Application Potentials of the planned RADARSAT Constellation

Dirk Geudtner and Guy Séguin
Canadian Space Agency (CSA), Space Technologies/Spacecraft Payloads
6767, route de l' Aeroport, Saint-Hubert QC, J3Y 8Y9, Canada
Email: dirk.geudtner@space.gc.ca

Abstract

The CSA is conducting a feasibility study on a constellation of low-cost small SAR satellites to ensure C-band data continuity beyond RADARSAT-2. The goal 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 provides an overview of the mission concept with a special focus on the application potential of the planned RADARSAT constellation.

1 Introduction

The Canadian Space Agency (CSA) is currently conducting a feasibility study on the development of a C-band SAR satellite constellation referred to as RADARSAT Constellation Mission (RCM). This is a follow-on project to the RADARSAT-2 program. For the implementation of the RCM a new approach is being used, which focuses on the use of low-cost small-satellites flying in a constellation configuration [1].

The main objective of the RCM 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. This is to meet specific revisit and coverage requirements defined by operational users in Canada for time-critical maritime surveillance applications such as ship detection, oil spill monitoring, and sea ice mapping. Other key applications focus on disaster management and SAR interferometry (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 [2].

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 1**. 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 1 (left)** also shows CIS' regions of interest.

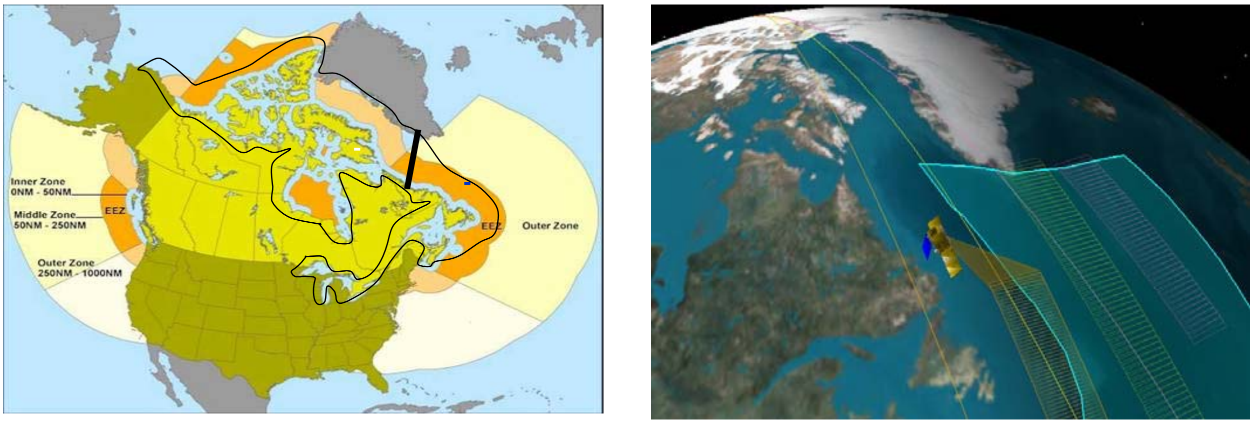

Figure1 Canadian zones of interest for maritime surveillance and sea ice mapping (left) and swath coverage by three satellites (right)

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.

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 also be sufficient to allow the derivation of additional geophysical parameters from the data such as wind speed

2.2 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. This requires ScanSAR imagery with daily acquisitions over areas of interest.

2.3 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 Stripmap beam modes to support high accuracy measurement techniques such as differential InSAR, permanent scatterer (PS-InSAR), speckle tracking, and coherence analysis. 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.

3 Mission Concept

The current mission concept considers a three-satellite constellation that covers Canadian territory and waters on average once daily by combining ScanSAR data with a 50 resolution, acquired from ascending and descending orbits. A full implementation of the constellation is planned for 2014-15. 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, a two-panel deployable SAR antenna was selected with the dimensions of 1.375m x 6.88 m.

3.1 Characteristics of SAR Beam Modes

The challenge for maritime surveillance is to achieve a wide-area SAR data coverage at a resolution that is also suitable for ship detection. Two principal imaging modes are considered: a wide-area, medium-resolution ScanSAR and a high-resolution Stripmap mode.

The ScanSAR mode is designed to have a swath width of 350 km with a 500 km accessible region, see **Figure 2 (left**). Using 4-looks in range and one look in azimuth, this ScanSAR mode provides a medium resolution of 50 m. The trade-off is that 8 ScanSAR subbeams will be necessary to achieve the desired swath width. In this respect, other parameters are currently being analyzed, 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.

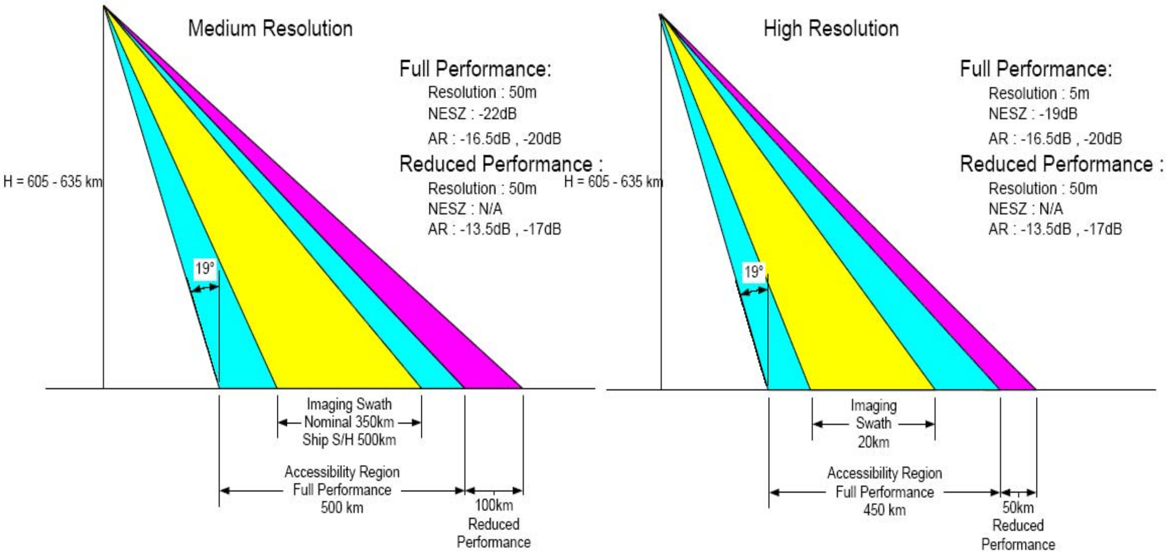

Figure 2 Characteristics of the RCM ScanSAR (left) and Stripmap (right) beam modes

The high-resolution Stripmap, see **Figure 2 (right**) beam mode with a spatial resolution of 5 m and a swath width of 20 km is intended for specific on-demand image acquisitions.

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

Radar frequency	C-band: 5.405 GHz
Chirp bandwidth	100 MHz
Swath width	20 – 350 km
Accessible swath width	500 km
Spatial resolution (1-look)	5-50 m
Orbit altitude	~ 600 km
Imaging time	12 min per orbit
Repeat orbit cycle	12 days
Polarization	HH or dual-pol (HH-VV)

Table 1 Key system parameters of the RADARSAT Constellation Mission (RCM)

3.2 SAR Interferomtry Capability

All satellites of the constellation fly in a sun-synchronous dawn-dusk orbit at an altitude of ~600 km with a 12-day repeat orbit cycle for each satellite. The satellites will be equally spaced in the same orbital plane, following each other with a time separation of ~32 min, see **Figure 3 (left)**. While the ground track of each satellite is slightly shifted due to the Earth rotation, this orbital configuration provides the required ground coverage over the Canadian maritime zones using the medium resolution ScanSAR mode, see **Figure 1 (right)**.

A genial side effect of this orbital configuration is that enables the implementation of a repeat-pass SAR interferometry configuration. Thereby, using SAR data from the different satellites, it will be possible to form InSAR scene pairs having 4-day acquisition interval. The short revisit interval is especially important for measuring velocities of fast moving ice related to climate change studies [3]. It also minimizes significantly the temporal decorrelation effect, which is a necessary precondition for enabling sensitive measurements of area-wide, small-scale surface deformations caused by tectonic processes, volcanic activities, landslides, and subsidence.

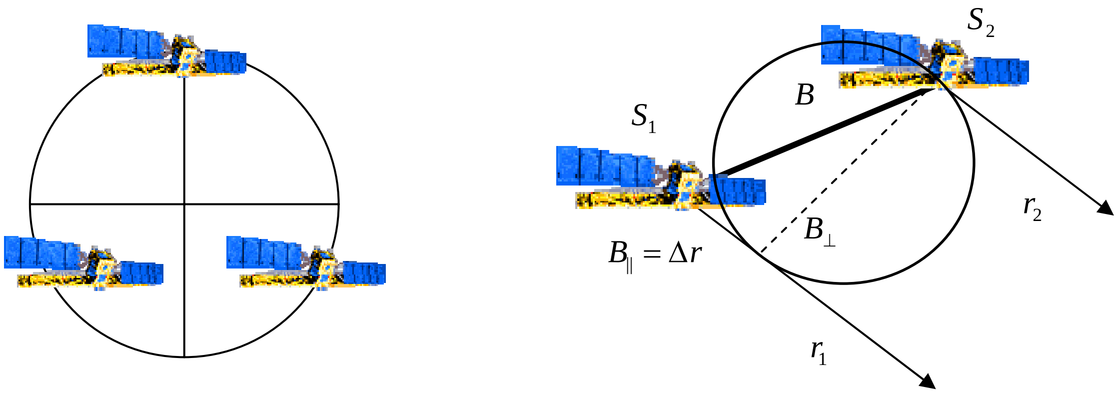

Figure 3 Orbital configurations for a constellation with three satellites (left) and sketch of the orbital tube (right)

A key parameter for an InSAR capable satellite constellation is the diameter of the orbital tube, which is determined by the perpendicular component of the interferometric baseline, see **Figure 3 (right).**

Generally, assuming unchanged surface scattering conditions between SAR data acquisitions, the InSAR phase ϕ, measures the difference in slant range Δr , and can be written as [4]

$$\phi = -\frac{4\pi}{\lambda}\Delta r = -\frac{4\pi}{\lambda}\frac{B_{\perp}}{r_0 \sin\theta}\left[\cos dr + h\right] + \frac{4\pi}{\lambda} dr_{disp} + \phi_{res} \qquad (1)$$

where B is the interferometric baseline, λ is the radar wavelength, θ is the look angle, r_0 is the slant range, h is the terrain height, dr is the change in slant range across the swath (i.e., flat earth imaging geometry), dr_{disp} is the surface displacement projected onto the radar line-of-sight (LOS) direction, and ϕ_{res} is an unknown residual phase term caused by path length differences and atmospheric heterogeneities.

Since the goal is to measure dr_{disp}, it is obvious from Equation (1) that small interferometric baselines are required to reduce the phase contribution from both the topography and the “flat earth” imaging geometry (first term in Eq. (1)). However, small baselines are difficult to obtain, because the maintenance of a small orbital tube requires additional fuel and orbital maneuvers of the satellites.
However, assuming an accurate knowledge of the (non-zero) baseline, it is then the accuracy of the Digital Elevation Model (DEM) that determines the error in the LOS deformation measurement.

$$\delta\phi_{topo} = \frac{4\pi}{\lambda}\frac{B_{\perp}}{r_0 \sin\theta}\delta h \qquad (2)$$

$$\delta r_{disp} = \frac{\delta\phi\lambda}{4\pi} \qquad (3)$$

Therefore, for analyzing the orbital tube requirement, it is necessary to consider the accuracy of the available global DEMs, see **Table 2**.

Accuracy	**DTED-1**	**DTED-2**	**HRTI-3**
Absolute Vertical	30 m	16 m	10 m
Relative Vertical	20 m	12 m (slope <20%) 15 m (slope > 20%)	2 m (slope <20%) 5 m (slope > 20%)
Horizontal	130 m	23 m	10 m
Relative Horizontal	90 m	15 m	3 m
Spatial Resolution	100 m	30 m	12 m

Table 2 Summary of the DEM accuracy. Note that DTED-2 is provided by SRTM/X-SAR and the planned TerraSAR-X TanDEM mission starting in 2009 will generate a global HRTI-3.

The plots in **Figure 4** show representatively the expected LOS deformation error across the accessible RCM swath for different DEM (type) bias considering a baseline of 100 m and 300 m, respectively. The plots illustrate that by using a HRTI-3 level DEM, the absolute LOS deformation error can be significantly reduced, relaxing the constraint on the baseline and hence orbital tube, as compared to the error obtained by using the DTED-1 DEM. Note that relative DEM errors can cause additional phase aliasing effects.

Generally, for a constellation of InSAR capable satellites it is important to note that maintaining a small orbital tube between all satellites of the constellation is only a relative requirement. However, considering the potential drift of the entire tube over time, the build-up of long time series for ground deformation analysis requires 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.

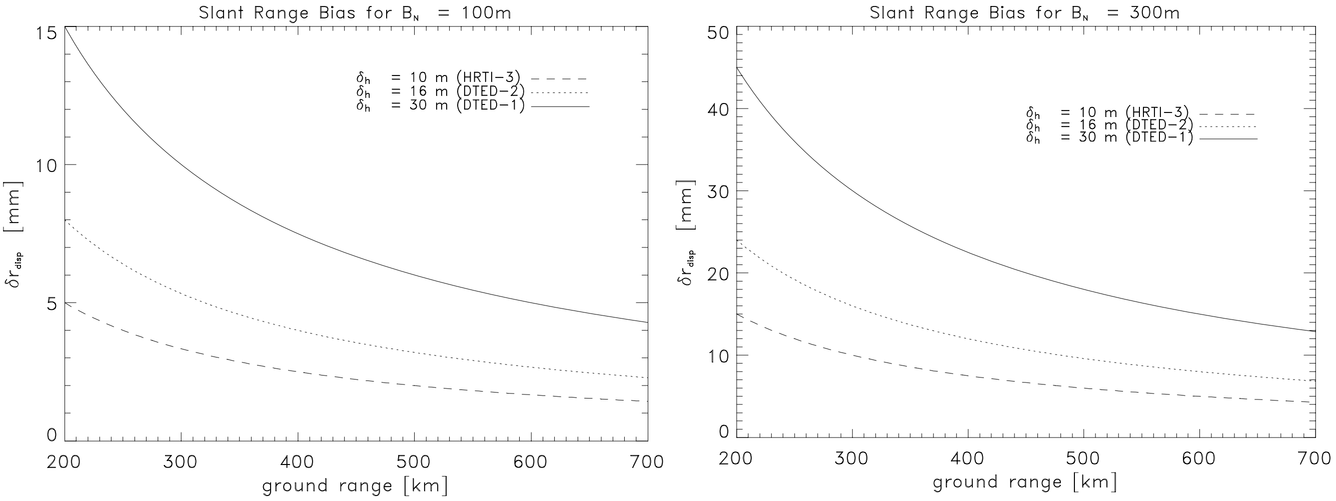

Figure 4 Plots of the absolute LOS deformation error (in slant range) across the RCM accessible ground range swath for different DEM (type) bias considering a baseline of 100 m and 300 m, respectively.

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