Focus on Space Applications for Resource Management in the Polar Regions

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With Canada assuming the role of Chair of the Arctic Council for the next two years, with a primary focus on responsible resource development in the North, there is no doubt that Canada has a monumental task ahead, and the world is watching. Striking a fine balance of traditional management of the North by First Nations with the economy of resource development is not only a challenge, but a question of capacity. A key driver to achieving success will be to utilize the space infrastructure that already exists and build competence in areas where there are critical gaps. One of the most successful examples responding to this critical equation in the North has been through the International Polar Year initiative.

In the face of economic opportunity, indigenous people and local communities must address potential cultural, social and environmental impacts while resource development companies are dealing with challenges of working in regions where the climate is harsh, the natural environment is fragile, transportation and communication infrastructure is limited and human resource capital is in short supply. Space technologies have helped to address many of these challenges by providing means for communications, mapping, resource exploration, navigation and search and rescue. The various stakeholders are described, and their requirements for information which can be provided in part through space assets are discussed. These requirements are treated under five main headings: Safety, Environment, Sustainable Economic Development, Sovereignty, and Indigenous and Social Development. Space programs that are planned for the near term and can contribute to these themes include but are not limited to the RADARSAT Constellation Mission (RCM), Sentinel-1 (European Space Agency mission) and Polar Communication and Weather (PCW). Many of these missions build upon technology heritage such as RADARSAT-2, Terra SAR-X, COSMO-Skymed, and others. Challenges for the future use of space technologies and space-based information include data continuity; data dissemination and public access; data fusion with other sensors; and in situ validation. A number of collaborative efforts to innovate and find solutions are described. The paper demonstrates that Canada is continuing on the path to meet

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challenges in the North, by leveraging Canada's niche science and technology expertise to meet strategic policy objectives of our Government. In a concerted effort to pursue common goals in the North, collaborating with international partners is essential to generate greater benefits of space to a far broader community and will serve as the bedrock of sustainable resource management.

Introduction

Resource Management

Canada is a northern country, rich in natural resources. As an example of the significance of natural resource management, the Canadian mining industry is projected to generate $137 billion in new mining projects in Canada in the next decade[1]. The annual contribution of mining to the Gross Domestic Product (GDP) has averaged 3.3% since 2005. The Canadian mining industry has attracted 19.2% of world budgeted spending, making Canada the leading global destination for exploration. A large share of this activity is in the north; in 2011, 23% of all regional exploration and deposit appraisal expenditures took place in the three northern territories: Yukon, Nunavut and Northwest Territories.

Canada's North also has large reserves of oil and natural gas. These are found both on land and in offshore regions. In 2008 the US Geological Survey estimated the Arctic hydrocarbon potential to include 90 billion barrels of oil, 1.7 trillion cubic feet of natural gas and 44 billion barrels of natural gas liquids[2]. While Canadian potential is only a portion of this amount, the importance of northern reserves relative to Canada's overall hydrocarbon potential is significant[3]. Figure 1 identifies the key oil and gas regions of Canada north of 60°[4]. Canada's oil sands region is not included in this figure.

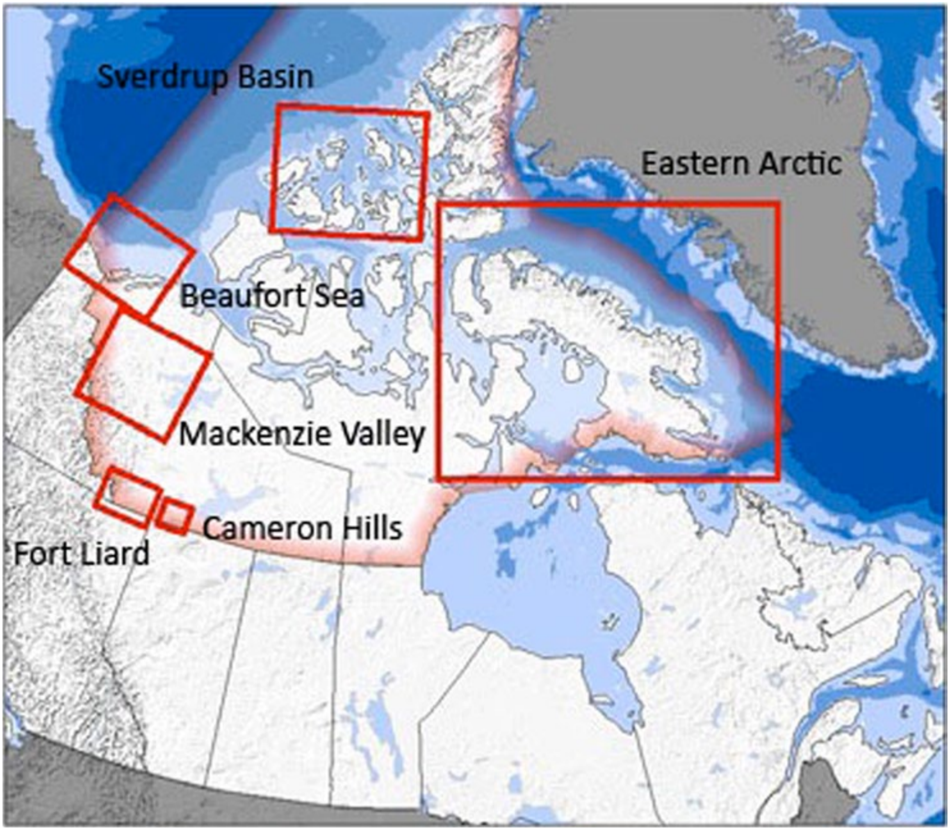
The challenges related to both mining and hydrocarbon development in Canada's North are significant from economic, social and environmental perspectives.

In recognition of the mining industry's social and environmental obligations, in 2004 the Mining Association of Canada (MAC) introduced its Towards Sustainable Mining (TSM) initiative, in which its members are required to participate[1]. TSM performance indicators focus on the following six areas:

- Tailings management
- Energy use and greenhouse gas emissions management
- Aboriginal and community outreach
- Crisis management planning
- Biodiversity conservation management
- Safety and health.

1 *Mining Sector Assessment,* LOOKNorth, December 2012
2 <http://pubs.usgs.gov/fs/2008/3049/fs2008-3049.pdf>
3 <www.parl.gc.ca/content/LOP/researchpublications/prb0807-e.pdf>
4 <www.aadnc-aandc.gc.ca/eng/1100100036125/1100100036129>

Fig 1: Canada's Northern Oil and Gas Regions (Source: AANDC)



Economic and Social Interests

Natural resource extraction and associated exploration, development and management are huge economic drivers in this region. Both large and small companies are active in the region. While Canada invests heavily in northern resource activities, foreign participation is also important. Multi-national mining companies that play a key role in Northern project development include Rio Tinto, DeBeers, BHP Biliton, Vale, Xstrata, MMG, ArcelorMittal, and Agnico-Eagle[5]. Today several producing mines exist in the North; however, considerable resources are being expended in exploration and definition of new deposits with sufficient economic potential for future development. In 2011 mineral production revenue in the three northern territories accounted for approximately 6% of Canada's total production. By contrast, exploration expenditure within the territories accounted for 23% of total exploration investment

5 *Canada's North and Resource Development*, LOOKNorth, March 2013

in Canada[6,7] illustrating the relative value importance of northern resources for Canada's future. The mining and oil and gas industries are significant employers in the North – in terms of both direct and indirect jobs.

Socially, the population is low and spread out. The three northern territories, Yukon, Northwest Territories and Nunavut, cover 39% of Canada's immense land mass. In the case of Nunavut and Northwest Territories, 85% and 51% of the population is of Aboriginal descent respectively. These two territories also have the youngest and second youngest median ages of all Canadian provinces and territories[8]. All of the territories are young in terms of self-government with all three in various stages of transferring province-like powers from the Canadian federal government to the territorial governments[9].

Challenges of the North

The northern people are facing numerous challenges. Remoteness and large distances, harsh climate, dispersed population, lack of trained labour, complex governance structure, unemployment and social issues are but a few. Infrastructure is extremely limited; for example, there are no roads at all connecting the communities of Nunavut. Another example is the fact that no fibre optic high speed communications link reaches to the high Arctic. The situation presents new opportunities but also poses many more challenges.

Environmental Concerns

In Canada's North, climate change is no longer an abstract idea. There is strong evidence, both from scientific data and local observations, that climate change has had and is having an impact. Substantial warming and increases in precipitation are projected for the 21st century[10]. The extent of sea ice has hit record lows in recent years, see Figure 2[11].

These rapid and obvious climate changes are disturbing habitat and animal populations. Hunters report that the sea ice, which was safe to travel on at specific times and places, is no longer safe. This adds difficulty to the already difficult lives of these remote people.

The environmental health impact of resource development and management is of great concern[12]. In some cases, mining has been shown to lead to contami-

6 *<http://sead.nrcan.gc.ca/expl-expl/sta-sta-eng.aspx>*

7 *<http://sead.nrcan.gc.ca/prod-prod/ann-ann-eng.aspx>*

8 *Northern Overview – Nunavut,* LOOKNorth

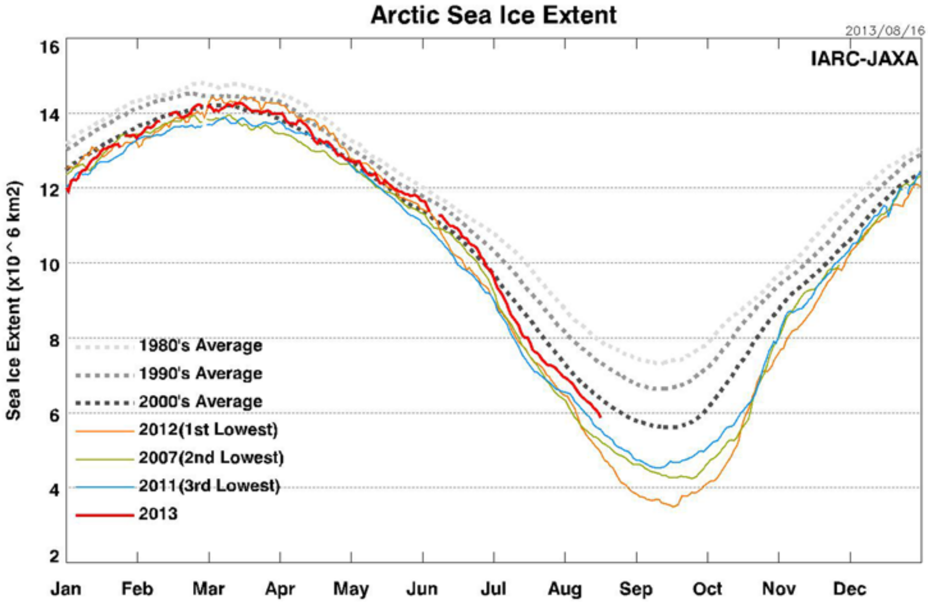
9 *A Northern Vision: A Stronger North and a Better Canada,* Governments of Yukon, Northwest Territories and Nunavut, 2007

10 *Climate Change Impacts and Adaptation in Northern Canada,* Ogden, Aynslie and Johnson, Peter; December 2002

11 Arctic Sea-ice Monitor, downloaded from <www.ijis.iarc.uaf.edu/en/home/seaice_extent.htm> on 21 August 2013

12 *Environmental Justice Goes Underground? Historical notes from Canada's Northern Mining Frontier,* Keeling A. and Sandlos J., downloaded from <www.cehe.ca/mining> on 21 August 2013

Fig. 2: Arctic Sea Ice Extent in Recent Years



nated water supplies and elevated incidence of cancer and other problems. The environmental health impacts of the oil sands are a subject of great debate in Canada at present.

Historical Use of Space in Northern Canada

Facing the challenges of a northern climate with vast remoteness, a small, dispersed population and lack of infrastructure, Canada has utilized space based technologies to address communication, information, access and safety issues in the North.

Telecommunications

Space-based systems are among the best methods for providing communications across the vast, but sparsely populated, Arctic[13]. The Anik satellites are a suite of geostationary communications satellites launched by Telesat Canada for telecommunications in Canada, from 1972 through 2013[14]. Current demand below 75°N (in most cases) is being met by existing geostationary systems. Above 75°N, there is a gap in coverage, with existing systems providing

13 *The Contribution of Space Technologies to Arctic Policy Priorities*, Polar View, March 2012

14 <http://en.wikipedia.org/wiki/Anik_(satellite)>

unreliable, limited capacity and low data rates. Most of the demand above 75°N is met from marine vessels and aircraft.

Remote Sensing

The Canadian Ice Service (CIS) of Environment Canada has been providing spatial information of ice cover in Arctic and east coast navigable waters since the 1970's, to assist maritime shipping and the Canadian Coast Guard. Initially, they used aircraft carrying expert ice observers and radar (side looking airborne radar and later synthetic aperture radar, or SAR). The launch of RADARSAT-1 in November 1995 allowed CIS to map greater extents more frequently and at lower operational cost, compared to airborne remote sensing[15].

The launch of Envisat in March 2002 with its Advanced Synthetic Aperture Radar (ASAR)[16] and the launch of RADARSAT-2[17],[18] in December 2007, both with advanced multiple polarization sensors, enabled users to extract additional information from SAR data. CIS continued and expanded their ice mapping capabilities, and also pioneered oil slick detection[19] and offshore wind measurement using SAR. The Department of National Defence became a major user of RADARSAT-2 data for vessel detection offshore and surveillance of the North.

The German TerraSAR-X and the Italian COSMO-Skymed missions provide high resolution polarimetric SAR coverage at X-band.

Navigation

The Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites[20]. The fact that it can be used in the North is very convenient for northern communities and resource management. The Russian GLONASS[21] is another operational global navigation satellite system (GNSS). China is in the process of expanding its regional Beidou navigation system into the global Compass navigation system by 2020[22]. The European Union's Galileo positioning system is a GNSS in initial deployment phase, scheduled to be fully operational by 2020 at the earliest. France, India and Japan are in the process of developing regional navigation systems.

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15 <www.asc-csa.gc.ca/eng/satellites/radarsat1/Default.asp>

16 <https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/instruments/asar>

17 <www.asc-csa.gc.ca/eng/satellites/radarsat2/Default.asp>

18 <http://is.mdacorporation.com/mdais_canada/Programs/Programs_RADARSAT2.aspx>

19 <www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=40897129-1>

20 <http://en.wikipedia.org/wiki/Global_Positioning_System>

21 <http://en.wikipedia.org/wiki/GLONASS>

22 <http://en.wikipedia.org/wiki/Satellite_navigation>

GPS·C, short for GPS Correction, was a Differential GPS data source for most of Canada maintained by the Canadian Active Control System, part of Natural Resources Canada[23]. When used with an appropriate receiver, GPS·C improved real-time accuracy to about 1–2 meters, from a nominal 15 m accuracy. GPS·C information was broadcast Canada-wide on MSAT (Mobile Satellite). The service was discontinued in April 2011.
Today various forms of GNSS provide the navigation backbone to support marine, air and land transportation in the North.

Search and Rescue
The International Cospas-Sarsat Program provides accurate, timely, and reliable distress alert and location data to help search and rescue authorities assist persons in distress[24]. The objective of the Cospas-Sarsat system is to reduce, as far as possible, delays in the provision of distress alerts to search and rescue services, and the time required to locate a distress and provide assistance, which have a direct impact on the probability of survival of the person in distress at sea or on land. The system of integrated satellite and land based stations was initially developed under a Memorandum of Understanding among Agencies of the former USSR, USA, Canada and France, signed in 1979. Cospas-Sarsat provides global coverage and in 2011, approximately 2,300 persons were rescued in over 600 events worldwide[25]. 49% of these were maritime, 28% related to land transportation and 23% dealt with aviation.

Users

Historically there has been a diversity of groups having an interest in the North. With increasing interest in natural resources and the effect of climate change on accessibility, this diversity is expected to grow.

Indigenous and Local Communities
Indigenous people have made their home in the North for thousands of years. In recent times, some non-indigenous people have been drawn north and settled. Combined, the numbers of residents in Canada's North is small. In 2012, the combined population of the three territories was approximately 113,000[26].
In Nunavut, there are 33,000 residents (Nunaviummiut) spread across 25 communities[8]. No communities are connected by road; airplane and sealift (weather permitting) are the only conventional forms of transportation between communities. Iqaluit (pop. ~ 7,000) is the largest community and the territory capital; however, in order to spread administration across the territory, there are government offices located in the capital and ten other communities.

23 <http://en.wikipedia.org/wiki/CDGPS>
24 <http://cospas-sarsat.org/index.php>
25 <www.cospas-sarsat.org/operatons/sar-events-rescue-stories/statistics>
26 <www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/demo02a-eng.htm>

Northwest Territories and Yukon have populations of 43,000 and 34,000 respectively. Yellowknife is the capital of Northwest Territories (pop. ~ 20,000) and Whitehorse the capital of Yukon (pop. ~ 26,000).

Many community residents still live off the land, hunting and trapping. They continue to rely on traditional knowledge of weather, ice movements, animal behavior and habitat. Increasingly they are looking for ways to integrate non-traditional sources of information (science and technology based) into their knowledge systems.

As communities and residents engage in the resource economy, they are faced with the need to exercise their governance responsibility with respect to proposed resource development projects. Increasingly they are drawing science-based data to complement traditional knowledge as they seek to understand both the benefits and risks associated with development projects.

Industry

Mineral and oil and gas resources in the North are drawing increasing attention from both southern Canada and the rest of the world. This interest is generating exploration activity and growing production operations that bring investment dollars and jobs to the North. While attractive, these projects also pose potential threats to both traditional culture and environment. Remoteness and a harsh climate are additional challenges faced by northern projects. Decisions about the advancement of new projects are complex and are not typically made in a short time frame.

An important element in assessing the viability of major projects is the infrastructure and energy requirements during construction and operation phases.

Roads are sparse in the North and the creation of new roads must address environmental challenges such as permafrost and changing ice conditions (if ice roads are considered). Transportation costs are high if equipment has to be flown to project sites and if marine transportation is feasible, timing becomes an issue as deliveries must be coordinated with seasonal sealift programs.

Shipping is an important industry for supply of communities and mines, and export of ore. With the reduction in sea ice in recent years, the volume of shipping between Europe, Russia and Asia through the Northwest Passage is expected to increase in the future.

Energy costs are also high. Today the North has limited hydropower capacity with the result that electricity requirements for many resource projects are typically derived from diesel driven generators.

Although exploration activity has declined in recent years as a result of competitive global prices for natural gas and oil, the North has substantial proven reserves. A pipeline will be key to future development of these resources. Although long-discussed, plans for a Mackenzie Valley pipeline to carry natural gas to southern markets have stalled and the mid-term future of the project is in doubt[27].

More recently, groups within the Yukon and Northwest Territories have begun to consider the economic viability of developing within territory gas produc-

27 <http://en.wikipedia.org/wiki/Mackenzie_Valley_Pipeline>

tion facilities and the use of liquefied natural gas as an alternative to diesel driven generators[28].

Outside parts of the Mackenzie Valley and southern Yukon, forests are sparse and as a result there is little commercial forestry in the North. However, the potential use of biomass for heating is in use and expansion is being considered[29].

Arctic Fibre Inc. has proposed to install a fibre optic high speed communications link connecting London, New York and Tokyo through the Canadian Arctic[29]. Arctic Link has made a similar proposal[30]. Communities like Iqaluit will be able to connect to this cable. If the cable is installed as proposed, it will increase the communications effectiveness of the industries operating in the North. The same comment will apply to northern inhabitants, government personnel and scientists. There is a push for a fibre optic link overland to Inuvik also[31].

Governments, Including Defence

The Canadian Federal Government requires a presence in the North. Departments such as Environment, Natural Resources, Aboriginal Affairs and Northern Development Canada have offices in cities such as Whitehorse, Yellowknife and Iqaluit, the three territorial capital cities. For example, Natural Resources Canada (NRCan) Earth Sciences Sector is currently working on Geo-Mapping for Energy and Minerals (GEM) program, Inuvik ground receiving station, Polar Continental Shelf Program, the Canadian High Arctic Research Station, and the development of an Arctic Spatial Data Infrastructure.

The territorial and municipal governments are also present, of course. The government offices deal with a wide variety of issues, including permits for mineral exploration, land claims issues, environmental impact reviews, environmental conservation, port management, natural hazards and construction management. Equally important in the overall governance structure are First Nations and Inuit who also have rights and responsibilities in decision making pertaining to resource management (among other things).

The Canadian Department of National Defence has had a renewed and increased presence in the North in recent years. They perform duties such as search and rescue, sovereignty patrol, national security coordination and contingency planning[32]. Joint Task Force (North) or JTF(N) is responsible for all Canadian Forces operations and administration in northern Canada, namely the Yukon, Northwest Territories, Nunavut and the waters of the Arctic Ocean (within Canada) and Hudson Bay. JTF(N) is headquartered in Yellowknife, Northwest Territories, and is part of Canadian Joint Operations Command.

The Canadian Rangers are a sub-component of the Canadian Forces reserve that provide a military presence in Canada's sparsely settled northern, coastal,

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28 <www.gov.yk.ca/aboutyukon/industry.html>

29 <www.nunatsiaqonline.ca/stories/article/65674Arctic_fibre_inc._picks_iqaluit_cable_landing_spot/>, downloaded on 22 August 2013

30 <www.extremetech.com/extreme/122989-1-5-billion-the-cost-of-cutting-london-toyko-latency-by-60ms>

31 <http://norj.ca/2013/05/inuvik-targeted-as-international-satellite-hotspot/>

32 <http://en.wikipedia.org/wiki/Canada_Command>

and isolated areas[33]. A primary role of this part-time force is to conduct surveillance or sovereignty patrols as required. Some Canadian Rangers also conduct inspections of the North Warning System (NWS) sites and act as guides, scouts, and subject matter experts in such disciplines as wilderness survival when other forces (such as Army units of the Regular Force or Primary Reserve) are in their area of operations. The Canadian Rangers are a volunteer force made up of Inuit, First Nations, Métis and non-Aboriginal Northerners; however, it is a common misconception that the organization is a First Nations entity.

Scientists

Scientific understanding of the North is recognized as an important priority driven by recognition of the environment's fragility, the reality of changing climate and the increasing interest in resource development. Science based knowledge is a key component to the current resource management process.

Fundamental scientific research is generally driven by government and academia. Equally important applied science is undertaken as part of resource project planning and implementation.

The Government of Canada has committed to build the Canadian High Arctic Research Station (CHARS) in Cambridge Bay, Nunavut[34]. The Station will provide a world-class hub for science and technology in Canada's North that complements and anchors the network of smaller regional facilities across the North. The new Station will provide a suite of services for science and technology in Canada's North including a technology development centre, traditional knowledge centre, and advanced laboratories. The Station will open in 2017.

The science community is active in the North, on land, sea and air. Scientists measure and monitor a range of phenomena, including toxic chemicals, habitat, wildlife, atmospheric composition, the Earth's magnetic field, gravitational field, and many others. They use space assets whenever possible.

Some scientists work to ensure that space assets can be effectively used. They conduct the necessary upstream R&D for existing and upcoming sensors to enable effective use of the data for northern studies related to ice, snow, permafrost, vegetation, and land cover, among others. Government scientists are also working towards the generation of consistent and long-term space-based data records over the terrestrial areas of the North, which will be a critical information source for long-term environmental monitoring.

Requirements

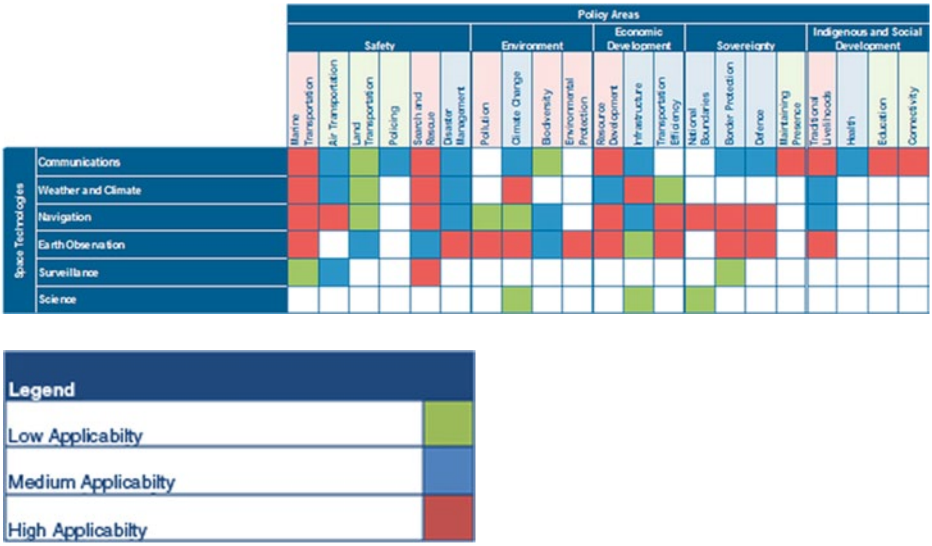
A recent study by the Polar View[35] partner network called "The Contribution of Space Technologies to Arctic Policy Priorities" examines the requirements of Arctic users in several categories[13]:

33 <http://en.wikipedia.org/wiki/Canadian_Rangers>

34 <http://science.gc.ca/default.asp?lang=En&n=6B43B3E0-1>

35 <www.polarview.org/>

Fig. 3: The Applicability of Space Technologies to Arctic Policy Areas



- Safety (marine, air and land transportation, policing, search and rescue and disaster management)
- Environment (pollution, climate change, biodiversity, environmental protection)
- Sustainable Economic Development (resource management, infrastructure and transportation efficiency)
- Sovereignty (national boundaries, border prtection, defence, maintaining presence)
- Indigenous and Social Development (traditional livelihoods, health, education, connectivity).

The report then demonstrates to what extent satellite systems can satisfy these requirements in whole or in part. The types of satellite systems analyzed are:
- Communications
- Weather and climate
- Navigation
- Earth Observation (EO)
- Surveillance
- Science.

A summary of the analysis is provided in Figure 3, The Applicability of Space Technologies to Arctic Policy Areas (source: Polar View.) The findings are too numerous to fully address here, however the overall message is that space-based technologies will continue to play significant roles in many areas of Arctic policy.

At a more granular level, the Canadian Space Agency (CSA) and the European Space Agency (ESA) jointly sponsored the MORSE workshop in 2008[36] with the aim of identifying user requirements for geospatial information in Arctic coastal regions, and the extent to which these requirements could be met using EO technology. The requirements for geospatial information in Arctic coastal areas were collected in the following four themes[37]:

- Environmental Monitoring of Land, Water and Air.
- Mapping, Characterization and Changes with Time.
- Sustainable Economic Development of Natural Resources.
- Safety, Security and Sovereignty.

The workshop results were further analyzed to determine the requirements that appeared to be most necessary and most feasible in the short term, in other words 'low hanging fruit'. These appeared to be the following:

- Digital elevation models
- Shoreline delineation, composition and change detection in the coastal zone
- Regional & local current weather & climate information
- Near-shore Ice Complex (including land-fast, thickness, floe edge)
- Land cover & land cover change
- Hydrology (lakes, rivers, streams) and changes
- Structures (camps & settlements, buildings, bridges, wharves, breakwaters, etc) & changes in structures
- Vehicles (including tracks).

While this analysis focused on EO only, it illustrates the type of high priority requirements that could be satisfied, at least in part, by applying space technology in new ways.

Planned Programs

This section provides an overview of the space programs, planned for the near term, which will respond to user requirements related to resource management in the north.

RADARSAT Constellation

Canada has identified radar remote sensing as a key technology to support both government and commercial needs. It is well suited to many northern applications. The RADARSAT Constellation is the evolution of the RADARSAT Program from the single satellite deployments of RADARSAT-1 (1995) and RADARSAT-2 (2007). The key objectives of the RADARSAT Constellation Mission are to ensure C-band data continuity, enhanced operational use of Syn-

36 <www.morseArctic.net/>

37 *MORSE User Requirements Document,* <www.morseArctic.net/docs/MORSE%20URD%20v1.1_25April2009.pdf>

thetic Aperture Radar (SAR) data and improved system reliability over the next decade[38]. The baseline mission includes three satellites, but the constellation is designed to be scalable to six satellites. This allows the system to address future requirements as they arise with greater flexibility. For example, new functionality could be added to a fourth satellite and these functions could be made available to all constellation users. In this fashion, RADARSAT Constellation is a paradigm shift from the earlier RADARSAT model. Instead of launching a single satellite, the capabilities of the system are distributed across several satellites, increasing revisit, and introducing a more robust, flexible system that can be maintained at lower cost and launched into orbit using smaller, less expensive launch vehicles.
The RADARSAT Constellation Mission is being designed for three main uses:

- Maritime surveillance (ice, wind, oil pollution and ship monitoring);
- Disaster management (mitigation, warning, response and recovery); and
- Ecosystem monitoring (forestry, agriculture, wetlands and coastal change monitoring).

In addition to these core user areas, there are expected to be a wide range of ad hoc uses of RADARSAT Constellation data in many different government applications, federally and provincially, and in the private sector, both in domestically and abroad.
The greatly enhanced temporal revisit combined with accurate orbital control will enable advanced interferometric applications in between satellites on a four-day cycle that will allow the generation of very accurate coherent change maps.
The satellite launches are planned for 2018.

Sentinel-1

The Sentinel-1 mission of ESA is a polar-orbiting satellite system which when launched will extend European operational SAR applications[39]. Sentinel-1 is a C-band imaging radar mission to provide an all-weather day-and-night supply of imagery for a range of user services. The first Sentinel-1 satellite is envisaged to launch in 2013 and will be followed by the second satellite a few years later. Sentinel-1 will ensure the continuity of C-band SAR data, building on ESA's and Canada's heritage SAR systems: ERS-1, ERS-2, Envisat ASAR and RADARSAT. Canada is a member of ESA, and so plays a role in the Sentinel-1 mission. CSA and ESA have harmonized the mission management of their SAR missions in the past, so that if either agency's SAR mission fails, users will be able to obtain data from the other agency's sensor.
Sentinel-1's revisit time, geographical coverage and rapid data dissemination are key to providing essential data for users. The Sentinel-1 pair is expected to provide coverage over Europe, Canada and main shipping routes in 1–3 days,

38 <www.asc-csa.gc.ca/eng/satellites/radarsat/Default.asp>
39 <www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1>

regardless of weather conditions. Radar data will be delivered within an hour of acquisition – a significant improvement over existing SAR systems.
The mission will benefit numerous services such as:
- monitoring of Arctic sea-ice extent, and routine sea-ice mapping,
- surveillance of the marine environment, including oil-spill monitoring and ship detection for maritime security,
- monitoring land-surface for subsidence and absidence,
- mapping for forest, water and soil management and
- mapping to support humanitarian aid and crisis situations.

Polar Communication and Weather (PCW)
Geostationary (GEO) satellites are a key element of global communication and weather forecasting services. However, the orbit geometry of geostationary (GEO) communications satellites limits their effectiveness in northern latitudes. Low Earth Orbit polar orbiting satellites provide good spatial resolution at high latitudes, but with a narrow swath. To address these limitations, a technical solution (PWC) is envisaged that would consist of two satellites in Highly Elliptical Orbit (HEO) capable of providing continuous 24/7 broadband communications services and monitoring weather and climate change at the required temporal and spatial resolution, throughout all of the Arctic[40].
The mission would have three main objectives:

1. Provide reliable 24/7 high data rate communications services in order to:
   - enable Canadian Forces, Canadian Coast Guard, Fisheries and Oceans Canada, Nav Canada, Transport Canada, Indian and Northern Affairs Canada, NRCan and Environment Canada activities in the high Arctic;
   - enhance the connectivity of northern communities to the broadband information backbone infrastructure;
   - facilitate exploration and exploitation of natural resources;
   - enhance research efficiency in the Arctic;
   - ensure that Canadians are benefiting from increased air and marine traffic in the Polar region.

2. Monitor Arctic weather and climate change for the benefits of Canadians and the Global community in order to:
   - significantly improve the accuracy of weather forecasting, including severe weather event warnings;
   - improve the understanding of global climate change and the ability to model and predict phenomena associated with it;
   - provide unique high-quality operational data acquired over the entire polar region, which is currently not available from any source.

3. Monitor space weather in HEO environment in order to:
   - support the development of an alerting system for Polar Cap Absorption (PCA) events which strongly affect High Frequency (HF) communication in the Arctic;

40 <www.asc-csa.gc.ca/eng/satellites/pcw/Default.asp>

- enhance the services of NRCan's Canadian Space Weather Forecast Centre (CSPWFC) to include HEO environment, and enable NRCan to develop a new service called "Space Anomaly Investigation System" which will identify Space Weather phenomena that contribute to satellite operation anomalies in HEO;
- support satellite developers and operators by improving existing models of Space Weather environment in HEO;
- support national and international Solar and Earth System scientific research in general.

Other Future Missions

Radar based missions will continue to play a vital role in northern resource management, in part because in the North, optical satellites are limited by lack of light during winter months. However, the importance of other sensor technologies cannot be forgotten. Various multispectral sensors currently provide important understanding of land cover conditions, and mineral exploration while very high-resolution sensors also assist in resource management activities. The NASA-led Landsat Data Continuity Mission recognizes the value of multi-year data availability for both science and operational purposes. With the recent launch of Landsat 8, a significant source of multispectral remote sensing data since 1972 has been extended. In a northern context, the availability of data such as these are increasingly valuable in the study of climate change impacts.

Very high resolution data from DigitalGlobe is important for site-specific purposes including resource exploration and environmental monitoring as well as security applications. Its stereo capability also provides an important means for creating high quality digital elevation models from space. DigitalGlobe's next satellite, Worldview-3, is planned for launch in 2014 and will provide significantly improved multispectral capability[41].

Other multispectral programs such as RapidEye and SPOT are similarly important for northern applications as standalone data sources but also as contributors to extended time series of data for monitoring long term change detection. Additional future missions of interest include Sentinel-2 and Sentinel-3. Sentinel-2 will be a two-satellite mission providing global multispectral imagery in an orbit complimentary to Landsat and SPOT specifically enabling the construction of long-term data time series for monitoring environmental change[42]. Launch is expected in 2014. Sentinel-3 will be a medium resolution land and ocean-monitoring mission. Its sensor configuration will include a wide swath Ocean and Land Cover Instrument (OLCI), a Sea and Land Surface Temperature Radiometer (SLSTR) a Sentinel Radar Altimeter (SRAL), a Microwave Radiometer (MWR) and a Precision Orbit Determination (POD) sensor[43]. Key northern applications will include ocean forecasting, sea ice mapping, water quality and land use change.

41 <www.digitalglobe.com/downloads/WorldView3-DS-WV3-Web.pdf>
42 <http://esamultimedia.esa.int/docs/S2-Data_Sheet.pdf>
43 <http://esamultimedia.esa.int/docs/S3-Data_Sheet.pdf>

The Japan Aerospace Exploration Agency (JAXA) plans to launch the ALOS-2 satellite carrying the PALSAR-2 L-band SAR in late 2013. The Argentina Space Agency CONAE plans to launch two SAOCOM satellites carrying L-band SAR in 2014 and 2015.
NASA is in the process of designing a follow-on to its successful ICESat mission, to continue studying polar ice changes, and biomass and carbon in vegetation[44]. The new satellite, ICESat-2, is tentatively planned for launch in 2016. Until the launch, NASA's Operation IceBridge is using a DC-8 aircraft to measure ice thickness and collect other data.

Challenges for the Future

This section examines some of the challenges that will be faced as we continue to exploit space applications for northern resource development, with an emphasis on remote sensing.

Data Continuity

In order to detect changes with time, it is crucial to maintain data continuity of space-based observations. Gaps in observations can blind our view in the short term, and hide or obscure what is happening in the medium to long term. EO missions are complex and expensive, and they do fail sometimes. For example, the Envisat mission (with its ASAR C-band SAR) ended[45] before Sentinel-1 is launched in late 2013 or early 2014, so ESA has no C-band SAR during that period. Since RADARSAT-2 is a polarimetric C-band SAR operating during this period, users can benefit from the similarity of the two sensors. In fact, Envisat ASAR and RADARSAT-2 approach the concept of interoperability, which has been defined as "Obtaining the same thematic results from different sensors"[46]. In contrast, since the end of the ALOS (Advanced Land Observing Satellite) mission in May 2011[47], there has been no civilian L-band SAR, although new L-band SAR missions are planned for launch soon by Japan and Argentina. Therefore at the present time, there is an unfortunate gap in L-band SAR coverage with no opportunity for interoperability with other sensors.

Data Dissemination and Public Release

Every EO sensor mission publishes a 'data policy' which describes who can request and access the data under what conditions and what they can do with the data (process, publish, copy, distribute, etc.) The missions range from free data with unrestricted licensing to payment for a licence to use the data under very restrictive conditions. Private sector satellite owners must recover the in-

44 <http://en.wikipedia.org/wiki/ICESat>
45 <http://en.wikipedia.org/wiki/Envisat>
46 GEO Forest Carbon Tracking Task 3rd Science and Data Summit, Arusha, Tanzania, 6 – 9 February 2012
47 <https://directory.eoportal.org/web/eoportal/satellite-missions/a/alos-2>

vestment in the mission by charging for the data and restricting its dissemination. Much of the data is dual-use for both civil and military applications, and governments are concerned that the sensitive and valuable information may be used for unintended purposes. Hence, control measures including the enforcement of rigid regulations are implemented in some cases to prevent or delay the data dissemination. For example, the licence under which MDA operates RADARSAT-2 is subject to Canada's Remote Sensing Space Systems Act[48]. MDA must ensure through third party licensing agreements who can access RADARSAT-2 data, and how it can be disseminated. A similar situation exists for many other high resolution space sensors.

Data Fusion from Multiple Sensors

Space-borne sensors each have strengths and weaknesses. Often, the information that can be gained by combining data from a combination of different sensors is richer than the sum of the data that can be gained from individual sensors. For example, when looking for vegetation stress as a marker of pollution, disease or toxic chemical contamination, multi-spectral optical sensors can detect vegetation stress through colour changes. However, cloud cover often prevents acquisition of multiple scenes in rapid succession to get a time series. Radar data can acquire data according to a schedule (since the microwave energy penetrates most cloud cover) but is poor at detecting changes caused by vegetation stress. By combining radar and optical data with appropriate algorithms, a more complete picture of changes with time can be obtained.

In situ Validation

Measurements of physical, biological and chemical properties of the Earth's environment from space must be validated using various quantitative calibration methods. One approach is to compare measurements from space with 'in situ' measurements taken at the location in question. Comparing these in situ measurements with space sensor results gives quantitative error information and ultimately greater confidence in the space-borne measurements. In the North, the remoteness and long distances make in situ validation extremely difficult. This is a continuing challenge for Arctic studies. Opportunities to travel to remote locations to conduct cal-val experiments are rare and must be used to the maximum extent possible.

Collaborative Innovation

This section describes a number of initiatives that Canada is involved with, both independently and with international partners, to address how best to utilize space assets to assist in sustainable northern resource management.

48 <www.international.gc.ca/arms-armes/non_nuclear-non_nucleaire/remote_sensing-teledetection.aspx?lang=eng#licences>

Canada's Northern Strategy

To meet the challenges and opportunities of a changing North, the Government of Canada has established a comprehensive Northern Strategy and is taking concrete action in four priority areas[49]:

- Exercising Canada's Arctic sovereignty
- Protecting Canada's environmental heritage
- Promoting social and economic development
- Improving and devolving Northern governance.

World-leading Arctic science and technology underpin the Northern Strategy and help ensure sound decision-making. In August 2012, Prime Minister Stephen Harper announced support for the construction and operation of the CHARS, and support for its Science and Technology Program[50]. The Government of Canada is also investing $85 million invested in the improvement and upgrading of northern research facilities through the Arctic Research Infrastructure Fund[51].

International Polar Year 2007-2008

International Polar Year (IPY) 2007-2008 was the largest ever international program of coordinated, interdisciplinary science focused on the Arctic and Antarctic[52]. Organized by the World Meteorological Organization and the International Council for Science, the official observing period for IPY took place over a 24-month period from March 2007 to March 2009. IPY involved conducting scientific activities in the Earth's polar regions to deepen the understanding of polar processes, global linkages and increase our ability to detect changes at the poles.

As a major polar nation - with nearly one-quarter of the Arctic falling within Canada's boundaries, more than half of our coastline in the Arctic, and communities throughout the region - Canada played a significant role in the global IPY initiative. This included research on human activities, societies, cultures and health as part of IPY 2007-2008.

On a national scale, the Government of Canada Program for IPY focused on two key priority research areas for the North: climate change impacts and adaptation, and the health and well-being of northern communities. IPY 2007-2008 was the largest investment of new funds the Government of Canada has ever made in northern science. Of the $156 million invested in IPY by the Government of Canada, $106 million supported 52 scientific research projects. The remaining $50 million went to other major components of Canada's IPY Program which included logistics, emergency preparedness, research licensing, communications, training, capacity building, and data management.

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49 <www.northernstrategy.gc.ca/index-eng.asp>

50 <www.pm.gc.ca/eng/media.asp?category=1&featureId=6&pageId=26&id=4971>

51 <www.science.gc.ca/Canadian_High_Arctic_Research_Station/Strong_Research_Presence/Arctic_Research_Infrastructure_Fund-WS9A8DE6D8-1_En.htm>

52 <www.api-ipy.gc.ca/pg_IPYAPI_016-eng.html>

New partnerships have also been forged, especially between Aboriginal/Northern organizations and the research community in Canada and internationally. Canada hosted the concluding IPY conference in Montreal in 2012.

Arctic Council

The Arctic Council is a high-level intergovernmental forum that addresses issues faced by the Arctic governments and the indigenous people of the Arctic[53]. It has eight member countries: Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and the United States. The 1996 Ottawa Declaration established the Arctic Council as a forum for promoting cooperation, coordination, and interaction among the Arctic States. Indigenous peoples' organizations have been granted Permanent Participants status in the Arctic Council.

Canada has recently assumed the Chair position on the Arctic Council which it will hold from 2013 – 2015. The theme of Canada's chairmanship is "development for the people of the North," with a focus on responsible Arctic resource development, safe Arctic shipping and sustainable circumpolar communities[54].

Polar Space Task Group

The Polar Space Task Group (PSTG) has been established under the auspices of the World Meteorological Organization's (WMO) Executive Council Panel of Experts on Polar Observations Research and Services (EC-PORS)[55]. The group's mandate is to provide coordination across space agencies to facilitate acquisition and distribution of fundamental satellite datasets, and to contribute to or support development of specific derived products in support of cryospheric scientific research and applications.

The PSTG actively pursues realization of benefits from the growing constellation of polar orbiting satellites by mobilizing the unique and complementary capabilities of each of the respective participating Agencies. The role is to support the scientific activities that may lead to improved numerical weather and climate forecasting, or development of improved operational polar products and services.

The PSTG is a successor of the successful International Polar Year Space Task Group (IPY-STG), established for the purpose of space agency planning, processing and archiving of the IPY Earth Observation legacy dataset[56]. One of many accomplishments, this group coordinated the successful acquisition of interferometric SAR data over Greenland by the space agencies of Canada, Germany and Japan as well as ESA, with NASA committing to process and distribute the resulting velocity products.

53 <http://en.wikipedia.org/wiki/Arctic_Council>

54 *Development for the People of the North: The Arctic Council Program during Canada's Chairmanship (2013-15)*

55 *Polar Space Task Group Terms of Reference V4*, Polar Space Task Group, June 2012

56 *IPY Legacy of Satellite Radar Data in Polar Regions*, IPY Space Task Group, 2010

LOOKNorth

LOOKNorth[57] is a national Centre of Excellence for Commercialization and Research (CECR) funded in part through the Government of Canada's Network of Centres of Excellence program[58]. LOOKNorth supports responsible, sustainable development of Canada's Northern natural resources through implementation of innovative remote sensing technologies. LOOKNorth is a five year program developed by C-CORE[59], and is currently approaching the midpoint of its mandate. Funding for LOOKNorth is provided by the Government of Canada (through the CECR Program) and by the Province of Newfoundland & Labrador through the Department of Innovation, Business & Rural Development and the Research & Development Corporation.

The objectives of LOOKNorth are to:

- Identify information needs & gaps in oil & gas, mining, hydro-power, transportation
- Use remote sensing to provide relevant information to support decision making
- Develop opportunities for industry, small-medium enterprises, researchers and northern people.

ArcticNet

ArcticNet is a Canadian Network of Centres of Excellence that brings together scientists and managers in the natural, human health and social sciences with their partners from Inuit organizations, northern communities, federal and provincial agencies and the private sector[60]. The prime objective of ArcticNet is to study the impacts of climate change and modernization in the coastal Canadian Arctic. Over 145 ArcticNet researchers from 30 Canadian Universities, 8 federal and 11 provincial agencies and departments collaborate with research teams in Denmark, Finland, France, Greenland, Japan, Norway, Poland, Russia, Spain, Sweden, the United Kingdom and the USA.

A desired outcome of ArcticNet is for it to contribute to the development and dissemination of the knowledge needed to formulate adaptation strategies and national policies to help Canadians face the impacts and opportunities of climate change and modernization in the Arctic. A major goal of ArcticNet is to engage Inuit organizations, northern communities, universities, research institutes, industry as well as government and international agencies as partners in the scientific process and the steering of the Network.

ArcticNet is conducting Integrated Regional Impact Studies on societies and marine and terrestrial coastal ecosystems in the Canadian High Arctic, in the Eastern Canadian Arctic, and in Hudson Bay. In addition to work conducted in northern communities, ArcticNet researchers from various fields use the Canadian research icebreaker CCGS Amundsen to access the vast expanses of the

57 <www.looknorth.org/>
58 <www.nce-rce.gc.ca>
59 <www.c-core.ca/>
60 <www.arcticnet.ulaval.ca/>

coastal Arctic. This integrated research offers a unique multi-disciplinary and cross-sectorial environment to train the next generation of Arctic specialists, from north and south.

Sustaining Arctic Observing Networks (SAON)

The Sustaining Arctic Observing Networks (SAON) was initiated by the Arctic Council and has been underway since early 2007[61]. Its purpose is to support and strengthen the development of multinational engagement for sustained and coordinated pan-Arctic observing and data sharing systems that serve societal needs, particularly related to environmental, social, economic and cultural issues. SAON promotes the vision of well-defined observing networks that enable users to have access to free, open and high quality data that will realize pan-Arctic and global value-added services and provide societal benefits. Its goal is to enhance Arctic-wide observing activities by facilitating partnerships and synergies among existing observing and data networks, and promoting sharing and synthesis of data and information. SAON also is committed to facilitating the inclusion of Arctic indigenous people in observing activities, in particular by promoting community-based monitoring efforts.

SAON is organized as an independent activity under the co-sponsorship of the Arctic Council and the International Arctic Science Committee. It is implemented as a Task-based activity allowing both bottom-up and top-down identification of needs. All countries are welcome to participate in SAON on an equal basis.

Conclusion

This paper has demonstrated that Canada has taken a proactive role in developing and implementing space-based technologies for the North. However, the resource demands are mounting, and climate change is increasing stress on the population and the ecosystems, so a greater level of vigilance and accountability is required.

Space-faring nations such as Canada continue to meet challenges in the North and expand its network of partners to use space-based technologies to advance responsible resource development and management. As global stewards of the rich diversity and culture that exists in the Polar regions, combining contemporary technologies with sage philosophies of our indigenous peoples, we remain committed to tip the scales in favor of preserving this pristine expanse.

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61 <www.arcticobserving.org/>