Importance of Data Standardization for Generating High Quality Earth Observation Products for Natural Resource Management

P.M. Teillet, G. Fedosejevs, R.K. Hawkins, T.I. Lukowski, R.A. Neville, K. Staenz, R. Touzi, J. van der Sanden, and J. Wolfe

Canada Centre for Remote Sensing
Earth Sciences Sector
Natural Resources Canada

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All authors are with the Canada Centre for Remote Sensing (CCRS), a Branch of the Earth Sciences Sector:
Philippe M. Teillet
Gunar Fedosejevs
Robert K. Hawkins
Tom I. Lukowski
Robert Neville
Karl Staenz
Ridha Touzi
Joost van der Sanden
John Wolfe

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GSDNR Program Manager:
Éric Loubier

General Enquiries:
GSDNR@nrcan.gc.ca

Communications Enquiries:
Cathryn Bjerkelund
Communications, Outreach and Assessment
Natural Resources Canada
588 Booth Street Ottawa, ON
Canada K1A 0Y7

T: 1-613-995-3987
F: 1-613-947-1385
E: bjerkelu@nrcan.gc.ca

http://gsdnr.nrcan.gc.ca/

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

A focus of immediate as well as longer-term interest to Canada is the improvement of natural resource management in the evolving framework of sustainable development. Sustainable resource management that seeks to safeguard the environment while deriving economic benefit necessarily requires information about past and current states of the geophysical and biospheric properties of the Earth. In particular, the establishment of monitoring frameworks for natural resource and environmental decision-support increasingly depends on geophysically consistent temporal series of Earth observation satellite data and the associated innovative methodologies. This addresses the first output of the Earth Sciences Sector (ESS) Program on Geomatics for Sustainable Development of Natural Resources (GSDNR). Ensuring that Earth observation data can be used reliably and quantitatively by non-specialists in the government and private sectors alike requires the development and use of product generation systems that include data standardization procedures developed by specialists. This too is in line with the GSDNR Program outcomes of more efficient and effective decision-making by communities, industry and sustainable development policy organizations involved in the sustainable development of natural resources and acknowledgement that ESS digital geospatial data are a definitive and essential source of information for sustainable development decisions.

Sensor characterization, data standardization, product validation and quality assurance (often collectively referred to as calibration and validation) play integral roles in strengthening the various links in the chain from remote sensing and other data to information of value to users and decision makers in many areas, including sustainable resource management. When new technologies come along, such as instruments that measure and monitor the Earth from space, calibration and validation research must be undertaken to provide sound underpinnings for the new capabilities that result. Government programs and the geomatics industry are then well placed to build these new capabilities into their programs and innovations, leading to information products that the user community is prepared to adopt. Thus, with a view to illustrating the critical role that calibration and validation plays, **the purpose of this report is to present a series of examples that illustrate for non-specialists what happens to the information content of Earth observation products with and without proper characterization and correction**. Without adequate quality assurance (QA), the technology will not deliver the whole product that is needed to create the compelling value proposition that can win over markets. Innovations in data standardization are all the more important with respect to the newer Earth observation technologies such as hyperspectral and radar remote sensing that are of particular interest for Canadian applications development.

Before presenting the examples, the report briefly reviews some user need and market studies carried out in the context of data standardization. A 1992 European study identified the lack of proper standardization in diverse applications, including those central

to natural resource management, as a bottleneck to the growth of the Earth observation applications market. A 1995 Canadian study of remote sensing market needs for calibration-validation concluded that Earth observation will only become a mainstream information technology when it provides consistent data quality, which implies the development of appropriate standardization tools for use with advanced Earth observation technologies of interest to our user community. Three national workshops held from 1996 to 1998 to help establish strategic priorities for Canadian calibration-validation efforts from both technical and market perspectives adopted the view that calibration-validation is a QA issue from the user's perspective and that QA is essential to bring remote sensing fully into the mainstream. A 2004 user needs study confirmed that there is a definite need, especially in government agencies, for standardization of Earth observation data in support of sustainable resource management. It also recommended that ESS continue to develop its expertise in the calibration and validation of satellite-based Earth observation data, with a strategic focus on the key areas that directly support sustainable resource management.

The examples in this report encompass both optical and microwave image data. In each case, the impact of not taking the extra steps of data characterization and standardization prior to or during product generation, including a variety of calibration steps, is provided in quantitative terms with respect to the products used for natural resource management. Examples of communities and agencies that currently benefit or will benefit from self-consistent data are noted in each case. The applications concerned are as follows:

- Mapping biophysical parameters for modeling and monitoring vegetation
- Mapping the land cover of Canada
- Mineral mapping for exploration purposes
- Plant liquid water for crop vigour assessment
- Canada's Stewardship Agenda and Water Resource Management
- Monitoring acid mine drainage impact on the surrounding environment
- Coastal zone wetland monitoring and accurate sea-level discrimination
- Ice classification and interpretation in petroleum exploration areas
- Wind farm site selection using ocean and coastal wind fields
- Monitoring of ice conditions on the Athabasca River

Geospatial information needs are growing dramatically, in government and private agencies alike. Many if not most Earth observation applications have advanced to the point where high quality digital image products are essential for success. Raw or uncorrected imagery can no longer be used to provide meaningful information for natural resource management. At the same time, satellite sensor systems and image information extraction methodologies are advancing rapidly in quality and quantity. The several dozen Earth observation satellite systems currently operating in orbit will be joined during the next five years by a very impressive manifest of new systems, including Canada's RADARSAT-2. As we work toward the sustainable development of natural resources, these new Earth observation technologies will contribute information of significant economic, social, environmental, strategic, and political value to the extent that developments in data standardization and quality assurance keep pace.

SOMMAIRE EXÉCUTIF

La notion de développement durable est en constante évolution : dans ce contexte, l'amélioration de la gestion des ressources naturelles représente à court et à long terme un enjeu majeur. Une gestion durable des ressources, qui vise à sauvegarder l'environnement tout en suscitant des retombées économiques, doit s'appuyer sur de l'information à propos des propriétés géophysiques et biosphériques de la Terre, présentes et passées. En particulier, la mise en place de cadres de surveillance des ressources naturelles et d'aide à la prise de décision en matière d'environnement s'appuie de plus en plus sur la production régulière de séries de données d'observations satellitales de la Terre et des méthodologies novatrices qui s'y rattachent. Ceci nous amène au premier extrant du programme « La géomatique à l'appui du développement durable des ressources naturelles » (GDDRN) du Secteur des sciences de la Terre (SST). Il faut s'assurer que les données d'observation de la Terre puissent être utilisées de façon fiable et quantitative par des non spécialistes, au gouvernement et dans le secteur privé. Pour ce faire, il est nécessaire d'élaborer et d'utiliser des systèmes de génération de produits qui comprennent des processus de normalisation des données développés par des spécialistes. Cela aussi est conforme aux résultats visés par le programme GDDRN : a) une prise de décision plus efficiente et plus efficace par les communautés, l'industrie et les organismes d'élaboration des politiques en matière de développement durable engagés dans le développement durable des ressources naturelles et b) la reconnaissance des données géospatiales numériques du SST comme source essentielle et définitive d'information pour la prise de décision en matière de développement durable.

La caractérisation des capteurs, la normalisation des données, la validation du produit et le contrôle de la qualité (souvent désignés dans leur ensemble sous les termes de calibration et de validation) font partie intégrante du renforcement des divers maillons de la chaîne entre la télédétection et les autres données, d'une part, et l'information utile transmise aux utilisateurs et aux décideurs dans divers domaines, d'autre part, y compris la gestion durable des ressources. Lorsque de nouvelles technologies se développent, comme les instruments qui mesurent et surveillent la Terre de l'espace, une recherche sur la calibration et la validation doit être entreprise de manière à étayer solidement les nouvelles capacités qui en résultent. Les programmes gouvernementaux et l'industrie de la géomatique sont alors en bonne position pour mettre en valeur le potentiel de ces nouvelles capacités dans leurs programmes et leurs innovations, ce qui se traduit par des produits d'information que la communauté des utilisateurs est prête à adopter. Ainsi, avec le souci d'illustrer le rôle indispensable que jouent la calibration et la validation, **le but de ce rapport consiste à présenter une série d'exemples qui montrent aux non spécialistes ce qu'il advient du contenu en information des produits d'observation de la Terre en présence ou en l'absence d'une caractérisation et d'une correction adéquates**. En l'absence d'assurance de qualité adéquate, la technologie ne livrera qu'une partie du produit nécessaire à la création d'une proposition de valeur convaincante et gagnante sur les marchés. Les innovations en matière de normalisation des données sont les plus importantes en ce qui a trait aux technologies récentes d'observation de la Terre, comme la télédétection hyperspectrale et radar, qui sont particulièrement intéressantes pour le développement d'applications canadiennes.

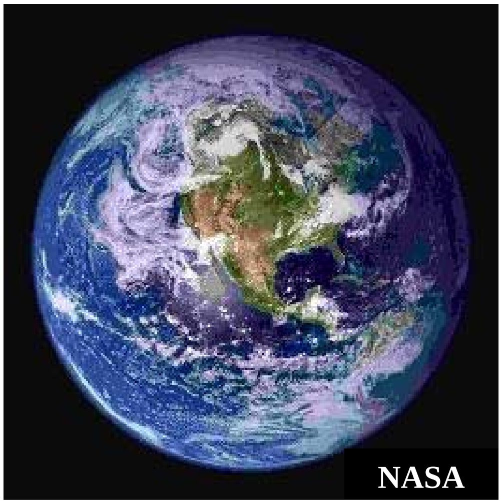
Avant de présenter les exemples, le rapport passe brièvement en revue quelques études de marché et des besoins des usagers menées dans le contexte de la normalisation des données. Une étude européenne effectuée en 1992 a identifié l'absence d'une normalisation appropriée pour diverses applications, notamment pour des applications essentielles à la gestion des ressources naturelles, qui ralentit la croissance du marché des applications en observation de la Terre. Une étude canadienne menée en 1995 sur les besoins du marché de la télédétection en matière de calibration et de validation a conclu que l'observation de la Terre ne deviendra une technologie courante d'information que lorsqu'elle fournira des données constantes en qualité, ce qui suppose l'élaboration d'outils appropriés de normalisation à être utilisés de concert avec les technologies avancées d'observation de la Terre qui intéressent notre communauté d'utilisateurs. Trois ateliers nationaux ont eu lieu entre 1996 et 1998 afin d'aider à établir des priorités stratégiques dans les efforts que déploie le Canada en matière de calibration et de validation, à la fois dans une perspective technique et de marché. Les participants à ces ateliers ont conclu que les utilisateurs perçoivent la calibration et la validation comme un problème d'assurance de qualité et que cette assurance est essentielle si l'on souhaite faire réellement de la télédétection une technologie d'usage courant. En 2004, une étude sur les besoins des utilisateurs a confirmé la nécessité, particulièrement dans les organismes gouvernementaux, de normaliser les données d'observation de la Terre pour appuyer la gestion durable des ressources. L'étude a aussi recommandé que le SST continue à développer son expertise dans la calibration et la validation des données d'observation de la Terre, dans une perspective stratégique mettant l'accent sur les éléments-clés qui soutiennent de façon directe la gestion durable des ressources.

Les exemples contenus dans ce rapport illustrent à la fois les données d'imagerie optique et d'imagerie hyperfréquence. Dans chaque cas, nous avons quantifié les impacts qu'entraîne l'omission des étapes de caractérisation et de normalisation des données en ce qui a trait aux produits utilisés pour la gestion des ressources naturelles, y compris diverses étapes de calibration, que ce soit avant ou pendant le processus de production. On trouvera aussi dans chaque cas des exemples de communautés et d'organismes qui profitent actuellement ou qui bénéficieront de l'utilisation de données cohérentes et fiables. Voici une liste des applications concernées :

- Cartographie des paramètres biophysiques à des fins de modélisation et de surveillance de la végétation
- Cartographie de la couverture terrestre du Canada
- Cartographie minérale à des fins d'exploration minière
- Évaluation de la vigueur des récoltes à partir du contenu en eau des plantes
- Programme d'intendance du Canada et gestion des ressources en eau
- Surveillance des impacts du drainage minier acide sur le milieu ambiant
- Surveillance des milieux humides en zone côtière et mesure précise du seuil de mobilité du niveau de la mer
- Interprétation et classification des glaces dans les zones d'exploration pétrolière
- Choix des emplacements de parcs d'éoliennes à partir des champs de vent océaniques et côtiers
- Surveillance de l'état des glaces sur la rivière Athabasca

Les besoins en information géospatiale connaissent une croissance remarquable, tant au gouvernement qu'au secteur privé. Plusieurs, sinon la plupart des applications en observation de la Terre en sont au point où la production d'images numériques de haute qualité est essentielle au succès. L'imagerie brute ou non corrigée ne peut plus être utilisée pour fournir de l'information significative et valable pour la gestion des ressources naturelles. En même temps, les systèmes de détection par satellite et les méthodes d'extraction des données-image progressent de façon rapide, qualitativement et quantitativement. Les quelques douzaines de systèmes d'observation satellitale de la Terre qui opèrent présentement en orbite vont être joints par un impressionnant manifeste de nouveaux systèmes, incluant le RADARSAT-2 canadien. Alors que nous nous dirigeons vers le développement durable des ressources naturelles, ces nouvelles technologies d'observation de la Terre contribueront à la production d'une information à caractère économique, social, environnemental, stratégique et politique de grande valeur, dans la mesure où l'on poursuivra de façon soutenue le développement de la normalisation des données et de l'assurance de qualité.

1. INTRODUCTION



> **"Man must rise above the atmosphere and beyond to fully understand the world in which he lives."**
> **Socrates, 700 BC**

Our monitoring requirements and responsibilities as nations and as members of the global community continue to multiply. We have some powerful science and technology tools at our disposal. In many countries, government agencies in particular have growing traditions of excellence in developing applications that make use of space-based observations of the Earth. Space-based systems provide unprecedented synoptic and visual coverage of the Earth. Indeed, with the advent of satellite remote sensing technology, particularly weather satellites to begin with and images of the globe taken from Earth orbit and beyond, our thinking about the planet we live on has taken on a global perspective that was not possible in the past.

Much of the focus of these satellite sensor systems over the years to come will be on improving predictions of Earth system changes, both short-term and long-term, with considerable priority given to severe weather phenomena and disaster events. By enabling proactive predictions on the state of our world with respect to changes in climate, population growth, land transformation, pollution, and biodiversity, these systems will help provide more solid underpinnings for decisions that impact us all in terms of quality of life and economic consequences. A focus of immediate as well as longer-term interest to Canada is the improvement of natural resource management in the evolving framework of sustainable development. Sustainable resource management that seeks to safeguard the environment while deriving economic benefit necessarily requires information about past and current states of the geophysical and biospheric properties of the Earth.

There is a clear need for innovative data and methodologies that help support definitive and essential sources of information for sustainable development decision-making. This addresses the first output of the Earth Sciences Sector (ESS) Program on Geomatics for Sustainable Development of Natural Resources (GSDNR).

Ensuring that Earth observation data[1] can be used reliably and quantitatively by non-specialists in the government and private sectors alike requires the development and use of sensor characterization, data standardization and quality assurance processes built into product generation systems, including image calibrations and corrections developed by specialists. This too is in line with the GSDNR Program outcome to have ESS digital geospatial data acknowledged as a definitive and essential source of information for sustainable development decisions. Thus, with a view to illustrating the critical role that data standardization based on calibration and correction play in this context, this report presents a series of examples that demonstrate what happens to the information content of Earth observation products with and without proper characterization and correction.

Appendix 1 defines acronyms used in the report and Appendix 2 provides a glossary of key technical terms. Appendix 3 includes a general selection of publications that have a primary emphasis on remote sensing characterization and standardization.

"The science and technology associated with capturing advantage from spatial resource knowledge is internationally regarded as an integral part of the global knowledge economy."

Landcare Research
New Zealand

[1] The expressions "Earth observation" and "remote sensing" are used interchangeably in this report.

2. USER NEEDS

2.1 Land Surface Parameters

The establishment of monitoring frameworks for natural resource and environmental decision-support increasingly depends on retrospective temporal series of Earth observation satellite data. Thus, land satellite data requirements are driven to a significant extent by the need for long-term monitoring of land surface parameters to determine surface condition and to detect change, as well as inputs to regional and global carbon, energy, and water process models. An initial documentation of these requirements was made at a 1992 workshop of the International Satellite Land Surface Climatology Project (ISLSCP) (Sellers et al., 1995; Hall et al., 1995). A compilation of parameter requirements encompassed the parameters listed in Table 1 (Guenther et al., 1997). Spatial and temporal resolution requirements vary, ranging from 100 m to 100 km and from every 6 hours to annually, respectively. Specific accuracy requirements for these parameters were also defined at the ISLSCP workshop based on the sensitivity of models to the various parametric inputs. A full, end-to-end sensitivity analysis remains to be done to translate the parameter accuracy requirements into requirement specifications for remote sensing measurements. Similar user parameter requirements have been documented for oceans (e.g., sea surface temperature and ocean colour) and atmospheres (e.g., temperature, water vapour, precipitation, ozone, clouds and aerosols, radiation, and trace species) (Guenther et al., 1997).

Table 1. Parameter Requirements for Land Surface Condition, Change Detection and Ecosystem Modelling.

Vegetation:
- Cover type
- Phenology
- Fraction of absorbed photosynthetically active radiation (FAPAR)
- Leaf area index (LAI)
- Disturbance
- Biomass
- Net primary productivity

- Evapotranspiration
- Land surface temperature
- Near-surface meteorology
- Precipitation
- Albedo
- Radiation fluxes
- Energy balance
- Surface roughness
- Soil physics and chemistry
- Topography
- Runoff
- Snow and ice
- Fires and biomass burning

Monitoring by satellite sensors combined with networks of in-situ observations is the only feasible approach for the measurement and long-term monitoring of terrestrial parameters needed by decision makers and scientific investigators around the world. The challenge is to ensure that such measurements yield self-consistent and accurate geophysical and biophysical parameters over time and space, even though the measurements are made with a variety of different instruments under different observational conditions. Hence, data standardization and product validation are critical aspects of Earth observations if they are to show terrestrial processes as they really are and not compromised by sensor and data processing artefacts.

2.2 User Needs and Market Studies

2.2.1 Growing the Earth Observation Applications Market: A 1992 European Study

Sweet et al. (1992) conducted a study for the European Commission to identify research needs to encourage the growth of the Earth observation applications market. The study report concludes that the value of information from Earth observation data is limited by many bottlenecks, several of which are attributable to the lack of proper standardization and validation in diverse applications, including those central to natural resource management.

2.2.2 Calibration-Validation User Requirements: A 1996 Framework Study

A 1995 study of remote sensing market needs for the calibration-validation (cal-val) of remotely sensed data (Horler, 1996) concluded that Earth observation data are increasingly being used as inputs to information systems where the spatial and temporal continuity of consistent information is of primary concern. Such uses have inherent requirements for standardisation and data quality as conditions for enabling the adoption of the technology. Quantitative applications of Earth observation rely on conversion of the data to physical units in order to enable the comparison of data from different scenes and different sensors over time periods ranging from days to decades as well as automated information extraction, particularly in the context of change detection and analysis. The study report states that remote sensing will only become a mainstream information technology when it provides reliability of supply, consistent data quality, and plug-and-play capability. Consistent data quality implies the development and implementation of appropriate cal-val tools for use with advanced Earth observation technologies of interest to our user community.

2.2.3 Canadian Earth Observation Calibration-Validation: A Workshop Series

Three national workshops were held from 1996 to 1998 to help establish strategic priorities and plans for Canadian cal-val efforts from both technical and market perspectives (Horler and Teillet, 1996: Teillet, 1997; Teillet, 1998). Most pertinent to this report is the adoption of the perspective, at the first workshop, that cal-val is a quality assurance (QA) issue from the user's perspective and that QA is essential to bring remote sensing to mainstream customers. The second workshop concluded that ocean colour and ocean productivity applications of Earth observation data have been successful because they have made cal-val an integral part of mission operations and devoted the necessary resources and coordination efforts to assure success.

2.2.4 Supporting Sustainable Resource Management: A 2004 User Needs Study

A user needs study was carried out by Hegyi Geomatics International Inc. on "Alignment of Earth Observation Calibration and Validation Activities" (Hegyi, 2004). Based on the results of a survey, interviews and Internet research, the report concludes that there is a definite need, especially in government agencies, for characterization and standardization of Earth observation data in support of sustainable resource management. The applications that benefit the most are listed in Table 2 in order of importance. In this context, change detection refers to change detection and monitoring with respect to planned activities such as mining, reforestation and harvesting, as well as natural disasters such as fires, landslides and insect damage. The survey found that greater emphasis should be placed on consistency than absolute calibration, but some applications do require calibration that is certifiably traceable to the International System of Units (SI) standards.

Table 2. Applications that benefit the most from the standardization of Earth observation data.

- Land use mapping
- Change detection
- Resource inventories
- Map revision
- Agriculture

The survey also clearly indicated that ESS needs to be active in the following areas:

- Continued development of its expertise in the calibration and validation of satellite-based Earth observation data, but with a refocus on the key areas that directly support sustainable resource management.
- Provision of expert advice to users of satellite based Earth observation data on calibration and validation procedures.

The user needs study emphasises the value of taking the time to describe how and why characterization and standardization are essential if Earth observation products are to contribute to natural resources management. Although the study report states that it will show impacts on "downstream information", the report does not actually provide any examples in this regard. Hence, the present report on "Importance of Data Standardization for Generating High Quality Earth Observation Products for Natural Resource Management" is devoted to filling that gap.

2.3 The Chain from Space Data to User Information

As emphasized by MacDonald (1997), the user community is not interested in data but rather in information of economic, social, environmental, strategic, and political value, necessitating a strong chain linking data to information. Moran et al. (1997) have nicely portrayed the various links in the chain in the context of remote sensing in precision crop management (Figure 1). Data standardization, product validation and quality assurance play integral roles in strengthening the various links in the chain from remote sensing and other data to information of value to users and decision makers in many areas, including sustainable resource management.

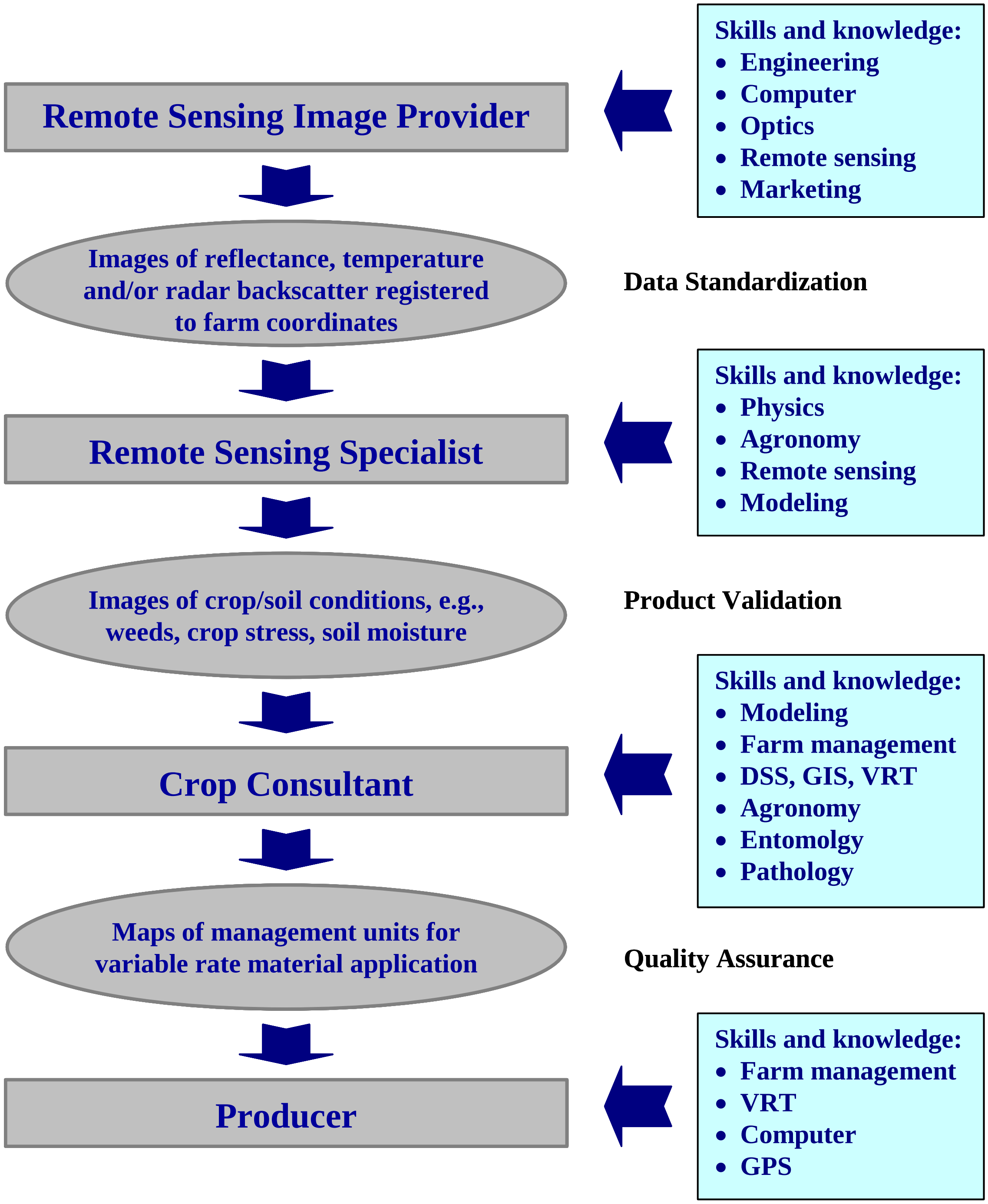


Figure 1. A schematic based on Moran et al. (1997) that shows the chain from remote sensing data to information for the example of precision crop management. DSS = decision support systems, GIS = geographic information systems, VRT = variable rate technology, and GPS = global positioning system. Data standardization, product validation and quality assurance come in at and strengthen various links in the chain.

3. DATA STANDARDIZATION

The nominal linkages between data standardization activities and sustainable development and natural resources communities are portrayed in Figure 2. There is seldom if ever a direct link between data standardization work and end users but the products and information required by the user community depend critically on the data standardization and QA having been done right. Thus, when new technologies come along, such as instruments that measure and monitor the Earth from space, sensor characterization and data standardization research must be undertaken to provide sound underpinnings for the new capabilities that result. Government programs and the geomatics industry are then well placed to build these new capabilities into their programs and innovations, leading to products and information that the user community is prepared to adopt.

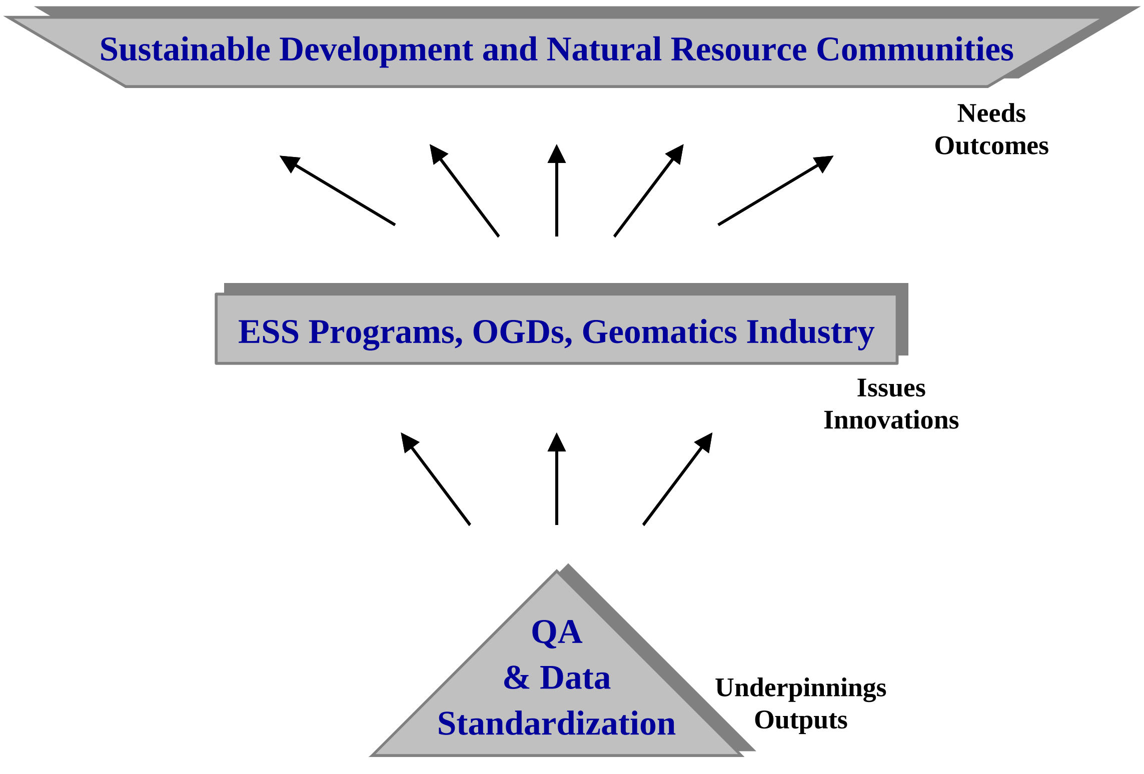


Figure 2. A schematic that shows the nominal linkages between data standardization / QA activities and the issues / innovations tackled by government and industry, who thence serve the sustainable development and natural resources communities. OGD = Other Government Departments.

There are many different aspects to consider in the world of characterization and standardization (Figure 3 lists a few). While this document is not intended to delve into the details of these different aspects, it is worth noting that they are important considerations for any measurement device, regardless of what part of the electromagnetic spectrum it covers (optical, microwave, or other) if it is to yield useful data and information.

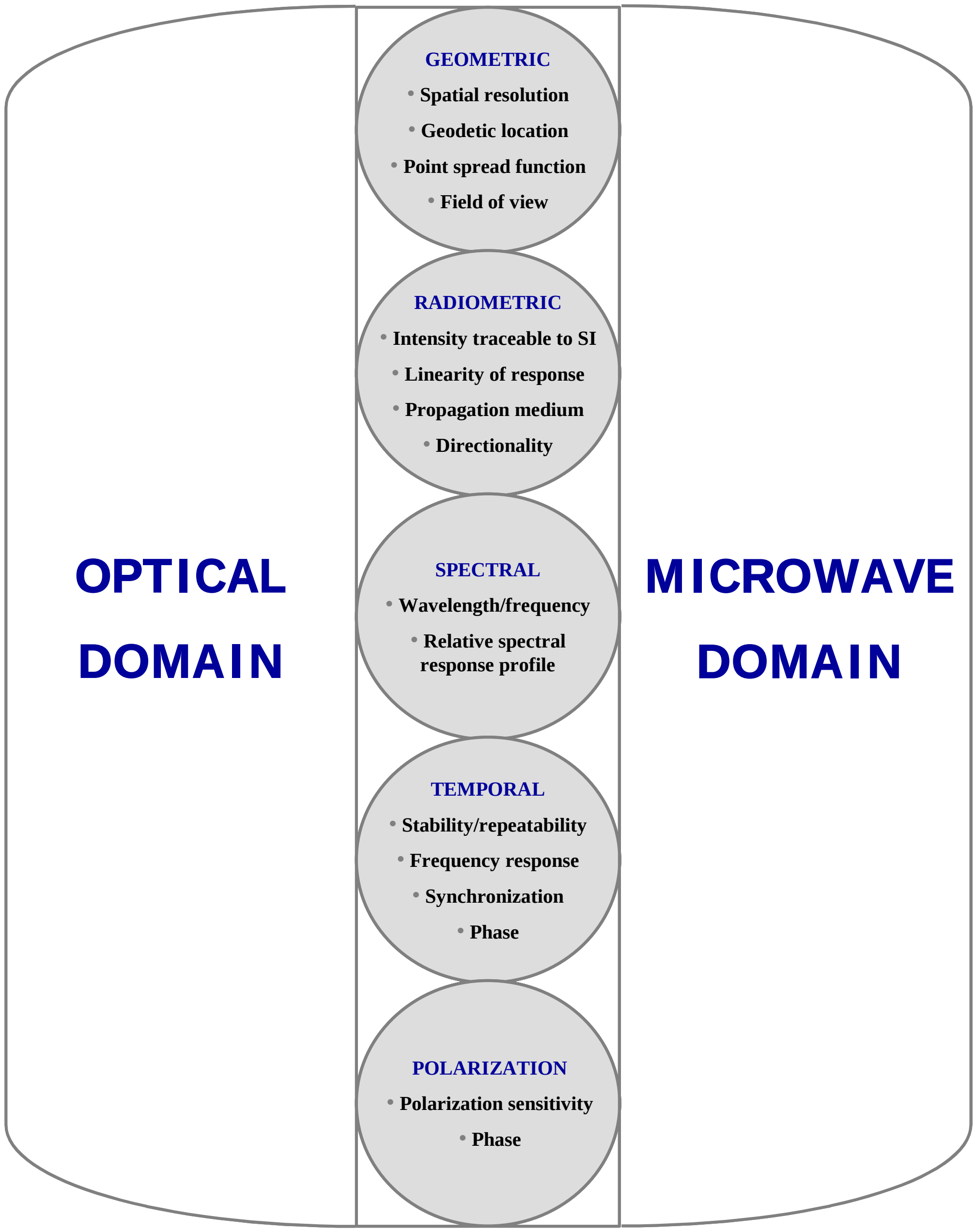


Figure 3. A schematic that shows some of the many physical domains involved in the proper characterization and standardization of Earth observation data whether it is in the optical domain or the microwave domain.

4. OPTICAL DOMAIN EXAMPLES

4.1 Mapping Biophysical Parameters for Modeling and Monitoring Vegetation

The sustainable development of natural resources necessarily requires the availability and use of appropriate tools and consistent data products for modeling and detecting change. In particular, a number of biophysical parameters are required for use in advanced models of climate, hydrology, biogeochemistry and ecology. These variables describe vegetation canopy structure and are related to functional process rates of energy and mass exchange. For example, leaf area index (LAI) and fraction of absorbed photosynthetically active radiation (FAPAR) are among the most widely used satellite-derived biophysical parameters, especially for calculation of surface photosynthesis, evapotranspiration, and net primary production. LAI is a biophysical parameter that has been extensively examined for its contributions to routine and even automated estimation from remotely sensed measurements. Today, maps of LAI and FAPAR are regularly produced in Canada using vegetation indices derived from Landsat imagery in conjunction with ground validation data**.** A wide variety of government agencies, university research groups and value-added companies make use of LAI in particular in their work. An example of a close CCRS collaborator in this domain has been and continues to be the Canadian Forest Service (CFS). Although the main workhorse continues to be Landsat, data from multiple satellite systems can be utilised for this purpose provided they are inter-calibrated. Figure 4 presents an example of the impact on Landsat-based estimates of LAI if the sensor radiometric calibration coefficients are not kept up to date.

One-third of the issue-driven Programs of ESS are making use of Landsat data to achieve their results. Radiometric and geometric calibration algorithms have been implemented in Landsat product generation systems in use in Canada and around the world. With ongoing calibration over the lifetime of the mission, Landsat capability makes it possible to examine a continuous, near-global data set reaching back to 1984 with a view to monitoring global and regional land dynamics at a 30-m scale where both natural and anthropogenic disturbances can be assessed.

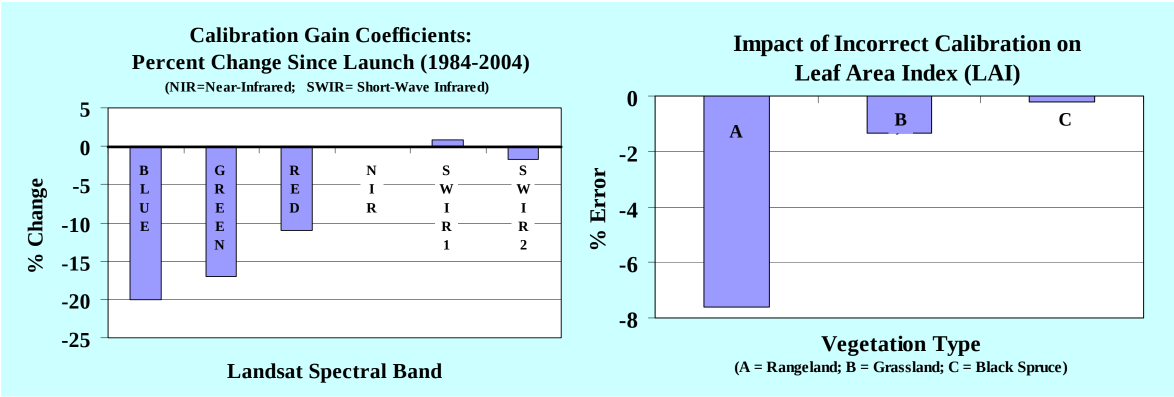


Figure 4. The left-hand chart shows the difference between using prelaunch instead of updated post-launch calibration coefficients for the indicated Landsat spectral bands. The right-hand chart shows the impact of not taking these Landsat calibration changes into account on satellite-based estimates of leaf area index for the indicated vegetation types.

4.2 Mapping the Land Cover of Canada

Cihlar et al. (2003) note that a nationally consistent map portraying the distribution of land cover at the Landsat scale (30 m) is a relatively recent but urgent requirement for various scientific, policy, and reporting purposes. Examples of areas that have a central need for national land cover information include land cover and land use assessment, carbon balance modeling and reporting, forest inventory, biodiversity, and water quality modeling. A major target user is Statistic Canada for national statistical reporting of various kinds and for the Crop Condition Assessment Program (CCAP). Environment Canada also uses national land cover and land cover change in reports to the United Nations Framework Convention on Climate Change and with respect to the Kyoto Protocol. Cihlar et al. note that the key to an effective approach to mapping land cover in Canada is an increase in the ratio of computer to human processing and analysis for high data volumes or large geographical areas without affecting product quality as a result of the greater reliance on automation. One of the main steps in generating regional image mosaics for input to a land cover classification algorithm is the radiometric normalization of satellite images to a common scale to achieve good quality, seamless outputs. In particular, apart from sensor calibration issues mentioned in the previous section, uncertainties in satellite-derived quantities can arise because of variations in atmospheric conditions on different image acquisition days and also because satellite measurements are subject to the anisotropy of terrestrial surface reflectance as a function of illumination and viewing geometries. For land cover mapping of Canada, for example, atmospheric aerosol haze corrections (illustrated in Figure 5) and compensation for reflectance anisotropy effects (Figure 6) ensure consistency among the component scenes and are integral parts of the methodology and automated processing algorithms. Without such corrections, errors in land cover mapping and other derived products can reach 20 percent or greater.

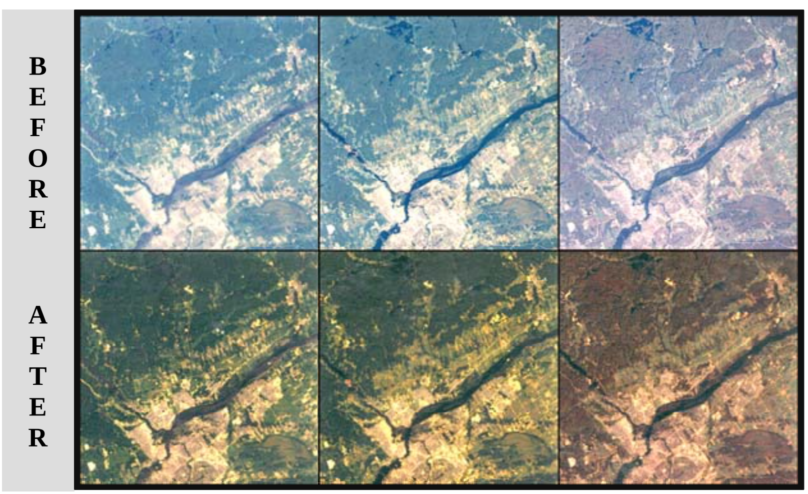


Figure 5. Landsat Thematic Mapper (TM) scenes of the Ottawa, Ontario, region before (top row) and after (bottom row) atmospheric correction (Teillet and Fedosejevs, 1995). Both before and after TM images are rendered on the same 8-bit scale in the blue, green, and red spectral bands, respectively. The three dates ranged from June to September over a five-year period and were characterised by significantly different sun angles and atmospheric aerosol haze conditions.

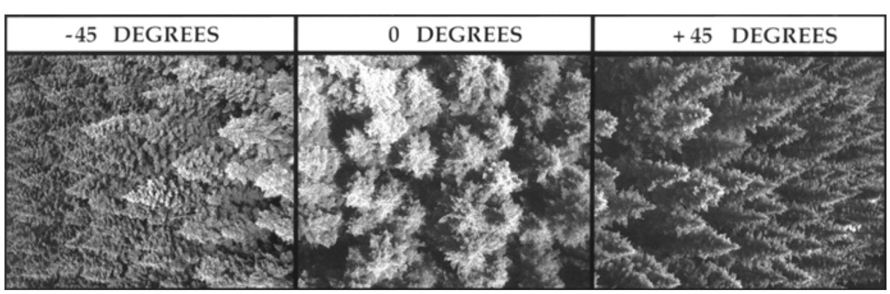


Figure 6. Digital images of the <u>same</u> black spruce canopy, taken at the indicated angles from a truck-based platform, showing the effect of reflectance anisotropy (solar illumination is from the right).

4.3 Mineral Mapping for Exploration Purposes

The identification and mapping of minerals for exploration purposes has increasingly benefited from the use of hyperspectral remote sensing (Huntington et al., 1989; Neville et al., 2003; Clark et al., 2003). The principal target communities are the mining industry (e.g., Falconbridge and Noranda) and the ESS Northern Resources Development (NRD) Program, which use hyperspectral data for large-scale lithological mapping in the Canadian north. The same technology is used to map mine tailings in the ESS Sustainable Development Through Knowledge Indicators (SDKI) Program. Outputs include acidity maps that are useful to Inco, the City of Sudbury, the Canadian Nuclear Safety Commission (CNSC), etc. Other targeted communities include data providers (e.g., Borstad and Associates, Earth Search Sciences Inc.) and firms that commercialize the data correction procedures (PCI and Atlantis Scientific). Hyperspectral remote sensing is a powerful technology because it produces a reflectance spectrum for every pixel in the image, offering the potential to identify and map every substance on the surface of the Earth. The realization of this potential requires the appropriate sensor characteristics coupled with the commensurate image data processing. To achieve the necessary image quality, the main data processing challenge is to ensure that the sensor data are calibrated spectrally, radiometrically, and geometrically, and that they are free of sensor-introduced artefacts. One must also compensate precisely for the atmospheric effects (Staenz and Williams, 1997). These two tasks are particularly demanding in the hyperspectral domain and hence are the subject of ongoing research and development.

Almost all hyperspectral data used for mineral mapping have been acquired using airborne sensors. However, there is now a satellite instrument, Hyperion, a technology demonstrator with limited coverage capabilities that is collecting data sets for development purposes (Pearlman et al., 2003). Cuprite, Nevada is the location of a hydrothermal alteration zone that is being used as a test site for this technology (Swayze et al., 1992; Kruse et al., 2003). Figures 7a and 7b display red-green-blue (RGB) image maps of the results of the use of Hyperion data of Cuprite to identify and map minerals, in particular alunite (red), kaolinite (green), and muscovite (blue). For Figure 7a the data have undergone a number of ‘preprocessing’ steps to correct calibration errors and to eliminate sensor artefacts (Neville et al., 2003 and 2004; White et al., 2004); for Figure 7b these steps have been bypassed. The data in both cases were analysed using spectral unmixing, a technique for identifying and mapping the abundances of the materials in a hyperspectral scene. Only the image map in Figure 7a shows good agreement with the US Geological Survey mineral map in Figure 7c (USGS, 2004). Clearly, one cannot produce a reasonable map without image preprocessing.

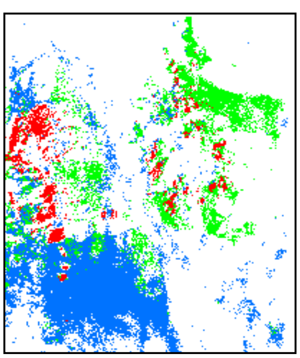


Figure 7a. Mineral map of three minerals at Cuprite, derived from preprocessed Hyperion hyperspectral image data (30 metre resolution).

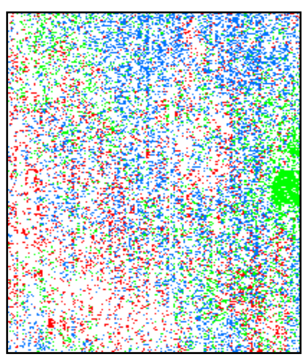


Figure 7b. Mineral map of three minerals at Cuprite, derived from Hyperion data provided by NASA.

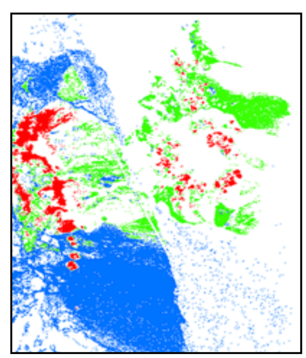


Figure 7c. Mineral map derived by USGS using high-resolution airborne (AVIRIS) data, with subsequent ground validation (20 metre resolution).

4.4 Plant Liquid Water for Crop Vigour Assessment

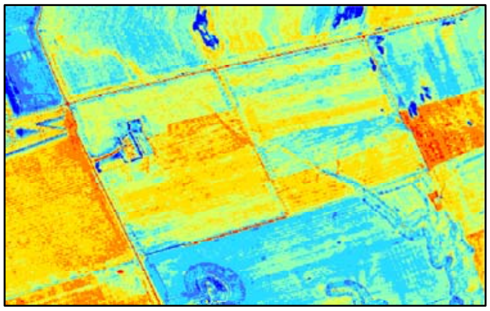


Figure 8a. Plant equivalent water thickness derived using the data as supplied by the data provider.

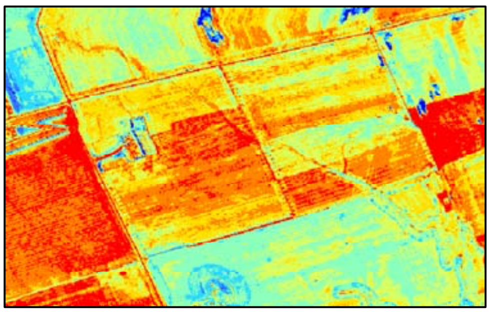
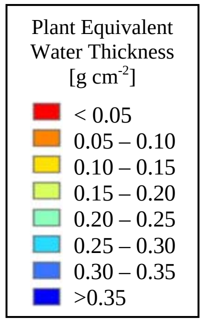


Figure 8b. Plant equivalent water thickness derived after applying radiometric correction factors to the image data.



Spatial and temporal information on crop vigour, combined with variable rate fertilizer (VRT) application equipment, allows producers to optimise costly fertilizer and pesticide utilization, resulting in lower production costs and reduced environmental impact. The high precision of this approach to agricultural production requires highly accurate information inputs (Champagne et al., 2003), including hyperspectral image data sets that are radiometrically accurate. Figure 8 shows maps of one of the crop vigour factors, plant Equivalent Water Thickness (EWT), for an agricultural region in southern Saskatchewan. Targeted users of plant EWT include the National Environmental Health Program of Agriculture and Agri-Foods Canada (AAFC), the Indian Head Agricultural Research Foundation, companies such as Noetix, and the ESS SDKI Program and its collaborators (e.g., City of Sudbury, Ontario Ministry of Environment). For SDKI, plant liquid water is an important stress indicator for monitoring and assessing the impact of mine activities on surrounding vegetation.

Figures 8a and 8b show the plant EWT map before and after radiometric correction, respectively. Without correction the resulting map is in error by over 100 % on average, a very significant error if this information is to be used for production modelling. The results of the ground validation for both of these image maps are shown in Figures 9a and b. Here the quantitative EWT estimates derived from the hyperspectral data are plotted versus laboratory EWT measurements using field biomass samples. These show that the values derived from the uncalibrated data are too high by >0.05 g cm^{-2}. While this example pertains to agricultural crops, the same measure of plant vigour is applicable to all terrestrial vegetation, including forests.

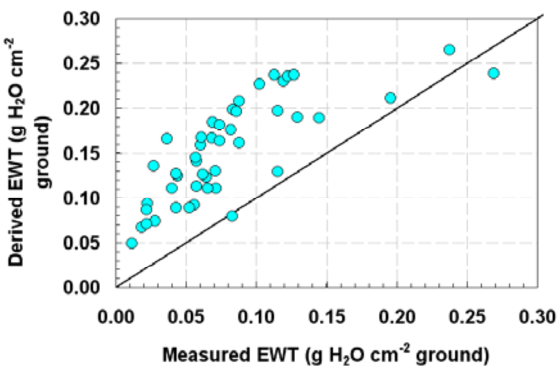


Figure 9a. Equivalent Water Thickness (EWT) derived from uncalibrated image data versus actual EWT measured from harvested biomass.

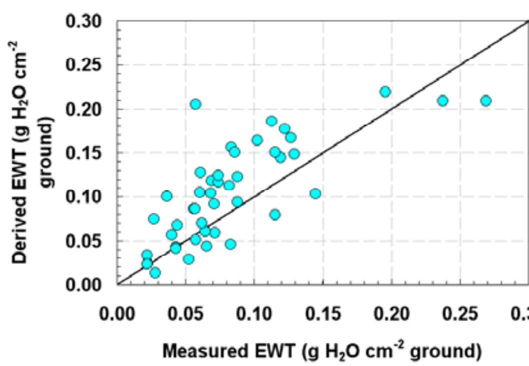


Figure 9b. Equivalent Water Thickness (EWT) derived from calibrated image data versus actual EWT measured from harvested biomass.

4.5 Canada's Stewardship Agenda and Water Resource Management

Borstad and Associates Ltd notes that "Canada's Stewardship Agenda (www.stewardshipcanada.ca) recognizes the need for a more integrated, ecosystem-based approach to landscape and water resources management. The agenda is a federal-provincial-territorial initiative based on consultations involving industries, landowners, communities and environmental organizations across the country. … There is a growing recognition that resource mapping and meteorological satellites can provide a unique, cost-effective source of data. … Image maps are particularly good at showing the drama and impact of land use changes. … There is also agreement that the basic geographic unit should be the watershed."

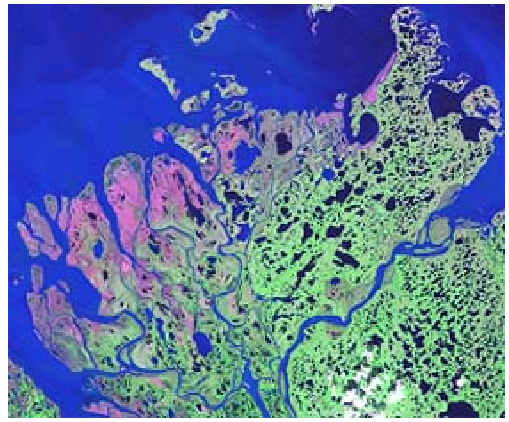


Figure 10. Mackenzie River estuary.

Ideal data to address the watershed management issue would come from frequent repeat coverage of large areas with high spatial resolution, multispectral imagery. Failing this ideal, the best available data are easily accessible through a huge archive of satellite imagery spanning over 30 years of data reception and maintained by Natural Resources Canada. A new methodology for processing Landsat imagery from this archive that circumvents traditional access and geocoding difficulties has been developed and validated. It is capable of handling multiple satellite passes, each containing multiple scenes, and results in an image product that has uniformly distributed sub-pixel registration errors and that makes accurate wide area watershed comparison and monitoring possible. This development offers a look into the past to establish baseline and vital trend information through time-series image comparisons. Figure 10 shows the result of this process for the Mackenzie Delta region. It features a sub-scene extracted from a larger mosaic, consisting of three Landsat-7 satellite passes each containing three scenes, that was widely lauded by northern stakeholders, including environmental, land use, aboriginal and energy industry groups.

In Figure 10, there are numerous water bodies and river channels that require accurate measurements for ecological studies. Geometric registration accuracy is one of the most important attributes of image maps in applications such this. More specifically, sub-pixel registration between time-series images is an absolute requirement for the reliable detection of changes. The delineation of water body boundaries involves pixel-level decisions and the consequences of pixel positioning errors can be significant. The Mackenzie Delta area contains many water bodies with, for example, a surface area of 100 km^2. A geometric registration error of one Landsat panchromatic pixel (15 m) between two Landsat images of such a water body would result in the false detection of an apparent surface area change of 0.5 % for each such water body. Since actual changes are expected to be this amount, change estimation could be off by 100 %.

Other watershed management applications include compliance monitoring of buffer zones to alleviate nutrient contamination of rivers and creeks by intensive agriculture involves change detection analysis with similar accuracy implications. The establishment of these buffer zones has become an indicator of environmentally sound farm management practices.

5. MICROWAVE DOMAIN EXAMPLES

5.1 Monitoring Acid Mine Drainage Impact on the Surrounding Environment

There is increasing interest in site characterization of mine tailings and mining-affected areas (Touzi et al. 2004a). Target communities for ESS Programs (Sustainable Development through Knowledge Integration and Minerals in the Environment) include the City of Sudbury, the Ontario Ministry of Mines and Northern Development, and the Ontario Ministry of Environment. In this type of work, accurate terrain elevation data are a critical requirement for a variety of uses. For example, digital elevation models (DEMs) are used in the Sudbury area for modelling re-vegetation and mapping baseline information on watershed divisions for use in modelling contaminant flows in the region. This latter information is important for assessing the health of drinking water and the safety of lakes used for recreation, and is of great interest to the municipal planning offices of the City of Greater Sudbury. Accurate DEMs are also needed to plan drainage networks for areas affected by acid mine drainage, such as the abandoned tailings dump at KamKotia near Timmins, Ontario and to provide baseline information to monitor the progress of reclamation efforts, being led by the Ontario Ministry of Mines and Northern Development.

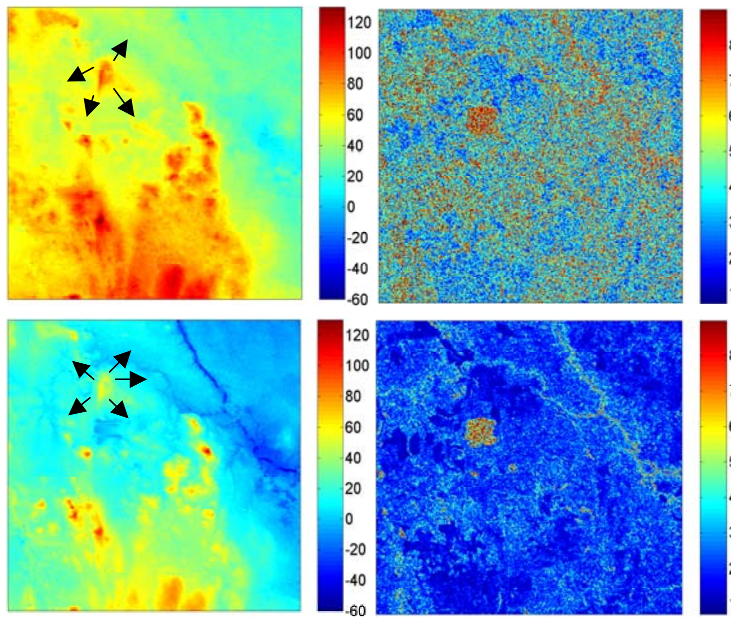


Figure 11. Digital elevation maps (left) for the region surrounding the abandoned KamKotia mine based on uncalibrated (top) and calibrated (bottom) RADARSAT-2 SAR image data. The arrows indicate the drainage pattern. The images on the right represent DEM precision extracted from the uncalibrated (top) and calibrated (bottom) cases.

The synthetic aperture radars (SARs) on the Canadian satellite RADARSAT-2 and the Japanese Advanced Land Observation Satellite (ALOS) will have the capability of measuring both phase and polarization information such that accurate and detailed DEM products (1 metre vertical resolution, 9 metres horizontal resolution) can be generated using the phase path difference of the radar wave scattered by the illuminated target. This will not work without polarization calibration. The necessary calibration methods are being developed in the ESS GSDNR Program for calibration of both RADARSAT-2 and ALOS SARs (Touzi et al., 2003; Touzi et al., 1993; Touzi et al., 2004b). An example is presented in Figure 11, which shows a DEM generated from uncalibrated and calibrated versions of a simulated RADARSAT-2 SAR image based on airborne SAR imagery collected over the KamKotia abandoned mine site. The uncalibrated RADARSAT-2 data yielded a DEM with significantly lower precision and significant bias errors (30 to 40 metres).

5.2 Coastal Zone Wetland Monitoring and Accurate Sea-Land Discrimination

A large percentage of the world's population and industrial activity is concentrated in coastal regions. These environmentally sensitive areas are under intense pressure from natural processes, urban growth, resource development, and pollution. These events, originating from both anthropogenic and natural sources, are highly dynamic and hence best monitored via synoptic satellite coverage. Among the various satellite imaging systems available, those with synthetic aperture radars (SAR) are particularly helpful in coastal areas because they provide reliable monitoring independent of light and weather conditions. Coastal zone monitoring applications of RADARSAT SAR imagery include monitoring of land-use and land-use change, ship surveillance for sovereignty control and fisheries management, detection of oil slicks due to shipping accidents and natural oil seeps, flood monitoring, ocean feature detection, and coastal mapping.

Canada, which has one of the longest coastlines in the world, adopted a Law on Oceans to develop a national management and monitoring strategy for marine and coastal ecosystems. Wetland monitoring is a particular interest in this effort. The principal target communities are the Canadian Wildlife Service of Environment Canada, Ducks Unlimited, and Fisheries and Oceans Canada. The same technology is used in several ESS Programs for wetland inventory mapping, measurement of wetland indicators, and monitoring of mine tailing effects on surrounding wetlands. Also targeted are firms such as Geomat International, Noetix, Radarsat International (RSI), PCI and Atlantis Scientific.

The following RADARSAT example concerns a tidal marsh wetland in the Montmagny area of Quebec along the Saint-Lawrence River. The topography is nearly flat and there is a high tidal amplitude range (4 to 6.6 metres) and there are extensive tidal marshes. At low tide, mud flats can reach over one kilometre wide. Providing access to the major ports and cities of Quebec and Ontario, the Saint-Lawrence River is an intensive commercial navigation route subject to major deposit build-up problems and requiring lots of dredging to maintain its usability by heavy tonnage commercial ships. The area is also an important migratory bird reproduction sanctuary. Figure 12 shows a simulated RADARSAT-2 SAR image of the Montmagny area, with and without calibration, used to map the spatial extent of tidal marsh wetlands (Touzi et al., 1999; Thibault et al., 2002). To the users involved, the arrows in the calibrated image indicate a clear presentation of tidal marsh wetlands that have shallow water and levels that usually fluctuate daily, seasonally and annually due to tides, flooding, groundwater recharge and/or seepage losses. Significant errors in the spatial wetland extent are introduced when uncalibrated data are used.

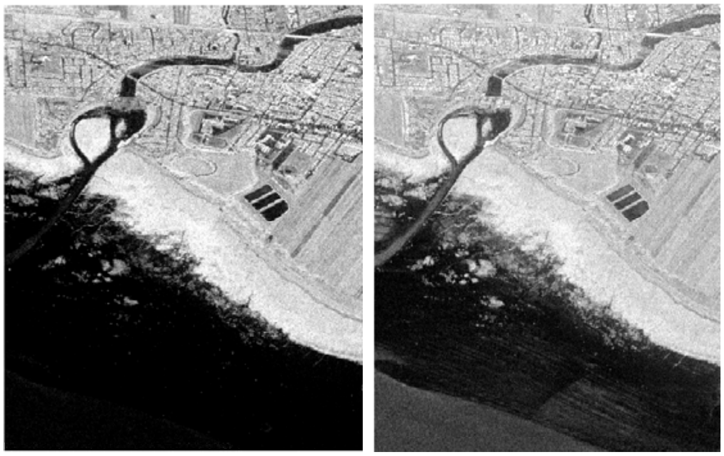


Figure 12. Simulated RADARSAT-2 uncalibrated (left) and calibrated (right) SAR image of Montmagny, September 8, 2001. The arrows indicate the tidal marsh wetlands, which are properly delineated only in the calibrated case.

5.3 Ice Classification and Interpretation in Petroleum Exploration Areas

RADARSAT-1 was born out of the energy crisis of the 1980s when energy development in Canada's offshore required a surveillance tool sensitive to ice and water, and with all weather, day or night imaging capability. Navigation and exploration in the ice-infested waters of the Beaufort Sea and in the Hibernia areas are particular examples. Research and development at Natural Resources Canada (Gray, 1982) during this period demonstrated that synthetic aperture radar (SAR) could meet this need as well as other applications (Henderson and Lewis, 1998) relating to the management and stewardship of Canada's vast array of natural resources. Indeed the largest single customer of RADARSAT-1 image data is the Canadian Ice Service (http://ice-glaces.ec.gc.ca/), which operationally collects and analyzes data, and disseminates the resulting ice information for Canada's internal and coastal waterways. It will continue to be a large user of RADARSAT-2 imagery. Moreover, most Government departments will be apportioned very significant levels of RADARSAT-2 SAR data. The ability to follow changes in resource development and depletion using radar remote sensing, especially in the energy sector, will depend critically on the provision of consistently processed and calibrated products.

Figure 13 shows one of the feature modes of RADARSAT-1 known as ScanSAR that allows wide area coverage (up to 500 km swath) appropriate for sea ice surveillance by stitching up to four smaller beams together. This is a very valuable mode but it is particularly delicate in that the beam boundaries are highly dependent on accurate systematic corrections. At the top is an image acquired January 30, 1997 off the coast of Labrador that has had these corrections poorly applied and at the bottom is the same acquisition in which these corrections are optimally applied. The image artefacts in the uncorrected image can stymie human ice interpreters and computer algorithms that rely heavily on continuity across these boundaries. Controlling such image artefacts has been a challenge throughout the RADARSAT-1 mission and has also been an issue for the Envisat Advanced SAR (ASAR) product generation system and a design issue for RADARSAT-2 SAR product generation system.

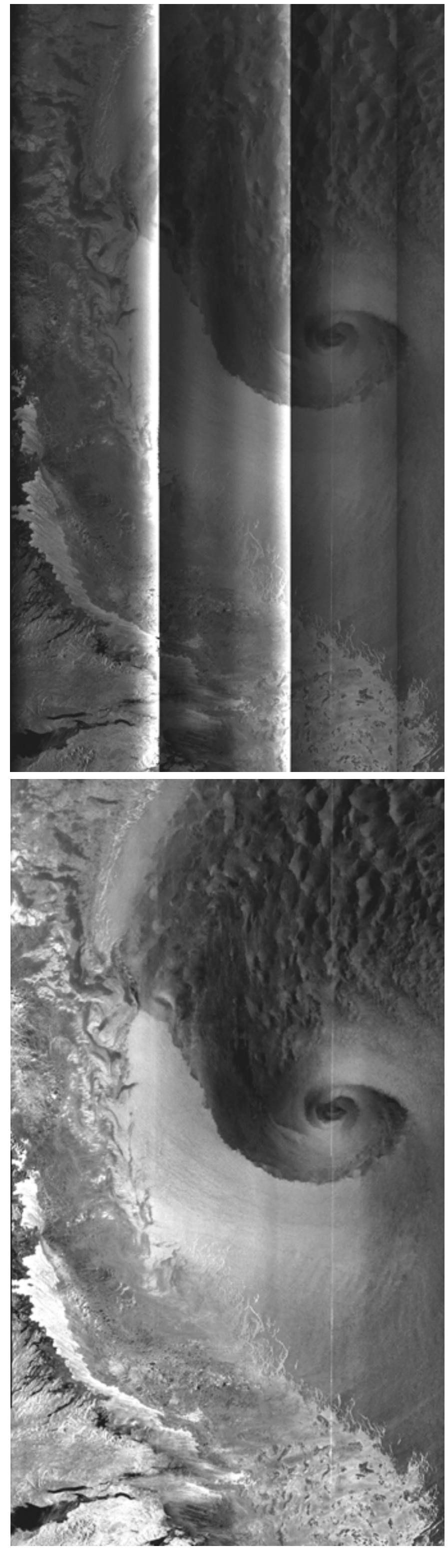


Figure 13. A RADARSAT-1 ScanSAR image acquired January 30, 1997 off the coast of Labrador with inadequate corrections (top) and optimal corrections (bottom). In this case, a three-beam mode was employed.

5.4 Wind Farm Site Selection Using Ocean and Coastal Wind Fields

Wind farms located offshore may prove to be a very significant supply of renewable energy that could be harvested in many regions. On October 5, 2004, the Federal Government in its Speech from the Throne declared its support for the development of 4,000 MW of wind energy in Canada, thus quadrupling the federal Wind Power Production Incentive's (WPPI) original target of 1,000 MW. The very next day, Hydro-Quebec awarded $1.9 billion in wind-power projects (990 Megawatts) to two groups: Cartier Wind Energy and Northland Power Income Fund. One of the problems associated with determining potential wind farm locations is the cost involved to accurately measure winds at a high enough spatial resolution over a long enough period of time (typically one year). Satellite SAR imagery is being used by a variety of agencies in Canada and elsewhere to generate wind fields at high spatial resolutions at any ocean or coastal location worldwide. For example, Helimax Energy Inc. of Montreal has used CCRS software and RADARSAT-1 SAR imagery to generate ocean wind fields off the Gaspé Peninsula. These products reduce the costs associated with the selection of appropriate wind farm sites. To generate valid and accurate ocean wind fields from a SAR image, a radar cross-section image product (i.e., a calibrated product) must be used together with the proper geometry in an appropriate wind retrieval model validated using in-situ data (Figure 14). The uncalibrated image product has an undesirable radiometric roller-coaster effect and the wind speed differences are readily observed (Figures 14 and 15).

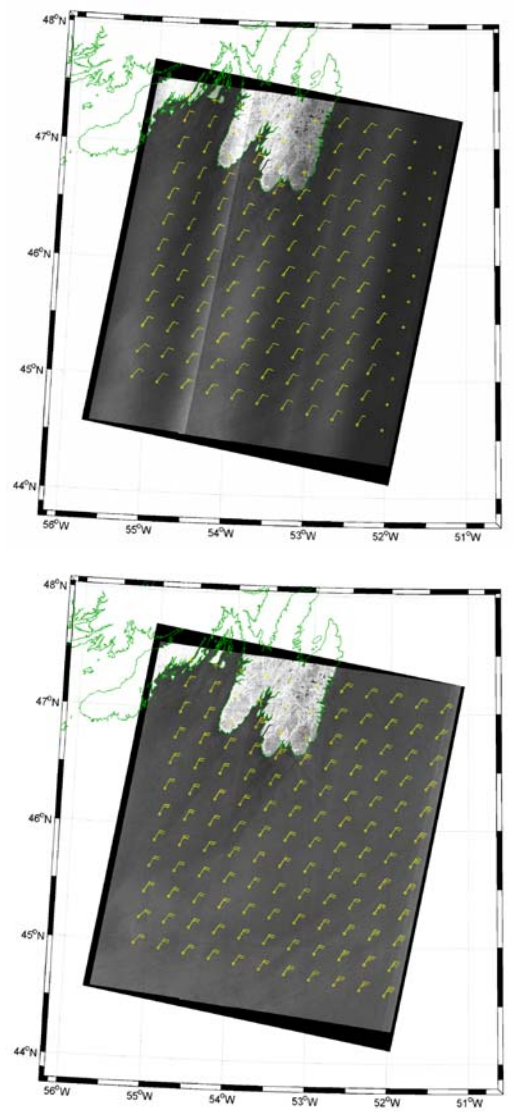


Figure 14. Wind fields generated for an uncalibrated (top) and a calibrated (bottom) RADARSAT ScanSAR product acquired off Newfoundland on March 21, 2000. Wind barbs, depicted as yellow symbols, indicate the wind speed and direction estimated from the SAR imagery. To interpret the wind barbs: the circle identifies the location for the wind speed estimate; the line pointing to the circle indicates the direction the wind is coming from; of the speed indicator lines, each short line indicates 5 knots, each long line indicates 10 knots, and a flag indicates 50 knots.

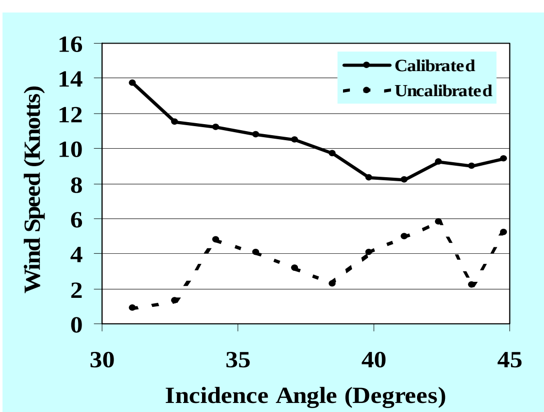


Figure 15. Full range-swath plot of wind speed versus incidence angle, illustrating difference between an uncalibrated and a calibrated RADARSAT-1 product.

5.5 Monitoring of Ice Conditions on the Athabasca River

The monitoring of river ice conditions and ice break-up in fresh water regions of Canada is important for a variety of reasons. Direct and indirect impacts on sustainable development of natural resources in particular cover a diverse range including transportation corridors (ice roads, water ways), damage to riverine ecosystems and fish stocks, and water supply and discharge for industrial and power generation operations. As an example, BC Hydro uses information on river ice conditions to optimise hydroelectric revenue and operate its facilities safely. Emergency response agencies in populated areas (e.g., Fort McMurray, Alberta; Badger, Newfoundland; Saint-Anne-de-Madawaska, New Brunswick) also benefit from ice condition monitoring. The Government of Newfoundland and Labrador recommends the use of remote sensing for this purpose. Flooding damage due to ice jams on the Saint-John River were estimated to be $30 million in 1987 (Humes and Dublin, 1988).

Spring ice conditions on the Athabasca River at Fort McMurray, Alberta have been monitored traditionally by means of visual observations from a lookout and aircraft. SAR images present a potential alternative source of information that is more accurate, more economic and more versatile. SAR image classification to map ice types and ice break-up relies critically on proper data standardization, in particular radiometric calibration to retrieve radar backscatter coefficients. The histograms in Figure 16 illustrate the differences in river ice backscatter coefficients retrieved from uncalibrated and calibrated versions of an Envisat Advanced SAR (ASAR) image in vertical-vertical (VV) polarization. To facilitate the comparison, an offset of 55.8 dB in the backscatter coefficient as retrieved from the two data sets was rectified. In Figure 17, both radar backscatter images have been classified into areas of various cover types (from high values for consolidated ice to low values for open water). To allow for classification of the uncalibrated image, the observed +55.8 dB backscatter offset was corrected. Nonetheless, interpretation of the image map based on the uncalibrated data would lead to erroneous conclusions and decisions.

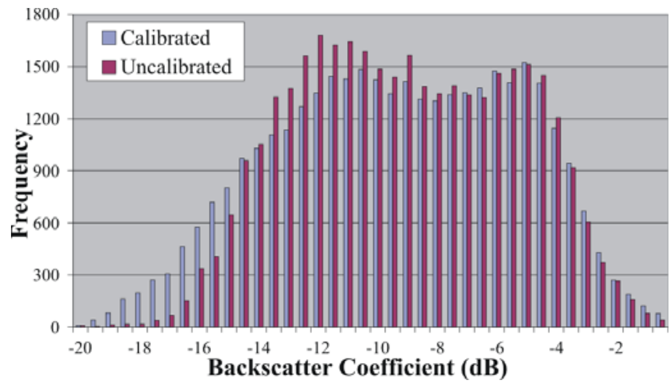


Figure 16. Histograms illustrating the difference between calibrated and uncalibrated radar backscatter coefficients for a section of river ice in the Athabasca River. To facilitate the comparison, a 55.8 dB offset between the two data sets was rectified.

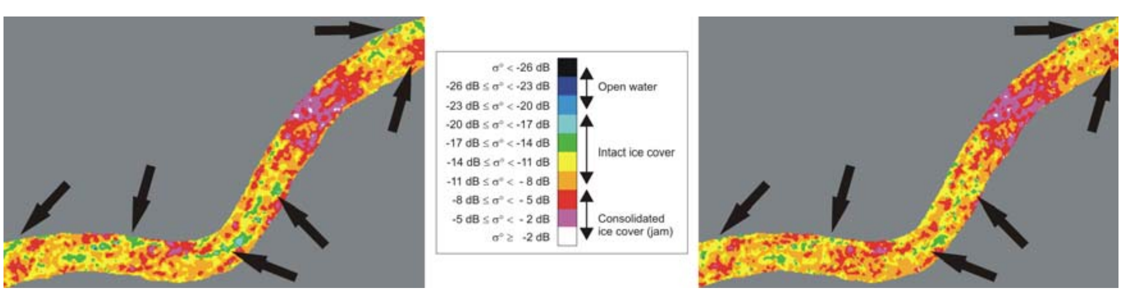
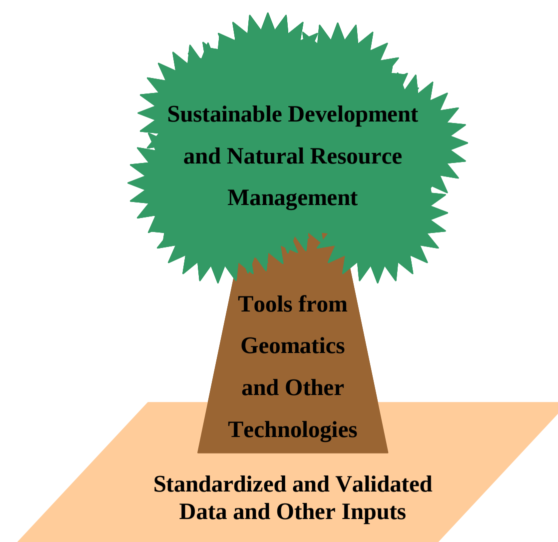


Figure 17. Ice cover type classification based on an uncalibrated (left) and calibrated (right) SAR image of an area of the Athabasca River. The arrows mark locations where differences between the two classifications are most obvious. To enable classification of the uncalibrated data, a backscatter offset of +55.8 dB had to be rectified.

6. CONCLUDING REMARKS

Canada has a vast land mass endowed with many resources. Consequently, Canadians have a vested interest in the improvement of natural resource management in the evolving framework of sustainable development. Sustainable resource management that seeks to safeguard the environment while deriving economic benefit necessarily requires information about the geophysical and biospheric properties of the Earth. In particular, the establishment of monitoring frameworks for natural resource and environmental decision-support increasingly depends on physically consistent temporal series of Earth observation satellite data and the associated methodologies, which the ESS Program on Geomatics for Sustainable Development of Natural Resources (GSDNR) is seeking to put in place. Innovative work on remote sensing data standardization is leading to appropriate techniques and methodologies for improved characterization of the Canadian land mass and the integration of basic geospatial information to support sustainable development, a key output of the ESS Program on GSDNR. The intended outcome is more efficient and effective decision making by communities, industry and sustainable development policy organizations involved in the sustainable development of natural resources.

However, the extent to which data acquired by space-based measurement systems can provide reliable and valuable information depends critically on independent measurements carried out at the surface and quality control activities behind the scenes. Indeed, in the early twenty-first century, innovation in Earth observation as well as the sub-field of data standardization requires making judicious choices. As molecular biologist Seymour Benzer once stated, “Subjects kill themselves off by their successes. … They are thriving but not at the cutting edge of intellectual advance. A student can take a course, train to fit in; it’s a discipline like every other. Adventurous minds look for somewhere else to go.” Thus, as Earth observation technologies approach adoption by mainstream information society, there is a risk that insufficient attention is paid to the details that ensure data quality and useful product validation to underpin sound



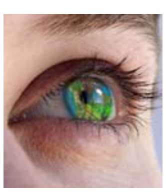
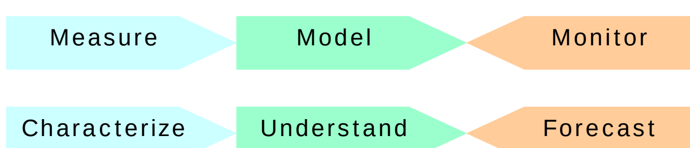
decision making. Without these quality assurance efforts, the technology will not deliver the whole product that is needed to create the compelling value proposition that can win over markets. Innovations in data standardization are all the more important with respect to the newer Earth observation technologies such as hyperspectral and radar remote sensing that are of particular interest for Canadian applications development.

This report is devoted to the presentation of examples that illustrate, without a lot of technical details, the importance of data standardization in the generation of high quality Earth observation products with particular emphasis on natural resource management. The examples presented concern the following applications:

- Mapping biophysical parameters for modeling and monitoring vegetation
- Mapping the land cover of Canada
- Mineral mapping for exploration purposes
- Plant liquid water for crop vigour assessment
- Canada's Stewardship Agenda and Water Resource Management
- Monitoring acid mine drainage impact on the surrounding environment
- Coastal zone wetland monitoring and accurate sea-level discrimination
- Ice classification and interpretation in petroleum exploration areas
- Wind farm site selection using ocean and coastal wind fields
- Monitoring of ice conditions on the Athabasca River

The examples encompass both optical and microwave image data. In each case, the impact of not taking the extra steps of data characterization and standardization prior to or during product generation, including a variety of calibration steps, is provided in quantitative terms with respect to the products used for natural resource management of various kinds.

Geospatial information needs are growing dramatically, in government and private agencies alike. Many if not most Earth observation applications have advanced to the point where high quality digital image products are essential for success. Raw or uncorrected imagery can no longer be used to provide meaningful information for natural resource management. At the same time, satellite sensor systems and image information extraction methodologies are advancing rapidly in quality and quantity. These new Earth observation technologies can contribute information of significant economic, social, environmental, strategic, and political value provided developments in data standardization and quality assurance keep pace.

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APPENDIX 1: ACRONYM DEFINITIONS

AAFC	Agriculture and Agri-Foods Canada
ALOS	Advanced Land Observation Satellite
ASAR	Advanced Synthetic Aperture Radar
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
CCAP	Crop Condition Assessment Program
CCRS	Canada Centre for Remote Sensing
CFS	Canadian Forest Service
CNSC	Canadian Nuclear Safety Commission
DEM	Digital Elevation Model
DSS	Decision Support Systems
ESS	Earth Sciences Sector
EWT	Equivalent Water Thickness
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
GIS	Geographic Information System
GPS	Global Positioning System
GSDNR	Geomatics for Sustainable Development of Natural Resources
ISLSCP	International Satellite Land Surface Climatology Project
LAI	Leaf Area Index
NASA	National Aeronautical Space Administration
NRD	Northern Resources Development
OGD	Other Government Departments
QA	Quality Assurance
RGB	Red – Green - Blue
RSI	Radarsat International
SAR	Synthetic Aperture Radar
SDKI	Sustainable Development Through Knowledge Integration
SI	International System of Units
USGS	United States Geological Survey
VRT	Variable Rate Technology
VV	Vertical – Vertical (polarization)
WPPI	Wind Power Production Incentive

APPENDIX 2: GLOSSARY

Calibration: The process of quantitatively defining the system response to known, controlled signal inputs.

Data Preprocessing: Those procedures required to correct the data for spectral misalignment, spatial misregistration, sensor random noise, sensor fixed-pattern noise (striping), and radiometric miscalibration.

Equivalent Water Thickness (EWT): The hypothetical thickness of a sheet of liquid water equivalent to the water in the target.

Hyperspectral Remote Sensing (Imaging Spectrometry): An instrument that measures electromagnetic radiation in many narrow contiguous, inherently registered spectral bands.

Radiometry: The science of measuring the electromagnetic energy emanating from a unit surface area, into a unit solid angle, per unit time.

Spectral Unmixing: The analysis procedure used to determine which materials are contained in a given image pixel and in what proportions. This technique finds the combination of the spectra of the constituent materials that best matches the sampled pixel spectrum, repeating this for every pixel in the scene and thereby creating a set of images that map the abundances of the individual constituents.

Validation: The process of assessing by independent means the quality of the data products derived from the system outputs.

APPENDIX 3: BIBLIOGRAPHY

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