The Joint Project provides a framework within which to put these pieces together and, with new work to fill gaps, build a coherent global picture. Finally, the Project will also encourage the exploration of new issues and future pathways of the carbon cycle that have not yet been envisaged (**Figure 11**).

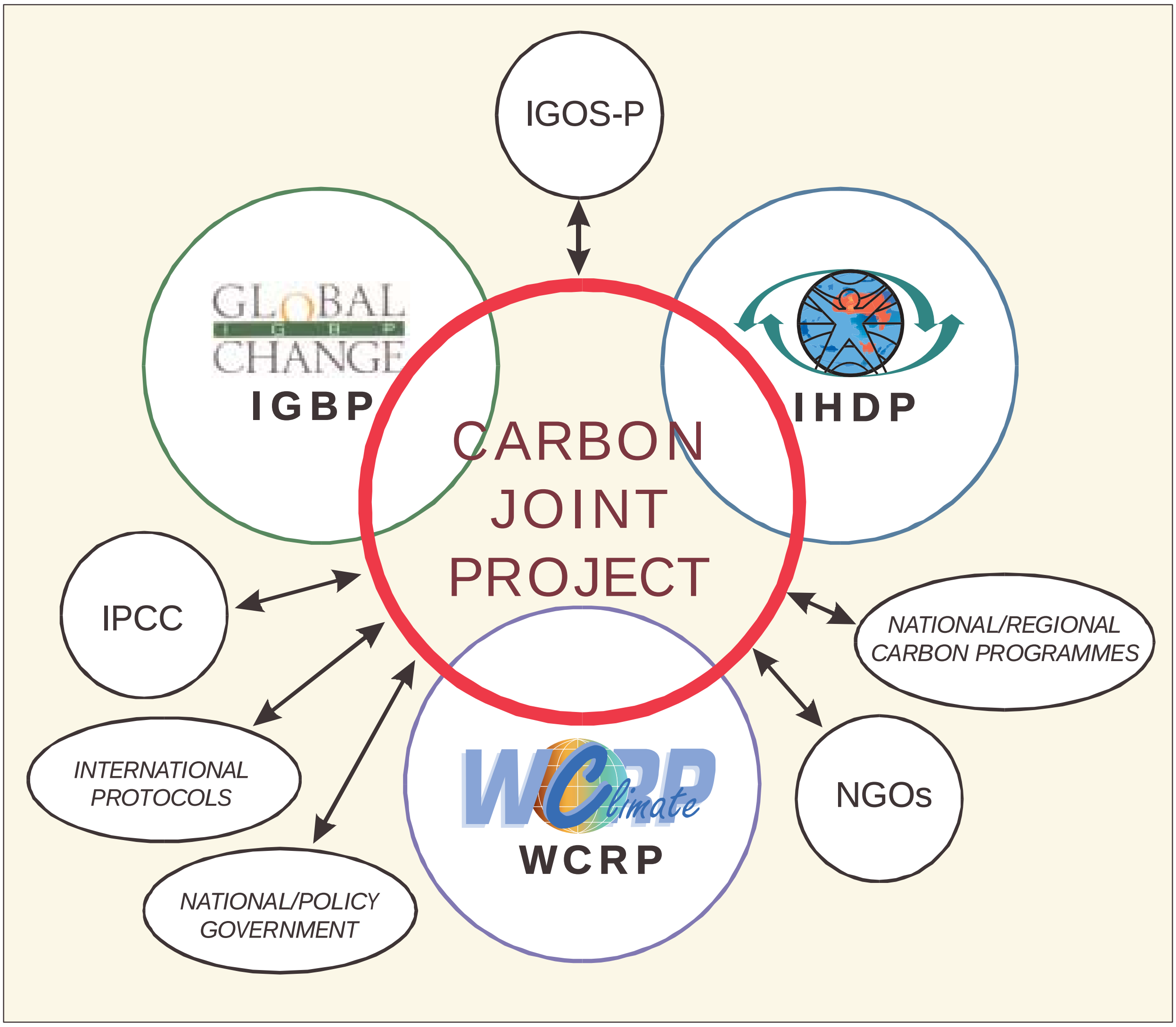


Figure 11. Conceptual diagram showing the relationship between the Global Carbon Cycle Joint Project and other groups involved in carbon science. Much of the research in the Project will come from existing and planned research in the three sponsoring global environmental-change programmes—IGBP, IHDP and WCRP. In addition, national and regional carbon programmes (e.g. CarboEurope, Carbon Australia, US Carbon Cycle Initiative) will contribute valuable research. The Global Carbon Cycle Joint Project provides a framework for integrating these many pieces of carbon science and for initiating new work where gaps are found. It will also work closely with the Integrated Global Carbon Observing Strategy being developed under the auspices of IGOS-P, and interact with the assessment community (e.g. Intergovernmental Panel on Climate Change, IPCC), the national and international policy community, and non-governmental organisations (NGOs).

POLICY IMPLICATIONS

The ultimate goal of the Global Carbon Cycle Joint Project is to provide societies with the scientific knowledge on which to base their discussions, debates and actions to influence the future dynamics of the carbon cycle. Although much excellent carbon-cycle research is being carried out at national and regional scales, its geographical focus prevents it from being accepted by *all* countries as a "common scientific currency" that can inform discussion and decision in a sound, objective fashion. The need for an international approach to such a knowledge base is undeniable (**Figure 12**).

It is also important to acknowledge the relationship of a research-driven activity (Global Carbon Cycle Joint Project) to assessment activities such as those of the Intergovernmental Panel on Climate Change (IPCC), and to the development of a global, carbon-observing system through IGOS-P. The importance of this trio of linked carbon-cycle activities—research, assessment and observation—cannot be overstated. Together they form an internationally coordinated attack on a major global environmental problem, and are perhaps the first systematic attempt to provide a comprehensive knowledge base for the ongoing management of a major Earth System function.

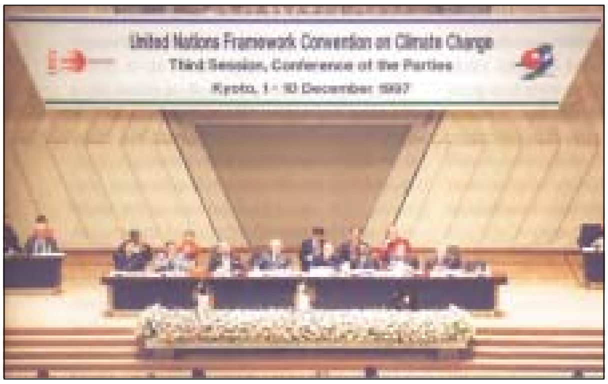


Figure 12. Institutions in action. The Third Session of the UNFCCC Conference of the Parties in Kyoto in 1997. (Photo courtesy of IHDP).

MANAGEMENT STRATEGY

The Global Carbon Cycle project is a joint venture involving three equal partners: the International Geosphere–Biosphere Programme, the International Human Dimensions Programme, and the World Climate Research Programme.

The project will be managed by a Scientific Steering Committee co-chaired by three people (one from each partner programme) who are jointly responsible for the management of the project. To complete the committee, up to five additional members will be selected by each programme. Staff support during the planning stage of the Global Carbon Cycle Joint Project was provided by IGBP's Global Analysis, Integration and Modelling project (GAIM). Dr. K. Hibbard of GAIM served as Executive Officer during the preparation of this document.

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