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Operational Highlights from Canada's Flagship RADARSAT Constellation Mission (RCM)

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Abstract

The RADARSAT Constellation Mission (RCM), launched in June 2019, is Canada's Earth observation (EO) flagship mission with the three identical satellites equipped with both synthetic aperture radar (SAR) and automated identification system (AIS) payloads working together to bring solutions to key challenges for Canadians. It provides effective maritime surveillance, disaster management and ecosystem monitoring. With their rapid revisit capability, the satellites are able to capture the exact same view of the exact same location on the Earth's surface once every four days.

Operations are conducted 24/7 from the Canadian Space Agency control centre along with the use of Natural Resources Canada and National Defence ground stations. Data archives are available and offering timely access to science and operational data to a variety of users. With a ground segment geographically dispersed all across Canada, the mission presents multiple challenges but also multiple opportunities for users as well as operations.

This paper will present some of the main operations special activities conducted over the first two years of RCM operations including eclipse season optimization; data consumption, data delivery through cloud, ground station load redistribution; response to space debris alerts and effect of increased solar activity on orbit maintenance.

Keywords: RCM, operations, data, ground stations, space debris

1. Background

Beginning in 2005, the CSA initiated a round of consultations with the Government of Canada (GC) SAR users to assess their future EO needs post RADARSAT-1. Consultations continued concurrently with the operation of the RADARSAT-2 mission, which allowed Government users to continue acquiring experience with SAR data use, and prepare clients to further integrate SAR data operationally, in the fulfilment of an increased number of mandates within the GC. This informed the formulation of future observational needs and requirements into a Mission Requirements Document, which set off the design and development of the GC-owned, RADARSAT Constellation Mission (RCM).

At the end of the design phase, it was determined that the GC SAR demand volume would increase 10-fold relative to the RADARSAT-2 GC Data consumption, and that coverage and revisit requirements called for a constellation of three SAR satellites. The RCM is Canada's new generation of Earth observation satellites. Launched on June 12, 2019, the three identical satellites work together to bring solutions to key challenges for Canadians.

2. RADARSAT Constellation Mission

The RCM is conceived to respond to the needs expressed by GC Departments to ensure continuity and enhanced exploitation of operational SAR imagery. At the highest level, these can be summarized as:

- Daily coverage of Canada's territorial and adjacent waters for maritime surveillance, including ship detection and monitoring of ice, marine wind, and oil pollution; and,
- Monitoring of all of Canada for disaster mitigation on a regular basis (monthly to twice-weekly) to assess risks and damage-prone areas; and,
- Regular coverage of Canada's land mass and inland waters, up to several times weekly in critical periods, for resource and ecosystem monitoring.

To achieve these objectives, CSA led the development of several critical technologies in partnership with Canadian industries in the area of small-satellite bus, transmit/receive modules for the SAR antenna, payload central electronics, SAR antenna design, and value-added applications utilizing SAR image products.

RCM was launched in June 2019 and declared operational in November 2019, RCM has since become the GC's premier EO mission, delivering all-weather, day and night imagery in support of Canadian priorities in the area of environmental monitoring, natural resources management, Northern development, sovereignty and security.

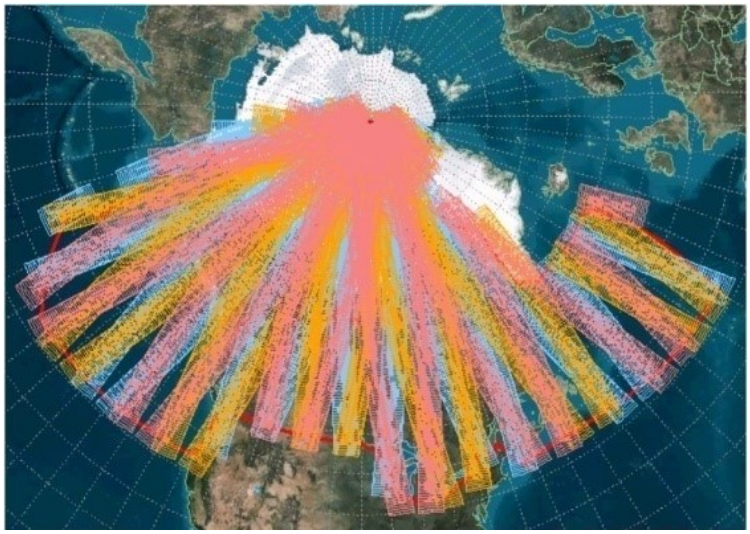

Figure 1. Twenty-four hour coverage of Canada and northern polar regions;
RCM satellites 1, 2 and 3 in blue, pink and orange respectively

The three-satellite constellation allows for daily revisit of Canada and its surrounding waters. Compared to previous RADARSAT missions, revisit capacity increases significantly in Canada's North, for example providing opportunity of coverage of the Northwest Passage three to four times daily (**Figure 1**). Increased revisit capacity improves likelihood of timely repeat coverages for emerging applications such as land deformation and operational disaster management.

The space segment is comprised of three small satellites (1,400 kg each), flying evenly spaced at 120° on the same orbit. The satellites operate in a sun-synchronous low-earth polar orbit, at an altitude of approximately 600 kilometres, corresponding to satellites following each other after 30 minutes. Each spacecraft consists of a bus module and two payloads: a Synthetic Aperture Radar (SAR) payload and an Automatic Identification System (AIS) payload. The bus module provides attitude and orbit control, power generation and storage, payload commands, telemetry, thermal control and the primary support structure. AIS payload operations is treated in the next section, while the rest of the paper focuses on the exploitation, operation and maintenance of the SAR payload.

Space-based AIS enhances Canada's goals of conducting national and continental operations and defending Canada. The International Maritime Organization (IMO) requires that all ships beyond 300 tons (Class A) transmit their identification, location, bearing and velocity with an AIS transponder. The on-board RCM AIS receiver captures the aforementioned information across a broad expanse of open ocean, which includes the swath of the imaged area. Incorporating AIS messages with RCM imagery provides a greatly enhanced product for maritime surveillance. The AIS payload enables the detection of illegal vessels in Canadian waters and up to about 1,000 nautical miles from the shore. Having SAR and AIS payloads on the same satellite provides near "real time" maritime surveillance, leading to an effective surveillance solution compared to the fusion of separate AIS and SAR data streams.

The value-added from coupling both technologies is that RCM can detect vessels that have lost their AIS signal or deliberately turned-off their AIS transmitter to avoid detection and identification. Both SAR and AIS payloads can be activated on-demand by the operations team.

The SAR instrument payload performs all imaging operations, stores, encrypts and transmits the SAR data to a ground receiving station.

Together, the three RCM satellites provide a four-day exact revisit, allowing high revisit coherent change detection. Many of the requests by Government users require re-look at least daily and an exact revisit once to twice weekly for interferometric change detection applications. Such frequent revisit capability is critical to disaster management.

The RCM can provide on average 15 minutes of imaging time per orbit per satellite, with peak imaging of 25 minutes per orbit per satellite outside the eclipse season (which is from early May to early August).

3. Operations highlights

3.1 Ground stations

In collaboration with Canada Centre for Mapping and Earth Observation, the RCM mission uses three different ground station sites in Canada (Inuvik, Prince Albert and Gatineau, **Figure 2**) and one additional northern site (Kiruna, Sweden) for data download and spacecraft commanding. Since the mission has low latency requirements from ordering to acquisition and download on the ground optimising the use of the antenna is critical. As planned but also unplanned maintenance activities may occur, it is important for the overall system to be robust to availability changes. The CSA antenna reservation system allows to optimize the planning of ground to space communication by taking into account planned maintenance. In the case of unplanned maintenance or outages, the system allows manual override followed by a re-planning activity accounting for resulting system availability. Over the last year, a number of unplanned maintenance activities were necessary and the system allowed for re-planning with an almost seamless effect to data users.

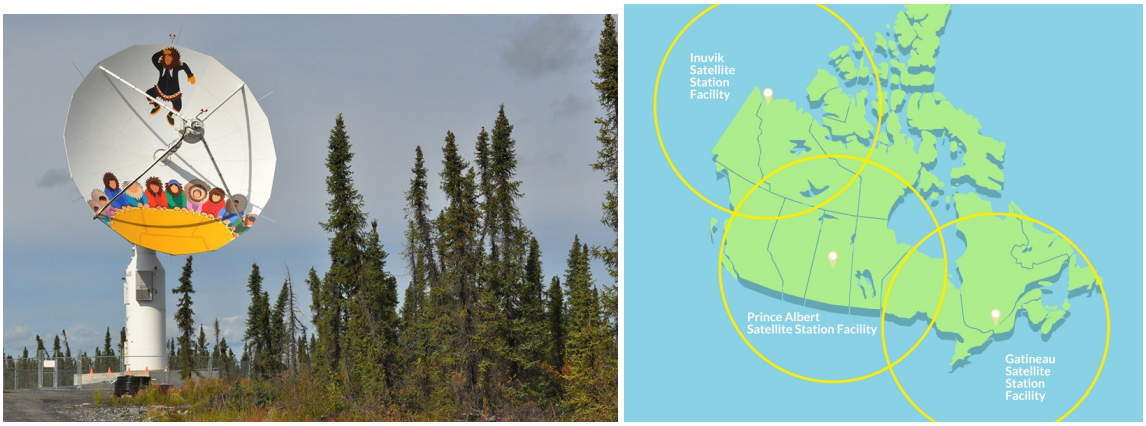

Figure 2. Inuvik ground station and stations network

Figure 3 below represents minutes downloaded including an unplanned outage (highlighted) on September 15. On the day of the outage the impact has been around 30% but quickly after the system was reprogrammed to optimize the use of the other stations and near nominal levels were regained about 24 hours after.

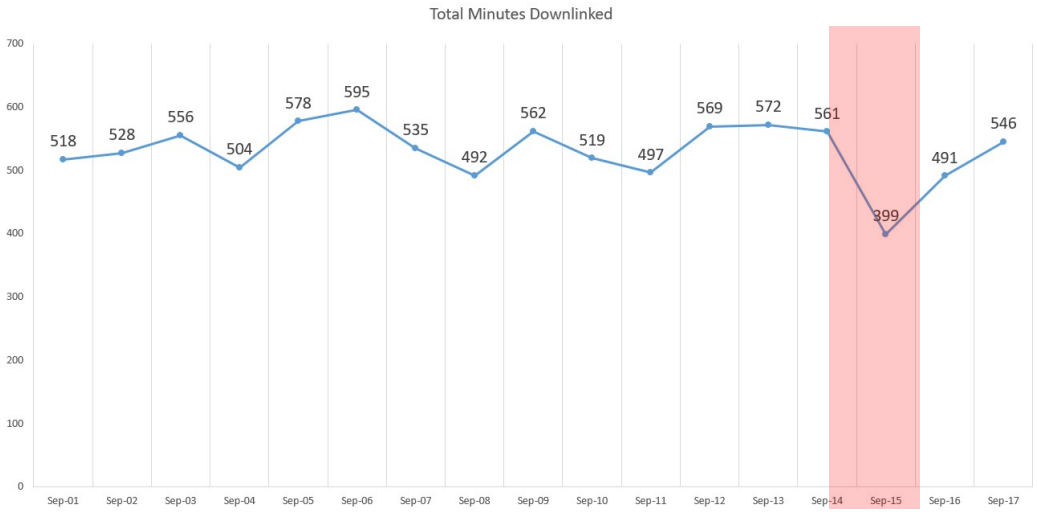

Figure 3. Minutes downloaded

3.2 Eclipse season

The RCM orbit calls for an eclipse season starting in May and ending in August (week 18 to 31) (**Figure 4**). The spring months also face increased demand for SAR data. During the design period, it was estimated that a 20% reduction of the SAR on-time availability would be required in order to ensure spacecraft safety and proper operations. The ground system was designed to apply a "step function" reducing the SAR on time by 20% from day 1 of the eclipse until the end. In practice the eclipse season is progressive leading to a maximum at midpoint and slowly recovering.

A thorough analysis of the various constraints allowed the operations team to minimize the overall SAR on-time reduction. In addition, the spacecraft power capacity constraints were, naturally, set to a very conservative limit. Based on in-flight data analysis, while respecting various safety features, the team managed to limit the SAR on time reduction from 20% to about 5% and hence limiting the impacts of eclipse for RCM data users (**Figure 5**).

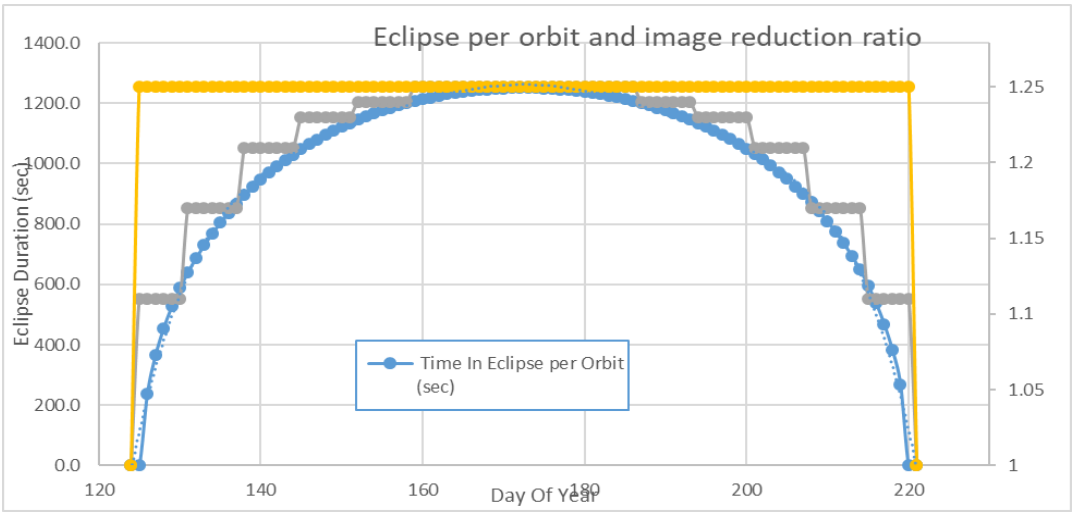

Figure. 4. Eclipse profile

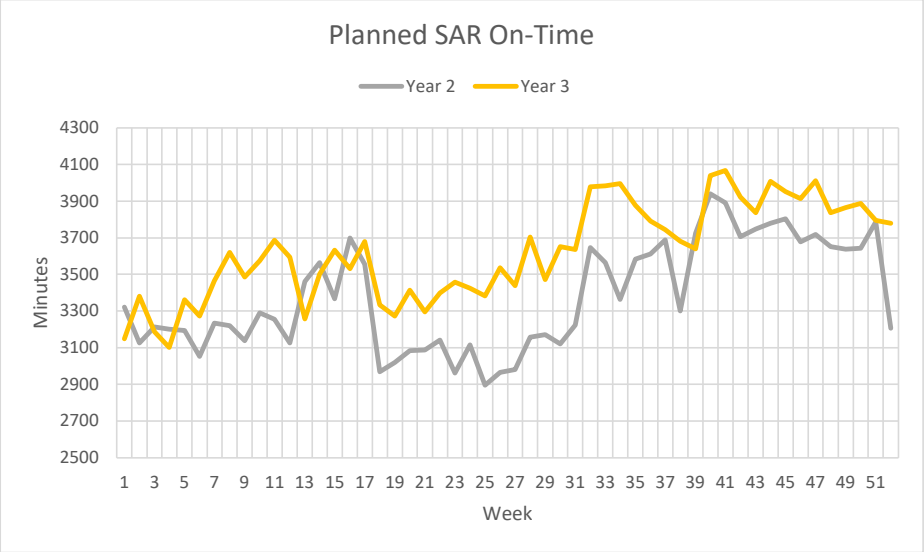

Figure. 5. Planned SAR on-time

3.3 Space debris

The continuously increasing space traffic and associated space debris alerts is part of nowadays operations. With a constellation of three satellites flying in a narrow orbital tube, any serious debris threat affecting one satellite and requiring an avoidance maneuver will typically also require a second maneuver to ensure that the orbital tube constraint and ground track requirement are met. CSA's conjunction risk analysis and mitigation system (CRAMS) continuously monitors and processes conjunction data messages affecting RCM. CRAMS computes possible avoidance maneuvers based on possible times when to execute the maneuver. **Figure 6** present a recent close approach for which a collision avoidance maneuver was prepared by the operations team and executed onboard. Since beginning of the mission, RCM has received over 30,000 conjunction messages associated to about 5,500 close approach events. From these about 65 were actionable and less than 10 led to a dedicated avoidance maneuver.

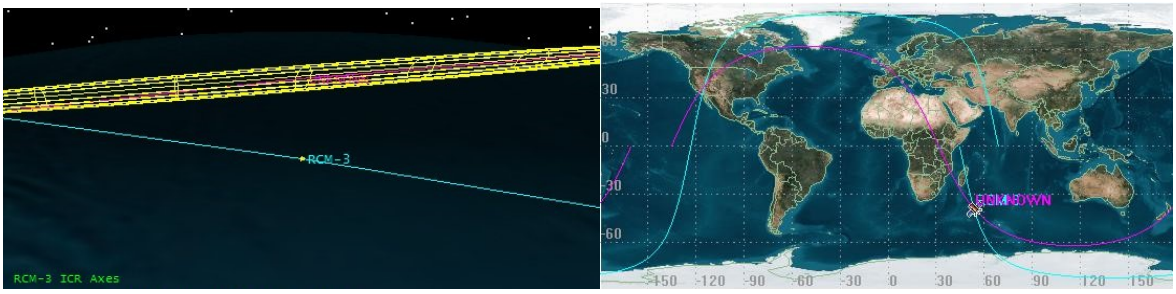

Figure. 6. RCM close approach

3.4 Solar activity

An earth observation mission such as RCM must ensure cohesion between the three satellites orbit to ensure each satellites orbit inside an orbital tube. This constraint aims to meet a planned ground track to ensure image planning and image acquisition match within a certain level of uncertainty. The high solar activity not only increases the drag but also its variability. These 2 elements lead to more frequent orbit maintenance activities but also variation in the amount of delta-v required to remain inside the orbital tube. The RCM flight dynamics systems has the capability to automatically plan orbit maintenance delta-v but the variability of the current solar activity required additional operational processes and skills to modify control parameters related to burn planning in order to guard against excursions from the nominal orbital tube. **Figure 7** presents the general trend of orbital tube compliance over the last month.

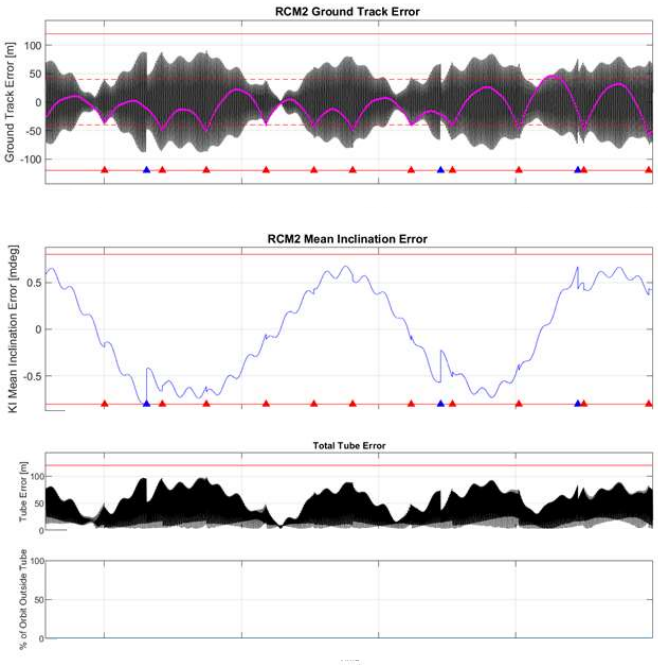

Figure 7. Orbit maintenance

3.5 Data consumption

With RCM, most acquisitions are part of standard observation scenarios known as Standard Coverages. Standard Coverages consist of pre-defined and pre-planned acquisitions based on common set of parameters such as imaging modes, area(s) of interest, revisit frequency, polarimetric configuration, delivery latency, and acquisition priority. The objective is to provide consistent and predictable SAR coverage for key applications over sustained periods and large geographic areas. Standard Coverages are governed by a working group where represented GC Departments coordinate coverages fulfilling both operational and R&D purposes. RCM image products are archived and made available to the broadest extent possible under Canadian regulations, on a web-based portal maintained by Natural Resources Canada.

Recent SAR-on-time trends indicate that the mission has almost reached its limit in terms of acquisition capacity, due to an increased demand from GC Departments, who since the advent of RCM, are further operationalizing Earth Observation for the delivery of their mandates. The SAR on-time values for both global and Canadian areas of interest have now attained the ceiling values of 4,200 min/wk and of 2,100 min/wk, respectively. These ceiling values were defined from pre-launch data acquisition scenarios simulated under planning patterns prediction at the time.

6. Conclusions

The RCM mission now in its 3rd year of operations continues with a system availability reaching an average above 96% thereby exceeding the initial requirement of 90%. The robustness of the system continues to be increased while facing typical operations challenges associated with orbit maintenance, space debris, ground segment outages. The mission ensures EO data continuity for Government of Canada RADARSAT users with its emphasis on repeatable and efficient observation coverage. The ground system elements and operations team ensure timely tasking, data reception and delivery to the users.

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