CCOS-Terre Development:

Needs, Initial Observing System, and Implementation Strategy

Report of a Workshop

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TABLE OF CONTENTS:

LIST OF TABLES:

Executive Summary

As part of developing a national response to the UN Framework Convention on Climate Change and the reporting requirements for this and other international conventions, as well as the need to understand the impact of climate change on Canadian ecosystems and economy, a workshop was organised under the sponsorship of the Climate Change Action Fund. The purpose of the workshop was to determine the feasibility of establishing an initial observing system for Canada's terrestrial ecosystems to meet the above needs, and also to contribute to the Global Climate Observing System. The specific workshop objectives were to:

1. Finalise objectives and scope of CCOS-Terre, and the basic design and implementation strategy
2. Identify/confirm critical satellite and in situ observations
3. Review current state, gaps, and options for improvements of the observations
4. Based on 3), identify elements of an initial observing system and a realistic implementation scenario
5. Prepare workshop report as a draft science and implementation plan for the national and international scientific community, and as a basis for discussions with decision makers responsible for the implementation of Canadian response to the climate change issue.

The workshop examined policy issues requiring climate-related information on Canada's major ecosystems (forests, agroecosystems, wetlands, and tundra) and the science questions motivated by these policy issues. The main focus was on the role of terrestrial ecosystems in the exchange of greenhouse gases (CO2, CH4, N2O), water and energy between the terrestrial ecosystems and the atmosphere given current international interest in global carbon cycles. Observation requirements for dealing with these questions were defined in detail, and existing data and observation capabilities were assessed. Based on the discussions, an initial observing system (CCOS-Terre) was defined that would provide the data and information needed for the assessment of the impact of climate change on terrestrial ecosystems of Canada, and the feedback from these to the climate system.

Workshop participants concluded that an integrated terrestrial climate-related observing system, which includes detailed site measurements, gridded observations, and analysis and modelling, can provide the essential data and information to meet the above needs. Secondly, the current status of the development of observation methods and capabilities in Canada allows the establishment of an initial observing system but significant effort is required to obtain a comprehensive, representative and integrated environmental monitoring system.

The following recommendations are made:

1. The specific interest in CCOS-Terre by the major potential contributors should be determined for four areas: input data, output products, system support, and effective use. The candidates include government agencies (AAFC, Research Branch; EC, Climate Branch; NRCA, Canadian Forest Service and Canada Centre for Remote Sensing; SC, Environment Accounts and Statistics Division), provincial agencies, university teams, and others.

2. Specific output products should be identified that have been or are now generated at the national level and are appropriate for CCOS-Terre needs. Such existing products should be assembled, together with appropriate documentation, as the initial slate of experimental CCOS-Terre products. Actions necessary to continue production of these output products should be identified, and the steps should be taken to ensure that their production continues. Actions needed to improve the quality of the output products should be defined and implemented, including the acquisition of the necessary in situ measurements.

3. A distributed, web-based capability should be established to support public access to CCOS-Terre data and products.

4. Implementation of CCOS-Terre should be supported through a scientific and technical working group and through the participation of scientific teams from the participating agencies. Furthermore, the necessary support should be provided to make CCOS-Terre operation feasible and effective through:
   - the operation of a modest but effective network of in situ observations, especially the flux tower sites.
   - the research of modelling and process studies leading to improved methods for estimating the GHG, water and energy fluxes between the terrestrial ecosystems and the atmosphere.
   - the development and implementation of systematic observation and modelling programs for Canadian wetlands and tundra, with the objective of obtaining credible estimates of GHG exchange.
   - ensuring that the appropriate institutional arrangements are put in place so that climate change-related issues for wetlands and tundra receive adequate attention.

The above recommendations should be implemented through collaboration among contributing departments and funding through CCAF, PERD, NSERC, and related programs.

1. Introduction and purpose

1.1 Background

In response to the climate change issues identified through various scientific (World Climate Conferences, International Geosphere-Biosphere Program, World Climate Research Program, others) and policy (UN framework Convention on Climate Change, the Kyoto Protocol, Biodiversity Convention, Convention to Combat Desertification) mechanisms, international organisations have agreed to initiate global observing systems for climate (Global Climate Observing System, GCOS), terrestrial environment (Global Terrestrial Observing System, GTOS), and oceans (Global Ocean Observing System, GOOS). These observing systems defined requirements and approaches for systematic, long-term global observations and also proposed implementation steps that emphasise building on existing capabilities and the key roles of national institutions. In particular, GCOS is intended to meet the needs for: (i) climate system monitoring, climate change detection and monitoring the impacts of and the response to climate change, especially in terrestrial ecosystems and mean sea-level; (ii) climate data for application to national economic development; and (iii) research toward improved understanding, modelling and prediction of the climate system.

The above planned global observing initiatives have implications for Canada, from both the policy and observation perspectives. As an example, Appendix 9.3 contains information on the national reporting requirements for the UN Framework Convention on Climate Change to which Canada is a signatory. The first national workshop on climate-related observations, held in February, 1999 produced a report: "Plan for Canadian Participation in the Global Climate Observing System" (Canadian Institute for Climate Studies, 1999). This report laid out initial steps to be taken in the preparation of a Canadian component of GCOS in five areas: atmosphere, oceans, cryosphere, hydrology, and terrestrial ecosystems. It also recognised that in addition to the global climate issues there are ongoing domestic requirements for understanding the climate of Canada and its likely response to global climate change processes. There is a need to understand not only the elements of climate change themselves but the impacts of these on the ecosystems and human economy of Canada in order to adapt to or mitigate them. This imposes additional requirements on the Canadian climate observing system. The 1999 report attempted to link these domestic requirements with the international ones and propose efficient and effective measures to satisfy both. In addition, the initial needs and considerations were addressed in greater detail through a separate document (Cihlar, 1999), building on the February workshop discussions and subsequent consultation.

One of the proposed activities identified in the Plan was to hold a follow-on workshop that would take steps toward designing an initial observing system for the terrestrial ecosystems of Canada. A subsequent (fall, 1999) proposal to the Climate Change Action Fund was accepted, thus paving the way to the present workshop. The workshop accordingly addressed the design and implementation of an ecosystem component of the Canadian Climate Observing System, called CCOS-Terre in this report.

1.2 Workshop objectives

To take the next steps in the design and implementation of a system of climate-related observations for the Canadian ecosystems (CCOS-Terre), the workshop objectives were to:

1. Finalise objectives and scope of CCOS-Terre, and the basic design and implementation strategy;
2. Identify/confirm critical satellite and in situ observations;
3. Review current state, gaps, and options for improvements of the observations;
4. Based on 3), identify elements of an initial observing system and a realistic implementation scenario; and

5. Prepare a workshop report as a draft science and implementation plan for the national and international scientific community, and as a basis for discussions with decision makers responsible for the implementation of Canadian response to the climate change issue.

The major focus of the workshop was on the exchange of energy and matter between ecosystems and the atmosphere, consistently with CCOS needs. Such observations would also contribute to defining the rloe of climate in relation to biodiversity and other issues, but other observations would also be necessary for those purposes which were outside the scope of this workshop.
2. Science and policy issues

Science and policy related to terrestrial ecosystems – climate interactions differ depending on the ecosystem under consideration, and are thus discussed separately below.

2. Science and policy issues

2.1 Forests

Forests cover approximately $4x10^6$ km^2 of the Canadian landscape. Renewal through various types of disturbances, combined with the interaction between species' ecological requirements and site conditions, makes the forest very patchy at various spatial scales. In addition, forests are by their very nature largely inaccessible, and located far from inhabited areas. All of these characteristics make the Canadian forest difficult to characterise solely by ground-based methods. Aircraft-based remote sensing is already widely used through the interpretation of aerial photography for forest classification. Satellite-based remote sensing, although limited in its ability to distinguish fine forest characteristics, has a large role to play in the assessment of the forest resource.

There are two levels of policies related to Canada's forests. At the national and international levels, a number of policy issues have put the management of forests on world agenda in the past few years. In addition to the questions of biodiversity and the need for sustainable development of the natural resources, there is the important issue of climate change and the emission/sequestration of carbon. The interaction between climate change and forests is of great concern to Canadian Forest Service researchers because the projected changes in the climate could threaten the forest resource in many regions of Canada. From a strictly international policy perspective, forests are an important component of Canada's carbon stock, and the depletion or accrual of that stock can influence significantly Canada's carbon balance sheet, if such a balance sheet includes natural forests. The current Kyoto protocol terms deal more specifically with change in carbon sequestration on lands which are converted either to or from forest land use. The vast majority of Canada's forests are likely to be excluded from this initial process because forest management does not lead to a change in land use.

The management of Canada's forest land is a provincial responsibility, and provincial agencies therefore have the primary role in the gathering and compilation of forest information on their territory. Provinces therefore have an additional set of policy issues, dealing to a large extent with the tenure of public lands and their management by industrial entities. Because of their operational responsibilities, provinces are sensitive to independent estimates of forest productivity that might contradict their own and be used to contest their forest management rules and regulations. Collaborative efforts with provincial agencies are likely the best method for achieving a productive sharing of information and guarantee access to plot databases.

Two important scientific issues regarding the terrestrial carbon cycle were discussed. First, the terrestrial component of the carbon cycle involves intrinsically long-term processes. The current global carbon balance in terrestrial ecosystems (and the ‘missing sink’) is thus the result of the impacts of long-term changes in climate and atmosphere as well as of anthropogenic activities. Second, the terrestrial carbon sink caused by these changes is small per unit surface area and therefore is exceedingly difficult to measure through carbon stock changes in soil and vegetation. While the two above issues exist for all ecosystems, they are particularly important in boreal forests because the carbon residence time (the mean duration of time that a carbon molecule fixed through photosynthesis stays in the ecosystem before it is released back to the atmosphere through heterotrophic respiration) is much longer than for temperate or tropical ecosystems. The level of productivity in boreal ecosystems is lower than at lower latitudes, and therefore the size of carbon sinks per unit area is also likely to be small. For example, if the global ‘missing sink’ (~1.6 Gt C yr^{-1}; Walker and Steffen , 1997) in land surfaces were evenly distributed in the approximately 4x10^{7} km^{2} of the forests of the globe, the sink magnitude would be 37 g C m^{-2} y^{-1} or 0.37 t C ha^{-2} y^{-1}. The mean value for boreal forests is expected to be smaller than this, and will be less than 0.2% of the boreal forest carbon stock (~200 t C ha^{-1}). Such small changes in stock are exceedingly difficult to measure over one or few years. Even at measurement intervals of 10 years, less than ~2% of change in stock is to be expected. However, sound process-based ecosystem modelling can provide the most needed information on terrestrial carbon sink and source distribution and their relationship to climate variability and change.

2.2 Agroecosystems

There are considerable uncertainties regarding the impact of climate change on agriculture and the role of agriculture with respect to climate change. Predicted changes in air temperature and precipitation will undoubtedly affect agricultural production. Crop production in the northern regions would clearly benefit from an increase in temperatures. This could result in an increase in the area of Canada’s agricultural land by about 10 % (Bailey, 1981). It could also cause a substantial shift in crop selection (Maxwell et al., 1997). For example, the area suitable for growing fruits and vegetables could expand beyond current southern location in Quebec, Ontario and British Columbia. The general consensus in agriculture is that changes in climate are likely to happen over a long enough period of time for the agriculture sector to adapt.

Agriculture presently accounts for about 10% of the anthropogenic sources of greenhouse gases in Canada (Desjardins and Riznek, 2000). Even though this contribution is relatively small, it is important because agroecosystems are intensively managed and some practices have the potential to affect greenhouse gas emissions more than others. For example, conventional tillage and the use of practices such as summer fallow have resulted in a loss of about 30% of the carbon from agricultural soils since cultivation began in Canada (Smith et al., 1997). Part of this carbon could be sequestered back into agricultural soils with improved management practices (Janzen et al., 1999). Some studies already report a substantial land carbon sink in the US resulting from CO_2 fertilisation and climate effects (e.g., Schimel et al., 2000).

Before the potential contribution of sinks, wetlands, shelterbelts, stored carbon in products, or others can be included in the Kyoto Protocol, several policy issues must be resolved. The rules for the flexibility mechanisms and credit for early action need to be set. This is likely to occur only if scientists can demonstrate that observations and models can be used to interpolate and extrapolate CO_2 flux measurements in time and space with a satisfactory accuracy. It should be remembered that carbon sequestration in soils has a large but finite capacity (50 – 200 Tg C; Bruce et al., 1999). This potential can be realised over a 20 – 40 year period. This is important because of its potential impact on crop production and on slowing down the increase in the atmospheric concentration of CO_2. This strategy should provide us with more time to find more lasting solutions.

2.3 Wetlands

The distribution of wetlands is determined by climate and by the morphology of the land surface (National Wetlands Working Group, 1988). Climate determines the amount of water received and retained, while the morphology of the land influences the distribution of the water and thereby the location of wetlands. Wetlands cover approximately 1,480 x 103 km2 in Canada, accounting for about 25% of the world's wetlands (Rubec, 2000). Peatlands (i.e., wetlands with more than 40 cm-thick organic layer) cover approximately 71% of the wetland area in Canada (Tarnocai et al., 2000). The diversity and distribution of wetlands in Canada varies greatly because of the wide range of climatic conditions. They are most widespread in the Boreal and Subarctic ecozones while they are least numerous in the dry Prairie and the cold and dry High Arctic ecozones. It has been estimated that peatlands (organic soils) in Canada contain 154 Gt of carbon, or 56% of the total organic carbon stored in all Canadian soils (Tarnocai, 1998; Tarnocai and Lacelle, 1996a, b).

Wetlands, especially peatlands, also act as carbon sinks. Although the annual sequestration is low per unit area (at an average rate of ~20 g C m-2 yr-1), they have accumulated large carbon storage over hundreds to thousands of years. The high carbon content of these wetlands makes them very sensitive to climate warming, especiallyif the hydrological regime is affected. In order to assess the effect of climate change on wetlands, it is important to develop a reliable database that contains all those wetland attributes needed to determine carbon concentrations and amounts and that provides the data needed to predict carbon fluxes using process-oriented models for various climate change scenarios.

It well known that they play an important role in the global climate, primarily in C cycle (CO2 and CH4). From the perspective of climate change and GHG exchanges, the critical science issues are (i) the security/permanence of the large present store of carbon in wetlands, and (ii) the modification of the contemporary stores and fluxes by land-use changes. Predictions based on the current understanding are very uncertain, one of the weakest elements being the link between climate and the atmospheric - biospheric exchange of GHGs.

From a policy perspective, wetlands are recognised for their ecological, hydrological, social, and educational functions. A key ecological function that has received attention by policy makers is carbon sequestration. This has led to discussions regarding the potential inclusion of wetlands among sinks acceptable under the Kyoto Protocol. However, at the present there are no reliable estimates of the contemporary carbon accumulation or release rates. For example, a recent Canadian Sinks Table Options Paper (Climate Change Secretariat, 2000) concluded that in spite of the ability of wetlands to sequester and retain carbon for a long time, the current state of scientific knowledge does not warrant pressing for an inclusion of wetlands as a carbon sink under the Kyoto Protocol. Studies of the effect of climate change on wetlands and their biogeochemistry are in their infancy. Based on the present knowledge it is difficult to determine the sign of the change with confidence, i.e. switches from sinks to sources or visa-versa, let alone the magnitude of possible changes (Moore et al., 1998). The second area of uncertainty concerns how the store and exchanges of GHGs changes with land-use conversion. Assumed stores of carbon could be lost with changes in land-use practices. Roulet (in press) concluded that almost all land-use changes that involve wetlands result in large emissions of CO2, CH4 and nitrous oxide (N2O).

2.4 Tundra

More than one half of the global tundra biome lies within Canada, and 40% of the landmass of Canada is north of the line of discontinuous permafrost. Tundra is a complex mosaic of wetlands, dry uplands, rocky polar deserts, ice caps, lakes and rivers. Low annual temperatures and permanently frozen ground are the defining physical factors and strongly influence the structure and function of the ecosystems of the taiga (forest-tundra) and tundra. These ecosystems vary along local moisture gradients, and across larger regional gradients of both latitude and longitude: from taiga the south to high arctic polar deserts in the north, and from more northerly white spruce taiga in the northwestern NWT and Yukon, to more southerly taiga dominated by black spruce in the Hudson Bay / Québec regions.

Taiga and tundra ecosystems are especially sensitive to changes in climate because of the initial conditions of low temperatures and short thaw periods, permafrost, and high reflectivity (albedo) of surfaces during most of the year.
A small increase in temperature will have a relatively large effect in taiga / tundra ecosystems which already operate at low temperatures, generally below the optimum of growth for most vascular plant species. Warmer, longer growing seasons will increase theground heat flux and influencepermafrost distribution, and increase growth and reproductive output of nearly all plant species, changing the structure, composition and potentially the species range of vegetation (Foley et al., 1994; Chapin et al., 1995).The consequences of these large changes in the permafrost regime of the Arctic are potentially large in both ecological and industrial terms. For example,melting of ice-rich permafrost will lower the land surface and change large areasinto wetlands, and disruptingdrainage patterns. Areas with ice-rich permafrost will experience greater "thermokarst" erosion, with large volumes of organic soils flowing into water bodies. In addition, coastal erosion, especially in the western arctic, is likely to increase. The degradation and loss of permafrost will also impact the design and costs of construction.

Taiga and tundra systems have enormous stores of carbon in organic soils and peatlands, the result of a nearly continuous positive carbon balance throughout the Holocene. However, the fate of these carbon stores in the current warming climate is unknown. Research in Alaska has shown that coastal wet tundra will likely change from a sink to a source of carbon to the atmosphere as the climate warms (Oechel et al. 1993; Vourlitis and Oechel 1999). Similar developments can be expected in permafrost-affected soils (Tarnocai, 1999). Carbon balance studies in warming experiments and from modelling indicates that the short-term responses are very likely to be different in magnitude and direction than the longer-term responses (Shaver et al., 2000).

Despite the spatial importance of tundra to Canada,and the potential for large ecological changes, our collective knowledge of tundra ecosystems is rather poor. Very little Canadian research is currently underway to determine the effects of climate change on this biome, especially regarding GHG fluxes. The existing information on possible responses to climate changeand potential feedbacksto the atmosphere are based on studies in Alaska and elsewhere, but their applicability to Canadian tundra is questionable in view of the much greater heterogeneity and spatial extent of taiga and tundra systems in Canada. This lack of knowledge impedes our ability to forecast the changes and potential feedbacks that may result from global warming.

2.5 Criteria and indicators of sustainable forestry

The Canadian Council of Forest Ministers (CCFM) has developed a framework of Criteria and Indicators of Sustainable Forest Management in Canada (CCFM, 1995). This framework provides measures of the sustainability of Canada's forest resources. Three criteria are particularly relevant to CCOS-Terre framework: #2 (Ecosystem condition and productivity), #3 (Conservation of soil and water resources), and #4 (Forest ecosystem contributions to global ecological cycles). For each criterion, the critical elements and several indicators have also been identified. Since these indicators are concerned with forests only, they do not capture the range of observations required. On the other hand, they are aimed at a more comprehensive ecosystem characterisation than required for CCOS-Terre.

Table 1 outlines the criteria and indicators from the CCFM framework that may be relevant to CCOS-Terre. In some cases, CCOS-Terre products may contribute to a given criterion or indicator. In particular, criterion #4 (Forest ecosystem contributions to global ecological cycles) is relevant mainly at large scales. The appropriate regional and sub-regional scales are likely to be inconsistent with political boundaries and thus a Canada-wide approach is necessary. In addition to providing information on sustainable development indicators, CCOS-Terre will have similar input data needs in some cases. Multiple use of the same data will enhance the effectiveness of field observation programs.

The Canadian Forest Service plans to report on these indicators every five years for the forested ecosystems of Canada, although the present schedule is every three years (1997, 2000 and quite possibly an update in 2003). Provincial agencies have all agreed to provide input to this reporting process (although there has not been a commitment to report on the complete slate of indicators as listed in the CCFM framework). Some of these indicators will thus have very good data sets; others will have no agreement on what is to be reported and what the reporting standards will be. It should also be noted that customised criteria and indicators of forest sustainability may be developed by some provinces, thus providing additional potential field data for CCOS-Terre purposes.

Table 1. Sustainability criteria and indicators for forest ecosystems (CCFM, 1995)

Criterion	**Critical Element**	**Indicator**
#2:	2.1 Disturbance and Stress	• Area and severity of insect attack • Area and severity of disease infestation • Area and severity of fire damage • Rates of pollutant deposition • Crown transparency in percentage by class • Climate change as measured by temperature sums
	2.2 Ecosystem Resilience	• Percentage and extent of area by forest type and age class • Percentage of area successfully naturally regenerated and artificially regenerated
	2.3 Extant Biomass	• Mean annual increment by forest type and age class • Frequency of occurrence within selected indicator species (vegetation, birds, mammals, and fish).
#3 Conservation of Soil and Water Resources.	3.1 Physical Environmental Factors	• Percentage of harvested area having significant soil compaction, displacement, erosion, puddling, loss of organic matter, etc. • Area of forest converted to non-forest land use, for example, urbanisation • Water quality as measured by water chemistry, turbidity, etc. • Trends and timing of events in stream flows from forest catchments • Changes in distribution and abundance of aquatic fauna
#4 Forest Ecosystem Contributions to Global Ecological Cycles	4.1 Contributions to Global Carbon Budget	• Tree biomass volumes • Vegetation (non-tree) biomass estimates • Percentage of canopy cover • Percentage of biomass volume by general forest type • Soil carbon pools • Soil carbon pool decay rates • Area of forest depletion • Forest wood product life cycles • Forest sector CO2 emissions

Criterion	Critical Element	Indicator
	4.2 Forest Land Conversion	• Area of forest permanently converted to non-forest land use • Semi-permanent or temporary loss or gain of forest ecosystems
	4.3 Forest Sector CO2 Conservation	• Fossil fuel emissions • Fossil carbon products emissions • Percentage of forest sector energy usage from renewable sources relative to total sector energy requirement
	4.5 Contributions to Hydrological Cycles	• Surface area of water within forested areas

2.6 Climate Modelling

The capability to obtain information on the current and future climatic conditions it critical to the estimation of GHG fluxes between the ecosystems and the atmosphere. In terms of climate change and ecosystem feedback, two groups of variables are of special significance. They describe, respectively, the radiation and energy exchange between the surface and the atmosphere, and the state and movement of water between the ecosystem and the atmosphere. These two categories are linked through evapotranspiration/latent heat transfer. In turn, each category includes a number of variables that together characterise the behaviour of that compartment of the earth system.

The knowledge of past and future climates is obtained using general circulation models (GCM), in combination with atmospheric and surface observations and other models where possible. These models describe the behaviour of the atmosphere over time, in relation to the earth's surface and subsurface, including the space- and time- dependent interactions among the various compartments. For regional applications, mesoscale regional circulation models (RCM) are preferred because they provide information with a higher spatial resolution. At the present, the Canadian RCM is run as a nested model within a GCM, however this may not be required in the future as the computational capacity improves. For estimating the meteorological daily conditions at specific locations, RCM should be nested within a numerical weather prediction model (NWP). While most of the data required by these models refers to the state of the atmosphere, some surface observations are also required. These describe the initial state or the boundary conditions of the climate system, and are required to run the models. Alternatively, they provide independent estimates of some model output variables and are thus needed to verify model accuracy.

A partial list of variables dealt with in the Canadian Regional Climate Model that are relevant to the quantification of fluxes between the terrestrial ecosystems and the atmosphere (e.g., Laprise et al., 1998) is given below. It is evident that many of the variables refer to the radiation/energy or water cycle aspects. The full list is provided in Appendix 9.4:

a) Initial conditions for land surface fields: ground surface temperature; liquid and frozen ground water; snow amount;
b) Prescribed surface for geophysical fields: topographic height; land-sea-ice mask; surface roughness; subgrid-scale topographic variability; surface albedo, near IR & short waves; soil type; vegetation indices (primary & secondary); rooting depth.
c) Archived surface fields output: top and deep surface temperature; liquid & frozen ground water; snow amount & age; surface albedo, including snow feedback.

d) Archived output surface fluxes and diagnostics: sensible heat flux; radiative fluxes (solar incident at & absorbed by the surface; terrestrial (net and downward) at the surface); evaporation (total & from snow); precipitation (total & as snow, stratiform & convective; 6-h cumulative & every time step); atmospheric values of near surface (temperature); instantaneous, minimum & maximum specific humidity; instantaneous, minimum & maximum wind components.

The above abbreviated list also includes variables that are needed by ecosystem models of GHG exchange or are produced by such models. All these provide connections between the atmospheric and ecosystem models, and areas where the observation needs of the different communities overlap.

It should be noted that other alternative methods of downscaling from GCM data that are being used. They include statistical downscaling, weather typing, and weather generators (e.g., IPCC-TGCIA, 1999; Wilby et al., 1998; Semenov and Barrow, 1997). While these approaches are suitable to downscaling GCM results, they are less suitable for estimating daily conditions at specific locations as the downscaling is based on typical relationships between the local and regional climatic atmospheric conditions.

2.7 Summary

Based on the above overview of issues for individual ecosystems, the key policy - related science questions with observational implications are:

1. What are the contemporary storage and annual exchanges of GHGs in Canadian forests, agroecosystems, wetlands and tundra?
2. How has the C storage changed since industrialisation, and what is the predicted rate of change for the next 10-100 years?
3. What are the effects of disturbance (including land use) on the storage and exchanges of GHGs?
4. What are the effects of land cover and land use change across Canada on the radiation and energy exchanges between the surface and the atmosphere?
5. What is the impact of climate change on the state and movement of water through the terrestrial ecosystems of Canada?

These basic questions imply the need for the following information:

- ➢ Current and past distribution of the ecosystems and the associated stores and fluxes of GHGs, water, and energy;
- ➢ Understanding of the relationships between the ecosystems and the atmosphere regarding the exchange of GHGs and water, at various time(and space?) scales;
- ➢ Understanding of the relationships between a) land cover, land use, disturbances and b) the radiation, water and GHG exchange;
- ➢ Evolution of climate and disturbances, permitting an assessment of the magnitude and distribution of GHG exchanges from the ecosystems at seasonal to decadal time scales.

3. Observation requirements and current status

3.1 Requirements

In CCOS-Terre, observations are required for three basic purposes:

i. to support and develop process-based models that provide the means for estimating the exchanges of GHGs, water or energy between the ecosystems and the atmosphere;

ii. to apply these models over large areas and generate the desired (map) output products;
iii. to validate both model inputs and the output products.

The needs regarding model application (ii) are fairly definitive for process-based models. These are also generally limiting for a country as large as Canada, where the acquisition of baseline data has historically been constrained by financial and administrative considerations (see section 3.2). In addition, they are essential for the production of CCOS-Terre outputs.

Requirements for (i) and (iii) overlap substantially but are not necessarily identical. Independent validation data are required for scientific credibility. To estimate carbon sink due to long-term ecosystem changes, a comprehensive modelling approach considering all major factors influencing ecosystem productivity and soil carbon can improve the accuracy of the estimates. The observation requirements overlap fully with ad (ii) in terms of the variables observed but the spatial, temporal and precision requirements are much higher than for (ii). While model application requires gridded data (i.e., an estimated parameter value at each grid cell (≤ 1 km^2 in size) across Canada, items (i) and (iii) require mostly point (site) data. The details regarding the amount and type of data for model development (i) and output validation (iii) also depend somewhat on the purpose and assumptions in a specific model. For these reasons, the two groups of observations are considered separately below.

3.1.1 Gridded data

The following are essential and desirable gridded data given current carbon budget modeling approaches. They can be used directly (i.e., estimates for individual grid cells) or values representing larger areas (e.g., polygons) can be computed. Such averaging can be also used in the time domain, provided that the data are available at the highest temporal resolution.

Table 1. Required gridded data

Variable	Type (a)	Spatial (b)	Temporal (c)	Method (d)	Comments
1. ESSENTIAL					
Air temperature	1	3	1,6	1	15 to 60 minute averages (continuous)
Precipitation	1	3	1,6	1	15 to 60 minute averages (continuous)
Solar radiation	1	3	1,6	1	15 to 60 minute averages (continuous)
Relative humidity	1	3	1,6	1	15 to 60 minute averages (continuous)
Wind speed	1	3	1,6	1	15 to 60 minute averages (continuous)
Net radiation	1	3	1,6	1	15 to 60 minute averages (continuous)
Snow water equivalent	1	3	1,6	1	15 to 60 minute averages (continuous)
Vegetation cover class	1	1	4	1	physiognomic classes, dominant species (overstory, understory)
Biota biomass (and biomass changes, e.g. due to harvest)	1	1	4	1	may be used to drive decomposition models
LAI	1	1	4	1	
Natural disturbance history	1	3	1	3,4	
Soil water holding capacity	1	1	3	4	
Elevation (DEM)	1	1	3	4	
2. DESIRABLE					
Aerosols	1	3	1,6	1	15 to 60 minute averages (continuous)
CO2 profile	1	3	1,6	1	15 to 60 minute averages (continuous)
Natural disturbance history	1	1	1	4	
Biota C, N concentrations	1	1	4	1	may be used to drive decomposition models
Temperature profile	1	1	1	2	also useful as a driver for soil processes
Maximum thaw depth	1	1	1	2	
Soil moisture	1	1	1	2	
Water table	1	1	1	2	
Foliage N	1	1	4	1	needed to drive decomposition rates
Foliage lignin	1	1	4	1	needed to drive decomposition rates
Chlorophyll	1	1	4	1	to drive canopy photosynthesis in some models
Rubisco	1	1	4	1	to drive canopy photosynthesis in some models

a: 1 = external forcing variable; 2 = internal status variable; 3 = output variable

b: 1 = gridded with a resolution of 1 km or better; 2 = each for a land cover class; 3 = gridded with a resolution of 0.5-1^{o}

c: 1, since industrialisation with desirable frequency; 2, periodical measurement once every 5-10 years; 3, one time measurement; 4: multiple-year continuous measurement; 5, daily in calibrations years; 6, continuous

d: 1 = site measurement; 2 = modelling; 3 = remote sensing; 4 = survey or inventory.

3.1.2 Point data

Similarly, the required atmospheric and ecosystem point data are given in Table 2.

Table 2. Required point data

Variable	**Type**	**Temporal**	**Method**	**Comments**
	(a)	**(c)**	**(d)**	
Atmosphere				
Air temperature	1	1,6	1	15 to 60 minute averages (continuous)
Precipitation	1	1,6	1	15 to 60 minute averages (continuous)
Solar radiation	1	1,6	1	15 to 60 minute averages (continuous)
Relative humidity	1	1,6	1	15 to 60 minute averages (continuous)
Wind speed	1	1,6	1	15 to 60 minute averages (continuous)
Net radiation	1	1,6	1	15 to 60 minute averages (continuous)
CO2 profile	1	1,6	1	15 to 60 minute averages (continuous)
Snow water equivalent	1	1,6	1	15 to 60 minute averages (continuous)
Aerosols	1	1,6	1	15 to 60 minute averages (continuous)
Ecosystem				
Natural disturbance history	3	4	1,4	Includes fires and insect-induced mortality
Management history	3	4	4	Includes harvest, thinning, fertilisation, etc.
Topography	2	3	3, 4	Influences radiation, and water fields
Ground water	2	3	2, 4	Influences wetland dynamics
Spatial patterns	2	3	3, 4	may assist spatial scaling
Vegetation cover class	1	4	1	Physiognomic classes, dominant species (overstory, understory)
Root carbon	2	4	1	coarse and fine
Aboveground biomass	2	4	1	stem, branch, foliage
Leaf area index	2	4	1	
Foliage N	2	4	1	used for canopy photosynthesis modelling
Soil biota C, N	1	4	1	may be used to drive decomposition models
Soil biota biomass	1	4	1	may be used to drive decomposition models
Soil temperature profile	2	4	1	Profiles are useful for process studies
Soil maximum thaw depth	2	4	1	critical for climate impact on permafrost-affected areas
Soil thermal conductance	2	4	1, 2	to estimate heat transfer and heterotrophic respiration
Soil thermal diffusivity	2	4	1, 2	related to thermal conductance but needs heat capacity information
Soil moisture	2	4	1, 2	affects heat transfer and decomposition
Hydraulic properties	2	3	1, 2	for vertical and horizontal water exchange
Water table	2	4	1	for lateral water flow and wetland processes
Soil C content (org. & inorg.)	2	3	4, 1	Directly affects heterotrophic respiration
Soil C age	2	3	4,1	needed to improve Rh calculation
Soil N, P content	2	3	4, 1	affect gross primary productivity
Soil bulk density	2	3	1	needed for diffusivity estimation
Soil percent clay fraction	2	3	1	

Soil pH	2	3	1	Important limitation to growth and soil biology
Macro & micro nutrients	2	3	1	these processes affect plant nutrient uptake
Microbial biomass	2	3	1	affects decomposition
Foliage N	1	4	1	needed to drive decomposition rates
Foliage lignin	1	4	1	needed to drive decomposition rates
Chlorophyll	1	4	1	needed to drive canopy photosynthesis in some models
Rubisco	1	4	1	needed to drive canopy photosynthesis in some models
C fluxes (above & near ground)	3	6	1	critical for model validation
Aboveground NPP	2	4	1	C storage flux
Belowground NPP	2	4	1	C storage flux
Litterfall N, P, C	2	4	1	C flux to soil & litterfall nutrients indicate nutrient availability
H, ET (above stand)	3	6	1	Important for C flux estimation
CH4	3	6	1	Important for wetlands
Volatile organic C	3	6	1	can be significant in total carbon budget
Dissolved organic C	3	2	1	C exchange can affect stocks and processes
Decomposition	3	6	1	needed to validate NPP and NEP components.

a: 1 = external forcing variable; 2 = internal status variable; 3 = output variable

c: 1, since industrialisation with desirable frequency; 2, periodical measurement once every 5-10 years; 3, one time measurement; 4: multiple-year continuous measurement; 5, daily in calibrations years; 6, continuous

d: 1 = site measurement; 2 = modelling; 3 = remote sensing; 4 = survey or inventory.

For model development and validation, flux tower data are required in multiple years for major ecosystems, and at two levels (above and below canopy) to separate the soil respiration component. Soil and vegetation C components are needed for multiple plots in major ecosystems and all age classes. The C/N ratio is required for various C pools in vegetation and soil, as is the response of plants to CO2 and N fertilisation. For soil respiration, heterotrophic and root respiration should be obtained separately at all tower sites and additional sites as well. Vegetation structural parameters are also needed for the different ecosystems (LAI, clumping index, etc.).

3.2 Existing networks and data bases

3.2.1 Overview

Sims (1999) conducted a survey of Canadian monitoring programs concerned with natural terrestrial ecosystems (forestry, environment, aquatic) with some potential relevance to climate monitoring priorities in Canada. He listed a total of 64 different programs at various levels, from national to provincial and more local ones. When comparing the programs with requirements for climate-related observations, he found among others that: "….

- Very few of the projects deal directly with the collection of extensive or long-term sets of climate measurements. The multidisciplinary BOREAS/BERMS Program is the only "fully comprehensive" terrestrial-based climate monitoring project undertaken within Canada that we encountered during our survey;

- A small number of the programs identified here are actively involved in suites of climatological data-gathering on a regular basis, undertaken to sufficiently high standards so as to be useful as baseline information to track climate change;

- There is lack of consistency of the monitoring methods over time, and of the relevant information in this area. For this reason for example, he recommended that use of inventory data from provincial inventory and growth and yield programs should generally be avoided;

- The CFS NatGRID project (McKenney et al., 1996) and some others have sought to provide some strong quantitative and objectively-derived interpretations of geological / climatological / vegetation patterning within Canada through analysis and spatial extension of site based observations with the development and integration of climate and topographic data and in some cases satellite data;

- There is a general dearth of longer-term terrestrial monitoring programs in Canada.

- In general, most of these do not have as high a degree of co-ordination as would be required for rigorous climate monitoring standards;

- Canada currently has not maintained network of terrestrial sites or locales that provide long-term (e.g., in the order of several decades or more) detailed climatological data gathering, undertaken in conjunction with a program of terrestrial vegetation monitoring. The best "candidates" for this role in future are probably sites associated with the Canadian Model Forests, selected sites from the network of EMAN sites, the BOREAS/BERMS installations, selected ITEX sites and sites associated with the Forest Ecosystem Research Network;

- The transition to climate monitoring protocols poses some problems, given that very few terrestrial-based programs in Canada were established for climate monitoring purposes specifically;

- In addition fiscal constraints of Environment Canada's have decreased the weather station network in Canada, making it more difficult to develop reliable gridded spatial models of climate, especially in mountainous terrain;

- There is also an important issue related to the funding of additional climate monitoring activities. Most of the programs that are underway are very under-funded and already are balking at national attempts to urge them to become more standardised. …. Given this, we would predict that, unless GCOS provided or leveraged such funds for climate monitoring, and to support some of the existing infrastructure, there would be limited cooperation from existing monitoring programs;

- Generally, data management and access issues do not pose a problem. Except for some of the older databases that were never brought to digital environments, most data exists in available digital form, and normally, with permission, it is available;

- There are only a few programs that currently are attempting to set up monitoring programs based on international protocols for site selection, layout, sampling, recording and summarising / archiving databases. Because there is not a widespread adoption of international standards, international integration could be a major issue in proceeding with GCOS…."

3.2.2 National Parks

Canada has 39 national parks covering 222,285.5 km^2, or approximately 3% of Canada. Parks Canada's legal mandate is to manage for ecological integrity, and the results are captured in a report to Parliament to be submitted every two years in accordance with the National Parks Act of 1998. The conceptual framework for monitoring ecological integrity is based on measuring: (1) ecological structure and function at a range of ecological scales (species richness, population dynamics); (2) elements of structure and function that have been shown in the literature to be sensitive to a range of stresses (succession, productivity, decomposition, nutrient retention); and (3) known stresses (human land use patterns, habitat fragmentation, pollutants, climate, other/local).

National Parks vary in size from 8.7 to 44,802.0 km^2. They have tended to collect data at a scale suitable to their individual needs. Since the parks have been established between 155 and one year ago, the data sets available for national parks are highly variable in terms of age, scale and even quality. Following are a set of parameters that are available (with effort) in virtually all parks:

- Biophysical inventories – bedrock, soil types, drainage, topographic class, vegetation cover (including understory vegetation in forests), hydrology, elevation;

- Permanent sample plots for vegetation;

- Species lists – vascular plants, vertebrates;

- Species abundance – vertebrates;

- Weather records – additional stations to the Meteorological Service of Canada.

Depending on the park, there can be good information of a whole range of other ecosystem attributes, but this is not consistent nationally. Such parameters include:

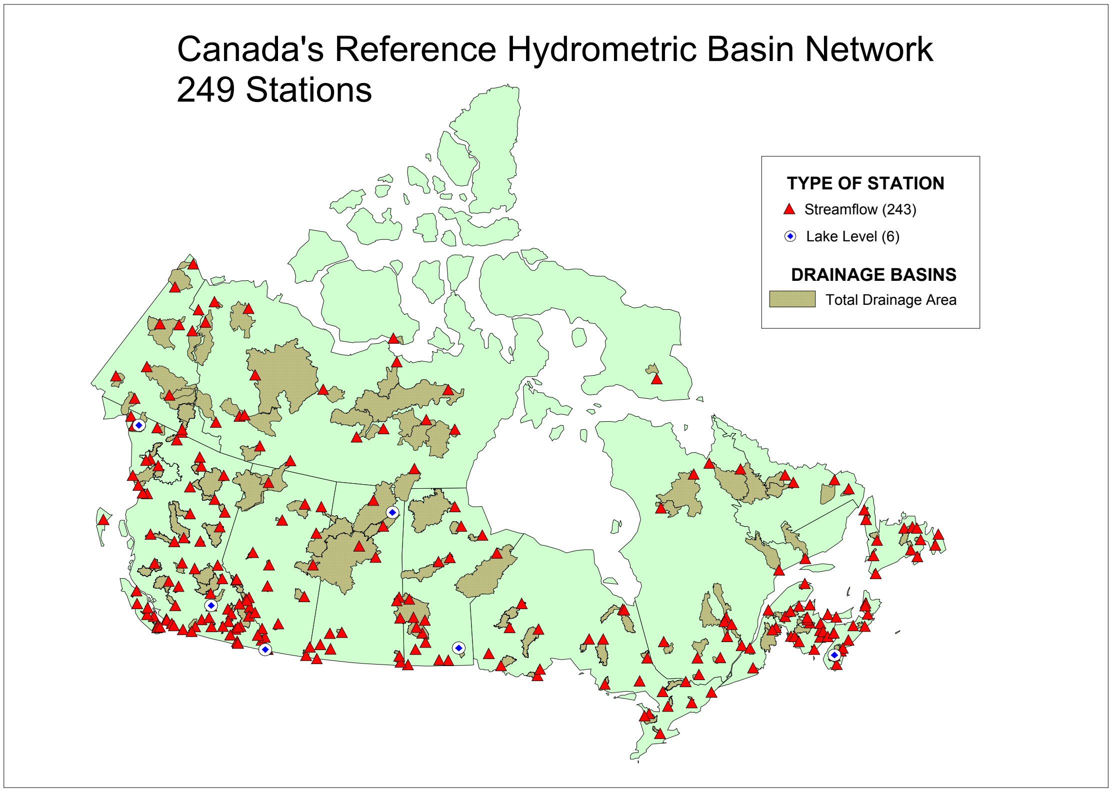
  - population information for selected species
  - studies in lake chemistry
  - atmospheric pollutants
  - fire history studies; etc.

3.2.3 Hydrological national network

Canada's Water Quantity (Hydrometric) Network provides a national coverage, with stations classified and funded on the basis of interest. The current network has 2650 stations (federal – 544; federal/provincial – 697; provincial – 939; contributed – 470). The Reference Hydrometric Basin Network (RHBN; Figure 1) is a 249-station sub-set of the national hydrometric network, identified for use in the detection, monitoring, and assessment of climate change, one of Environment Canada's highest priorities. RHBN is concerned with the monitoring, assessment, and science and requires collaboration at regional, national and international levels.

At the present, the main gaps are: sparse northern network (due to high costs); loss of regional hydrology (natural flow) stations; small scale - research (processes); and monitoring outflow to oceans.

Figure 1. Canada's Reference Hydrometric Basin Network



3.2.4 Flux tower network

The flux tower network is presently a loose association of flux tower sites located in various ecosystems across Canada. The most coherent network existed during the BOREAS project between 1994 and 1996 in Saskatchewan and Manitoba. A subset of the sites continues under BERMS. Most of the present Canadian sites are members of the AMERIFLUX network (http://cdiac.esd.ornl.gov/programs/ameriflux/). Individual sites record a range of environmental variables that are critical for modelling ecosystem processes; typically, these include:

Ecosystem flux measurements: ecosystem net CO2 exchange, latent heat flux (evapotranspiration), sensible heat flux, soil heat flux, gross photosynthesis, total respiration, canopy conductance to water vapour.

Meteorological measurements: net radiation, photosynthetic photon flux density, albedo, wind speed, atmospheric CO2 concentration, air temperature, air water vapour content, soil temperature profile, precipitation, soil moisture, water table depth, snow on surface.

Biophysical/ecological measurements: above- & below-ground biomass, predawn plant water potential, leaf and soil C and N content, leaf area index (LAI), phenology or LAI vs. time, rooting depth and distribution, soil texture, litter fall, litter decomposition, nitrogen mineralisation, species list, number of plant species, slope and aspect, land-use history (e.g., fire, grazing, tree age, etc.)

Table 3. Existing Canadian flux sites

Location	Principal Investigator	Ecosystem	Species
Van. Island, B.C	T.A. Black et al.	Temp. Conifer	D. Fir
P.A. Sask.	T.A. Black, A. Barr	Boreal	Aspen
P.A. Sask.	T.A. Black, A. Barr	Boreal	B. Spruce
P.A. Sask.	H. McCaughey, A. Barr	Boreal	J. Pine
Thompson, Man.	S. Wofsy	Boreal	B. Spruce
Camp Borden, Ontario	K. Puckett et al.	Temp. Broad Leaf	Red Maple, ++
Lethbridge, Alberta	B.Elert	Agroecosystem	Rangeland (soil respiration only)
Lethbridge, Alberta	L. Flanagan	Agroecosystem	N. Wheat Grass
Lethbridge, Alberta	S. McGinn	Agroecosystem	Wheat-fallow rotation
Ottawa, Ontario	N. Roulet, P. Lafleur	Wetland	Peatmoss

Table 4. Proposed new BIOCAP network sites

Location	Principal Investigator	Ecosystem	Species
MacKenzie Basin	P. Lafleur, N. Roulet	Wetland	Peatmoss
Rocky Mountain House, Alberta	L. Flanagan	Boreal	Lodgepole Pine
N. Ontario	H. McCaughey	Boreal	B. Spruce
Quebec City, P.Q.	H. Margolis, P. Bernier	N. Hardwood	Maple, Birch +
New Brunswick	P. Arp, M. Lavigne	Temp. Conifer	Balsam Fir

Cihlar and Tarnocai (2000) also provide a list of wetland sites.

3.2.5 Tundra networks

Two basic, interrelated networks of tundra sites exist in Canada: the International Tundra Experiment (ITEX) and the Canadian Taiga & Tundra Experiment (CANTTEX), respectively:

ITEX

ITEX is a network of sites throughout the global arctic tundra biome at which essentially the same measurements are made at the species and plant community level. It was founded by an international group of tundra scientists determined to co-ordinate research on effects of climate change on tundra plants and ecosystems. The ITEX Manual (Molau and Mølgaard, 1996) contains an extensive set of mutually defined protocols for observations of climate, active layer depth and soil characteristics; for measurements to be made on individual species (growth, phenology, reproduction); and for the establishment of permanent plots to follow changes in the composition and structure of tundra plant communities. A typical ITEX site involves a warming experiment using small, open top chambers (OTC) constructed of transparent greenhouse fibreglass. The OTCs usually cover 0.8 - 1.8 m^2 and allow the average near-surface air and soil temperatures to increase by 1-3ºC during the growing season, mainly by blocking the wind (Marion et al., 1997). Plant and community responses are followed in and out of the OTCs. Some ITEX sites have been in operation since 1992. Two recent publications (Henry, 1997; Arft et al., 1999) demonstrate the benefits the ITEX network of sites and scientific teams in assessing biome-wide responses to climate change. The latest ITEX Newsletter and the ITEX Manual are available online at www.dpc.dk/About_us/NSN/ITEX.html.

In Canada, there are currently four ITEX sites with OTCs, and two additional sites which use plastic greenhouses. The main Canadian ITEX site was established at Alexandra Fiord (Ellesmere Island) in 1992 by Greg Henry, University of British Columbia. The research at Alexandra Fiord involves an extensive set of warming experiments in 7 different plant communities along a moisture/exposure gradient. Ecosystem level studies at this site include litter decomposition, nutrient cycling, and CO_2 flux measurements using large chambers to determine net ecosystem production. The carbon flux research was initiated in 1999, and this is the only tundra site in Canada with measurements of NEP. However, there are no flux towers installed at any of the ITEX or any other sites in Canadian tundra.

CANTTEX

CANTTEX is the Canadian counterpart to ITEX, a loose network of 12 sites and programs established in 1999 as part of the Ecological Monitoring and Assessment Network (EMAN) - North. Although all the Canadian ITEX sites are also part of CANTTEX, the remaining sites involve mostly simple monitoring of climate and plant species response to annual variations in climate. Plans developed at the most recent CANTTEX meeting include establishing protocols for monitoring plant and animal species, documenting basic initial conditions at each site, and incorporating traditional knowledge and practice of aboriginal northerners. The list of sites and their metadata can be accessed at www.taiga.net/cantem-net. EMAN-North is a larger network of sites and scientists throughout the three northern territories, and involves monitoring studies in terrestrial, freshwater and marine systems. More information on EMAN-North can be found at www.nwtresearch.com/eman.

3.2.6 Soil benchmark sites in Canada

In the late 1980s, sites in every province were selected to represent agroecosystems under typical farm management in order to monitor changes in soil quality, identify environmental degradation indicators, and evaluate the sustainability of current farming systems in Canada. The experimental area of each site was relatively large (5 to 10 ha, or, in some cases a small watershed) in order to adequately represent the natural landscape and variability and to extrapolate the findings to broad regional areas. Some sites also had side-by-side comparisons of management practices (e.g. conventional vs. no till) or ecosystems (e.g. native grassland/forest vs. agriculture). A large baseline of data was collected when the network of sites was established by measuring the chemical, physical, biological soil properties, and by collecting topographical information and the management history, at each site. Monitoring of each site was conducted by measuring selected soil properties, crop yields and climatic information every year. Other ‘sensitive' variables (e.g. organic C and N) were measured every 3-5 years and ‘moderately sensitive' variables were to have been measured every 10 years. During the study period staff in the regions collected the local site data and ECORC staff conducted the laboratory analysis and has maintained the general database of all information collected from each site as well as a historical archive of several thousand soil samples collected.

Nine of the original 23 soil benchmark sites established in 1989-91 are currently being maintained as AAFC research sites. As a result of the 1994 budget cuts active monitoring on the others was phased out between 1995 to 1997. A roll-up report is currently being written and will contain the experimental results and data from all of the sites. The active sites are currently being sampled for the ‘10 yr. repeat' sampling and, with the other periodic measurements made, these sites will have at least 3 complete samplings on which to assess changes in soil properties. The total annual cost of running the benchmark study was approximately $65,000 which includes only the cost of maintaining the site (e.g., rent of land), and not salary costs. The estimated total investment, to date, in the benchmark study is $2 million.

The distribution of sites in all the regions of Canada, the extensive baseline data which was collected, the archive of soil samples and the periodic monitoring of various land, crop and climatic variables all suggest that this network has the potential to be used in large regional studies requiring terrestrial information. Inquiries have been received about the site network and the existing database from groups studying or proposing to study climate change, carbon sequestration, watershed assessment and agricultural model validation. A recent survey indicated that all of the farmers will allow access to the sites and that the farmers are maintaining their cropping records. Further information is provided by Wang et al. (1994, 1997).

3.2.7 Satellite observations and products

This section briefly describes the current status of remote sensing to extract the relevant information for carbon flux modelling of Canada's landmass, focusing on coarse spatial resolution satellite programs and examples of information products from the AVHRR sensor generated by the Canadian GeoComp-n image georeferencing and compositing system.

Current sensor and satellites particularly well suited to provide the fundamental remote sensing observations needed in estimating carbon fluxes and the carbon budget of Canada are limited to the NOAA AVHRR series and SPOT Vegetation sensors. In the future the MODIS sensor package, part of the Earth Observing System (EOS), will likely be one of the main data sources for continental and global data sets. In the CCOS-Terre monitoring system, it is probable that remote sensing observations will be considered in a hierarchical (or nested) sampling design. Higher spatial resolution imagery from Landsat and Landsat-like satellites, Radarsat, and others (VCL, hyperspectral) will fit within this hierarchical observation framework. All of these observations are linked to three basic types of models: 1) reflectance, 2) ecosystem process, and 3) landscape structure. GeoComp-n is the system for handling these data and currently represents the next generation of image geocoding and compositing system being developed at the Canada Centre for Remote Sensing with the partnership of PCI Inc.

The GeoComp-n system performs geocoding of AVHRR image strips using orbital information and georeferencing with image chips; the system converts digital numbers to radiance using sensor calibration coefficients, and to reflectance using atmospheric correction algorithms based on the 6S code and a new temporal interpolation scheme. For the Canadian landmass (from NOAA AVHRR data), the three main output products of GeoComp-n are: 1) daily composite images, 2) 10-day 'cloud-free' composite images (normalised to a common solar zenith angle of 45 degrees and nadir view angle), and 3) brightness temperatures. An example of the corrections and the resulting information products in provided in Figure x. From the 10 day composite basic product, the following information is derived (Cihlar et al., 1997a,b):

Reflectance of channels 1, 2, and 3;
Date of observation used for each composite;
Solar zenith angle, view angle and azimuthal difference between sun and view angles;
NDVI-TOA, NDVI-surface, and NDVI-BRDF;
LAI (Cihlar et al., 1997b; Chen et al., 1999)
FPAR-instantaneous, FPAR-daily (Cihlar et al., 1997b);
Surface temperature (Cihlar et al., 1997a,b);
NPP (using land cover, LAI, etc.; Liu et al., 1997, 1999);
NEP (in progress; J. Chen, personal communication).

Based on the daily composite, the following information is derived:

Active fires (Li et al., 2000);

APAR instantaneous, APAR-daily mean, APAR-10 day mean (Li et al., 1997).

From all the composites in a season, the following information is derived:

Fire scar area (Fraser et al., 2000).

GeoComp has been in operation since 1993. Thus a 7-year long, consistent data series exists for all Canada and permits generation of the above derived products for this time period.

Follow-on work in GeoComp-n will focus on automatic landcover classification at the end of the growing season and near real time NPP calculation (with access to gridded daily meteorological data). Adding support for new sensors, such as VEGETATION, and future sensors, such as the recently launched MODIS (36 bands, 250 m to 1km spatial resolution) is a high priority. Addressing scaling issues and the role of multiple resolution observations nested within the coarser resolution imagery is presently focused on three information products: 1) a water mask, 2) forest change, and 3) forest biomass. Improvements in LAI and other derived products can be obtained by partitioning the AVHRR pixels into land and water areas; the water mask may be obtained from DEM data or wall-to-wall image coverage of the country using Landsat data (perhaps based on a one- two- or three-year Landsat composite). Detection and identification (attribution) of forest change is a subject of continuing research; at the present time systems exist for the identification and mapping of clearcuts and some partial harvest conditions (seed tree and shelterwood cuts, some thinning and group selection harvest). Reasonable accuracy has been achieved in New Brunswick and Alberta study areas using Landsat data. Better estimates of forest biomass may require additional work with the double-bounce term provided by satellite radar data (Radarsat, JERS-1), which may be related to standing biomass, and lidar systems (such as VCL), which may provide necessary stand height data. The CFS EOSD Earth Observations for Sustainable Development Project is aimed at providing similar type products at higher resolutions (J. Wood pers. comm.). The project is in early stages but should eventually provide important inputs into multi-scale assessments.

3.2.8 Gridded data bases

This section provides a brief overview of existing data bases. The discussion is limited to the essential gridded data sets because of their importance to CCOS-Terre outputs (section 3.1.1). Related information is also provided in the satellite data section (3.2.7).

a) Atmospheric data (air temperature, precipitation, solar radiation, relative humidity, wind speed, net radiation, snow water equivalent). For historical periods, these are provided through reanalyses of atmospheric observations using GCMs and all available atmospheric measurements. Such processing takes advantage of all atmospheric data recorder at the time and the best current models of atmospheric processes. The reanalyses generate consistent, multiyear series of gridded data. Table 5 gives the current (2000) status of data availability for the Canadian landmass. – Gridded atmospheric data for the present are available from the Meteorological Service of Canada, DOE based on NWP models.

Table 5. Reanalysed gridded atmospheric data sets*

Data set name	**Agency**	**Variables of interest***	**Spatial coverage**	**Spatial resolution**	**Temporal coverage**	**Temporal resolution**	**Availability**	**Contact or reference**	**Comments**
NCEP/NCAR Global Reanalysis Products	NCAR, USA	R, T, H, P	Global	Various with parameters, mostly in 2.5 degrees	1948-present	6 hours & daily	Yes	NCAR	
The NCEP MRF Global Flux Archive	NCAR, USA	R, T, H, P, Snow	Global	~0.9 degree	1991-present	6 hours & daily	Yes	NCAR	Radiation overestimated. Yearly precipitation values agree, daily may disagree at some locations
ECMWF Re-analysis basic global surface data & supplementary fields	ECMWF, UK	T, H, W, IR, P	Global	2.5 degrees	1979-1993	6 hours & daily	Yes	ECMWF/ NCAR	
ECMWF Re-analysis advanced global surface data & supplementary fields	ECMWF, UK	T, H, W, IR, P	Global	~1.125 degrees	1979-1993	6 hours & daily	Yes	ECMWF/ NCAR	
ECMWF TOGA Global Sfc Anals & supplementary fields	ECMWF, UK	T, H, W, R	Global	~1.125 degrees	1985-present	6 hours & daily	Yes	ECMWF/ NCAR	
CRU05	University of East Anglia, UK	T, H, Cloud cover	Global	~0.5 degree	1901-1996	Monthly	Yes	CCRS	
Canadian climate averages	NRCan – CFS	T, P, R and others	Mostly Canada and N. A.	Spatially continuous, various grids	1961/90 1930/60 1901-96	Monthly	Yes*	CFS	
Canadian Climate Normal	Environment Canada, Canada	R, T, P, W, Soil temperature	Canada	Station Data	1961-1990 normal	Monthly	Yes	CCRS	

Modified from: Cihlar and Tarnocai (2000); * requires a collaborative agreement

Beside the reanalysed gridded, data sets with a high temporal resolution, numerous climatic data sets are available for Canada. They are not useful for estimating GHG exchange during specific time periods, but can be used to study typical or average conditions, for future projections, etc. The major sources are listed for completeness below.

- 100 km grid square climate data, 1951-1980 monthly averages for temperature, precipitation, solar radiation, wind speed and vapour pressure (1290 grid points for Canada). Description and source information is available at: http://ceonet.cgdi.gc.ca/cs/en/index.html

- The IPCC Data Distribution Centre has historical climate data available at a 0.5 degree Lat./Long grid. Mean monthly data for the 1961-1990 period are available for 11 surface variables. Monthly time series are available for 9 variables for the period 1901-1995. These data are available at: http://ipcc-ddc.cru.uea.ac.uk/index.html or from their CD-ROM database.

- Canadian Forest Service have developed a number of climate surfaces that have been gridded at various resolutions from 1-10 km for the 1961-1990, 1930-1960 periods for all of Canada, 1961-1990 for all of North America and monthly values from 1901-1996 for Canada and the U.S. These grids incorporate elevation effects (see also McKenney et al., in press; Price et al, 2000; more information at http://www.glfc.forestry.ca/english/res/natgrid/nattitle.html).

- A gridded prairie climate database for the 1960 - 1989 period exists at approximately 50 km intervals. This includes temperature, precipitation, solar radiation, and snow depth. The data are available on a CD-ROM (McGinn et al., 1999).

In addition, there are a number of climatic databases available based on polygons such as soil map units from the old Soils of Canada map and the more recent ecodistrict map units. They include:

- Monthly climatic normals data for the 1961-1990 period for variables such as temperature, precipitation, vapour pressure, wind speed, sunshine, solar radiation, dew point, potential evapotranspiration, water deficits, growing degree-days, etc. are available at: http://res.agr.ca/CANSIS/NSDB/ECOSTRAT/DISTRICT/climate.html

- Daily weather data for the 1955-1985 period, monthly climate data and various derived climatic indices are available for Agroecological Resource Areas (ARA, similar to ecodistrict spatial units) for the prairie provinces (Kirkwood et al., 1993).

- Climate data for the 1951-1980 period are available for 755 soil map units designated by the Soils of Canada map. These data are contained in the Land Potential Data Base for Canada (LPDB), and are described by Kirkwood et al., 1989).

b) Aerosols: No spatially explicit data area available for land, although research in this area in underway, e.g. as part of the Earth Observing System program (http://terra.nasa.gov/).

c) Vegetation cover class. The most up-to-date and consistent is a land cover map derived from 1995 satellite data (Cihlar et al., 1999). This map contains 29 land cover categories, has a pixel size of 1 km, and emphasises differences in forest classes. While wetlands are not dealt with adequately n this data set, a separate project is underway to provide initial information on the distribution of wetlands in Canada (Cihlar and Tarnocai, 2000).

d) Biota biomass. There is no current map of biomass t high resolution. The most recent biomass database for forests was compiled in the early 1990s.(more detail available at http://www.pfc.cfs.nrcan.gc.ca/main/index2.html#programs).

e) Leaf area index. The best current source are satellite data (refer also to section 3.2.7). Based on initial work under the BOREAS project, LAI estimation methods have been developed for forests and extended to other ecosystems (Chen and Cihlar, 1995, 1996; Chen et al., 1996). LAI maps are available at 1 km resolution and 10-day intervals for Canada (April to October), for all growing seasons starting in 1993.

f) Natural disturbance history. The best forest disturbance data are available from CFS. Forest fire maps have been compiled based on provincial maps. They are fairly detailed for the last ~40 years, but for the earlier period the reporting has been inconsistent and not very detailed, so that only national-level summaries have been prepared so far going back to the last century (see also section 5.6 for future options).

g) Soil water holding capacity. For large areas, this parameter is typically estimated based on soil texture. The best current data source for soil texture is the Soil Landscapes of Canada (SLC; Shields et al., 1991). For use in the modelling of carbon fluxes, the data base has been refined, gaps filled, and the texture data translated into soil water holding capacity (Liu et al., 1997; 1999).

h) Elevation (DEM): A national coverage at the scale of 1:250,000 has been compiled by CFS for the Canada Centre for Topographic Information (D. McKenney, personal communication). This is adequate for a modelling at the spatial resolution of 3 arc seconds and has been aggregated for applications from 1-10 km. A more detailed data set, based on 1: 50,000 topographic data is under preparation, but only 25% of the required effort has been funded so far.

4. **CCOS-Terre initial observing system**

The policy and science issues (section 2.) imply a range of observations that are required to provide credible answers. Some of the observations are common to all ecosystems, others are specific to each ecosystem. The CCOS-Terre needs to be designed in a manner that satisfies these information needs.

4.1 Objective and key questions

4.1.1 Objective

To provide the data and information needed for the assessment of the impact of climate change on terrestrial ecosystems of Canada, and the feedback from these to the climate system.

4.1.2 Key questions

From the CCOS -Terre viewpoint, the following two questions are most important:

1. What are the spatial and temporal patterns of changes in the exchange of energy, water, and trace gases between northern terrestrial ecosystems and the atmosphere, the causes to which these patterns can be attributed, and how do they contribute to climate variability and change?
Examples include:

- What are the contemporary storage and annual exchanges of GHGs in Canadian forests, agroecosystems, wetlands and tundra?
- How has the C storage changed since the industrialisation, and what is the predicted exchange rate under future climate change over next 10-100 years?
- What are the effects of climate variability and of disturbances (including land use) on the storage and exchanges of GHGs?
- How can the storage and exchanges in Canadian wetlands be managed to mitigate and adapt the climate change?
- What changes are occurring in vegetation structure that affect climate? What are the changes in albedo (particularly at high latitudes)?
- How much of change in the historical climate data can be attributed to changes in land cover/ land use compared to increased GHG concentrations?

It should be noted that information on the baseline situation (and interannual variability) are also needed to deal with changes in fluxes. This may not be always possible because many relevant variables were not recorded in the past. For carbon fluxes, modelling strategies may be employed to overcome this deficiency (e.g., Chen et al., 2000a).

2. What is the impact of climate variability and change on northern terrestrial ecosystems? What are the spatial and temporal patterns of the changes (especially natural vs. human-induced), and how have the ecosystems responded?
Specific issues include:

- What is the impact of climate variability and change on the past, present and future ecosystem productivity, land use (coastal zone, crop production, permafrost), and land cover (vegetation structure, types)?
- What is the impact of climate and climate change on the spatio-temporal distribution of hydrological resources (runoff, surface water storage, soil moisture)?

The above questions are important from Canadian perspective, but also from the viewpoint of GCOS (Global Climate Observing System, 1997; Canadian Institute for Climate Studies, 1999). Therefore, there is no essential difference between the requirements of the two observing systems as regards Canadian ecosystems. Workshop participants also agreed that the above listed key questions will most likely remain a priority for at least the next 10 years.

Meeting the CCOS-Terre objective in relation to the key questions implies that spatially, CCOS-Terre must address all major terrestrial ecosystems of Canada, within the framework of circumpolar temperate and boreal zones: forest, wetlands, agroecosystems (croplands and grasslands), and tundra. The needed temporal extent is from industrialisation (-100 yrs.) to the present, to the next +50 years, with a resolution of days to decades depending on the issue of and the relevant processes. Since future projections are very important, it is essential that CCOS-Terre be based on models mimicking ecosystem behaviour in relation to climate, disturbances, and land use.

4.2 Clients and outputs

4.2.1 Clients

The major target clients of the CCOS-Terre are policy and scientific communities related to carbon cycling although there are numerous other applications for these data and information. While different parts of the scientific community will be involved with CCOS-Terre directly as both provider and user, the issues dealt with by the scientific community are expected to be those identified by the policy community as the ultimate users (section 2.). Regarding particular policy interests, CCOS-Terre products will contribute to:

- Reporting to the UN FCCC on annual GHG emissions from Canadian landmass
- Contribution to the reporting for the Kyoto Protocol (the extent and details are to be determined after the Kyoto reporting guidelines are agreed upon)
- Projections of GHG emissions in the future and the expected spatial and temporal patterns of sources and sinks across Canada.

Both Canadian and international scientists are among the expected users of CCOS-Terre products. The knowledge gained from CCOS-Terre will be translated into policy terms through analyses of national trends, and internationally by placing Canada in the context of continental and global sources and sinks and analyses carried out through GCOS and by the Intergovernmental Panel on Climate Change. It is therefore important to ensure that that the impacts identified and information products provided can be translated into socioeconomic terms.

In addition to the policy dimension, CCOS-Terre outputs will also be useful to resource managers. They will provide highly integrated measures of ecosystem performance, such as net primary productivity and biomass increase which are among the best measures of the sustainability of ecosystems. They will be available in a consistent form across large areas, thus providing quantitative measures for the evaluation of ecosystem status and performance. Eventually, they may become candidates for replacing earlier methods for the collection of data on the status of forests and other ecosystems.

4.2.2 Outputs

As noted in sections 2. and 3.1, the main climate-related observation needs in the terrestrial environment are concerned with fluxes of energy, water, and GHGs between the surface and the atmosphere. The principal cycles/gases of interest are CO2, CH4, H2O, and N2O. While the main exchanges are with the atmosphere, the runoff to the stream network and eventually into oceans is also an important mechanism to be considered.

The ability to provide realistic estimates of these various quantities is at various stages of development. Initially, the main outputs of CCOS-Terre should therefore initially concentrate on the exchanges involving carbon:

- CO2, as the main GHG of interest is important in all four biomes (forests, agroecosystems, wetlands, tundra);
- CH4 should be considered in the exchange between wetlands and the atmosphere, as it plays minor role in agroecosystems (except for farm animals where a different monitoring strategy is adopted; see IPCC, 1996) and potentially in tundra where the estimation methodology has not yet been developed;
- CO will be considered in forest fire emissions.

In addition:

- Estimates of N2O exchange should be provided for agroecosystems only where this GHG plays a significant role;
- Evapotranspiration and runoff should also be estimated to account for the major exchange mechanisms with the atmosphere and hydrosphere, respectively.

The principal outputs of CCOS-Terre's Initial Observing System should be spatial data sets portraying the distribution of the above fluxes. The spatial coverage of these data sets should encompass the entire Canadian landmass, with the highest practically achievable spatial resolution (~0.25-1.0 km) and with a temporal resolution of 1 year or less. The highest temporal resolution will be model-dependent and could be adjusted based on requirements.

Although fluxes of radiation and energy are also very important in assessing the impact of terrestrial ecosystems on climate, they will not be provided by CCOS-Terre. This is because such fluxes are better estimated within general circulation models (GCM) or numerical weather prediction models (NWP).

4.3 Approach

4.3.1 Considerations

In principle, two basic approaches have been followed in the past to estimate GHG fluxes between the ecosystems and the atmosphere (e.g., IPCC, 1996): a) fluxes determined from a change in storage at two different times, and b) fluxes estimated directly.

Approach a) requires that accurate data be available on all ecosystem compartments involving carbon. Since such data are not available in most cases, many simplifying assumptions are usually made and the methodology often relies on nominal, 'default' values. Thus an accurate estimate of the net exchange is difficult to obtain through the change in storage approach. Another disadvantage is that while estimates of the current changes may be obtained in this manner, it is not feasible to make projections of future changes in response to natural or human-induced interventions; this is a critical deficiency from the policy perspective. Furthermore, the stock approach does not allow to assess the impact of climate change on ecosystem functioning (section 2). The fundamental advantage of this approach, and the main reason why it have been used in the past, is that one does not need to understand the processes of GHG exchange between the ecosystems and the atmosphere, as well as within the ecosystems. Thus, until this understanding progressed to a certain level (and the requisite data for model application were available), the change in stocks approach was the main viable option.

Approach b) aims to mimic the processes involving GHG exchange in the part of the cycle related to the ecosystem. It does not suffer from the above deficiencies, provided that the process models are sufficiently accurate and that the data to drive the models are also available. This approach also allows modelling the net difference in fluxes (e.g., Chen et al., 2000) rather than the fluxes themselves, thus avoiding errors caused by uncertainties in precise estimation of large gross exchanges.

The GHG fluxes between the ecosystems and the atmosphere can be measured directly using eddy covariance technique. However, since there are only few towers currently in operation in Canada (Table 3), and given that a flux tower represents only a small ecosystem patch (~1km), upscaling of the tower measurements to large regions is the essential step in obtaining plausible regional and national estimates of carbon sink or source distribution. The options for upscaling include: (a) using remote sensing data and models, (b) planetary boundary-layer carbon budgeting based on atmospheric sounding or aircraft CO2 concentration measurements, and (c) aircraft flux measurements over large areas. Much discussion was devoted to the first method. Scientists from the Canada Centre for Remote Sensing have demonstrated the use of satellite data for Canada-wide mapping of land cover, leaf area index, fire scar area and age, and how these quantitative information is used for long-term pixel-based carbon cycle modelling for Canadian forests (http://www.ccrs.nrcan.gc.ca/ccrs/eduref/ref/biblioe.html). A preliminary Canada-wide map of net ecosystem productivity, showing carbon source and sink distributions, has been produced. Although uncertainties still exist in the map due to lack of historical and spatialised disturbance data and simplification of some processes, general patterns of the carbon source and sink distributions are available for examination and for further improvements. The existing flux tower data can thus be used for validating these source/sink output products.

The approach b) of planetary boundary-budgeting can be useful as an intermediate scale for upscaling (Flechard et al., 2000). It can provide reliable estimates under certain circumstances, e.g. during clear days with a well-developed mixed layer and uniform landscape and wind direction, etc. As only a few representatives with expertise in this area were present at the workshop, the discussion in this subject was tentative. Approach c) (aircraft flux measurements) may also be useful in this context. Such aircraft measurements have the advantage of larger sampling areas than flux towers, but the measurements can only be made at discrete times on a day and the methodology for temporal scaling for longer time periods is not possible at this time (Desjardins, 1991).

4.3.2 Approach selected

At the present, not all processes of GHG exchange are adequately described by process models, and others are unlikely to be in the foreseeable future (e.g., carbon removal through harvest). Consequently, CCOS-Terre strategy is to estimate fluxes using process models where possible, and supplement this by stock-based approach where modelling fluxes is not feasible due to the processes involved, lack of models or understanding, or absence of data for model application.

It should be pointed out that this approach is concerned primarily with generating the outputs products. In the development and validation of the process models, both storage- and flux- related data are needed (Table 2). The same is true for the validation of the output products (refer also to section 5.5).

The estimation of the GHG balance at regional scales involves several interrelated activities. From the viewpoint of motivation for these activities, they are:

- application of process models of carbon and water exchange at landscape to regional scales, using inputs from satellite remote sensing and other data sources;
- development and validation of these models for various ecosystems; and
- measurement of ecosystem carbon fluxes and stocks at the field or stand scale, over complete annual cycles, and under various land use conditions (including disturbance,..).

The initial CCOS-Terre strategy for the estimation of fluxes relies on the use of models mimicking the response of an ecosystem to prescribed atmospheric conditions (Table 1), the latter being derived from separate atmospheric models with highly simplified representations of the ecosystem. In reality, the atmosphere and the surface are both dynamic, and should be represented within one model. While this requires much further research and development, it is very likely that within the next 10-15 years such models will start to emerge (e.g., Claussen, 1994; Texier et al., 1997; Foley et al., 1998) and will employ the principles of data and data product assimilation within the models. Once they are perfected, the incorporation of gridded and point data sets and operation of these models will be much easier and will lead to near-real time monitoring and assessment capability.

4.4 Candidate components and sources

4.4.1 Gridded data inputs

4.4.1.1 Meteorological data

The main data sources are model reanalyses outputs for historical time series (Table 5), data sets based on the compilation of atmospheric measurements (e.g., Leemans and Cramer, 1991); and numerical weather prediction model outputs for near-real time data. Section 3.1.1 provides additional information.

4.4.1.2 Satellite data and derived products

Satellite data at 1 km resolution are available from the Canada Centre for Remote Sensing (CCRS) for NOAA AVHRR, and from satellite operators for other sensors. Processed data are available from CCRS for the 1993-1998 period, and it is expected that this time series will continue into the future practically without interruption. Although changes in sensors and processing algorithms are anticipated, this should be carried out so that the consistency of the time series of the derived products remains unaffected (including data reprocessing where needed). In the near future, superior data sources are expected, mainly from new sensors being launched by France, the US, and Japan. Land cover, leaf area index, fraction of photosynthetically active radiation, fire scars and other products have been derived from AVHRR data (e.g., Cihlar et al., 1997b; Li et al. 1997; Fraser et al., 2000).

4.4.1.3 Surface data

These data sets are available from various federal agencies: AAFC for soils, CFS for forests, AAFC for wetlands (Cihlar and Tarnocai, 2000), and SC for land use changes. In addition to common data sets (section 3.2.8), specific data needs exist for individual biomes, all at as high a spatial resolution as possible:

Forest:

Disturbance history
Digital maps of forest cover (from provinces).

Agroecosystems: at least at the resolution of a crop reporting district (for applying e.g. the Century model):

> Management parameters: planting date, harvest date, cultivation events (date / depth), fertilisation events (date / type / amount);
> Soil parameters: clay, sand, silt content (any two), bulk density, soil pH, soil organic C;
> Crop parameters: type, rotations, yields (calibration).

Wetlands:

Water table depth
Soil carbon content
Land use change (peat harvest, fire history

Tundra:

> Active layer depth
> Soil carbon content.

Because of the importance of land use history on the current processes affecting carbon budget, information on past land use is important in obtaining accurate flux estimates. Such detailed information is available locally or provincially, but has not so far been compiled at the national level. For forests, it may be possible to obtain pixel-specific disturbance history (especially fires) back to approximately 1950 using archived satellite data from the 1970s.

4.4.2 Point data inputs

a) Data for model development and model validation. These will be obtained from various sources, primarily flux tower sites. These measurements are currently collected and processed by scientists responsible for the operation of individual flux tower sites (section 3.2.4, 3.2.5). Most of these sites are members of Ameriflux, a network of flux tower sites in North America. A data documentation and access protocol has been developed. More information is available on http://cdiac.esd.ornl.gov/programs/ameriflux/. Important data for tundra ecosystems are available from CANTTEX sites (http://www.taiga.net/cantem-net/).

b) Data for output validation. These data sets cover larger areas and contain fewer parameters. Some are obtained as part of one-time research activities (e.g., Chen et al., 1999). For forest ecosystems, there is a potentially important data set from growth and yield plots that could be used to evaluate NPP maps. These data are available in some cases (e.g., Liu et al., 1997) but at the present time, it is not easy to access and use these data for various parts of Canada. These plot-based datasets are a provincial responsibility, resulting in disparate reporting standards, quality and access across Canada. However, the Canadian Forest Service is launching a national initiative, the National Forest Inventory (NFI), that is aimed at providing a nationally uniform reporting base for the state of forests. NFI is designed to periodically provide species diversity, wood volumes and other detailed data through a combination of ground-based and remote observations. It is structured as a provincial-federal collaborative initiative to ensure a systematic coverage of all of Canada’s forests.

4.4.3 Data processing, output generation, access, and archiving

Data processing involves:

- compilation, standardisation, and quality control of all inputs;
- application of the process models to generate the required outputs;
- quality checking of the processing; and
- evaluation of the outputs.

Similar steps have previously been followed by research groups such as at CCRS (Cihlar et al., 1997a; Liu t al., 1997, 1999), CFS (Bernier and McKenney, personal communication), and AAFC (Smith et al., 1997, 2000). These activities are expected to continue, especially for research purposes and during the initial periods of CCOS-Terre, until the quality and stability of processing is established. It is essential that compatibility among the various products be established through a common reference framework. Continuation of these activities under CCOS-Terre should be based on increased co-ordination and collaboration among groups and agencies.

To be successful, CCOS-Terre must ensure timely availability of data needed to generate and validate the outputs products. Procedures to ensuring this need to be developed and adopted by the participating agencies. For access to input data to other parties CCOS-Terre should advocate a policy of openness and accessibility, and should work with major government agencies, other data providers and research teams toward this end.

There is a fundamental need for a data and product archiving capability that would serve CCOS-Terre needs. Input data sets will be required for time series comparisons, model validation studies, trend analyses, etc. Output products will be needed by CCOS-Terre clients, also for various periods. Data sets for these purposes need to be readily available, in a consistent format, well documented, and easily located. At present, there is no single national database for an integrated terrestrial observing system. Perhaps the simplest data management strategy is to leave the responsibilities with the agencies that gather data, (e.g., AAFC for agricultural ecosystems, CFS for forests, CCRS for remotely sensed data, Ameriflux database at ORNL DAC for tower-flux data), and to find an agency that would handle the output products. However, the essential requirement for consistency of formats, documentation, and access would have to be addressed. Fortunately, there is a strong trend by government agencies to making geospatial information available on the web, and the needed tools are being developed. Technology development programs have been funded that have already produced systems for this purpose with data access capabilities, including searches, metadata, etc. The most appropriate candidate is the Canadian Earth Observation Network (CEONet; http://ceonet.ccrs.nrcan.gc.ca/), also linked to GeoGratis (http://geogratis.cgdi.gc.ca/) and Geoconnections (http://cgdi.gc.ca/). Such a system would be suitable to meet CCOS-Terre needs regarding client data and output product support. However, it would have to be modified to meet CCOS-Terre internal needs (i.e., product development, product validation, R&D). Initial effort will also be required in data set documentation and in transforming existing datasets to common projections and resolutions. Opportunities for leveraging funding may arise by tying such projects to the GeoConnections initiative and related activities.

5. Implementation issues

As evident from sections 2.-4., the requirements for CCOS-Terre are well understood and Canada has the elements needed to establish an initial observing system (IOS). However, an IOS would have implications for the various components. In this section, some of these issues are briefly discussed.

5.1 Satellite data

Satellite-derived products have so far been generated as part of a research program. This means that timely or guaranteed availability of data were not critical issues. NOAA AVHRR data reception has been provided by CCRS. Prior to 1999, data reception and delivery for initial processing has not been done in a timely manner. In 1999, a second receiving station was added to cover eastern Canada (owned and operated by DFO under an agreement with CCRS). In addition, high speed links have been installed between the receiving stations, CCRS (Ottawa), and the Manitoba Remote Sensing Centre (MRSC). Since 1993, the initial processing of NOAA AVHRR data has been carried out by MRSC using the GeoComp-1 system (section 3.2.7). So far, this has been a lower priority task in comparison with the support of near real time operations such as the Crop Information System. The added post-processing and modelling of carbon fluxes has been carried out as part of research activities, also in delayed mode supported by model development and other research projects.

For CCOS-Terre, the above arrangements would need to change in several respects. First, satellite data reception and timely delivery needs to become an operational commitment by CCRS. Second, AVHRR pre-processing needs to become a priority for MRSC to ensure that complete and reliable data sets are produced for CCOS-Terre. Third, there needs to be a transition from research to a routine operational mode. This must take place gradually, to ensure that the quality of the output products does not suffer. It implies that researchers must remain involved in the process. The actual timing must also take into consideration the evolution in satellite technology and information extraction algorithms, and thus must be decided at the appropriate time.

5.2 Flux tower sites

As noted above, flux towers provide an essential input to the development and validation of models used in estimating GHG fluxes, and are therefore a key measurement tool in the study of ecosystem processes. They can also provide the most reliable output validation data. Among the issues that need to be considered regarding the role of flux towers in CCOS-Terre are:

- optimum configuration of the flux tower network from the CCOS-Terre perspective, as a trade-off between costs and impact of measurements. Considerations include biomes represented, and particular sites selected for each biome;
- duration of measurements (both within a year and the number of years) at each site (including fixed vs. roving towers);
- data processing and timely access to the processed data; and
- funding for these activities.

The current flux sites have not resulted from a purposeful design to meet national needs, but rather were selected based on the needs of specific research programs. While the data obtained will undoubtedly been valuable for CCOS-Terre, their adequacy and comprehensiveness is uncertain at this point (see also section 9.2). These issues have not been examined in detail at the workshop.

5.3 Provincial point data sets

At this point, it is not clear if and how provincial growth and yield data could be effectively used as part of CCOS-Terre. The relevance the data is high, but the questions of measurement protocols, formats and others (Sims, 1999) make uncertain the likely impact these data could make in the initial phase of CCOS-Terre. This requires further discussions with provincial data management agencies.

In addition to existing provincial data bases and monitoring networks, improved systems are being organised by some provinces. For example, in Ontario the existing growth and yield program, wildlife assessment, ecological land classification and some components of wildlife inventory have recently been combined into one long-term monitoring program that will continue to develop over the next few years. The growth and yield program uses two types of permanent sample plots: a level one plot on which a whole suite of growth, mortality and some wildlife habitat characteristics are measured; and a level two plot that represents one of the growth plots on the level one plot. The level one plot consists of a mortality sub-plot, in which are nested three growth plots and nine shrub/regeneration plots. The standard measurements and the minimum standards have been established (Hayden et al., 1995).

5.4 Research data sets

To date, many of the observations and data sets needed for CCOS-Terre have been produced as part of research activities. This is the case for many reasons, including the fact the development of the observation tools and models has been a research task. At the present, important research questions remain regarding the two-way relationship between terrestrial ecosystems and climate change. They are concerned with various ecosystem processes and their role at different timeand space scales. Addressing these questions requires multiyear data sets. Thus, research needs and activities have direct interest in CCOS-Terre outputs. In turn, they can contribute to ensuring high quality of the output products, their temporal continuity and consistency (e.g., with changes in satellite sensors), and their effective utilisation. This means that the research community should be a full partner in the initial implementation of CCOS-Terre. The key components where researchers need to be involved are in situ observations; model validation and enhancements; satellite data and processing; data integration and model application; output quality control; output utilisation. In this manner, the existing data and expertise can be employed to the best advantage.

5.5 Output validation

In general, there is a requirement to confirm the validity of model estimates of GHG fluxes, and to report the uncertainty/error associated with the estimates (e.g., Cihlar et al., 1997c). This is especially critical if the fluxes are sufficiently small to be comparable to the measurement errors. In the process of validation, it is essential that the data employed in validation be independent from those used in model development. Also, a distinction should be made between 'model' validation and 'output' (mapped product) validation.

CO2 flux measurements made on micrometeorological towers are currently the only reliable means of validating <u>models</u> that estimate carbon sinks resulting from climate change. In forests, stock-based approaches are useful for estimating large changes in carbon balance due to disturbance and regrowth, but are not useful for detecting small changes in carbon stocks due to climate change (temperature, precipitation, growing season length,..). For model validation, the various components of the model should be tested against independent data including internal variables, partial fluxes, and final outputs. From the flux perspective and for time scales of days to years, the model estimates should be validated against both NPP and NEP and, where feasible, the partitioning of (a) NPP between above and below ground biomass, (b) NEP between trees, plants, moss, and soil, and (c) ecosystem respiration between heterotrophic and autotrophic respiration. Such testing requires detailed measurements of a number of parameters and can therefore be carried out at a limited number of sites only.

If the number of flux towers were sufficiently large and representative, a subset could be used to independently validate the output products. However, this is not so at the present or likely to be the case in the near future, so other approaches need to be considered. Top-down (e.g., atmospheric mass balance) methods hold promise for the future but are not currently applicable at regional or even continental scales (Cihlar et al., 2000). Thus, for the near future independent bottom-up estimates provide the best validation strategy. Two main practical approaches are a) use of roving flux towers, and b) traditional mensuration techniques (note, however, aircraft-based validation for N2O above).

The roving flux towers can be used as part of a flux tower network. The principle is to use a fixed tower for continuing measurements, and a movable tower that is placed on a nearby, ecologically different site. Because of the spatial proximity, the climatic conditions are similar between the two towers but the ecosystem response differs due to the different site conditions (ecosystem types, age classes and land-use/management/disturbance history). The cost of a roving tower may be comparable to, or even greater than, that of a fixed tower operation, but a much wider variety of conditions can be captured in this way. It should also be noted that the operation of the roving towers for ‘output’ validation can be adjusted to the product generation and validation needs. The roving towers concept is the preferred validation strategy for CCOS-Terre outputs. This should be supplemented by high resolution remotely sensed data to establish the characteristics and variability of the ecosystem represented by the flux tower measurements.

The above top down and roving tower methods are applicable to all terrestrial ecosystems. On the other hand, mensuration techniques tend to be specific to individual biomes; some aspects are discussed below.

Forests

Mensuration techniques may be used to evaluate some components of forest GHG fluxes. For example, above ground biomass increments in the forest may be obtained by determining (i) annual growth increments in tree stems (core samples), (ii) the allometric relations between stem measures and other tree components (branches, …), (iii) litter traps, and (iv) core samples or allometric equations for root biomass. In general, these techniques require careful calibration for various species and site conditions and, except for some components (e.g., above ground NPP), may not be applicable on an annual basis. However, they provide valuable independent information for longer time periods. The strength of plot mensuration data is in the detection of state and of detailed forest characteristics. These include the structure and composition of stands, their biomass, necromass, nutrient contents, and growth rates. As such, they provide a basis for assessing the representativeness of flux towers because the same ecological variables are observed at these sites. Stratification by forest type/ecological region/biome may permit extrapolation of the results to larger geographical area. Georeferencing permits combination with other spatial data sets to map some of these properties.

It is important to emphasise that mensuration techniques also provide the information necessary to validate the components of carbon balance that are not due to the impact of climate variability or change (e.g., harvest, land use,..). Satellite-based multi-spectral sensors are optimal for detecting change because of their ability to cover large areas of the country repeatedly. Recent work has shown how the processing of successive Landsat-TM images could highlight even subtle differences in forest composition and structure induced by human intervention. Fire, insect epidemics, change in forest health, management actions and the like could all be detected and interpreted from satellite images over the whole country in a timely fashion.

In the mensuration approach to product validation, multiscale data in selected areas across the country would be the preferred approach. It helps capture the local/landscape heterogeneity, yet provide quantitative measurements from surface sampling. Thus, well-defined regions with intensive ground sampling and multi-level modelling should provide an adequate spatial base for a reliable validation (Bernier et al., 1999).

Agroecosystems

Several techniques have been developed to obtain carbon fluxes at a regional scale. These are primarily based on simulation models and various aggregation methods (Smith et al., 1997). The models have usually been based on soil carbon change at long term experimental research plots at a few locations in Canada where a whole range of management practices have been carried out (Campbell et al., 1995). More recently, another approach has also been investigated across the prairies. A team of Canadian scientists and a group of farmers have initiated a pilot project using a system to quantify and verify the soil C changes due to the adoption of a no-tillage system. The pilot project involves 150 benchmark fields covering the agriculturally developed portion of the province of Saskatchewan. The benchmark fields include every important combination of soil type, texture and climate. It should be noted that this mensuration approach can be applied to other component fluxes, e.g. NPP.

To complement the measurements of the change in soil carbon, a number of techniques are now available to quantify greenhouse gas fluxes. A complete description and their operating assumptions have been described by Desjardins (1991). The strength of flux tower methods is their capability to measure fluxes and provide valuable information for a larger area with minimal disturbance to the underlying surface. They provide information over a wide range of scales (cm^2 with enclosures to 10^9 m^2 with aircraft). Until recently, most of these measurements were made for short periods, but over 70 scientific teams are now doing long-term flux measurements world-wide of CO2, H2O and energy fluxes (Baldocchi et al., 1996; http://www-eosdis.ornl.gov/FLUXNET/).

Since some of the efforts to increase soil carbon sequestration affect other greenhouse gases, particularly N_2O emissions, it is important to also estimate these emissions. Recently tower-based N_2O fluxes have been measured all year round at a few locations. Because of the episodic nature of N_2O emissions these data are essential to complement N_2O fluxes using enclosure measurements. In order to verify model estimates at a regional scale, an aircraft-based flux measuring system has recently been developed (Desjardins et al., 2000). This approach is feasible for N_2O because it has been estimated that 50 – 70% of N_2O fluxes occur during a short period in early spring around snow-melt (Wagner-Riddle and Thurtell, 1998).

Wetlands

As with other biomes, model output validation is also critical for wetlands. Two types of data are especially useful here. One is the long-term flux measurements of CO_2 and CH_4 for model validation at site level. The other is the C accumulation rate measured using isotopic dating, which allows the model performance being validated over century to millennial time scales.

Interannual variability in C cycle is dominated by climatic and hydrological variables, which have a range of inter-annual variation that often exceeds that of changes in the long-term means. In contrast, the interannual variability of other factors, such as atmospheric CO_2 concentration, nitrogen deposition, and others, are generally much smaller. Due to the dominant effect of interannual climate variability on the relative difference between annual NEP values, a few years of eddy covariance CO_2 flux measurements can be successfully used to discern the possible effects of climate change on carbon cycling in a wetland ecosystem. Indeed, the uncertainty in the relative difference between annual NEP values is likely to be smaller than the respective annual NEP values, provided a consistent measurement technique and calculation method are used so that many of the systematic errors are minimised. Therefore, long-term (5-10 years) continuous flux data can best be used to validate the model estimates of climatic and hydrological effect on C cycling of a wetland ecosystem.

While the above "long-term" tower flux measurements generally span a few years, the C accumulation rate measured using isotopic dating contains information over thousands years. Applying C cycle models over thousands years and then comparing the model output with the C accumulation rate determined through isotopic analysis, offers a real long-term test. Such tests may also be useful in detecting the long-term effect of changes in slow-changing factors, e.g. CO_2 increase and N deposition. The possibility of obtaining information on long-term C accumulation rate is unique for the wetlands which have very slow decomposition rate. In contrast, the recycling of C in agricultural and forest ecosystems are relatively rapid, and so this validation approach is not applicable under those conditions.

In addition to the above site-level test against flux measurements and C accumulation rate, regional and national GHG budget is also affected by spatial heterogeneity caused by natural factors and human induced disturbances. Satellite-based multi-spectral sensors are optimal for documenting this heterogeneity and for detecting changes because of their ability to cover large areas of the country repeatedly. Since the definition of "verifiable" in Kyoto Protocol includes also validation for methodology, input data (such as area), and final output, spatial explicit gridded data derived from remote sensing data have much to contribute to the validation process.

Tundra

Validation of model output for tundra is also critical. As mentioned before, there is essentially no current research on fluxes of CO_2 or other GHGs in Canadian tundra ecosystems, and even basic information on initial conditions of various ecosystems is lacking. The methods for these types of studies are the same as those in other ecosystems, although sensors and data loggers must be able to withstand the extreme winter weather (Vourlitis and Oechel 1999). Model validation for tundra ecosystems will require expansion of flux tower and other research into the Arctic.

5.6 Beyond the initial observing system

Although Canada presently has the tools and capabilities to establish a viable initial operating system for CCOS-Terre, important gaps have been identified in the workshop discussions. In no particular order, they include:

- Continuity and improvements in the network of flux towers and sites. Details of the design have not been addressed in a comprehensive manner so far. For wetlands, a previous workshop (Cihlar and Tarnocai, 2000) recommended that five long-term flux measurements are required for 5 wetland classes (bog, fen, swamp. marsh, and shallow open water) to facilitate model development, validation, and application. BIOCAP also considered the gaps and desirable additional sites (section 3.2.4). In reality, this is one area where budget limitations have a direct effect, as the possibilities for resource sharing and leveraging are limited. Thus, an implementation of an expanded network needs to be developed, and needs to consider various funding levels and scenarios.
- Development of new satellite-based products. This activity comprises two categories: improvements in present products using more recent, higher quality data sets (section 3.2.7); and the development of new products (Table 1) that will improve the spatial and thematic accuracy of the estimated fluxes. These important additional products that may be derived from new satellite data include above

ground biomass, leaf nitrogen content, leaf dispersion parameters in addition to LAI, chlorophyll content (also to serve as a measure of vegetation 'health'), GHGs due to fire emission, evapotranspiration runoff, and others (see also below).

- Improved understanding of climate change-related ecosystem processes, supported by sound data and leading to reliable models. The models are at various stages of evolution in different ecosystems, and are particularly deficient for tundra and wetland ecosystems (section 2.3, 2.4). Process studies are the foundation for model development and validation, thus to future projections. They lead to an understanding of processes, of interactions among processes, and of limits to our ability to model them. For example, in a forest ecosystem the allocation of carbon, fine root turnover rates, soil respiration, CO2 fertilisation effects and measurements of NEP are all processes/flux that can be quantified only through detailed studies. There is room for much more of these intensive field studies than what currently exists in Canada.
- The lack of data and process understanding from the taiga/tundra regions will impede the usefulness of the initial CCOS-Terre products. The greatest improvement would come from studies along transects through taiga to low arctic tundra to high arctic tundra. Four such transects would be desirable (far northwestern arctic extending into the western high arctic islands; the central region of NWT-Nunavut; along the western coast of Hudson Bay; and in northern Quebec, Labrador to Baffin Island). Along each transect climate, C-flux measurements, and experiments (e.g. ITEX warming experiments) would be conducted over the long-term.
- Lack of coverage in some other areas of the country and integration of different ground-based measurements/data will challenge modelers. This requires special scrutiny because it affects the reliability of mapped outputs. Database development activities are required in tandem with model developments
- Complete treatment of greenhouse gases. As mentioned in section 4.2.2, not all GHGs can be handled with confidence in the initial observing system. The estimation of CO2 is the best developed so far for Canadian ecosystems. CH4 is most important for wetlands (in addition to farm animals where a different observing strategy is appropriate), and the initial effort in wetlands would thus focus on CO2 and CH4. For CH4, the recent launch of the Canadian sensor MOPITT on the EOS Terra satellite (http://terra.nasa.gov/Gallery/MOPITT/) should provide useful independent data for CH4 studies (as it should for CO). On the other hand, N2O is most important for agroecosystems, and substantive progress has been made in this area to include its estimation in IOS. The recent development of an aircraft-based N2O validation at the regional scale (Desjardins et al., 2000) is a key addition to the output validation strategy. These are the GHGs of first-order importance, and need to be included in IOS as soon as feasible. Ultimately, the GHG exchange should be considered for all the gases in all ecosystems.
- Non-GHG CCOS-Terre products. In addition to GHGs, the radiation and energy exchange are very important aspects regarding the role of terrestrial ecosystems in climate change. Of critical importance are surface spectral albedo, photosynthetically active radiation (PAR), UVB radiation, latent heat (i.e., evapotranspiration, see below), and sensible heat. Among these, the first three are well-developed (Li et al. 1996, 2000) and initial products have been generated (Li et al. 1997; Wang et al., 1997; Cihlar et al., 1998). There are outstanding issues that need to be addressed to produce high quality products, including bi-directional effects, determination of surface albedo over snow-covered land and obtaining aerosol optical properties, and additional validations. Nevertheless, version 0 products can be provided as part of CCOS-Terre. To some extent, these products can also draw on research and validation studies carried out in other biomes.

- Systematic treatment of the aquatic component of the terrestrial environment. So far, the spatial distribution of GHG sources and sinks has been considered for the 'dry land' part of Canada. The issue of wetlands is beginning to be addressed, and given the development of relevant models (Cihlar and Tarnocai, 2000) it should be possible to make a rapid progress. Since these are a transition between land and water surfaces, some aquatic aspects will be addressed in this manner. However, there are additional components that need to be dealt with if a full carbon budget is of interest in the future: a) contribution by inland water bodies (rivers, lakes, reservoirs); and b) movement of GHG-related materials (DOC,..) from land to water bodies through overland flow, sediment loss, and ground water flow. The basic CCOS-Terre approach (section 4.3) can accommodate these aspects but much work is required to develop reliable models for the estimation of these components. At the landscape level, the future availability of more detailed satellite, topographic and other gridded data will make the application of such models practically feasible (Geng et al., 2000).

The above activities should continue in parallel through combined efforts of government- and university-based research groups. A strategy for addressing these issues should be developed in parallel with the implementation of IOS.

6. Next steps

At the workshop, required CCOS-Terre components have been discussed, and their current status reviewed. In this section, the actions considered appropriate for advancing the CCOS-Terre concept are summarised.

6.1 CCOS-Terre development and implementation

- Peer review of the CCOS-Terre plan as described in this report should be arranged. This should be complementary to the review of the initial concept (Cihlar, 1999). The appropriate mechanism for this review needs to be developed but could include a wide distribution of the report, presentation(s) at scientific conferences

- It is highly desirable to increase the awareness of the need for a CCOS-Terre among managers and specialists responsible for policy decisions in Canada. A peer-reviewed article in Canadian Public Policy or similar journal could begin to start filling this gap.

- Administrative arrangements and responsibilities of CCOS-Terre participants need to be developed and discussed, leading to an agreement regarding the participation by individual agencies.

- A CCOS-Terre scientific and technical working group should be established. It should consist of lead, active scientists in government departments and universities; and should be guided in its work by an appropriate overview mechanism. One option is to establish this group within the existing 5NR Working Group on Climate Change. The primary initial task would be the implementation of recommendations of this workshop.

- Articles in the national newspapers and programs on local and national television are also an excellent means to publicise the need for and promote a program such as CCOS. Any article or paper on observations or observatories in Canada should involve the Ecological Monitoring and Assessment Network

6.2 Data products development

<u>Development of improved gridded data sets.</u> There are several areas where progress is needed:

- The historical cover and land use data sets compiled so far for land-use change, management and disturbance are rather coarse. The uncertainties in the estimated fluxes could be reduced significantly if full use were made of such information. Unfortunately, it is rather dispersed in various archives at provincial or local levels, and not available in digital form. Thus, its compilation will entail significant effort and resources. For forests, much better use could be made of the age information in provincial forest inventories, as in the existing national data bases this information is aggregated to grid cells ≥ 100 km^2.
- Water fraction. The site to Canada scaling through process models relies on the availability of land cover information. At the present, this information is available at the nominal resolution of 1km^2, but in reality coarser due to the limitations of satellite data (Cihlar et al., 1999). Chen (1999) showed that significant improvements in upscaling would be obtained if the fraction of each pixel were known. With the upcoming data sources (section 3.2.7), a much improved land cover information (and water fraction to $\ll 1$ km^2) can be derived.

- Estimation of forest biomass. At the present, there is no satellite data source from which biomass data could be extracted accurately and reliably for woody vegetation. This is expected to change, with a lidar mission under development (http://essp.gsfc.nasa.gov/vcl/). The Vegetation Canopy Lidar is designed to measure the vertical distribution of canopy components along profiles spaced approximately 2 km apart. The currently scheduled launch is for the year 2000. Once combined with land cover information from sensors such as MODIS, VGT or AVHRR, very good estimates of biomass distribution can be expected.
- Estimation of emissions from biomass burning. Forest (and to a much lesser extent grassland and cropland…in Canada, but globally savannah fires in Africa and South America are responsible for between 17-59% of biomass burned. Burning of agricultural waste is responsible for another 11-28% (Andreae, 1991). However, various authors provide widely different estimates, mainly due to uncertainties in burned area. Andreae (1991) estimated that tropical, temperate, and boreal forests are responsible for only 18% of biomass burned. This is probably too low because burning in boreal Asia has been vastly underestimated. In addition, the net annual contribution from savannah is much less because CO2 is rapidly sequestered by regrowth. The amount of each GHG from a given fire varies greatly, depending on a number of factors related to forest pre-fire characteristics (fuel loading) and concurrent fire weather conditions. Most current approaches to estimating continental-scale gas emissions make many simplifying assumptions about fuel loading, fuel consumption, and area burned, thus yielding estimates with large uncertainties. Recently, Scholes et al. (1996) calculated fuel loading in Africa using a productivity model driven by rainfall data. Remote sensing techniques hold great promise for improving estimates of burned area (Cahoon et al., 1994; Scholes et al., 1996; Fraser et al., 2000), fuel conditions (Barbosa et al., 1999) and fuel consumption (Kasischke et al., 2000). The challenges are to extend the applicability of process-based models and satellite remote sensing for determining fuel loading and consumption for Canadian forest fires. The most important variables for the initial CCOS-Terre period are burned area, fuel loading, and fraction of fuel consumption.
- Evapotranspiration (ET). Mechanistic ecosystem models compute ET in the process of determining carbon uptake because of ET's influence on soil moisture which is one of factors controlling stomatal opening (Running and Coughlan, 1988). In this manner, ET gridded products can be generated (Liu et al., 1997; Running et al., 1989; Sellers et al., 1997) with a temporal resolution of 1 hour to 1 year. However, it is important that these products are properly validated; this in turn requires independent flux tower data from different ecosystem conditions. In both cases, the quality of gridded precipitation inputs is a critical factor affecting the accuracy of the CCOS-Terre output products. The accuracy of outputs could be assessed using observations from the Canadian hydrological network (section 3.2.3).
- Land cover. So far, the emphasis has been placed on data products that provide information on land cover type. For GHG estimation, it is important to have information on land use and management. In addition, model requirements refer more to the characteristics of the land cover (e.g., vegetation fraction, within pixel composition, leaf type and longevity) than the type itself. Therefore, new land cover products are required for improved estimates of GHG emissions and their projections into the future.
- Improved high resolution data on land cover and land cover change In addition to the routinely available Landsat ETM and SPOT data, very high resolution (pixel size <~4 m) data are becoming available from commercial missions. The first example is IKONOS (http://www.spaceimaging.com/ikonos/) but several other similar missions are under development. These data will be very useful for the development and refinement of algorithms, product validation, etc.

Development of improved point data sets:

- Soil and necromass carbon data are inadequate for most biomes. For instance, most forest inventories do not include soil and necromass carbon. Also, few reliable estimates exist for coarse roots, dead and standing necromass and large organic debris. This information is needed across biomes and age classes to help in validating net ecosystem exchange. Gaps in these areas could be addressed by ground-based sampling campaigns, and scaling up through a GIS-based integration with a forest classification scheme. Eventually, these data should be available through NFI (section 4.4.2).
- An important area of research and associated data requirements is the relationship between NPP and stand age for different forest ecosystems. This relationship provides the basis for (i) interpreting tower measurements made in stands of specific ages and for (ii) model estimation of NEP at different stand ages. Such information is key for large area NEP estimates with models and satellite-derived data of landcover, leaf area and fire scar age (related to stand age). This information can be obtained from forest yield data previously acquired by provincial agencies for various purposes.

7. Conclusions and Recommendations

7.1 Conclusions

1. An integrated terrestrial climate-related observing system, which includes detailed site measurements, gridded observations, and analysis and modelling, can provide essential data and information for the assessment of the impact of climate change on terrestrial ecosystems of Canada, and the feedback from these to the climate system. The CCOS-Terre concept will meet the requirements of such an observing system and help fulfil international committments.

2. Because of the urgent need for data and information for the assessment and report on the impact of climate change on the Canadian ecosystems, an initial observing system for CCOS-Terre should be established immediately on the basis of current capacities in various agencies, universities, and others teams.

3. A continuing, vigorous R&D is essential to improve the observation system and its products.

7.2 Recommendations

1. The interest in participating to CCOS-Terre by the major potential contributors in four areas: input data, output products, system support, or effective use. The candidates should include government agencies (AAFC, Research Branch; EC, Climate Branch; NRCA, Canadian Forest Service and Canada Centre for Remote Sensing; SC, Environment Accounts and Statistics Division), university teams, and others.

2. Specific output products should be identified that have been or are now generated at the national level and are appropriate for CCOS-Terre needs. Such existing products should be assembled, together with appropriate documentation, as the initial slate of experimental CCOS-Terre products. Actions necessary to continue production of these output products should be identified, and the steps should be taken to ensure that their production continues. Actions needed to improve the quality of the output products should be defined and implemented, including the acquisition of the necessary in situ measurements.

3. A distributed, web-based capability should be established to support public access to CCOS-Terre data and products.

4. Implementation of CCOS-Terre should be supported through a scientific and technical working group and through the participation of scientific teams from the participating agencies. Furthermore, support should be provided which is necessary to make CCOS-Terre operation feasible and effective through:
   - the operation of a modest but effective network of in situ observations, especially the flux tower sites;
   - the operation of an effective satellite observation, data processing, and product generation systems, to be used alone or as inputs into models that quantify the exchange of GHGs, water and energy with the atmosphere;
   - the research of modelling and process studies leading to improved methods for estimating the GHG fluxes between the ecosystems and the atmosphere;

- the development and implementation of systematic observation and modelling programs for Canadian wetlands and tundra, with the objective of obtaining credible estimates of GHG exchange;
- the appropriate institutional arrangements are put in place so that climate change-related issues for wetlands and tundra receive adequate attention.

These recommendations should be implemented through collaboration among contributing departments and funding programs such as NSERC, CCAF, PERD, and LTSP.

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9. Appendices

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Appendix 9.2 Agenda

Workshop on the Canadian Climate Observing System for terrestrial ecosystems (CCOS-Terre)

A) VENUE:
Dates: March 7-9, 2000
Hotel Novotel
Ottawa, ON

B) CONTACTS at the Canada Centre for Remote Sensing:
Workshop organisation: J. Cihlar (tel. 613 947 1265)
Local arrangements: L. Bloess (tel. 613 947 1256)

C) AGENDA:

Day 1: Presentations: science and policy information requirements, issues

Chair: McKenney
0830 Welcome and introduction
0840 Background, context, objectives: Cihlar
0900 1999 workshop (presentation of the document): TBD
0930 Forests: science and policy issues and observation needs: Bernier
0955 Agroecosystems: science and policy issues and observation needs: Desjardins
1000 Refreshment break
1015 Observation needs for regional climate modeling: Laprise
1040 Observation needs for ecosystem modeling and upscaling: Chen
1115 Wetlands Workshop: science and policy issues and observation needs: Tarnocai
1140 Terrestrial Carbon Synthesis Workshop report: Barr and Ahern
1215 Lunch (on premises)

Chair: Flanagan
1300 Breakout 1: Key questions and information requirements with respect to climate-related observations of ecosystems (review and revision of pre-workshop material)
a) Science
b) Policy

1400 Plenary presentations and discussion
1430 Breakout 2: Observation requirements (satellite and in situ; consider pool and or flux observations as appropriate; consider desirable and minimum sets, with spatial and temporal resolution specific to each case; data transmission issues etc.): review, revision and improvement of pre-workshop material
a) agroecosystems
b) forests and tundra
c) satellite and atmospheric (all ecosystems)

Day 2:
Chair: Desjardins
0830 Plenary presentations and discussion
0930 Existing in situ networks and data bases (survey results): Sims
0955 National forestry networks: Allen
1025 Refreshment break
1040 EMAN: Vaughan
1100 Provincial forestry database: Jones
1120 ITEX: Henry
1140 Parks database: Woodley
1200 Hydrological data bases: Harvey

1220 BIOCAP plans for observations: Flanagan
1240 Satellite observations of Canada - present and near future: Franklin and Chen
1240 Lunch (on premises)

Chair: Sims
1330 Breakout 3: Elements of a climate observing system for Canadian landmass: which existing networks can participate, and which critical data will they provide? What obstacles, if any, need to be overcome to initiate their involvement? What gaps will remain? How to address the gaps?
a) soils and agroecosystems
b) forests, wetlands and tundra
1530 Plenary presentations and discussion

Day 3:

Chair: Cihlar
0830 Breakout 4: Possible initial observing system and data issues (metadata, access, continuity of observations), management and governance issues, way forward
a) satellite (and international) data
b) in situ data (various agencies)
1100 Plenary presentations and discussion
1200 Lunch (on premises)
1245 Way forward and action plan
1330 Report outline
1345 Writing session

Appendix 9.3 Decisions of Conference of Parties

This Appendix provides information on some decisions of the UN FCCC Conference of Parties that are relevant to the workshop subject. The full documents may be found at http://www.unfccc.de.

FCCC/CP/1999/7 Decision 5/CP.5 Research and systematic observation

The Conference of the Parties,

……

6. Urges Parties to address deficiencies in the climate observing networks and invites them, in consultation with the secretariat of the Global Climate Observing System, to bring forward specific proposals for that purpose and to identify the capacity-building needs and funding required in developing countries to enable them to collect, exchange and utilise data on a continuing basis in pursuance of the Convention;

7. Adopts the UNFCCC reporting guidelines on global climate observing systems;

8. Invites all Parties to provide detailed reports on systematic observation in accordance with these guidelines, for Parties included in Annex I to the Convention in conjunction with their national communications, pursuant to decision 4/CP.5, and on a voluntary basis for Parties not included in Annex I.

FCCC1999/7 C. Systematic observation

64. Parties should provide summary information on the current status of national plans, programmes and support for ground- and space-based climate observing systems, including long-term continuity of data, data quality control and availability, and exchange and archiving of data in the following areas:
(a) Atmospheric climate observing systems, including those measuring atmospheric constituents;
(b) Ocean climate observing systems;
(c) Terrestrial climate observing systems;

…

3. Parties shall describe the status of their national programme for systematic observation to meet the needs for meteorological, atmospheric, oceanographic and terrestrial observations of the climate system as identified by the Global Climate Observing System (GCOS)1 and its partner programmes

D. Terrestrial observations

15. Parties should describe their participation in GCOS and GTOS programmes for terrestrial observations including the Global Terrestrial Network - Glaciers (GTN-G), Global Terrestrial Network - Permafrost (GTN-P), and the Global Terrestrial Network – Carbon (FLUXNET),11 and other networks monitoring land-use, land cover, land-use change and forestry, fire distribution, CO2 flux, and snow and ice extent. Additionally, a general description of programmes for hydrological systems should be given. Parties should describe to what extent the observations correspond to the GCOS/GOOS/GTOS climate monitoring principles (appendix 2) and relevant best practices.

Appendix 9.4 Variables for the Canadian Regional Climate Model

A) Initial and Lateral Boundary Conditions

1. Atmospheric Fields

3-D, every 6 or 12 h
Temperature or Geopotential Height
Horizontal wind components
Water vapour

2-D, every 6 or 12 h
Surface pressure

2. Surface fields

2-D at initial time
Land
Ground Surface Temperature
Liquid and Frozen Ground Water
Snow Amount
Oceans and Lakes
- Open water

Water Surface Temperature
- Frozen
Ice Amount
Snow Amount

3. Prescribed Geophysical Fields
Atmospheric
- Ozone
- Greenhouse gases
Surface
- Topographic Height
- Land-Sea-Ice Mask
- Surface Roughness
- Subgrid-scale topographic variability
- Surface Albedo, near IR & short waves
- Soil type
- Vegetation indices (primary & secondary)
- Rooting depth

B) Archived Outputs

4.1 Atmospheric Fields

3-D, every 6 or 12 h:

Temperature
Horizontal and Vertical wind components
Water vapour
Cloud amount

2-D, every 6 or 12 h:

Surface pressure
Total cloud cover

4.2 Surface Fields

Land:

- Top and Deep Surface Temperature
- Liquid & Frozen Ground Water
- Snow Amount & Age

Surface Albedo, incl. snow feedback

Water Ice:

- Surface Temperature
- Snow Amount & Age

Ice Amount (interactive Sea Ice)

Open water:

- Sea Surface Temp. (interactive mixed-layer)

4.3 Archived Output: Fluxes and Diagnostics

At the Surface

Sensible Heat Flux
Radiative Fluxes
- Solar incident at & absorbed by the surface
- Terrestrial (net and downward) at the surface

Evaporation
- Total & from snow

Precipitation
- Total & as snow, Stratiform & Convective
- 6-h Cumulative & every time step

Momentum Stress components
- Total & non gravity-wave

Balance of Surface Energy & Water
- Land & Oceans

Atmospheric values of Near Surface
- Temperature

Instantaneous, Minimum & Maximum
- Specific Humidity

Instantaneous, Minimum & Maximum
- Wind components

Instantaneous & Maximum speed

In Atmosphere (3-D)
Heating rates
- Turbulent (incl. surface sensible heat flux)
- Convective and condensation
- Radiative

Solar
Terrestrial

Moistening rates
Turbulent (incl. surface evaporation)
Convective and condensation
Vertically integrated water vapour fluxes
Horizontal Momentum tendencies
- Turbulent (incl. surface stress) and gravity-wave drag
Top of the atmosphere
- Outgoing Long-wave Radiation
- Reflected Solar Radiation
- Planetary Albedo
Total Atmospheric absorption
- Solar
- Terrestrial