SBR MTI Impact on Coastal and Border Surveillance

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ABSTRACT

Achieving information superiority is a primary goal in a defence or security operation, but data source management and processing is becoming more challenging as the number and types of these data sources increase. The integration of these diverse sources into a Common Operating Picture (COP) involves a complex interplay between Intelligence, Surveillance & Reconnaissance (ISR) sensors, network architecture and exploitation capacity. A great deal of research and development effort has been expended in improving these capabilities. Canada's very long coastlines and the increased threat of terrorist infiltration present a great security challenge, which requires a more capable coastal surveillance system.

One of these new surveillance tools is Moving Target Indication (MTI) from Space-based Radar (SBR). Canada has been developing such a system on the RADARSAT-2 satellite in order to demonstrate the feasibility and utility of making routine MTI measurements from space and to explore possible improvements to current coastal surveillance. The fusion of data from SBR MTI and other ISR sources will improve the overall surveillance architecture capabilities such as area coverage, response times, detection, and tracking performance.

Interoperability between national coastal and coalition ISR assets with Command and Control centres improves the timeliness of information distribution and processing. Common data exchange formats are crucial to achieving this, but since existing North Atlantic Treaty Organization (NATO) formats do not readily handle SBR MTI data, they must be updated. This capability will result in earlier detection and identification of possible hostile targets.

This paper will discuss the contribution that SBR MTI sensors can add to coastal surveillance capabilities. It will also discuss improvements made to NATO MTI interoperability standards to accommodate SBR MTI data and to enhance its usefulness to exploitation systems. Finally, it will show how SBR MTI data can be integrated with other data sources into a COP to improve overall efficiencies and capacity. This should therefore improve the overall situational awareness available to commanders engaged in coastal surveillance and border security operations.

1.0 INTRODUCTION

"Global-reach terrorism has exposed some important gaps in many country's defences",
M.B. MacLean, VAdm, Chief of Maritime Staff [1].

The maritime security requirements for homeland defence have been constantly under review and have undergone changes since 9/11 to address new types of threats, such as global terrorism. The longest coastline in the world has always presented a defence challenge for Canada. However, due to the nature of recent terrorist threats against North America, the improvement of security along the East and West coasts, as well as in the sprawling North, has become a priority for the Canadian Forces and other government security organizations. Therefore, requirements for border and coastal surveillance have changed to address these issues, from lower-level sensors to higher Command and Control (C2) levels.

ISR assets determine the capabilities that are available and can be brought to bear to help protect land, borders, and coasts, both during peacetime and wartime. Due to the nature of the Canadian coastal border and the limitation of existing ISR capabilities, there is a special need for persistent wide area surveillance to monitor the coasts and provide situational awareness and early warning functions in order to achieve surveillance superiority. The aim of this paper is to assess the impact of a new Canadian Space-Based Sensor (SBS) – RADARSAT-2, in addressing deficiencies by exploiting the advantages of both space platforms and SAR-MTI sensors. The interoperability of such space-based sensors with exploitation stations and command & control centres is crucial to fully exploiting these advantages.

DND has been interested in developing a mechanism to collect information from space-based assets and integrate this data into a commander's information environment. The RADARSAT-2 Ground Moving Target Indication (GMTI) Technology Demonstration Project (TDP) [2] is investigating the technical feasibility and military value of collecting MTI data from space, and will point the way forward in the development of future operational SBR MTI sensors. The tactical nature of MTI data expands the role of space sensors beyond their traditional strategic application in supporting theatre operations.

The integration of all the ISR sensors to achieve information superiority raises a challenging problem. Integration is essential to make the surveillance architecture more robust for persistent surveillance. The interoperability between the ISR sensors and exploitation workstations has been the driving force behind the development of new common communication protocols. These protocols are designed based on the requirements for information needed from sensors in order that an exploitation workstation can generate products and update the COP for better situational awareness.

NATO Standardization Agreement (STANAG) 4607 is one of the ISR formats, developed by coalition nations under the NATO Intelligence, Surveillance, and Reconnaissance Interoperability Architecture (NIIA) [3]. It addresses ground/surface moving targets, and allows each sensor to broadcast their detection reports in a common format. It is constantly being modified and updated to address new sensor capabilities and new exploitation requirements. However, the baseline edition of STANAG 4607 was developed based on detection data from airborne ISR sensors. Therefore, there was a requirement to update the STANAG to support data from space-borne platforms such as RADARSAT-2, which carry SAR-MTI sensors.

This paper therefore provides an overview of

- Selected Canadian maritime ISR capabilities
- Space-based (SB) SAR-MTI capabilities and the augmentation they can provide to maritime ISR assets
- Integration of SB SAR-MTI data within a maritime ISR environment
- Exploitation of SB SAR-MTI data and results of modelling and simulation

2.0 SELECTED CANADIAN MARITIME ISR CAPABILITIES

Canada's East Coast, West coast and large Northern frontier are shown in Figure 1. The figure also shows the security zones that are of interest to Canada, and a selection of some baseline maritime ISR capabilities. These capabilities include, but are not limited to [4]

- Transport Canada:
    - National Aerial Surveillance Program (NASP) – Its function is to detect ship-source pollution in waters within Canadian jurisdiction. Through an agreement with the Department of

Fisheries and Oceans, the program uses Provincial Airlines Limited (PAL) aircraft to patrol the East and West coasts. The requirements are presently being expanded to include coverage of the North.

  - Integrated Satellite Tracking of Polluters (I-STOP) – This program uses RADARSAT-1 to complement NASP surveillance capability, by providing early warning on the locations for potential pollution incidents.
- Canadian Forces (CF)
  - Naval Patrol Frigates – combat capability
  - Maritime Coastal Defence Vessels (MCDV) – conduct boarding operations, presence, escort duties, coastal surveillance and monitoring.
  - CP-140 Auroras – CF maritime surveillance aircraft
- Canadian Coast Guard (CCG)
  - Marine communications and traffic services
  - Maritime patrol and search and rescue
  - Arctic Ice breakers
- Royal Canadian Military Police (RCMP)
  - Task patrol vessels
  - Helicopters conduct conservation and fishery patrols and monitor ice flow
  - Fixed-wing aircraft conduct pollution control patrols over the Great Lakes, St. Lawrence Seaway and the East coast
- Coastal Automated Identification System (AIS) receivers operated by various government departments

The current capabilities do have limitations. Three major areas require improvement.

- The capacity to perform persistent wide area surveillance.
- The ability to identify and classify targets and determine intent.
- The timely integration of data from all sensors available from different government and non-government security departments.

The following sections discuss the enhanced capabilities available from space-based SAR-MTI sensors such as RADARSAT-2. They also discuss the integration of such data into a common environment with the use of extended common data formats such as STANAG 4607. Finally, they describe the extended exploitation possibilities available from this integration.

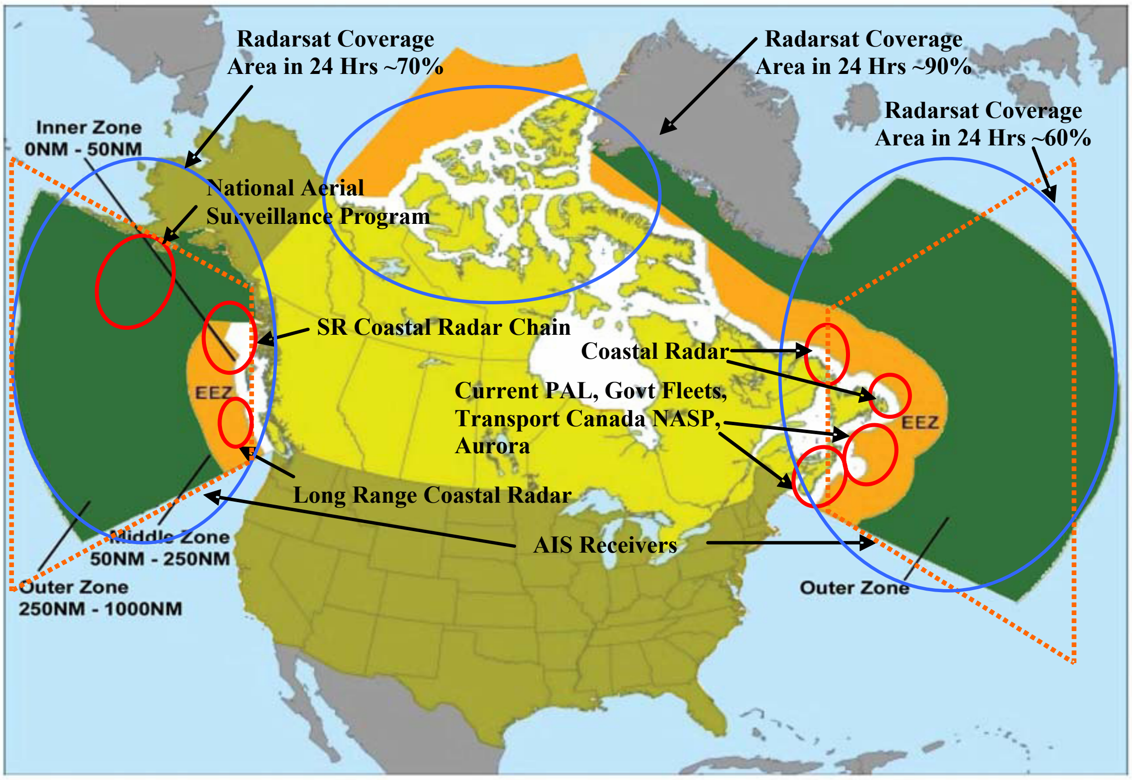


Figure 1. The Canadian coasts

3.0 SPACE-BASED SAR-MTI CAPABILITIES

Space-based surveillance concepts have generated interest among nations for several decades. Recently, technological advances in hardware and in data processing capacity have made a space-based SAR-MTI surveillance concept a near-term reality. The main function of this concept is to provide a previously unavailable information layer to exploitation or C2 stations. The construction of this new information plane takes advantage of capabilities unique to space-based platforms, and to multichannel SAR-MTI sensors, respectively. The main improvements offered by this approach for maritime ISR are in the areas of wide-area land and maritime surveillance, provision of early warning, and the cueing of other sensors to areas of interest.

Space-based surveillance platforms have the following useful properties:

- Wide-Area Surveillance Capability: The SBR concept provides a coverage area not matched by current non-space-based sensors. SBR satellites are capable of surveying large areas of terrain, day or night, and in all weather conditions.
- Response Time: A measure of the overall delay or latencies involved in the provision of surveillance information by the space platform(s) to the requestor. Space-based sensors generally have an advantage over airborne ones for open ocean or outer zone surveillance, and their response time only improves with the number of available platforms.
- Global Surveillance: An SBS is able to scan multiple areas of interest around the world. However, for consistent coverage more space-based assets are required (for example, a constellation). The flexibility of coverage provided by a single SBS is limited by its orbit characteristics, dwell time,

and time lags to re-task.

- Change Detection: SBS have the ability to image or survey multiple areas, from pre-hostility through to post-hostility environments, regardless of geographic or political issues. An analyst using change detection techniques to provide early warning would enable more timely responses to political or strategic changes.
- Vulnerability: Space-based sensors are not easily incapacitated. Current, conventional counter measures and measures available to poorly financed groups do not have the capabilities required to search and destroy space-based platforms. Developments in the area of ballistic missile availability and space launch capabilities are becoming more widely available and may provide the capability of destroying space assets to these groups.

In addition, multichannel SAR-MTI offers three main advantages over 'classical MTI' radars.

- Enhanced Cross-Range target localization: A "classical MTI" radar is a real aperture radar. As such, its ability to resolve targets in the cross-range direction is limited to the radar's along-track (azimuth) beamwidth at the target. In a SAR, the cross-range or azimuth position is obtained by coherent processing of a target's radar returns over the entire time said target was within the footprint of the radar beam [5]. This is known as synthesizing an aperture. Coherent processing positions the target in azimuth at the along-track location where the target was broadside to the sensor (neglecting beam squint). Therefore, a SAR can localize a target in the cross range (azimuth) direction to a much greater precision than the synthetic aperture length, providing much better cross-range resolution than classical MTI radars.
- Additional degrees of freedom to exploit: Multiple simultaneous receiving channels offer flexibility in analyzing targets by providing additional independent measurements (degrees of freedom, or DOF), which can be exploited in different ways [6]. These DOF can be used to enhance moving target detection by increasing their contrast with the stationary background (clutter suppression), or to aid in target motion estimation by increasing the statistical significance of the motion measurements (moving target enhancement). This ability is especially useful for radar returns from slow, weak targets.
- Imaging Capability: Unlike 'Classical MTI' radars, a SAR with MTI capability is fundamentally an imaging system. When MTI is conducted with typical SAR operating parameters (i.e. beam modes), MTI and SAR processing functions can be simultaneously performed in parallel. This permits a SAR-MTI system to generate a radar image of the stationary background on which to overlay MTI detections.

Canada has been involved in the implementation of SBR concepts since 1995 with the launch of RADARSAT-1 and is pursuing this under the RADARSAT-2 GMTI project [2]. The concept design is driven by the need for the primary SAR sensor to provide MTI capability in addition to SAR imagery. RADARSAT-2 [7] is located in the same 800km polar, sun-synchronous, "frozen" dawn-dusk orbit, as RADARSAT-1. It retains all the RADARSAT-1 beam modes as well as providing new high resolution and polarimetric modes. It also has the ability to roll in order to utilize these modes, as shown in Figure 2, to the left or right of the satellite track, greatly increasing terrain access opportunities. RADARSAT-2 has also been augmented with the addition of a DND experimental MTI capability, called the Moving Object Detection Experiment (MODEX), which aims to demonstrate the capabilities and the utility (including bi-lateral or multi-lateral interoperability with NATO/coalition partners) of space-based SAR-MTI data [8]. RADARSAT-2 MODEX will not be an operational system, but will assist in identifying design issues and defining properties of future operational MTI spacecraft, processing systems, and concepts of operation. Also, it will demonstrate how the combination of space-based assets with current ISR sources will help alleviate some of the issues that face today's surveillance systems. However, space-based SAR-MTI sensors are to provide an additional military capability and are not intended as replacements for existing platforms, technologies, or capabilities.

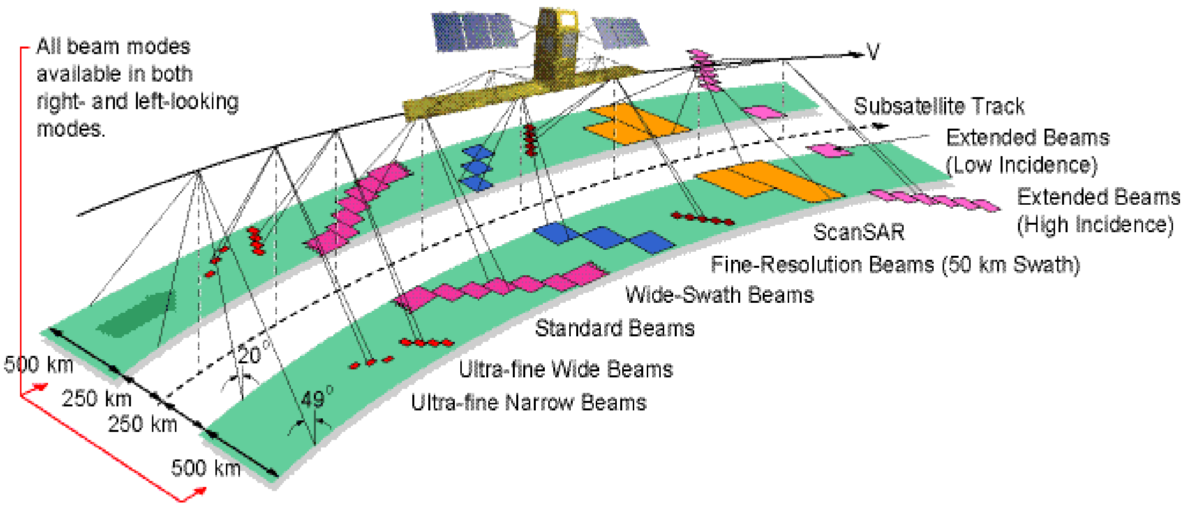


Figure 2: RADARSAT-2 beam modes

The current ISR protocols (such as STANAG 4607) are not fully capable of accommodating data from SBS. Therefore, there is a requirement to modify these protocols to enable exploitation systems to receive and exploit SBS data to their fullest capability. The following section provides information on how and why these protocols require improvement.

4.0 INTEGRATION OF SPACE-BASED SAR-MTI WITHIN A MARITIME ISR ENVIRONMENT

"Interoperability: the ability of two or more systems or components to exchange information and to use information that has been exchanged" [9]. Technical interoperability between various sensors and ground processing workstations can be achieved through the standardization of network and protocol formats. Projects such as "Coalition Aerial Surveillance And Reconnaissance" and "Multi-sensor Aerospace/Ground Joint ISR Interoperability Coalition" (CAESAR/MAJIIC) [10,11] have defined, developed and demonstrated the methods and standards to interconnect these various sensors and ground exploitation systems to allow the sharing of data and intelligence in a real-time shared networked environment. The integration of ISR assets in an interoperable environment provided more robust surveillance architecture, through networking and the use of standard formats. Exploitation workstations were able to receive and process sensor data from multiple assets and generate a common operating picture. The RADARSAT-2 Simulator was successfully integrated into this CAESAR/MAJIIC network and was the first simulated space-based radar sensor to provide MTI data using the (baseline) STANAG 4607, demonstrating the concept of SBS integration into present ISR architectures.

Figure 3 shows the interoperability between the sensors, exploitation workstations, and the C2 system. This interoperability was established by using NATO protocols, and also shows how sensor data are being processed and converted to C2 products.

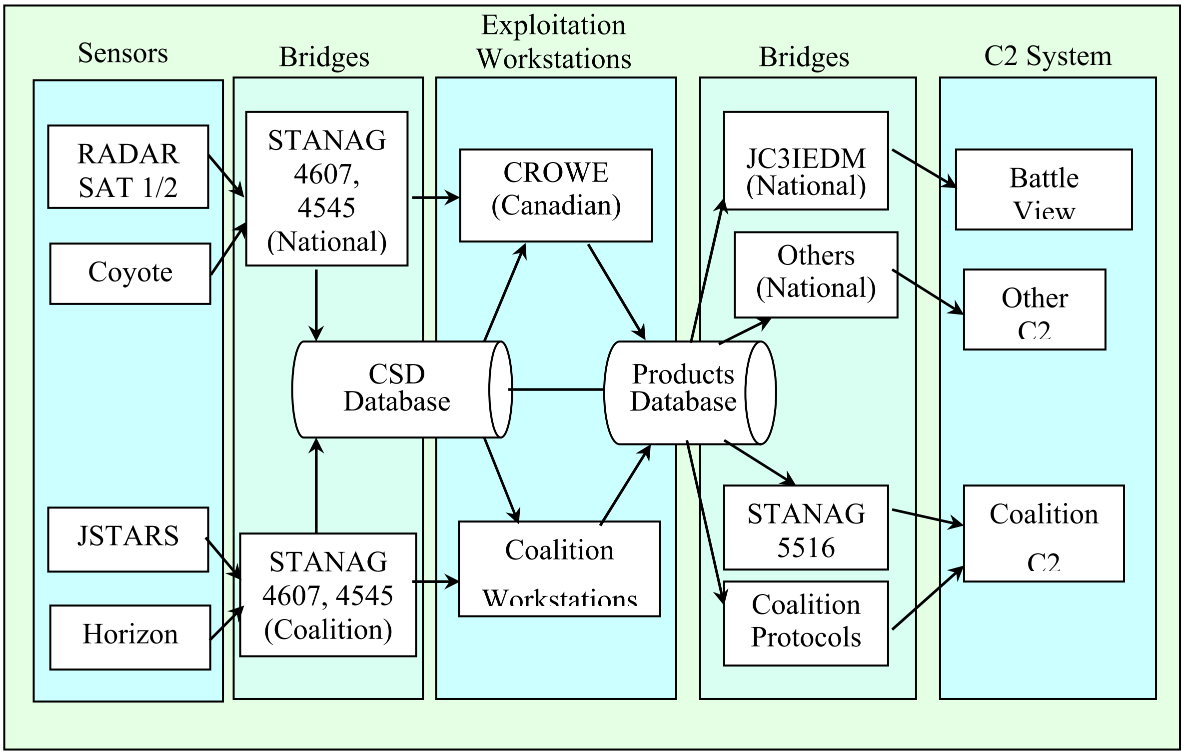


Figure 3. Interoperability between sensors, exploitation workstations, and C2 systems

4.1 The baseline (airborne) STANAG 4607

STANAG 4607 [12], is primarily intended for data exchange between GMTI radar sensors and exploitation systems, and it defines a common standard for the MTI data. It provides a structured approach for various types of users (for example, low or high bandwidth users). The format is scalable to all levels of capability. Small-scale systems can use only those elements of the format required to transmit their data, while more robust systems can use more aspects of the format to encode all available information. To accomplish this scalability, the format uses two technical approaches.

- The format is divided into segments, with no predefined order or sequence other than the requirement to preface data segments with appropriate header segments, as shown in Figure 4. Each system using the standard is free to select the particular segments it requires for the data produced.
- Not all of the data fields within the segments need be sent, but may be transmitted if they are available and if they provide added value or utility and are not constrained by communications or operational considerations.

The format is not tailored to any specific communications systems and their requirements must be tailored to each system on a case-by-case basis. With these approaches, each segment can be tailored to the data format requirements of the particular system. Therefore, it can be used to disseminate data at any processing/exploitation stage shown in Figure 3.

4.2 STANAG shortcomings and solutions with respect to SBR-MTI

The baseline version of STANAG 4607 was originally developed based on the capabilities of “classical MTI” sensors aboard airborne platforms. Therefore, it contains some shortcomings in its ability to support space-based SAR-MTI data. The following discusses the modifications made to the baseline STANAG

4607 to accommodate data from SBS, in particular from RADARSAT-2.

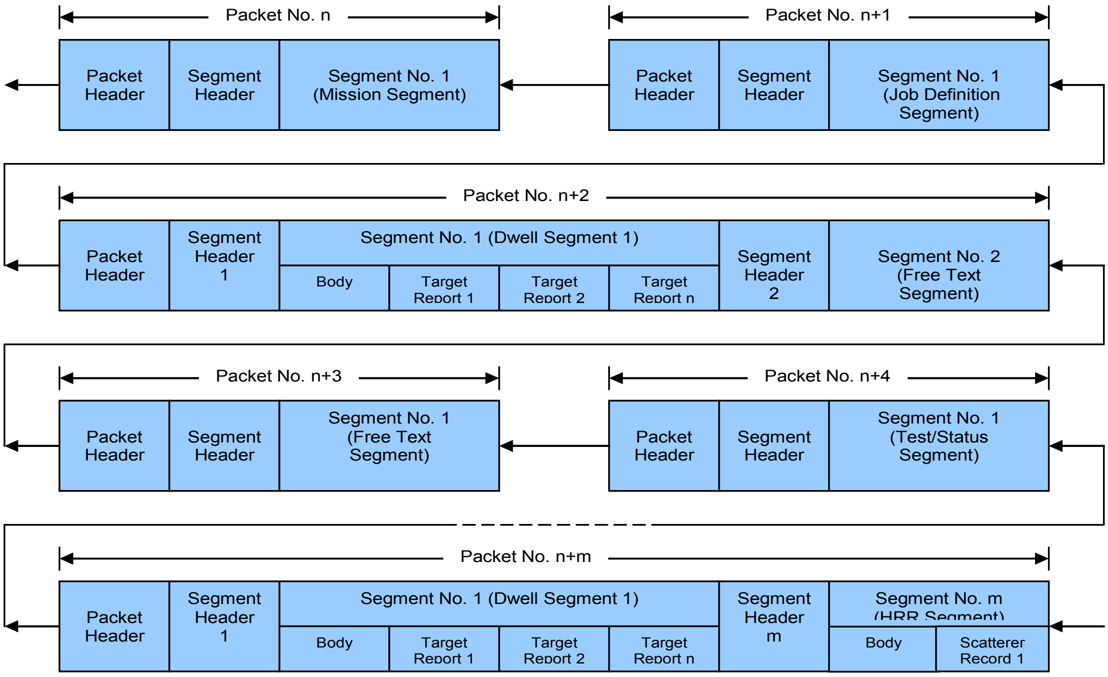


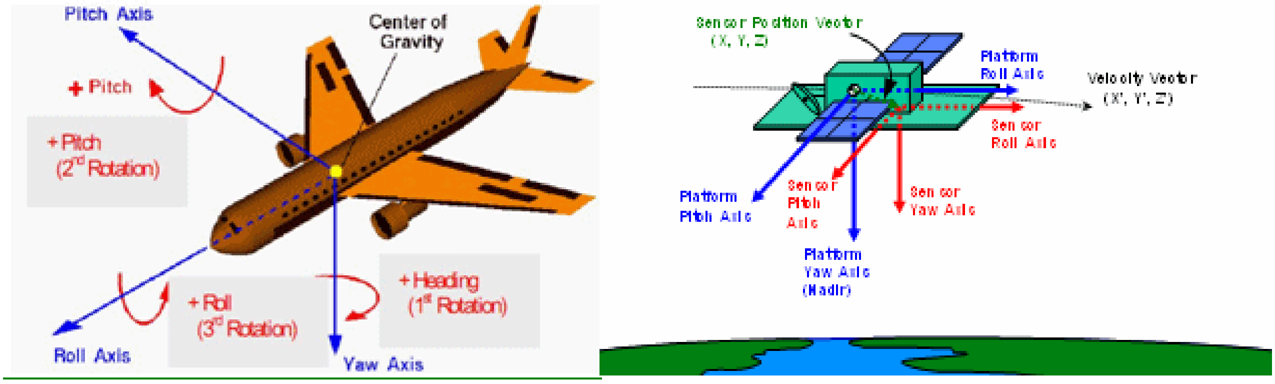
Figure 4- Notional GMTI Format Structure (from [12])

4.2.1 Coordinate systems for space-based platforms

In the baseline (airborne) STANAG, sensor and platform positions are measured in a geodetic system. This works well for airborne platforms but not for space-based ones. The cost of reporting spacecraft position in a geodetic system is a loss in the accuracy of the position specification and its dependence on the particular ellipsoid and/or geoid models used in the transformation [13]. Orbiting platform position coordinates are naturally expressed, to a high degree of accuracy, in an Earth-Centred Cartesian coordinate system. It was therefore decided that the advanced dwell segment extension should contain fields specifying the satellite position in such a system.

The baseline STANAG also defines a platform orientation system at the platform location. The platform orientation is expressed in terms of Heading from true north (or Yaw), Pitch, and Roll as a series of rotations with respect to level flight, as shown in Figure 5(a). Again this attitude specification is sufficient to describe the orientation of an airborne platform, but fails for one in space. A satellite on orbit follows a specified path in inertial space, but the projection of its track onto the ground follows a more complicated path due to the rotation of the earth beneath the satellite. As such, the ground track heading from true north is constantly changing. It was therefore decided that the advanced dwell extension should support the specification of platform attitude in a standard spacecraft-centred coordinate system, as is illustrated in Figure 5(b).

These additions allow for the complete specification of platform and sensor positions and velocities, as well as antenna pointing information, to as high a degree of accuracy as can be provided by the platform in question.



(a) (b)

Figure 5 Coordinate systems for (a) airborne platform (from [9]) (b) spacecraft

4.2.2 SAR dwell definition and sensor-centered coordinates

The dwell segment as defined in the baseline STANAG does not necessarily have a one-to-one relationship to a radar dwell. It allows a sensor to report on a grouping of zero or more target reports for which the sensor provides a single time, sensor position, reference position, with simple estimates for the observed area at the reported time. All of the target reports within a dwell segment are valid for the same time [14]. This presents problems for side-looking SAR systems such as RADARSAT-2, where the radar returns are coherently processed to improve resolution in the cross-range direction. This cross-range "direction" can be expressed as an angle, or, in the case of a SAR, as the along-track or azimuth position.

The solution chosen for reporting RADARSAT-2 SAR-MTI data is to define a 'dwell' as a subset of the coherently processed SAR image and "pretend" that all targets detected within that image subset were observed at the dwell time reported in the dwell segment. This is shown conceptually in Figure 6. Radar returns are coherently processed over Coherent Processing Intervals (CPIs) to compress target energy in azimuth. Azimuth subsets (groups of CPIs) are assembled into dwells, and revisits are not applicable to RADARSAT-2.

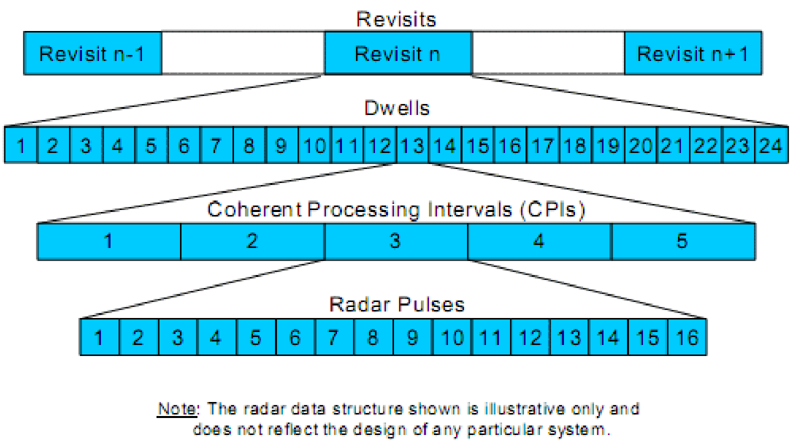


Figure 6. Notional radar dwell structure (from [12])

The baseline STANAG lacks capability to report a target position as measured by the radar, that is, in native sensor-centered coordinates. Access to these direct measurements, along with knowledge of platform position, antenna pointing, and an earth model, permit highly accurate geographic coordinates to be calculated. This enables an exploitation station to recalculate more accurate geographic positions based on better maps, elevation models, or other ancillary information, than may be available to the sensors or their ground stations.

It was therefore decided that target slant range and cross range measurements should be included in the STANAG. The slant range is reported simply as the linear sensor to target distance at broadside. The cross-range position is reported in sensor centred coordinates using angles from the sensor to the target, or in the case of SAR, an along-track azimuth position. The azimuth position is reported not as a linear distance, but as a (slow) time (the pulse transmission time). The absolute time at which the target is detected specifies where on orbit the platform was located when it was broadside to the target. These additions allow for the complete specification of target position in sensor-centred coordinates.

4.2.3 Additional target characterization and error estimates

This subsection discusses additional data related to target, sensor and data processing properties. Most of the quantities listed are optional and need only be transmitted if platforms can or wish to provide the data. It was decided that these quantities should be added to the baseline STANAG in order to provide additional sensor and target ancillary data, as well as error estimates, to enhance exploitation possibilities.

Target radial (line of sight) velocity

The baseline STANAG provides a single field to report the target radial (line of sight) velocity. However, certain MTI sensors can measure more than the radial velocity. RADARSAT-2 will be able to resolve two velocity components for ground moving targets; one in the along-track (azimuth) direction and the other in the cross-track (ground range) direction. These components can also be expressed as a target speed and heading. The addition of these quantities allows more accurate reporting of the target velocity vector in the format most appropriate to the platform in question.

Target classification

The baseline STANAG target report contains fields for target classification and its probability. However, a sensor or its groundstation may not have access to enough information to appropriately classify a target type. Hence the inclusion of additional target properties like the incidence angle at the target and its radar cross section to the target report extension provides additional information that can be used by an exploitation station to either classify an unknown target, or to update a previous classification provided in the base target report.

Radar and processing parameters

A number of potentially useful radar and processing parameters are also included in the advanced segment extensions. These include the radar carrier frequency, the 3 dB beamwidths in azimuth and elevation, the slant range resolution (impulse response width) and pixel spacing, the cross-range resolution and pixel spacing, the range aliasing distance (wrap range), the minimum range of the dwell and the terrain elevation at the centre of the dwell. These allow an exploitation station to perform any calculations necessary. They also provide a level of redundancy; that is, certain data elements can be used to cross check other elements and ensure internal consistency of the data.

Error quantities

Certain quantities in the baseline STANAG are accompanied by estimates of the error in that quantity, while others have no associated error. Therefore, error estimates are provided not only for quantities added to the advanced extensions, but also for quantities for which no error estimates are provided in the baseline STANAG. The addition or error estimates for all the reported quantities should provide powerful tools to assist in data-based decision making.

5.0 EXPLOITATION OF SB SAR-MTI DATA: ANALYSIS AND RESULTS

The effectiveness of SBS in enhancing baseline maritime ISR sensors capability can be measured with different figures of merit and these figures can be selected based on maritime requirements [15]. Space-based SAR-MTI assets can augment the local ISR sensors in different areas (defined in Section 3), such as wide area surveillance or coverage capability [16]. In order to fully exploit these augmentations, the new data must be integrated into the COP available to exploitation and C2 stations. This integration requires that existing common data formats, such as STANAG 4607, be modified to support new data, as discussed in Section 4. This will improve the coastal surveillance by looking into open ocean or outer zone areas and detecting the potential targets as early as possible and provide early warning. It is highly important to recognize moving objects as early as possible and determine in advance if they are Friend or Foe. This allows strategic responses to be formulated in a timely and effective manner to conduct classification/identification and tracking of the potential targets as they get closer to the shore.

5.1 Exploitation

As shown in Figure 3, the data from RADARSAT-2 (SAR-MTI) and baseline ISR sensors are fed to exploitation workstations to fuse the information and produce products which provide better situational awareness for operators. In order to achieve this, all the data from sensors need to be commonly registered. Therefore, through this standard network and data formats, the national and coalition exploitation workstations are able to receive and exploit sensor data such as SAR-MTI and able to generate a robust common operating picture with exploitation products, such as tracks, target classification and/or identification, prediction on target movements, and intent, etc.

SAR-MTI data can be exploited in different ways, for example:

- Create target clusters or tracks from SAR-MTI detections.
- Evaluate the target (Ship) reporting integrity, by correlating space-based SAR-MTI information with AIS data. AIS signals can be received by transponders on other ships, land bases, aircraft, or satellites. In this manner, a “filter” can be constructed which will highlight only those ship detections of interest to the particular user.
- Evaluate the target features or properties, by correlating the space-based SAR-MTI information with other imagery (SAR, EO, IR) and data from other MTI or other Measurement And Signatures Intelligence (MASINT) sensors to aid in target classification.
- Attempt to evaluate target intent by correlating the space-based SAR-MTI information with intelligence obtained from signals (SIGINT) or human (HUMINT) sources.
- Provide early warning for cueing other ISR assets: airborne assets can be tasked to collect more information from targets of interest identified from space-based SAR-MTI, using specified criteria.

5.2 Modelling and simulation environment

For modelling and simulation, there are two environments that were used in this analysis: Simulation Laboratory (SIMLAB), which was developed at DRDC Ottawa, and Satellite Tool Kit (STK), which was developed by Analytical Graphics Inc. The SBS and other types of ISR sensors can be modelled in great detail with the SIMLAB. This environment allows one to develop different ISR architectures and evaluate ISR sensor architecture performance. STK is another modelling environment, which offers a suite of satellite, sensors, targets, and coverage model entities for building high-level early-phase performance assessment of different ISR sensor architectures [16].

5.3 Scenarios, results and analysis

Two scenarios have been considered here for analysis. In generating these scenarios, a baseline surveillance capability was modelled in SIMLAB using a sample of typical ISR sensors. These baseline sensors are listed in Tables 1 and 2. As such, they are not intended to evaluate the effectiveness of current Canadian ISR assets, but rather as a demonstration of how space-based SAR-MTI can enhance a baseline surveillance capability. The first scenario is based on overall coverage of coastal areas, to evaluate the coverage improvement provided by SBS. The second scenario focuses on (simulated) maritime target detection, and demonstrates (a) the detection performance of SAR-GMTI sensors and (b) the benefits of integrating space-based SAR-GMTI with baseline ISR sensors.

Table 1. A coverage simulation analysis of all Canadian coasts

		Location		
		East Coast	**West Coast**	**North**
1	**Coverage Percentage (of the area is covered in 24 hours)**			
	RADARSAT-2	~ 60%	~70 %	~ 90 %
	Baseline Sensors	EEZ: Smaller gaps Outer Zone: Larger gaps	Same as East coast	Reduced capability vs. other coasts.
2	**Revisit overall (# of revisit per 24 hours) – Based on overall coastal zones**			
	RADARSAT-2	9	7	10
	Baseline Sensors	EEZ: More frequent Outer Zone: much less frequent or accessible	Same as East Coast	Reduced capability vs. other coasts.
3	**Revisit based on .2 Deg. Resolution (# of revisit per 24 hours) – based on the resolution within the coastal areas**			
	RADARSAT-2	Max=5, Min=0, Avg=1.32	Max=4, Min=0, Avg=1.24	Max=7, Min=0, Avg=3.43
	Baseline Sensors	EEZ: More frequent Outer Zone: much less frequent or accessible	Same as East Coast	Reduced capability vs. other coasts.
4	Response Time			
	RADARSAT-2	In both zones (EEZ & Outer) ~12 hours	Same as East Coast	~8-9 hrs
	Baseline Sensors	EEZ Zone: 98% faster with respect to RADARSAT-2 Outer Zone: 30% slower than RADARSAT-2	Same as East Coast	About 50% more than RADARSAT-2, or not accessible

The coverage simulation results from the first scenario are shown in Table 1 and also summarized in Figure 1. They show the coverage of the baseline assets and of RADARSAT-2, and demonstrate that RADARSAT-2 can provide wide-area surveillance in both the Exclusive Economic Zone (EEZ) and outer zones. The baseline assets can provide frequent coverage, with some gaps, over the EEZ. The largest coverage gap is in the outer zone. RADARSAT-2 provides even more consistence coverage over the northern part of Canada. If the zones are divided in 0.2- degree sub-sections, each sub-section can be scanned by RADARSAT-2 an average of 3.4 times per day, and a maximum of 7 times per day for the Northern Zone, and provide coverage for almost 90 percent of area. The East and West coasts are also being scanned by RADARSAT-2 a few times per day, but due to the size of the zones and the lower latitude, on the average each sub-section is visited 1.3 times per day and a maximum of 5 times per day, which provides coverage over 60 to 70 percent of the area.

The second scenario is based on a few maritime targets off the Canadian East coast, as shown in Figure 6. These targets were detected by baseline sensors and also by RADARSAT-2 SAR-MTI. The results are given in Table 2 and show that RADARSAT-2 can provide more area coverage, but that the limitation was the revisit time to the targets. The satellite passes over the area of interest 1 to 5 times, whereas the current assets can provide much more frequent revisits of the area of interest, as long as it is located in the EEZ. RADARSAT-2 provides much more contribution in the outer zone or in the open ocean. The results also show the augmentation of capabilities possible by integrating SAR-MTI data with data from baseline ISR sensors. This is demonstrated by the 29% reduction in the maximum detection gap time provided by the addition of a single space-based asset. To further reduce this time, a constellation would be required. This combination of both baseline assets and RADARSAT-2 provides more robust and consistent surveillance capability.

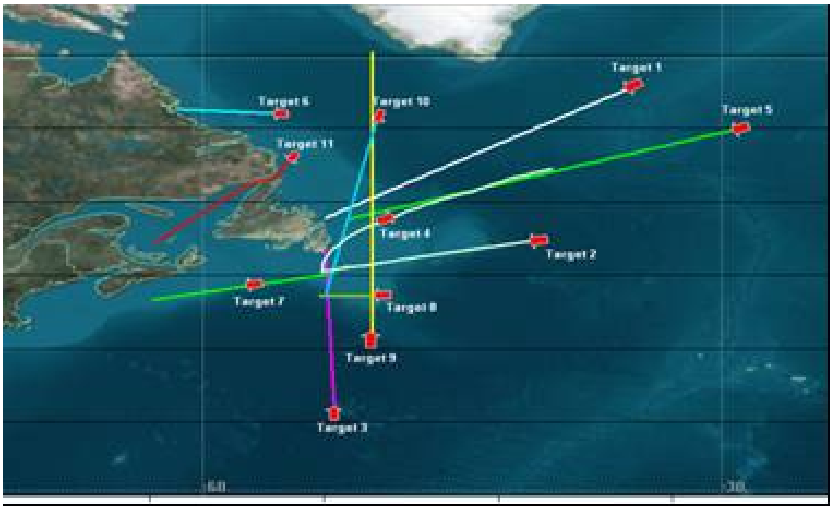


Figure 6. Canadian East coast maritime scenario

Table 2. Maritime Scenario results and analysis

	ISR Sensor Architecture			
	Baseline Sensors	**RADARSAT-2**	**Baseline + RADARSAT-2**	**Comments**
Percentage of targets Detected	n	1.25n	100	25% more targets detected by RADARSAT-2 alone; all targets detected by the combination

Average # of revisits	large	2 (dawn/dusk)	large	Much less revisits provided by RADARSAT-2 alone
Maximum detection gap – over all targets	N	0.985N	0.71N	29% reduction in maximum detection gap time from combination

6.0 CONCLUSIONS

This paper has provided evidence for how an augmented architecture of current maritime ISR assets and SBR assets can achieve mandated military goals and overcome some of the significant limitations exhibited by the individual assets. Specifically, it has discussed the following points

- A selection of Canadian Maritime ISR capabilities
- Improvements to baseline capability by taking advantage of unique features of space-based SAR-MTI data.
- Integration of space-based SAR-MTI data into a maritime ISR environment and the changes required to existing MTI data exchange protocols.
- Increased exploitation possibilities and an overall improvement in situational awareness or the COP

RADARSAT-2 demonstrated limited capability in providing wide-area surveillance. It was capable of covering both the East and West coasts about 60 percent of time within a 24 hour period and 90 percent for the northern part of Canada. RADARSAT-2 can have a major impact on costal security by providing coverage in the outer zone. It can augment coastal ISR assets by providing coverage in gap areas and by providing early warning to cue other assets for further investigation. The RADARSAT-2 data can also be exploited by correlating them with data from current assets to identify potential hostile targets, which will enhance the overall situational awareness.

The Canadian Department of National Defence intends to use MODEX to demonstrate the feasibility and military utility of space borne SAR-MTI measurements for various situational awareness, surveillance, and monitoring applications. MODEX will also provide information and recommendations for the conception and design of future operational space-based MTI systems. These future systems would need to consist of multiple satellites in order to provide more complete and timely coverage of areas of interest. They would also have a scan-and-dwell capability to enable: (a) large area searches in a scan mode to detect targets, and (b) dwelling on selected targets several times to refine measurements and compile target tracks.

Common data protocols must also continue to evolve in support of new sensor capabilities. Future versions of STANAG 4607, for example, could contain features such as a maritime mode segment, where the extensions provide additional information not available in existing segments. This extension could provide extremely useful data for enhanced detection and parameter estimation of ships [17].

Overall, the enhanced sensor and interoperability capabilities described in this paper provide an increased capacity to exploit MTI data, as well as an additional information layer, which should therefore improve the overall situational awareness or COP available in coastal surveillance and border security operations.

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