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RADARSAT-2 POLARIMETRY APPLICATIONS

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Abstract. RADARSAT-2, planned for a mid 2004 launch, is an advanced polarimetric SAR satellite. Key features of RADARSAT-2 are high resolution (3 m), polarimetric modes, enhanced ground system providing rapid satellite tasking and near-real time data processing, improved image location accuracy, and on-board solid state recorders. The focus of this paper is on the RADARSAT-2 polarimetric applications including agriculture, cartography, disaster management, forestry, geology, hydrology, oceans, and sea ice.

Keywords: RADARSAT-2, SAR, Polarimetry, SAR Applications

1. Introduction

RADARSAT-2, the second in a series of Canadian spaceborne Synthetic Aperture Radar (SAR) satellites, is being built by MacDonald Dettwiler, Richmond, Canada. RADARSAT-2 builds on the heritage of the RADARSAT-1 SAR satellite, which was launched in November 1995 and continues to perform extremely well (Srivastava *et al*, 2001). Scheduled for launch in mid 2004, RADARSAT-2 will be a single-sensor polarimetric C-band SAR (5.405 GHz).

RADARSAT-2 retains the same capability as RADARSAT-1 (Luscombe, 2001). For example, the RADARSAT-2 orbit parameters will be the same as RADARSAT-1 thus allowing co-registration of RADARSAT-1 and RADARSAT-2 images, and radiometric and geometric calibration will also be implemented permitting correlation of time series data for applications such as long-term change detection (Luscombe and Thomson, 2001). Key features of the RADARSAT-2 satellite include:

- 3 m high resolution mode
- Selective and Polarimetry modes
- Enhanced ground system
- Routine left and right looking capability
- Increased geometric accuracy
- On-board solid state recorders

While each of the RADARSAT-2 features are deserving of individual discussion, the focus of this paper is on the polarimetry modes and what these modes will bring to the end-users in terms of better information for SAR-based applications. To date, SAR data have been widely available from single channel (single frequency and polarization) spaceborne radars including ERS-1 and 2 (C-VV), JERS-1 (L-HH), and RADARSAT-1 (C-HH). In this paper, we preview and demonstrate how the technical improvements included in RADARSAT-2 will impact the system's potential utility for applications in the fields of agriculture, cartography, disaster management, forestry, geology, hydrology, oceans, and sea and land ice. Our evaluation relies on bibliographic sources and, in particular, case studies drawn from ongoing applications development work at the Canada Centre for Remote Sensing (CCRS, 2001).

2. RADARSAT-2 Polarimetry Modes

The intent here is not to outline polarimetry theory, but to present the concepts in an intuitive manner so that those not familiar with polarimetry can understand the benefits of polarimetry and the information available in polarimetry data. Many articles are available that discuss polarimetry theory, applications, and provide excellent background information (CCRS, 2001; Ulaby and Elachi, 1990). Notwithstanding the inherent complexity of polarimetry, polarimetry in its simplest terms refers to the orientation of the radar wave relative the Earth's surface and the phase information between polarization components.

RADARSAT-1 is horizontally polarized meaning the radar wave (the electric component of radar wave) is horizontal to the Earth's surface. In contrast, the ERS SAR sensor was vertically polarized, implying the radar wave was vertical to the Earth's surface. Spaceborne SAR sensors such as RADARSAT-2, ENVISAT, and the Shuttle Imaging Radar have the capability to send and receive data in both horizontal (HH) and vertical (VV) polarizations. Both the HH and VV polarization configurations are referred to as co-polarized modes (co-po,). A second mode, the cross-polarized mode (cross-pol), combines horizontal send with vertical receive (HV) or vice-versa (VH). Polarization configurations are shown in Fig. 1. As a rule, the law of reciprocity applies and HV ≅ VH (Ulaby and Elachi, 1990).

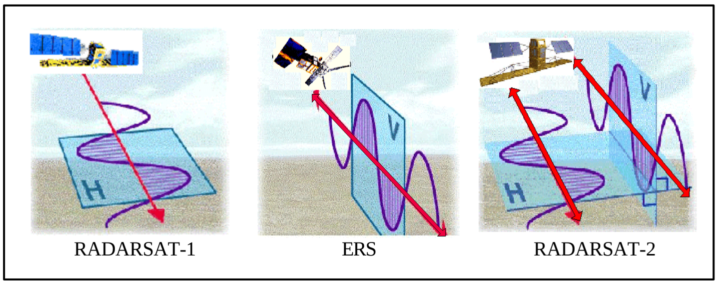

Fig. 1. RADARSAT-1, ERS, and RADARSAT-2 polarization configurations.

A unique feature of RADARSAT-2 is the availability of polarimetry data, meaning that both the amplitude and the phase information are available. The amplitude information is familiar to SAR users, but the phase information is likely new and rather non-intuitive. In its simplest term, phase can be thought of as the travel time for the SAR signal: the travel time is the two-way time between the sensors and the Earth, and includes any propagation delays as a result of surface or volume scattering. It is the propagation delays and the scattering properties of the HH and VV polarization configurations that make polarimetry data so powerful. In effect, SAR interferometry exploited the phase information, not by the time delay between, for example, the HH and VV modes at the same time (RADARSAT-2 case), but the time delay between the HH and HH mode at different times (RADARSAT-1 case).

The RADARSAT-2 program has adopted terms to define the polarization modes, which are consistent with accepted definitions. The polarization terms are Selective Polarization (SP), Polarimetry (QP), and Selective Single Polarization (SSP). Selective Polarization and Selective Single Polarization imply the availability of only amplitude data. For example, amplitude data may be HH, VV, or HV imagery. Other terms for Selective Polarization include dual, alternating, and multi-polarization. Polarimetry implies the availability of both amplitude and inter-channel phase information. The amplitude information is the same as the SP and SSP cases, but adds phase information, such as the co-phase term (i.e. $\rho_{HH\text{-}VV}$). Other terms include quadrature polarimetry (quad-pol) and fully polarimetric. The RADARSAT-2 modes are shown in Table 1.

Table 1. RADARSAT-2 modes. Beam mode name, swath width, swath coverage, and nominal resolution.

	Beam Mode	Nominal Swath Width	Swath coverage to left or right of ground track	Approximate Resolution: Rng x Az
Radarsat-1 modes with Selective Polarisation Transmit H **or** V Receive H **or** V **or** (H **and** V)	Standard	100 km	250km - 750km	25m x 28m
	Wide	150 km	250km – 650km	25m x 28m
	Low Incidence	170 km	125km – 300km	40m x 28m
	High Incidence	70 km	750km – 1000km	20m x 28m
	Fine	50 km	525km – 750km	10m x 9m
	ScanSAR Wide	500 km	250km – 750km	100m x 100m
	ScanSAR Narrow	300 km	300km – 720km	50m x 50m
Polarimetry Transmit H **and** V on alternate pulses Receive H **and** V on every pulse	Standard QP	25 km	250km – 600km	25m x 28m
	Fine QP	25 km	400km – 600km	11m x 9m
Selective Single Polarization Transmit H **or** V Receive H **or** V	Multiple Fine	50 km	400km-750km	11m x 9 m
	Ultra-fine Wide	20 km	400km-550km	3m x 3m

3. RADARSAT-2 Polarimetry Applications

RADARSAT-2 will offer a rich source of data for a variety of applications. As with any spaceborne sensor, there are trade-offs, which for SAR sensors are mainly spatial coverage and resolution. Typically high resolution is available at the expense of reduced spatial coverage, and increased spatial coverage at the expense of coarser resolution. These trade-offs will apply to RADARSAT-2, although mitigated by the availability of left and right looking SAR.

The availability of polarimetry data adds additional imaging choice, with trade-offs that depend on application needs. Referring to Table 1., the polarimetric trade-offs are reduced for the RADARSAT-1 Selective Polarization modes, since there is no impact on swath width or resolution as a function of polarization choice. By default, data products are one co-pol channel (HH or VV) and the cross-pol channel (HV). The only impact will be on the ground segment due to the extra channel of data which adds to the processing and delivery (if electronic) time.

Depending on application needs, a decision is required between the use of SP, QP, and SSP modes. The QP mode offers a choice of resolutions (25 m and 10 m nominal), four channels of data (HH+VV+HV+VH), and both co-pol and cross-pol phase information, subject to the caveats that as aforementioned HV $\cong$ VH, and the cross-pol phase information does not provide as much information as the co-pol phase. From an applications perspective, a key parameter of the QP mode is the 25 km swath. Therefore, the end user must decide, depending on the application requirements, whether the Selective Polarization mode or the Polarimetry mode will provide the information needs. The SSP mode offers a choice of only one polarization channel, but has the highest resolution.

Table 2 summarizes our assessment of the effect of the most important technical enhancements of RADARSAT-2 on the information content and hence the application potential of its data. The table shows that the SSP mode of operation will moderately advance the potential of RADARSAT-2 for applications the information needs of which can generally be met by single channel C-band data but for which the HH-polarization as offered by RADARSAT-1 is not the most favourable. As a rule, the information needs associated with hurricanes, oil spills and winds are better met through application of VV-polarized images. Similarly, the requirements pertaining to clear-cuts, fire-scars, ships, and selected sea and land ice applications are more easily satisfied when HV or VH images can be applied.

The capability to operate in SP mode is projected to moderately improve the potential of RADARSAT-2 to provide information in support of applications dealing with targets that include transparent vegetation / ice volumes with varying structural properties or land / ice surfaces with varying degrees of roughness. Applications that are expected to gain little information from having access to two image channels instead of one image channel (in SSP mode) have been given the ‘minor’ rating. For example (Fig. 2), it has been shown that the co-pol mode (HH) provides ice type information, and the cross-pol mode (HV) provides ice edge information (Scheuchl *et al*, 2001).

Data acquired in the QP mode will facilitate the computation of a wide variety of variables that relate to the strengths, polarizations or phases of the radar return signals as received from the observed objects. The introduction of this imaging mode is expected to moderately advance the potential of RADARSAT-2 for most applications. Applications for which the QP data are anticipated to be particularly valuable or essential ('major' rating) are concerned with crop type, crop condition, DEM polarimetry, and search & rescue. Once again, 'minor' ratings have been given whenever the increase in terms of radar data is not expected to result in a significant increase in applicable information. Implicit in the assessment of the QP mode is the reduced swath width which will impact the operational use of QP data in applications that require information on extended areas, e.g. forestry, oceans.

The RADARSAT-2 capacity to acquire images in the 3 m Ultra-Fine spatial resolution is restricted to the SSP imaging mode. It is our expectation that this capability will enhance the potential of RADARSAT-2 for cartographic applications and applications concerned with point targets, that is, ships and icebergs, in particular. In addition there is a considerable number of applications that are foreseen to moderately benefit from the upcoming availability of these very high resolution space-borne SAR data. Like the QP data products, the Ultra-Fine data products have a limited swath width (20 km). Again, this will restrict the operational use of this data type in certain applications.

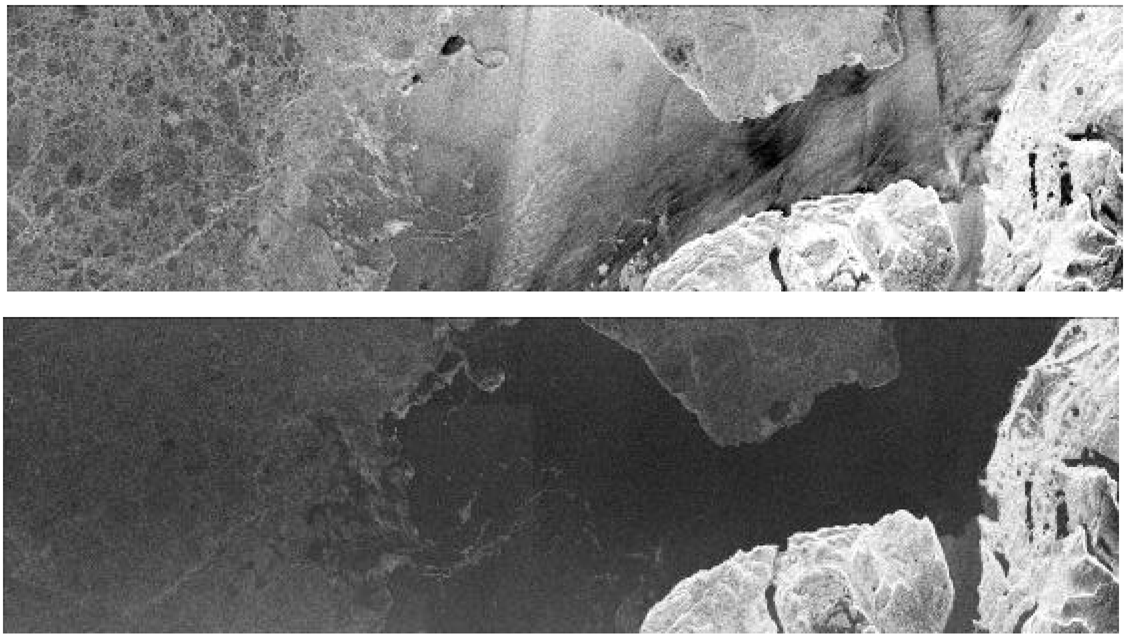

Fig. 2. SIR-C imagery showing HH polarization (top) and HV polarization (bottom). Ice type is easier to discern in the HH image, and ice edge is more apparent in the HV image.

Table 2. Anticipated benefit of RADARSAT-2 features in terms of image information content. SSP (Selective Single Polarization); SP (Selective Polarization), QP (Polarimetry). Key: (-) minor, (-/+) moderate, (+) major. The potential benefit of the 3 m resolution Ultra-Fine mode is also shown.

	RADARSAT-2 Feature			
APPLICATION	**SSP**	**SP**	**QP**	**Ultra-Fine**
Agriculture				
Crop type	-	-/+	+	-
Crop condition	-	-/+	+	-/+
Crop yield	-	-	-/+	-/+
Cartography				
DEM interferometry	-	-	-	+
DEM stereoscopy	-	-	-	+
DEM polarimetry	N.A.	N.A.	+	N.A.
Cartographic feature extraction	-	-	-/+	+
Disaster Management				
Floods	-	-	-	-
Geological hazards	-	-/+	-/+	-/+
Hurricanes	-/+	-	-/+	-
Oil spills	-/+	-	-	-/+
Search and rescue	-	-	+	-/+
Forestry				
Forest type	-	-	-/+	-/+
Clear-cuts	-/+	-	-	-/+
Fire-scars	-/+	-	-	-/+
Biomass	-	-	-	-
Geology				
Terrain mapping	-	-/+	-/+	-/+
Structure	-	-/+	-/+	-/+
Lithology	-	-	-	-
Hydrology				
Soil moisture	-	-	-/+	-
Snow	-	-	-/+	-
Wetlands	-	-/+	-/+	-/+
Oceans				
Winds	-/+	-	-	-
Ships	-/+	-	-/+	+
Waves	-	-	-/+	-
Currents	-	-	-	-
Coastal zones	-	-/+	-/+	-/+
Sea and Land Ice				
Sea ice edge and ice concentration	-/+	-	-/+	-
Sea ice type	-	-	-/+	-
Sea ice topography and structure	-/+	-/+	-/+	-
Icebergs	-/+	-	-/+	+
Polar glaciology	-/+	-/+	-/+	-

4. Exploiting Polarimetry To Meet User Needs

The use of the Selective Polarization mode for a given application will be better understood following the availability of ENVISAT data, with better understanding of the Polarization mode following the launch of RADARSAT-2 (ENVISAT does not have Polarimetry-like mode). It is important to point out that RADARSAT-2 can be readily configured even after launch. Subject to three main parameters, namely resolution, swath width, and noise-equivalent sigma-0, new modes can be defined to meet users needs (T. Luscombe, pers. comm.).

Polarimetry, while intrinsically challenging from a scientific perspective, is daunting to the end user. The commercial focus of the RADARSAT-2 mission dictates the development of operational applications, and ultimately the extraction of information from the SAR data. Polarimetry represents a steep learning curve for even the radar knowledgeable user, and perhaps a step-function for many new users. To facilitate better understanding of polarimetric data, the following approaches should be considered:

- Much of the polarimetry reference material has been written from the engineering perspective, but many end users are geoscientists, so polarimetry theory, explained from the geoscience perspective is required;
- Polarimetry "tool kits" that provide sample data sets and functionality for simple analysis. Of note is the observation that through NASA's Jet Propulsion Laboratory, a polarimetry toolkit called Sigma-0 is available. A similar toolkit, called the Polarimetry Work Station is available from the Canada Centre for Remote Sensing;
- Provide guides as the appropriate use of a given polarization mode for a given application. This will have to be done following the launch of RADARSAT-2 and data validation, but can be initiated with ENVISAT data;
- There is a need to combine good R&D directed toward the development of operational applications. This type of initiative has been fostered during the RADARSAT-1 program where R&D institutes such as the Canada Centre for Remote work with both the private and the public sector to develop applications.

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