Application Potential of Planned SAR Satellites – a Preview

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Abstract

To date, space-borne SAR data have been widely available from single channel, that is, single frequency and single polarization, radar systems. In the near future, we expect SAR satellites with enhanced capabilities in terms of polarization, frequency, spatial resolution, spatial coverage and temporal resolution. In this paper, we will introduce some of the satellites planned and deliberate upon the increase in applications potential resulting from the progress in SAR technology. The application fields discussed are 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 satellites and multi-frequency satellites is expected to improve the overall application potential.

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 space borne Synthetic Aperture Radar (SAR) systems for earth observation. ERS-1 and its successors, that is, JERS-1, ERS-2 and RADARSAT-1, have in common that they transmit and receive microwaves of a single frequency and polarization. The operating frequency and polarization of a SAR system govern the interaction of the incident microwaves with the targets observed and control the sensor's sensitivity to structural and dielectric target characteristics. Consequently, the frequency and polarization of a SAR system have much impact on its application potential.

The future for remote sensing from space includes plans for the launch of SAR satellites with enhanced capabilities not only in terms of frequency and polarization but also in terms of spatial and temporal resolution. Moreover, blueprints exist for satellite systems that are capable of acquiring SAR data in conjunction with optical data. It is reasonable to expect that these technological enhancements will result in improved applications potential. In this paper, we will introduce some of the satellites planned and deliberate upon the increase in applications potential resulting from the progress in SAR technology. Our preview relies on bibliographic sources and case studies drawn from ongoing applications development work at the Canada Centre for Remote Sensing (CCRS, 2000). In terms of the application fields, the focus will be on agriculture, forestry, geology, hydrology, oceans, and sea ice.

Planned SAR Satellites

Table 1 lists selected characteristics for three forthcoming satellites that will carry SAR systems. The construction of these satellites is already underway. The Envisat-1 ASAR, ALOS PALSAR and RADARSAT-2 demonstrate technological innovation in terms of polarization, in particular. With the exception of RADARSAT-2, these satellites will also carry optical sensors. Plans for other SAR satellites have been proposed. In Europe, for example, there are plans for a quad-polarized L-band system (LandSAR) and for a quad-polarized X- and L-band system

Table 1 : Planned SAR satellites.

Specification	Satellite System		
	ALOS PALSAR	**Envisat-1 ASAR**	**Radarsat-2**
Agency	NASDA	ESA	CSA
Launch Date	2002	June 2001	2002
Frequency	L-band	C-band	C-band
Number of Modes	7	11	12
Transmit Polarization	H and/or V	H or V	H and/or V
Receive Polarization	H and/or V	H and/or V	H and/or V
Spatial Resolution	10 – 100 m	30 m – 1 km	3 – 100 m
Swath Width	30 – 350 km	60 – 405 km	10 – 500 km
Temporal Resolution	46 days	35 days	24 days

(TerraSAR). Similarly, the USA and Argentina have plans to launch advanced multi-frequency SAR satellites (e.g.LightSAR).

Anticipated Applications Potential

Table 2 summarizes our assessment of the potential of space borne SAR systems for selected application fields. Although this table is organized based on polarization and frequency, the applications potential of a particular sensor will depend on more than just these two configuration variables. Additional variables of relevance are 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 true 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. Beaulieu et al., 1994). 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 four configurations shown, that is, C-band / Selective Single Polarization (SSP) and C-band / 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 Envisat-1 ASAR, 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. In the latter mode, H and V polarized microwaves are transmitted and received in all possible combinations to acquire a fully polarimetric dataset. The ALOS PALSAR will operate in L-band and therefore does not fit Table 2 in terms of frequency. However, in terms of polarization this satellite will have capabilities similar to those of RADARSAT-2. Satellites that operate with multi-frequency, quad-polarized configurations are not likely to be in orbit prior to 2005.

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

Agriculture

Individual images from presently orbiting single-frequency / single-polarization SAR satellites usually offer a poor to limited potential for the assessment of land cover, crop type, crop condition, and crop yield. To date, acceptable results for assessment of land cover and agricultural variables can be attained only by applying multiple satellite SAR images from different dates (e.g. McNairn et al., 1998). Studies based on airborne SAR have shown that C-HV (or C-VH) data are more suited for assessment of land cover, crop type and crop condition than C-HH or C-VV data (e.g. McNairn et al., 2000). Future satellites with the capability to acquire C-band linear cross-polarized data alone or in combination with linear like-polarized data (e.g. 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 polarizations. This explains why, in Table 2, the ratings improve when the configuration changes from C-band / SSP to C-band / SDP and to C-band / 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 poor to limited potential for crop yield assessment. This application may benefit from the advance of systems that use frequencies lower than C-band. Low frequency radar signals are sensitive to a larger range in aboveground biomass, i.e. an indicator of crop yield.

Relative to C-band / QP systems, systems with multi-frequency (e.g. X-, L-band) / QP configurations will yield data sets with considerably more intrinsic information. Due to their complexity, agricultural applications like crop condition assessment and crop yield assessment are anticipated to benefit more from the introduction of such advanced systems than others.

Forestry

The ratings in Table 2 show that forthcoming C-band SAR satellites 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. Le Toan et al., 1991; van der Sanden and Hoekman, 1992; Ranson and Sun, 1994). Even so, the aboveground biomass of many forests will cause the backscatter measurements of such low frequency SAR systems to saturate. Hence, the potential for timber yield assessment by means of space borne SAR satellites is not rated higher than ‘limited’.

Analysis of C-band radar data acquired by airborne sensors suggests that linear cross-polarized images offer better potential from clearcut (and road) mapping than linear like-polarized images (Ahern et al., 1995). Future SAR satellites with configurations that facilitate imaging in C-HV are thus anticipated to have 'acceptable' 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. The ALOS PALSAR and future multi-frequency satellites that carry a SAR that operates in a frequency lower than C-band can be expected to offer 'good' potential for the assessment of clearcuts.

Geology

The potential of future C-band SAR systems for the assessment of geological structures and lithology (rock type) are rated as 'acceptable' and 'limited', respectively. Results of studies based on airborne radar data indicate that geological structures show alike 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. Singhroy et al., 1999). Forthcoming SAR satellites 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 C-HH and C-VV satellites. The application potential of satellites with multi-frequency configurations is rated higher than that of systems with C-band configurations. This can be explained from the fact that these multi-frequency systems are likely to include a low frequency that will facilitate the collection of information on structures covered by vegetation or dry soil (e.g. Abdelsalam and Stern, 1996).

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 for three out of the four radar system configurations in Table 2 is therefore rated as 'limited'. Like in the case of structural mapping the higher rating for the multi-frequency configuration can be explained from the capability to penetrate vegetation and soil.

Hydrology

The potential of systems like the Envisat-1 ASAR and RADARSAT-2 for the assessment of floods is rated 'acceptable' and is fixed for the polarization configurations identified. Indeed, the multi-polarization capabilities of future C-band SAR satellites will add little to the potential for flood mapping since the present HH and VV sensitive satellites 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. The 'good' rating associated with the multi-frequency / QP configuration assumes a capability to image in a low frequency and can therefore be explained from an increased depth of penetration in vegetation (e.g. Crevier and Pultz, 1996). 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 C-band SAR satellites with quad-polarized configurations are expected more useful soil moisture mapping than current systems or systems without this capability. This is explained from 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. With the introduction of multi-frequency satellite SAR systems the potential for soil moisture mapping is expected to improve further. These systems are likely to include a low frequency channel that will (a) facilitate penetration of vegetation and dry soil and (b) be less sensitive to small-scale soil roughness differences.

Results of studies that investigate the potential of fully polarimetric C-band data sets for snow cover mapping sensors suggest that these data provide valuable information on snow state (wet/dry) and the structure of the snow pack (Sokol et al., 1999). Hence, the introduction of C-band satellites 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 satellites as 'acceptable'. The application potential of future multi-frequency satellites is rated as 'good'. This rating assumes a satellite with a configuration that includes a channel with a frequency higher than C-band, e.g. X-band.

Because of their sensitivity to moisture SAR systems have often found to make 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 a function of the number of polarizations and frequencies observed. In Table 2 the potential for wetland assessment is therefore shown to range from 'limited' (for C-band / SSP and C-band / SDP) to 'acceptable' (for C-band / QP) and to 'good' (for multi-frequency / QP).

Oceans

The ratings in Table 2 indicate that the planned SAR satellite systems are expected to offer 'acceptable' to 'good' potential for the identified oceans applications. In fact, the information acquired by current systems like RADARSAT-1 and ERS-2 may already be considered 'acceptable' for most of these applications. The capability of future C-band SAR satellites 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. Touzi, 1999). Ship detection is a striking example of the type of applications that will benefit most from the enhanced spatial resolutions of satellites like RADARSAT-2.

The study by Engen et al. (2000) shows that wave spectra computed from C-HH and C-VV images contain complementary information. For this reason we have assigned the C-band / QP configuration a higher rating than either the C-band / SSP or the C-band / SDP configuration. The introduction of multi-frequency satellites is not expected to further advance the potential for wave spectra assessment since this application is limited by unfavorable geometry of polar orbiting SARs. For this reason, we refrained from rating the multi-frequency / QP system configuration. For similar reasons, these particular ratings are missing in connection the wind fields and slicks applications.

The potential of C-HH and C-VV images for the extraction of wind vectors has been demonstrated by among others Vachon and Dobson (2000). 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 C-band / 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 observed backscatter contrast. However, slicks are perceived as dark and not as bright image features. For slick detection it is therefore of advantage 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 C-band / QP configuration is therefore rated as 'good'.

Similar to the ship detection application, the coastline extraction application is expected to benefit from the introduction of satellites 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. Images acquired in frequencies lower than C-band are anticipated to show an even more distinct land / sea backscatter contrast. For this reason the multi-frequency configuration has been given the highest rating. The application potential associated with the C-band / QP configuration is also rated as 'good'. 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.

Sea Ice

The potential for mapping ice edges and concentrations is governed by the ice - ocean backscatter contrast. 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 multi-frequency configurations was rated as 'good' (as was C-band Dual or Quad Pol alone), but the additional frequency is expected to add only small incremental benefit for ice-water discrimination.

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. Lower-frequency systems such as L-band allow greater penetration into both first- and multi-year ice types, and is thus dominated by volume scattering behaviour. This reduces the contrast between the two ice types but enhances large-scale deformations, fractures and ice structures. A multi-frequency system would be expected to provide complementary information on ice type and structures, as well as provide improved penetration through snow cover under wet conditions (e.g. Anonymous, 1999).

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.

Summary

Two C-band satellites and one L-band satellite with multi-polarization capabilities are scheduled for launch within the next three years. SAR satellites that can image concurrently in more than one frequency are not to be expected in orbit prior to 2005. The introduction of new satellites is expected to be of benefit for land applications in particular. This is not surprising because most of the currently orbiting satellites were developed with oceans and sea ice applications in mind. The capacity of future C-band satellites 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 C-band polarimetric data sets is still to be assessed. The advance of satellites with multi-frequency configurations that include frequencies lower than C-band (e.g. L-band) will enhance application potential. For land applications this can be explained from the capacity of low frequency radar signals to penetrate vegetation and dry soil. In the case of ocean and sea ice applications the added potential results from the fact that water will generate little backscatter.

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Table 2 : Anticipated applications potential as a function of system configuration. Key: '-' poor, '+/-' limited, '+' acceptable, '++' good.

	System Configuration			
Application	**C-band Selective Single Pol.**	**C-band Selective Dual Pol.**	**C-band Quad Pol.**	**Multi-frequency 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	+	+	++	++