Applications Potential of Planned C-Band SAR Satellites: Leading to RADARSAT-2

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***Abstract* - To date, satellite SAR data for civilian purposes, have been routinely available from single channel, i.e., single frequency and single polarization, radar systems. In the near future, we expect satellite SAR systems with enhanced capabilities in terms of polarization, frequency, spatial resolution, spatial coverage and temporal resolution. In this paper, we discuss the increase in applications potential resulting from the progress in SAR technology, in particular in C-Band systems. The application fields discussed include agriculture, forestry, geology, hydrology, oceans, and sea ice. Most applications are anticipated to benefit from the upcoming availability of cross-polarized C-band data. Likewise the introduction of fully polarimetric C-band satellite SAR systems is expected to improve the overall application potential.**

I. INTRODUCTION

The launch of the first European remote sensing satellite ERS-1 in July of 1991 marked the beginning of an era of uninterrupted availability of satellite Synthetic Aperture Radar (SAR) systems for earth observation. ERS-1 and those that followed, (JERS-1, ERS-2 and RADARSAT 1), transmit and receive microwaves of a single frequency and polarization. Since the operating frequency and polarization of a SAR system govern the interaction of the incident microwaves with the targets and control the sensor's sensitivity to structural and dielectric target characteristics, they are major parameters in examining its application potential.

The future for remote sensing from space includes plans for the launch of civilian satellites carrying SAR systems with enhanced capabilities in terms of frequency and polarization as well as spatial and temporal resolution. In this paper, we discuss the increase in applications potential resulting from the progress in C-Band SAR technology. This preview relies on bibliographic sources and case studies drawn from ongoing applications development work at the Canada Centre for Remote Sensing (CCRS) [1]. The focus will be on agriculture, forestry, geology, hydrology, oceans, and sea ice applications.

II. PLANNED SATELLITE SAR SYSTEMS

Space-borne SAR systems to be launched in the future include the Envisat-1 ASAR, ALOS PALSAR and RADARSAT-2. Relevant parameters of the C-Band systems in this group are presented in Table 1.

III. ANTICIPATED APPLICATIONS POTENTIAL

Table 2 summarizes our assessment of the potential of satellite C-Band SAR systems for selected types of applications. Although this table is organized based on the polarization, the applications potential will depend on more than just the polarization. Additional relevant variables include incidence angle, spatial resolution, spatial coverage, temporal resolution, image quality / calibration, orbit control, and order lead time. For certain applications, the potential of a system may also vary as a function of its interferometric capacities. The ratings shown in the table are general in nature. In specific cases the application potential may therefore vary from the one shown. For example, images from C-band systems with a single or selective single polarization are perfectly suited for the assessment of banana crops (e.g. [2]). On the other hand, conditions like mountainous terrain may seriously hamper the application of any type of radar data. Envisat-1 ASAR will have the capability to operate in two out of the three configurations shown, that is, Selective Single Polarization (SSP) and Selective Dual Polarization (SDP). In the SSP mode the ASAR will image either in HH or VV polarization. In the SDP mode images are acquired simultaneously in two polarizations, that is, HH+VV, HH+HV or VV+VH. Compared to the Envisat-1 ASAR,

TABLE 1: PLANNED SPACE-BORNE SAR SYSTEMS

Specification	Envisat-1 ASAR	RADARSAT-2
Agency	ESA	CSA
Launch Date	2001	2003
Frequency	C-band	C-band
Number of Modes	11	11
Transmit Polarization	H and/or V	H and/or V
Receive Polarization	H and/or V	H and/or V
Spatial Resolution	30 m – 1 km	3 – 100 m
Swath Width	60 – 405 km	20 – 500 km
Temporal Resolution	35 days	24 days

TABLE 2: ANTICIPATED APPLICATIONS POTENTIAL AS A FUNCTION OF SYSTEM CONFIGURATION

Key: '-' minimal, '+/-' limited, '+' moderate, '++' strong

Application	C-band Selective Single Pol.	C-band Selective Dual Pol.	C-band Quad Pol.
Agriculture			
Land cover	+/-	+	++
Crop type	+/-	+	++
Crop condition	+/-	+/-	+
Crop yield	-	+/-	+/-
Forestry			
Clearcut	+	+	+
Forest type	+/-	+/-	+/-
Timber yield	-	-	-
Geology			
Structure	+	+	+
Lithology	+/-	+/-	+/-
Hydrology			
Floods	++	++	++
Soil moisture	+/-	+/-	+
Snow	+/-	+/-	+
Wetlands	+/-	+/-	+
Oceans			
Ships	+	+	++
Wave spectra	+	+	++
Wind fields	+	+	++
Slicks	+	+	++
Coast line	+	+	++
Sea Ice			
Ice edge / concentr.	+	++	++
Ice type	+/-	+/-	+/-
Icebergs	+	+	++

RADARSAT-2 will have the additional capacity to acquire HV or VH polarized images in its SSP mode as well as to image in the Quad Polarized (QP) mode (H and V polarized microwaves are transmitted and received in all possible combinations to acquire a fully polarimetric dataset). However, in the SDP mode, RADARSAT-2 will not be able to image simultaneously in HH and VV.

In the following sections, we will motivate the ratings shown in Table 2 according to the field of application.

A. Agriculture

Individual images from presently orbiting single-frequency / single-polarization SAR systems usually offer a minimal to limited potential for the assessment of land cover, crop type, crop condition, and crop yield. To date, moderate results for assessment of land cover and agricultural variables can be attained only by applying multiple satellite SAR images from different dates (e.g. [3]). Studies based on airborne SAR have shown that C-HV (or C-VH) data are better suited for assessment of land cover, crop type and crop condition than C-HH or C-VV data (e.g. [4]). Future satellites with the capability to acquire C-band linear cross-polarized data alone or in combination with linear like-polarized data (i.e. Envisat-1 and RADARSAT-2) can therefore be expected to offer an improved potential for application to agriculture. Clearly, the information content and hence application potential of a data set will increase as a function of the observed number of polarization combinations. This explains why, in Table 2, the ratings improve when the configuration changes from SSP to SDP and to QP.

The ratings for crop condition assessment fall behind those for the assessment of land cover and crop type because the former application requires detection of more subtle differences in plant structure. This requires application of advanced systems in terms of polarization, in particular. All of the C-band configuration scenarios show minimal to limited potential for crop yield assessment. This application may benefit from the advance of systems that use frequencies lower than C-band since low frequency radar signals are sensitive to a larger range in above ground biomass, i.e. an indicator of crop yield.

B. Forestry

The ratings in Table 2 show that forthcoming satellite C-band SAR systems are expected to be at best of limited value for the assessment of forest types and timber yields. The information needs for both of these applications are met best by SAR systems with configurations that include a low frequency, e.g. a L- or P-band (e.g. [5] [6] [7]).

Analysis of C-band radar data acquired by airborne sensors suggests that linear cross-polarized images offer better potential for clearcut (and road) mapping than linear like-polarized images [8]. Future satellite SAR systems with configurations that facilitate imaging in C-HV are thus anticipated to have 'moderate' potential for this particular forestry application. It should be noted, however, that for clearcut mapping to be successful, the cuts must be free of residue and the SAR data acquired soon after logging. Failure to do so, will have a negative impact on the results since regenerating forest vegetation is easily misinterpreted as mature forest.

C. Geology

The potential of future C-band SAR systems for the assessment of geological structures and lithology (rock type) are rated as 'moderate' and 'limited', respectively. Results of studies based on airborne radar data indicate that geological structures appear similar in C-HH and C-VV images. Conversely, the matching C-HV images were found to contain structural information not present in either C-HH or C-VV (e.g. [9]). Forthcoming satellite SAR systems with the capacity to image in C-HV can therefore be expected to offer better potential for the mapping of geological structures than the currently available satellite C-HH and C-VV systems.

The information requirements for lithological mapping are not easily met through the application of imaging radar. For this particular application optical remote sensing systems offer significantly more potential. The application potential is therefore rated as 'limited'.

D. Hydrology

The potential of systems like the Envisat-1 ASAR and RADARSAT-2 for the assessment of floods is rated 'strong' and is fixed for the polarization configurations identified. Indeed, the multi-polarization capabilities of future satellite C-band SAR systems will add little to the potential for flood mapping since the present satellite HH and VV systems provide most of the information required. Even so, HH polarization is preferable to VV polarization because HH polarized radar signals are more capable of penetrating overlying vegetation. Flood management and other applications that demand near real-time information will benefit from the capability of RADARSAT-2 to acquire images to either the right or the left of its ground track. This capability will reduce the time lapse between the occurrence of a flood and the first opportunity to image the area at stake. Moreover, it will reduce the time interval between subsequent data takes.

The disturbing effects of soil roughness complicate the assessment of soil moisture. Future satellite C-band SAR systems with quad-polarized configurations are expected to be more useful for soil moisture mapping than current systems or systems without this capability. This is explained by the fact that this capability enables the simultaneous acquisition of HH and VV images the ratio of which is less sensitive to soil roughness and hence better suited for soil moisture assessment.

Results of studies that investigate the potential of fully polarimetric C-band data for snow cover mapping suggest that these data provide valuable information on snow state (wet/dry) and the structure of the snow pack ([10]). Hence, the introduction of satellite C-band systems with full polarimetric capabilities (e.g. RADARSAT-2) is expected to improve the potential for the mapping of snow cover from space. In Table 2, we rate the potential of such satellite systems as 'moderate'.

Because of their sensitivity to moisture, SAR systems have often been found to be good tools in support of wetland / non-wetland mapping. However, more detailed assessment of wetlands requires the capability to identify differences in ground surface condition (e.g. flooded / non-flooded) and vegetation properties. The potential of SAR sensors to acquire information on the state of the ground surface was discussed earlier in connection with the flood mapping application. The capacity to discriminate between vegetation types will improve as the number of polarization combinations increase. In Table 2 the potential for wetland assessment is therefore shown to range from 'limited' (for SSP and SDP) to 'moderate' (for QP)

E. Oceans

The ratings in Table 2 indicate that the planned SAR satellite systems are expected to offer 'moderate' to 'strong' potential for the identified oceans applications. In fact, the information acquired by systems like RADARSAT-1 and ERS-2 may already be considered 'moderate' for most of these applications. The capability of future satellite C-band SAR systems to image in the HV (or VH) polarization is an advantage for the detection of ships in the near range, in particular. As a rule, the return signal of the sea surface will be lower in C-HV than in C-HH and C-VV. Given the strong radar return signal from ships it follows that the ship / sea backscatter contrast and the ship detection potential are highest in C-HV images. Forthcoming systems with configurations that enable the acquisition of C-band or multi-frequency quad-polarized data are expected to extend the potential for ship detection and identification (e.g. [11]). Ship detection is a striking example of the type of applications that will benefit most from the enhanced spatial resolutions of satellite systems like RADARSAT-2.

The study by Engen et al. [12] shows that wave spectra computed from C-HH and C-VV images contain complementary information. For this reason we have assigned the QP configuration a higher rating than either the SSP or the SDP configuration.

The potential of C-HH and C-VV images for the extraction of wind vectors has been demonstrated (e.g. [13]). Relative to RADARSAT-1, RADARSAT-2 will offer improved potential for wind retrieval since VV polarization provides a better signal to noise ratio at larger incidence angles. In Table 2, the QP configuration has been given the highest rating because simultaneous acquisition of HH and VV images is expected to result in a larger information content.

Like the potential to detect ships, the potential to detect natural surfactant slicks or oil spills is a function of the contrast in observed backscatter. Slicks are perceived as dark and not as bright image features. For slick detection it is therefore advantageous to receive a strong return from the sea surface. For this reason C-VV images offer better potential for slick detection than either C-HH or C-HV images. The potential of fully polarimetric C-band radars for slick detection is not well known at present. However, the results of the earlier referred to ship detection studies give reasons to believe that polarimetric systems may well prove to be offer more potential. In parallel with the ship case, the QP configuration is therefore rated as ‘strong’.

Similar to ship detection, the coastline extraction application is expected to benefit from the introduction of satellite systems that are capable of imaging in C-HV. This can be explained from the large land / sea backscatter contrast in C-HV relative to C-HH and C-VV. The application potential associated with the QP configuration is rated as ‘strong’. Data acquired by systems with this type of configuration are expected to allow for improved discrimination between land and sea by means of information on backscattering mechanisms.

F. Sea Ice

The potential for mapping ice edges and concentrations is governed by the contrast in ice - ocean backscatter. Sea ice is a relatively bright target and hence it is preferable that the ocean clutter background is minimal. Particularly in the near range, this condition is met better at C-band in cross-polarization than in the like polarizations. Consequently, future satellites that will provide cross-polarization modes are foreseen to offer enhanced potential ice edge and ice concentration mapping. The ratio of C-HH and C-VV may also be used to improve ice-water discrimination but unfortunately the planned satellites will not be capable of acquiring both data types in the preferred reconnaissance modes (i.e. ScanSAR). The potential of systems with Dual or Quad Pol was rated as ‘strong’.

Ice type mapping is dependent on the discrimination of small-scale surface roughness characteristics, surface versus volume scattering, and large-scale ice structures and deformation. Backscatter at C-band is dominated by surface scattering (new and first-year ice) and near-surface volume scattering (multi-year ice) and offers acceptable discrimination of these ice types in cold conditions. Under wet conditions, volume and surface scattering from overlying snow becomes the dominant return, thus masking the contrasts between the underlying ice types. This reduces the contrast between the two ice types but enhances large-scale deformations, fractures and ice structures.

Icebergs, like ships, manifest themselves in C-band radar images as bright point targets. The earlier justifications of the ratings shown for ship detection may therefore be extended to iceberg detection. Information contained in data acquired by fully polarimetric radar systems is expected to facilitate the discrimination of icebergs from ships.

IV. SUMMARY

Two satellite C-band SAR systems with multi-polarization capabilities are scheduled for launch within the next three years. The launch of Envisat and RADARSAT-2 are expected to be of benefit for land applications in particular. This is not surprising because most of the currently orbiting satellite SAR systems were developed with oceans and sea ice applications in mind. The capacity of future satellite C-Band systems to image in the HV polarization is expected to enhance their potential for most land and specific ice / oceans applications. In many application fields, the full potential of satellite C-band polarimetric data sets is still to be assessed.

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