K&C Science Report – Phase 1

Synergetic Use of ALOS PALSAR, ENVISAT ASAR and Landsat TM/ETM+ Data for Land Cover and Change Mapping

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***Abstract*—Interferometric ALOS PALSAR Fine Beam Single/Dual, multi-temporal ENVISAT ASAR Alternating Polarization, and Landsat-5 TM/-7 ETM+ data are used for the generation of land cover and change maps. In synthesis, the product generation foresees two main steps: The first one consists in a rigorous data pre-processing, including interferometric processing (PALSAR), geometric / radiometric calibration (PALSAR, ASAR, TM/ETM+), and multi-temporal speckle filtering (PALSAR, ASAR); as result, terrain geocoded coherence, sigma nought, and top-of-atmosphere reflectance products are obtained. The second part is dedicated to data classification and fusion. Classification is performed by means of a prior knowledge-based approach exploiting interferometric, multi-temporal intensity, and spectral signatures. Data fusion and change detection are subsequently applied at semantic level. Results – based on acquisitions over Malawi (country-wide) and on an area in Brazil – show that the synergetic use of data provided by these sensors allows the reliable identification of key land cover types (in primis cropped areas, bare soil areas, sparse and dense vegetated areas, forest clear cuts and burnt areas, water bodies) and their evolution over time, aimed at gathering essential information on the land cover status. In addition, it is shown that using the same repeat-pass interferometric ALOS PALSAR data pair, a Digital Elevation Model (DEM) with higher quality than the Shuttle Radar Topographic Mission (SRTM) can be generated unless the area is densely vegetated.**

***Index Terms*—ALOS PALSAR, ENVISAT ASAR, K&C Initiative, data calibration, prior knowledge-based classifier, data fusion, change detection.**

I. Introduction

Spaceborne Remote Sensing is the only reliable system to collect systematic data at frequent rates over large areas. Therefore, it can be considered as a tool to observe the spatial and temporal aspects of land cover changes. Although an analysis of current and forthcoming sensors pointed out that there is a wide range of information which can be derived from SAR (Synthetic Aperture Radar) and optical data – in particular high resolution – it remains a fact that its use is still limited today. In order to transform this (often) huge amount of multi-temporal multi-source data into information, automated data understanding techniques are mandatory, as ground truth data, required by traditional inductive supervised data learning image classification techniques to be trained on a scene-by-scene basis, and ancillary (e.g., atmospheric) information are typically tedious, expensive, and either difficult or impossible to gather at several locations within image area at the time of image acquisition.

Prior to the ALOS mission, JAXA in collaboration with the K&C team, performed a careful PALSAR data acquisition planning, leading – for the first time – to the acquisition of a multi-temporal, multi-scale L-band data set at global level. Thanks to the availability of this unique multi-temporal data set and to the synergy with other remote sensing spaceborne systems, valuable remote sensing based products – country-wide – can be generated for the mapping and monitoring of land use and natural resources of our planet.

The work proposed within this initiative is essentially focused on the synergetic use of SAR (ALOS PALSAR and ENVISAT ASAR) and optical (Landsat TM/ETM+) data, by considering:

- A rigorous data pre-processing aimed at obtaining terrain geocoded coherence, sigma nought and top-of-atmosphere reflectance products.
- A first level prior knowledge classifier requiring, as input, data radiometrically calibrated into physical values belonging to a common radiometric scale.
- A second level prior knowledge classifier requiring, as input, the semantic layers of the first level classification and temporal features derived from SAR intensity time-series.

II. Method

The processing chain, as illustrated in the data flow diagram in Figure 1, consists of six modules (yellow boxes). Each module, which includes one or a set of functions (grey boxes), provides an intermediate (bright purple boxes) or final product (dark purple boxes). Remote Sensing input data are highlighted in magenta, while Digital Elevation Model (DEM) data are in cyan.

Purpose and functionality of each module are:

1. First Level Optical Classifier

The purpose of this module is to generate, based on top-of-atmosphere calibrated reflectance data, spectral classes. Recently, an original fully automatic modular hierarchical top-down prior spectral knowledge-based classifier capable of detecting a set of kernel (i.e. reliable) spectral layers in calibrated optical data was proposed by Baraldi et al. [1].

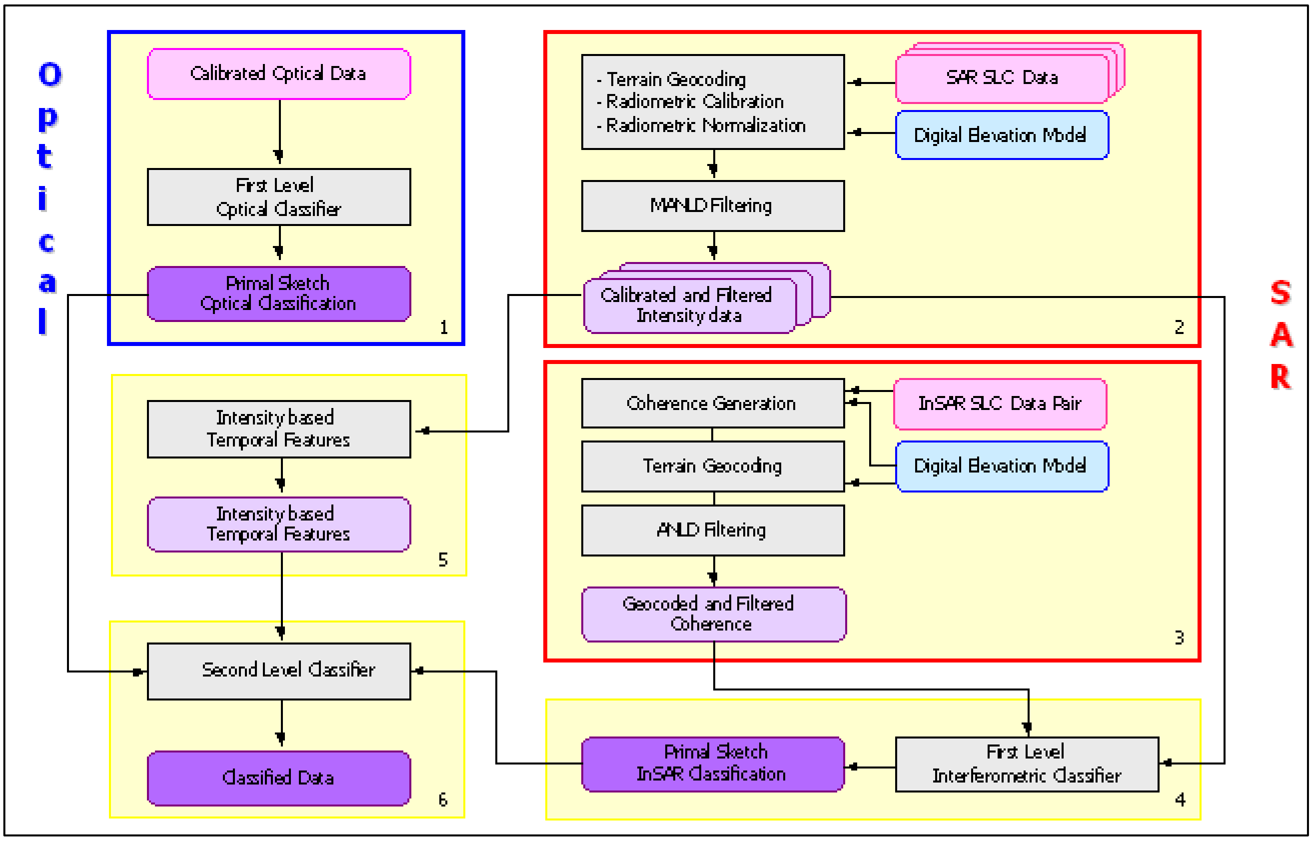

Figure 1. Data Flow Diagram.

In essence this system uses kernel spectral to mimic well-known spectral signatures of target land covers. Based on prior knowledge exclusively, the proposed classifier requires no training and supervision to run, i.e., it is fully automatic. Its output map consists of spectral classes provided with a symbolic meaning. Each of the identified spectral classes is associated with a USGS land cover index, thereby enabling a link between spectral and thematic categories. Furthermore, the proposed algorithm allows to generate a set of spectral features – such as Canopy Chlorophyll Content, Canopy Water Content, Greenness Index, and Water Index – determining, for each pixel, additional (and complementary) quantitative information.

Although this work is based on the use of Landsat TM/ETM+ data, the same approach can be applied to other optical sensors, as the implemented algorithms fully support data acquired by AVNIR-2, SPOT-1,2,4,5, LISS III,IV, AWiFS, and MODIS data.

2. Processing of multi-temporal SAR Intensity

The aim of this module is to generate calibrated (in geometric and radiometric terms) and multi-temporal speckle filtered SAR intensity data. It is anticipated that the provided algorithms [2,3] are sensor independent, hence supporting the process of SAR Single Look Complex (SLC) data of all existing spaceborne, prior the availability of the necessary processing and platform parameters.

Within this initiative, three data types are considered, i.e. ALOS PALSAR Fine Beam Single / Dual polarization and ENVISAT ASAR Alternating Polarization data.

For what concerns the SAR filtering method, conventional single-date and multi-temporal approaches which are based on probability density functions, perform well under strictly controlled conditions, but they are often limited with respect to sensor synergy and to the temporal aspect, where complex joint probability density functions must be considered. The drawback of existing speckle filters is that they are strongly sensor and acquisition mode dependant, because based on the scene statistic. Moreover, if features masks are used, an accuracy loss is introduced when regarding particular shape preservation. This is mainly due to the lack of a priori information about size and type of the features existent in the image. By taking advantage of the redundant information available in multi-temporal series, while being fully independent regarding the data source, a multi-temporal anisotropic diffusion scheme is proposed [4].

3. Interferometric Processing

The purpose of this module is to generate terrain geocoded coherence data. As in the previous module, the provided algorithms are sensor independent. Within this initiative ALOS PALSAR Fine Beam Single and Dual polarization interferometric data are exploited. Due to the temporal decorrelation at C-band, ENVISAT ASAR could not be used.

Concerning coherence estimation, usually it is estimated by setting a moving window with fix dimensions. The drawback of this method is that, due to the fix window size, coherence values are not optimally estimated (in particular when the window is too small), because the filter is not spatially adaptive. For this reason an alternative approach is proposed, which takes advantage from an anisotropic non linear diffusion method.

4. First Level Interferometric Classifier

An interferometric data pair enables the estimation of coherence, which is a measure of the phase noise of the interferogram, and it depends upon sensor parameters, parameters related to the imaging geometry, and object parameters. A general rule of thumb is that high coherence values correspond to small changes (coherent changes) or no temporal variations – meaning that the objects are stable – while volume scattering and temporal changes (incoherent changes) are related to low coherence values. In this latter cases, where the coherence values tend to approach the noise level, the backscattering coefficient of both acquisitions – in primis in terms of average and difference – provides useful information to determine the main land cover types and their changes.

The proposed algorithm has been developed based on the characteristics of interferometric Fine Beam Single and Dual polarization data. It is worth mentioning that the use of these images for interferometric applications have been extensively demonstrated within the ESA project *Prototype Processor for ALOS PALSAR Data and Polarimetric Interferometric Products Generation* [5]. The adopted algorithm's strategy has been derived from [1]: obviously, in this case, kernel spectral rules are not designed to mimic well-known spectral signatures of land covers, but to the object's single- and multi-date backscattering properties at L-HH and/or L-HV polarization and to the corresponding coherence signature. The classification therefore, intrinsically, does not include only main classes related to the object, but also classes linked to the object's temporal changes. It has to be pointed out that the rules have been derived from the literature, in particular from [6], and through the analysis of PALSAR interferometric scenes acquired over different agro-ecological zones, geographic areas and time periods. Finally, the class names, indicate general land cover categories (for instance dense vegetation) rather than thematic classes (for instance forest).

5. Temporal Features

The purpose of this module is to generate key temporal features based on multi-temporal ENVISAT ASAR Alternating Polarization data set.

6. Second Level Classifier

The purpose of this module is twofold. The first one is to provide a classification based on the synergy of interferometric PALSAR Fine Beam Single polarization and multi-temporal ENVISAT ASAR Alternating Polarization data. The second one is to derive a land cover and change detection map based on interferometric PALSAR Fine Beam Dual polarization data and optical (Landsat-5 TM in this case). It is anticipated that, in both cases, a prior knowledge-based approach underpins the inference of land cover classes and changes. In the first case, the primal sketch interferometric classification (outcome module 4) drives the use of temporal features derived from SAR intensity time-series (outcome module 5). In the second one, primal sketch classifications (outcome module 1 and 4) are inputted into the classifier.

The fundamental idea, in both cases, is based on the fact that thematic information and/or changes can be retrieved in a semantic way (since a common denominator between the different data sources has been established) rather than at signal level, as conventionally done. In fact, knowing the symbolic (spectral, interferometric, multi-temporal or pseudo-thematic) name of two input classes, the output class can be assigned by means of logic relationships. For instance, if in the first acquisition date, the identified pseudo-thematic class is snow, and, in the second date, the pixel is classified as clear water, the resulting class will be melted snow.

III. DATA SETS

Two different data sets are used: Malawi – country-wide, i.e. around 100,000 sqkm area coverage – and Brazil – the area covered by an ALOS PALSAR standard frame.

Malawi – The following data are used:

- ALOS PALSAR Fine Beam Single polarization SLC data acquired on:
  - 20 November 2007
  - 05 January 2008
  - 20 February 2008
- ENVISAT ASAR Alternating Polarization Mode SLC data acquired on:
  - 23 July 2007
  - 27 August 2007
  - 01 October 2007
  - 05 November 2007
  - 18 November 2007
  - 10 December 2007
  - 14 January 2008
  - 18 February 2008
  - 02 March 2008
- Shuttle Radar Topographic Mapping Digital Elevation Model.

All products are referenced to the UTM zone 36, Northern hemisphere, WGS-84 system, grid size of 15m.

Brazil – The following data are used:

- Landsat-5 TM data acquired on September 1986;
- ALOS PALSAR Fine Beam Dual polarization SLC data acquired on 20 June and 5 August 2007;
- Shuttle Radar Topographic Mapping Digital Elevation Model.

All products are referenced to UTM zone 22, Southern hemisphere, WGS-84 system, grid size of 15m (PALSAR) and 30m (Landsat-5 TM).

IV. RESULTS AND SUMMARY

The results based on the two data sets – and illustrated in Figure 2, 3, and 4 – are generated according to:

- Malawi: modules 2,3,4,5,6;
- Brazil: modules 1,2,3,4,6.

Note that all data processing are performed using SARscape® a sarmap proprietary software.

The results obtained so far indicate that the synergetic use of interferometric PALSAR Fine Beam Single and Dual polarization data with multi-temporal ASAR Alternating Polarization or single-date Landsat TM/ETM+ data enables the reliable identification of main land cover types and their evolution over time. Furthermore, the proposed approach provides, additionally and in an automated way, the location (where) and the type (what) of the change.

Concerning product's reliability, the obtained accuracy is in the order of 80% for Malawi [7], and significantly higher than 90% for Brazil [8]. It is worth mentioning that, in both cases, the products have been validated using in situ data: 1,213 points in 76 clusters for Malawi, 30 points for Brazil. The main reason of the lower accuracy reported in Malawi, with respect to the Brazil, is primarily due to the fact that some features (for instance cropped areas), in general, are heterogeneous and of limited dimension (i.e. less than 1 ha).

In these specific cases, due to the mixed nature of the pixels, classification inaccuracies are observed. A higher spatial resolution, which will be available with ALOS PALSAR-2, would strongly reduces the presence of mixed pixels, hence significantly contributing to improve the overall accuracy.

Furthermore, given the spatial resolution of ALOS AVNIR-2 data (10 meters) and the radiometric high quality of these data, it is planned, in the next phase (2009-2011), to additionally exploit images acquired from this sensor. Moreover, very high resolution stripmap SAR data (3 meters), acquired by the COSMO-SkyMed satellite constellation [9], will be integrated in the current processing chain. Based on this new data scenario, it is thereby planned to extend the second level classifier to support the use of textural features and geometric descriptors.

Finally, given the availability of suitable interferometric ALOS PALSAR data pair, the capability of, and the limitation to, the generation of a Digital Elevation Model in the two areas is additionally analyzed. In synthesis: in Brazil – due to the presence of very dense forest – the quality of the resulting DEM is very poor. In Malawi, on the other hand, the obtained quality is doubtless higher than the SRTM DEM, particularly with respect to the spatial details resulting from the better spatial resolution (10 meter of PALSAR Fine Beam Single polarization against the 90 meter interpolated SRTM DEM).

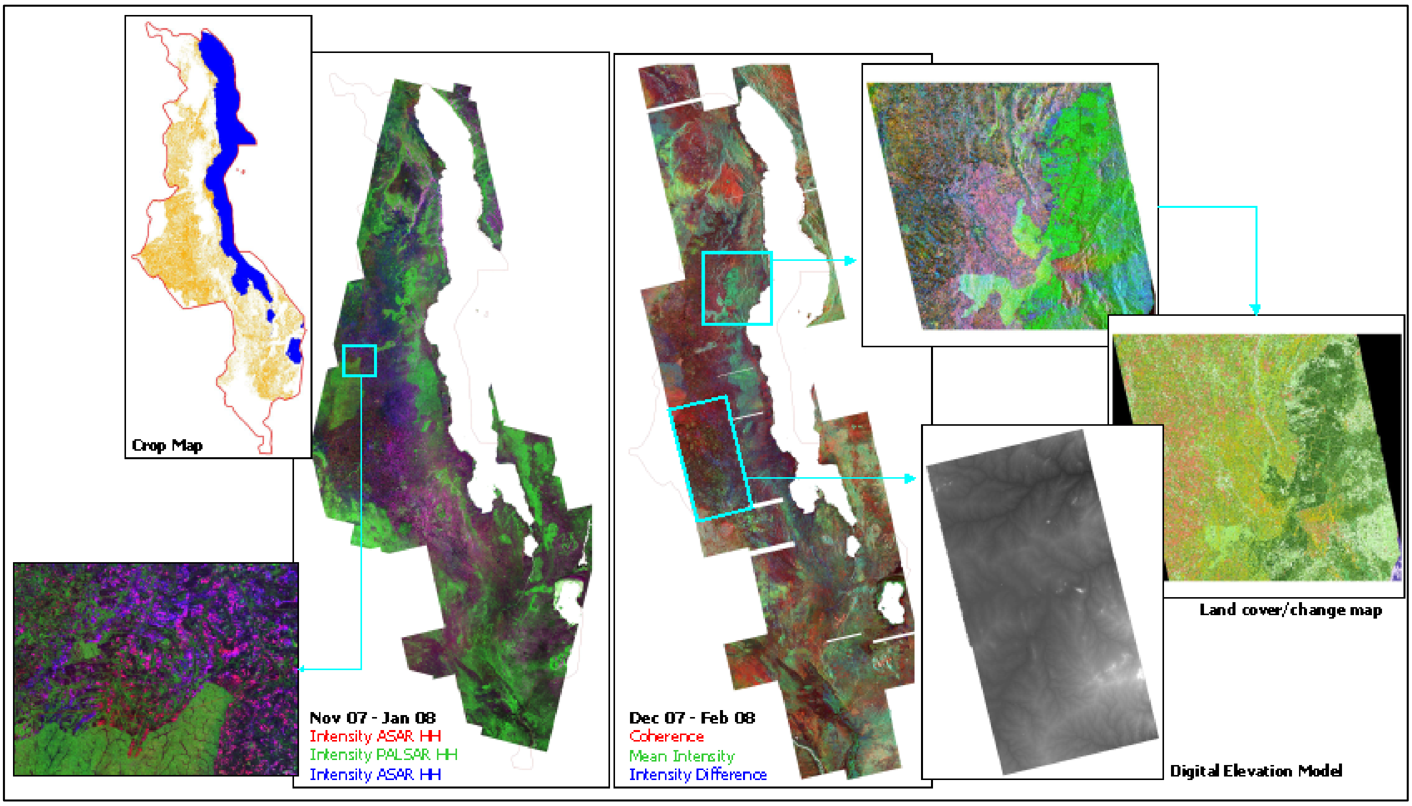

Figure 2. The color composite on the left illustrates a multi-temporal data set based on 120 ENVISAT ASAR AP images and 70 ALOS PALSAR FBS scenes ("© *JAXA/METI)* data covering the whole Malawi (100,000 sqkm, 15m resolution). The image on the right shows an interferometric color composite based on ALOS PALSAR FBS data (70 image pairs). The enlargements highlight the extensive information included in this type of multi-temporal multi-source data set, which allows the generation of products such as crop map, main land cover/change classes, and digital elevation model. All processing has been performed starting from SLC data. ALOS K&C © *JAXA/METI.*

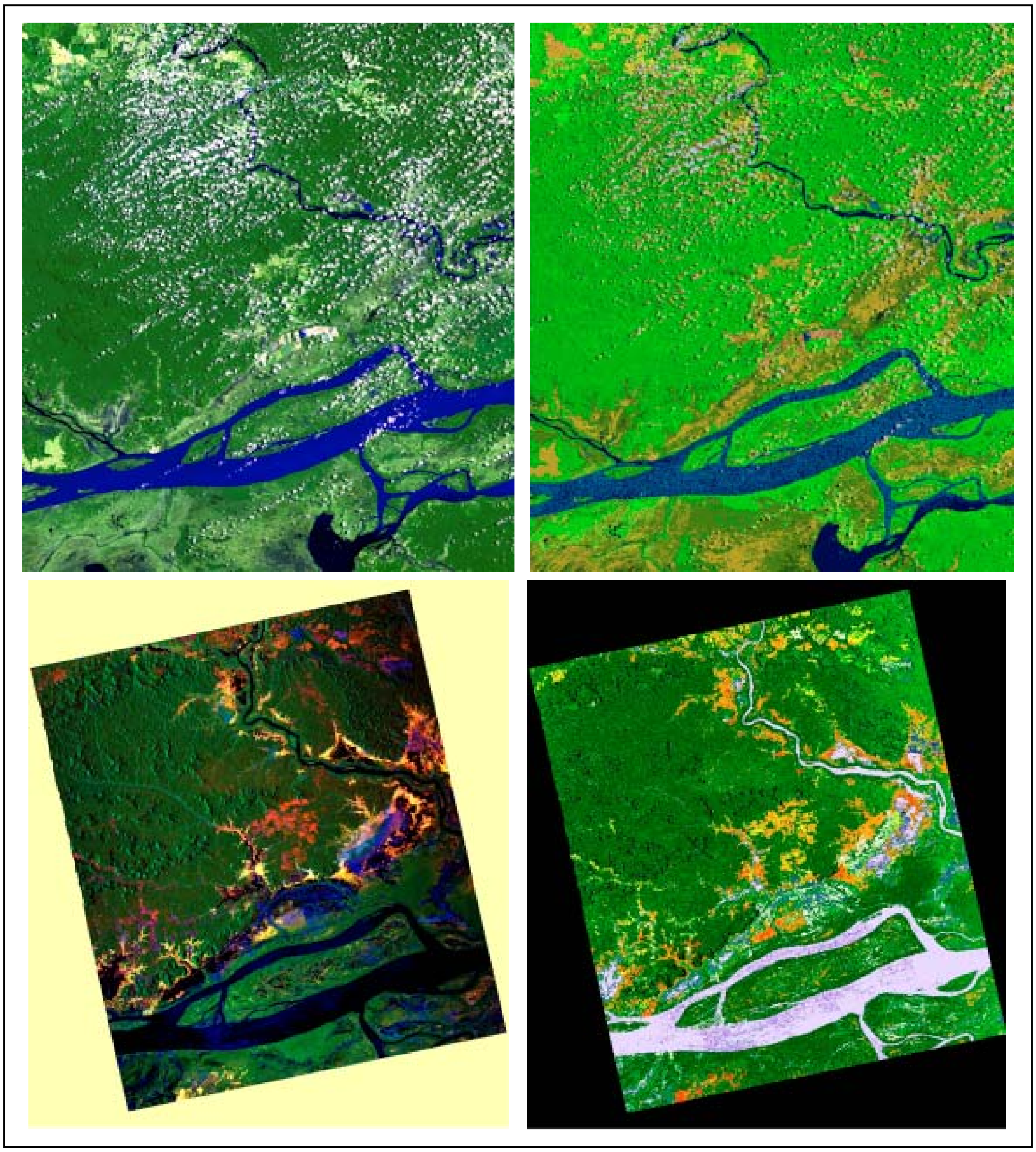

Figure 3. Landsat-5 TM color composite acquired on 1986 (top left) and corresponding classification (top right). ALOS PALSAR interferometric color composite acquired on 2007 (bottom left) and corresponding classification (bottom right).

Legend Optical (main classes): Green tones: Forest and sparse vegetation; Brown tones: barren land and built-up areas; Blue tones: water types; White tones: clouds.

Legend SAR (main classes): Green tones: Thick and sparse forest; Brown tones: Bare soil; Yellow tones: short vegetation and short dry vegetation; Blue tones: water types; Red: rocks/settlements.ALOS K&C © *JAXA/METI.*

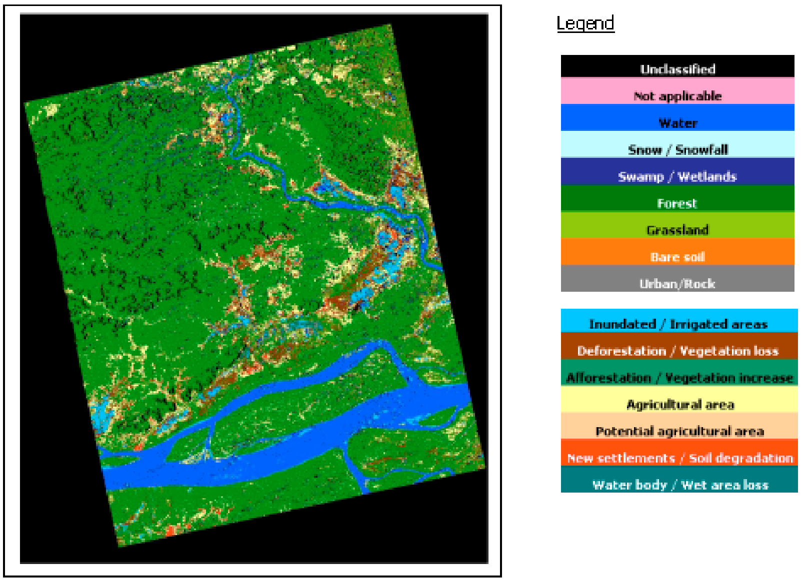

Figure 4. Land cover and change map between 1986 and 2007.

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sarmap S.A. – a Swiss company, www.sarmap.ch – currently constituted by 6 employees, was founded in January, 1998 to provide product / service development in the field of remote sensing (SAR and optical), particularly airborne and spaceborne Synthetic Aperture Radar (SAR) data processing. Training courses are also offered to extend the understanding of the utilization of SAR data, products and services. Application areas of expertise include Digital Elevation Model, agriculture, forestry, ground deformation, and change detection. In the past 10 years, sarmap has been involved in around 80 projects: approximately 2/3 on algorithm/product/service developments at the European Space Agency. The remaining 1/3 focused on the developments of innovative remote sensing based products/services for the World Bank, EC Joint Research Centre, JAXA, and private sector (re-insurance sector in primis). sarmap developed SARscape®, a software tool for the processing of airborne and spaceborne SAR data integrated in ENVI® and world-wide commercialized by Creaso GmbH, ITT Visual Information Solutions Ltd., and Sierra Atlantic Ltd..