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Impacts of trace gas fluxes in mid-latitude ecosystems

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Introduction

The temperate region is highly populated, with most ecosystems in the region subject to at least some human influence. Large areas of forest and grassland, for example, have been converted to agriculture, and many systems are receiving increased inputs of sulfur and nitrogen compounds associated with acid rain and industrial activity. These changes have the potential for having major effects on trace gas production and consumption within the region.

Although there have been many trace gas studies in the midlatitudes, only a few flux estimates, however, have been based on frequent measurements made over an entire year: most studies have been mechanistic in nature and have focused on small areas (e.g., individual fields). Consequently, the effects on trace gas fluxes of converting native to agricultural lands, and of loading ecosystems with nutrients (N and S) and potential toxins are just beginning to be understood on a regional scale.

Because mechanistic controls on trace gas fluxes are best understood for temperate ecosystems, these systems provide an opportunity for modeling fluxes at a regional level that is not available for most other regions. Moreover, the geographic information base necessary for developing reliable large-scale models is available. Temperate regions thus offer the opportunity to rapidly develop the approaches necessary for spatial and temporal extrapolations in all regions worldwide.

We have identified five critical questions that need to be addressed in order to improve substantially our understanding of mid-latitude trace gas fluxes and their impacts on global processes. Four questions address specific scientific issues and the fifth is a methodological problem:

1. How important are mid-latitude ecosystems as net CO_2 sinks?
2. How important are mid-latitude ecosystems as net sinks for CH_4?
3. How important are mid-latitude agronomic systems as sources for the atmospheric N_2O increase?
4. How important are mid-latitude ecosystems as sinks for atmospheric oxidants and sources of oxidant precursors?
5. What further techniques are needed for modeling, extrapolation, and validation of trace gas fluxes in heterogeneous landscapes to regional and global levels.

Each of these questions will require a combination of measurement, manipulation, and modeling approaches. Developing regional extrapolations and models will require extensive international cooperation to be successful.

We suggest a single unified approach for addressing each of these questions. At its center is a network consisting of core and satellite sites that will encompass an appropriate variety of community composition, land-use, chemical deposition, climate, and soil-type categories. Where possible these sites will be part of existing national research networks. At core sites appropriate trace gas fluxes should be measured and the mechanistic studies necessary to develop process-based models undertaken. Process-based models will be integrated into large-scale models that can then be validated and used to estimate regional gas fluxes and how they may respond to changes in climate, chemical deposition, and land-use.

Project 1: How important are mid-latitude ecosystems as a net CO_2 sink?

Atmospheric CO_2 concentrations continue to rise as a result of human activity. The CO_2 increase reflects only a fraction (40–60%) of the CO_2 that is released via anthropogenic sources (Berner and Lasaga 1989, Tans et al. 1990). Tracer and modeling studies (linked to the global CO_2 monitoring network) indicate that the oceans cannot account for the imbalance in the global carbon budget (Tans et al. 1990).

Some estimates suggest that terrestrial ecosystems are a source of CO_2, yet new data and analyses suggest that increased mid-latitude carbon storage may account for the "missing" carbon (Tans et al. 1990). Several events support this idea. Large portions of the mid-latitudes have undergone substantial land-use changes since 1900, including extensive reforestation with the resulting C-storage in woody biomass and soil organic matter. With much of the present forest area in the region now in a midsuccessional, aggrading stage, it is possible that mid-latitude forests are a significant net C-sink. Moreover, increased levels of precipitation-N and atmospheric CO_2 may have boosted net primary production, amplifying this potential sink. In addition, new agricultural practices (e.g. reduced tillage) focus on increasing soil organic matter pools, thereby acting as a C-sink. On the other hand, the potential mid-latitude C-sink may be reduced or reversed if acid deposition, accumulation of toxic ozone levels, or nitrogen saturation (Aber et al. 1989, Loucks 1989) result in significant forest decline and production losses in agricultural ecosystems.

We believe the potential for significant carbon storage in mid-latitude forest is sufficiently strong to warrant immediate, intensive investigation. If such storage is occurring, and if changes in CO_2 concentration and chemical deposition affect the potential trend, it may help to balance estimates of the global CO_2 budget. This could also suggest new strategies for ameliorating the global atmospheric CO_2 increase.

Objectives

1) To determine the consequences of changing land use (reforestation, succession, deforestation, and urbanization) on C-storage in mid-latitude ecosystems.
2) To evaluate the effect of changing physical climate (temperature, moisture) on CO_2 exchange.
3) To evaluate the effects of chemical deposition (N, S, and acid) on CO_2 exchange.
4) To determine the effects of elevated CO_2 on the gross and net CO_2 exchange of representative mid-latitude biomes.

Research plan

Measurement

We propose to establish site networks in temperate forests and agricultural ecosystems, which will include forests of varying successional age and both forest and agricultural sites on different soil types and management regimes. Where possible, these networks will be the same as those used for the CH_4 and N_2O studies (Projects 2 and 3). We will measure net primary production (NPP), soil respiration, decomposition, C-fixation, ecosystem CO_2 exchange (by micrometeorological methods), and the climatic and biotic variables that drive these processes. These will be measured intensively over at least 2 years to determine seasonal patterns and key environmental controls of CO_2 exchange. After this intensive sampling period is over, measurements will be continued at a reduced level to determine interannual variation and long-term changes in site C-dynamics.

Manipulations

Plots in each core site of the networks will be manipulated to improve our understanding of the long-term effects of various climatic drivers (physical and chemical) on ecosystem function and trace gas exchange. These manipulations will include: increased air and soil temperature, altered moisture, elevated CO_2, and fertilization (N and S). Field and laboratory studies should examine the interactions of different perturbations (e.g., temperature and moisture).

Manipulative studies need to evaluate whole plant physiological responses, as well as soil microbial responses (e.g., root respiration, decomposition and mineralization rates). These studies must operate continuously for several years (at least 3 and preferably 5 to 10 years) to study several growth cycles, which will affect the cumulative N-availability and carbon storage of the system.

For studies in agricultural systems, manipulations should be based in field-greenhouse systems, in which all of the parameters of interest (temperature, moisture, nutrients) can be controlled. In forest studies, the size of the vegetation makes air temperature and CO_2 experiments difficult. Most such experiments have been done on seedlings and saplings, but the physiological responses of immature plants differ from their mature counterparts (Kramer and Kozlowski 1979). In forest systems, therefore, work should start with soil manipulations on plots several tens of meters per side. This should include combinations of soil temperature (several degrees above ambient), moisture (increased and decreased), and nutrient addition.

Parallel experiments should start at a more limited scale, evaluating whole tree responses to increased CO_2 and temperature. These studies may be done in either open-top chambers or in field-greenhouses. Both systems have their limitations: in open chambers it is more difficult to control CO_2 and temperature, but chambers leave plants exposed to actual environmental conditions (e.g. light and precipitation), for which greenhouses require extensive engineering. Whichever approach is used, it must address the role of CO_2 enrichment on all of the components of the ecosystem: photosynthesis, respiration, allocation, leaf nitrogen content, and their consequent effects on decomposition and mineralization. Moreover, the experiments must be run through a sufficient number of growth cycles to identify potential system-level feedbacks.

Resources
For the field experiments, there are a number of national research networks that will be valuable, including the Long Term Ecological Research (LTER) sites in the USA, site networks in western Europe, and in the Peoples Republic of China. There are a number of teams worldwide capable of measuring CO_2 fluxes by micrometeorological methods, including groups in the USA, Canada, Europe, and Asia. Facilities for doing whole tree studies are somewhat limited and new facilities may need to be established.

Timetable

1991–	Establish site networks. Begin experimental work. Begin model development.
1992–93–	Continue field and laboratory experiments.
1994–	Integration and validation.

Project 2: Are mid-latitude ecosystems important net sinks for CH_4?

Especially in the northern hemisphere, the temperate region is highly populated, and humans may be significantly altering the regional CH_4 budget. Industrial activities have dramatically changed local environments and altered regional precipitation chemistry. Landfills in industrial countries and waste-water lagoons in developing countries may represent intense but highly localized sites of CH_4 production: landfills may be collectively responsible for as much as 7% of the global CH_4 budget (Cicerone and Oremland 1988). Drainage may have shifted many wetlands from being net to neutral CH_4 sources or even to net CH_4 sinks.

Nitrogen inputs in precipitation have increased substantially over the past 40 years in much of the temperate northern hemisphere . Today, some areas receive as much as 50 kg N ha^{-1} y^{-1} in atmospheric deposition (wet and dry fall). This can represent as much as 15 Tg N added annually to temperate region forests, such an increase in N-deposition may significantly reduce CH_4 oxidation in forest soils (Melillo et al. 1989, Steudler et al. 1989).

We need to evaluate the effects of N-deposition, landfills, and wetland drainage on CH_4 fluxes in mid-latitude ecosystems. Two subprojects are outlined; the primary project addresses the effects of N-availability and fertilization on CH_4 consumption, and the second addresses CH_4 emissions resulting from landfills and drained wetlands.

Project 2a: The effects of N-availability (added-N, native-N) on CH_4 oxidation

The linkages between N-availability and CH_4 flux are poorly understood but perhaps significant; Steudler et al. (1989) reported that two years of low-level N-additions to both coniferous and deciduous forest soils in central Massachusetts, USA reduced CH_4 uptake rates by 45 and 34%, respectively. Moreover, both forests and agricultural ecosystems with high rates of nitrogen cycling and nitrification appear to exhibit low CH_4 oxidation rates (Melillo et al. 1989). If such relationships hold in general, major changes in land-use (e.g., native to agricultural) and widespread chemical deposition may be having major impacts on regional CH_4 fluxes. This project is designed to test the generality of the linkage between N-availability and CH_4 fluxes.

Objectives

1) To quantify the role of mid-latitude ecosystems as sinks for atmospheric CH_4.
2) To quantify the relationship between N-availability and CH_4 oxidation in grassland and forest systems of the temperate zone.
3) To formulate a model for quantitative estimates of CH_4 oxidation in forest and grassland that accounts for the effects of three major controls on oxidation-temperature, moisture, and N-cycling rate (includes both N-deposition and native-N).

Research plan

This project should have both intensive and extensive components:

Intensive research plan
1. Locate 10 grassland sites and 10 forest sites around the world that are well characterized in terms of climate, vegetation, soils, and N-cycling rates.
2. Establish fertilization plots at each site. Two levels of fertilization would be established, 50 and 100% increases over annual net N-mineralization rates, which will be measured prior to study.

3. Perform monthly measurements of CH_4 uptake; these will be made throughout the diurnal cycle. At the same times, measure temperature, moisture, and various N-stocks.
4. Perform month-long integrative measurements of soil N-dynamics to establish mineralization and nitrification rates.
5. Develop a model to estimate CH_4 production and consumption as a function of temperature, moisture, and N-cycling.

Extensive research plan
Extensive research will be focussed on testing the models developed in the intensive component of the project. To do this, additional well-characterized sites (forest and grassland) will be identified. Methane fluxes will be estimated from the models and tested by field measurements of CH_4 uptake.

Project 2b: Net CH_4 emissions from landfills and wetlands

Landfills, feedlots, and wetlands may be major temperate-zone biogenic CH_4 sources. Maximum CH_4 fluxes from landfills may be up to 600 g m^{-2} yr^{-1} (Bogner et al. 1989), while wetland fluxes may be up to 100 g m^{-2} yr^{-1} (Harriss 1989). Temperate wetlands have decreased in area over the last century while landfills have increased. The changing role of these areas is a poorly understood component of the global CH_4 cycle. We need to determine how wetland drainage and changing landfill designs have affected and will continue to affect the global CH_4 cycle.

Objectives

1) To estimate long-term changes in mid-latitude CH_4 production from wetlands, landfills and feedlots.
2) To elucidate CH_4 production/consumption relationships in landfills and how these are controlled by changing landfill management, with a view to reducing CH_4 emissions.

Research plan

Basic field measurements
1. Establish field sites for CH_4 flux measurement in landfills and feedlots. These should cover humid, semi-arid, and arid sites. Establish sites in landfills with various management regimes.
2. Establish field sites in temperate wetlands and drained wetlands.
3. Measurements at each sites should include: CH_4 flux by chamber techniques, soil gas profiles (CH_4, CO_2, O_2), stable-C-isotope profiles, and soil moisture/temperature/soil gas profiles.
4. Measure both diurnal and seasonal CH_4 fluxes in wetlands, landfills, and feedlots over a two year period.

Manipulation experiments
Manipulations of soil water content, gas pressure, and landfill type will be combined with $^{14}CH_4$ field studies to evaluate CH_4 and CO_2 production, consumption, and transport.

Extrapolation and modeling
Gas flux modeling for landfills will be based on two dimensional diffusional and convective gas flux models incorporating production/consumption reactions. This will be combined with areal estimates of different landfill types.

Reduction in CH_4 source due to wetland drainage will be estimated from the difference in net CH_4 production by drained and undrained wetlands and by the reduction in wetland area, as determined from geographic data bases.

Resources
There are several valuable research site networks in North America, Europe and Asia for determining CH_4 fluxes from natural systems. There are established programs on landfill trace gas emissions in both the USA and Europe.

Timetable

1991–	Establishment of site networks.
	Begin monitoring studies for both natural and landfill projects.
	Begin model development.
1992–1993–	Continue studies.
1994–	Begin validation exercises.

Project 3: How important are mid-latitude agronomic ecosystems as sources for the increase in atmospheric N_2O concentration?

The N_2O concentration of the atmosphere has increased from 280–285 ppb 100 years ago to c. 310 ppb today. The present rate of increase is estimated at c. 0.25% yr^{-1}, corresponding to a net global emission of 3.5 Tg yr^{-1} (Robertson et al. 1989, Stewart et al. 1989) and c. 4–5% of global warming effects can be attributed to N_2O. In spite of its relatively low concentration, the long atmospheric lifetime of this gas (100–200 yr) and its strong IR absorption make it significant in the earths radiation balance. Nitrous oxide is also the primary non-synthetic compound involved in the depletion of stratospheric ozone.

Bouwmann (1990) estimated that c. 90% of N_2O emissions are from soils, but the specific sources are not all well characterized. World-wide agricultural inputs of N from biological and industrial N_2 fixation are c. 60 and 90 Tg yr^{-1} respectively (Hauk 1988), and the loss of only 2–3% of this N as N_2O could account for the entire observed annual increase in atmospheric concentration. Few studies, however, have found more than 1% of fertilizer being lost as N_2O, but data are far from complete (Stewart et al. 1989).

Almost 45% of the world fertilizer consumption currently takes place in North America and western Europe (most of the remainder being used in Asia). The need to increase food production in temperate Asia and eastern Europe has and will continue to stimulate increased fertilizer use in these areas (Crosson and Rosenberg 1989). The extent to which fertilizer use may exacerbate the current N_2O increase – either directly by N_2O production in the farm field or indirectly via N_2O production in riparian, coastal marine, and other downstream systems – needs to be understood.

We also need to know the system-level mechanisms responsible for N_2O fluxes. Nitrous oxide production in soils results predominantly from two microbial processes: nitrification and denitrification. Nitrification may be the most important source of N_2O in well-drained agricultural soils, whereas denitrification may be more important in poorly drained soils (and wetlands receiving NO_3^--rich drainage water).

Key questions regarding N_2O emissions from mid-latitude agricultural systems include:

1) What is the relative importance of nitrification vs. denitrification vs. other potential biological sources?
2) To what extent can these processes be ameliorated by acceptable changes in agricultural practices, e.g.: improved water management (irrigation and drainage), improved fertilizer management, inhibition of nitrification/denitrification, alterations to tillage practices and livestock management.
3) How much to the NO_3^--N that leaves agricultural fields as surface runoff and groundwater is ultimately lost as N_2O following transfer in drainage water to wetlands and estuaries?

Objectives

1) To improve regional estimates of N_2O emission from mid latitude agricultural ecosystems by the use of quantitative modeling.
2) To determine the principal factors governing N_2O emissions from agricultural ecosystems. This is critical both for modeling and developing management practices that will reduce N_2O emissions without jeopardizing food production.
3) To determine the extent of N_2O emissions from natural systems receiving N-inputs from agricultural lands as a result of N-transport in drainage water and the atmosphere.

Research plan

Regional extrapolations need to be based on precise and representative measurements of N_2O fluxes from agricultural ecosystems on the scale of the individual farm field (i.e., of the order of 1 to 100 ha, depending on the region). This is necessary because management systems, including N-fertilization, vary widely between adjacent fields. Scaling from the individual fields to the regional level will rely on geographically-based models that incorporate key management practices. For many countries good data bases already exist, which contain information on N-inputs, tillage, N-losses, and other management factors expected to affect N_2O fluxes.

We propose the establishment of core networks in major agricultural regions, each with sites covering a range of crops, soil types, and management systems typical of the region. At each site, N_2O fluxes should be determined and related to the controlling factors, some of which (N-input, irrigation, inhibitors, etc.) may be manipulated. N_2O fluxes from these sites should be periodically monitored over 24 h periods for two years. The sampling frequency should be centered around conditions of particular significance (e.g., following rainfall). Parallel measurements will be made on those factors which control N_2O fluxes, including N-pools, N-cycling rates, temperature, moisture, etc. Fluxes of N_2O should also be determined in selected sites (terrestrial and aquatic) receiving N-inputs as a result of agricultural operations.

We also suggest that the development and application of promising N_2O detection technologies be accelerated. At present, N_2O flux data are primarily dependant on the use of small (i.e. <1 m^2) chambers and gas chromatographic analysis. Low N_2O flux rates relative to background concentrations have made N_2O fluxes difficult to measure by micrometeorological methods (Desjardins and MacPherson 1989). Even though tunable diode laser sensors (TDLAS) for N_2O are still at an experimental stage, they appear to be sufficiently sensitive to measure N_2O fluxes using the eddy correlation technique. In order to arrive at large area flux estimates, sensors also need to be developed for aircraft-based systems. The use of new measurement techniques may also be used with more traditional chamber methods. Tunable diode lasers or Fourier transform infrared (FTIR) may be used in conjunction with extended chambers (up to 10 m long) to take advantage of the sensitivity gain achieved by containment, while at the same time overcoming much of the spatial variability associated with the traditional chamber design by enclosing a long strip of land. Cross calibration of chambers against tower-based measurements using TDLAS will make it possible to use data already gathered by chambers and to continue their use where logistical/financial constraints preclude the use of other techniques.

Along with these measurements, process-based models of N_2O fluxes will be developed and integrated into ecosystem and regional models (e.g. Parton et al. 1988). After development, the models will be tested by extensive flux survey measurements.

Resources
Many groups have been studying N_2O dynamics in agricultural systems around the world, and a number of well characterized longterm agricultural experiment sites have been established, including such sites as the Broadbalk plots in England, which have been studied for over a century.

Timetable
1991– Workshop to bring together workers who have been examining nitrification, denitrification, and N_2O fluxes, to coordinate this program with their efforts.
1992– Establish site networks.
Begin measurements.
Begin model development.
1993– Continue experimental work and modeling.
1994– Begin validation efforts.

Project 4: How important are mid-latitude ecosystems as sinks for atmospheric oxidants and sources of oxidant precursors?

The mid-latitudes contain a substantial fraction of the terrestrial surface of the globe, and have been assumed to provide a substantial fraction of the natural CO and NOx emissions to the atmosphere (Johansson 1989, Khalil and Rasmussen 1990). The magnitude of the emissions, and the processes controlling them are poorly understood, yet the supply of CO and NOx to the atmosphere constitutes a primary control of oxidant production (O_3, H_2O_2; Bouwman 1990). Terrestrial ecosystems also represent a major sink by dry deposition for tropospheric O_3, a process that while better understood than NOx emissions, is still subject to uncertainties. Fluxes have been measured in very few mid-latitude ecosystems, and the presence of large areas of enhanced O_3 concentrations within and downwind of industrial regions presents a phytotoxic stress to many plant communities (Loucks 1989). Effects of this stress on physiological processes and on the exchange of heat, water vapor, CO_2 and a range of trace gases have been observed but cannot be quantified on regional scales with our current understanding.

Volatile organic compounds (VOCs) emitted by plant canopies provide a further control on the production of photochemical oxidants. Mid-latitude ecosystems are thought to be important source areas of volatile organic compounds (VOC) including isoprene, terpenes, and possibly alkenes, yet the magnitude of the fluxes and the controlling physical, chemical, and biological processes remain poorly understood.

Lastly, mid-latitude ecosystems contain large areas in which regional modification of chemical deposition, notably but not exclusively in Europe and North America, has altered the cycling of major plant nutrients (e.g., nitrogen and sulfur). The effects of N, S and acid deposition on nutrient cycling and trace gas exchange (including N_2O, NOx, O_3, and CH_4) remain unclear.

Objectives

1) To quantify the strength of mid latitude ecosystems as sources for atmospheric oxidant precursors (NOx, VOC) and sinks of oxidants (O_3 and NOx).
2) To evaluate the response of mid-latitude biogenic sources of NOx and VOC to changes in the climate and chemical deposition.

Research plan

Three areas of scientific activity are required to meet the above objectives:
1. Long-term field measurements of O_3, NOx, and VOC fluxes in representative ecosystems, and of the associated physical, chemical, and biotic controlling variables.
2. Process directed field and laboratory studies to determine the fundamental mechanisms and controls on the production, transport and dispersion of oxidants and their precursors.
3. Modeling of O_3, NOx, and VOC gas exchange processes, extrapolation to regional scales and field validation.

We propose establish networks of sites in areas subject to intensive ozone deposition (eastern North America and western Europe) and in control regions. Stations should be established within these regions to measure concentrations of O_3, NOx, and VOCs. Sets of measurements should be carried out diurnally through the year to determine seasonal patterns of exchange and to evaluate the primary environmental controlling factors. Experimental work should be carried out to determine the specific process controls necessary to model gas exchanges. These mechanistic models will be used to develop regional and temporal extrapolations.

Resources
There are several established national projects evaluating biotic interactions with the oxidant cycle, including groups in North America (LTER), western Europe (European experiment on transport and transformation of environmentally relevant trace constituents in the troposphere over Europe [EUROTRAC]), the former Soviet Union, and the Peoples Republic of China.

Timetable

1991–	Workshop to coordinate efforts of the different national and international programs and to plan the activities needed to scale these projects to the global perspective called for in this program.
1992–4–	Coordinated experimental work. Work on model development.
1995–	Begin model validation studies.

Objectives

1) To develop models of CO_2 fluxes capable of depicting fluxes over landscapes and producing regional-scale estimates of CO_2 fluxes.
2) To develop a georeferenced data base necessary for extrapolation of process-level models of CO_2 fluxes to a regional estimate.
3) To develop and apply methods for validating these models.

Project 5: Modeling, extrapolation and validation of trace gas fluxes in mid latitude ecosystems: A CO_2 pilot study

A need in most IGBP research programs is to extrapolate flux estimates from plot-based measurements to regional scales. This extrapolation requires the development of large-geographic-scale, process-based models and their subsequent validation. Several programs have initiated research to this end for areas with relatively homogeneous vegetation (e.g. First International Satellite Land Surface Climatology Project Field Experiment [FIFE], Atmospheric Boundary Layer Experiment [ABLE], Northern Wetland Study [NOWES], etc.). The next step is to develop scaling techniques for complex landscapes. We propose a pilot study to develop such techniques, and have targeted CO_2 because the necessary components are all available: conceptual understanding of the processes, flux measurement techniques (chamber, micrometeorological, and aircraft based) and powerful process-based models. This study will relate directly to Project 1, and will also help develop techniques needed for the other projects and for other regions as well.

A key tenet of scaling efforts is to integrate data on trace gas fluxes into overall ecosystem nutrient cycling models. Development of large-area-estimates of trace gas fluxes requires linking process-level models with georeferenced data sets containing variables relevant to both process and region levels. Geographic information system (GIS) development has been vigorous for the mid-latitudes and a wide range of variables at different scales are available for extrapolation efforts. Ecosystem models have already been adapted to incorporate N_2O and CO_2 fluxes into regional models (e.g. CENTURY for grassland; Parton et al. 1988, Burke et al. 1989) and ongoing efforts will expand this application to other gases (e.g., CH_4) and ecosystem types (forest, agriculture). The availability of the data sets and ecological understanding described above, in combination with the technical resources and institutions in the mid-latitudes, make it logical to conduct this pilot study in the mid-latitude regions.

Research plan

We propose a specific case study where each step in the extrapolation from process studies to a regional flux estimate is coordinated. Strong interaction and cooperation will be necessary between investigators performing detailed process studies, mesoscale modeling, and meteorological measurements using either aircraft or towers. This coordination is crucial since the object of the study is to cross-validate measurements made at differing spatial and temporal scales. CO_2 is the best candidate gas for this study due to its intermediate half-life, multiple source-sink characteristics in the soil, vegetation, and atmosphere, and heterogeneous spatial and temporal fluxes from various target areas within a region.

During the first stage of the pilot study, a measurement area of c. 100 km on a side should be selected. Preferably it will consist of a limited number of ecosystem types (e.g., a forest-agricultural mix would be ideal). At several sites in this area, measurements will be made of trace gas fluxes (including diurnal and seasonal patterns) and of other parameters needed for driving flux models. At a smaller number of sites, micrometeorological methods will be used to produce estimates of fluxes at scales of up to several kilometers. Preferably these will be automated methods so that a large number of environmental conditions will be covered and a large data set will be obtained.

After two years of process level measurements, a large boundary layer experiment will be performed. In this experiment, aircraft will be used to estimate fluxes over a large area. The fluxes will be derived from aircraft data and supporting measurements of boundary layer conditions using a budget approach so that flux estimates will be obtained for an area of up to several tens of km^2 (Schuepp et al. 1990). These estimates will be compared with those derived from models capable of depicting fluxes over the same spatial and temporal scales. The results of these comparisons will be used to evaluate both the modeling and aircraft approaches to estimating large-area fluxes in heterogeneous landscapes. We can then use high resolution data bases to identify areas responsible for the divergence of results. This divergence analysis will form the basis for changes in the models to more accurately reflect flux patterns across the region.

Specific needs

A. Data bases

The development and use of GIS for regional and global scale extrapolation of trace gas fluxes has increased in recent years. Global coverage of soils, vegetation, climate, and land-use parameters are available in a variety of formats at different locations. The IGBP global environment data directory (GEDD), which will be produced by the IGBP working group on Data and Information Systems, will provide a centralized summary of available data sets. A major challenge in the extrapolation area will be developing and evaluating geographic data that are relevant to both small-scale process models and large-area validation techniques. Balancing detail and resolution versus size and cost in global data bases will be a major concern.

B. Micrometeorological methods

Micrometeorological methods using towers and aircraft have been used for years but have mainly been applied on special selected sites with relatively homogeneous vegetation cover. In order to be useful for our purposes research is necessary to extend the applicability of these methods to heterogeneous or patchy areas of scales up to 100 km^2.

At this stage several aircraft campaigns using measurement strategies and flight patterns based upon budget or eddy correlation techniques have been successful for gases such as H_2O, CO_2 and even O_3 (Desjardins and MacPherson 1989). The nature of aircraft studies however requires that flux estimates derived from the process studies are available on timescales smaller than days. This problem could be overcome if micrometeorological methods are applied using high towers (up to 200 m) to measure fluxes over longer periods. Unfortunately this method is only applicable over spatial scales of a maximum of several kilometers. Even to this scale there have not been many attempts to compare fluxes derived from process studies with micrometeorological measurements

C. Modeling and extrapolation

It will be important to evaluate extrapolation models relative to validation approaches that will be taken. The extrapolation techniques must produce flux estimates consistent with the scale of the aircraft and/or micrometeorological approaches that produce area-averaged flux estimates. Moreover, the extrapolation techniques must be able to produce estimates at higher resolution than the validation efforts to determine where the modeling and/or validation methods fail. This information will be important to evaluation and refinement of both modeling and validation techniques.

Resources

There are a many groups worldwide with some expertise in measuring or modeling CO_2 exchanges that relates to this project. There are few groups, however, that have the expertise to handle all the components of the program. The availability of personnel trained in ecological applications of geographic data bases and modeling may be a particular problem; IGBP should consider sponsoring educational and training initiatives in these areas.

Timetable

1991–	Workshop for developing conceptual models and planning the program. Personnel from involved groups meet to identify data base needs, models, and validation approaches that the program needs. The site for the CO_2 pilot study will be chosen and the organizational structure will be planned. Other efforts (e.g. FIFE, ABLE) will provide an organizational model.
1991–1995–	Experimental work, modeling and integration studies proceed. Yearly meetings will be held to exchange information on model and database development and evaluation.

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