Tropical Forest Mapping by Radar Remote Sensing: Operational Applications at Global Scale.

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ABSTRACT

Large scale and operational applications based on contiguous coverage with SAR data require a set of dedicated techniques in terms of signal handling and product interpretation.

The GRFM SAR map of the West African rainforest domain is derived from some 340 JERS-1 SAR images acquired in a time span of 45 days. The original data with a pixel spacing of 12.5 m are spatially compressed by wavelet transform resulting in products representing the estimated cross section as well as textural features at different spatial scales. The SAR mosaic is assembled by projecting the derived products into a compatible map projection.

A tentative thematic interpretation is presented at a further reduced pixel spacing. A synoptic view on the vegetation gradients in West Africa is obtained and compared to the TREES map derived from NOAA/AVHRR and the sources of coincidence and divergence are discussed.

INTRODUCTION

Numerous case studies demonstrating the potential of spaceborne Synthetic Aperture Radar (SAR) data for land cover mapping have been presented since the launch of the first operational SAR satellites (ERS by ESA and JERS by NASDA) in the early nineties. Taking these experiences to large scale and operational applications requires a set of dedicated techniques in terms of signal handling and product interpretation.

The TREES project (Tropical Ecosystem Environment Monitoring by Satellites) of the SAI (European Commission Space Applications Institute) aims at the global mapping and monitoring of the state of the tropical rain forest based on 1km resolution NOAA/AVHRR imagery. Within the R&D activities of the TREES project, the mission originally attributed to SAR observations mainly concerned localised and detailed analyses. These analyses mainly served the validation of the low resolution thematic products and the monitoring of areas under rapid evolution [1, 2].

With the initiation of the CAMP project in 1994, aiming at the production of SAR maps covering an entire bio-geographical domain, the use of SAR remote sensing for vegetation mapping has moved from the locally focused to the continental scale. The basic rationale behind the initiative is to take full advantage of the all-weather capacity of the SAR instruments and to produce a canvas acquisition of the target area within a minimal time frame.

Two such international projects are currently ongoing, in which the attempt is made to provide the user community with continental scale SAR maps suitable for vegetation and primarily forest mapping purposes. In order to produce valuable vegetation maps, the SAR derived products need to provide a view of the vegetation cover which is contiguous in space and consistent in time. Further assets that the SAR products need to feature are adequate pixel spacing and radiometric quality and accurate geographic positioning.

- The JRC-MTV Central Africa Mosaic Project (CAMP) covers the equatorial forest domain in Central Africa with two complete ERS SAR acquisitions representing contrasting seasonal situations. The first acquisition was made in July – August 1994 during the southern dry season and the second in January – February 1995 during the northern dry season [3, 4].

- The Global Rain Forest Mapping Project (GRFM) is a collaboration between NASDA (Japan), JRC (EC) and JPL-NASA (USA) and covers the entire global tropical forest area with JERS SAR imagery. The Amazon and Congo rive basins are covered twice for assessing low water status (January - February 1996) and high water status (October - November 1996) in flooding forest areas [5].

In both cases continental scale snap-shot SAR maps are produced with a 100 m pixel spacing and matching positioning accuracy. Given the limited number of acquisitions, temporal signatures are not available as a source of information. Both projects therefore dedicate significant effort to exploit both the tonal and textural information content of the SAR data.

OBJECTIVES

The poster presents the actual status of the results obtained with the GRFM JERS mosaic over West Africa. For this part of the African continent a set of JERS images acquired during a single time slot is available.

The core objectives so far have been to implement and optimise the data processing procedure accounting for the data compression, calibration and acquisition strip balancing and geographic projection and mosaic assembly.

On the thematic field, the primary goal is to evaluate the potential of mono-temporal SAR image mosaics to map dense forest vegetation and vegetation gradients in a synoptic way and on a continental scale. In order to understand the value of SAR data as a complementary information source for tropical vegetation mapping, the results obtained are compared to the TREES map derived from NOAA/AVHRR data.

THE GRFM MOSAIC OF WEST AFRICA

The GRFM SAR map of the West African rainforest domain is derived from some 340 JERS-1 SAR (L-band, HH polarised) images acquired in a time span of 45 days (January - February 1996). It covers the south coast of West Africa from Senegal to Nigeria (Fig. 1).

The time slot was chosen based on experiences with ERS SAR data over the Ivory Coast in the centre of the West Africa target window [2]. Experience with the C-band data indicates that the optimal single acquisition slot for land cover and vegetation mapping is situated at the end of the dry season. At this stage the contrast between dense evergreen forest and all other land cover types is at its highest due to dehydration of the vegetation cover outside the forest blocks. This effect is especially critical to separate dense forest from the rural mosaic containing isolated trees, as well as from plantations of woody crops such as coffee and cocoa.

Little experience was available with L-band SAR data over seasonally dry tropical areas. The assumption was made that even with the marked difference in sensitivity of C- and L-band SAR to the vegetation structure and moisture content, the end of the dry season would be the optimal acquisition window.

DATA PROCESSING

The original SAR data set acquired as standard 12.5 m pixel spacing images represents a data volume of some 45 Gb. The first stage in the data processing consists of a spatial down-sampling of the individual scenes. It serves at the same time two goals: data volume reduction and speckle component suppression. A more manageable product with more consistent radiometry for display, reproduction and classification purposes is obtained

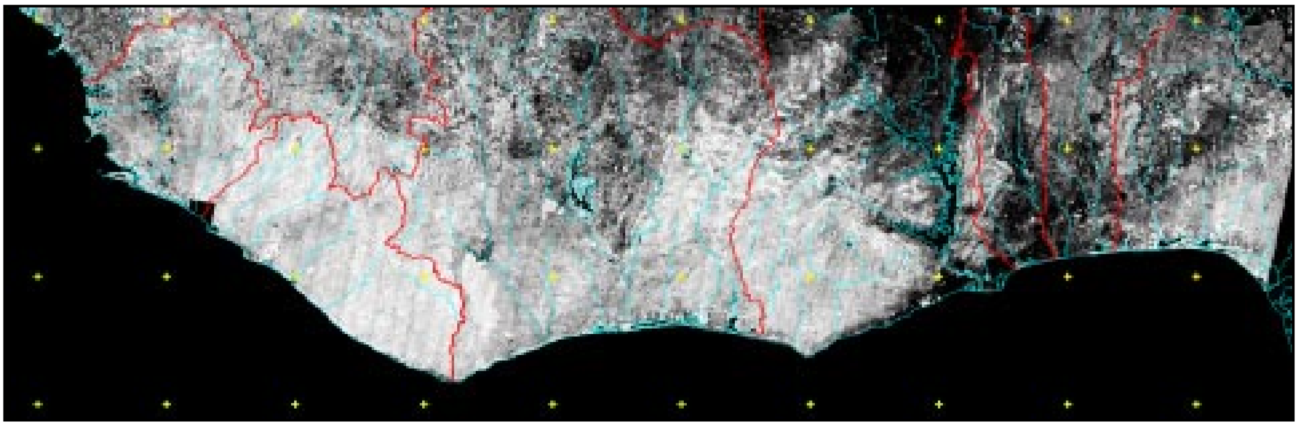

Fig. 1: The GRFM JERS SAR mosaic of West-Africa with country borders and main rivers overlain.

The original data with a pixel spacing of 12.5m are spatially compressed to products (imagettes) with a reduced 100m pixel spacing on an individual scene basis. This is achieved by applying multi-scale decomposition based on the wavelet transform [6]. The resulting products represent the estimated cross section as well as textural features at different spatial scales [7]. The wavelet pyramid generates approximations of the original radar imagery at successive dyadic scales. The projection of the signal into the complementary orthogonal space (detail signals) can be interpreted as texture measures.

The second main processing phase consists of the assembly of the SAR mosaic by projecting the imagettes into a compatible map projection. The mosaic canvas with spatial positioning accuracy matching the pixel size is computed by exploiting both the annotated corner point coordinates and coincidence measures on the overlap areas between neighbouring scenes. The imagettes are then projected into the geographic canvas frame using Nearest Neighbour resampling and an roof-tile decision criterion for the overlapping areas.

The third main component in the processing chain consists the balancing the radiometry between neighbouring strips. Even after the system calibration consisting of removing the geometric range dependency of the effective scattering area, marked differences in radiometry between the near and far range are observed. These radiometric differences are due the different back scattering properties of extended targets when viewed under different angles. Bi-linear correction factors are determined for each scene, in a global adjustment very much along the lines of the geometric adjustment. Radiometric differences in the overlap areas are minimised by least-squares fitting.

The final result is a balanced and consistent SAR map suited for both visual interpretation and computer aided interpretation techniques (Fig. 2).

THEMATIC INTERPRETATION

In accordance with the multi-scale approach of the data processing and analysis, the first thematic interpretations are performed at a further reduced pixel spacing. After down-sampling to 1km grid cells, a manageable product is obtained facilitating the stages of familiarising with the thematic potential of the GRFM SAR maps for such a wide bio-geographical domain (Fig. 1). At the same time, compliance is obtained with the current TREES maps such that a comparison can be set up at the same spatial scale.

Also at this stage image layers representing the average intensity as well as a measure for the variance within each of the 10 x 10 pixel blocks is computed (Fig. 3 and 4). The rationale behind the combined use of tonal and textural image information is that both parameters contain significant information for the separation of the land cover or vegetation types at stake.

- At the given scale of this reduced product, the tonal information relates to the overall target signature within the square kilometre block. It is useful for the determination of target types extending homogeneously over large areas, such as primary forest and natural savannah.

- The textural information extracted in the passage from 100 to 1000 m pixel spacing relates to landscape structure characteristics such as small scale field mixtures and fragmentation patterns. It is therefore an adequate feature for use in synoptic large scale land cover mapping.

Fig. 2: Illustration of the spatial definition of the 100 m GRFM JERS SAR mosaic in the coastal area around Abidjan (Cote d’Ivoire).

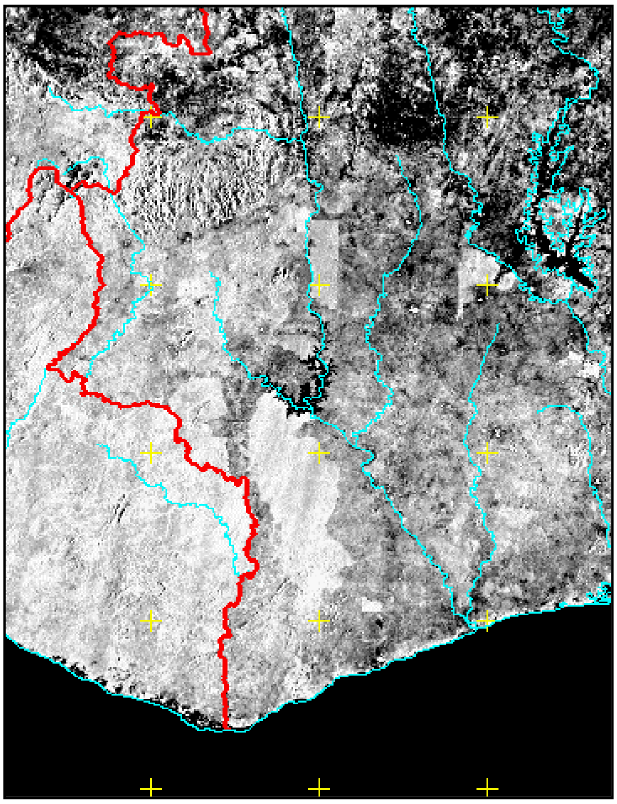

Fig. 3: Mean intensity product at 1 km spatial resolution derived from the GRFM JERS SAR mosaic.

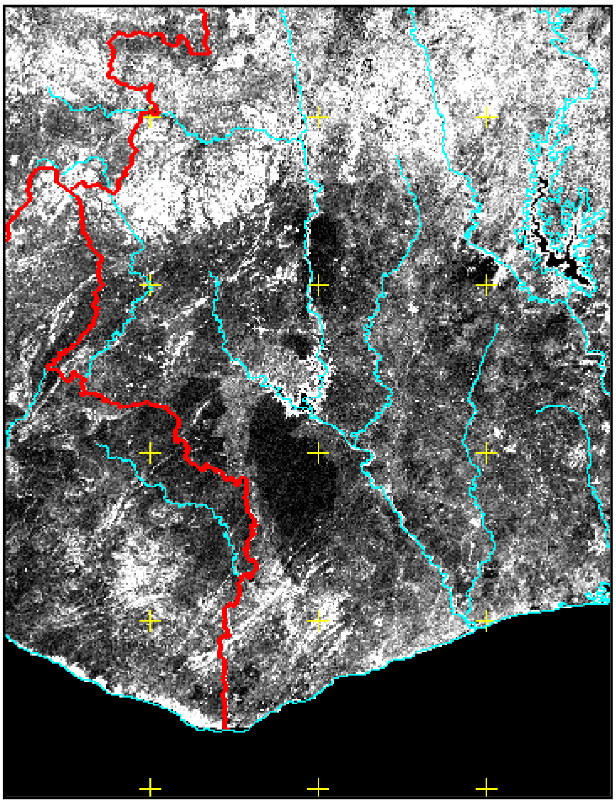

Fig. 4: Texture component at 1 km spatial resolution derived from the GRFM JERS SAR mosaic (coefficient of variation in 10 x 10 pixel blocks).

The thematic interpretation presented (Fig. 5 and 7), is based on joint classification of the radiometric products at 1 km pixel spacing and its associated texture measures. The resulting map represent homogeneous areas in terms of target signature and contextual composition derived from a single time slot acquisition.

The unsupervised classification algorithm (isodata) is tuned in an iterative manner, masking out ocean, built up and mountainous areas during the first runs, and forcing the production of a large number of classes over the remaining land area. Cluster are then interactively merged based on prior studies over the area using ERS and Landsat data, vegetation maps and field observations.

The resulting map shows clear distinction between the major vegetation types over the West-African forest domain. Remaining forest blocks stand out sharply and the climatic gradient in vegetation distribution is well marked.

COMPARISON TO THE TREES MAP

The resulting tentative forest map of West Africa is compared to the widely used tropical forest map produced by the EC TREES project on the basis NOAA-AVHRR data. These optical data have an original spatial resolution of 1 km (at nadir view) and the collection of the necessary individual cloud free images took years to accomplish. The thematic TREES product represents the vegetation cover in three classes: (1) primary rain forest, (2) secondary and degraded forest and (3) non forest areas.

The TREES classification is performed on the original NOAA/AVHRR images rather than using NDVI composites. The latter technique can provide useful temporal information on the vegetation evolution through the seasons, but is often hampered by residual effects of cloud cover in the NDVI values.

Using individual cloud free scenes however implies that data are used collected during different years, and mainly acquired during the dry season. The resulting map therefore represents a specific seasonal state of the vegetation. For the class primary rain forest this should not form a major problem since its seasonal variability is restricted. The class of secondary and degraded forest however may also contain semi-deciduous and deciduous forests. These forest types are natural and represent a different ecological value than for instance degraded rain forest.

The GRFM vegetation map is compliant with the current TREES maps in terms of spatial resolution such that a comparison can be set up at the same spatial scale. Issues such as mixed pixel signatures and the impact of small scale fragmentation apply equally to both data sets such that the comparison is of lesser complexity than when confronting different scale products. The comparison therefore focuses on the thematic information content within comparable grid cells and the understanding of sources of coincidence and divergence.

Good agreement between the TREES and GRFM products is observed in most areas of dense moist forest and grassland savannah. Both classes can be seen as both extremes of the spectrum of vegetation classes present in the bio-geographical window studied. This applies to their biomass level as well as to their seasonal behaviour. In addition they both generally cover large and contiguous areas.

Clear disagreement is however to be noted in vast areas of secondary forest and dry woodlands. In these areas the TREES map shows either non-forest or degraded forest classes, whereas the GRFM map shows a far higher degree of differentiation outside the rain forest domain. Many patches are classified as dense forest in the GRFM product where no or degraded forest is found in the TREES map.

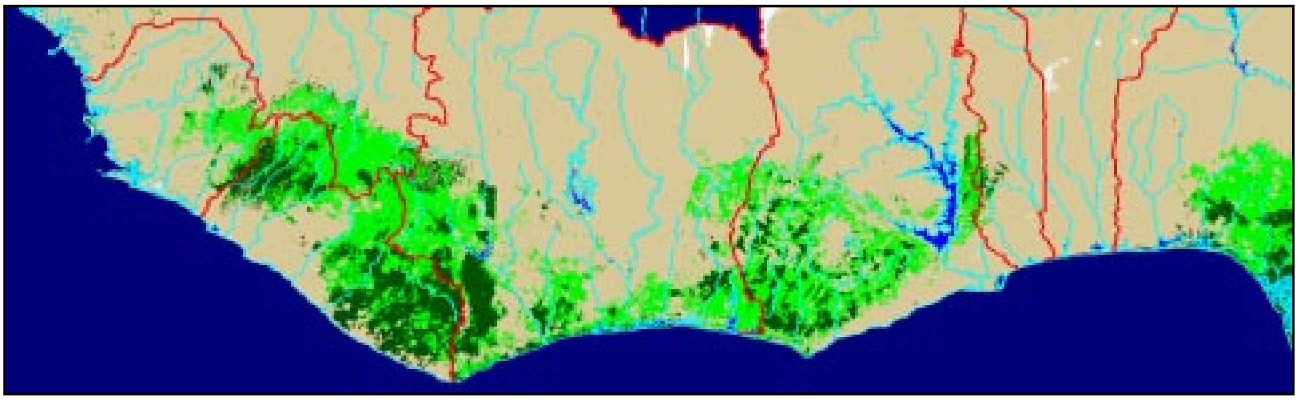

Fig. 5: Vegetation map of West Africa derived from the GRFM JERS SAR mosaic at 1 km spatial resolution.

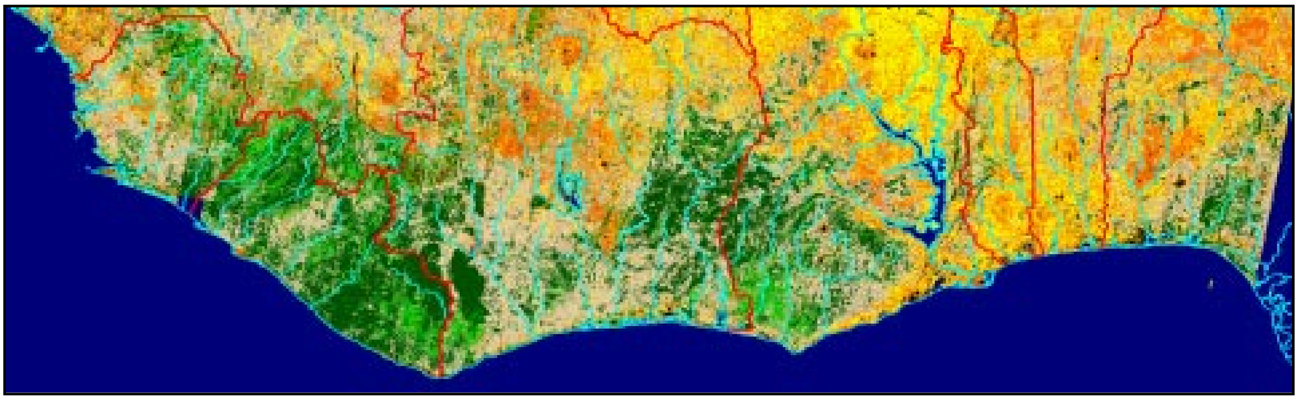

Fig. 6: TREES forest map of West Africa derived from NOAA/AVHRR images (legend: dark green: primary rain forest - light green: secondary and degraded forest – yellow: non forest areas).

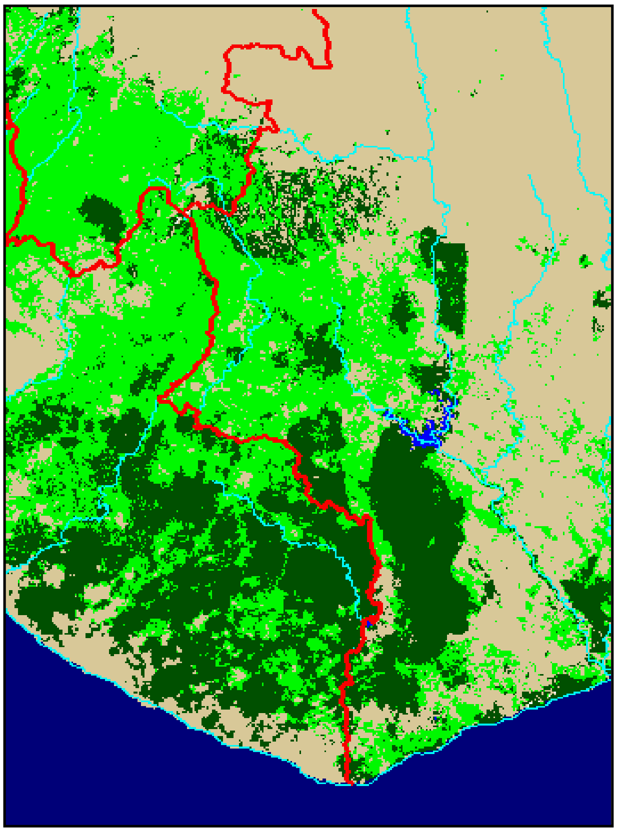

Fig. 7: Extract from the TREES forest map of West Africa derived from NOAA/AVHRR images.

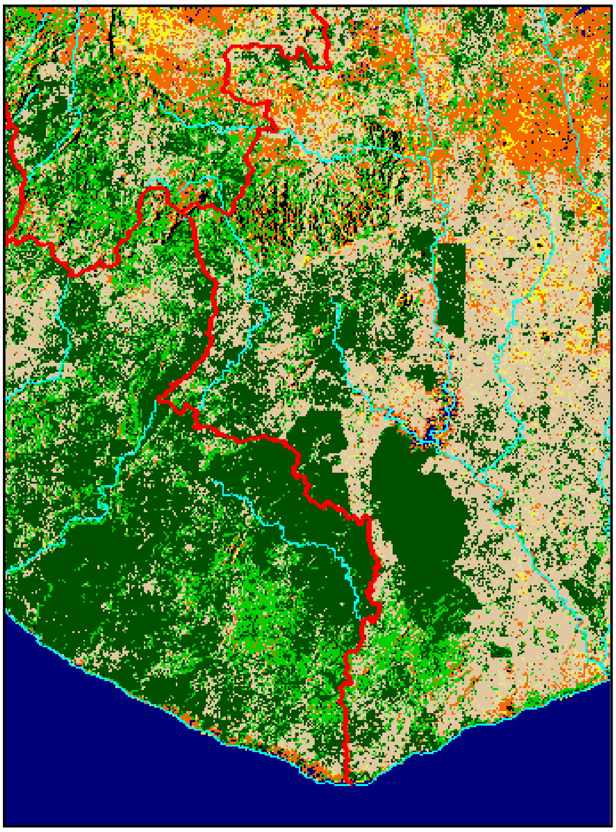

Fig. 8: Extract from the vegetation map of West Africa derived from the GRFM mosaic. Sharply delimited forests stand out clearly and compare well to the TREES map. Disagreement is mainly observed in areas classified as secondary and degraded forest in the TREES map.

DISCUSSION

The sources of agreement and disagreement between both remote sensing derived vegetation maps are to be sought in:

- the nature of the signal used
- the acquisition timing of the data
- the derived data layers fed to the classification process.

The TREES map is based on NOAA/AVHRR visible and near-infrared radiance measurements which are primarily sensitive to leaf reflectance and absorption, linked to chlorophyll contents and activity. A composite of such measurements consisting of individual cloud free images is used, basically representing the dry season situation of the vegetation. For many vegetation types such as the semi-deciduous forest and dry woodlands this represents the leaf-off state, such that they are not associated with forest in the image interpretation process.

The GRFM map is based on JERS SAR measurements of the L-band radar back scattering coefficients. These are primarily sensitive to a combination of the structure (density, size, orientation) and the dielectric properties (moisture content) of the vegetation elements with sizes comparable to the wavelength. Whereas for C-band radar the interaction is mainly restricted to the leaves, in the case of L-band radar this extends to a mix of leaves, branches and trunks.

Since a dry season snapshot is used in the present case, dry forest in leaf-off state may still be discerned on the basis of the woody elements. On the other hand, the West Africa SAR mosaic acquisition slot does not coincide with the end of the local dry season throughout its extent. In certain areas it covers wet conditions with decreased contrast between forest and low woody biomass vegetation types.

Finally the GRFM mapping scheme involves the use of an image texture layer representing the medium scale landscape structure within the 1 km grid cell. This type of information is in no form available to the TREES mapping scheme. Differences in spatial variability allow for the discrimination of areas of comparable average intensity, hence the higher degree of differentiation in the GRFM map in the domain of intermediate vegetation classes.

CONCLUSION AND PROSPECTS

The paper demonstrates the power and usefulness of the approach of constructing continental scale SAR mosaics for synoptic land cover mapping purposes. Even with a single slot acquisition product, when supplemented with textural information, relevant and consistent vegetation maps can be derived. The paper also demonstrates that in accordance with the different nature of the source data, marked differences in thematic information contents are observed between a single slot JERS SAR mosaic and optical AVHRR data. This necessitates the application of a dedicated interpretation scheme and thematic legend, and cautious comparison or combination of both products.

The main line of current work is to fully exploit the thematic potential of the GRFM mosaics at their target spatial resolution of 100 m. Special attention is being paid here at the incorporation of the texture layers extracted in the process of multi-scale decomposition. Where available, the combination with additional SAR data layers is being worked out, both in term of multi-temporal acquisitions and of multi-sensor combinations. The marked difference of the C-band ERS data in sensitivity to seasonal variations is expected to add significant improvements in thematic mapping confidence.

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