GEOMATICS AND THE NEW CYBER-INFRASTRUCTURE

J.A. Rod Blais, Department of Geomatics Engineering
Pacific Institute for the Mathematical Sciences, University of Calgary, Calgary, Alberta
Harold Esche, Chief Information Officer and Haskayne School of Business
University of Calgary, Calgary, Alberta

Geomatics is a very active field of applied science and engineering which deals with multi-resolution geospatial and spatio-temporal information for all kinds of scientific, engineering and administrative applications. Rapidly changing communication and High Performance Computing (HPC) technologies have brought about fundamental changes in the handling of geospatial and related information. As a result, new specialized knowledge and expertise are expected and refined in the workplace. Cyber-infrastructure refers to the new virtual environments in which advanced data processing and management services are accessible through high-performance communication networks, primarily for collaborative research, development and instructional purposes. These new trends are very likely to transform the community by bringing scientists, researchers, students and practitioners to share the same data, tools, procedures and expertise when dealing with geospatial and related information. Such exciting possibilities as virtual observatories and workplaces are discussed, with examples to illustrate some of the far-reaching implications for not only users in Geomatics, but society in general.

La géomatique est un domaine très actif des sciences appliquées et du génie qui s'occupe de l'information géospatiale et spatio-temporelle à multi-résolution pour divers genres d'applications scientifiques, de génie et administratives. Les communications en évolution rapide et les technologies High Performance Computing (HPC) (à haut débit) ont entraîné des changements fondamentaux dans la manipulation de l'information géospatiale et l'information connexe. Ainsi, de nouvelles connaissances et expertise spécialisées sont attendues et raffinées dans le milieu de travail. La cyber-infrastructure fait référence aux nouveaux environnements virtuels dans lesquels les services de traitement et de gestion avancés de données sont accessibles par l'entremise de réseaux de communications à rendement élevé, surtout pour des fins de recherche, de développement et de formation en collaboration. Il est très probable que les nouvelles tendances transformeront la collectivité en permettant aux scientifiques, chercheurs, étudiants et praticiens de partager les mêmes données, outils, procédures et expertise en travaillant avec les renseignements géospatiaux et l'information connexe. On discute des possibilités excitantes comme des observatoires et milieux de travail virtuels et on donne des exemples pour illustrer certaines répercussions de grande portée non seulement pour les utilisateurs du domaine de la géomatique, mais pour la société dans son ensemble.

J.A. Rod Blais
blais@ucalgary.ca

Harold Esche
esche@ucalgary.ca

1. Introduction

Geomatics has come a long way from the days when simply measuring distances and angles was considered high technology, and computations were done manually by workers. Surveying, which played a leading technological role in earlier times, has essentially become positioning and navigation; while topographical mapping has become a byproduct of Geospatial Information Systems (GISs). Survey networks and photogrammetric adjustment computations have largely been replaced by more sophisticated digital processing with adaptive designs and implementations. The transition from analogue to digital methodologies has not only resulted from the availability of ubiquitous computers, but has shown to be superior in just about every aspect of data processing and information extraction and identification. Furthermore, as in many other fields of endeavour, computation is now regarded as a primary driver of innovation.

In a well-connected digital world, Geomatics can play a new role in research and development involving geospatial and related information, as well as creating entrepreneurial opportunities. The following are some potential areas of application that are closely related to Geomatics:

i) better understanding and protecting the natural environment;
ii) monitoring habitat and studying global climate change;
iii) guaranteeing and assessing the availability and efficiency of essential services;
iv) improving the general quality of life in rural and urban environments;
v) optimizing the utilization of natural resources in a sustainable manner; and
vi) predicting, protecting against and recovering from natural and human disasters.

These and other Geomatics applications involve integrating multiple data sets (which may have inconsistent metadata) over a wide variety of spatial and temporal scales into standardized data structures for research, using a broad variety of software and hardware. This is a challenging task, even with an environment in which all the data sets, data-processing tools and support services are readily available. The development of the appropriate tools and services is one of the key challenges in the creation of the new "Cyber-infrastructure."

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The term "cyber-infrastructure" was coined by a National Science Foundation (NSF) Blue-Ribbon Committee to describe the "organized aggregate" of technologies that enable us to access and integrate today's information technology resources—data and storage, computation, communication, visualization, networking, scientific instruments, and technical expertise—to facilitate science and engineering goals [*Berman* 2004]. The term is now widely used across many scientific disciplines to include a range of electronic-based environments that are emerging from the changing and innovative practices, often called "e-science" or "e-research." Cyber-infrastructure is more than just hardware and software. An effective cyber-infrastructure will include computing facilities, data storage and high-speed networking, and will integrate remote instrumentation, visualization services, grid middleware and collaboration facilities [*ACTF* 2006a]. Another critical aspect of a successful cyber-infrastructure will be the effective use of local support services and federated support services via national and international collaborative programs.

Many countries around the world have been investing hundreds of millions of dollars into cyber-infrastructure research and development [*ACTF* 2006a]. For example, through the National Science Foundation, the U.S. government has established the Office of Cyberinfrastructure to coordinate its national cyber-infrastructure program and invests some US$500 million annually in cyber-infrastructure [*ACTF* 2006a; 2006b]. Overall figures are not available in Canada, but the Natural Sciences and Engineering Research Council (NSERC), Canada Foundation for Innovation (CFI) and provincial governments (*http://www.compute-canada.org*) have made major investments.

The rapidly evolving communication and computer technologies, together with this new vision of cyber-infrastructure as a more cohesive and linked set of technologies and services, are enabling a transformation of Geomatics and other fields. From past experiences with the Internet and the World Wide Web, simple linear predictions in terms of today's experience are not particularly useful. However, a better understanding of current technologies and general features can greatly help anticipate and adapt to new working environments. Advanced collaboration can include videoconferencing, application sharing, interactive whiteboarding, video streaming, remote data manipulation, collaboration grids, shared visualization tools and other technological developments. Geomatics researchers, developers and industry analysts need to be proactive to remain on the leading edge of geospatial information science and technology. Educational programs are also most likely to benefit from new virtual environments that have so much to offer in the training of tomorrow's professionals. Examples of applications relatively close to familiar positioning and mapping activities will illustrate the potential of Geomatics and other disciplines.

2. From Surveying to Geomatics

A few decades ago, surveying technology and engineering involved only distance and angle measurements and their reduction to geodetic networks for cadastral and topographical mapping applications. Survey triangulation, trilateration and even precise levelling have now largely been replaced by Global Positioning System (GPS) applications for positioning and navigation in various modes of implementation. Aerial film (analogue) photography has become digital and is often complemented with multispectral and radar measurements. Satellite imagery of various types and specifications are becoming available globally in near real-time for environmental and related applications. Multi-resolution geospatial data (and metadata) refer to the observations and/or measurements at multiple scalar, spectral and temporal resolutions, such as digital imagery at various pixel sizes, spectral bands and seasonal coverages.

Space-based sensors and observational technologies have revolutionized our understanding of the solid Earth we live on and reveal subtle changes that occur on regional and global scales. Understanding these complex processes requires large global data sets and sophisticated computational models, coupled with the associated computational infrastructure [*Berman* 2004]. Subfields of solid Earth research that must use computational resources include earthquake dynamics, surface processes, landscape evolution, gravity, magnetic fields, cryosphere, ice modelling and hydrology. Obviously, the oceans and the atmosphere are also contributing to various environmental systems and need to be integrated into the global and regional dynamic models.

However, even with the most advanced observation systems, complete temporal samples of geophysical phenomena are unavailable, as Earth processes can span hundreds and thousands of years. Therefore, while programs of continuous observations are ongoing, simulations need to be carried out by integrating the collected data into computational models, together with constraints and validation schemes. Because Earth processes occur on many different spatial and temporal scales, it is often convenient to use metamodels, or model hierarchies, rather than focus on a single or limited set of scales or other characteristics. Increasing interoperability and distributed Web-based computing are becoming more and more appropriate for such computational research and development activities [*Donnellan et al*. 2004].

A major problem facing scientists today is that quantities and resolutions of scientific data are increasing faster than computational power. This is really challenging for researchers who are working to make sense of the current observations using the available computational facilities. For instance, with several GPS receivers being deployed at a large crustal deformation array for real-time observations, the data processing and archiving can easily present serious computational challenges. Specifically, Earthscope (*http://www.earthscope.org*) has been collecting seismic and geodetic data over the North American continent in the amounts of terabytes (or millions of megabytes) per year. Also, new space-based Earth Observation missions will generate tens of terabytes of data per week. Obviously, our approaches to data and information processing have to change to keep up with data collectors and for society to benefit from the new technologies and observations.

The availability of free geospatial data from Natural Resources Canada through the Web sites *http://www.geobase.ca* and *http://www.cgdi.ca* ushered in a new era in Canadian Geomatics. The RésEau initiative, led by Environment Canada in partnership with Natural Resources Canada and Health Canada, focusses on water information. RésEau supports clean, safe and secure water for all Canadians and ecosystems, and aims to establish partnership support projects to demonstrate the sharing, discovery, access and use of water information over the Internet (*http://map.ns.ec.gc.ca/reseau/*). RésEau provides the user with modern search tools, interactive mapping and downloadable applications, all accessible in one place. The sharing of geospatial data is a central component of this new cyber-infrastructure, which is likely to revolutionize information technology—particularly geospatial information technology.

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3. The New Cyber-infrastructure

Cyber-infrastructure is the research community's equivalent to the physical infrastructure of roads, bridges, power grids, telephone lines and water systems that support modern society [*NSF* 2003]. Specific components include high-performance computing facilities, advanced network infrastructure, grid software or middleware, scientific visualization, remote instrumentation, data-storage infrastructure and databases, and collaboration tools. A critical non-technological element is people and organizations (perhaps virtual organizations) that develop and maintain software, operate services and directly assist researchers in the development and use of applications.

Since 1993, the Top 500 project has been creating a list of the 500 most powerful computer systems (http://*www.top500.org*). The trend toward more and more powerful systems is illustrated by several observations accompanying the latest list [*Top500* 2007]:

- The 500th system on the list would have been listed at position 216 in the TOP500 just six months ago.
- The entry point for the top 100 increased in six months from 6.65 TFLOPS to 9.29 TFLOPS.

While the magnitude of computing power now available is impressive, perhaps as important is the fact that these technologies are becoming more widely available to all researchers. Technology facilities once only used by a handful of select researchers are now necessary infrastructure for most researchers in science and engineering [*NFS* 2007]. This change in both quantity and background of the customer of the services will likely require significant changes to the manner in which the services are provided to researchers.

Advanced communication networks are making similar leaps in capacity. High-speed networks, such as Internet2 and CA*net 4, plus the communication linkages between the international research networks, now allow high-speed connectivity between most of the research institutions around the globe. But simply providing networks to the edge of the campus will not fulfill the requirements for cyber-infrastructure. Increasingly, it will be essential to provide high bandwidth and low latency network services to computer and storage clusters, desktops and remote instruments.

Another technology critical to cyber-infrastructure is “Grid” software and services. While the term “grid” is widely used, often with a variety of meanings, “grid computing” was initially motivated by the needs of scientists (*http://www.gridcanada.ca*). The original design was to facilitate access to high-end computational resources via a parallel computing model.

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The “grid” conceptual model has expanded to include other resources and services, such as storage, networks and scientific instruments. Common to all of these applications was the need to form and maintain virtual communities, within which resources and/or services could be shared and applied to common problems [*Berman et al*. 2002; *Plaszczak and Wellner* 2006].

Ian Foster suggested that a grid is a system that: i) coordinates resources that are not subject to centralized control; ii) uses standard, open and general purpose protocols and interfaces; and iii) delivers non-trivial qualities of services such as response time, throughput and availability in a way we would expect from our local network environment [*Foster* 2002].

The need to share resources, such as instrumentation, data, tools and procedures, turns out to be fundamental to commerce as well as science. The Grid is the computing and data management infrastructure that provides the electronic fabric for a global society in business, government, research, science and entertainment [*Berman* 2004]. The Grid is actually transforming science, business, health and society.

In short, Grid computing is a technology that enables resource virtualization, on-demand provisioning and service- (or resource) sharing between organizations. Using the utility computing model, Grid computing aims at providing ubiquitous digital services. Frameworks providing these virtualized services must adhere to a set of standards that ensure interoperability, and need to be well described, open, non-proprietary and commonly accepted in the community [*Plaszczak and Wellner* 2006].

Service Oriented Architecture (SOA) will also impact researchers’ use of cyber-infrastructure. SOA is simply a collection of “services” which communicate with each other. The services can be built using languages such as Java, C# or even Cobol or FORTRAN, but use standards such as XML for data parsing. The basic construct of service modules that communicate provides a much more flexible framework, with a major benefit being that a service can be replaced without having to “rip and replace” the whole system. Using SOA, one should be able to create new applications simply by connecting existing software services. Furthermore, according to *Carter* [2007], SOA and Web 2.0 are fast becoming the new language of business.

Another key component of the cyber-infrastructure is remote instrumentation. Wireless networking is now widely available via Wi-fi, cellular or two-way satellite. These near-ubiquitous networks, coupled with increased commoditization of sensors, will likely result in an immense growth in data over the next several years. Cyber-infrastructure will be challenged to develop appropriate standards and toolkits to collect, manage and share these large data sets.

An inspirational example for the possible impact of a new cyber-infrastructure is the Internet itself. At one time, the Internet was a new infrastructure component, initially with the narrow purpose of enabling new research in distributed systems. But policy, technology and application changes transformed the Internet into both infrastructure and a set of services that now deeply impact all research disciplines. Just as email, the World Wide Web, broadband and other disruptive technologies enabled the Internet to significantly change how research is carried out and communicated, new technologies and approaches are poised to further transform research via the development of widespread cyber-infrastructure.

The emerging vision is to use cyber-infrastructure to build more ubiquitous, comprehensive digital environments that become interactive and functionally complete for research communities [*NSF* 2003]. These environments involve people, data, information, tools and instruments that operate at unprecedented levels of computational, storage and data-transfer capacity. Such a vision obviously has profound implications for education, research and development, and commerce—including Geomatics and, actually, society in general.

4. Spatial Information Resources

These days, there are plenty of spatial information resources to exploit and build upon for cyber-infrastructure research and development activities. Distributed Information and Communications Technology (ICT), complemented by sophisticated tools and highly qualified support personnel, enable today's technological evolution in research, production and commerce. However, legacy databases of observations, measurements, softwares and procedures bring about all kinds of technological challenges to the scientists and engineers in the field.

The concept of a National Spatial Data Infrastructure (NSDI) goes back to reports of the U.S. Mapping Science Committee (MSC) in the early 1990s. In those days, few users or producers of geospatial data made use of the Internet. In 1998, a Panel on Distributed Geolibraries coordinated the preparation of a series of white papers, which led to an MSC Workshop on Distributed Geolibraries—Spatial Information Resources in 1998 [*NRC* 1999].

A geolibrary is a digital library filled with geoinformation and for which the primary search mechanism is place, or location of interest, on or near the Earth's surface. Such a place might be a single point, an extended area or a neighbourhood above or below the surface, defined by name or coordinates and with exact or ill-defined specifications. The term "distributed" in Distributed Geolibraries refers to the locations of the physical and functional parts of the library and the locations of its users. Libraries have responded to this new networked environment by establishing coordinated, collaborative and multi-institutional relationships. Digital libraries—in particular, digital geolibraries—have greatly evolved over the past decade and, in the coming years, will likely bring about more fundamental changes.

These days, Earth scientists are likely to spend much time and effort identifying and acquiring data sets. Centralized data repositories often serve as a single entry point for acquiring and disseminating scientific data. One such central data repository is the World Data Centre System [*WDC* 1996], which supports international exchanges of geophysical observations in accordance with principles set forth by the International Council for Scientific Unions. These centres collect data and publications for various geoscience disciplines such as glaciology, meteorology, oceanography, the space sciences (from rockets and satellites), solar-terrestrial physics (geomagnetic variations, aurora, cosmic rays) and solid-Earth geophysics (seismology, gravimetry, Earth's rotation and tides, tectonic movements). Four open-source data management systems—the International Virtual Observatory Alliance (IVOA; *http://www.ivoa.net*), the Virtual Solar Observatory (VSO; *http://vso.nso.edu*), the Live Access Server (LAS; *http://www.ferret.noaa.gov/Ferret/LAS/*) and the Distributed Oceanographic Data System (DODS; *http://www.unidata.ucar.edu*)—are prominent examples in networking astronomy, space and geoscience data.

Earth observations from satellites and ground-based collection sites have the potential to provide scientifically valid input for solutions to many of the world's most pressing environmental problems. However, the data sets tend to be very large, poorly documented, widely distributed and difficult to access. The Federation of Earth Science Information Partners (ESIP; *http://esipfed.org*) is a unique consortium of more than 90 organizations that collect, interpret and develop applications for remotely sensed Earth observation information. The ESIP is building an interface where Earth science data, products and tools will be available and understandable to researchers, educators, policy-makers and the general public. Such an Earth Information Exchange will be a portal that provides access to the vast information holdings of member organizations through one Web-based location, and a robust marketplace in which the products and services needed to use and understand this information can be readily acquired. As the U.S. federal government's Earth observing data centres are members of ESIP, the impact of the Exchange on Earth science research on education and environmental policy-making is expected to be significant.

Among the early initiatives in this realm, the GEOsciences Network (GEON) project was established in 2002 under the Information Technology Research (ITR) program of the National Science Foundation. GEON (*http://www.geongrid.org*) has been developing cyber-infrastructure and related tools for data integration, analysis and visualization in support of integrative science across the Earth sciences. The goal of GEON is to advance the field of geoinformatics and to prepare and train current and future generations of geoscience researchers, educators and practitioners in the use of cyber-infrastructure to further their research, education and professional goals. In other words, the main objective is to give geoscientists an "IT headstart" in view of the emerging cyber-infrastructure [*NSF* 2005].

GENESIS (Global Environmental and Earth Science Information System;

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http://genesis.jpl.nasa.gov) is a suite of data services that brings together Earth science products generated by space-borne GPS receivers flying in international missions, such as CHAMP, SAC-C and GRACE. GENESIS is planned to expand its role to support more general Earth science investigations involving data from multiple flight instruments, along with specialized tools for mining, visualization, fusion and analysis of large scientific data sets. In other words, such plans are really for collaborative computational research in appropriate virtual environments.

In astronomy, a New Virtual Observatory (NVO; *http://www.virtualobservatory.org*) is an effort to make all the astronomy data in the world easy to access using a simple set of Web interfaces. This will allow scientists to compare enormous data sets from all wavelengths of the electromagnetic spectrum observed with various instruments in different places and at all times. Recently, a Virtual Global Magnetic Observatory Network (VGMO.NET; *http://mist.engin.umich.edu*) has been proposed along similar lines and is under construction for world-wide distribution of geomagnetic data [*Papitashvili et al.* 2006]. A similar network has been proposed for a 2007-2009 International Polar Year project and will be discussed briefly in this paper.

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For the vast majority of Earth-system explorations, syntax interoperability of information systems is a major limiting factor. In order for scientists and non-scientists to discover, access and use data from unfamiliar sources, they are forced to learn details of the data schema, other people's naming schemes and syntax decisions. Much research is underway to enable higher level interconnections using the technology of ontologies, ontology-equipped tools and semantically aware interfaces between science components. Ontologies fill a major technology gap in machine-to-machine communication across multiple disciplines by enabling data integration with only minimal human intervention. A project entitled Semantically-Enabled Science Data Integration (SESDI; *http://sesdi.hao.ucar.edu*) will demonstrate how ontologies implemented within existing distributed systems can provide essential, re-usable and robust support for data, information and other systems for NASA Science Focus Areas and Applications.

Planetary ontologies (*http://www.planetont.org*) aim to facilitate the use, re-use, development, evolution, alignment and merging of ontologies through a community of best practices in the broad fields of Earth and space sciences. Apart from GEON and SESDI, there is a Semantic Web for Earth and Environmental Terminology project (SWEET; *http://sweet.jpl.nasa.gov*), which will enable software programs, applications and agents to find meaning and understanding on Web pages. Other related initiatives are the Earth and Atmospheric Science Smart Search (NOESIS; *http://noesis.itsc.uah.edu*) and Scientific Dataflow (SciFlo) (*http://sciflo.jpl.nasa.gov*), a system for scientific knowledge creation on the Grid using a semantically enabled dataflow execution environment. The goal of SciFlo is to enable large-scale, multi-instrument, Earth science investigations using high-performance Grid services.

5. Geocomputations and Visualization

Today, with Google Earth™ (*http://earth.google.com*), Microsoft Virtual Earth™ (*http://www.microsoft.com/virtualearth*), the open source 3D interactive world viewer World Wind (*http://worldwind.arc.nasa.gov*) from NASA, and others in the works, there has never been a better time to explore our planet from the comfort of our living rooms. With NASA's World Wind, one can also explore the Moon, Venus, Mars and Jupiter.

Google Earth™ is Google's new satellite imagery-based mapping product that combines global coverage of imagery with new navigational features, including integrated Google search capabilities. It is a (broadband) mapping tool that enables users to fly from space to street-level views to find geographic information and explore places around the world (*http://earth.google.com*). Using imagery from Keyhole (which Google acquired in 2004) and other commercial suppliers, the resolution varies from 1 km square to 15 cm square pixels. Screen displays are photo-realistic views and users can zoom, tilt and rotate around whatever they see. Google Earth is a free downloadable application for personal use, with higher end consumer versions available for professional and commercial use.

The Goddard Earth Sciences Data and Information Services Center's (GES DISC) Interactive Online Visualization and Analysis Infrastructure (GIOVANNI; *http://giovanni.gsfc.nasa.gov*) provides researchers with advanced capabilities to perform data exploration and analysis directly on the Web, using data from NASA Earth observation satellites. The primary data consist of global gridded data sets with reduced spatial resolution. GIOVANNI allows researchers to rapidly explore the data, so that spatio-temporal variability, anomalous conditions and patterns of interest can be directly analysed online before the optional downloading of higher resolution data [*Acker and Leptoukh* 2007].

As solid Earth data sets grow more extensive, researchers are likely to discover new phenomena. Anticipating a flood of new data, advanced knowledge-discovery computing techniques for new and realistic computational simulations, data mining, visualization and pattern-analysis techniques should be given high priority. For instance, pattern-recognition techniques are exploiting methods based on principal component analysis and hidden Markov models [*Granat and Donnellan* 2002]. New computational methods will be based on Web services, federated database services and novel Grid-computing methodologies. An anticipated fusion of computational and mission-oriented sciences will enable remarkable new discoveries for solid Earth dynamics.

Geoscientists, primarily those focussing on modelling crustal deformation and earthquake processes, are developing the International Solid Earth Research Virtual Observatory (iSERVO; *http://www.servogrid.org*), which will let investigators seamlessly merge multiple data sets and models and create new queries. The iSERVO will archive simulation data with analysis and animation tools, including the original simulation code. Observational data will be accessible through cooperative federated databases [*Donnellan et al*. 2004]. Among the tools available will be visualization, data mining, pattern recognition, data fusion and others in a problem-solving environment for model and algorithm development, together with testing, visualization and data assimilation to address multi-scale modelling challenges.

Realistic earthquake-fault system simulations have been realized within the QuakeSim project (*http://quakesim.jpl.nasa.gov*), which aims at constructing general earthquake models (GEMs). The project focusses on three modelling areas: Virtual California for the dynamics of stress evolution on a complex fault system, such as the San Andreas fault system; GeoFEST for finite-element modelling of earthquake fault surfaces, along with their elastic and other rheologies; and PARK for boundary-element modelling of unstable slips at segments of faults. More information on the library of GEM software codes is at *http://www.servogrid.org* and sample outputs from Virtual California computations are at *http://pat.jpl.nasa.gov/public/RIVA*.

The Earth's fluid outer core is in convection, driven by gravitational energy released from the planet's slow cooling. Over the past 150 years, the main component of the Earth's magnetic field has decayed by nearly 10 percent. Any variations in the Earth's magnetic field above its surface could have serious implications for low Earth-orbiting satellite operations by altering the degree of radiation exposure. The Japan Earth Simulator, which is a 40-TFLOPS massively parallel-processing system with 5,120 CPUs and 10 terabytes of memory, has been used to develop realistic convection models with lateral heterogeneity in the mantle electrical conductivity (*http://www.es.jamstec.go.jp*).

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6. Examples of Applications in Geomatics

Over the past decade, numerous service centres have started offering digital products over the Web, perhaps best exemplified by the transition from cartographic maps on paper to rectified digital imagery distributed over the Internet. Such digital products are often supplemented with functions and operations for GIS and similar environments. However, few service centres have feedback mechanisms from the users in terms of data, operators and processors, and none provide a virtual working environment over the Web for real collaboration.

Three examples of current projects in Geomatics are described to illustrate how the new paradigm is bringing about new perspectives in research and development. These projects are largely multi-disciplinary, with multi-jurisdictional characteristics, involving multi-scalar, spectral and temporal data sets for wide-ranging research and applications. Although first conceived as data libraries or repositories, the project Web sites are expanding with tools, procedures and other support services generally available to the public at no direct cost to the users. With the new cyber-infrastructure environment, interactive communications and information transfers will be enabled with appropriate concurrency and security protocols to ensure the integrity of the system at all times.

(a) The Crown of the Continent Ecosystem Project

This project started with the Crown of the Continent Ecosystem Data Atlas (CCEDA), which was launched in May 1995 after years of discussion and planning to integrate data and information about the internationally recognized ecosystem of the Western Cordillera from Yellowstone to the Yukon (Y2Y) [*Blais et al.* 1997*; Gourdeau et al*. 1996]. This atlas was conceived as a computerized repository of properly integrated biophysical and socio-economic information related to the ecosystem, with online access and retrieval by ecologists and the general public, to promote research and better resource management. The complexity of such natural regions and the existence of inter-jurisdictional differences in data sets present real obstacles to ecosystem-scale management [*Rajabi et al*. 2000].

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A central objective has been to work towards continuous, harmonized geospatial data sets for environmental analysis and sustainability across multiple jurisdictions. Through partnerships with government, industry, non-governmental organizations and academia, the Miistakis Institute for the Rockies (MIR) at the University of Calgary has been involved in numerous research projects that address core issues and critical data gaps identified by stakeholders in the region (*http://www.rockies.ca*). The availability of geospatial data sets and biodiversity information does not resolve complexity and related issues for the scientists, managers and the general public. However, online interactive tools and technical support with appropriate user-friendly interfaces can greatly help everyone involved. Such Web-based tools and procedures have been shown to function extremely well as planning and information-exchange tools within or between organizations, communities and individuals [*MIR* 2005 and 2006].

The use of remote sensors has changed environmental research by providing researchers and managers with critical data often in near real-time. For instance, collaring wild animals, such as grizzly bears, provides location and other environmental data that have tremendous implications for researchers and park managers [*Herrero* 2005]. Another example is the Crowsnest Pass Road Watch Project, which uses a Web-based GIS—not only for remote sensing, but for input from interested citizens about wildlife–vehicle collisions and human safety along a stretch of highway in southwestern Alberta (*http://www.rockies.ca/roadwatch*). Similarly, cattle and other farm animals are being monitored using GPS and other sensors for any anomalous behaviour related to animal nervous-system diseases (*http://www.prioninstitute.ca*). The possibilities are practically endless with miniature sensors for tracking and/or monitoring environmental conditions such as temperatures, water levels, snow conditions, etc.

With the new cyber-infrastructure providing high-bandwidth communications, advanced languages and protocols, such as the Sensor Model Language (SensorML; *http://vast.uah.edu/joomla*), can be used to network plug-and-play sensors, simulations and processes, into seamless contributions to management- and decision-support systems. The Open Geospatial Consortium (OGC) SensorML specifications would allow interoperability across monitoring programs and data-extraction tools (e.g., Environment Canada's RésEau initiative). With SOA and Web 2.0 developments, collaboration and participation can only be expected to improve at the national and international levels.

(b) Information System for Emergency Response Management

Natural disasters and accidents happen in all kinds of environments at mostly unexpected times. Earthquakes, tornadoes and hurricanes are the most potentially dangerous to life and property. Outdated topographical maps and related geographical information can only bring about confusion and delays in major emergency situations. The recent hurricanes around the Gulf of Mexico have confirmed the need for more research and development to be in a better position to reduce the impacts of another hurricane season in that region. However, Google Earth proved very useful in assisting the Katrina response and recovery operations [*Yarbrough and Easson* 2005]. This is extremely important for Geomatics researchers in the field, who need to reconsider how to best exploit the new cyber-infrastructure in the very near future. Emergency responders should always have access to all the available required information. The situation for natural and other disasters in other parts of the world is often much more serious, especially when such disasters are entirely unpredictable.

For nearly a decade, the Emergency Medical Services of metropolitan Toronto, Ontario, have been using a Geocode Street Guide© to improve the efficiency of ambulance and related services with multi-layered map information [*Hamilton* 2003]). Such street-map guides started with analogue paper products and have recently become specialized GIS modules for the needs and requirements of emergency personnel. MacLeod [2005], who developed the system, has proposed a generalization for emergency and security response applications based on the National Topographic Data Base (NTDB) digital map files. This new approach, called mapPAGEing America™, would incorporate near real-time updating of the map files from GPS receivers carried by emergency responders [*El-Sheimy and Hassan* 2007]. This map-paging approach could easily incorporate a satellite map-image tiling system [*Lukatela and Russell* 2005], and even be generalized to a multi-resolution object-based information system using

Hierarchical Data Format (HDF), as in NASA's Earth Observing System Data and Information System (EOSDIS: *http://romulus.gsfc.nasa.gov/*).

The United States has developed the Homeland Security Critical Infrastructure Program (HSIP), with some 13 layers/themes of information to support domestic operations. A cross-border critical Infrastructure Program would provide similar critical information some 100 nautical miles on each side of the border. Cross-Canada efforts are underway to establish a National Infrastructure Data Base (NIDB) to support domestic operations [*Testa* 2005]. Compatibility of emergency response systems across the Canada–U.S. border is a fundamental requirement for homeland security and emergency response.

Alberta is a geographically diverse province. Topography, climate, water resources, traffic volumes, and weather and road conditions can vary significantly across the province, regions and even districts. Weather information is provided by Environment Canada using satellite and various remote sensors in numerous locations. For Alberta's national highway system, a Road Weather Information System (RWIS) is being developed using remote pavement and nearby sensors in order to increase safety through enhanced winter maintenance practices and traveller information. Such an Information System combines the road maintainers' knowledge, meteorological information, other relevant environmental and geographical data, traffic and safety data, and multi-jurisdictional station data from passive and active sensors [*Pinet* 2003]. The RWIS is part of a larger network of RWIS sites across Canada, so that more accurate forecasting of storms can be achieved in real time by following their progress across the network. The analysis of such weather, highway and other infrastructure data will undoubtedly lead to more powerful models that will influence highway design, highway maintenance and support emergency-response decision systems.

In an extreme emergency, all first responders (fire, police, ambulance services or the military) need to be able to use GPS coordinates linked to a digital map base to navigate to any point in Canada and elsewhere. This requirement is critical to avoid confusion in multi-jurisdictional areas that have their own mapping reference systems and conventions. It is also important to note that different map representations and other visualization graphics can readily be generated "on the fly" using an appropriate computer system.

Among the available technological solutions containing the most comprehensive and up-to-date information, Google Earth, RésEau and others provide convincing evidence of what is possible with today's Web technology and tomorrow's cyber-infrastructure. It is extremely important for Geomatics researchers to consider how to best exploit the new cyber-infrastructure—assuming that our emergency responders should always have access to, and be able to share, all relevant information, whenever and wherever required.

(c) Reference Crustal Modelling for Arctic Research

The International Polar Year (IPY) 2007–2009 provides an unprecedented opportunity to collect data from the cryospheric regions of the globe in a coordinated fashion (*http://www.ipy.org*). The legacy of IPY will be the rich data sets generated during those two years of intensive measurements and ongoing monitoring that may follow. The IPY framework document outlines policies that the data will be interdisciplinary, and freely and openly accessible, along with data-management strategies to encourage international coordination and collaboration in research [*Moore* 2006].

The U.S. NSF has funded efforts to develop a National Virtual Observatory (NVO) for all kinds of astrophysical data. These efforts have resulted in an evolving, Web-based, virtual observatory that provides services in three broad areas:

a) Data Services for access to data;
b) Compute Services for computation and federation of data; and
c) Registry Services for services and other entities to be published and discovered.

These could also serve the IPY community well for concentrated activities in 2007–2009 and, subsequently, in Arctic research [*Walker and Kulesa* 2006; *Papitashvili* 2006].

From a Geomatics perspective, the first phase of the reference polar crustal model would consist of a reference density and density variation model of the crust and mantle lithosphere for the Canadian and neighbouring Arctic regions. The subsurface density distribution and shape of density discontinuities (Mohorovičić discontinuity, topography), together with glacial isostasy and dynamic topography, are the major contributors to the observed geopotential and gravity fields. Subsequent phases are most likely to include environmental glacial and coastal monitoring through field and space observations, such as using satellite imagery.

First, a detailed three-dimensional surface and subsurface geological and geophysical model of the

In an extreme emergency, all first responders…need to be able to use GPS coordinates linked to a digital map base to navigate to any point in Canada and elsewhere.

The new cyber-infrastructure aims at creating virtual environments for access, collaboration and contribution to information and knowledge.

North polar region needs to be assembled by compiling publicly available topographic and bathymetric data sets (GTOPO30, TerrainBase, ETOPO5, GeoBase). Second, the depth and shape of the Mohorovičić and other major density discontinuities in these polar regions are necessary, starting with the radial density profile from the Preliminary Reference Earth Model (PREM) [*Dziewonski and Anderson* 1981], the U.S. Geological Survey CRUST5.1/CRUST2.0 global crustal models [*Bassin et al*. 2000] and the global geopotential models [*Provins* 2004]. Then the structural properties of the lithosphere can be estimated from the available geothermal and related data, and the important effects of dynamic topography and post-glacial rebound integrated. A number of other dimensions can be added to the crustal model, depending on the priorities and advances in polar research.

This reference polar crustal model is being conceptualized for interactive use by scientists and other researchers, in a manner similar to iSERVO, to study crustal deformation and earthquake processes. Considering the numerous multi-disciplinary research projects in Arctic science, the development of Web-based tools, procedures and related services appears imperative.

7. Concluding Remarks

Surveying has played a leading role in designing and implementing the transcontinental railways and road networks for a resource-based economy. The obvious challenge is for Geomatics to play a significant, if not a leading, role in the new cyber-infrastructure to help develop the new knowledge-based economy. Geomatics has a lot to contribute in ensuring proper geo-referencing of information and interpretation of multi-resolution geospatial data, along with appropriate metadata. The concern about data and metadata standards cannot be overemphasized when discussing collaboration in data- and tool-sharing in multi-disciplinary scientific research and development, and in all kinds of value-added engineering products and services for commercial exploitation.

Three examples of ongoing research and development projects related to ecosystem management, emergency response and arctic research have demonstrated some of the advantages of the cyber-infrastructure for Geomatics. Among other potential areas of development are optimizing our community education and support services; our communication and transportation systems; various environmental monitoring systems; water; and air quality. In academia, education and training would become more meaningful and interesting for all concerned by using real-world examples and assignments involving current geospatial data and metadata, with tools and procedures that are available in government and industry.

The new cyber-infrastructure aims at creating virtual environments for access, collaboration and contribution to information and knowledge. Users would gain access to data, tools and other support services to collaborate in research and development, and could contribute to the improvement of the data, their interpretation and further analysis. Hence the interactive environment ensures up-to-date and reliable information and knowledge for everyone. In other words, the cyber-infrastructure offers great possibilities to improve our quality of life, and Geomatics can contribute most significantly to that vision!

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Authors

Dr. J. A. Rodrigue Blais, Professor Emeritus, (P.Eng, PhD, New Brunswick) developed several computational software packages in topographical mapping and geodetic referencing at Natural Resources Canada before becoming a faculty member in Geomatics Engineering at the University of

Calgary in 1979. His current research activities centre around the applications of spherical harmonics, advanced geocomputations, and the new cyberinfrastructure. For many years, Dr. Blais has been very active as an Executive Member of the Canadian Geophysical Union, and also as a Director of the Miistakis Institute for the Rockies. He is also a member of the Pacific Institute for the Mathematical Sciences, University of Calgary. Current information can be found at: *www.ucalgary.ca/~blais*

Harold Esche (MASc, MBA, P.Eng) is the Chief Information Officer at the University of Calgary as well as an Associate Professor (Adjunct) in the Haskayne School of Business. Harold has over 20 years' experience in Information Technology in Higher Education and is currently responsible for the strategy and delivery of campus IT in support of teaching, learning, research, and administration. For many years Harold has been active in research computing, and recently co-chaired the Alberta Cyberinfrastructure Task Force. ❑