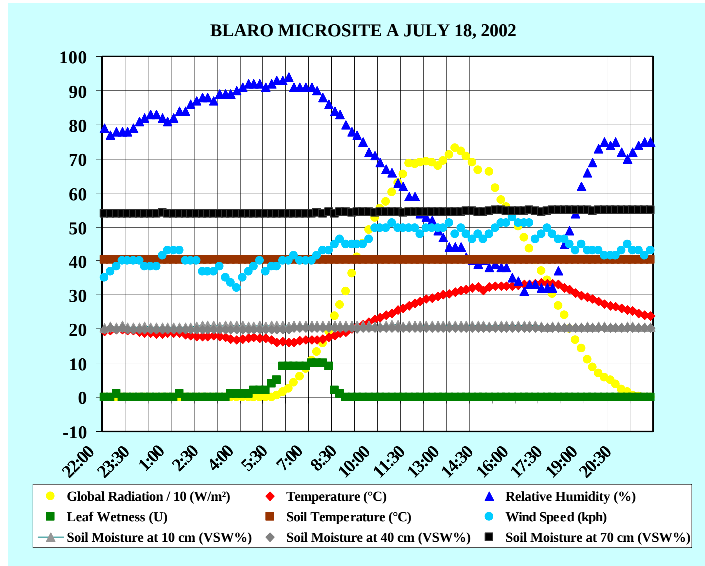
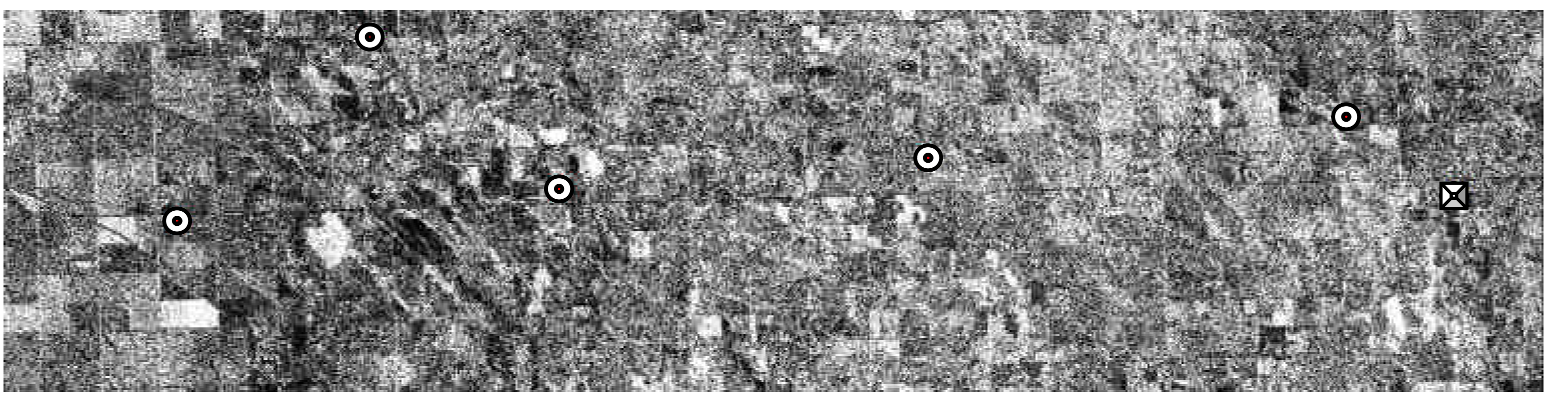
Natural Resources Canada | Ressources naturelles Canada

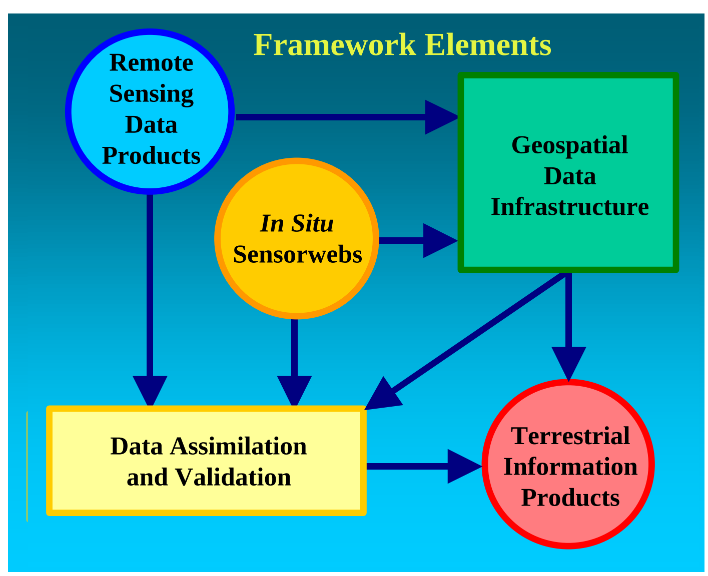



issmap

# Towards Integrated Earth Sensing for Resource and Environmental Monitoring: *In Situ* Sensor Measurement Assimilation Program (ISSMAP)

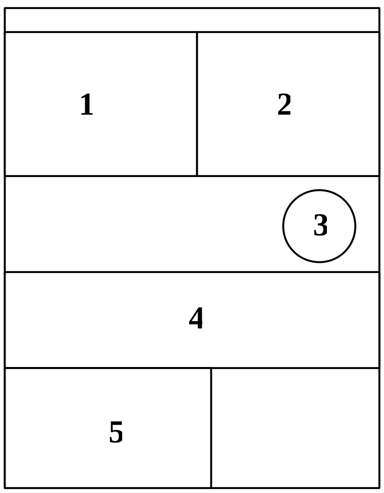
## ISSMAP Report 2001-2002





**"In the next century, planet earth will don an electronic skin. It will use the Internet as a scaffold to support and transmit sensations. This skin is already being stitched together. It consists of millions of embedded electronic measuring devices: thermostats, pressure gauges, pollution detectors, cameras, microphones, glucose sensors, EKGs, electroencephalographs. These will probe and monitor cities and endangered species, the atmosphere, our ships, highways and fleets of trucks, our conversations, our bodies -- even our dreams."**

Neil Gross, "The Earth Will Don An Electronic Skin", in "21 Ideas for the 21st Century", *BusinessWeek online*, August 30, 1999.




### Key to the front cover illustrations

1. **In-situ sensorweb field deployment at Bratt's Lake, Saskatchewan.**
2. **In-situ sensorweb measurements from Bratt's Lake, Saskatchewan, July 18, 2002.**
3. **Symbol of the international Integrated Global Observing Strategy (IGOS).**
4. **Radarsat-1 SAR image (W1, ascending, 12 m pixels) of the Roseau Basin of the Red River, Manitoba on October 1, 2002. The sensorweb nodes and "hub" are indicated by the five circular and one square symbols, respectively.**
5. **In-situ sensorweb field deployment in the Roseau Basin of the Red River, Manitoba.**


Ce document est aussi disponible en français.

# Towards Integrated Earth Sensing for Resource and Environmental Monitoring:

# In Situ Sensor Measurement Assimilation Program (ISSMAP)

## ISSMAP Report 2001-2002


**Data Acquisition Division**

**Canada Centre for Remote Sensing**

**Earth Sciences Sector**

**Natural Resources Canada**

# BASIC Elements of ISSMAP Activity

## Overview:

The "First Canadian Workshop on On-Line In-Situ Quantitative Sensor Networks" in Ottawa in summer 1999 was a highly visible event attended by participants from industry, government and universities. CCRS failed to take advantage of the momentum gained by the workshop. The strategic CCRS push towards in-situ sensor measurement and data assimilation was reinitiated in autumn 2000 and the In Situ Sensor Measurement Assimilation Program Definition Project (ISSMAP-DP) was established in the Applications Division of CCRS. An internal CCRS mini-workshop was held in November 2000 to help ensure that all parts of CCRS have a similar concept of what is being attempted with ISSMAP and to try to engage staff in this strategic activity.

In May 2001, CCRS initiated a new group to work on ISSMAP, the In Situ Measurement Development Section (ISMDS) in the Data Acquisition Division of CCRS. Having grown from one person to the current team (as of December 2002), ISMDS now consists of two Research Scientists (R.P. Gauthier, P.M. Teillet), two Systems Engineers (G. Ainsley, K.B. Fung), and two Physical Scientists (A. Chichagov, G. Fedosejevs). Selected research and development tasks were contracted out to specialists from Canadian industry (L. Campbell, B. Cho, M. Maloley). The Ground Station Operations Section and the Informatics and Computer Services Section of the Data Acquisition Division provided very valuable engineering and informatics support, respectively, to ISSMAP. Additional assistance was received in 2002 from Co-op students from the University of Ottawa (P. Curtis and Q. Zhang). Administrative support from C. Burke, K. Davis, C. Kizito, and P. Denemoustier is gratefully acknowledged.

This report outlines ISSMAP perspectives and achievements for 2001 and 2002 and includes a bibliography of publications. Henceforth, the efforts of the small but very active ISSMAP team will continue to be focused on projects and activities in Natural Resources Canada's Earth Sciences Sector (ESS) in the context of geomatics for sustainable development of natural resources, sustainable development through knowledge integration, and natural hazards and emergency response, among others.

## Mandate:

ISSMAP's goal is to make significant advancements in the practical use of Earth observation data by developing intelligent in-situ measurement capabilities that open new pathways towards the generation of quantitative geophysical and biospheric information products.

# Framework:

Because numerous independently managed networks and archives of in-situ sensors and data currently exist, ISSMAP focuses its activities carefully and leverages existing infrastructures wherever possible. Thus, ISSMAP activities must fit within the following framework (Teillet et al. 2001b). They must:

1. Lead to the generation of terrestrial information products that address clearly defined science and technology questions and/or user information requirements;
2. Utilize in-situ sensorwebs;
3. Utilize remote sensing data products;
4. Encompass data assimilation and validation components;
5. Routinely provide in-situ data products and/or metadata on in-situ data holdings to a geospatial data infrastructure.

Complementary to current efforts towards an Integrated Global Observing Strategy[1] and Global Monitoring for Environment and Security[2], the integrated Earth sensing concept being developed by ISSMAP provides a framework for the research and development of advanced data acquisition and integration elements of environmental monitoring/information systems used for local, regional, or global decision-making. In-situ sensor measurement assimilation efforts focus as a priority on issue-driven science and technology activities such as the monitoring of remote environments, risk assessment and hazard mapping, and time-critical decision-making (e.g., disaster and renewable resource information management).

# Objectives:

1. Design and deploy autonomous networks of sensors (sensorwebs) for in-situ data acquisition.
2. Develop approaches to fuse in-situ and remote sensing data for assimilation into models that generate validated information products.
3. Facilitate the integration of in-situ sensor data and/or metadata into on-line geospatial data infrastructures.

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[1] IGOS, http://www.igospartners.org/
[2] GMES, http://gmes.jrc.it/

# The State of the Earth and Its Environment

> **"It must be stated that space-derived information generally needs to be combined with in-situ measurements and models to obtain a holistic picture of the Earth's environment. … There is no Sustainable Development without adequate information about the state of the Earth and its environment".**

Josef Aschbacher
European Space Agency (ESA) and Committee on Earth Observation Satellites (CEOS)
Economic and Social Council, Commission on Sustainable Development
World Summit on Sustainable Development (2002)

## Geomatics for Sustainable Development of Natural Resources and Knowledge Integration:

ISSMAP is endeavouring to provide new sources of data, techniques, and methodologies for improved characterization and integration of geomatics information to support sustainable development. ISSMAP's focus is on standardized autonomous ground-based (in-situ) sensorwebs that measure key geophysical and biospheric parameters to validate remote sensing data and contribute to the Canadian geospatial data infrastructure. Thus, the activities are in line with strategies to have digital geospatial data acknowledged as a definitive and essential source of information in Canada for sustainable development decisions.

ISSMAP is contributing advanced data acquisition capabilities to drought monitoring efforts and hence helping to integrate information for modeling and forecasting as input into decision-making. Significant components of ISSMAP are designed to transfer technology and build Canadian industrial capability in integrated Earth sensing. Many of the research activities are being undertaken by university groups, which will lead to the generation of highly qualified personnel in new areas involving converging technologies that support advanced resource and environmental monitoring.

## Natural Hazards and Emergency Response:

ISSMAP is contributing advanced data acquisition capabilities to flood forecasting efforts and hence helping to provide detailed hazard assessments for Canadians in high-risk areas as well as information for emergency response to complex crisis events and emergencies.

# Towards Integrated Earth Sensing

## In Situ Sensing:

A short dictionary-based definition for **in-situ sensing** could be "sensing in place". Because many observations are made from nearby locations that are not strictly speaking in-situ, the expression **proximal sensing** has been adopted in a variety of disciplines to describe "sensing from close range" (as in close-range photogrammetry, for example). For the present purposes and in practice, in-situ sensing is considered to encompass proximal sensing as well. Networks of in-situ sensors continue to evolve even as unattended sensor and wireless telecommunication technologies advance at a rapid pace and new uses are invented. It is becoming increasingly feasible to provide quality-controlled network-wide data to users via the Internet in near real time and information products from data fusion and assimilation into models within hours or days.

## Converging Technologies:

The converging technologies of sensors, micro-computers, and wireless telecommunications have led to new developments such as Wireless Integrated Network Sensors (WINS) (Asada et al. 1998) and smart networks of in-situ sensors called sensorwebs (Delin and Jackson 2000, 2001; Delin 2002). These systems form the technology base for new monitoring capability for a wide variety of applications in sectors such as transportation, manufacturing, health care, environmental monitoring, and safety and security. Sensorwebs consist of spatially distributed sensor nodes that combine sensing, signal processing, smart systems, and wireless networking. With the advent of increasingly compact, low power, and relatively inexpensive devices, it will soon be possible to deploy large numbers of sensor pods (Pister et al. 1999; Hollar 2000). Combined with powerful geospatial visualization tools, these technologies will provide an ongoing virtual presence in remote locations and many monitoring uses will be developed.

## Integrated Earth Sensing:

Satellite Earth observation sensors provide unique measurements of terrestrial variables. These measurements are critical because the Earth system changes constantly over a wide range of temporal and spatial scales. Nevertheless, it is recognized that ground data collection will always remain an essential source of information. Indeed, a growing perspective today is that significant advancements in Earth observation are expected to come about only by developing more systematic capabilities for the fusion of remote sensing observations and in-situ measurements to generate geophysical and biospheric information products. This integrated Earth sensing approach will include the deployment of autonomous sensorwebs on the surface of the Earth in various application contexts. Such systematic capabilities can provide essential validated information for decision-making if they involve interagency cooperation, common data processing standards, and timely access to data and information products on a long-term basis.

# Initial ISSMAP Activities

ISSMAP is undertaking science and technology activities that contribute to sustainable development of natural resources and natural hazards and emergency response, and that have the potential to contribute to development of the north. Initial foci of attention include watershed monitoring, flood forecasting, drought monitoring, and disaster mitigation. The primary ISSMAP outputs and contributions will be autonomous in-situ sensorwebs, integrated moisture sensing, data fusion and assimilation methodologies, and enhanced CGDI data holdings.

ISSMAP's multi-faceted effort to develop an integrated Earth sensing capability in Canada involves a mixture of external and in-house R&D activities addressed by the following two activities, described in the material that follows.

- ***TREATIES*: Towards Remote Environmental Assessment Through Integrated Earth Sensing**. The objective of TREATIES is to facilitate external investigations on in-situ sensing via contracts with industry, leveraged collaborations, various linkages, and R&D collaborations. TREATIES establishes ties and works with selected partners on integrated Earth sensing approaches to resource and environmental monitoring.
- ***ProWISE*: Prototype Wireless Intelligent Sensorweb Evaluation**. ProWISE tackles the first objective of ISSMAP by deploying and testing unattended, wireless in-situ sensorwebs in Earth science applications contexts.

# Towards Remote Environmental Assessment Through Integrated Earth Sensing (TREATIES)

## Contracts to Canadian Industry:

- Prototype flood information management system (Isosceles Information Solutions, Inc.) - completed.
- Improved crop specific projections (Noetix Research, Inc.) - completed.
- Web services for atmospheric correction parameters (Centre for Research in Earth and Space Technology (CRESTech) and Université de Sherbrooke) - completed.
- Integrated wearable computer and satellite communications solutions (Halltech Atmospheric Services) - completed.
- Agriculture and hydrology remote sensing applications development and technology transfer (Noetix Research, Inc., with CCRS Applications Division) - completed.
- Integrated Earth sensing R&D support and technology transfer (ACG Space, Inc.) – in place.
- New data mining tools for monitoring land surface temperature using integrated Earth sensing data (GlobVision, Inc.) – March 2003 completion.

## Leveraged Collaborations:

- Laser-induced fluorescence for in-situ chemical analysis in agriculture (with Agriculture and Agri-Food Canada (AAFC)).
- Concept studies on applications of integrated Earth sensing with emphasis on in-situ sensing (with CRESTech).
- Characterization of atmospheric aerosols across Canada in the context of climate change studies, using AEROCAN, a Canadian ground-based network of automated solar radiometer instrumentation (with Université de Sherbrooke, CRESTech, Environment Canada's Meteorological Service of Canada (MSC), Natural Sciences and Engineering Research Council (NSERC), and NASA's Goddard Space Flight Center (GSFC), among others).
- Study on satellite Earth observation in support of watershed management programs (with the Canadian Space Agency and Borstad Associates Ltd.) – March 2003 completion.
- Geomatics-enabled monitoring of geotechnical sites (with the Geomatics for Informed Decisions (GEOIDE) Network of Centres of Excellence (NCE) and Queen's University).
- Understanding soil moisture characteristics as a function of the spatial resolution of remote sensing systems and the spatial distribution of in-situ sensing systems (University of Ottawa).
- Intelligent sensorweb for integrated Earth sensing for enhanced drought monitoring (with Precarn) – submitted.

## Linkages:

- Procurement and evaluation (with applications development scientists at CCRS) of the ArcPad-iPAQ-GPS equipment combination.
- Provisions of technical and strategic advise to Indian Head Agricultural Research Foundation on its RoboScout initiative.
- Membership on the US Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) User Working Group.
- Membership on the international Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV).

## Additional R&D Partnerships:

- Enhanced geospatial information systems for timely and interoperable access, management and visualization in support of emergency planning and response (with various agencies).
- Mer Bleue wetlands carbon modelling (with Centre for Climate and Global Change Research, McGill University, and part of the Ameriflux network).
- Drought monitoring (with Water Institute for Semi-arid Ecosystems (WISE), Lethbridge University).
- Dialogues towards R&D partnerships with specialists at CCRS, the Geological Survey of Canada (GSC), the Canadian Space Agency (CSA), and the Communications Research Centre (CRC).

# Prototype Wireless Intelligent Sensorweb Evaluation (ProWISE)

## Prototype Sensorweb Overview:

The main objective of the Prototype Wireless Intelligent Sensorweb Evaluation (ProWISE) involves the field deployment of a sensorweb with full inter-nodal connectivity and remote access and control. The project is also testing and demonstrating remote webcam operations and telepresence at remote field sites. A technology test-bed is being used to integrate the various components of a sensorweb so that it can be remotely controlled and eventually remotely configured. The process involves solving the engineering problems associated with the interfaces between the sensors at a given node and the wireless telecommunications devices that will include the addition of smart control and decision drivers.

Field trials are taking place to evaluate deployment and remote operation issues as well as considerations relevant to the use of sensorwebs in specific data acquisition, information extraction and decision contexts. The initial prototype sensorweb consists of five nodes and a base station. The initial configuration for each node of the sensorweb consists of a compact mast with sensors recording temperature, relative humidity, downwelling solar radiation, rainfall, wind direction, wind speed, leaf wetness as appropriate, soil temperature, and soil moisture. Soil moisture in particular is considered a key parameter that can also be estimated by satellite radar data such as those from Canada's Radarsat. The microspectrometer subsystems for surface radiance and downwelling irradiance measurements are still in the integration and testing phases.

Different wireless telecommunication and telepresence strategies have been examined. Access and control are remotely operated and have been tested from the individual nodes to the IESW in Ottawa (Internet web-enabled) as well as from the nodes to the base station and then to the IESW. Control of the microsensors is achieved through embedded systems specifically tailored to the geospatial application being investigated.

These deployments do not yet take advantage of fully miniaturized or smart systems, but they utilize commercial-off-the-shelf (COTS) technology in operational settings in remote environments. Smart inter-nodal communication is planned for the next phase of development. In that phase, the current style of nodes will likely become the base stations for local-area sensorwebs with the addition of more numerous, smaller sensor nodes. Thus, hierarchically, there will be (at least) two levels to the in-situ sensorweb. Even in its current form, the prototype sensorweb activity is ahead of the curve in many ways. Use of the sensorweb is being sought by numerous Earth science applications groups, including various government agencies. The capability represents a big step towards faster, denser, and more autonomous ground-based data acquisition, Earth observation data validation and, in due course, real-time triggering of alerts in appropriate contexts.

## First Field Trials - Ottawa and Bratt's Lake 2002:

Early in 2002, a prototype network of sensors was deployed in an outdoor environment near Ottawa, Canada, to facilitate the debugging of the protocol conversion between the microsensor/microcontroller packages and the satellite transceivers. RF telemetry ranges were tested to identify possible distances and optimal area coverage for sensorweb deployments.

In July 2002, a test deployment was made at Bratt's Lake Atmospheric Radiation Observatory (BLARO) in Saskatchewan, Canada, in collaboration with Environment Canada's Meteorological Service of Canada (EC/MSC). This field campaign included tests of the full access/control system through the Integrated Earth Sensing Workstation (IESW) at CCRS in Ottawa. The initial sensorweb configuration consists of a compact mast with sensors recording temperature, relative humidity, downwelling solar radiation, rainfall, wind direction, wind speed, soil temperature, and soil moisture. Highlights of the BLARO deployment are as follows.

- First CCRS field deployment of a five-node prototype in-situ sensorweb, with near-real-time data accessible from the IESW in Ottawa via RF and satellite telecommunications.
- First CCRS use of microspectrometers over agriculture targets near BLARO, with data sent to the IESW in Ottawa via satellite.
- First CCRS field trial of telepresence at BLARO via webcam and satellite modem, with live image transmissions as well as remote trouble-shooting and resolution of webcam firmware problem via telepresence.
- Demonstration of data retrieval from the IESW database in Ottawa via satellite from BLARO.
- Validation of sensorweb meteorological and soil moisture data against independent measurements by EC/MSC/BLARO (in progress).

## Red River Basin Deployment 2002-2003:

A more elaborate test deployment followed in autumn 2002 in the context of a flood forecasting application in the Roseau Basin of the Red River in Manitoba, Canada, in collaboration with CCRS hydrology specialists and the National Water Research Institute (NWRI) of Environment Canada (EC). Highlights are as follows.

- The five-node prototype in-situ sensorweb is currently deployed in the Roseau Basin of the Red River in Manitoba and will remain there through the flood season in the spring of 2003.
- The five-node sensorweb operates autonomously and standard meteorological parameters and soil moisture measurements are accessed remotely from the IESW in Ottawa. This is to be compared with the three bulkier met stations with data loggers and the labour-intensive soil moisture measurement techniques used by the hydrologists participating in the project.
- Validation of sensorweb meteorological and soil moisture data against independent measurements by CCRS and EC/NWRI (in progress).

Deployment of the current and possibly the next-phase sensorweb will be targeted at drought monitoring applications.

# Benefits and Impacts

## Commercial Impact:

Pilot projects have been completed with Canadian industry to demonstrate advanced information products in priority areas with operational and commercial benefits arising from the use of new technologies for in-situ data acquisition, archiving, fusion, and assimilation.

## Cost Savings:

ISSMAP is demonstrating the utility of unattended wireless intelligent sensorwebs, leading to lower-cost and wider participation in what have traditionally been resource-intensive activities. Web-enabled access to resources in the field also has the potential to facilitate asset management and remote support of instrumentation when required.

## Technology Transfer:

A significant proportion of the ISSMAP funding has been made available to develop in-situ data acquisition and integration capabilities in Canadian industry and universities. Pilot projects demonstrating the utility of the integration of in-situ and remote sensing data have directly involved operational agencies.

## Partnerships:

ISSMAP projects have involved completely new synergistic partnerships between agencies to develop and archive Earth science information products that benefit from in-situ and remote sensing data acquisition and integration.

## Knowledge Advance:

State-of-the-art in-situ data acquisition technologies and data processing systems are being adapted and optimized for selected Earth science utilizations of strategic significance. New data and information products are being developed and validated from the fusion and assimilation of remotely sensed data, in-situ measurements, and modelling. Access to a national data archive of in-situ measurements and to metadata on other in-situ data holdings facilitates new research and development in Earth science.

## Building Capacity:

ISSMAP represents a strategic initiative into a new area involving converging technologies that support advanced resource and environmental monitoring. As such, it has created new opportunities to expand skills, capabilities, and reputation and to allow staff to participate in new, challenging, and career expanding work.

## National Skill Base:

In the context of resource and environmental monitoring, ISSMAP has involved the converging technologies of micro-sensors, computers, and wireless telecommunications and new concepts such as in-situ sensorwebs, which should provide excellent opportunities for skill development in Canada in general and for the training of highly qualified personnel in particular.

## Societal/Policy Impact:

A more systematic and timely approach to capturing, archiving and integrating data makes it possible to provide validated information for strategic decision making in the context of resource and environmental monitoring.

## Access to Information:

Better access to Earth science activities, data, and information via the Internet are high priorities for the Government of Canada. ISSMAP is contributing to the availability of in-situ data through the Canadian Geospatial Data Infrastructure (CGDI).

## Transparency of Government and Connectivity of Canadians:

ISMAP is demonstrating how the public could have access to information about the field activities of government scientists and engineers and how the government could increase the visibility of these resources in action.

**“The power of technological convergence will bring measurable benefits to each and every individual.”**
Douglas Mulhall, *Our Molecular Future*, 2002.

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(* Organised or sponsored in whole or in part by CCRS.)

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