RADARSAT-1 COVERAGE OF AFRICA

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ABSTRACT:

Canada's RADARSAT-1 satellite has accomplished several systematically planned coverage campaigns for Africa in the past nine years of satellite operations under the Canadian Space Agency's 'Background Mission'. The Mission is about creating uniform Synthetic Aperture Radar (SAR) data archives to serve as global benchmarks for change monitoring, land mapping and disaster management.
The first coverage of Africa was completed in 1997 for a rapid overview of the continent and was conducted using the wide area ScanSAR imaging beam of the satellite. Another continent-wide coverage was undertaken a few years later by using 25 m resolution Wide beam for the sub-Saharan Africa and 50 m resolution ScanSAR Narrow beam for the Saharan and the northern portion of the continent. In parallel, and as part of the baseline data acquisition objectives of the satellite mission, 25 m resolution radargrammetric data were collected over the whole of Africa by making use of the unique capability of RADARSAT-1 that allowed electronic steering of the incident radar beam. Shallow incidence angle Standard 7 beam coverage was thus combined with steeper Standard 4 or Wide 2 beam to create the first ever radar beam-pair stereo data set.
A radar image mosaic of the entire continent was generated with the temporally coherent data of the ScanSAR Narrow and Wide 2 beam coverage. This mosaic is shown to be a flexible digital tool for synoptic observation as well as detailed regional studies of Africa's natural resources and ecosystems. The radargrammetric data collection can be exploited for topographic mapping and terrain modeling. This article presents a complete status report of RADARSAT-1 coverage of Africa and describes a few of the image products generated so far with the Background Mission data.

INTRODUCTION

Coverage of the African continent has been included in all phases of RADARSAT-1 Background Mission ever since the inception of the Mission in early 1996. The Background Mission concept was developed for the RADARSAT-1 Program in response to the Canadian Space Agency's objectives of systematic global Synthetic Aperture Radar (SAR) data acquisition for the various land and sea applications (Mahmood, et al., 1998) by making use of the surplus imaging time of the satellite, or the 'SAR on-time', which is left unclaimed after the government and commercial users' data requests would have been satisfied. The data acquisition objectives were determined in order to provide also proof of demonstration of the first ever multi-mode SAR imaging device that could be tasked to respond to time and site-specific user requirements and data deliveries to support operations. These requirements and data deliveries necessitate guaranteed imaging of a ground target following successful data acquisition planning, which can not be offered with the electro-optical devices because of the conditions of illumination of the ground target. The imaging capability of a SAR device is independent of the conditions of illumination. The SAR on board RADARSAT-1 satellite has additional attributes in terms of variable swath width, pixel resolution and the angle of the incident beam that can be adjusted for the most optimal viewing of the ground target. Details on these attributes can be found in Mahmood et al., 1996 and Parashar et al., 1993.

The wide area ScanSAR beams of RADARSAT-1 with swath width of 300 km to 500 km, for example, have been used for rapid coverage to produce seasonal 'snapshots' of large continental areas, which are most useful for ecological studies requiring temporal equilibrium across these areas. This coverage type enables, to the greatest extent possible, the separation of the small vegetation signal from the large landform background.

The global land stereo data collection was planned with two independent RADARSAT-1 beams. The satellite furnished for the first time among radar satellites the opportunity of stereo viewing with two independent angles of the incident beam, as it happens in the optical world with two different angles of sight. A beam-pair of Standard 7 and another beam of comparable resolution was chosen. At first a region was covered with shallow Standard 7 beam (incidence angle range of 45º to 49º). This constituted the base layer in the stereo couple, on which was later built the second steeper radar beam image layer, with the assumption that the intersection angle between the two beams ('parallax') was appropriate enough to generate stereo effects (Mahmood and Giugni, 2002). In order to optimize to the maximum the intersection angle, and thus the 'parallax', initially Standard 7 beam was combined with very steep Standard 2 beam, but later, in the high relief regions, Standard 2 beam was replaced by Standard 4 beam (incidence angle range of 34º to 40º) to avoid the radar layover effects. Another modification to the stereo coverage planning that was implemented after the start of the Mission related to the use of a Wide beam instead of a Standard beam for stereo-pairing with base Standard 7 beam. This was done for the tropical regions, those contained roughly between 30º north and south of the equator, where the use of Standard beams with their narrower swath left gaps between adjacent orbits. Wide 2 beam of an incidence angle range comparable to that of Standard 4 beam, but with a swath width of 150 km, instead of 100 km of Standard beams, ensured the elimination of the coverage gaps.

After nearly nine years of operation, RADARSAT-1 Background Mission has demonstrated that sufficient amount of the satellite imaging resource even in the case of satellites launched with operational and commercial motives, such as RADARSAT-1, is left unused, and that this additional resource can be managed to generate uniform global data sets for various remote sensing applications, particularly in those regions where optical sensors can not ensure data acquisition at the desired time and frequency because of cloud cover, haze, darkness and other climatic conditions. The current global data acquisition strategies call for exploiting the complementary capabilities and information content of optical and microwave sensors to address thematic issues at appropriate scales and acquisition frequencies. Optical sensors provide both high spatial and thematic resolution, but as noted above require suitable illumination conditions, whereas microwave sensors provide all weather, day or night, acquisition capability, at high spatial although low thematic resolution. RADARSAT-1 has an obvious advantage over other microwave systems in view of its imaging parameters that are adjustable as a function of the geomorphology over a range of spatial resolutions. Its on-board recorder (OBR) can be used for covering the regions lying outside the reception mask of a ground data receiving station. As can be inferred from the following descriptions, these capabilities of the satellite were fully exploited in the various phases of the RADARSAT-1 Background Mission coverage of Africa.

AFRICA COVERAGE

Africa was included in all the three main Background Mission coverage campaigns, namely the ScanSAR Wide coverage of the world's continents, continental shelves and polar caps, the ScanSAR Narrow follow-on coverage of the continents for seasonal change detection, and the beam-pair land stereo coverage. These coverage types are described below for Africa in terms of the data acquisition planning strategies and constraints.

ScanSAR wide coverage

This coverage was intended for a rapid overview of Earth by making use of RADARSAT-1's ScanSAR Wide beam with 100 m pixel spacing and 500 km wide imaging swath. It was suggested that such a seasonal coverage would enable accentuation of small landcover signal against large landform and observation of near-shore phenomena, and would serve as benchmark for change detection studies when compared with the subsequent ScanSAR Narrow coverage. In the early years of the Background Mission implementation, the OBR was a heavily contested satellite resource among the various RADARSAT-1 data requesters. In addition, the baseline acquisition planning of Background Mission was generally assigned a lower order of priority in the conflict management. Consequently, the Africa coverage remained rather sporadic in the first year of the satellite operations and only about a quarter of the continent was covered with ScanSAR Wide beam swaths, which were furthermore concentrated over the horn of Africa. In order to time constrain the coverage, a dedicated phase of Background Mission was launched in the second quarter of 1997, and the entire continent was covered with this beam within the same northern spring period. The ScanSAR Wide coverage is reproduced in Figure 1.

Figure 1. RADARSAT-1 ScanSAR Wide coverage of Africa.

Beam-pair stereo coverage

The absence of ground receiving stations needed to downlink large volumes of higher resolution Standard and Wide beam data caused a delay in planning the stereo coverage of Africa, and it was not until the certification of a station in Saudi Arabia for receiving RADARSAT-1 data that the Standard 7 beam coverage was made possible. As mentioned above, the Standard 7 beam coverage was planned first in the stereo-pair data collection for reasons related to the fact that this beam imaged with the least geometric distortion and therefore the resulting imaging products could be interpreted with greater ease. Generally speaking, there is better thematic information at larger radar incidence angles than at smaller angles. The priority given to the Standard 7 beam coverage also fit well with CSA's campaign of contingency data collection. Shallow incidence angles were exclusive to RADARSAT-1, and it was thought that in the event of an early satellite failure, data collected with this beam could be coupled with the data from the steeper ERS imaging beam to generate the same beam-pair stereo effects.

The reception mask of the Saudi station covers a large portion of northeastern Africa, including the Horn, The Sudan and the eastern half of the Sahara. The Standard 7 coverage started in early June 1999, and by the end of the northern summer the said region had been almost entirely covered with this beam. The Standard 7 beam coverage was backed up by the Wide 2 beam coverage of the region in late September 1999, which reached its completion level by the end of the following spring season in 2000.

For the remainder of the continent, the beam-pair stereo coverage was accomplished with the OBR, and for that reason the coverage duration was longer than for the real-time coverage conducted by means of direct downlink at the Saudi station. The Standard 7 OBR coverage was completed in mid-2002. The Standard 4 coverage of Africa north of 30° north and south of 30° south over the tip of the continent, and the Wide 2 coverage in the portion in between were both completed in the second half of 2001. Even though these coverage periods appear long, the coverage with one beam was immediately followed by the coverage with the other beam in the stereo-pair for given parts of the continent. This back-to-back coverage planning was done to maintain as much as possible the temporal coherence between the two stereo data sets for the quality of image co-registration. The status of the beam-pair stereo coverage of Africa is shown in Figure 2.

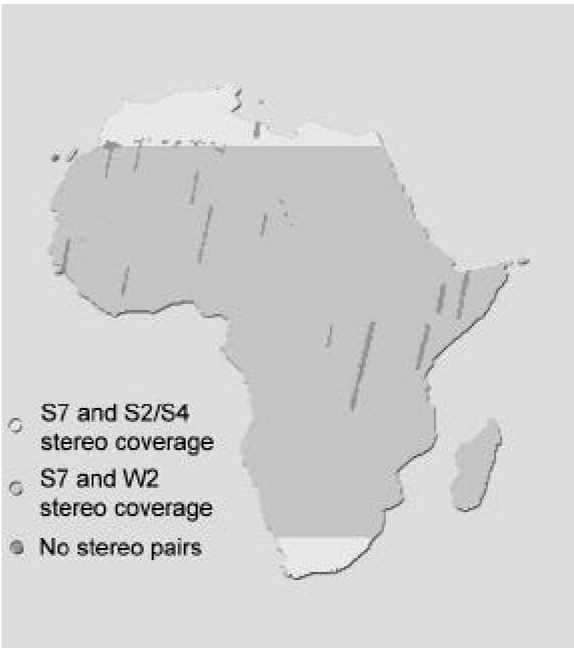

Figure 2. RADARSAT-1 beam-pair stereo coverage of Africa.

AFRICA MOSAIC

The second global ScanSAR coverage of the continents with the higher (50 m pixel) resolution Narrow beam was meant to provide seasonal contrasts in comparison with the first ScanSAR Wide coverage reported above. The seasonal constraints of data acquisition planning and the larger amount of data to be acquired for the ScanSAR Narrow beam coverage, compared to ScanSAR Wide beam, depended on real-time downlink opportunities with the use of ground receiving stations. The ScanSAR Narrow coverage was therefore completed for those continental regions where such an opportunity existed. The data were systematically processed immediately following acquisition and the resulting images were mosaicked together to generate 'snapshots' of the continents in given seasons. The summer mosaic of Australia, the winter mosaic of Canada and the spring mosaic of the United States of America have been produced with RADARSAT-1 data.

Africa came under special scrutiny in the course of the RADARSAT-1 Background Mission wide-area coverage. A special OBR allocation for the coverage was obtained, and a part of the continent was covered with high resolution, 25 m pixel Wide beam. This was done to enhance the vegetational contrast. The continent was split along the 10º N parallel coinciding roughly with the vegetation line. The part of the continent north of the line was imaged with ScanSAR Narrow beam, as for the other continents, and the part south of it with Wide 2 beam. Later the two parts were joined in a single mosaic, which is presented in Figure 3. Data acquisition followed by scene processing in near real-time allowed the identification of data dropouts, because of scene coherence problems or processing errors, and immediate re-planning for the acquisition of the affected scenes. With proper quality control and radiometric balancing across the swaths and at the Wide 2 - ScanSAR Narrow beam joint, it could be possible to generate this seamless and uniform mosaic product.

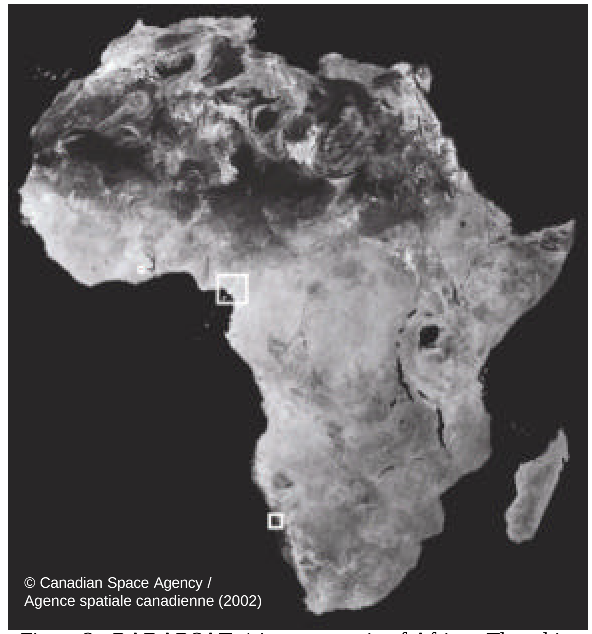

Figure 3. RADARSAT-1 image mosaic of Africa. The white boxes refer to image locations of Figures 4, 5 and 6.

The wide-area mosaics are important for synoptic viewing and observing large-scale structural trends of a territory for geological mapping and exploration. Not only the mosaics can serve as the base layer for integrating detailed cartographic, geophysical, geochemical and optical data, the unique viewing geometry of orbital SAR accentuates aspects of landscapes that can not be sensed at optical and infrared wavelengths. The global multi-spectral imaging databases must account for slope and aspect affects in order to derive quantitative indices of value in terrain assessment. SAR is partially controlled by local relief (slopes and tilts) and has an advantage in the recognition of textural elements. The SAR imagery also exhibits the tendency to suppress the superficial landcover effects and to bring out subjacent geological structures. This has led to the idea of using preferentially the wide area radar image mosaics for the re-examination of the impact flux of Earth using synoptic searches for the "missing" impact features in the existing world record (Mahmood et al., 2003).

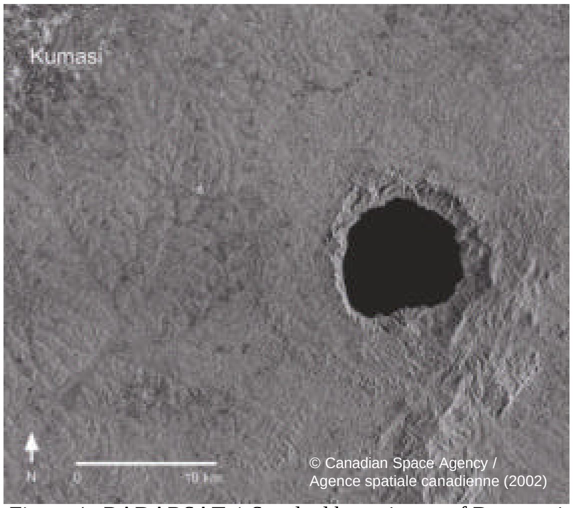

Figure 4. RADARSAT-1 Standard beam image of Bosumtwi impact crater, Ghana.

Figure 4 is focused on the famous Lake Bosumtwi impact crater in Ghana, and clearly shows the annular crater rim, an outer elevated ring, and depicts the truncation of the regional northeast-southwest basement trend by the more recent impact structure. The crater is located in a tropical region that is dominated by rain forest and frequent cloud cover. The cloud free, texturally explicit SAR imagery is therefore particularly useful for the investigation of impact features at sub-kilometric scale in this type of regions. The digital mosaic can be used for identifying scars that may have been be caused by slope or crater wall failures. If it can be generated periodically, the mosaic should serve as a useful tool for monitoring lake water level. The variations in the water level may be indicative of any tectonic movements affecting the crater floor.

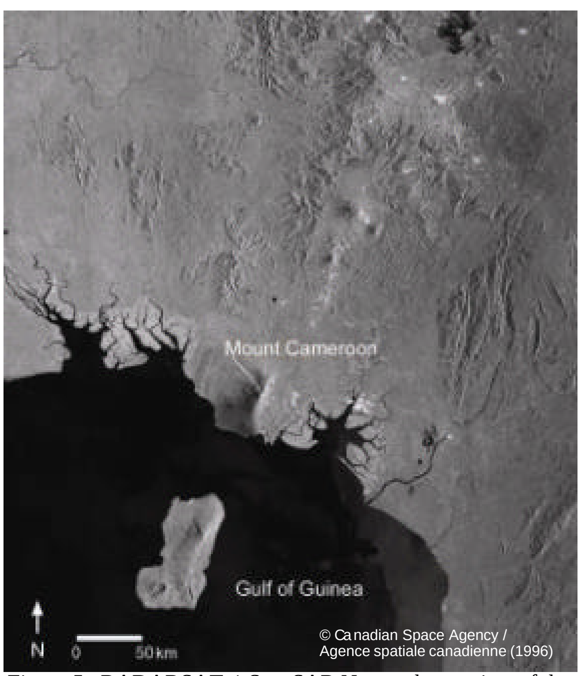

Figure 5. RADARSAT-1 ScanSAR Narrow beam view of the Cameroon Volcanic Line, West Africa.

The radar imagery is routinely used for lineament mapping and Figure 5 of the Cameroon Volcanic Line (CVL) is one example of the sharpness with which a regional structural feature like this 1,600 km long line appears on the ScanSAR image of RADARSAT-1. The CVL marked by the alignment of several volcanic peaks, including the active Mount Cameroon, extends northeastward from the Atlantic island of Pagalu through the Gulf of Guinea into the West African Craton. The gray tone variation of the RADARSAT-1 image signifies lithological differences. The estuaries associated with river deltas have characteristically lighter tones, and the cities, towns and other human habitations display the brightest radar return. Equally prominent in the southeastern part of the imaged area is an east-west trending fracture system in the basement rocks.

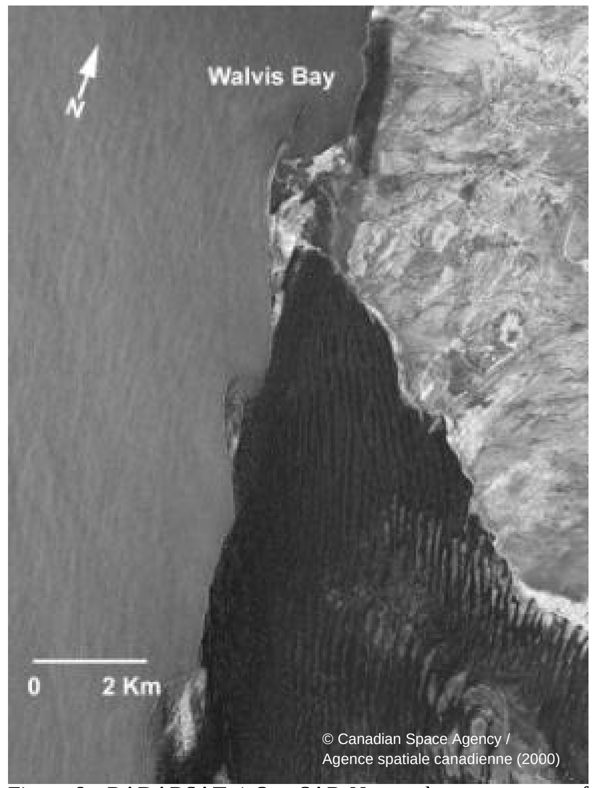

Figure 6. RADARSAT-1 ScanSAR Narrow beam coverage of the Namib Desert, southwestern Namibia.

Another example of radar data application is the coastal and desert zone monitoring. Figure 6 is centered over the famous Namib Desert. The image covers a vast region from the Atlantic coast in the west to Namib escarpment. The mega sand dunes appear as dark wavy bands with bright crests, which is a radar foreshortening effect. The Namib escarpment marking the eastern contact of the desert with the basement rocks of the African shield figures prominently on the RADARSAT-1 image. The Namib Desert is enshrouded in thick fog because of atmospheric phenomenon and radar imagers can alone provide unhindered view of this ecoregion at the desired time and frequency.

CONCLUDING REMARKS

The coverage of Africa has received special attention in the course of the global monitoring phase of RADARSAT-1 data collection for the Canadian Space Agency's Background

Mission. The resulting wide area, temporally coherent mosaics can be critical to ecosystem change and human development studies. Parts of the African continent, where SAR sensors have an advantage over other sensors can be revisited for higher resolution RADARSAT-1 imagery to monitor landcover change and to map natural resources in further detail. An example of the utility of these SAR mosaics could be for updating the Africover maps and for filling the many gaps left from the coverage with electro-optical imagers that are hampered by cloud cover. The various programs in Africa for environmental information, forest resource inventory, sustainable development and food security could benefit from these mosaics in terms of fulfilling their requirements for base map as well as landcover information. A great deal of this information could be provided by the georeferenced and geocoded RADARSAT-1 mosaic and easily included in existing information systems. The data from the stereo coverage of the whole of Africa can be used for deriving digital terrain models needed for image rectification before integration in the geographic information and other referential databases.

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