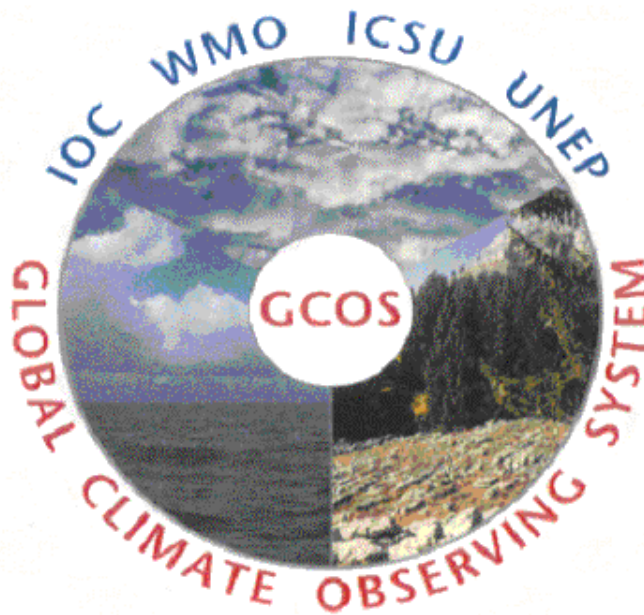


**THE CANADIAN NATIONAL REPORT ON SYSTEMATIC
OBSERVATIONS FOR CLIMATE**

THE CANADIAN GLOBAL CLIMATE OBSERVING SYSTEM PROGRAM



**Submitted to the Conference of the Parties to the United Nations
Framework Convention on Climate Change (UNFCCC)**

Acknowledgements

This report was produced as a result of the extensive input and review by experts in federal, provincial and territorial government agencies across Canada; the contributions of these agencies is gratefully acknowledged.

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EXECUTIVE SUMMARY

In 1995, an ad-hoc Task Group recommended that Canada should play an active role in GCOS and a Canadian National GCOS Committee was subsequently established. This committee sponsored the development of a preliminary Canadian GCOS plan, published in February 1999. The national GCOS plan, a living document that continues to evolve, has given direction and momentum to Canada's efforts to contribute meaningfully to the establishment and operation of GCOS. Its practical impact has, moreover, been substantially reinforced by contributions from the Canadian government's Climate Change Action Fund that have accelerated both the planning process and the implementation of important observational enhancements.

As detailed in this report, excellent progress has been made in implementing the atmospheric components of the GCOS Initial Observing System in Canada, despite continuing budgetary pressures which have necessitated reduction and re-engineering of the monitoring programs. To date, 72 GSN and 4 GUAN stations have been designated and are fully operational and a 5th upper air station (Cambridge Bay) has been proposed for GUAN designation in order to fully meet our commitment to that global network. Moreover, funds have been allocated to undertake station upgrades and the installation of new stations needed to fill some of the remaining gaps in the Canadian portion of the GSN. Finally, the Canadian GAW station at Alert is functioning at a high level as a primary global background GAW station.

Canada also continues to make a solid contribution to the oceans component of GCOS and GOOS through provision of oceanographic and marine atmospheric observations from tide gauges, subsurface floats, moored and drifting buoys and the Ship of Opportunity and Voluntary Observing Ship programmes. A recent review of the nation's ocean observing networks has, moreover, provided a firm basis for future enhancements. As a follow-on to this review, Canada will be making further strategic contributions to global oceanographic programs in the near future, highlighted by major Project Argo deployments, the establishment of additional Arctic tide gauges and initiatives related to sea ice.

Systematic observation of the multi-faceted terrestrial sector presents special challenges in Canada due to the immensity and variety of the country and to jurisdictional complications arising from the Canadian constitution. Despite these complexities, however, Canada is already providing solid support to the formalized global terrestrial networks, the GTN-P, GTN-G, FLUXNET and the proposed GTN-H, and expects to further enhance these contributions. As an active participant on the GTN-P organization and implementation committee, the country contributes 19 key active layer (CALM) stations to that global network and has identified 75 existing permafrost borehole thermal monitoring sites as potential additional contributions. Canadian support for the GTN-G encompasses 9 operating glacier sites already designated as part of the global network and this

number will increase to 11 glacier sites by 2005. Where carbon flux measurements are concerned, 4 Fluxnet-Canada sites are already operational and an increase to 7 sites is projected over the next year or so. These FLUXNET contributions are reinforced by several associated carbon flux measurement sites which are operational but have not been classified as part of the global network.

Canada is also engaged in a number of other activities which are supportive of the broader objectives of GCOS. These include capacity building, network support and related programs at the global level, such as assisting China in maintaining a GAW station in that country, operating the World Data Centre for Ozone and Ultraviolet Radiation and the World Calibration Centre for Brewer instruments in Toronto and international committee work. Equally, they include domestic thrusts such the organization of focussed GCOS workshops, comprehensive planning for a terrestrial IOS within the country, ongoing operation of important observational and research networks such as EMAN and CANTTEX and participation in research and development related to satellite remote sensing of climate variables.

In summary, Canada has made solid progress with implementation of GCOS components for which it is directly responsible. The country remains committed to supporting the further development of this global program, a commitment that is clearly reflected in the allocation of scarce resources for domestic implementation actions and in the high priority that continues to be assigned to the climate issue by the Canadian government. It is also expected that the Climate Science initiatives in the Federal Government's Action Plan 2000 on Climate Change will contribute significantly to enhancing the climate observing program in Canada.

1.0 INTRODUCTION

In 1995, an ad-hoc Task Group, established under the umbrella of the Canadian Climate Program Board and the Canadian Global Change Program Board, recommended that Canada should play an active role in GCOS (1) and a Canadian National GCOS Committee was subsequently established. The GCOS Committee promoted the development of a Canadian GCOS plan through a process that culminated in a widely-attended national workshop¹ held in Victoria, British Columbia in February 1999. This national workshop represented a significant milestone in bringing together the broader climate community, developing a common understanding of GCOS requirements and setting the stage for the next steps in Canadian GCOS development. Building upon the workshop discussions², a preliminary Canadian GCOS plan was drafted and published in April 1999 (2). The plan defined the implications of GCOS for Canada, assessed the country's existing observational capacity and proposed cost-effective options for fulfilling our national GCOS obligations while, at the same time, satisfying domestic needs for climate system observations.

Canada's national GCOS plan is a living document, one that continues to evolve. It has provided focus and direction for the many players involved in climate system observations in Canada, generating momentum for a subsequent series of workshops that have addressed individual components of the climate system (3; 4; 5; 6; 7). The preparation and the subsequent implementation of early initiatives in the national plan have been greatly facilitated by the existence of the federal government's Climate Change Action Fund (CCAF), a fund which provides "seed" money for carefully selected climate-related initiatives. CCAF-funded activities have encompassed the development of the national GCOS plan, the conduct of workshops, provision of support for international GCOS liaison and the completion of high priority studies³. It is clear that such a funding mechanism represents a very useful adjunct to national planning and, in the Canadian circumstance, has substantially accelerated the development and implementation of a national response to GCOS in the face of continuing budgetary pressures which have necessitated reduction and re-engineering of government's monitoring programs.

¹ Sponsored by the Climate Change Action Fund (CCAF)

² Five component plans were drafted, addressing the atmosphere, oceanic, hydrologic, cryospheric and terrestrial domains respectively, and then refined at the national workshop and integrated into a national plan.

³ The following are the titles of these study reports: - "Assessment of Requirements for the Supplementary Climate Networks"; "Digitalization and Accessibility of Climate Station History Metadata"; "Enhancements to Moored Buoy Data and Metadata for GCOS"; "Climate Monitoring and Canada's Water Resources"; "Assessing the Utility of Coastal Sea Level and Hydrographic Data in the Estimation of North Atlantic Circulation Variability"; "Delineation of an Optimal Sea Level Network"; "Definition of a Core Canadian Cryospheric Network of *in situ* and Remotely Sensed Data for Monitoring the Canadian Cryosphere in Support of GCOS"; "Wetlands Distribution and the Carbon Cycle"; "Design of a Canadian Network for Terrestrial Climate Related Observations" and "Delineation of Temporal/Spatial Scales of Primary Productivity on Canadian Shelves".

Canada places special emphasis on the cryospheric components of GCOS in its national planning as the cryosphere is among the most important features of the physical and biological environment^{4,5}. Most of the country experiences several months of snow cover each year, more than half is covered by the permafrost region, many of its waters are affected by ice and its terrestrial ice masses are the most extensive in the hemisphere outside of Greenland. Moreover, large areas exist at temperatures close to melting and are highly sensitive to changes in temperature regime.

The present report draws heavily from the national GCOS plan and workshops mentioned above. It is structured in accordance with the United Nations Framework Convention on Climate Change (UNFCCC) Reporting Guidelines on Global Climate Observing Systems and, to the extent possible, with the supplementary guidance provided by an informal meeting of National GCOS Coordinators held in Melbourne, Australia, 9 – 11 August 2000.

Systematic Climate Observations in Canada

As in other countries, the collection, quality assurance, archiving and provision of systematic observations of the climate system in Canada involve many agencies and institutions and arise out of a broad spectrum of requirements, applications and obligations. The constitutional division of responsibilities between Canadian federal and provincial/territorial governments, however, means that no single jurisdiction has responsibility for all components of the climate system. This constitutional reality is reflected in the varying degrees to which climate system observational networks and systems are nationally coherent and, in addition, complicates national-level GCOS planning and implementation.

Where the atmosphere and the oceans are concerned, the Canadian federal government's lead role is unambiguous with coherent and long-established national planning and management systems in place for atmospheric and oceanic observations⁶. In contrast, provincial/territorial jurisdiction is generally paramount where natural resources (e.g. forestry, agriculture) are concerned⁷ and terrestrial observations are, as a result, addressed in a more dispersed

⁴The cryosphere is the portion of the climate system which consists of snow and ice deposits, including ice sheets, ice caps and glaciers, sea ice, snow cover, lake and river ice, permafrost and frozen ground.

⁵ In 2000, two CCAF-sponsored workshops assessed cryospheric observational programs in Canada, identified regional/thematic gaps and provided recommendations for the national GCOS Plan.

⁶ While provinces collect some atmospheric data, atmospheric observations for Canada are generally coordinated by and available from the Meteorological Service of Canada (MSC) of the Department of Environment Canada (EC). Oceanographic observations from internal and external sources are archived by the Marine Environmental Data Service (MEDS) of Fisheries and Oceans Canada (DFO).

⁷ With federal agencies largely restricted to national coordination, responsibility for inter-provincial and cross-border issues and the conduct of research.

fashion. Relevant federal departments⁸ acquire, process and archive many terrestrial-component observations and attempt to coordinate national systems for forestry, agriculture, soils, hydrometric and other data, but many terrestrial observations are collected and held in provincial, university and other hands or by individual scientists. While Canada continues to make every effort to adhere to the published GCOS/GOOS/GTOS Climate Monitoring Principles, the above reality has meant that the current level of adherence to these principles is uneven, particularly in the terrestrial sector.

Data Access

As a general principle, Canada subscribes to free and open access to Canadian GCOS data and will make every effort to facilitate exchange of these data. This may, depending on individual circumstances, involve application of modest charges for reproduction and delivery but no charges will apply to the data themselves. In addition, Canada subscribes to relevant World Meteorological Organization (WMO), Intergovernmental Oceanographic Commission (IOC) and other internationally agreed policies with respect to atmospheric, hydrologic, oceanographic and other data and products and has undertaken to provide agreed datasets to the designated Data Centres. Subsequent sections of this report identify access points for Canadian GCOS data and other supporting datasets.

2.0 ATMOSPHERIC OBSERVATIONS

Atmospheric observations are needed to monitor climate, detect and attribute change, improve understanding of the dynamics of the climate system and its natural variability and provide input for climate models. Several global observational networks have already been identified for the atmospheric component of the GCOS Initial Observing System (IOS). In particular, a geographically representative **GCOS Global Upper Air Network (GUAN)** has been specified, a **GCOS Global Surface Network (GSN)** has been defined and the **Global Atmosphere Watch (GAW)** network is now considered a component of the GCOS. It is also recognized that other networks will be needed to address additional variables and that satellite observations of the atmosphere can make an important contribution to GCOS.

⁸ Natural Resources Canada (NRCAN), Agriculture and Agri-Food Canada (AAFC) and Environment Canada (EC).

2.1 GCOS Networks

Canada is committed to contributing to the GCOS Surface Network (GSN), GCOS Upper Air Network (GUAN) and to the observation of atmospheric constituents through participation in the Global Atmosphere Watch (GAW). Table 1 summarizes Canada's contributions to these global programs and the subsequent sections discuss these contributions in greater detail.

Table 1. Canadian participation in the global atmospheric observing systems.

	GSN	GUAN	GAW
How many stations are the responsibility of the Party?	72	4 ¹	44
How many of those are operating now?	72	4	43
How many of those are operating to GCOS standards now?	72 ²	4	43
How many are expected to be operating in 2005?	92	5	44
How many are providing data to international data centres now?	72	5	43

Notes: ¹ Canada has proposed the high-Arctic station at Cambridge Bay as a GUAN station to replace Mould Bay which has been closed.

² Currently the Global Data Centre is receiving monthly CLIMAT messages for all GSN stations. Action is underway to increase Canada's GSN contribution by the addition of "gap-filling" stations.

The Global Surface Network (GSN)

GCOS bodies have promoted the establishment of a land-based, global reference network of surface climate observing stations at an approximate density of one station per 250,000 square kilometres. Responding to GCOS requirements for identification of appropriate Canadian GSN stations has not presented insurmountable difficulties and Canada has already designated 72 GSN stations⁹ and is placing a high priority on ensuring the future operation of these stations to specified GSN standards. Action is also underway to establish additional stations in some areas where gaps in national coverage exist with respect to the GSN station spacing criteria. In such areas, five or six new GSN stations will be installed and up to 14 existing climate stations will be upgraded to become standard GSN stations. Figure 1 shows the current Canadian GSN station network of 72 stations and the new and upgraded stations which will be added to the network by 2005.

⁹ The Meteorological Service of Canada (MSC) has identified 287 stations (February 2001) as Reference Climate Stations (RCS) and considerable effort is being invested in protecting them for the long-term. Canadian GSN stations are primarily a subset of the RCS network.

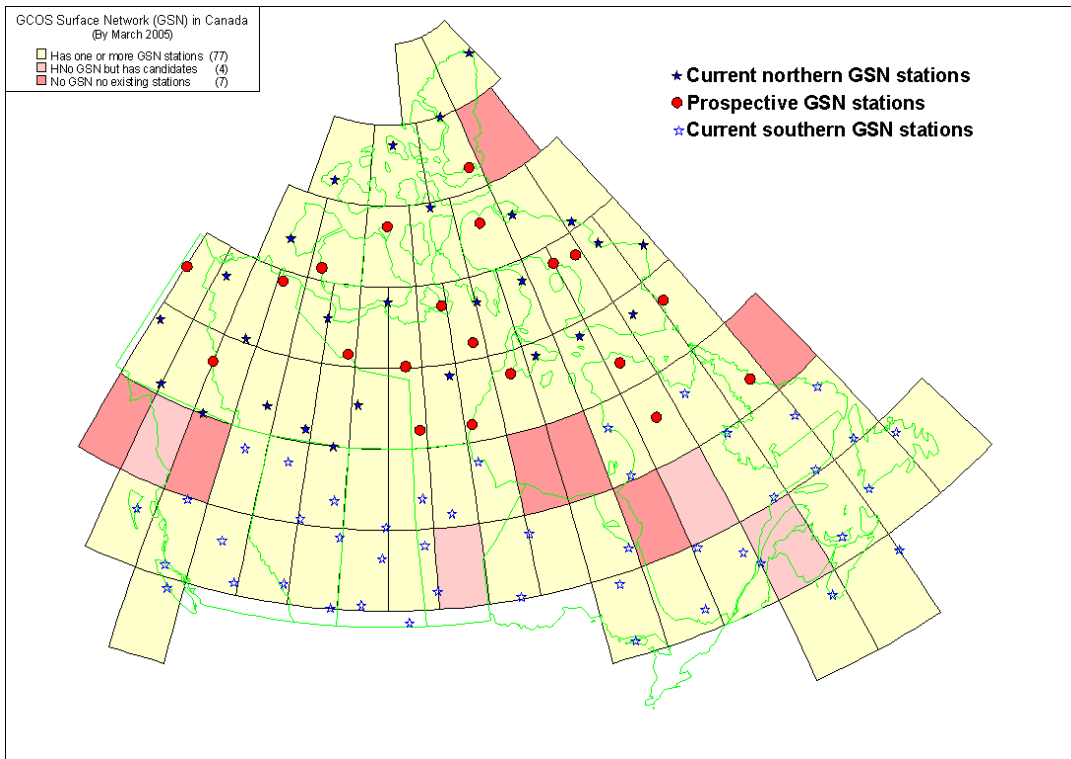


Figure 1. The current and projected (2005) Canadian GSN network. Planned locations for new and upgraded stations are identified.

The Global Upper Air Network (GUAN)

The GCOS Global Upper Air Network (GUAN) network is intended to supply globally representative suites of upper air observations and Canada has been requested to designate 5 radiosonde stations as part of this global network. One of the original stations suggested for designation (Mould Bay) was closed as a result of government budget cuts but an alternative high-Arctic station (Cambridge Bay) has been proposed as a replacement. Four Canadian upper-air stations (Alert, Goose Bay, Moosonee and Fort Smith) are presently operating as formal GUAN sites and the proposed station at Cambridge Bay is also operational. Figure 2 illustrates the Canadian upper air network, including the GUAN stations.

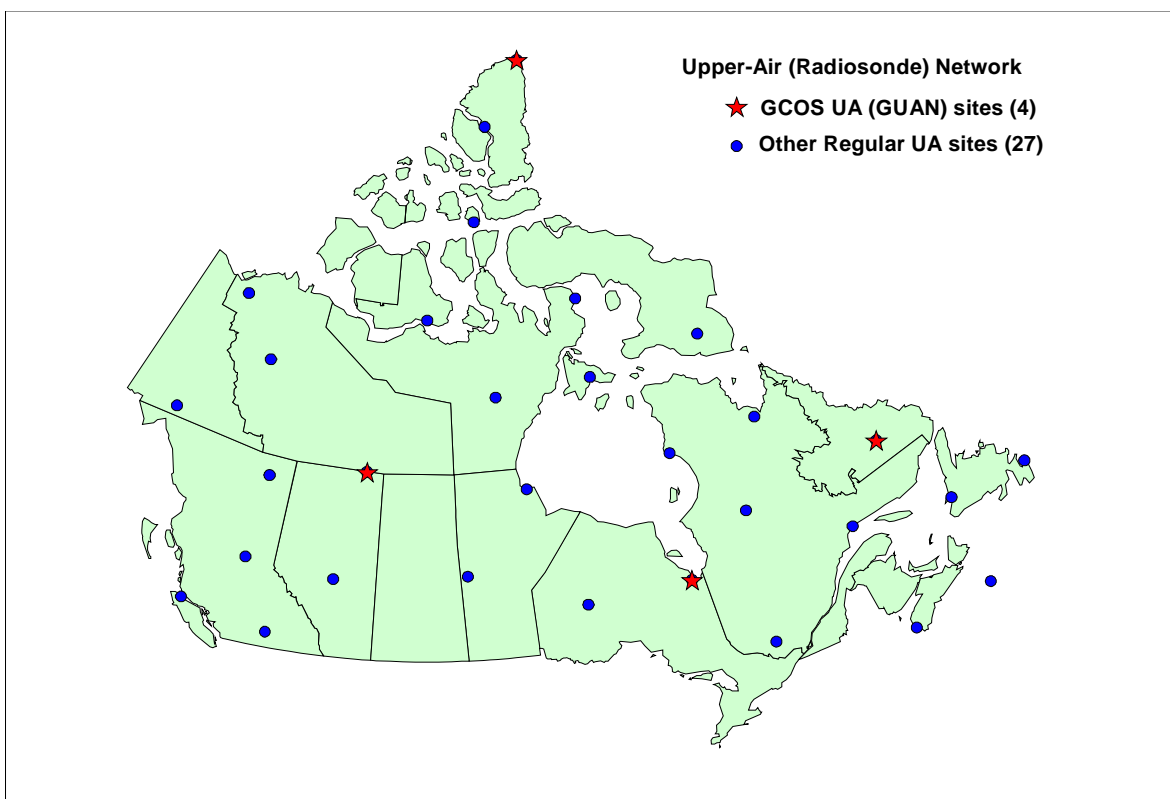


Figure 2. The Canadian upper air network including the 4 designated GUAN sites.

Global Atmosphere Watch

Systematic observations of atmospheric constituents are needed to simulate the climate system, initialize and evaluate models and monitor the effectiveness of emission controls. The Global Atmosphere Watch (GAW) system, established in 1989, addresses this requirement and is a coordinated network of global and regional stations, along with associated infrastructure¹⁰. Canada currently operates 43 GAW stations. Notably, the station at Alert (Nunavut) has been designated as a primary global background GAW station. Alert's baseline measurement program includes trace gas measurements of the greenhouse gases (CO₂, CH₄, CFC-11 and 12, O₃, N₂O), along with aerosol measurements of black carbon, condensation nuclei and aerosol chemistry. Important GAW-related observational programs are also in place at Fraserdale (Ontario), Sable Island (Nova Scotia) and Estevan Point (British Columbia). Fraserdale is a key boreal forest site with a measurement program that includes continuous CO₂, CH₄, N₂O and SF₆ along with radon measurements. The two remaining coastal sites have more limited weekly flask sampling programs for CO₂, CH₄, N₂O, CO

¹⁰ It incorporates the former BAPMoN (Background Air Pollution Monitoring Network) and GO₃OS (Global Ozone Observing System) programs and integrates both monitoring and research activities.

and SF6. Routine stable isotope measurements are also undertaken at Alert and Estevan Point. Another continental site is to start CO₂ concentration measurements in Saskatchewan's Prince Albert Park in 2002.

Additional measurements of atmospheric constituents are provided by two Canadian programs – CORE and CAPMoN.

The “CORE” network of 6 stations has been developed to provide long-term, high quality, observations of atmospheric composition and radiation at locations representative of major atmospheric regimes and geopolitical regions¹¹.

The Canadian Air and Precipitation Monitoring Network (CAPMoN), consisting of 22 stations, was created to study the regional patterns and trends of acid deposition in Canada and is an integral component of the GAW network¹².

Canada also provides GAW with column ozone and spectral UV radiation data from its twelve-station network of Brewer spectrometer and with ozone profile data from its six station Ozonesonde network.

In addition to the preceding, several noteworthy contributions are being made at the global level. Canada operates both the World Data Centre for Ozone and Ultraviolet Radiation and the World Calibration Centre for Brewer instruments. Canada also provides ongoing, capacity-building, assistance to the Chinese Meteorological Administration in operating a GAW station within that country.

2.2 Other Observing Programs

Canada's national (atmospheric) Climate Network¹³ is, in practice, the composite of several rather distinct sub-networks:

- A Daily Temperature and Precipitation (T&P) Network, operated by cooperating agencies, volunteer and contract observers and including an increasing number of automatic stations;
- A Principal (Hourly) Network of automated and manned real-time reporting stations established primarily to support weather forecasting;

¹¹ It is intended to serve as a national reference network that maintains standards, provides expertise and fulfills international monitoring commitments.

¹² Precipitation chemistry is measured at all CAPMoN sites, aerosol is measured at 11 of these sites and ground-level ozone at 7 sites.

¹³ The Meteorological Service of Canada is the federal lead agency for atmospheric observation networks and for management of the data from them.

- An Upper Air (Radiosonde) Network, of manned stations to support weather forecasting;
- Supplementary Networks established to acquire observational data on variables such as:

Rate of Rainfall	Wind Speed and Direction	Ozone
Evaporation (Pan)	Soil Temperature	Sunshine
Snow Cover/Depth	Radiation	
- Air Quality and Precipitation Chemistry Networks.

There are also, as discussed later, observational programs for ice thickness and freeze-up and break-up dates(FU/BU) on inland and coastal waters and marine meteorological observations are acquired from Voluntary Observing Ships (VOS), satellites, moored and drifting buoys and as an extension of Canada's national sea-ice program.

Much of the national atmospheric climate network has been developed in response to specific local, regional or national requirements, often on an opportunistic basis. The temperature and precipitation network is dependent on cooperating agencies and volunteers, who provide much of the data, with a small number of contract and a growing number of automatic stations making up the remainder. The Principal (hourly) Network's primary purpose is to provide data for the preparation of weather forecasts for the public and other applications, with the resulting climatological data considered to be secondary to this purpose. The Supplementary Networks, for their part, are built largely through various partnership arrangements and the locations of stations reflect this reality. Air Quality and Precipitation Chemistry Networks have developed over the past several decades in response to growing public concerns regarding environmental issues such as air pollution and acid rain. Subsequent sections provide a condensed overview of these various networks and programs and Tables S1 through S3 contain additional details.

Canada's atmospheric climate networks are currently being re-engineered with the objective of ensuring their long-term financial sustainability while at the same time meeting essential needs for data. Life-cycle management is progressively being implemented, access to data is being improved and emphasis is being increased on adherence to WMO standards. This modernization process will result in future networks which have reduced numbers of stations but produce higher quality, more readily accessible data and can be supported within a realistic budgetary framework.

The National Temperature and Precipitation Network

The extensive national climatological network of temperature and precipitation stations has undergone significant, budget driven, reductions over the past decade and now totals 2147 stations. Station distribution is illustrated in Figure 3, reflecting a bias towards lower and more populated latitudes and elevations.

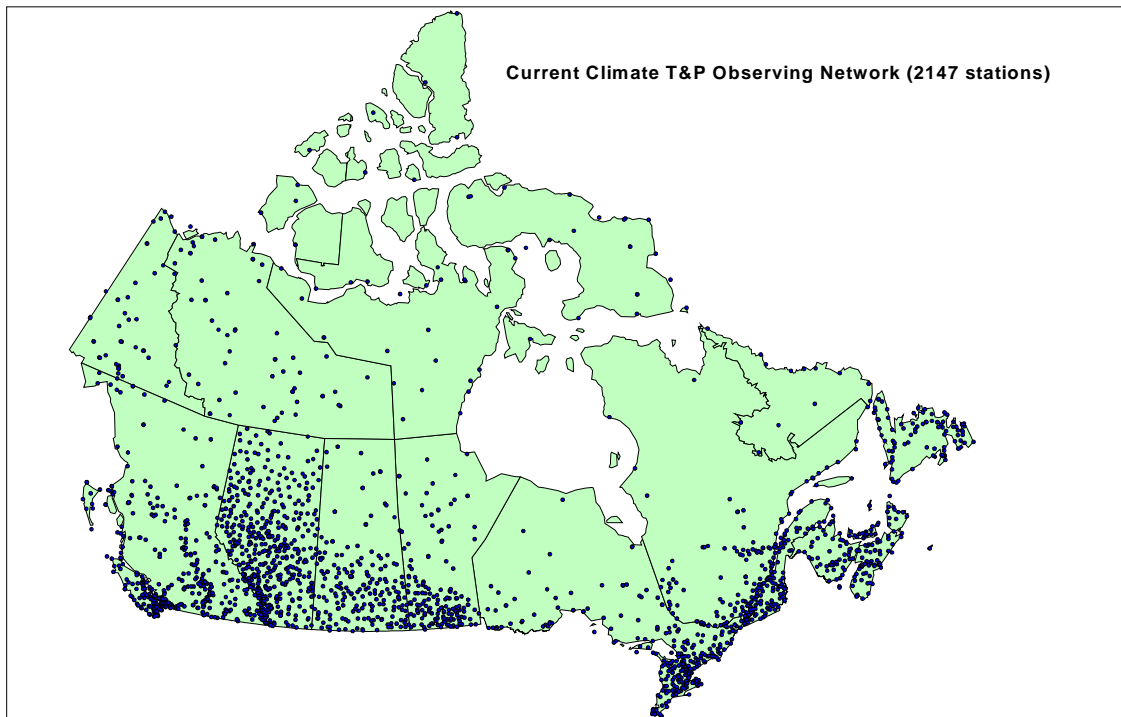


Figure 3. The Canadian temperature and precipitation network.

Recent efforts to address the attrition in this network and its uneven distribution have focussed on the identification of a Reference Climate Station (RCS) Network of about 300 of the best stations and targeting these for long-term maintenance and enhancement through automation, addition of variables and other measures. These efforts will continue to be a priority during the coming decade. Figure 4 illustrates the RCS Network.

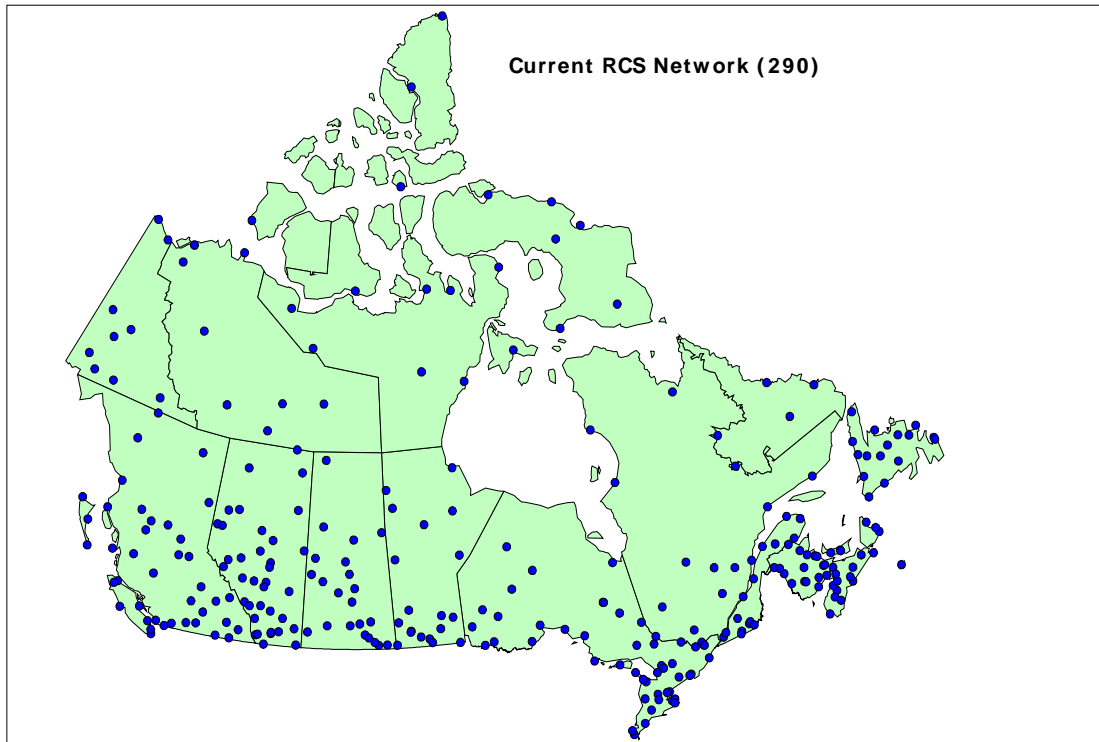


Figure 4. The Canadian Reference Climate Station network.

Snowfall and Solid Precipitation

Reliable snowfall and solid precipitation¹⁴ data are essential for climate monitoring, determining the global and regional hydrological balance and in understanding key components of the cryosphere. Identified GCOS requirements are for daily measurements of solid precipitation adjusted for systematic errors¹⁵. Observations of snowfall and precipitation are currently made at first-order synoptic meteorological stations in Canada and most of these data are distributed over the WMO GTS in near-real time. Snowfall is also recorded at a much larger number of climatological stations and these latter records are held in the national climate archive. At climate stations with human observers, the depth of new snow is measured at each observation (generally twice daily) and the snowfall precipitation is then estimated by assuming a fresh snowfall density of 100kg m^{-3} (i.e. a 1:10 ratio). At principal and synoptic stations snowfall is measured every 6

¹⁴ Snowfall is the depth of freshly fallen snow that accumulates during the observing period. Solid precipitation is the amount of liquid water contained in the snowfall intercepted by a precipitation gauge.

¹⁵ This will necessitate continued work on the correction and standardization of solid precipitation measurements, development of data assimilation strategies for *in situ* and remotely-sensed (radar and satellite) measurements and development of a global archive of adjusted precipitation estimates for liquid and solid precipitation. Development of more reliable techniques for remote-sensing of solid precipitation must also continue, particularly in high latitudes.

hours and recorded separately from the precipitation measurement. Automated methods of measurement are currently being implemented at an increasing number of stations. Figure 5 illustrates the Canadian snowfall network¹⁶.

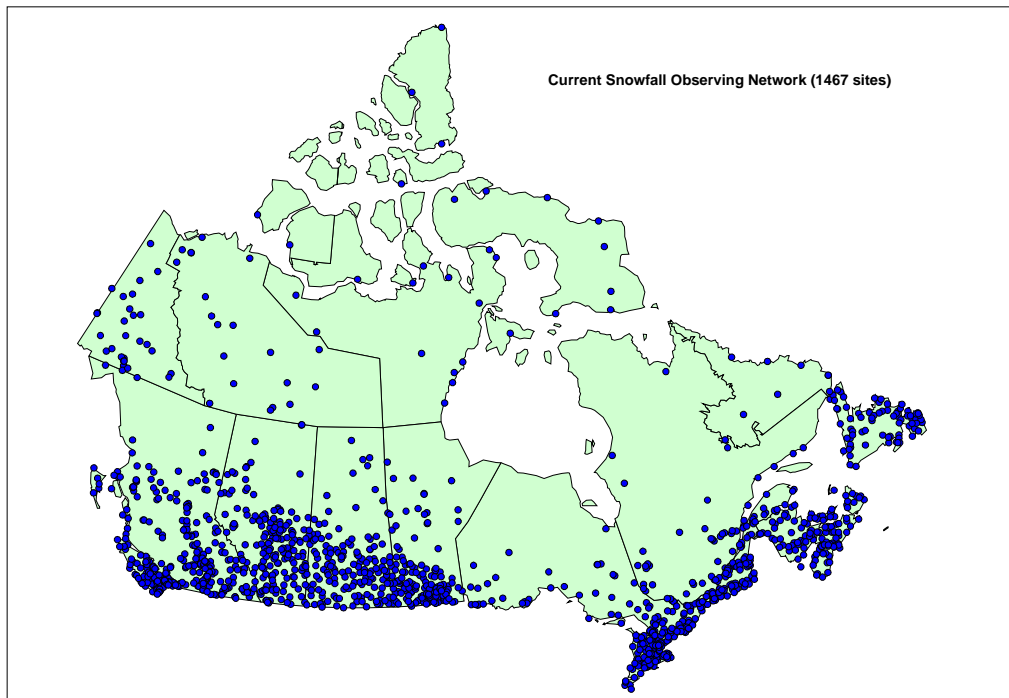


Figure 5. The Canadian snowfall network.

The Supplementary Climate Networks

The Supplementary Climate Observing Networks supply important observations of a number of variables some of which, most notably upper air soundings, radiation fields, snow depth, soil temperature, are particularly relevant to GCOS. A formal assessment of requirements for data from these networks was completed in March 2000. Based on the identified requirements, specific work plans have now been completed to guide their future development, ensure the stability of critical networks and position the country to address domestic issues and GCOS requirements.

¹⁶ Observations of other snow parameters (snow cover area, snow depth and snow water equivalent) are discussed in section 4.2 of this report.

The Canadian Upper Air Network

The Canadian radiosonde network (Figure 2) currently consists of 31 regular radiosonde stations, with balloon launches twice daily¹⁷. Occasional upper-air observations are also carried out by the Canadian Forces at 5 locations on land and onboard naval vessels. The radiosonde network has been upgraded to multi-mode Nav aids (GPS/VLF/LORAN) and a substantial degree of automation has been implemented. Observational, communications, quality assurance and archiving procedures are consistent with WMO guidelines.

The Canadian Radiation Network

At present, the Canadian Radiation Network, illustrated in Figure 6, consists of 43 stations located at agricultural research stations, national and provincial parks, airports, universities and Meteorological Service of Canada (MSC) sites. All of the stations measure global solar radiation (RF1) and many measure additional radiation fields (RF2, RF3, RF4 and RF9). In addition, the Brewer Spectrometer is used for ozone measurements at 12 stations and there are Vital BW100 sensors for Ultra-Violet radiation measurements at some locations. Radiation data acquisition is largely automated with instruments at most observing sites being interfaced to Campbell Scientific data loggers (CR10X). Inspection and maintenance of instrumentation, data quality assurance and archiving are carried out by the MSC in accordance with WMO-recommended standards and procedures.

¹⁷ There are, in addition, 6 mobile units for deployment in the event of environmental emergencies.

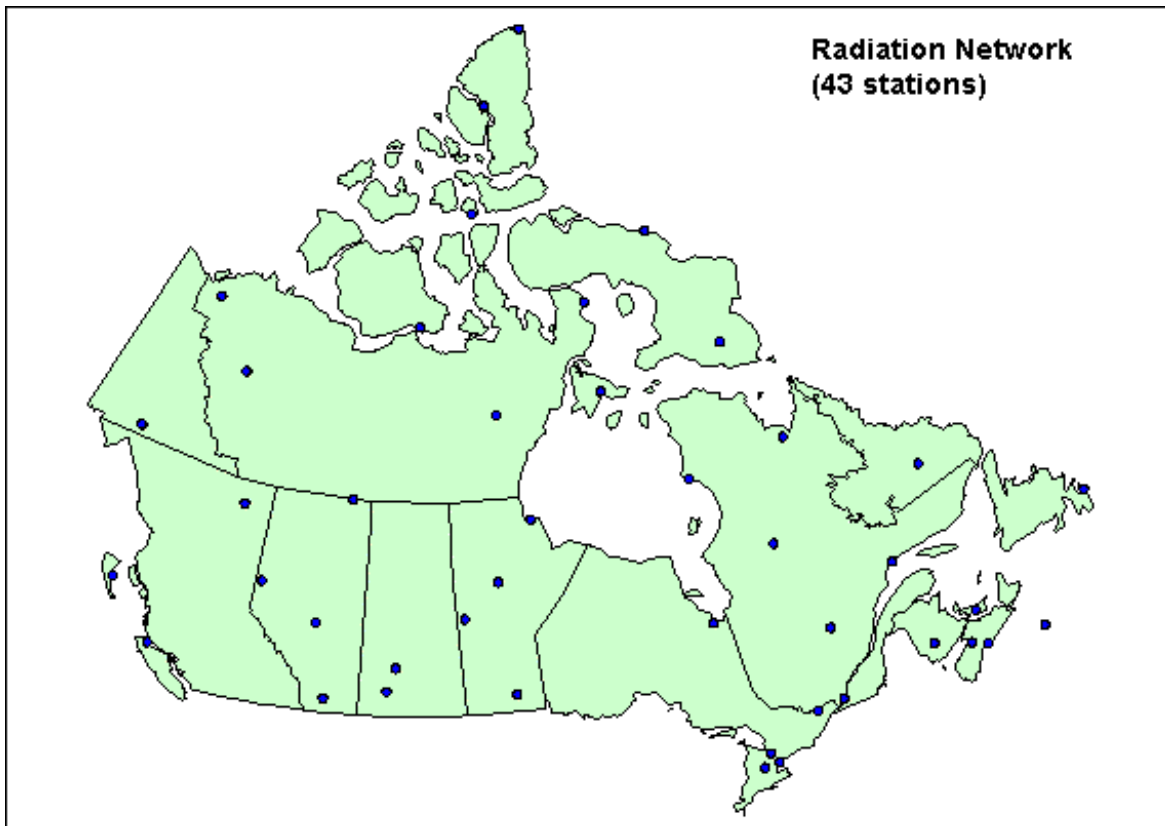


Figure 6. The Canadian radiation network.

Others

Several other Canadian supplementary networks and related activities are particularly relevant to GCOS. The following provides a snapshot of these programs:

- Agriculture and Agri-Food Canada is a major partner in the operation of a soil temperature network of 28 stations, mostly located at agricultural research stations. Instrument installation, maintenance and data quality assurance and archiving associated with this program are carried out by MSC personnel and every effort is made to follow WMO guidelines and procedures. Figure 7 below illustrates the current network.

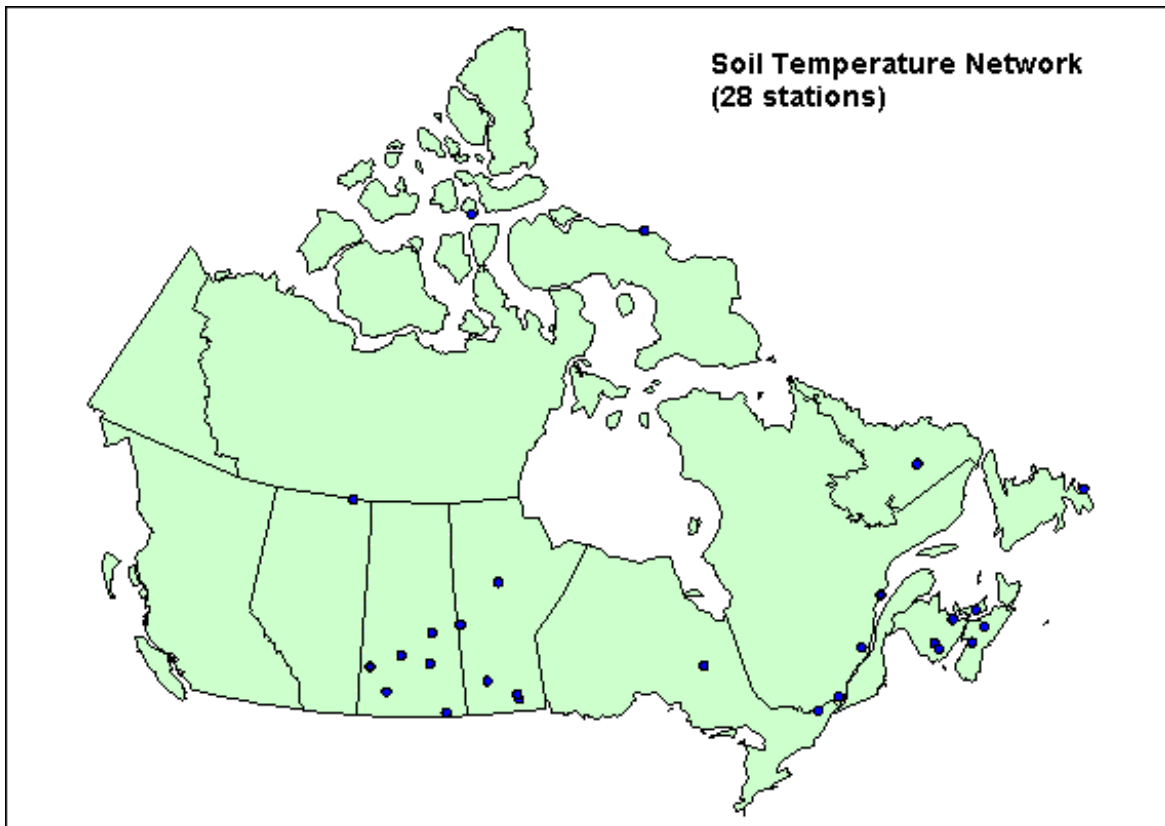


Figure 7. The Canadian soil temperature network.

- Canada has maintained an extensive daily snow depth measurement network since 1981 (about 2000 stations) at climate stations making up the National Temperature and Precipitation Network (Figure 3). Prior to 1981, daily snow depth measurements were made at several hundred synoptic stations and many of these sites have data going back to 1955.
- Human observations of freeze-up/break-up are undertaken on a number of lakes and rivers (along with corresponding ice thickness measurements). These are discussed later in the cryospheric section of the report.
- The Network for the Detection of Stratospheric Change (NDSC) station at Eureka¹⁸, a Primary Station, is an important site for monitoring the development of the Arctic ozone hole.

¹⁸ The NDSC consists of a small number of Primary Stations conducting measurements with primary NDSC instruments (lidars; UV/Visible spectrometers; FTIR spectrometers; and balloon sondes) supplemented by additional observations conducted at nearly 30 Complementary NDSC sites throughout both hemispheres.

- Measurements taken at Bratt’s Lake, Saskatchewan and at the Arctic stratospheric observatory at Eureka contribute to the international Baseline Surface Radiation Network (BSRN) that measures radiatively active gases and surface radiation.

2.3 Data Management and Data Exchange

The MSC collects, quality assures and archives observations collected by the Service and its collaborators and disseminates data, data products and services to designated World Data Centres (WDC) and domestic and international clients. The MSC maintains Canada’s national climate data archive containing official records of weather and some related observations in Canada dating back as far as 1839. Some of these records exist on paper, microfilm and microfiche but the vast majority are stored in digital database files. Datasets in the Archive include:

- Hourly observations of temperature, humidity, wind speed and direction, atmospheric pressure, cloud types, amounts, and heights, and occurrence of rain, snow, thunderstorms and other types of weather. At any time, there are about 300 to 400 active hourly reporting locations but the digital archive contains records from over 800 such locations some of which no longer support active observing programs.
- Once or twice-daily observations of maximum and minimum temperature, and rainfall and snowfall amounts for almost 10,000 Canadian locations. For many of these locations, observations of other climate elements are also recorded, such as the depth of snow on the ground and days with various weather occurrences such as hail, freezing rain, water spouts.
- Many additional observations from the supplementary climate networks, including bright sunshine, solar radiation, pan evaporation, soil temperature, short duration (5, 10 minute, etc.) rates of rainfall amongst many others.

The Canadian National Archive System (NAS) is contained in an Oracle™ database comprising 8 billion individual observations using 550 gigabytes of hard disk storage and about 200,000 new observations are ingested into the Archive on average every day. The NAS may be accessed at:

http://www.msc-smc.ec.gc.ca/climate/index_e.cfm

Atmospheric constituents observations from Canadian observing stations are also retained by the MSC, though in a separate database. Relevant data are routinely forwarded to WMO’s World Centre for Greenhouse Gases, Tokyo, maintained by the Japan Meteorological Agency, and are also supplied to the Global View Database (GVD) in the United States.

In all of its data acquisition and data management activities, the MSC strives to follow international standards and procedures promulgated by WMO and other relevant bodies. Where atmospheric constituents are concerned, every effort is made to ensure transferability by participation in international inter-comparison exercises. Guiding principles have been enunciated for GCOS data and information management and Canada has undertaken to implement these guidelines. In particular, GCOS observational, communications, metadata and archival standards and protocols are and will be applied to all data from Canadian stations designated as contributions to GSN, GUAN, GAW and to any subsequently approved global networks.

3.0 OCEAN OBSERVATIONS

Observations from marine areas are a vital component of GCOS in view of the fact that about 70% of the earth's surface is oceanic. It is not surprising, therefore, that GCOS Panels have emphasized the importance of observation programs in oceanic areas and stressed the need for these to be enhanced in data sparse regions.

3.1 GCOS Observing Programs

Canada participates actively in GCOS and GOOS through provision of oceanographic and marine atmospheric observations and these observations correspond to the GCOS/GOOS climate monitoring principles and other relevant best practices wherever possible. A national review of the nation's ocean observing networks has, moreover, recently been undertaken in order to identify shortcomings and systematically consolidate and enhance the long-term effectiveness of these systems. As a follow-on from this review, Canada will be making further, strategic, contributions to GCOS and GOOS in the near future, highlighted by Project Argo deployments and by the establishment of additional Arctic tide gauges. Table 2 summarizes Canada's contributions to global marine observation programs and these and related activities are briefly discussed in subsequent sections.

Table 2. Canadian participation in the global oceanographic observing systems.

	VOS	SOOP	Tide Gauges	Sfc Drifters	Sub- sfc Floats	Moored Buoys	ASAP
For how many platforms is the Party responsible?	275	48	25	6	2	46	0
How many are providing data to international data centres?	0	48	25	6	2	46	0
How many are expected to be operating in 2005? (NA = not available)	NA	40	29	6	90	46	0

Voluntary Observing Ships (VOS)

GCOS Panels have stressed the requirement for long term maintenance and selective enhancement of the WMO Voluntary Observing Ship (VOS) program. The Canadian VOS program has, however, suffered from financial reductions imposed in recent years¹⁹ and the number of recruited ships has declined to 275 today with this trend being expected to continue. In the face of this reality, Canada has recently undertaken a major initiative aimed at installing automated observing systems on VOS. This automated VOS program (AVOS) will result in a dramatic increase in the quality, frequency and number of observations²⁰. In particular, all Canadian AVOS vessels will produce data that meet VOS Climate Project (VOSCLIM) standards with these observations being relayed on the GTS round the clock, at hourly or three-hourly intervals. Furthermore, emphasis is being placed on automating VOS that operate in data sparse areas and a substantial increase will result in observations from high latitude waters such as the Beaufort Sea and Eastern Arctic.

Meteorological observations from Canadian VOS are relayed, in real-time, on the WMO GTS. Unfortunately, however, quality controlled data from these vessels have not been forwarded to the World Data Centre for a number of years. A major effort is currently underway to remedy this deficiency.

Ship Of Opportunity Programme (SOOP)

Profiles of temperature and salinity are obtained from all stations sampled, processed and archived on all major Canadian DFO research cruises and all information acquired is exchanged internationally. Equally, all major and minor Canadian naval vessels take routine Expendable Bathythermograph measurements (XBTs) when at sea, normally every six hours. All profiles of

¹⁹ On the other hand, there is a very successful VOS-based CO₂ flux research program operated by DFO in the north Pacific.

²⁰ At the time of writing, 13 selected VOS had been or were being equipped as AVOS ships. It is planned that this number will rise to 75 AVOS by 2005.

temperature obtained from stations sampled are processed and archived and this information is exchanged internationally.

Tidal Gauges

Canada's main contribution to the GOOS network of sea level stations on the Atlantic (east) coast is at Halifax, Nova Scotia. A second site will, however, likely be established on the Labrador coast (Nain) and several other high latitude Arctic sites added over the next several years. As illustrated in Figure 8 below, twelve other tide gauges are operated in order to support marine transportation along the Atlantic coast

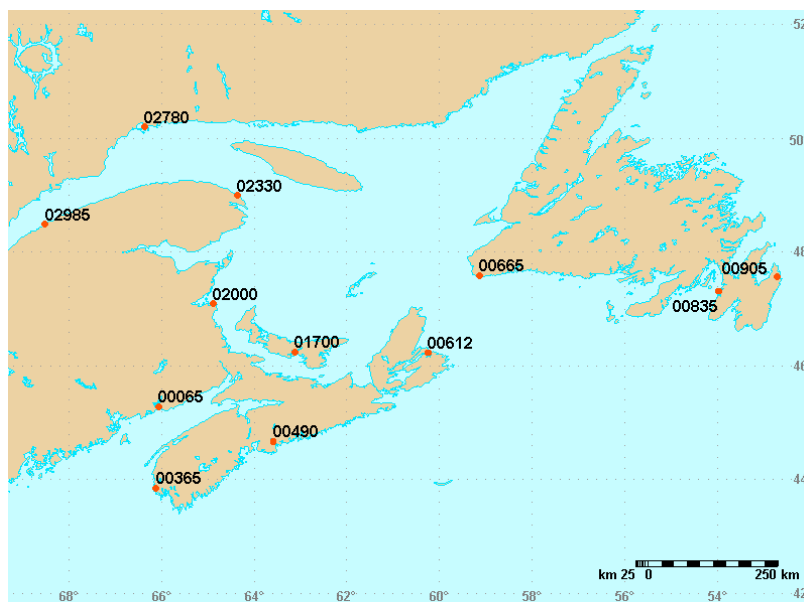


Figure 8. East coast tide gauge locations.

A network of 13 sea level gauges is also operated on the Pacific (west) coast as illustrated below. These stations are used for coastal observation programs for fisheries predictions, crustal movement studies, flood warnings and navigation in addition to providing GOOS contributions. The Canadian enhancement to GCOS proposes that several of these key stations be linked to continuously running Global Positioning System (GPS) stations.

As a related initiative, a CCAF research project “Delineation of an Optimal Sea Level Network”²¹, has defined an optimal network of sea level monitoring

²¹ Being undertaken by DFO and Dalhousie University.

locations, determining trends and rates for sea level change^{22,23} and creating sea level change databases.



Figure 9. West coast sea level gauge locations.

Surface Drifters

Canada maintains several weather and ocean drifting buoys in the North Pacific that report air pressure, sea and Sea Surface Temperature (SST) through the GTS in real time and up to 3 buoys are also contributed to the International Arctic Buoy Program (IABP). Drifting buoys are normally deployed by Department of National Defense (DND) Maritime Patrol Aircraft, on a cooperative basis, with some deployments also being carried out by Canadian Coast Guard and US NOAA vessels.

Sub-Surface Drifters

The “Global Array of Profiling Floats” (Argo) is an international program that will collect ocean data necessary for understanding and predicting phenomena that influence our global climate and facilitating the development of integrated atmospheric and oceanographic models. Canada has already undertaken to purchase more than 20 floats and plans to commit to at least 90 floats to the overall program.

²² The Atlantic coastal analysis demonstrated that the rate of sea-level change is non-uniform, primarily due to post-glacial rebound which accounts for about 60% of the observed change.

²³ Satellite altimetry has been shown to be a valuable monitoring tool for the build-up of sea-level along the Pacific coast and the subsequent migration off Canada and Alaska as meso-scale eddies as well as to detect inter-annual variability in sea-level. This study also demonstrated the need for coastal sea level records to supplement deep-sea satellite measurements.

Moored Buoys

Canada operates a network²⁴ of fixed buoys on its Pacific coast, illustrated in Figure 10. These moored buoys report winds, wave height and spectrum, air pressure, water and air temperature each hour via the GTS and Internet access is provided to these real time data sets. The buoys have space, battery and channel capacity for additional sensors to measure nutrients, phytoplankton and to count fish (once the technology is available) and such systems are being investigated. Optical sensors have been added to some of these buoys. The sensors, installed on two 3-meter discus buoys, measure insolation, water colour, salinity and fluorescence. They are intended to provide time series of surface water properties that can be linked to water colour images from satellites such as SeaWiFS in order to illustrate coastal physical and biological patterns in space and time for fisheries management and climate-related studies. The first time series began at the end of 1997.

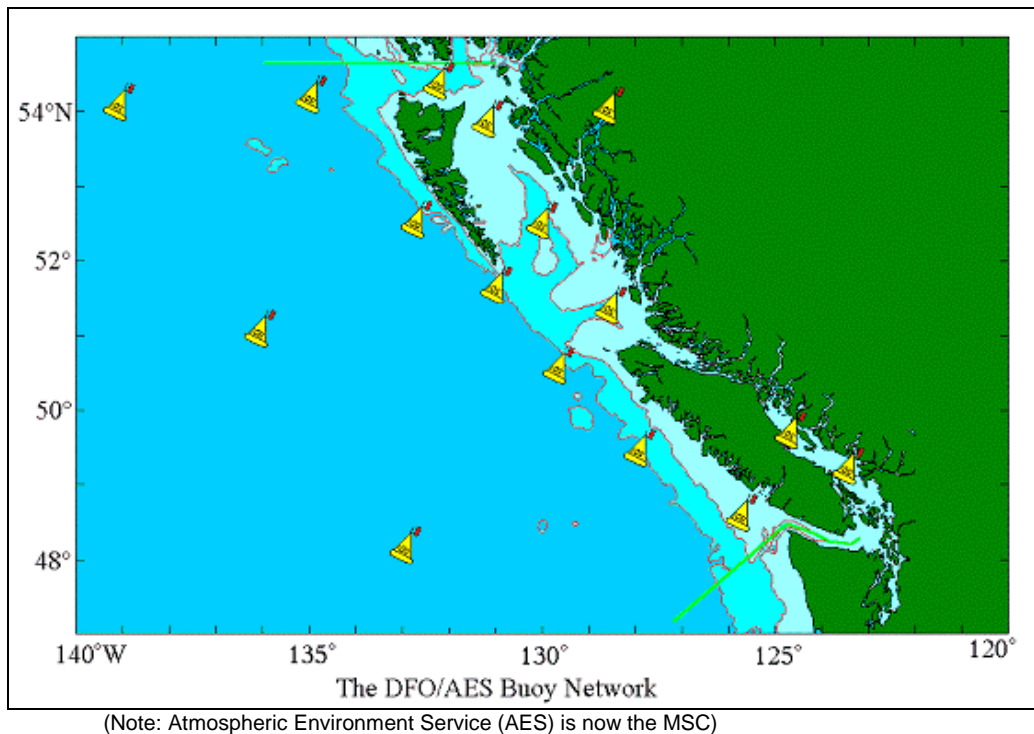


Figure 10. The DFO/MSc moored buoy network off Canada's Pacific coast.

The east (Atlantic) coast ocean buoy observing network comprises moored buoys deployed off Nova Scotia and Newfoundland at locations illustrated in Figure 11. These buoys measure surface weather, wave and ocean data and transmit observations in near real time.

²⁴ Maintained by MSC and DFO.

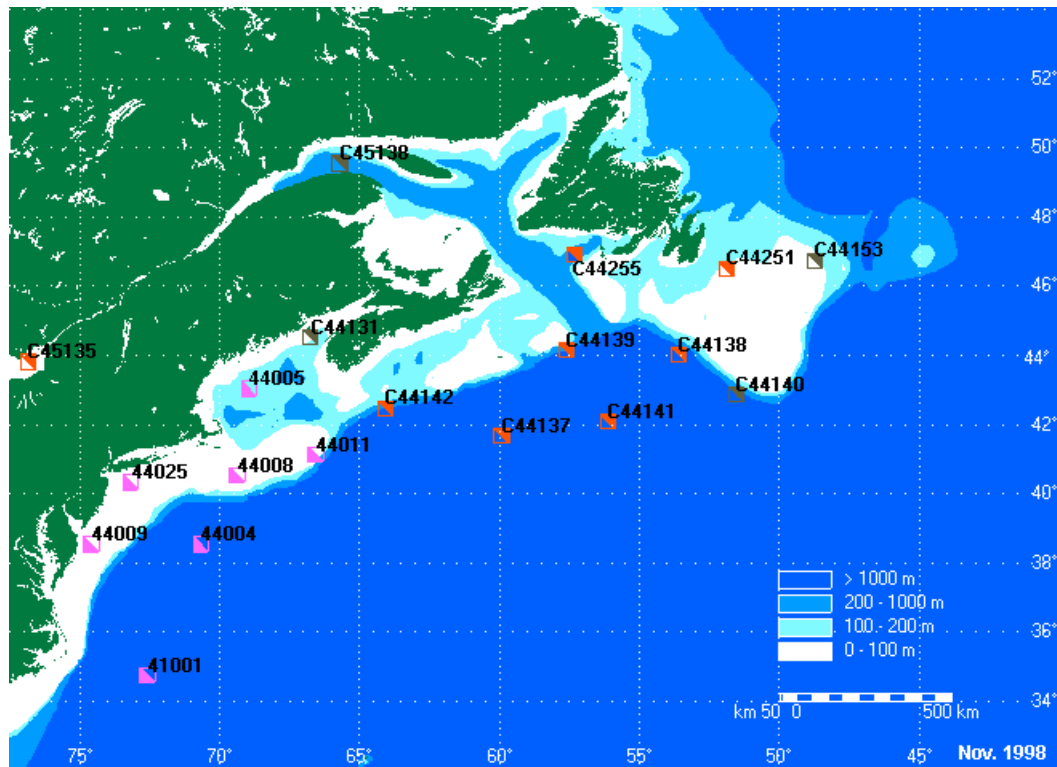


Figure 11. The moored buoy network off Canada’s east coast*.

*(Note: Canadian Buoys have designations beginning with the letter “C”.)

In addition to the coastal networks described above, moored buoys are also deployed on some inland water bodies (e.g. the Great Lakes), usually on a seasonal basis.

Automated Shipboard Aerological Programme (ASAP)

Canada no longer operates ASAP-equipped vessels but continues to assist the global ASAP program by providing logistical support and technical assistance to ASAP vessels calling at Canadian ports.

3.2 Other Ocean Programs

Natural or man-induced fluctuations in the marine environment can have drastic socio-economic implications for Canadians who live in coastal areas. Faced with the problem of estimating fisheries resources in a changing environment, Canada is applying a more global, or ecosystem, approach to management. As a result, a systematic and integrated monitoring program based on field sampling and

remote sensing of various in-situ biological, chemical and physical variables is being established by Fisheries and Oceans Canada (DFO). The number of monitoring programs in place is large and increasingly well documented. Two examples follow.

The Pacific (west) coast network of temperature and salinity stations has been maintained by DFO for almost the entire century. All data were originally gathered by lighthouse keepers and their families but stations are now gradually being automated as the lighthouses are abandoned. Locations of these daily sampled stations are shown in Figure 12 below.

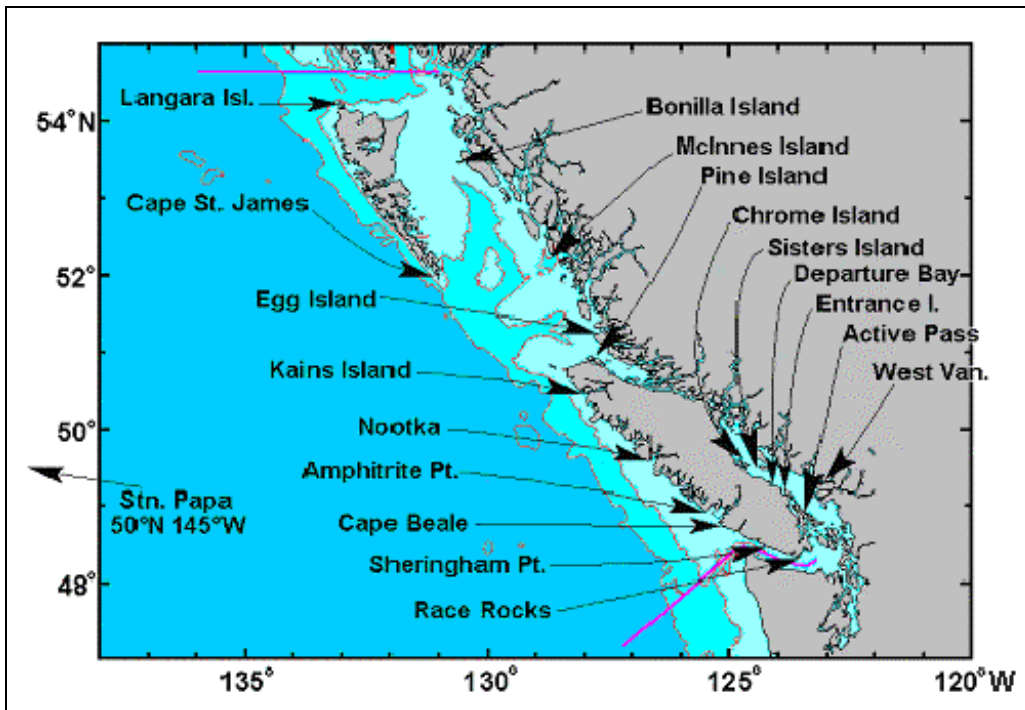


Figure 12. West Coast temperature and salinity profiles.

On the Atlantic (east) coast, the present observing system consists of thermographs laid out in a Long Term Temperature Monitoring (LTTM) network that is very useful to the aquaculture industry and the lobster fishery. This network is illustrated in Figure 13.

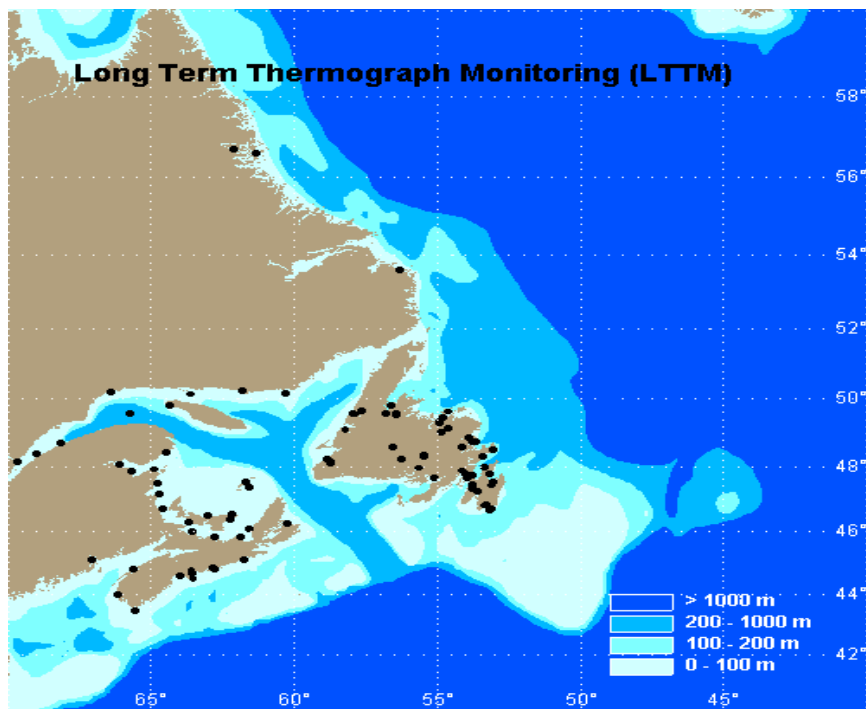


Figure 13. Sites of DFO's Long Term Temperature Monitoring (LTTM) program on Canada's east coast.

3.3 Ocean Data Management and Data Exchange

The Marine Environmental Data Service (MEDS) of Canada's Department of Fisheries and Oceans (DFO) has the mandate to manage and archive ocean data collected by DFO, or acquired through national and international programmes conducted in ocean areas adjacent to Canada, and to disseminate data, data products and services to the marine community.

MEDS maintains an extensive series of databases:

- a continuously updated database of all Tides and Water Levels data measured in Canada;
- a continuously updated database of all physical & chemical oceanographic profile data measured by DFO Regions and Laboratories;
- an up-to-date archive of all surface gravity wave data measured by DFO Wave Climate Study and from other instrumented sources in the area of interest;

- a continuously updated database for the world's oceans of all real-time Bathy, Tesac, and Drifting Buoy data flowing daily on the GTS; and
- an up-to-date archive of offshore oil and gas environmental data collected by the industry and submitted to Canada's National Energy Board.

MEDS actively participates in international data exchange and supports international quality control and archiving programmes. MEDS may be accessed on the Internet at:

http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Home_e.htm

Where the marine atmosphere is concerned, the MSC is responsible for the quality assurance, archiving and relay of observations from Voluntary Observing Ships and moored buoys. While, as noted earlier, VOS and buoy observations are relayed in real time on the GTS and Port Meteorological Officers (PMO) continue to promote high quality observations, data from ships logs is no longer entered into the national digital archive. Moreover, since 1990, Canadian VOS data have not been quality controlled and submitted to the designated Global Data Centre. From a GCOS perspective, therefore, the archiving of reports from VOS (and some reports from the moored buoy networks) is less than optimal with many observations and related metadata still stored in hard copy form only (e.g. in ship's logs).

3.4 Sea Ice

From a climate monitoring perspective, the important sea ice variables are ice concentration and extent, ice motion and ice thickness. As outlined in the following paragraphs, Canada can make useful contributions to the global effort to acquire observations of these variables through the operations of the Canadian Ice Service (CIS), a component of the MSC which has the primary sea ice monitoring and archiving responsibility for Canada²⁵.

Sea Ice Concentration/Extent

Changes in sea ice concentration and extent play a major role in ocean-atmosphere fluxes of heat, moisture, and momentum, an important reality given that climate models predict major changes in ice cover under a doubled CO₂

²⁵ Fisheries and Oceans Canada (DFO) maintains active sea ice R&D programs on the east coast and in the Beaufort Sea and these programs produce additional observational data.

scenario. Observations of ice concentration and extent are required to validate sea ice models and for climate change detection. GCOS needs for such observations are largely satisfied by operational monitoring by means of passive microwave satellites and by weekly hemispheric sea ice analyses prepared by the U.S. National Ice Center (NIC). However, the Canadian Ice Service (CIS), produces high quality, weekly, composite charts containing information on ice extent, concentration and type in support of shipping²⁶. These products can be used for model validation, impact analysis and regional-scale climate monitoring²⁷, and are routinely sent to the NIC for inclusion in the northern hemisphere sea ice analysis.

Sea Ice Motion

Model outputs of sea ice motion require validation by observed ice drift vectors. The corresponding GCOS requirements are for the determination of surface velocity twice per day over ice-covered oceans. The International Arctic Buoy Program²⁸ is a major source of observations of sea ice motion and Canada participates actively in the IABP²⁹ with DFO's MEDS providing the archive centre for IABP data. Ice motion is, in addition, measured with Doppler sonar at specific locations in the Beaufort Sea and continuous time series have also been acquired since 1990 at two sites over the continental shelf. In addition, the CIS has developed an automated method for extracting surface displacement vectors from satellite imagery ("Tracker") and this has been used successfully³⁰ to estimate large scale sea ice motion.

Sea Ice Thickness

Ice thickness observations are needed to validate sea ice models and for climate change detection. Identified GCOS requirements are for weekly observations of ice thickness at a spatial resolution of some 200 km over the main sea ice covered areas of the globe. Very limited in-situ data are, however, available on ice thickness and there has been no coordinated effort to collect and monitor this variable, though some Upward Looking Sonar (ULS) observations from Arctic submarine cruises have recently been released, a few scattered ULS measurements have been made from fixed moorings and some sporadic direct measurements exist from holes in the Arctic and Antarctic. Canada can, therefore, make a useful contribution in this area. Until recently, the MSC undertook regular weekly in-situ measurements of fast ice thickness and on-ice

²⁶ Winter season on the Great Lakes and East Coast and summer season in the Arctic Islands and Beaufort Sea.

²⁷ Information is at a much higher spatial resolution than current SSM/I-derived products and CIS analyses contain information on fast ice and coastal ice, unobtainable from current and previous DSMP satellites.

²⁸ With approximately 30 buoys collecting position and pressure data over the Arctic Basin.

²⁹ Canada has contributed up to 3 buoys and, until recently, chaired the IABP executive committee.

³⁰ With SSM/I 85 GHz and RADARSAT data.

snow depth at key climate monitoring sites in the Arctic³¹, with continuous measurements extending back to the 1940s at some sites. This program was suspended in 2000 but funding has been obtained to re-establish a network of up to 10 Arctic ice thickness sites starting in winter 2001/2002. DFO's Institute of Ocean Sciences (IOS) also carries out a program of sea ice thickness measurements over the Beaufort Sea³² shelf, using an ocean bottom moored Ice Profiling Sonar (IPS) to measure ice draft, and observations have been acquired there since 1990. Ice thickness measurements are, in addition, made on seasonal pack ice in the Labrador Sea by DFO's Bedford Institute of Oceanography (BIO), using bore hole measurements and aircraft remote sensing techniques.

3.5 Sea Ice Data Management and Data Exchange

The Canadian Ice Service maintains an extensive archive of sea ice products and derived information in the Canadian Ice Service Archive (CISA). Access to active collections such as daily and regional ice analysis charts is provided online through the CIS web site (<http://www.cis.ec.gc.ca>). The online collections also include an extensive database of derived standard ice climate products such as maps of 30-year median ice concentration and predominant ice type, and a sea ice climate atlas providing weekly maps of 30-year median ice concentration. Satellite and aircraft imagery are archived offline. There is a regular transfer of data from the CIS to the World Data Centre A at Boulder in the US.

4.0 TERRESTRIAL OBSERVATIONS

The terrestrial component of the climate system is a multi-faceted one incorporating forests, agricultural areas, surface and subsurface water resources, wetlands, snowpacks, permafrost and glaciers and other features. The TOPC has defined a Global Hierarchical Observation Strategy (GHOST) in an attempt to construct seamless, global, observational coverage of this complex component. Systematic observation of the terrestrial sectors present particular challenges in Canada due to the immensity and variety of the country, jurisdictional complications arising from our constitution and the many players involved.

Consequently, a Canadian national workshop was organized³³ in March 2000 to address the design of an initial observing system for the country's terrestrial ecosystems, working within the above GCOS framework. Subsequent sections draw heavily on the output from that workshop as well as from other sources in

³¹ These sites are also RCS or GSN stations.

³² This is part of the Arctic Ice-thickness Project of the WCRP.

³³ Under the sponsorship of the Climate Change Action Fund.

summarizing the current status of Canada’s terrestrial monitoring programs and future plans for their enhancement.

4.1 Contributing to GCOS

Though systematic observation programs for the terrestrial sector are at varying stages of development in Canada, a great deal of observational activity is underway and significant progress has, in fact, been made towards implementing our national contributions to the terrestrial component of GCOS. Table 3 summarizes Canada’s current contributions to the GCOS terrestrial observing effort and subsequent sections of this report provide an expanded overview of national activities.

Table 3. Canadian participation in the global terrestrial observing systems.

	GTN-P	GTN-G	FLUXNET	Other
How many sites are the responsibility of the Party?	19^a + 75^{b*}	11	4	
How many of those are operating now?	86	9	4	
How many are providing data to international data centres now?	19	8	1	
How many are expected to be operating in 2005?	86	11	7	

*(NOTE: The GTN-P has two components, active layer and permafrost thermal state. Active layer sites, flagged by “a” in the above table, contribute to the Circumpolar Active Layer Monitoring Program (CALM) established by the International Permafrost Association in 1991. The permafrost borehole thermal monitoring component, flagged by “b” in the above table, is still under development and Canada has identified existing sites as potential contributors to the GTN-P network. Some locations monitor both “a” and “b”. The Geological Survey of Canada (GSC) is developing the data submission, data management and web site for the permafrost thermal component. Data from the selected sites would ultimately be provided to the National Snow and Ice Data Center (NSIDC) at the University of Colorado, Boulder.)

The Global Terrestrial Network - Permafrost (GTN-P)

Permafrost degradation under climate warming has important implications for many landscape processes (terrain, slope and coastal stability), hydrology (surface and ground water regimes), surface energy budget and for ecosystems, engineering and infrastructure, as well as for greenhouse gases sources and sinks. In recognition of this fact, a Global Terrestrial Network for Permafrost (GTN-P) was approved by GCOS in February, 1999. The GTN-P’s initial parameters for monitoring are active layer thickness and permafrost thermal state. The GTN-P will build on the International Permafrost Association’s (IPA’s)

existing 80-site Circumpolar Active Layer Monitoring Network (CALM) and on various national monitoring programs. Nineteen Canadian sites contribute to the CALM. Canada, through the Geological Survey of Canada (GSC) of the Department of Natural Resources Canada, is also an active participant on the GTN-P organization and implementation committee, and is establishing the data management center and web site for the thermal monitoring component (8).

Permafrost monitoring is an important national priority for Canada since one third of the permafrost regions of the northern hemisphere lie within the country and 50% of Canadian land mass is covered by the permafrost zone. A permafrost network definition workshop (3), held in January 2000³⁴, assessed the current status of permafrost monitoring activities in the country, identifying some 100 active layer and/or thermal monitoring sites³⁵, with observation periods ranging from a few to over 20 years (Figure 14). Seventy-five of these sites have been proposed as candidates for the thermal monitoring component of the GTN-P. These sites involve many agencies and institutions and have been supported in an ad-hoc fashion with no formal organization or co-ordination of a national permafrost monitoring network.

Action is now underway, however, to establish a Canadian national network, building upon the infrastructure provided by the permafrost monitoring activities described above. The GSC has been identified as the lead agency for co-ordination and management of the Canadian Permafrost Monitoring Network. Formalization of the Canadian Permafrost Monitoring Network will include the establishment of a database structure, standards/quality control routines and methodologies for formatting, manipulating and archiving the data and associated metadata. Observational data and metadata will be archived at the World Data Centre A for Glaciology in Boulder, as a contribution to the IPA's Global Geocryological Database. A web site and node will be established for national data and metadata submission and access and these will form the Canadian permafrost data link to other cryospheric nodes or networks such as GTN-P, CCIN (Canadian Cryospheric Information Network) and CRYSYS (CRYosphere SYStem in Canada).

³⁴ Sponsored by the GSC and CCAF.

³⁵ Existing regional networks are concentrated in the western arctic and Quebec and extensive gaps exist notably in the Yukon and Nunavut Territories.

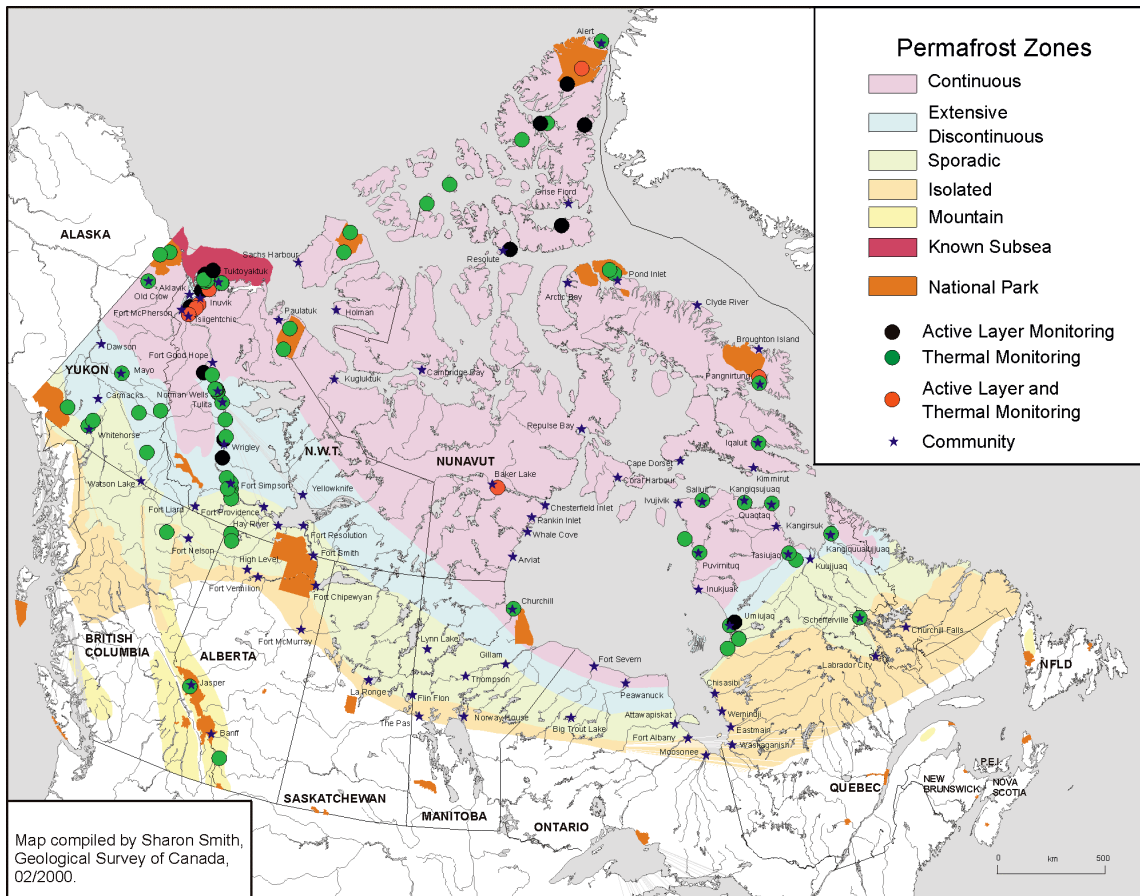


Figure 14. Existing Canadian permafrost thermal and active layer monitoring sites proposed or contributing to the GCOS/GTOS global permafrost monitoring network, the GTN-P. (Source: Burgess *et al.*, (3))

The Global Terrestrial Network for Glaciers (GTN-G)

Glacier signals have considerable potential for detection of climate change and, in consequence, the GCOS/GTOS Terrestrial Observation Panel for Climate (TOPC) initiated the development of a specialized glacier observation network - the Global Terrestrial Network for Glaciers (GTN-G)³⁶. Canada has extensive terrestrial ice, covering a wide range of glacio-climatic zones, and is therefore expected to make a significant contribution to the GTN-G. Canada has gathered an extensive, if somewhat temporally fragmented, glacier database which includes information for over 50 glaciers and ice caps for various periods from the

³⁶ The GTN-G builds upon the foundation provided by the glacier monitoring program which has operated for many years under the aegis of the World Glacier Monitoring Service (WGMS).

1940s³⁷. Figures 16 and 17 illustrates glacier sites at which monitoring activities have been undertaken or are underway.

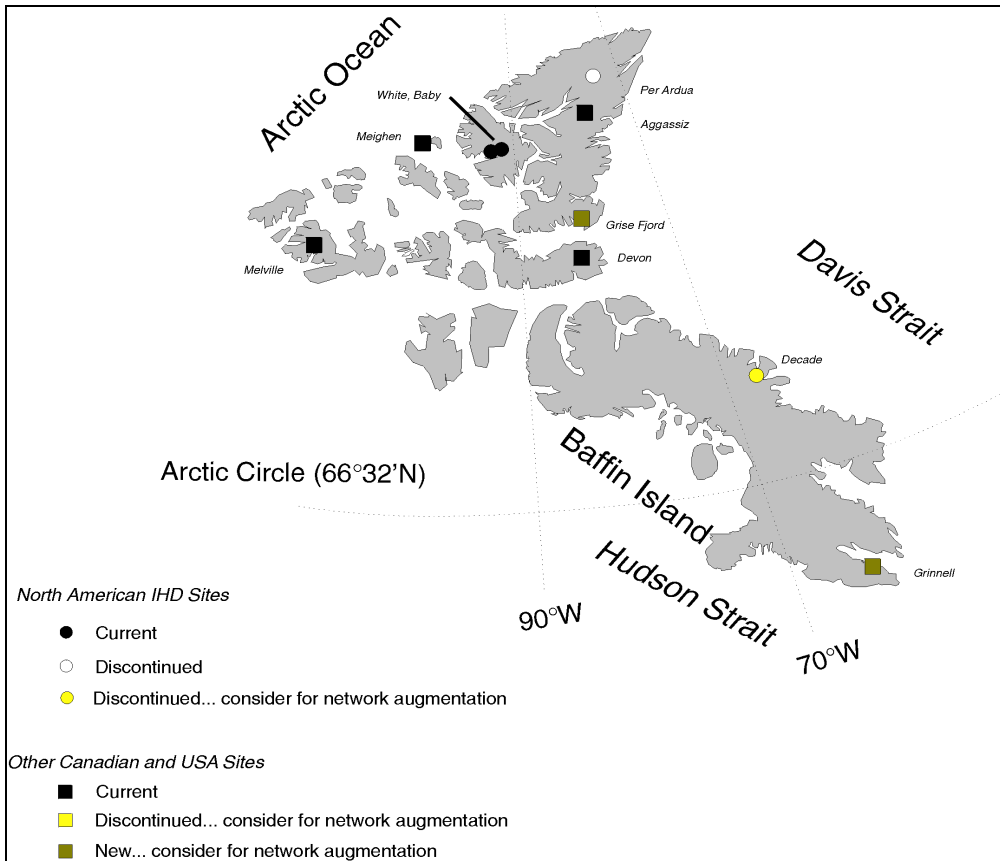


Figure 15. Glacier monitoring sites in Canadian Arctic. (M.Demuth, GSC)

³⁷ Substantial portions of these datasets have been provided to the World Glacier Monitoring Service (WGMS).

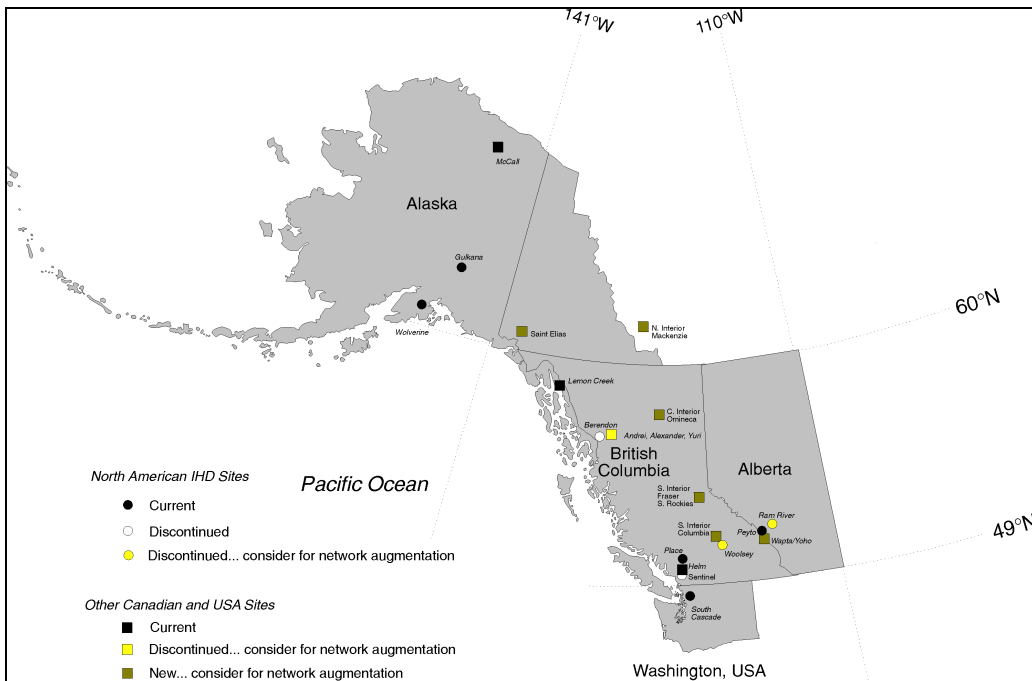


Figure 16. Glacier monitoring sites in the Cordillera. (M.Demuth, GSC)

Canadian glacier-monitoring work has traditionally separated along natural geographical lines - the Cordillera and the Arctic. Though mass balance and mass balance-elevation band reporting involved up to 22 glaciers nation-wide in the mid-1980s, the current “official” mass balance program has dwindled to six Arctic and three sites in the Cordillera. The Arctic Islands glacier/ice cap mass balance has been well covered for the past 30-40 years and now forms the world’s longest and most continuous polar record³⁸. Several sites in the Cordillera have continuous records exceeding 35 years, however, the situation is not so favorable as far as spatial representation is concerned. Only 3 glaciers remain of a formerly more extensive network (Helm and Place glaciers: Southern Coast Mountains of British Columbia; Peyto Glacier: Rocky Mountain Eastern Slopes). To address this situation, the Canadian Glacier Variations Monitoring and Assessment Network (CGVMAN) was established in 1993. At that time, this joint government-university effort centered around studies at the three remaining principal mass-balance network sites in the Cordillera and a renewed effort on the White Glacier (Axel Heiberg Island). More recently, several sites in the Cordillera (Ram River Glacier in the Rocky Mountain Eastern Slopes and Andrei Glacier in the central Coast Mountains) have been or are currently being re-established as part of a federally funded rejuvenation effort towards improving national climate observing and climate science capacity. In addition, Canada’s federal

³⁸ The GSC supports mass balance measurements on: Agassiz, Meighen, Melville South and Devon Ice Caps; Trent University (w/ GSC-CGVMAN support) on White and Baby glaciers (Axel Heiberg Island).

government glaciological expertise³⁹ has been consolidated in the “National Glaciology Program” of the Geological Survey of Canada (GSC), Natural Resources Canada (NRCan). As a result, the GSC-CGVMAN now represents glacier-observing sites in the Arctic and Cordillera, with Universities⁴⁰ continuing to contribute towards the observing goals at many of these sites while at the same time advancing the goals of their own research studies and degree programs.

No systematic collection of firn temperature data for climate monitoring purposes is currently underway in Canada though a number of glacier core hole sites exist that have been previously measured. There are several Arctic sites (e.g. ice caps on Ellesmere, Devon, Axel Heiberg and Baffin islands) where 10-15 m firn temperatures have been taken in the past and these sites can be easily re-drilled and monitored at relatively low cost. It should also be noted that the Ice Core Circum-Arctic Paleoclimate Program (ICAPP) is a Canadian-led international program that collects and studies ice cores around the Arctic in order to determine the timing, rate and cause of past global changes.

A number of other university and government monitoring and research programs are also underway or have been completed. A combination of modeling and shallow ice core analysis is being used to reconstruct glacier mass balance in the high Arctic and increasing model resolution in GCMs has created an interest in including glacier processes in climate models. In addition, several studies on the future of glacier-related water resources in the Cordillera and freshwater exports to the Arctic Ocean are underway and make use of recent and past-century glacier fluctuation data and hydrologic/hydrodynamic models coupled to RCMs to enable scenario-based modeling studies for these critical issues. These modeling activities have considerable potential for expanding our understanding of glacier-climate response and impacts and for filling in gaps in the existing mass balance record. The well-established GSC ice coring program⁴¹ should have important input in this respect as the cores from various ice caps in the Canadian Arctic and a recently collected ice-core from Mount Logan will permit recent climatic change to be put into a long term perspective⁴² particularly for the Western Arctic and North Pacific regions. As far as advancing Canada’s observing capacity, several research programs focusing on monitoring glaciers using remote sensing are underway or have been completed. These studies involve both airborne and space-borne instruments including SAR and LiDAR for both short and longer-term change detection. Notably, the Canadian Space Agency RADARSAT-2 and NASA ICESat/GLAS missions will play an important

³⁹ Formerly, two departments (Environment Canada and Natural Resources Canada (NRCan) had mandates to monitor glaciers in the Cordillera and Arctic Islands respectively

⁴⁰ British Columbia, Northern British Columbia, Simon Fraser, Alberta, Calgary, Toronto and Wilfred Laurier.

⁴¹ GSC is expected to continue this program.

⁴² Records to date show that modern Eastern Arctic temperatures are 1^o to 2^o C colder than they were at the beginning of the present interglacial period, 10,000 years ago.

role in these studies, while data from ASTER/GLIMS is generating a great deal of interest especially as it concerns updating glacier inventory data for Canada's terrestrial ice. To this end, a Regional GLIMS Data Centre has been established for the Canadian Arctic islands at the University of Alberta.

Standardized glacier data collected at Canadian glaciers and ice caps are provided, through the Canadian Correspondent, to the World Glacier Monitoring Service (WGMS) in Switzerland and archived by that body. Data from the Arctic sites are also provided to the International Arctic Science Committee (IASC) which represents circumpolar interests specifically⁴³.

Global Terrestrial Network – Carbon (FLUXNET)

The establishment of a Global Terrestrial Network – Carbon (FLUXNET), aimed at measuring the exchanges of carbon dioxide, water vapour and energy between terrestrial ecosystems and the atmosphere, has been identified as a vital component of GCOS. Its goals are to provide the observational data needed to understand the mechanisms controlling these exchanges across a spectrum of time and space scales and for validation of satellite estimates of net primary productivity and other parameters. The following paragraphs summarize the current status of Canadian efforts related to the development of a global FLUXNET network.

Fluxnet-Canada, the Canadian contribution to the global network, aims to provide continuous, multi-year, measurements of the exchanges of CO₂, water and sensible heat (and, in some cases, other greenhouse gases) for mature and disturbed forest and peatland ecosystems in Canada's southern ecoregions. To that end, it is planned that a combination of measurements and modeling will be undertaken at several Canadian-run flux stations⁴⁴ located along an east-west national transect, supplemented by information from other associated flux sites that are not part of the formal network. Efforts are currently underway to obtain the funding needed to support the operation of these stations over the next several years.

From west to east, the seven proposed Fluxnet-Canada carbon flux research stations are located or proposed as follows:

- A. Coastal conifers, British Columbia – This station has two operational flux towers, in a mature Douglas-fir stand and in a recent cut-over area, respectively.
- B. Mixed white spruce, lodgepole pine, aspen forest, Alberta – An initial set of equipment for a roving tower has been purchased for this site.

⁴³ The WGMS and IASC Canadian Correspondent office resides with the GSC National Glaciology Program.

⁴⁴ A flux station is defined as an area having at least two flux tower sites that are close enough together to experience similar weather (E.g. < 20km). The basic minimum design for a Fluxnet-Canada station is a flux tower located in a mature stand with a second site located in an area that has undergone disturbance.

- C. Southern boreal conifers and hardwoods, BERMS station, Saskatchewan – Three towers are currently operational in mature stands of trembling aspen, jack pine and black spruce. Two roving towers are being run at burn sites. In addition, a tower was installed in a recently harvested pine stand during the summer of 2001 and another tower had been purchased.
- D. Boreal mixed wood, Ontario – An initial set of tower equipment has been purchased for this site in 2000-2001 but is not yet operational.
- E. Eastern peatland (PCARS), Ontario and Quebec - A "permanent" tower has been running since 1998 and a roving tower has been recently obtained.
- F. Boreal black spruce, Quebec - An initial set of tower equipment was purchased in 2000 -2001 for a disturbed site but is not yet operational.
- G. Balsam fir, New Brunswick – The PI for this station has an existing set of tower equipment for use in short stature vegetation.

In addition, the following flux sites have been identified as associated sites, although their operation is outside the Fluxnet-Canada initiative:

1. Boreal black spruce, Manitoba -This associated station is financed and operated by US investigators. A tower has been continuously operational since 1993 in a mature black spruce stand and a new project was recently begun to establish low-cost, remote towers in five stands along a fire chronosequence
2. Temperate broadleaf, Ontario - This site (Camp Borden) has been run by Environment Canada since 1995. It is considered to be an associated site since there are no plans to study disturbance at this location.
3. Short-Grass Prairie, Alberta - This site has been operational since 1998 and is a valuable data source since it represents an ecological type having more extensive moisture deficits than any of the Fluxnet-Canada sites.

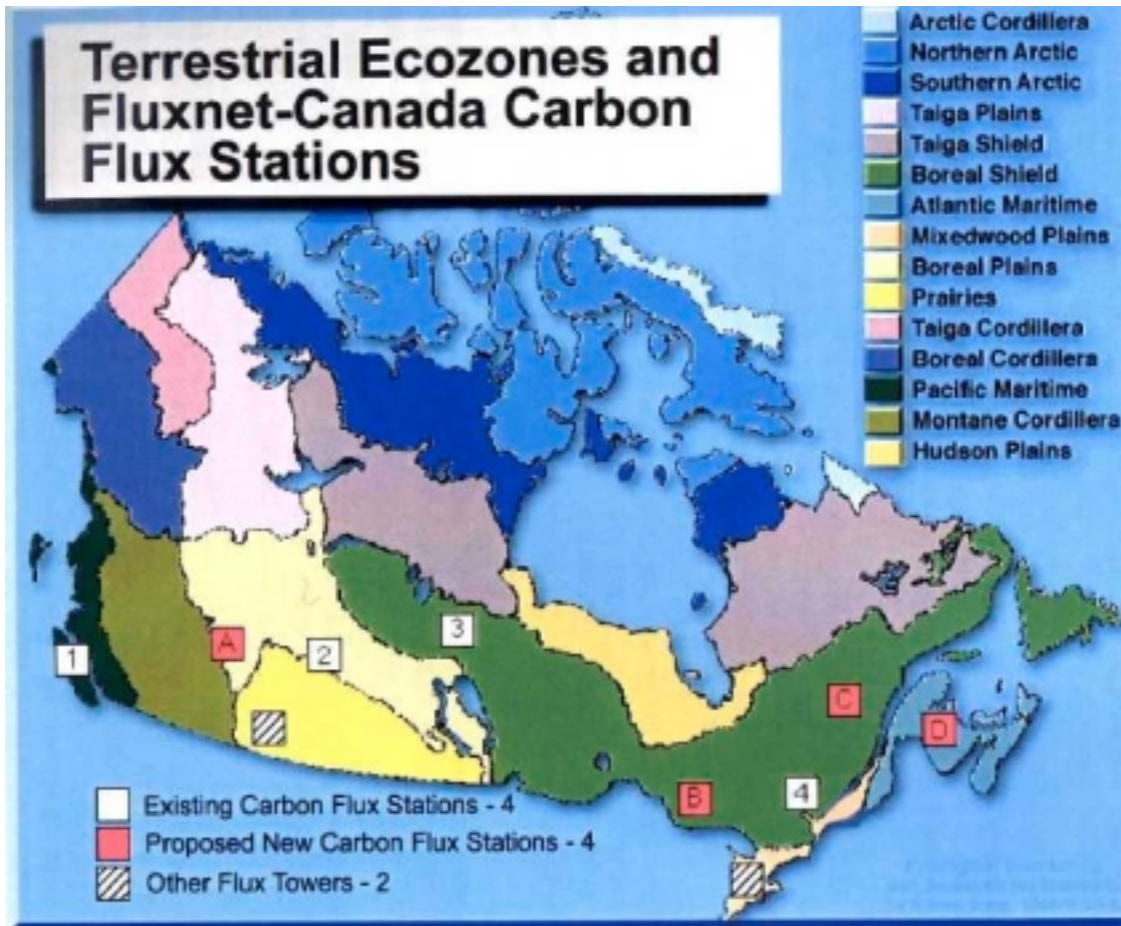


Figure 17. Planned Fluxnet-Canada carbon flux stations and associated sites.

It should be noted that the above network, illustrated in Figure 17, is considered to represent a minimum necessary to make an attempt to address the carbon sink issue in Canadian forests, rather than representing an optimal network.

A Canadian data repository is planned for Fluxnet-Canada data and it will be linked to international centres including FLUXNET. It is intended that the international community will have access to Fluxnet-Canada data after an initial holdback period.

4.2 Other Observing Programs

The following sections provide a brief overview of other relevant terrestrial observing programs underway in Canada. Recent workshop discussions have

identified a number of weaknesses in some of these programs including geographical gaps in coverage, requirements for observations of additional variables and the need for the development of new satellite-based products.

The Cryosphere

The terrestrial cryosphere encompasses not only glaciers and permafrost but other elements that are of significant importance in the global climate system. Snow and ice, in particular, exercise substantial influence on radiative transfer and on turbulent fluxes of heat and moisture between the atmosphere and earth's surface and, in addition, modify the characteristics of hydrologic systems. Monitoring networks and programs for snow and ice parameters are, therefore, essential elements of any comprehensive climate observation system.

Snow Cover Area and Snow Depth

Identified GCOS requirements relating to snow cover area are for information on global snow cover extent at 25 km resolution. While these requirements are largely met by the operational snow cover product prepared by the US National Environmental Satellite Data Information Service (NESDIS), Canadian in-situ observational records can be used to infer additional information on regional snow cover extent, variability and change⁴⁵. Equally, operational snow water equivalent monitoring undertaken by the MSC, using all-weather passive microwave data, provides detailed weekly information on snow cover extent over the Canadian prairies that is useful for monitoring and model validation.

Snow depth is an important property of snow cover, influencing surface radiative exchange and heat transfer and affecting frozen ground and permafrost distribution and moisture recharge. It also has important operational and ecological implications and observations of this variable are used for a multitude of applications⁴⁶. Identified GCOS requirements are for point measurements of daily snow depth at GSN stations but these requirements are expanded by wide ranging domestic needs for such data. As noted earlier, Canada has a substantial database of daily snow depth measurements at synoptic stations, extending back to the 1950s. In the early 1980s, the daily snow depth measurement program was extended to climatological stations, quadrupling the number of observations in the national climate archive. As a recent development, an automatic snow depth sensor is now being deployed at an increasing number of sites.

⁴⁵ These records have been combined with historical data from the U.S. to generate a useful reconstruction of North American snow cover extent back to 1915.

⁴⁶ Examples include roof snow load computations, assessment of winter survival of crops, biological studies, calculation of forest fire indices, validation of satellite algorithms and land surface process models and snow depth analyses in support of numerical weather prediction.

Snow Water Equivalent (SWE)

Knowledge of the snow water equivalent (SWE), or amount of water in the snowpack, is critical in the assessment of the energy and water cycle in the climate system, in validating GCM snow cover simulations and for hydrology and water resource planning. Stated GCOS requirements for SWE include a requirement for daily global satellite coverage at 25 km resolution. Meeting this requirement, however, necessitates satellite algorithm development and validation over all representative vegetation and terrain types. As a further requirement, bi-weekly snow course measurements, representative of terrain and land-cover, are needed in the vicinity of GSN stations and this requires the assembly of an archive of snow course data.

MSC coordinated a national hard-copy compilation of snow course observations from 1955 to 1985⁴⁷. At peak levels, in the early 1980s, there were over 1700 snow course observations contributed by various agencies but this number declined to around 800 in the early 1990s. A number of agencies continued to send snow course data, in digital format, to MSC after 1985 and in 1995 a CRYSYS data rescue project was initiated to digitize all the available snow course data and place it on CD-ROM. MSC also carry out near real-time monitoring of SWE over the Canadian prairies from passive microwave satellite data and this approach has recently been extended to the adjacent boreal forest region. Work is currently in progress to apply these methods to the entire period of passive microwave data coverage (1978 onwards) to generate consistent gridded SWE datasets for model validation and other applications. MSC is planning to establish a national snow course monitoring network and database in collaboration with the various provincial agencies and utilities that maintain snow course networks.

Lake and River Freeze-Up (FU) and Break-Up (BU)

Dates of freeze-up and break-up of ice cover on lakes and rivers are a useful indicator of climate change⁴⁸, being well correlated with air temperature during the transition seasons, and are an important ecological indicator. Identified GCOS requirements are for daily observations of ice conditions in spring and fall for selected large lakes and several hundred medium-sized lakes distributed across middle and high latitudes. There are also associated needs for the selection of a set of GCOS reference lakes for assessing long-term variability, development of methods for merging in-situ and remotely sensed information on this parameter, and for a central or several regional archive(s) of FU/BU information.

⁴⁷ Taken by MSC, provincial water resource agencies and hydroelectric companies.

⁴⁸ Data on river ice are less useful as climate indicators than are data on lake ice (Walsh, 1995) because inflow (and human) effects are generally more significant in rivers.

Canada has contributed significantly to GCOS in this area since in-situ FU/BU observations exist at several hundred Canadian lake and river sites for various periods, with some sites going back to the early 1800s⁴⁹. Though the in-situ network has declined significantly over the past 10 years, efforts are underway to reverse this trend e.g. the EMAN volunteer “Icewatch” program (see page 54 for EMAN web site address). Satellite-based methods have demonstrated excellent potential and FU/BU monitoring for large Arctic lakes has already been implemented using passive microwave observations. This record is being extended back in time using the available satellite record (1978-present). The Canadian Ice Service (CIS) began weekly monitoring of ice extent on small lakes in 1995 using NOAA AVHRR and RADARSAT imagery in support of Canadian Meteorological Centre (CMC) needs for lake ice coverage in numerical weather models. The program started with 34 lakes and was increased to 118 lakes by the end of 1998. Canadian researchers are currently working on an ESA-supported project to develop an operational method for mapping freeze-up and break-up dates over large areas of Canada using SAR (ASAR Global Monitoring Mode) and optical (AATSR) data from the ENVISAT satellite.

Cryospheric Data Management and Data Exchange

There are a number of groups involved in the collection and archiving of cryospheric data in Canada. In some cases the data contribution to GCOS is in place and operational (e.g. CIS weekly ice charts to NIC, and GSC permafrost and glacier data to GTN-P and WGMS). In others, dataset compilations have been made available to the monitoring community (e.g. MSC snow depth and snow course CD-ROM) that contribute to GCOS capacity. The development and maintenance of high quality on-line datasets is a common goal of all the cryospheric data collection agencies in Canada, but this requires significant resources, particularly for developing accurate, digital metadata. Several recent initiatives should help improve the amount and availability of Canadian cryospheric data online for climate monitoring and other needs: a Canadian Cryospheric Information Network (CCIN) is being implemented at the University of Waterloo as a virtual data portal to improve access and awareness of Canadian cryospheric information; the CCAF has supported a number of data rescue initiatives; and some resources were made available under the *Action Plan 2000* initiative to support national databases for snow, permafrost and glaciers.

⁴⁹ Canadian FU/BU data up to 1994 have been supplied to the WDC-A and were used in the recent synthesis of Northern Hemisphere trends in FU/BU dates by Magnuson *et al.* (2000; Science, 289, 1743-1746)

The Hydrosphere

A GCOS/GTOS/HWRP expert meeting, held in Geisenheim, Germany in June 2000, recommended that a Global Terrestrial Network – Hydrology (GTN-H) should be established to meet needs for global hydrological observations for climate. Important hydrologic variables for an Initial Observing System (IOS) have been identified as including discharge (surface water flow), surface water storage, ground water storage and biogeochemical transport from land to oceans along with several variables addressed elsewhere in this report. Canada is playing an active part in the development of the GTN-H concept⁵⁰ and, as outlined in the following paragraphs, is positioned to contribute substantively to a global network, though the groundwater component will present difficulties.

Discharge

Freshwater discharge from rivers influences oceanic circulation at interannual to decadal time scales and records of discharge from pristine river basins may also be useful in detecting climate change. Discharge is a high priority observation for GCM validation and climate impact modeling. Water Survey of Canada (WSC), which is part of MSC, collects streamflow and water level data at 2,423 hydrometric gauging stations across Canada under formal cost-sharing agreements with the provinces and territories. An additional 347 stations are contributed by other organizations, bringing the total number of active stations to 2,770⁵¹. A subset of the national network, the Reference Hydrometric Basin Network (RHBN) has been identified for use in the detection, monitoring, and assessment of climate change⁵². The RHBN, illustrated in Figure 19, covers most of Canada's major hydrologic regions, although there are gaps in some regions of the country and there are no RHBN stations north of 70 degrees latitude.

⁵⁰ Canada currently chairs the coordinating committee for the proposed network.

⁵¹ This network comprises 719 federal stations, 704 shared federal/provincial stations, 828 provincial/territorial stations, 347 stations contributed by other agencies and organizations, and 172 cost-recovered stations from other agencies.

⁵² RHBN basins are characterized by either pristine or stable hydrological conditions, with 20 or more years of good quality record of daily discharge or water level measurements.

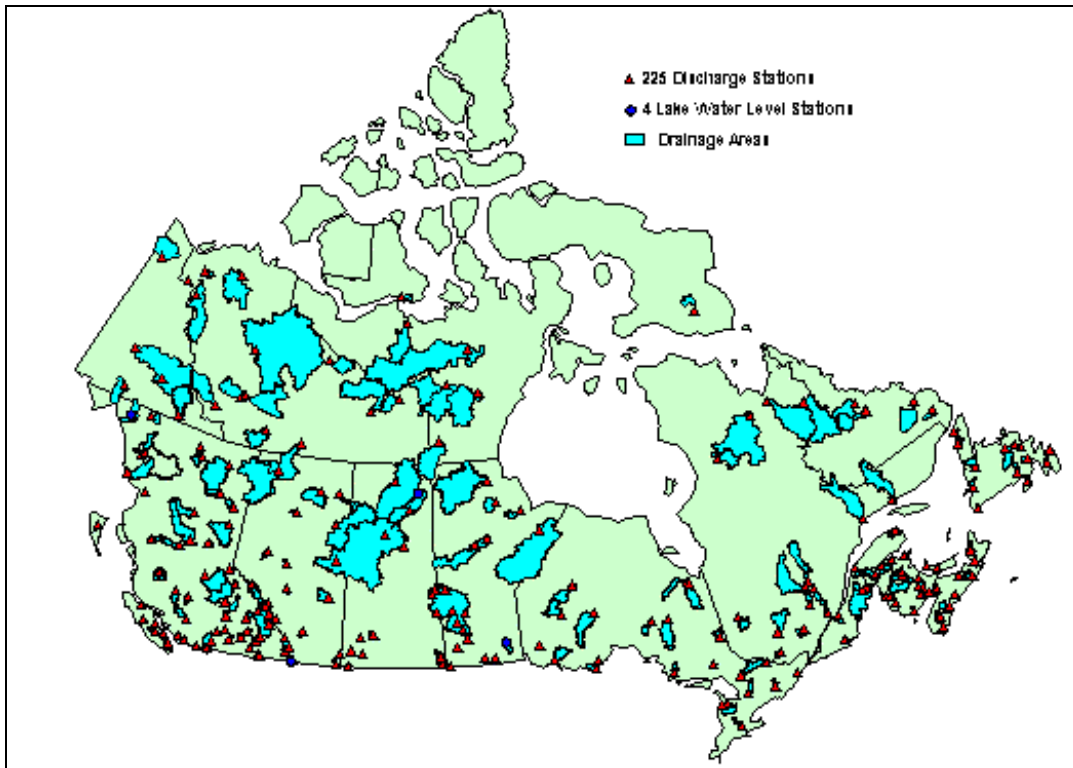


Figure 18. Current Reference Hydrometric Basin Network

A recent study identified 243 streamflow stations and 6 lake water-level stations as being critical to the climate issue and, of these, 225 streamflow and 4 water-level stations are still operational. Though there is an on-going challenge in maintaining these stations, as many of them are either fully or partially funded by provincial governments, GCOS requirements for freshwater discharge data are likely to be well-served by Canada's hydrometric network and, more particularly, by the RHBN sub-network.

Surface Water Storage

Lakes and wetland areas are strongly driven by climatic conditions and also play a critical role in the cycling of carbon. Canada has 24% of the world's wetlands and these clearly need to be monitored. The country is also blessed with immense aquatic resources in its lakes (e.g. the Great Lakes, shared with the United States, contain about 18 per cent of the world supply of fresh water). The Canadian Hydrographic Service, part of DFO, collects data for the Great Lakes and other large Canadian lakes and possesses records going back to 1918 while a number of smaller lakes have also been monitored for many years, for water management or research purposes. The Ecological Monitoring and Assessment

Network (EMAN), discussed later in this report, is a link to many such research and monitoring sites in Canada⁵³.

Ground Water Storage

Depletion of ground water is already occurring around the world and a change toward hotter and drier climates would encourage additional withdrawal. Research suggests that the mobilization of carbon through the hydrologic system, especially in shallow aquifers, may also be an important mechanism controlling carbon exchange between terrestrial systems and the atmosphere. Unfortunately, however, Canada has no coordinated national program of groundwater monitoring and, as a result, there are at present no national groundwater databases suitable for climate change assessment. The present status of groundwater monitoring networks is, moreover, poorly documented though it is known that substantial datasets have been collected by provincial agencies. In summary, considerable effort will be required to assemble the Canadian groundwater data needed to underpin the proposed GTN-H.

Biogeochemical Transport from Land to Oceans

Ocean systems are overall net stores of carbon and other biogeochemicals, being "topped-up" by inputs from continental areas. Streamflow measurements and water quality observations are critical for calculation of the fluxes between the land, freshwater hydrosphere and the oceans. Canada currently submits water quality data from 17 stations as its contribution to GEMS. Of these 17 stations, 7 sites are used for "flux to oceans" computations. The data collected at these sites include major ions, metals, nutrients and various indicators. This information is presently being updated and efforts are also underway to significantly increase the number of monitoring stations.

Water Data Management and Data Exchange

Surface water quantity data have been collected and archived in Canada since the middle of the last century⁵⁴. Hydrometric data are systematically collected to national standards. Much of the data and metadata from the water monitoring network resides in centrally managed databases residing with the MSC in Downsview, Ontario. HYDEX is a relational database that contains metadata about the monitoring stations such as location, equipment and type(s) of data collected. HYDAT is a relational database that contains the actual computed data for the stations listed in HYDEX, including daily and monthly means of flow,

⁵³ The Experimental Lakes Area (ELA) in western Ontario, the Turkey Lakes in southern Ontario, and Lake Kejimikujik in Nova Scotia are examples of such research initiatives that are useful in the assessment of ecosystem and aquatic impacts of climate change.

⁵⁴ Beginning in 1908, this data has been published in a variety of printed formats. Since 1991, most of this data has been available on CD-ROM.

water levels and sediment concentrations (for sediment sites). Annual peaks and extremes are also recorded and archived. Internet access to these databases is through the following web site:

http://www.msc-smc.ec.gc.ca/climate/data_archives/water/index_e.cfm

Canadian water quality data are managed regionally by Environment Canada or by provincial agencies. Current efforts are underway to coordinate and link this information.

While substantial amounts of groundwater data have been collected by provincial agencies, accessibility to these data is a problem. Considerable effort would be required to assemble sufficient groundwater data to make a national assessment of climate change impacts on groundwater resources in Canada.

The Land Surface

Recent reviews^{55,56} have identified a wide variety of other terrestrial monitoring programs in Canada. However, when these programs were assessed against the broad requirements of GCOS, existing databases were generally inadequate without enhancement, displaying gaps in coverage, gaps in continuity or gaps in detail. The following sections provide a brief overview of monitoring activities and databases which, nevertheless, have value in the context of GCOS.

The Ecological Monitoring and Assessment Network (EMAN)

Canada's Ecological Monitoring and Assessment Network (EMAN) was instituted in the early 1990s as a national network to provide an understanding and explanation of observed changes in ecosystems through long-term multi-disciplinary ecosystem monitoring and research. This network represents a significant, long-term, asset in addressing the impacts of climate and climate change on Canadian ecosystems. Today, EMAN has rallied together almost 100 ecological case-study sites into landscape-based research collectives in each of Canada's 15 natural ecozones. An EMAN Coordinating Office, in Environment Canada, provides centralized support to the program, connecting the large network of monitoring sites and researchers and pursuing initiatives such as the development and implementation of standardized methods of monitoring, the creation of a core set of environmental variables and the development of a national early warning system for environmental change. Additional information on the EMAN program and access to the EMAN Coordinating Office can be obtained via the Internet at the following URL:

⁵⁵ MacDonald, K.B. 1999. Agricultural, crop, range land and soil data bases for climate monitoring. Report to CCAF/Natural Resources Canada, February, 1999. 34p.

⁵⁶ Sims, R. 1999. A review of forestry, environmental and aquatic databases for climate monitoring in Canada. Report to CCAF/Natural Resources Canada, R.S. Sims and Associates, February, 1999. 102p

<http://www.eman-rese.ca/>

Forestry

Sources of forestry datasets include a range of installed plots, such as the Canadian Forest Service forest health plot network, the provincial growth and yield measurement programs, the national Forest Ecological Land Classification (FEC) plots, selected International Tundra Experiment (ITEX) plots and EMAN installations, cooperative research projects (university and others) and various others. The Forest Indicators of Global Change (FIGC) project, established in 1998, is of particular interest. This project comprises 26 forested sample plots arranged along a 1800km transect extending from northern Ontario to the Bay of Fundy in New Brunswick. The transect comprises plots from the Canadian Forestry Service's Acid Rain National Early Warning System (ARNEWS), plots from the Canada/US North American Maple Project (NAMP)⁵⁷ plus new plots selected to fill geographical gaps.

An initial access point for information on Canadian forestry networks and data is through the following web site:

http://www.nrcan-rncan.gc.ca/cfs-scf/index_e.html

Agriculture

Agriculture and Agri-Food Canada and other institutions within the Canadian agricultural sector have a long history of active participation in systematic monitoring of the climate system. Many of the supplementary climate stations mentioned earlier in this report are located at agricultural research stations, supplying high quality observations of soil temperature, radiation parameters, Class A pan evaporation, hours of bright sunshine, rainfall intensity and other key climate variables to the National Archive System. Observational records for these agricultural sites often extend back in time more than 50 years. It should be noted that progressive automation of the agricultural network is currently underway, making possible more frequent climate data collection and even "near real time" data relay.

A broad spectrum of other Canadian agricultural databases also exists, ranging from detailed characterizations of physical and chemical properties of soil to the location and extent of various land use activities and types of vegetation. An entry point to many of these latter data is through the CanSIS web site at:

<http://sis.agr.gc.ca/cansis/intro.html>

⁵⁷ ARNEWS plots have been monitored for up to 15 years; NAMP plots for over 10 years.

This Internet site provides access to a variety of products and datasets including the Canada Land Inventory (CLI), Soil Landscapes of Canada, detailed soil surveys, ecozone/ecoregion maps and others.

National Parks

Canada has 39 national parks of varying sizes ranging from 9 to 45,000 km². These parks are operated by Parks Canada, a federal agency whose legal mandate is to manage them for ecological integrity. This management approach involves monitoring ecological structure and function at a range of scales with emphasis on elements that are sensitive to known stresses. The national parks data sets are, however, highly variable in terms of age, scale and quality since the parks have been established at different times and have tended to collect data appropriate to their individual needs. Observational records available (with effort!) for virtually all national parks, however, include biophysical inventories, information on permanent sample plots for vegetation, species lists, species abundance – vertebrates and weather records. The Parks Canada web site is:

http://parkscanada.pch.gc.ca/main_e.htm

Tundra

About 40% of Canada's landmass lies north of the line of discontinuous permafrost and more than one half of the global tundra biome lies within the country. Taiga and tundra systems contain enormous stores of carbon in organic soils and peatlands and these systems are, therefore, especially sensitive to changes in climate⁵⁸. Two interrelated networks of tundra monitoring sites exist in Canada - the International Tundra Experiment (ITEX) and the Canadian Taiga and Tundra Experiment (CANTTEX). The International Tundra Experiment, ITEX, established in 1990, is today one of the most active international field programmes in arctic ecology with over twenty active ITEX field sites throughout the Arctic and in some alpine areas. Its purpose is to monitor the performance of plant species and communities on a circumpolar basis in undisturbed habitats with and without environmental manipulations. The basic experiment is a temperature enhancement where the field mean surface temperature is increased by 2-3 degrees C to simulate GCM predictions of the climate at the middle of the next century. The main Canadian ITEX site was established at Alexandra Fiord (Ellesmere Island) in 1992⁵⁹ and there are at present four ITEX sites with open top chambers (OTCs) in Canada and two additional sites which use plastic greenhouses.

⁵⁸ Research in Alaska has shown that coastal wet tundra will likely change from a sink to a source of carbon as climate warms and similar developments may occur in permafrost soils.

⁵⁹ Ecosystem level studies at this site include litter decomposition, nutrient cycling, and CO₂ 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, no flux towers are installed at any of the ITEX sites in the Canadian tundra.

CANTTEX is a loose network of 12 sites and programs established in 1999 as part of the Ecological Monitoring and Assessment Network (EMAN) - North⁶⁰ and is the Canadian counterpart to ITEX. The overall goal of CANTTEX is to improve capability to detect and predict large-scale tundra and taiga ecosystem response to climate change, building partnerships among researchers and establishing a monitoring network with common protocols and methods. Canadian ITEX sites are also part of CANTTEX but the remaining sites in the latter network mostly involve simple monitoring of climate and plant species' response to annual climatic variations.

Additional information on the CANTTEX and ITEX programs can be found at the following web sites:

CANTTEX <http://www.taiga.net/canttex/>

ITEX <http://www.systbot.gu.se/research/itex/itex.html>

Wetlands

Canada has about 25% of the world's wetlands and peatlands cover approximately 71% of the nation's wetland area. Wetlands, and particularly peatlands, act as carbon sinks and it has been estimated that Canada's wetlands contain 154 Gt of carbon, or 56% of the total organic carbon stored in all soils. It is, therefore, important to develop a reliable database that contains all those wetland attributes needed to determine carbon concentrations and amounts, predict carbon fluxes and assess the effects of climate change. Field measurements on Canadian wetlands are available from a variety of sources, including archival data from the National Wetlands Working Group (NWWG), the CanSIS database, various research databases, provincial/regional databases for peatland inventories and selected ITEX and EMAN installations.

Data Management and Data Exchange

In view of the complexity of Canada's terrestrial systems, the wide variety of associated observational needs and the fact that the country is a federation, it is not surprising that a variety of terrestrial data management systems exist. In his review of terrestrial databases, Simms concluded that data management and access issues did not, in general, pose a problem with most data available and accessible in digital form⁶¹. At the same time, he noted that there were only a few programs that were attempting to set up monitoring programs based on international protocols for site selection, layout, sampling, recording and archiving and that this could be a major issue as GCOS proceeds. In general, therefore,

⁶⁰ EMAN -North is a network of sites and scientists throughout Canada's northern territories.

⁶¹ Except for some of the older databases that were never converted to digital environments.

access to terrestrial databases must be pursued on an individual basis with a starting point being the departmental web sites and contacts listed in this report.

5.0 SPACE-BASED OBSERVING PROGRAMS

The Global Climate Observing System is expected to rely heavily on remotely sensed data from satellites and during its IOS phase this means on the present generation of operational satellites. With the exception of RADARSAT, Canada does not operate earth satellites, but the country does have a strong program in developing and applying space based data and information to climate system monitoring. These data complement in-situ information and are especially useful for covering Canada's vast data-sparse regions. The improved integration of space-borne observations clearly has potential for achieving substantial improvements in coverage for many climatically significant variables.

Several of the priorities in the GCOS Space Plan are priorities for Canada's domestic NWP and climate modeling community⁶². Canadian atmospheric scientists are, for example, involved in the CLOUDSAT and PICASSO-Cena⁶³ missions, both of which address GCOS space priorities. In addition they are supplying several new sensors which will contribute to monitoring capabilities. Measurements of Pollution in the Troposphere (MOPITT) is a Canadian remote sensing instrument launched aboard the EOS Terra satellite on December 18, 1999 to measure tropospheric CO and CH₄. The sensor is scheduled to continue operating for the next five years. Data assimilation experiments will be undertaken with these observations, using the Canadian numerical forecast model, GEM, as well as a chemical transport model and a Kalman filter scheme. The SWIFT (Stratospheric Wind Interferometer For Transport studies) experiment has been selected as an additional payload for the Japanese GCOM-A1 satellite (launch 2007). SWIFT will produce about 7000 profiles daily of horizontal winds, ozone and temperature in the 15-45 km altitude range, using an ozone thermal emission line. The Ozone Research with Advanced Cooperative LIDAR Experiment (ORACLE) proposes to measure ozone and aerosol vertical distribution via a spaceborne LIDAR. Since March 2000, the Canadian MOPITT instrument on NASA's Terra spacecraft has been gathering data on carbon monoxide and methane concentrations in the troposphere.

Satellite data have become an essential input to numerical weather prediction. Since September 27, 2000, the operational 3D-Var system at CMC incorporates

⁶² These include cloud measurements from radar and lidars to improve cloud parameterizations, low frequency microwave measurements for soil moisture and remote measurements of snow on the ground sea and lake ice, glaciers.

⁶³ PICASSO-Cena – Pathfinder Instruments for Cloud and Aerosol Spaceborne Observations- Climatologie Etendue des Nuages et des Aerosols

automated aircraft observations, (ACARS and AMDAR data), as well as satellite radiances from NOAA-14 TOVS and NOAA-15. SATOB winds and HUMSAT profiles (locally produced GOES 8 and GOES 10 moisture profiles) are also assimilated. Development of a data assimilation capability around the Canadian Middle Atmosphere Model (CMAM) using the 3D-Var package continues. Future work will involve the assimilation of temperature and ozone data obtained from satellite measurements. Additions have been made to the 3D-Var system in order to assimilate middle atmosphere observations such as those from MLS (Microwave Limb Sounder), HALOE (Halogen Occultation Experiment) and HRDI (High Resolution Doppler Imager). This work demonstrates the effective combination of in-situ and satellite data with models to provide improved monitoring.

The Canadian oceanographic community has a continuing interest in observations of sea level from precision altimetry, SST by AVHRR and other satellite-based sensors, scatterometer-derived surface wind stress and ocean colour from satellites. The application of RADARSAT observations to GCOS priorities related to sea ice extent, concentration and thickness is a Canadian contribution to the oceanic component of GCOS, along with selective data interpretation, processing and ground-truthing activities. RADARSAT SAR imagery is the primary data source used for sea ice monitoring at the Canadian Ice Service, with additional sources including ERS SAR, SSM/I and OLS data from the U.S. DMSP satellites and NOAA AVHRR. Near real-time ice products also become the data base for subsequent climate monitoring of sea ice regimes at high resolution. Analysis of variability and trends in sea ice cover in Canadian waters is undertaken using the passive microwave SSM/I satellite sensor and compared with changes in large scale climate variables, mainly temperature, wind and atmospheric circulation. These trends and changes are then compared with projected changes in climate derived from the Canadian Global Climate Model. Decreases in sea ice cover are evident in the western Canadian Arctic and Hudson Bay but the most recent analysis finds little or no long term trend towards reduced ice cover over the eastern Canadian Arctic and east coast. This pattern is consistent with temperature trends over Canada.

Where the terrestrial component of the climate system is concerned, the monitoring networks and programs discussed in the preceding sections employ ground-based, in-situ methods of data collection and there are, naturally, many gaps, particularly in the north and other remote areas of the country. For GCOS, remote sensing provides a means of improving climate, hydrological and ecosystem information, as well as facilitating periodic national assessments of the changing state of terrestrial systems such as Canada's lakes and wetlands. In particular, satellite-based monitoring of the cryosphere (snow, sea-ice, freshwater ice, glaciers and ice caps, frozen ground/permafrost) represents an important contribution to GCOS and Canada has an active R&D program that has produced products that contribute to the Canadian GCOS initiative and complement the in-situ data.

CRYSYS is an Interdisciplinary Science Investigation (IDS) in the NASA Earth Observing System Program, hosted and funded by Canadian agencies and universities, and led by the Meteorological Service of Canada. CRYSYS is currently supporting research on the development and validation of satellite-based approaches for monitoring several components of the cryosphere - snow water equivalent (SWE), frozen ground, lake ice (extent and freeze-up/break-up), sea ice and glaciers. A sample of significant recent satellite-related accomplishments includes: application of RADARSAT-1 and SSM/I data to study the break-up, removal and subsequent reforming of decades-old sea ice plugs in the Canadian Arctic Islands during the extreme warm summer of 1998; application of RADARSAT-1 for detecting the onset and areal coverage of melt ponds; application of SAR data for monitoring ice freeze-up/ break-up and related processes of subarctic lakes; investigation of the influence of sensor overpass time on the derivation of snow water equivalent from SSM/I data; the potential for monitoring wet snow with RADARSAT-1; potential and limitations of RADARSAT-1 for glacier mass balance monitoring; and application of *in situ* and satellite-derived snow cover data to reconstruct northern hemisphere snow cover extent variations. Further details on CRYSYS research projects and examples of products can be obtained from the CRYSYS website:

(<http://www.crysys.uwaterloo.ca>).

Canada has been one of the leaders in developing satellite based cryosphere products that meet GCOS monitoring requirements. Algorithm development research has continued using SSM/I passive microwave satellite data for the determination of snow water equivalent (SWE), snow extent and snow state (wet/dry) for different landscape regions of Canada (e.g. prairie, boreal forest, tundra). Algorithm development has been focussed on the following Canadian study sites: Arctic islands, Quebec tundra, Mackenzie River Basin (contribution to GEWEX), southern Ontario, and western Canada boreal forest. Walker and Goodison⁶⁴ provide a summary of Canadian accomplishments and challenges in passive microwave SWE determination. Weekly SWE maps for the Canadian prairie region have been produced using SSM/I each winter since 1989. Recent enhancements to these products are the incorporation of new algorithms for the boreal forest areas (starting with 1999/2000 winter) and “deviation from normal SWE” products that are based on a 10 year average of SSM/I-derived SWE conditions. The temporal and spatial variability in prairie snow cover has been investigated using principal components analysis of SSM/I derived SWE imagery to identify dominant patterns and potential relationships with atmospheric circulation.

⁶⁴ Walker, A.E. and B.E. Goodison, 2000: Challenges in Determining Snow Water Equivalent Over Canada using Microwave Radiometry. Proc., International Geoscience and Remote Sensing Symposium (IGARSS 2000), 24-28 July 2000, Honolulu, Hawaii, 1551-1554.

In addition to sea ice monitoring, the CIS is using RADARSAT to monitor, in season, over 120 inland Canadian lakes to ascertain weekly total ice coverage. These data are provided to the CMC, part of MSC, for input to heat budget calculations required for the national weather prediction modelling program, and in addition lake freezeup/breakup dates are derived and archived for climate change monitoring. Glacier snow line mapping using SAR imagery has been used for applications in glacier mass-balance and hydrology. This work demonstrates the effectiveness of ERS-1 and RADARSAT synthetic aperture radar (SAR) imagery for mapping movement of the transient snow line in a temperate glacier basin, showing that this method is reliable for applications in alpine/glacier hydrology. Canada has also established a regional center for GLIMS (Global Land Ice Monitoring from Space) and uses ASTER, Landsat, and Radarsat SAR to monitor Canadian glaciers in the high Arctic and western Cordillera.

In 1999, a State of the Canadian Cryosphere (SOCC) website (<http://www.socc.uwaterloo.ca>) was established by the CRYSYS project to disseminate up-to-date information on the current state of the cryosphere in Canada, including documented variability and changes, anomalies, and future predictions. Satellite imagery and derived products document the current state of cryospheric parameters including: snow cover extent, regional snow water equivalent, Arctic sea ice extent and animations of daily sea ice motion for Canadian regions. Canada's contributions to cryosphere monitoring for GCOS are contained in the cryosphere report for Canadian GCOS.

Spurred on by research programs such as the BOREal Ecosystem-Atmosphere Study (BOREAS⁶⁵) and the Northern Biosphere Observation and Modeling Experiment (NBIOME⁶⁶), the capabilities of satellite sensors to produce data sets of other terrestrial variables for climate purposes in Canada has grown significantly during the 1990s and Canada's Space Plan reflects initiatives to support climate change in the context of earth and environment monitoring. As a result of these and related activities, national data sets of key variables have been produced in research mode and scrutinized by the research community through peer-reviewed publications. Although rapid progress has been made and several important ecosystem variables (land cover type, leaf area distribution, net primary productivity, forest fire areas) have been mapped for the Canadian landmass in specific years, the process of developing the algorithms, product validation and integration with surface measurements is still in relatively early stages.

Current sensors and satellites particularly well suited to estimating carbon fluxes

⁶⁵ Sellers, P.J., F.G. Hall, R.D. Kelly, et al. 1997. BOREAS in 1997: experiment overview, scientific results, and future directions. *Journal of Geophysical Research* 102 (D24): 28731-28769.

⁶⁶ Cihlar, J., L. Band, J. Beaubien, J. Chen, R. Desjardins, T. Fisher, C. Holling, Z. Li, A. Royer, B. Stocks, and P. Teillet. 1995. Northern Biosphere Observation and Modeling Experiment (NBIOME). Progress Report, July 1995. 34p.

and the carbon budget are limited to the NOAA AVHRR series and SPOT Vegetation sensors⁶⁷. In Canada, it is probable that remote sensing observations will be considered in a hierarchical (or nested) sampling design and that higher spatial resolution imagery from Landsat and Landsat-like satellites, Radarsat, and others (VCL, hyperspectral) will fit within this hierarchical observation framework. GeoComp-n is the system for handling these data⁶⁸ and currently represents the next generation of image geocoding and compositing system being developed at the Canada Centre for Remote Sensing (CCRS). Follow-on work in GeoComp-n will focus on automatic land cover 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. Detection and identification (attribution) of forest change is a subject of continuing research. Reasonable accuracy has been achieved in New Brunswick and Alberta study areas using Landsat data. The CFS EOSD (Earth Observations for Sustainable Development Project) is aimed at providing similar type products at higher resolutions. This project is in early stages but should eventually provide important inputs into multi-scale assessments.

All of these requirements will necessitate a continuing effort to develop and validate satellite methods over terrain/surface conditions that are typical and important for Canada, to refine methods to combine and relate information from different satellite sensors and to integrate in-situ data, physical models and remotely sensed observations to fill in the spatial and temporal gaps in parameters of interest. In consequence, over the longer term, requirements for new or improved forms of remotely sensed data will provide opportunities for Canadian R & D to contribute to the maturing of GCOS while at the same time advancing national interests.

⁶⁷ 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.

⁶⁸ 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 (normalized to a common solar zenith angle of 45 degrees and nadir view angle), and 3) brightness temperatures.

6.0 CONCLUSION

In summary, Canada has made substantial progress in responding to the challenges presented by participation in the Global Climate Observing System, despite ongoing budgetary pressures and reductions in government programs. The development of a national GCOS plan has provided direction and focus to efforts to meet our global obligations while at the same time responding to domestic needs for climate system observations. The practical impact of this national plan has, moreover, been greatly enhanced by the targeted allocation of funds from the Canadian government's Climate Change Action Fund. These focussed contributions have not only encouraged domestic GCOS planning but also accelerated the implementation of important observational initiatives, as discussed earlier in this report. Moreover, funding obtained under the Federal Government Action Plan 2000 program is contributing to the filling of data gaps and enhancing national monitoring networks.

At the operational level, national implementation of GCOS components is generally progressing in parallel with the development and refinement of the global program. Action on the atmospheric component is proceeding satisfactorily, with Canadian GUAN stations identified and operating, the domestic portion of the GSN network nearing completion and GAW-related obligations being addressed. The oceans component has seen substantial Canadian commitments to the Argo program and enhancements planned to the nation's sea-level (tidal gauge) network in addition to continued provision of support for the SOOP, VOS and IABP programs, maintenance of significant moored buoy networks and initiatives related to sea ice.

Where the terrestrial component of GCOS is concerned, however, the picture is somewhat more uneven. On the positive side, Canada is making important contributions to GCOS in permafrost and active layer monitoring and in monitoring glacier mass balance within the framework of the GTN-P and GTN-G. Release of Canadian snow depth and snow course information and weekly fast ice thickness data⁶⁹ to the international community can also be cited as significant. Moreover, several Canadian FLUXNET stations have been designated and the Reference Hydrometric Basin Network provides a solid basis for responding to the evolving hydrologic monitoring requirements of GCOS. Conversely, while many other terrestrial datasets exist, most observational networks in this sector are incompletely developed to address GCOS requirements and this must remain an area of emphasis over the coming years.

Canada's satellite remote sensing efforts are, with the exception of RADARSAT, directed towards the applications of such data in the Canadian context and the conduct of related R&D activities. Where GCOS is concerned, however, Canadian work on satellite-based determination of important cryospheric

⁶⁹ Used in International Sea Ice Model Intercomparison Project.

parameters such as snow water equivalent, dates of freeze-up and break-up on lakes and others have, however, broader hemispheric or global applications. In addition, RADARSAT observations can contribute directly to addressing the important sea ice dimension of the climate system. For climate impact assessment and scaling up of site measurements to the national level, data from foreign satellites are used extensively in research mode.

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LIST OF ACRONYMS

AAFC	(Department of) Agriculture and Agri-Food Canada
ACARS	Aircraft Communication Addressing and Reporting System
AMDAR	Aircraft Meteorological Data Reporting System
AOPC	GCOS Atmospheric Observation Panel for Climate
ARNEWS	Acid Rain National Early Warning System
ASAP	Automated Shipboard Aerological Programme
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVOS	Automated Voluntary Observing Ship
BAPMoN	Background Air Pollution Monitoring Network
BERMS	Boreal Ecosystem Research and Monitoring Sites Project
BIO	Bedford Institute of Oceanography
BOREAS	Boreal Ecosystem-Atmosphere Study
BU	Break-up
CALM	Circumpolar Active Layer Monitoring Network
CANSiS	Canadian Soil Information System
CAPMoN	Canadian Air and Precipitation Monitoring Network
CCAF	Climate Change Action Fund
CCIN	Canadian Cryospheric Information Network
CCRS	Canada Centre for Remote Sensing
CFS	Canadian Forestry Service
CGVMAN	Canadian Glacier Variations Monitoring and Assessment Network
CIS	Canadian Ice Service
CISA	Canadian Ice Service Archive
CLI	Canada Land Inventory
CMAM	Canadian Middle Atmosphere Model
CRYSYS	CRYospheric SYStem in Canada
DFO	(Department of) Fisheries and Oceans Canada
DMSP	Defense Meteorological Satellite Program
DND	(Department of) National Defence
EC	(Department of) Environment Canada
EMAN	Ecological Monitoring and Assessment Network
EOS	Earth Observing System
EOSD	Earth Observations for Sustainable Development
ESA	European Space Agency
FEC	Forest Ecological Land Classification
FIGC	Forest Indicators of Global Change
FLUXNET	Global Terrestrial Network – Carbon
FU	Freeze-up
GAW	WMO Global Atmosphere Watch
GCM	Global Climate Model
GCOM	Global Change Observation Mission

GCOS	Global Climate Observing System
GEM	Global Environmental Model
GEMS	Global Environmental Monitoring System
GHOST	Global Hierarchical Observation Strategy
GLAS	Geo-science Laser Altimeter System
GLASS	Global Land Atmosphere System Study
GLIMS	Global Land Ice Mapping from Space
GOOS	Global Ocean Observing System
GO ₃ OS	Global Ozone Observing System
GOSSP	Global Observing System Space Panel
GPS	Global Positioning System
GVD	Global View Database
GSC	Geological Survey of Canada
GSN	GCOS Surface Network
GTN-G	Global Terrestrial Network - Glaciers
GTN-P	Global Terrestrial Network – Permafrost
GTN-H	Global Terrestrial Network - Hydrology
GTOS	Global Terrestrial Observation System
GTS	(WMO) Global Telecommunications System
GUAN	GCOS Upper Air Network
HALOE	Halogen Occultation Experiment
HRDI	High Resolution Doppler Imager
HUMSAT	(GOES) Satellite-derived humidity profiles
HWRP	(WMO) Hydrology and Water Resources Program
HYDAT	National Hydrometric Database
HYDEX	National Hydrometric Metadatabase
IABP	International Arctic Buoy Program
IASC	International Arctic Science Committee
ICESat	Ice, Clouds and Land Elevation Satellite
ICSU	International Council of Scientific Unions
IDS	Interdisciplinary Science Investigation
IGBP	International Geosphere-Biosphere Programme
IGOS	Integrated Global Observing Strategy
IOC	Intergovernmental Oceanographic Commission (of UNESCO)
IOS	(GCOS) Initial Observing System
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change
IPS	Ice Profiling Sonar
LANDSAT	Land Satellite
LIDAR	Light Detection and Ranging
LTTM	Long Term Temperature Monitoring (network)
MEDS	Marine Environmental Data Service
MLS	Microwave Limb Sounder
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurement of Pollution in the Troposphere
MSC	Meteorological Service of Canada

NAS	National Archive System
NAMP	North American Maple Project
NBIOME	Northern Biosphere Observation and Modelling Experiment
NDSC	Network for the Detection of Stratospheric Change
NESDIS	National Environmental Satellite Data Information Service
NIC	National Ice Center (US)
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Production
NRCAN	(Department of) Natural Resources Canada
NSIDC	National Snow and Ice Data Center
NWWG	National Wetlands Working Group
OLS	Operational Linescan System
OOPC	(GCOS/GOOS/WCRP) Ocean Observation Panel for Climate
ORACLE	Ozone Research with Advanced Cooperative Lidar Experiment
PICASSO-Cena	Pathfinder Instruments for Cloud and Aerosol Spaceborne Observations – Climatologie Etendue des Nuages et des Aerosols
PMO	Port Meteorological Officer
RCS	Reference Climate Stations
RCM	Regional Climate Model
RHBN	Reference Hydrometric Basin Network
SAR	Synthetic Aperture Radar
SATOB	Satellite Observation (WMO code for satellite cloud wind data)
SFC	Surface
SOCC	State of the Canadian Cryosphere
SOOP	Ship of Opportunity Programme
SPOT	Systeme Pour l'observation de la Terre (satellite)
SSM/I	Special Sensor Microwave Imager
SST	Sea Surface Temperature
SUB-SFC	Sub-surface
SWE	Snow Water Equivalent
SWIFT	Stratospheric Wind Interferometer for Transport Studies
TOPC	GCOS/GTOS Terrestrial Observation Panel for Climate
ULS	Upward Looking Sonar
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCC	United Nations Framework Convention on Climate Change
VCL	Vegetation Canopy Lidar (satellite)
VEGETATION	Sensor carried on SPOT satellite
VOS	Volunteer Observing Ship
VOSclim	Voluntary Observing Ship Climate Project
WCRP	World Climate Research Programme
WDC	World Data Centre
WGMS	World Glacier Monitoring Service
WHYCOS	World Hydrological Cycle Observing System
WMO	World Meteorological Organization

WSC	Water Survey of Canada
WWW	WMO World Weather Watch
XBT	Expendable Bathythermograph
3D-Var	Three Dimensional Variable

APPENDICES

CONTACT POINTS AND INTERNET SITES

1. ATMOSPHERE

Meteorological Service of Canada

URL: <http://www.msc-smc.ec.gc.ca/>

National Climate and Water Archive

URL: http://www.msc-smc.ec.gc.ca/climate/index_e.cfm

e-mail address: climate.services@ec.gc.ca

World Ozone and UV Data Centre

URL: <http://www.msc-smc.ec.gc.ca/woudc/>

2. OCEANS

Marine Environmental Data Service (MEDS)

URL: http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Home_e.htm

e-mail address: services@meds-sdmm.dfo-mpo.gc.ca

Canadian Ice Service (CIS)

URL: <http://ice-glaces.ec.gc.ca/>

3. TERRESTRIAL

Permafrost

URL: <http://sts.gsc.nrcan.gc.ca/permafrost/>

e-mail addresses mburgess@nrcan.gc.ca
ssmith@nrcan.gc.ca

Glaciers

URL: <http://sts.gsc.nrcan.gc.ca>
e-mail address mdemuth@nrcan.gc.ca

CRYSYS (*Note: This site contains information and links on all cryospheric components*)

URL: <http://www.crysys.uwaterloo.ca/>

Ecological Monitoring and Assessment Network (EMAN)

URL: <http://www.eman-rese.ca/>

e-mail address Hague.Vaughan@ec.gc.ca

Agriculture and Agri-Food Canada

URL: <http://www.agr.ca>

CanSIS URL: <http://sis.agr.gc.ca/cansis/intro.html>

Canadian Forestry Service

URL: http://www.nrcan-rncan.gc.ca/cfs-scf/index_e.html

Natural Resources Canada

URL: <http://www.nrcan-rncan.gc.ca/inter/index.html>

SUPPLEMENTARY TABLES

Atmospheric Observations

Table S1. Atmospheric observing systems for climate at the land surface (Meteorological land surface observations).

SYSTEMS	CLIMATE PARAMETERS	TOTAL NO. OF STATIONS	APPROPRIATE FOR CHARACTERIZING NATIONAL CLIMATE?			TIME SERIES			ADEQUATE QUALITY CONTROL PROCEDURES?			METADATA AVAILABLE Total No. Stns. (% Digitized)	CONTINUITY No. expected operational in 2005
			Fully	Partly	No	30 - 50y	50 -100y	> 100y	Fully	Partly	No		
Stations useful for National Climate Monitoring Purposes	Temperature	2145	x			842 (997)	330 (419)	44 (65)	x			2147	NA
	Precipitation	2145	x			973 (1200)	360 (469)	49 (75)	x			2147	NA
	Snowfall	1557	x			759 (933)	316 (388)	45 (61)		x		1557	NA
	Snow depth	1557	x			759 (933)	316 (388)	45 (61)		x		1557	NA
	Radiation RF1	43	x			23 (24)	0	0	x			43	NA
	Bright Sunshine	220		x		96 (112)	1	0		x		220	NA
	Evap.(Class A pan)	47		x		21	0	0		x		47	NA
Rate of Rainfall	436			x	155 (178)	2	0			x	436	NA	
Stations Reporting internationally	Regional Basic Synoptic Network standard	207				Temp: 172 Precip:160	Temp: 119 Precip:107	Temp: 11 Precip:5	*			207	207
CLIMAT Reporting Stations	Global Climate Observing System Surface Network (GSN) standard	72 (GSN)				Temp: 69 Precip:66	Temp: 56 Precip:53	Temp: 7 Precip:3	*			72 (GSN)	92
Reference Climate Stations	Temperature	290				Temp: 265 Precip:256	Temp: 214 Precip:198	Temp: 47 Precip:34	*			290	300
	Precipitation	290							*			290	300

Notes: The numbers in parentheses are the numbers of active stations at which historical data series exist within 2 km radius.
NA means "not available".

Table S2. Atmospheric observing systems for climate above the surface (Meteorological upper air observations).

SYSTEMS USEFUL FOR NATIONAL CLIMATE MONITORING PURPOSES	TOTAL NO. STATIONS	APPROPRIATE FOR CHARACTERIZING NATIONAL CLIMATE?			TIME SERIES No. Stns./Platforms(# Data Digitized)				ADEQUATE QUALITY CONTROL PROCEDURES?			METADATA AVAILABLE Total No. Stns. (% Digitized)	CONTINUITY No. expected operational in 2005
		Fully	Partly	No	5 -10y	10 - 30y	30 - 50y	> 50y	Fully	Partly	No		
Radiosonde stations	31	x			31	28	10	5	x			31	31
Wind-only stations	0												
Stations reporting internationally	31	x							x			31	31
CLIMAT TEMP reporting stations	31												
ASAP stations	0												
Profilers	0												
Aircraft (land locations)	0												
GPS													
Others	5			x						x		5	5
Total Upper Air Network	36											36	36

Table S3. Atmospheric constituent observing systems for climate.

CONSTITUENT	TOTAL NO. OF STATIONS OR PLATFORMS	APPROPRIATE FOR CHARACTERIZING NATIONAL CLIMATE?			TIME SERIES No. Stns./Platformns(# Data Digitized)				ADEQUATE QUALITY CONTROL PROCEDURES?			METADATA AVAILABLE Total No. of Stns.	CONTINUITY No. expected operational
		Fully	Partly	No	10 -20y	20 - 30y	30 - 50y	> 50y	Fully	Partly	No	(% Digitized)	in 2005
Carbon Dioxide	4			x	4				x			4	4
Ozone (surface)	7			x	1				x			7	7
Ozone (column)	12				1		5					yes, all*	11
Ozone(profile)	6						5					yes, all#	5
Atmospheric Water Vapour													
Other Greenhouse Gases	4			x	4				x			4	4
Aerosols	11			x	11				x			11	11
Other													

* station info + images

file header info on each sonde

Table S4. Oceanographic observing systems for climate*.

System Component	Total # Stations	Appropriate for Characterizing National/Regional Climate? (tick one box) Fully Partly			Time Series #stations/platforms (#Data Digitized)			Adequate Quality Control Procedures? (tick one box) Fully Partly No			Metadata available Total # Stations (%Digitized)	Continuity # expected operational in 2005
		No			30-50y	50-100y	>100y					
Sea Level e.g., Tide gauges	936		X		69	71	10			84		

Note: The above Table reflects the level of information that could be provided at the time of writing.