Capabilities of Canada's planned RADARSAT Constellation

Dirk Geudtner, Canadian Space Agency, Canada
Guy Séguin, Canadian Space Agency, Canada

Abstract

The CSA has initiated a feasibility study for a constellation of low-cost small SAR satellites to ensure C-band data continuity beyond RADARSAT-2. The concept involves three satellites with an option of flying up to six satellites. This is to provide operationally SAR imagery for key maritime surveillance applications such as ship detection, oil spill monitoring, and sea ice mapping. Other applications focus on disaster management and SAR interferometry (InSAR) coherent change detection of land surfaces for geohazards, climate change, and environment monitoring. This paper describes the applications requirements and provides an overview of the mission concept with a special focus on the imaging capabilities of the planned RADARSAT constellation.

1 Introduction

1.1 SAR Constellation Concept

The Canadian Space Agency (CSA) is currently conducting a “Phase A” feasibility study on the development of a C-band SAR satellite constellation referred to as RADARSAT Constellation. This is a follow-on project to the RADARSAT-2 program. However, for the RADARSAT Constellation a new approach is being used, which focuses on the use of low-cost small-satellites flying in a constellation configuration. The low-cost small-satellite concept allows a significant reduction of costs specifically for the launch because of reductions in the satellite's mass and volume [1]. It also, enables long-time operations of such a SAR constellation due to the possibility of an affordable progressive replacement of defective satellites [2].

In general, a constellation of SAR satellites can provide a larger coverage, increased revisits, and higher system reliability [3] than is possible with only one satellite. This reduces significantly the risk of data interruption in the case of a spacecraft failure. Furthermore, the constellation approach increases the availability of SAR imagery, which supports specifically operational and time-critical applications. Also, depending on the number of satellites and their orbital configuration, the constellation concept enables the implementation of SAR interferometry (InSAR) capabilities including suitable baselines and short time intervals between SAR data acquisitions. The trade-off for using small SAR satellites is a somewhat limited variability of imaging modes due to the smaller SAR antenna size and lower available power as compared to a RADARSAT-2-type satellite. However, this constraint can be compensated by designing the SAR system to fulfil specifically user requirements for key applications envisaged as primary mission objectives.

1.2 Mission Objectives

The main objective of the RADARSAT Constellation mission is to ensure C-band SAR data continuity beyond RADARSAT-2 and to provide SAR imagery for operational applications and services.

The current concept involves three satellites with an option of flying up to six satellites (see **Figure 1**). This is to meet specific revisit and coverage requirements defined by operational users in Canada for key maritime surveillance applications such as ship detection, oil spill monitoring, and sea ice mapping. Other key applications focus on disaster management and InSAR coherent change detection of land surfaces for geohazards, climate change, and environment monitoring. In addition, the constellation shall also be capable of acquiring globally SAR data to serve the international SAR user community. Furthermore, to achieve a low-cost implementation, a cost cap has been imposed on the satellite bus, the SAR system, and the launcher.

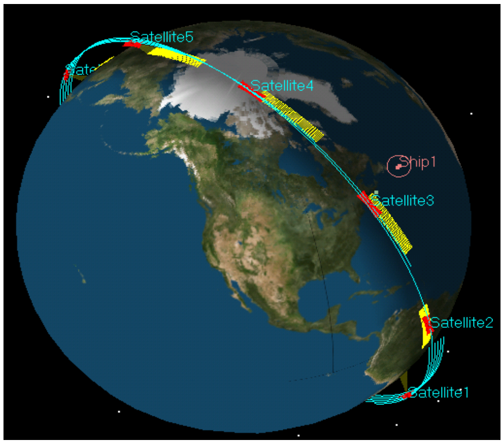

Figure 1 Constellation with six SAR satellites

2 Application Requirements

2.1 Maritime Surveillance

Canada's coastline is the world's longest at 243,792 km bordering the North Atlantic Ocean on the east, North Pacific Ocean on the west, and the Arctic Ocean on the north. Because of this geographic location, Canada has a strong need for coastal and maritime surveillance, sea ice mapping, fisheries and environmental monitoring. Therefore, user requirements for operational maritime surveillance represent the primary mission goals.

2.1.1 Ship Detection

Canada’s coastal and marine security requires a frequent monitoring of the waters off the coasts of Canada. Specifically, the Department of National Defense (DND) and Transport Canada require information on the location and identification of ships being in Canadian waters and approaching from nearby areas. The region of interest extends up to 1000 nm and is grouped into three zones: the inner, middle, and outer zone (see **Figure 2**). There is a requirement to provide daily SAR data coverage of all zones with the objective to reliably detect and track vessels of 25 m sizes under sea state 5 conditions.

Also, Canada's Department for Fisheries and Oceans (DFO) requires the identification of ships fishing illegally in Canadian waters. The main areas of interest are off Canada’s west coast and the Great Banks region in Newfoundland.

2.1.2 Sea Ice and Oil Spill Monitoring

The Canadian Ice Service (CIS) uses operationally ScanSAR data from RADARSAT and ENVISAT to produce ice cover maps for safe maritime navigation in the Arctic, in the Gulf of St-Lawrence, and in the Great Lakes. **Figure 2** also shows CIS' regions of interest.

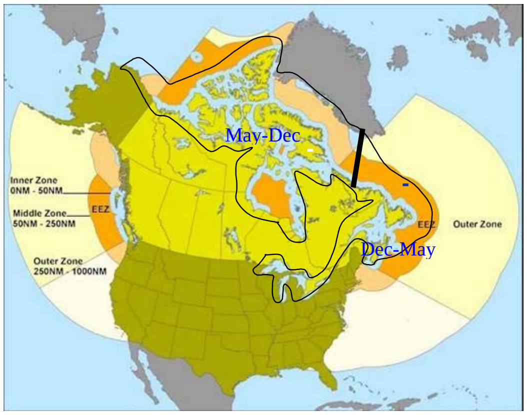

Figure 2 Canadian zones of interest for maritime surveillance and sea ice mapping

From May to December, ice-monitoring activities are centred on the northern Canadian waters, from Hudson Bay up to Ellesmere Island, and from the Alaskan coast to Greenland and Labrador. From December to May, ice-monitoring activities focus on the Great Lakes and Gulf of St-Lawrence, as well as waters off the Labrador coast and Newfoundland.

CIS' near real-time ice mapping service requires a daily SAR data coverage of the regions of interest at a spatial resolution of ~100 m. The performance of the ScanSAR beam mode shall be similar to RADARSAT ScanSAR modes, having a mean NESZ of –26 dB and a maximal NESZ variation of 6 dB.

Another CIS application for SAR imagery involves the detection and tracking of icebergs in Baffin Bay during the fall season and in the Grand Banks throughout the summer months.

In addition, the CIS will be responsible for providing data to Environment Canada’s "Integrated Satellite Tracking of Polluters Program" (ISTOP). This requires daily monitoring of the major shipping lanes in Canadian waters, including the Great Lakes, to detect potential oil slicks caused by vessels dumping illegally oil into the water. The detection of oil spills requires steep incidence angles and a NESZ of at least 6 dB below the sea surface radar reflectivity.

In support of the above-mentioned maritime applications, the quality of the SAR imagery acquired over ocean waters shall be sufficient to allow the derivation of additional geophysical parameters from the data such as wind and wave height.

2.2 Land Surface Change Detection Monitoring

The SAR user community for land surface applications and solid Earth science requires a frequent monitoring of Canada's land territory and other target areas in the world. This is to allow change detection monitoring of areas affected by geohazards, climate change related processes, and man-made activities. Specifically, coherent change detection monitoring requires repeat-pass InSAR capable ScanSAR and high-resolution strip-map beam modes to support high accuracy measurement techniques such as differential InSAR, permanent scatterer (PS-InSAR), speckle tracking, and coherence analysis. Generally for C-band InSAR applications, short time intervals between SAR data acquisitions are required to minimize temporal decorrelation effects. Also, there is a requirement for small interferometric baselines to reduce the topographic phase contribution.

The objective is to acquire InSAR data pairs that are suitable for generating geographically comprehensive maps of surface change at the required sensitivity, spatial resolution and temporal frequency. Furthermore, land use applications such as forest, crop growth, wetland and eco system monitoring require frequent SAR observations during the growing seasons.

2.2.1 Geohazards Monitoring

Geohazard applications require sensitive measurements of small-scale surface deformations caused by tectonic processes, volcanic activities, landslides, and subsidence.

Crustal deformations resulting from inter-seismic accumulation of strain leading up to earthquakes as well as post-seismic strain relaxations following earthquakes have usually mm-sized displacements and long wavelengths. The measurement of such subtle geophysical signals requires repeated observations over large areas. Especially, frequent ScanSAR acquisitions having a swath-width of at least 200 km are required over tectonic active areas along plate boundary deformation zones and regions of mid-plate volcanism. Also, the spatial resolution of the InSAR capable beam modes needs to account for specific deformation gradient and rotation limits.

For volcano monitoring, the key observable is the spatial and temporal extent of ground deformation prior to, during, and after volcanic eruptions or intrusive events. Surface changes caused either by the emplacement of new lava flows or by the collapse of volcanic craters can also be derived from InSAR coherence maps.

The measurement of terrain subsidence caused my man-made activities such as mining, underground construction, and fluid withdrawal from hydrocarbon reservoirs or aquifers also requires long-term observations over large areas.

For landslide monitoring, the evolution of InSAR correlation signatures can be used to detect early signs of incipient ground failure. The steep slope angle and the relatively small extend of landslides usually require high-resolution strip-map modes with a large look angle range.

2.2.2 Climate Change Monitoring

Monitoring of Earth’s polar regions and the measurement of the dynamic processes in the cryosphere are important parts of climate change studies. Changes in the extent, thickness, and dynamics of ice shelves, ice streams and glaciers in Antarctica, as well as in Arctic sea ice and permafrost are significant indicators of global warming.

Ice velocity is the fundamental parameter representing cryosphere dynamics. Based on experiences with data from the ERS-1/2 tandem and the RADARSAT Antarctic Mapping missions, differential InSAR measurements of large ice velocities (i.e., more than 300 m/a) require revisit time intervals on the order of a few days and a wide-area coverage.

Another important observable is the detection of the grounding line, which is the transition between floating and grounded ice. Knowledge of its position using InSAR coherence maps with a spatial resolution on the order of 30 m permits changes in ice thickness to be inferred. These measurements are important in assessing ice mass balance and in understanding the flow dynamics of ice sheets [4].

In Arctic regions, melting of ground ice or permafrost can lead to terrain subsidence and landslides, which can cause severe damage to infrastructure such as pipelines and roads. The resulting InSAR imaging requirements are similar to those as discussed for geohazard monitoring.

In addition, the velocity estimation of fast moving mountain glacier ice requires a high-resolution strip-map beam mode and short revisit intervals.

For monitoring coastal change to due erosion processes and sea level rise, InSAR coherence maps can be used, having a spatial resolution of ~30 m.

2.3 Disaster Management

For the disaster management community to effectively respond in fast evolving natural disaster situations such as floods and hurricanes, a high temporal and wide-area SAR data coverage is required. This is to provide an early warning and operational support for disaster mitigation. For this, ScanSAR imagery with daily acquisitions over the area of interest is required.

3 Mission Concept

The mission concept that is currently being developed considers two configuration options for the implementation of the constellation. The first option is a three-satellite constellation that could provide on average once daily coverage of Canada. The second option involves six satellites that could cover Canadian territory and waters on average twice daily. In both cases the coverage can be achieved by using a 50 m ScanSAR resolution. Similarly, both options also provide SAR coverage accessibility to most parts of the world once or twice per day, respectively.

The low-cost concept requires that the design of the SAR system is in terms of mass, power consumption, volume, and antenna size, in compliance with the constrains imposed by using a low-cost launch vehicle and a small satellite bus. In this regard, two concepts for a deployable SAR antenna are currently being studied: a 2-panel and a 4-panel (mini RADARSAT) antenna with a length of 6.88 m and 9.15 m, respectively. Thereby, the challenge for maritime surveillance is to achieve a wide-area coverage at a resolution that is suitable for ship detection. Two principal imaging modes are considered: a wide-area ScanSAR and a high-resolution strip-map mode. The ScanSAR mode is designed to have a swath width of 350 km with a 500 km accessible region (see **Figure 3**).

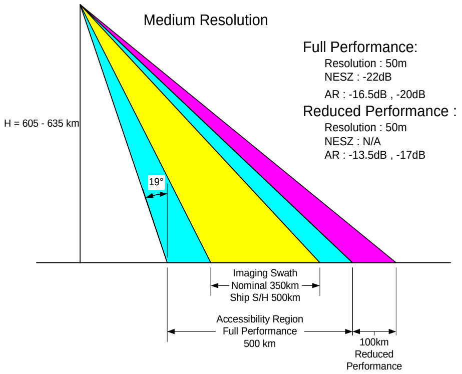

Figure 3 Characteristics of the ScanSAR swath

Using 4-looks in range, this ScanSAR mode provides a medium resolution of 50 m. The trade-off is that depending on the SAR antenna length, between 12 and 16 ScanSAR beams will be necessary to achieve the desired swath width. In this respect, other parameters are currently being analysed, involving variations of the NESZ and resolution across the swath. Regarding image quality assurance, there is a requirement on the ScanSAR beam to provide a mean NESZ of –22 dB with an acceptable radiometric variation of 0.2 dB at the beam boundaries. Additionally, no nadir returns shall be visible in the ScanSAR image.

The high-resolution beam mode with a spatial resolution of 5 m and a swath width of 20 km is intended for specific on-demand image acquisitions. Involving a ground station for commanding, this allows the use of medium resolution ScanSAR data to cue high-resolution SAR data acquisitions over selected areas of interest within a timeframe of ~10 min.

Furthermore, a single radar polarization HH is foreseen with an option of adding a dual polarisation capability for HH and VV. The key system parameters are summarized in **Table 1**.

Radar frequency	C-band
Orbit altitude	~ 600 km
Swath width	20 – 350 km
Accessible swath width	500 km
Spatial resolution	5-50 m
Polarization	HH or dual-pol (HH-VV)
Imaging time	6- 12 min per orbit
Repeat orbit cycle	12 days
Orbit control	100 m tube

Table 1 RADARSAT constellation key system parameters

All satellites of the constellation shall fly in a sun-synchronous dawn-dusk orbit at an altitude of ~600 km. Thereby, the orbital configuration is such that the satellites fly in the same orbital plane, following each other with a time separation of ~32 min and ~16 min, respectively, depending on the number of satellites in the constellation (e.g. three or six satellites). While the ground track of each satellite is slightly shifted due to the Earth rotation, it provides combined ground coverage of up to 1000 km using the medium resolution ScanSAR mode.

The preliminary configuration concept envisages a 12-day repeat orbit cycle for each satellite with the goal to maintain its orbit within an orbital tube of 100 m in diameter with respect to other satellites in the constellation. Using data from these different satellites, this allows the formation of InSAR scene pairs having 4-day (three satellites) or 2-day (six satellites) time intervals, respectively. **Figure 4** shows the orbital configuration of the satellites for both implementation options.

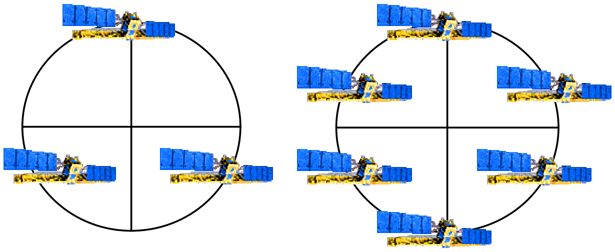

Figure 4 Orbital configurations for a constellation with three satellites (left) and six satellites (right)

Maintaining an orbital tube of 100 m between the satellites of the constellation is only a relative requirement due to the potential drift of the tube. However, for the build-up of long time series for ground deformation analysis it will be necessary that the constellation as a whole needs to maintain its orbit with respect to a stable reference orbit within a tight tolerance. This ensures the availability of suitable baselines over time.

Generally, InSAR applications require a tight orbit and attitude control to provide a sufficient bandwidth overlap of 80 % or more in both range and azimuth. In addition, the implementation of Scan-InSAR requires the synchronization of the azimuth scanning patterns of all satellites. This in terms requires a small number of bursts with long durations as well as a high timing, satellite position, and antenna pointing accuracy.

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