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Crop Mapping Services for the Sudanese Government in Frame of the ESA Global Service Element "*Global Monitoring for Food Security*"

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Summary: The Global Monitoring for Food Security (GMFS) focuses on those aspects of food security monitoring where satellite derived technology can bring added value. These include monitoring parameters reflecting crop condition, agricultural production and overall vegetation health. It aims to establish an operational service for crop monitoring in support of Food Security Monitoring to serve policy makers and operational users on various scales by providing spatial information on variables affecting Food Security.

This article focuses on the service implementation, the modular processing systems and algorithms, applied to provide needed multi scale information on crop extent, cultivated area, crop condition and production for Food Security assessments and how this was demonstrated in the Sudan during the past crop seasons.

Zusammenfassung: *Agrarkartierungsdienste für die sudanesische Regierung als Teil des „Globalen Monitoring zur Ernährungssicherung" der Dienste-Projekte der ESA*. Aufgabe des Global Monitoring for Food Security Projektes (GMFS) ist es, bestehende Frühwarnsysteme zur Ernährungssicherung mit Informationen zu unterstützen, die im Besonderen durch den Einsatz von Satellitenfernerkundung präziser und schneller geliefert werden können, als durch bisherige Verfahren. Die hier benötigten Dienste beziehen sich vor allem auf die Erfassung und Dokumentation von Bestands- und Wuchsbedingungen entsprechender Hauptnahrungsmittel liefernder Kulturen, deren Ausdehnung der Anbauflächen sowie deren entsprechende Produktion. GMFS zielt darauf ab, hierzu operationelle Dienste zu etablieren, die zukünftig politischen Entscheidungsträgern und bestehenden Frühwarnsystemen auf unterschiedlichen administrativen Ebenen zur Erfassung und Vermeidung von Nahrungsmittelengpässen oder Hungerkatastrophen von Nutzen sein können.

Der vorliegende Artikel fokussiert auf die Darstellung und Umsetzung der Dienste mittels modularer Prozessketten und Methoden, die durch das GMFS Konsortium speziell dazu entwickelt wurden, um die multiskalaren Anforderungen der unterschiedlichen Nutzer im Bezug auf die Überwachung der Ernährungssicherung abzudecken. Dies wird anhand der Realisierung im Sudan in den vergangenen Vegetationsperioden veranschaulicht.

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1 Introduction

The Global Monitoring for Food Security project (GMFS) is a part of the European Space Agency (ESA) Global Monitoring for Environment and Security (GMES) Programme (European Commission 2005). GMFS aims to establish an operational service to serve policy makers and operational users by providing advanced crop information derived from Earth Observation data and to contribute to the transparency of the production, management and distribution of agriculture. The ultimate goal is to identify and assess food insecure areas and populations and to quantify their level of vulnerability with particular emphasis on food security (GMFS 2004). The GMFS project runs since 2003 and is scheduled to run up to March 2009.

The GMFS Stage 2 consortium consists of 12 European based companies and institutes and is lead by VITO the Flemish Institute for Technological Research (Haub 2007 & www.gmfs.info). As a GMFS demonstration case, the Sudan plays an important role. The country is located in a climatically highly variable region and in the rainfed sector as dominating agriculture the production is strongly depending upon the amount and distribution of seasonal rains. This affects the total cultivated area per season and leads to severe localized food insecurities (FAO 2006). In this respect it is one major aim of the agricultural policy of the Sudanese Government to combat poverty and hunger with a number of programmes, initiatives and international cooperation's.

More than 20 years ago, the Federal Ministry of Agriculture and Forest of Sudan (FMoAF) started to work with Satellite Earth Observation methodologies on the estimation of agricultural production. The FMoAF renewed in July 2007 this engagement with the agreement of a Memorandum of Understanding with the European GMFS partnership represented in East Africa by EFTAS Fernerkundung Technologietransfer GmbH and VITO.

EFTAS is coordinating the regional implementation of the GMFS activities in East African countries (see Fig. 1). In this respect EFTAS links the European base activities from the GMFS service providers with the activities implemented on the ground, provides a communication channel and sup-

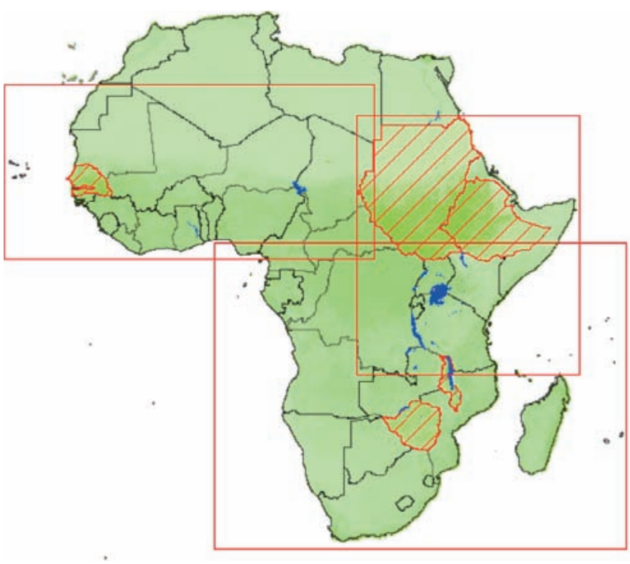

Fig. 1: GMFS geographical extent in three regions in East, West and Southern Africa (according to IGAD – Intergovernmental Authority on Development, CLISS – Comité Inter-états pour la Lutte contre la Sécheresse au Sahel, SADC – Southern Africa Development Community) and five countries (red = Sudan, Ethiopia, Senegal, Malawi and Zimbabwe).

ports the regional partners, in particular with the FMoAF in Sudan, the Central Statistic Agency (CSA) in Ethiopia as well as with the Regional Centre for Mapping of Resources for Development (RCMRD) in Kenya. For Sudan EFTAS forms a strong partner network together with General Administration of Planning & Agricultural Economics (PAEA) of the FMoAF as well as other relevant public authorities in Khartoum and shares knowledge beyond the provision of crop information. Specifically the assessment of the yearly cultivated area in the rain fed dominated sectors are of major interest for the PAEA.

2 GMFS Services

GMFS provides four types of food security services which are as shown in Tab. 1: i – support to the FAO/WFP Crop and Food Supply Assessment Missions (CFSAM). ii

Tab. 1: GMFS Service Portfolio.

Service	Product Name
Support to CFSAM	GMFS Support Kit for FAO/WFP CFSAM missions (SK)
Early warning	Vegetation Productivity Indicator (VPI)
	Fraction of Absorbed Photo synthetically Active radiation (fAPAR)/DMP
Agricultural mapping	Crop Emergence Period (CEP)
	Cultivated Area (CA)
	Extent of Cultivation (EoC)
	Agricultural Productivity (AP)
Crop Yield assessment	Crop Yield (CY)

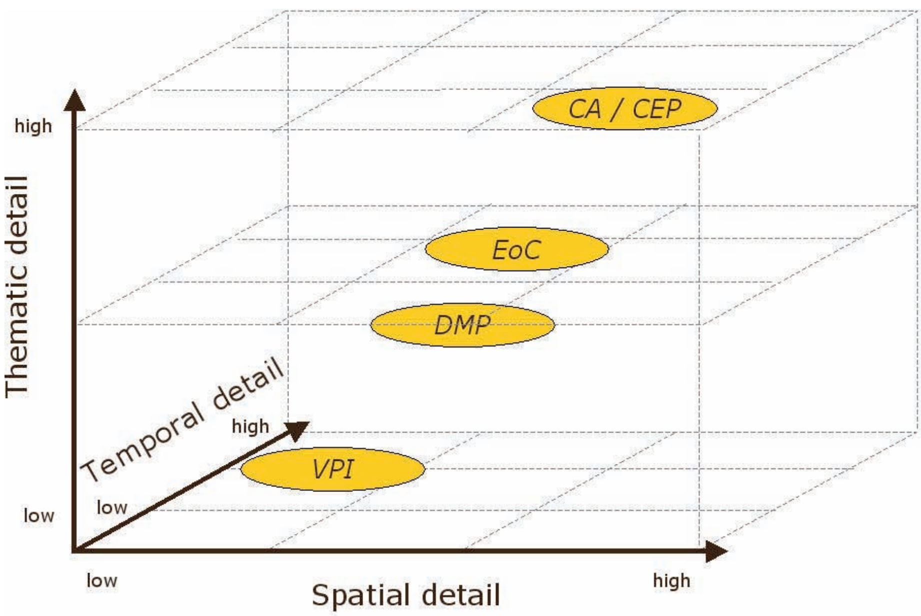

Fig. 2: Advanced multi scale crop information services (GMFS services, see Tab. 1: CA = Cultivated Area; CEP = Crop Emergence Period; EoC = Extent of Cultivation; DMP = Dry Matter Productivity; VPI = Vegetation Productivita Indicator).

– Early Warning Services. iii – Agricultural mapping services. iv – Yield assessments.

These services are developed in extensive exchange and under permanent review with core user organisations such as the FMoAF in Sudan, as well as other national authorities, regional centres such as the RCMRD in Kenya, United Nations (UN) organisations such as UN Food and Agriculture Organisation (FAO), UN World Food Programme (WFP) in Rome and the European Commission Directorate General Joint Research Centre (JRC) (GMFS 2006a, Bydekerke et al. 2007).

The broad range of user requirements scaling from national authorities, regional institutions, up to the UN level are reflected in specific solutions regarding the thematic, spatial and temporal resolution (see Tab. 2 and Fig. 2).

Tab. 2: GMFS Service Portfolio.

Service	Product Name	Spatial resolution	Temporal resolution	Used Sensors
Early warning	Vegetation Productivity Indicator (VPI)	1 km	10 daily	SPOT-VGT
	Fraction of Absorbed Photo synthetically Active radiation (fAPAR)/DMP	100–300 m	10 daily	MERIS
Agricultural mapping	Crop Emergence Period (CEP)	15–20 m	Once per main crop season	ASAR, ALOS/PALSAR LANDSAT TM/ETM
	Cultivated Area (CA)	15–20 m	Once per main crop season	ASAR, ALOS/PALSAR LANDSAT TM/ETM
	Extent of Cultivation (EoC)	100–300 m	Once per main crop season	ASAR, ALOS/PALSAR LANDSAT TM/ETM MERIS FR/MODIS
	Agricultural Productivity (AP)	100–300 m	Once per main crop season	ASAR, ALOS/PALSAR LANDSAT TM/ETM MERIS FR/MODIS

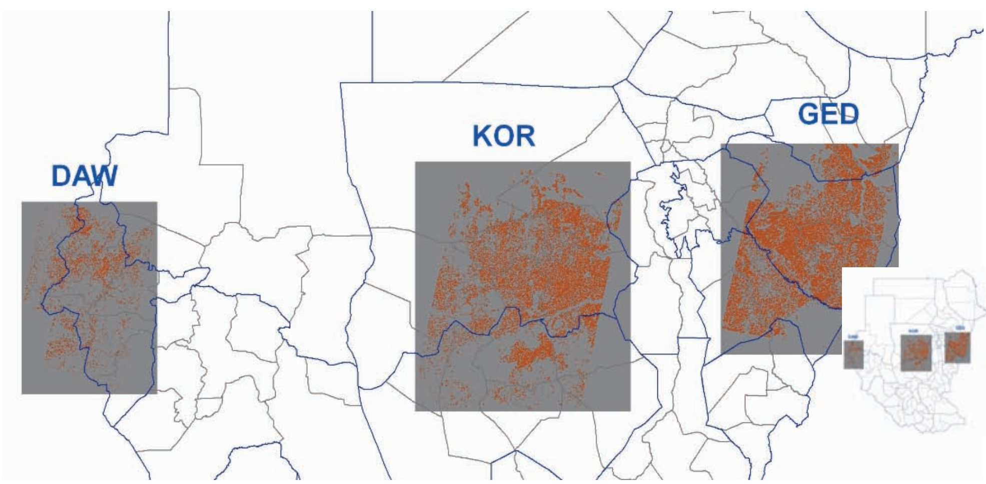

Fig. 3: GMFS case study areas for CA (high resolution Cultivated Area product) in Sudan 2007 (DAW = Darfur West; KOR = Kordofan; GED = Gedaref).

As shown in Tab. 2, the Early Warning services are based upon the processing of low resolution data and are covering in a fully unsupervised generation regional to continental scales (GMFS 2006b & 2008). The Agricultural mapping services are generated once per main cropping season. The medium resolution product is here covering entire Sudanese territories'' crop extent (EoC). These product is up scaled on basis of high resolution cultivated area maps (CA), which are produced for main agricultural production areas or specific Areas of Interest (AOI) on a local level. For Sudan three AOIs had been defined over Darfur (DAW) and Kordofan (KOR), which are dominated by rain fed sorghum & millet production, and over Gedaref (GED), dominated by mechanized agriculture and huge irrigation schemes (see Fig. 3). Mainly the Early Warning & Agricultural mapping services are provided to the Federal Ministry of Agriculture and Forest in Sudan.

3 GMFS Crop Mapping in Sudan

The methodology used is strongly based upon the multi-temporal characteristics of the satellite data in response to the changing environment. It is a modular processing system (see Fig. 4), which is aimed to be systematically up scaled with recent ground truthing field data. In essence it is based upon the fact that agricultural land has a specific 'growing profile' to that of its surrounding vegetation or land cover types. These changes are picked up, both in the SAR signal (see Fig. 5) and the optical signal throughout the growing season on the basis of which cropped land is identified (GMFS 2006b; Bydekerke et al. 2007). The accuracy and efficiency of the used algorithms in relation to the spatial and temporal resolution of the used data are strongly influenced by the employed management techniques of the agricultural land, in particular the field sizes and degree of fragmentation of the landscape. Subsistence agriculture in Africa is predominant and in some areas agriculture is characterized by small, highly fragmented and scattered fields. In these cases ground resolution of the input satellite data is the most limiting factor. Other areas are easier to identify due to larger field sizes. The use of the product depends upon the final accuracy achieved and ranges from the use as generic crop mask to an input layer for the assessment of total cropped area. The mapping products are repetitive and cover every growing season. Fig. 6 illustrates one of the products for Sudan for the Gedaref area.

MERIS and ASAR data are used in both the Agricultural mapping service and the Early Warning service. MERIS is used in both resolutions namely the Full Resolution (FR, 300 m pixel size) and the Reduced resolution (RR, 1,2 km pixel size). From the acquired MERIS RR images 10-daily fAPAR composites are made covering the entire Africa. The 10-daily images are typically completed 3–4 days after the last acquisition and are then further distributed to the partner organizations in Africa, showing the specific region of interest. Users are notified by email, including a quick look, upon new arrival of a product and the products itself are made available through the ESA Data Dissemination System (DDS) or via regular FTP.

A multi-temporal series of MERIS FR and ASAR covering the entire growing season of the monitored areas are analyzed in combination with other satellite data (SPOT-4, Landsat) and ground observations in order to derive the cropped area at local and national scale. The methodology and classification algorithms used (see Fig. 4) are as far as possible multi-mission compatible and under continuous improvement. Based on the results and products' evaluations obtained during the Stage 1, the overall service strategy is critically reviewed as well as the different processing chains (in terms of algorithms and requested EO data) used for the products generation. In essence, key issues were:

- To take into account, as far as possible, the synergetic use (spectral, temporal, and spatial) of EO data;
- To optimise and harmonise the processing chains;

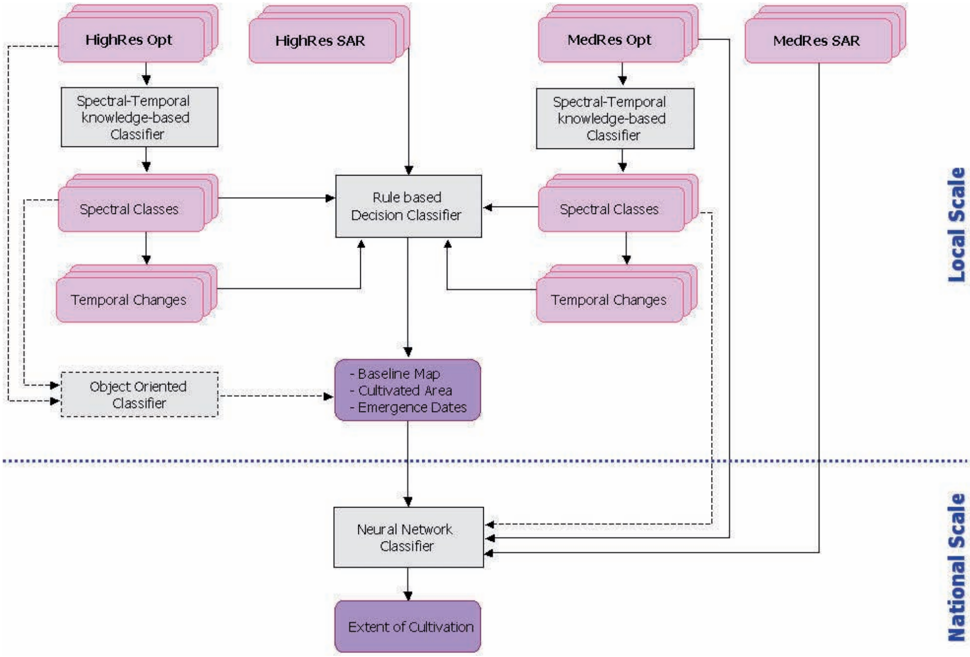

Fig. 4: GMFS Agricultural Mapping Services process chain. Dashed lines are back-up solutions (GMFS, 2006b).

- To consider back-up solutions in terms of EO data and algorithms;
- To provide scalable (from local to national) information.

Fig. 4 gives an overview of the improved and harmonised GMFS processing chain. The basic strategy is that in a modular approach High Resolution SAR (ASAR Alternating Polarization, ALOS PALSAR Fine Beam) and Optical (Landsat TM/ETM+, SPOT-4, a.o.) data are used to generate Baseline Map, **Cultivated Area (CA)**, and **Emergence Period (CEP)** products at local level in the different Agro-Ecological-Zones and/or agricultural areas. Basis of this step is a knowledge based classifier. Medium Resolution Optical (MERIS Full Resolution, MODIS) complemented by SAR (ASAR Wide Swath, ALOS PALSAR ScanSAR) data are calibrated, i. e., trained, using of the Baseline Map, and classified to up-scale the High Resolution products at country level, hence obtaining the **cultivation extent product (EoC)** using Neural Network classifier (see Sections 3.1 and 3.2).

3.1 *GMFS High resolution "Agricultural Mapping" Module*

The pre-processing part – which includes all data processing steps from raw to geocoded/ortho rectified and calibrated product – for both Optical and SAR, is fully automatic. The standard product is a multi-temporal mosaic ranging from local to national scale.

During the Phase 1 a spectral knowledge-based per-pixel classifier (Baraldi et al. 2006) capable of detecting a set of kernel spectral layers in calibrated optical images has been considered. In essence, in this system, kernel spectral rules are designed to mimic well-known spectral signatures of target land covers. Based on prior knowledge exclusively, the established spectral classifier component requires no training and supervision to run, i. e., it is fully automatic. Its output map is an input into the "Rule Based Decision Classifier" and consists of spectral strata, e. g., strong vegetation, provided with a symbolic meaning intermediate between those (low) of clusters and segments

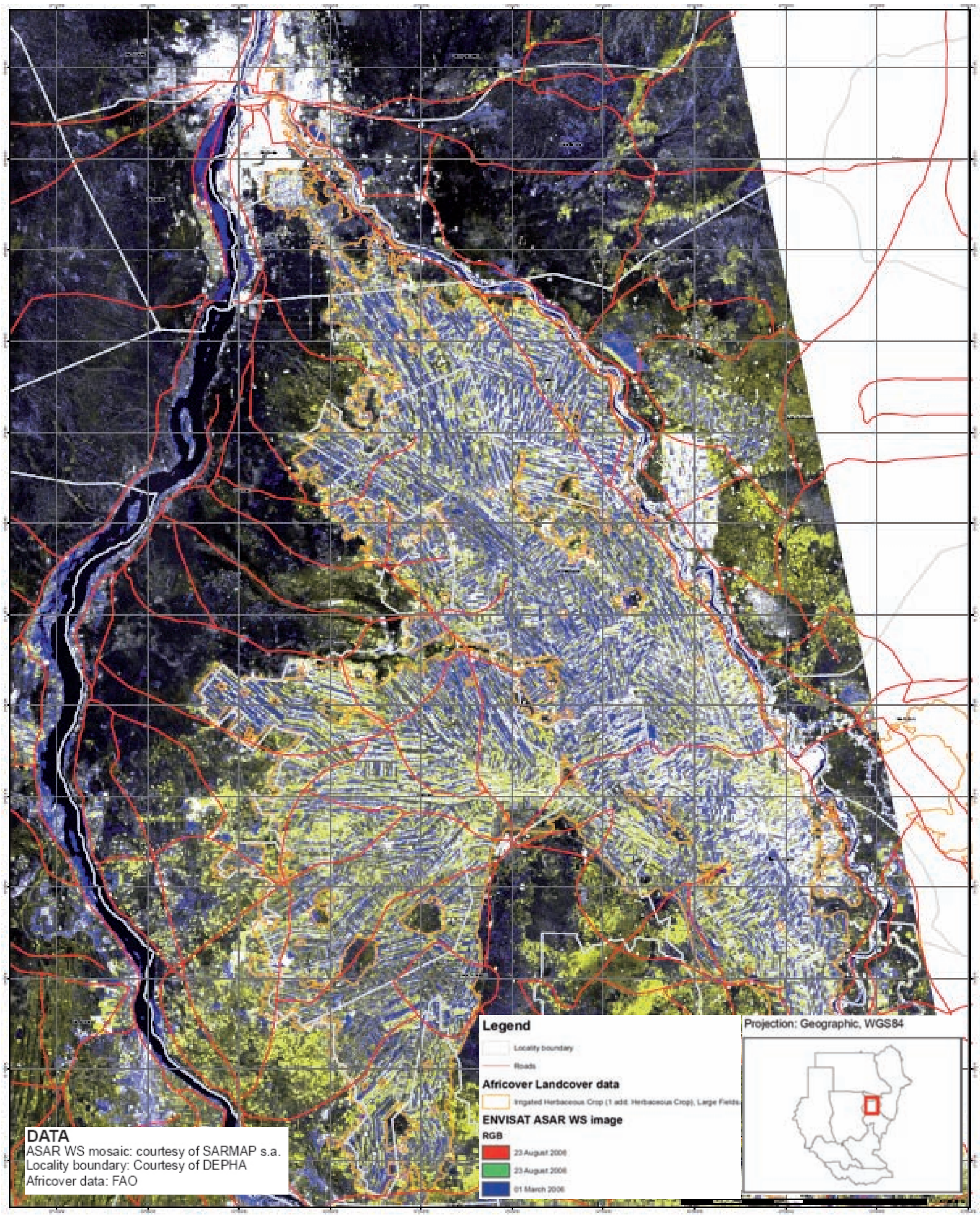

Fig. 5: Large irrigated fields in Gezira scheme south of Khartoum as seen by ENVISAT ASAR. (The Gezira irrigation scheme, which uses water from the upstream Sennar dam along the Blue Nile, can clearly be indentified on the ENVISAT ASAR WS images with a main ground resolution of about 100 m. The Gezira scheme is one of the largerst irrigation projects in the world. The network of canals is about 4,300 kilometers long and the irrigated area covers about 8,800 square km. The characteristic rectangular shape is adopted to allow individual fields to access water in the irrigation canals along its narrow side. Additionally, the ENVISAT ASAR images taken in the evening of 23 August 2006, shows evidence of the recent floodings in Sudan (Blue coloured zones around the river). Torrential rainfall in the highlands of Ethiopia, early August 2006, caused extensive flooding in Sudan, an event which was also captured by the continuous agricultural monitoring activities of GMFS).

and those (high) of land cover classes, e. g., forest. As a consequence, prior knowledge-based kernel spectral categories are naturally suitable for driving stratified application-specific classification, clustering, or segmentation of EO imagery which could involve training and supervision.

This GMFS process chain and the knowledge-based classification strategy is developed by sarmap (Switzerland) and applied to the SAR data (GMFS 2006b). Considering in this case, not the spectral, but the temporal variations of the backscattering coefficient and (whenever relevant) coherence, which – for targeted applications as agriculture – are characteristic for this type of instruments. Moreover, combining the spectral layers with geometrically and radiometrically calibrated multi-temporal SAR data, the temporal-spectral rule-based classifier takes full advantage of data synergy, making the system not only more efficient but reliable, due to information redundancy. This approach has been designed and developed using Landsat TM/ETM+ and ENVISAT ASAR AP data, and subsequently extended

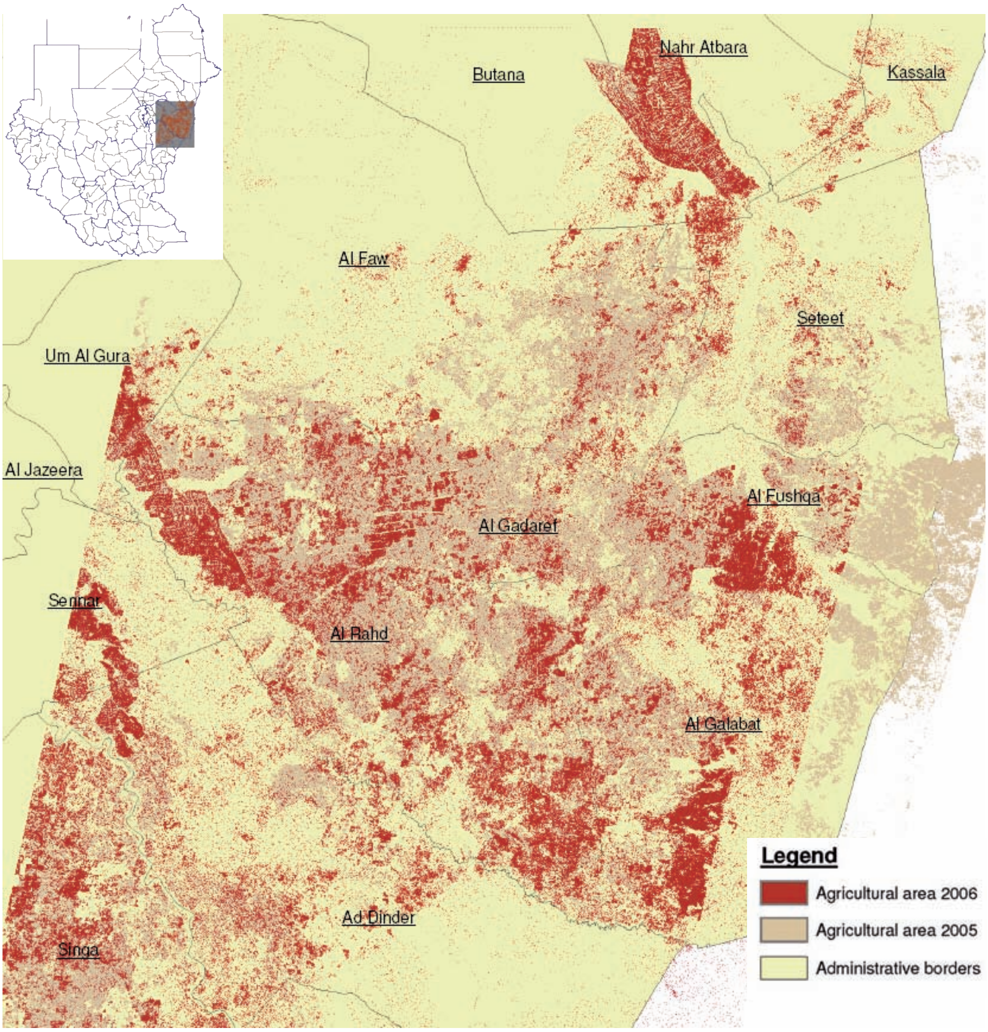

Fig. 6: GMFS Cultivated Area map (CA) annual variations over Gedaref area (East Sudan) between 2005–2006 (dark red areas = increas cultivation in 2006).

to SPOT-4, MODIS data, hence enabling to support the processing of High to Medium Resolution data sets. Future improvements also include the use of ALOS/PALSAR, SPOT VEGETATION P-products and others. In addition, the methodology used minimizes the needs for operator intervention, automating the procedures to the extent possible.

For the generation of the CA map for Sudan 2007 ASAR AP amplitude images (acquisitions spanning from January to November 2007), Landsat 5 TM and Landsat 7 ETM+ multispectral archive images acquired between 1999 and 2000, the Crop Acreage Map of the year 2006 and ALOS PALSAR acquisitions of the year 2007 were used (GMFS 2008).

3.2 *GMFS Medium resolution ''Agricultural Mapping'' Module*

The aim of the medium resolution product (EoC map) derived from MERIS FR and/or MODIS data is to upscale the local scale product (CA) to the national scale, using a Neural Network (NN) technique. Area Fraction Images as in Fig. 6 (AFIs) are generated from the CA product (the CA product either being produced directly from the SAR imagery in combination with the baseline map in year 1; or updated with new imagery for year 2. In one AFI each pixel represents the fraction of a certain class within that pixel. These AFI's are then up-scaled using a multi-temporal stack of medium resolution images covering the entire area under consideration. It is based upon multi-temporal medium resolution fAPAR images (pixel size 300 m), the CA product, multi-temporal characteristics of vegetation, and specific changes of agricultural land during the growing season (field clearance, sowing, senescence, harvesting, etc.). This requires repetitive acquisitions of satellite data during the growing season, typically once every 10 days. This technique has been thoroughly applied by VITO through work in previous Belgian Research projects, GEOLAND (within the Observatory for Food Security and Crop Monitoring) and the EC funded ASIAITC project (Eerens 2006).

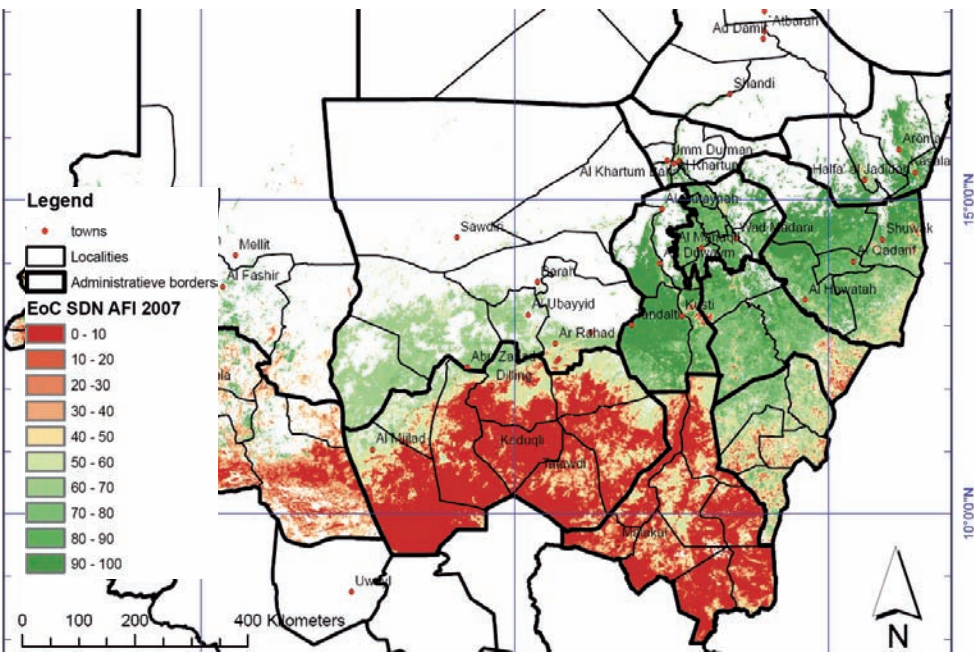

Fig. 7: GMFS Extent of Cultivation (EoC) 2007. GMFS EoC-AFI map SDN 2007.

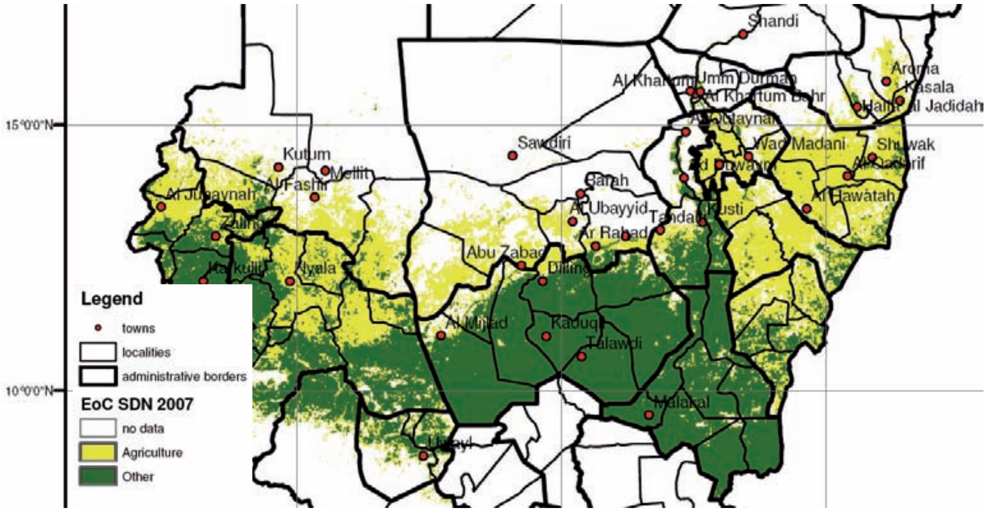

Fig. 8: GMFS Extent of Cultivation (EoC) 2007. GMFS EoC-map SDN 2007.

The Extent of Cultivation (EoC) product (see Fig. 7) intends to give a qualitative indication of cropped areas for a given growing season. Because the EoC product is repetitive and generated every growing season over the main production areas of Sudan it allows to assess annual variations of the cultivated areas (see Fig. 8).

For the 2007 generation five MERIS FR fAPAR images were used as input for the neural network (from April until November), covering the major growing season. The CA products for the three regions Darfur West, Kordofan and Gedaref were converted to AFI's and corresponding pixels were selected as training output for the neural network (GMFS 2008).

The software used for the processing is GLIMPSE (GLobal IMage Processing SoftwarE), developed by VITO. The dominant classes from the AFI (see Fig. 7) were selected to create the EoC product (see Fig. 8).

4 GMFS Outcomes

In addition to the remote sensing data GMFS considers systematic ground truthing, whereas in Sudan a dedicated area frame survey campaign was undertaken in October 2007. In advance of an on site campaign in KOR and GED a central training had been arranged by EFTAS for three days in Khartoum to introduce the field survey methodologies to the most relevant authorities in Sudan. The initiative followed a standard field work protocol (GMFS 2007) with the objective to accomplish a harmonized data format for integration into the process chains. For Sudan the interactive GIS field data base contained in 2007 more than 500 predefined samples, which had been used for calibration and implemented into the Quality Control (QC) procedures.

As final component those QC procedures are mandatory for all GMFS services in order to support the implementation, delivery and evaluation of particular end-to-end services. Each GMFS service and constituent data product delivered to end-users is accompanied by a quality control record. This principle GMFS strategy, i. e. to complement the processing of user requested Earth Observation products with systematic ground truthing of the recent season, thorough validation and participative integration of local experts knowledge, could be demonstrated as a sustainable approach to provide reliable information.

Generally this particular service cycle over Sudan 2007 could confirm that the developed GMFS services, such as the information about crop conditions and the extent of cropped areas at different scales, provides powerful information upon the most pressing issues in terms of Food Security.

Although the GMFS services are still considered to be in a pre operational stage the Sudan users have a detailed perception of the potential of GMFS products and how they can contribute to improve cost-effectively existing Food Security assessments. However, prior to full integration into existing services the quality of the products needs to be confirmed. Therefore, GMFS service providers are continuously improving their products.

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