PFG 2013 / 5, 0459–0472
Stuttgart, October 2013

Report

Monitoring Services for Food Security – Successful Transfer of Technology to the Sudanese Government

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Keywords: Technology transfer, multi scale services, seasonal monitoring, agricultural mapping, food security, data fusion, GMES, GMFS, Sudan

Summary: Food security remains a raising challenge between poverty reduction and population growth worldwide but for us with direct concerns in Africa. The initiative of the European Space Agency (ESA) for a service element called Global Monitoring for Food Security (GMFS) is being designed to apply remote sensing and GIS services for food security purposes. Several African countries were addressed not only to use such specific information but to benefit from a transfer of technology and institutional strengthening.

The paper provides as one of the first articles a comprehensive essay about the successful technology transfer of ESA GMFS services to selected government authorities. It particularly discusses the frame conditions of agriculture in Sudan and the corresponding GMFS services for Sudan. After a brief introduction of the applied methods a stronger focus shall be given on the operational results of this six years collaboration with the Federal Ministry of Agriculture and Irrigation of Sudan. There were a wide range of state-of-the-art techniques involved, such as the combined use of medium and high resolution remote sensing data, the integration of optical and radar data as well as the incorporation of agronomic ground sampling. The full documentation of the technological developments goes beyond this paper, but is freely available via the cited references and at www.gmfs.info. Until today documentations which are covering the entire process from scientific developments to the successful implementation at beneficiary institutions are rarely available. Especially the combination of research and development work, professional training and the implementation of operational Earth Observation & Geographic Information System based services emphasizes not only the success of the project but furthermore may rise hope to contribute to the amelioration of the food security situation in Africa.

Zusammenfassung: *Monitoringdienste für die Ernährungssicherung – Erfolgreicher Technologietransfer für die Regierung des Sudan.* Das Thema Ernährungssicherung bleibt eine ständige Herausforderung zwischen Armutsbekämpfung und weltweitem Bevölkerungswachstum, allerdings für uns mit direktem Bezug zu Afrika. Die Europäische Weltraumagentur (ESA) entwickelte ein Dienstleistungselement namens *Global Monitoring for Food Security* (GMFS, Globales Monitoring für Ernährungssicherung), um verschiedene Erdbeobachtungs- und GIS-Dienste im Rahmen der Ernährungssicherung anzuwenden. Mehrere afrikanische Staaten wurden ausgewählt, um nicht nur die Ergebnisse zu nutzen, sondern vom Technologietransfer und der Institutionenförderung zu profitieren.

Der Beitrag stellt als einer der ersten den erfolgreichen Technologietransfer von ESA GMFS-Diensten zu ausgewählten Regierungsbehörden vor. Insbesondere diskutiert er die Rahmenbedingungen für die Landwirtschaft im Sudan und die dafür geeigneten GMFS-Dienste für den Sudan. Nach einer kurzen Einführung in die angewandten Methoden soll ein stärkerer Fokus auf die operationellen Ergebnisse dieser sechsjährigen Zusammenarbeit mit dem Bundesministerium für Landwirtschaft und Bewässerung des Sudan gerichtet werden. Eine umfangreiche Auswahl von Anwendungen entsprechend des Standes der Technik wurde genutzt, wie etwa die kombinierte Nutzung von mittel- und hochaufgelösten Fernerkundungsdaten, die Integration von optischen und Radar-Daten sowie die Einbeziehung landwirtschaftlicher Feldstichproben. Eine vollständige Dokumentation der technischen Entwicklungen würde den Rahmen dieses Beitrags sprengen, ist aber unter www.gmfs.info frei verfügbar.

Bis heute liegt wenig Dokumentation über den gesamten Prozess der wissenschaftlichen Entwicklungen bis hin zur erfolgreichen Umsetzung vor.

DOI: 10.1127/1432-8364/2013/0192 1432-8364/13/0192 $ 3.50

Speziell die Kombination von Forschungs- und Entwicklungsarbeiten, professionellem Training und die Einführung operationeller Erdbeobachtungs- und GIS-Dienste unterstreicht nicht nur den Erfolg des Projekts, sondern gibt vielmehr Anlass zur Hoffnung, einen Beitrag zur Verbesserung der Ernährungssicherung in Afrika leisten zu können.

1 Introduction

The worried questions on the Earth's life-sustaining capacity in view of more than seven billion people to be fed are of overall importance for the political, ecological and economic survival of mankind. Therefore, the issue of food security is a primary concern of many international institutions like the World Bank, United Nations World Food Programme (WFP), United Nations Food and Agricultural Organisation (FAO), Joint Research Centre (JRC) of the European Union (EU) and many national institutions of the public development aid. The project series of Global Monitoring for Food Security (GMFS) is part of the European Space Agency's (ESA) contribution to the EU / ESA Global Monitoring for Environment and Security (GMES) programme, recently renamed as Copernicus. The GMFS project aims to 1) establish a platform to provide operational Geoinformation services for crop monitoring in support of Food Security Monitoring Systems and to 2) sustainably serve policy makers and operational users. It is an ESA Earth Watch GMES Service Element which started in 2003 by a first phase. Since 2006 EFTAS is part of the extended second and third project phase, which will be funded until September 2013. The recent last funding phase focuses on the sustainable transfer of operational services to the user community aiming at a continuation by the involved African ministries beyond the funding period of the ESA project (Haub & Gilliams 2010).

Although the whole project setup of GMFS covers a total of nine African countries (GMFS 2013a) this paper focuses particularly on the promising results achieved in Sudan. The engagement in Sudan was recommended by the GMFS advisory board consisting of FAO, WFP and JRC upon request of the Federal Ministry of Agriculture and Irrigation (FMoAI) of Sudan. The main reason was the demand for assistance in monitoring the highly varying cropping conditions and the related vulnerability of the people in Sudan. The encouraging cooperation has been realized with strong commitments from both sides covered through a high level Memorandum of Understanding with the FMoAI.

2 Agriculture in Sudan

In many African countries, information on the annually cultivated land is not available. Mapping of the main cultivated areas is therefore a first step towards a better understanding of annual cultivation in these countries and an important input for generating statistics on agriculture production.

The agro-climatic zoning of Sub-Saharan Africa is mostly based on the precipitation zones. The equatorial zones with nearly permanent vegetation periods have almost no dry seasons in the inner tropical zone, which has been traditionally a forest based farming system. In the adjacent sub-equatorial and sub-sahelian zones with distinct dry season there is mostly enough precipitation for cropping of roots and cereals. Farther away from the equator agro-pastoral schemes with millet and sorghum are common, mostly suitable only for extensive rain fed agriculture due to the very short vegetation periods affected by a certain natural variability. This is the case for the central and northern half of the Sudanese territory. The seasonal variability of cropping in these areas is largely depending on intensity, duration and distribution of rain which as well significantly varies from year to year. Related to this the total of the cropped area in a given growing season can differ significantly from the previous growing seasons. As a result, large differences in crop production from season to season are affecting the subsistence of the local population. Huge parts of Sudan's agriculture are affected by this kind of tremendous seasonal variation. Fig. 1 shows

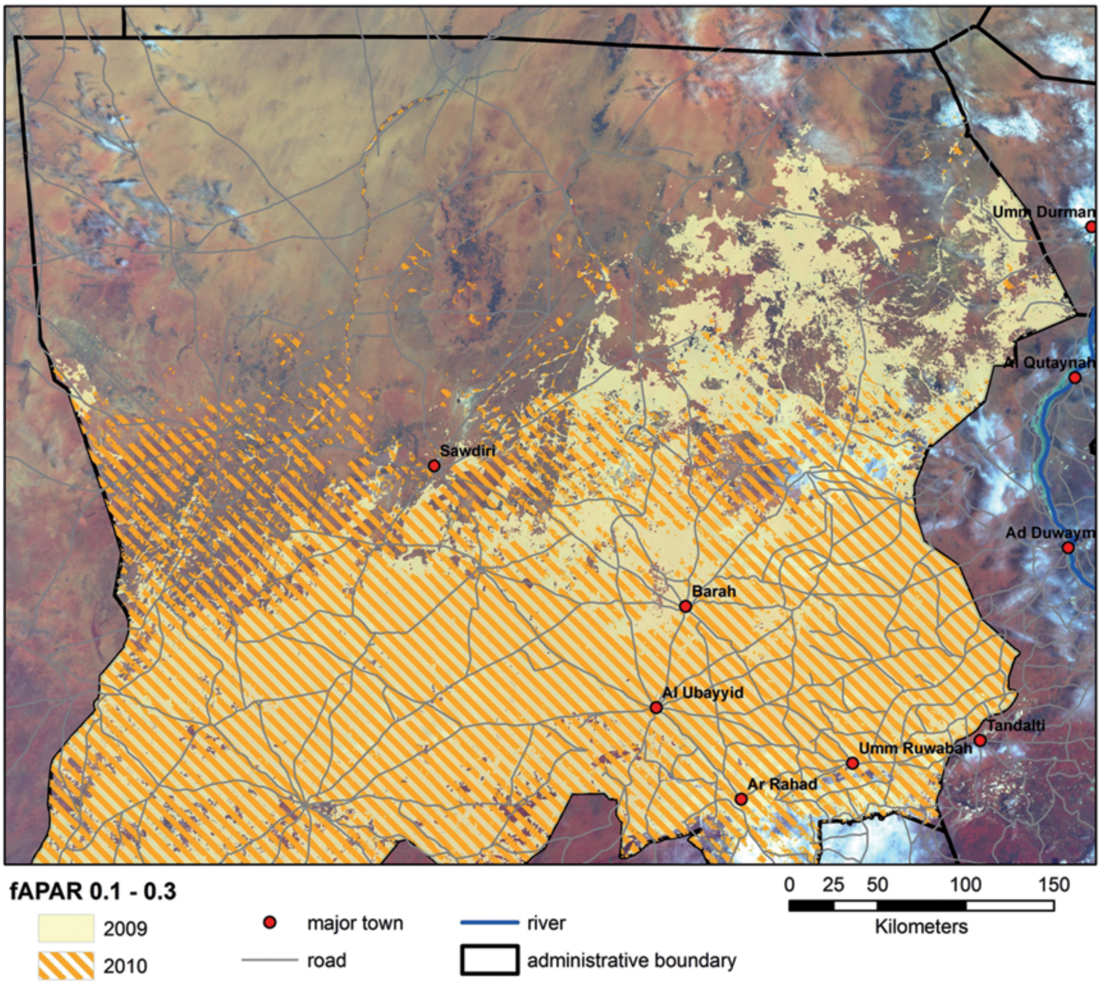

Fig. 1: Annual change of agriculture in North Kordofan, Sudan. The map shows the distribution of potential rain fed areas for the crop seasons 2009 (light yellow) and 2010 (hatched, light brown) (Brockmann et. al. 2011). Source: False colour composite ENVISAT MERIS FR (2010-09-12 – bands 13-5-1) overlaid with MERIS FR level 2 fAPAR data from 2009 versus 2010.

the distribution of the overall vegetation and the related potential rain fed areas for the crop seasons 2009 (light yellow) and 2010 (hatched, light brown) in North Kordofan State, Sudan (Brockmann et al. 2011).

The annual precipitation in the central part of Sudan ranges between 150/200 mm and 400/500 mm with strong local variations. Large areas in central Sudan are depending on traditional rain fed agriculture mainly in small scale subsistence farming (Fig. 2). These conditions are causing high vulnerability of certain parts of the Sudanese population. About 60% of the Sudanese people who are depending on subsis-

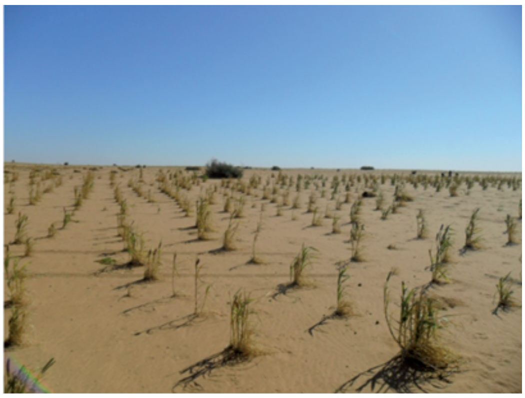

Fig. 2: Millet field in North Kordofan, Sudan 2011.

tence agriculture are living in rural areas with an average population density of 14 – 17 people per km^2.

3 Agricultural Monitoring Services by Means of Remote Sensing

In the above given context the FMoAI is considering that Earth Observation (EO) technologies are one of the most important means to strengthen the agricultural monitoring framework in Sudan. In this regard the FMoAI requested the GMFS partnership to investigate advanced EO contributions in particular for the assessment on traditional rain fed areas. Therefore, the yearly monitoring of agricultural extent and condition constitutes a real information demand of the Sudanese administration, which has been addressed through the definition of key GMFS services. Nowadays, these services provide processing routines for a seasonal monitoring and the mapping of the seasonal cultivated area using medium and high resolution satellite data. For future continuation these services have been developed for the use of the forthcoming ESA Sentinel missions 1-3. As such the potential service continuation is expected to last until 2020.

The cooperation between the FMoAI and the GMFS partnership started in 2007 during the second project phase of GMFS (2005 – 2009) (Haub et al. 2008). Within the third stage of GMFS (GMFS3), lasting from 2010 – 2013, two major agricultural mapping products have been investigated, following recommendations of the FMoAI: 1) an indicative inter-seasonal map on vegetation growth dynamics by means of medium resolution satellite data (MR) and 2) a high resolution (HR) cultivated area map based on optical and synthetic aperture radar (SAR) data.

Along all activities extra attention was drawn to the compliance of the GMFS products and processes with the day-to-day workflows of the FMoAI and the systematic participation of the users in the entire processing chain by dedicated consultancies and professional trainings. The following chapters depict the applied methods, the status of the product outcomes and the degree of technology transfer and integration into the institutional framework of the FMoAI.

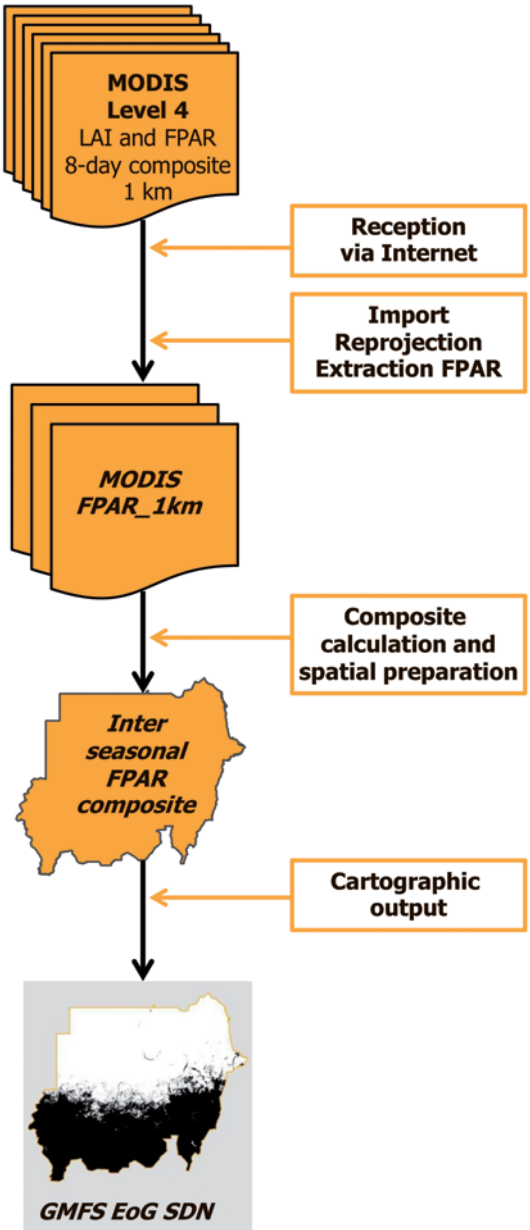

Fig. 3: Processing scheme of the indicative inter-seasonal growth map (GMFS EoG SDN). (LAI = leaf area index, FPAR = *Fraction of Absorbed Photosynthetically Active Radiation*, EoG = *Extent of vegetation Growth*, EoG SDN = EoG in Sudan).

3.1 *Seasonal Monitoring by Remote Sensing of Medium Resolution*

With the aim of having at least indicative but regular information about the distribution of overall vegetation and potential agricultural production during the growing season, the indicative inter-seasonal monitoring services forms the basis to get standardized monthly maps. These maps are generated by means of bio-physical indicators covering the entire Sudan. The extraction of these parameters is based on the *Fraction of Absorbed Photosynthetically Active Radiation* indicators, a bio-physical variable directly correlated with the primary productivity of the vegetation (Gobron et al. 2004). For the GMFS product a processing chain has been originally defined on the basis of the ENVISAT MERIS indicator called *fAPAR* and had to be adapted after the

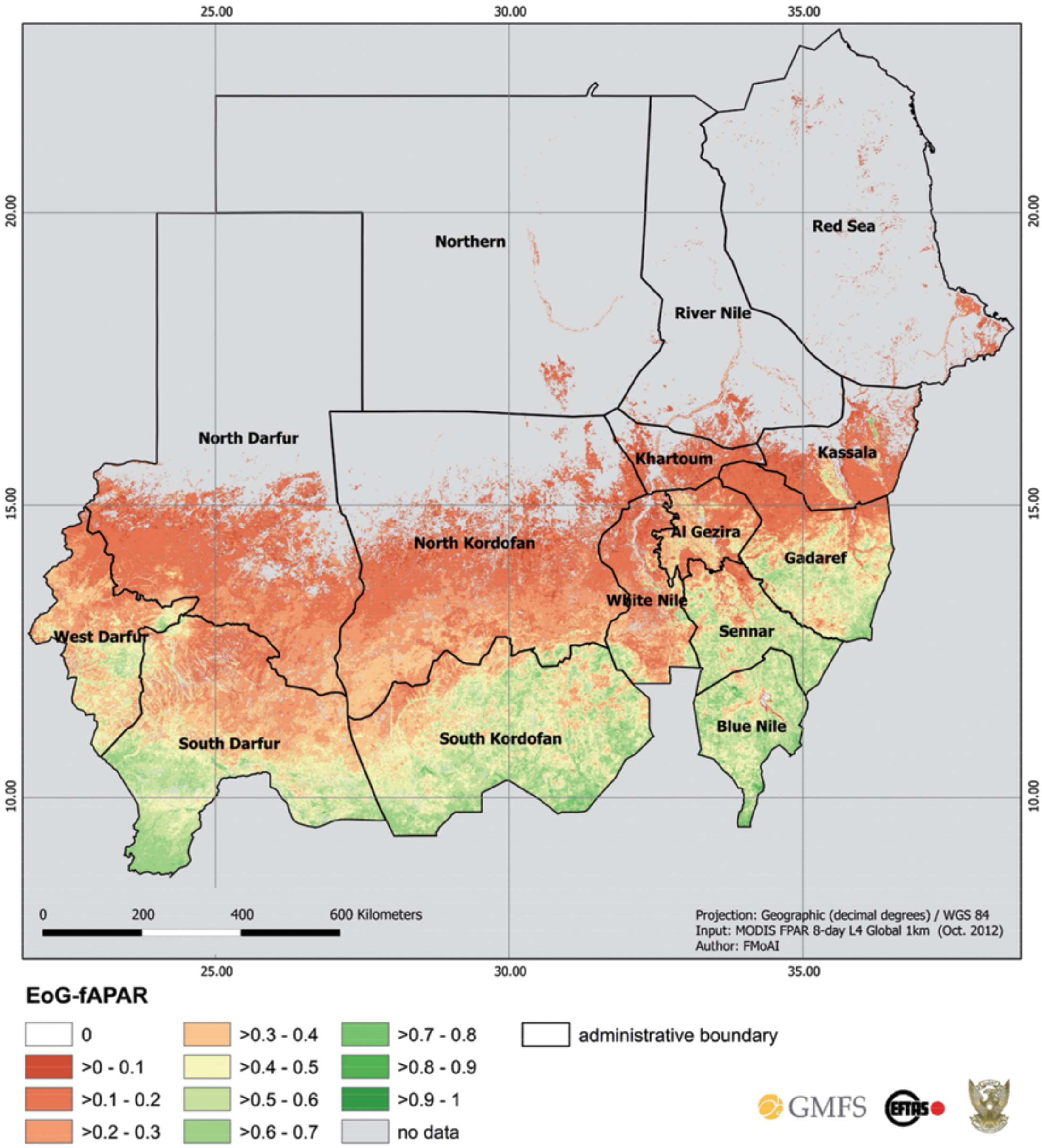

Fig. 4: Indicative inter-seasonal growth map in Sudan – October 2012 (based on MODIS FPAR), processed by FMoAI, Sudan.

loss of ENVISAT to the *fPAR* indicator from the Terra MODIS sensor (Fig. 3). Based on its origin, the GMFS monitoring product is called indicative *fAPAR Extent of vegetation Growth* (EoG-fAPAR) and reflects the fraction of the solar energy which is absorbed by the vegetation within each pixel. It is foreseen to use Sentinel 3 satellite data once it will be available in the coming years. More information is available in the technical specifications in GMFS (2013e).

Further analysis steps as requested by the FMoAI had been elaborated and systematically embedded into an open source GIS environment. The following figures show 1) an example of an EoG map of a given month (Fig. 4), 2) a change map of a given month compared to the same month of the previous year (Fig. 5) and 3) a map comparing a given month with the five years average as a standard reporting parameter of the FMoAI (Fig. 6).

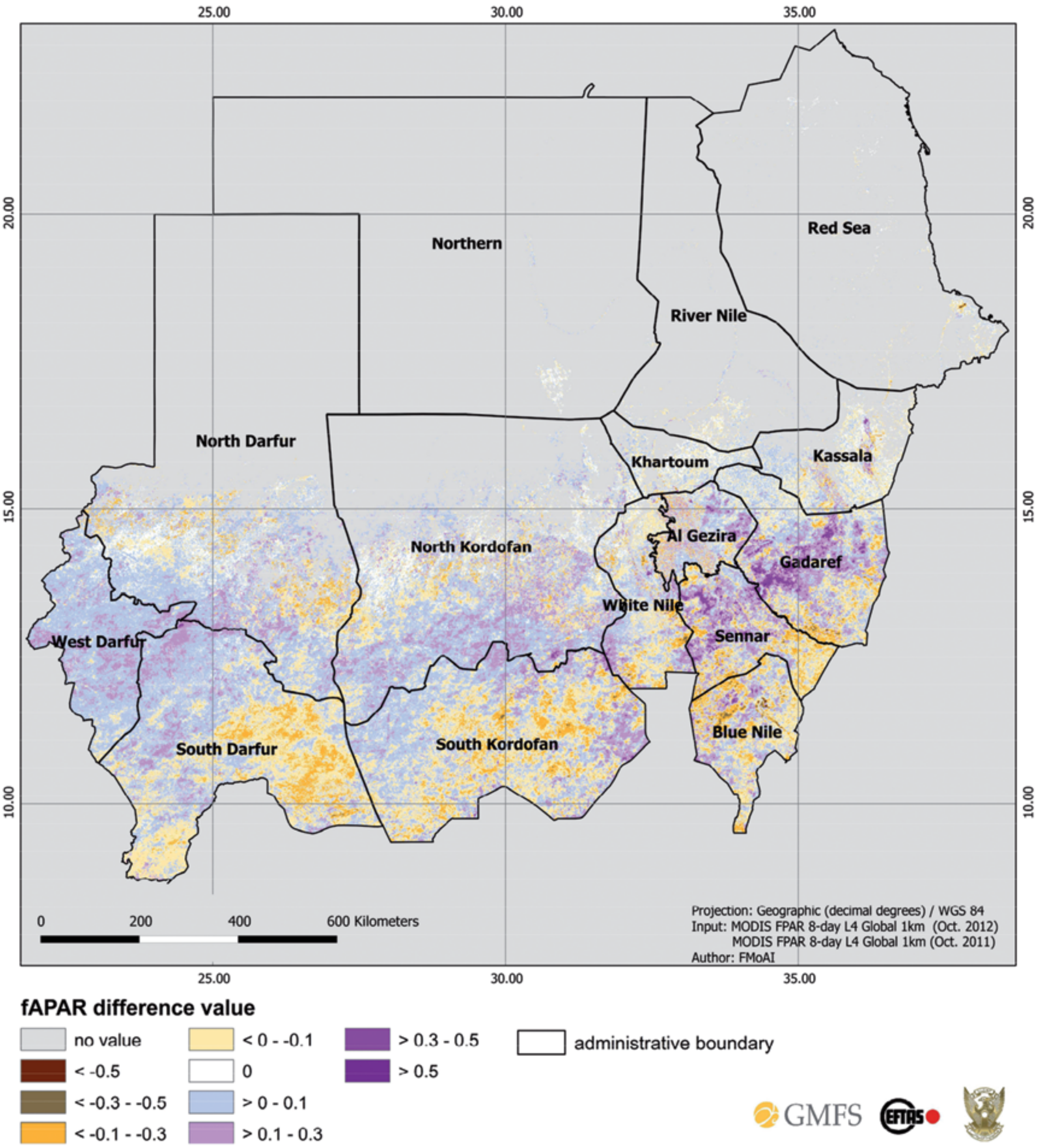

Fig. 5: Indicative inter-seasonal growth map in Sudan – October 2012 versus October 2011 (based on MODIS FPAR), processed by FMoAI, Sudan.

3.2 *Mapping Cultivated Area by High Resolution Remote Sensing*

Throughout the participative evaluation processes since 2006 it was a clear request of the Sudanese users to get solutions to monitor the traditional rain fed areas at an appropriate scale. Therefore, a first step was to establish procedures which are capable of mapping the spatial extent and agro ecological conditions in Sudan with high resolution satellite data (10 m – 20 m) and to start with a *cultivated area* mask (CuA). As agreed in this project the generation of a cultivated area map at state level would be an adequate intermediate solution. It would cover the official reporting level of the FMoAI for official purposes and could serve as a next step for future developments towards crop estimates. The recent CuA product discriminates two classes, *cultivated* and

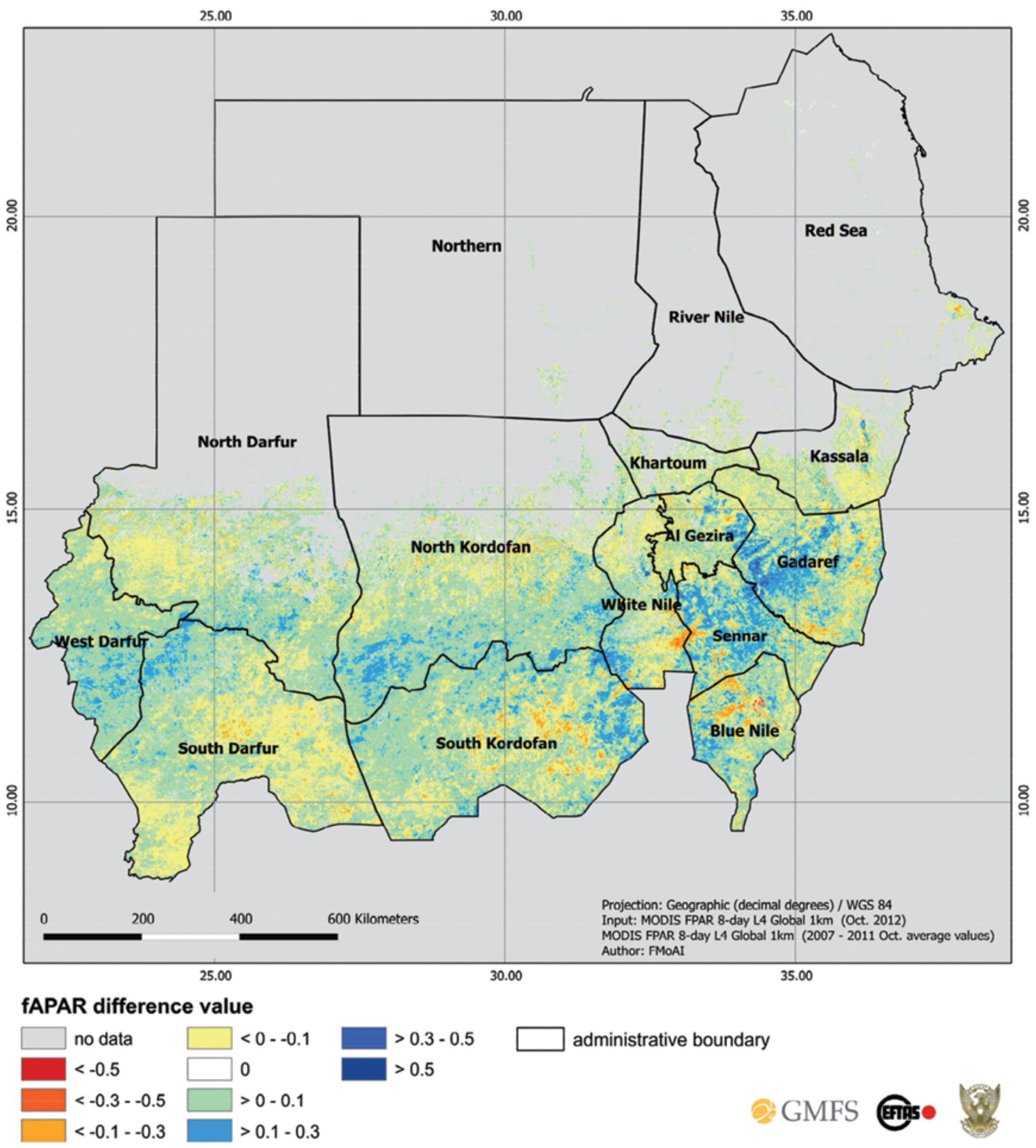

Fig. 6: Indicative inter-seasonal growth map change in Sudan – October 2012 versus the five years average (based on MODIS FPAR), processed by FMoAI, Sudan.

non cultivated land. Cultivated land contains the major annual rain fed crops in Sudan such as Sorghum, Millet, and Sesame. Non-cultivated land contains bare soil, natural vegetation, rocks, water, artificial area and other non cultivated areas such as fallow land. North Kordofan state (approximately 240,000 km^2) has been selected as pilot area in order to 1) explore the feasibility of high resolution processing routines, 2) to test the accessibility and availability of relevant HR satellite data for this task over Sudan and 3) to explore the service applicability to provide one full GMFS high resolution CuA map at state level.

Beyond the generation of a map, one additional aim of the CuA product was to provide an entire and robust work flow to the FMoAI, capable of allowing them to operationally apply this implementation with a medium to long term vision. Provided that the Sentinel satellites 1 and 2 will be operational in due time this will be technically the case until 2020 (GMFS 2013b). The generation of the CuA product is based on optical and SAR data. For this pilot two cloud free SPOT 4 coverages over North Kordofan were acquired in 2010, processed and controlled as optical input for the CuA classification (Figs. 7a and 7b).

To cover the SAR component, another sensor of the Envisat satellite has been used – the ASAR sensor, an Advanced Synthetic Aperture Radar operating at C-band with the choice of five polarisation modes. Due to capacity requirements of ASAR the acquisitions had to be split. One part of the data was acquired for the eastern part of North Kordofan in 2010 and another for the western part of North Kordofan in 2011 (Fig. 8). The acquisition mode was Single Look Complex with a H/H polarization.

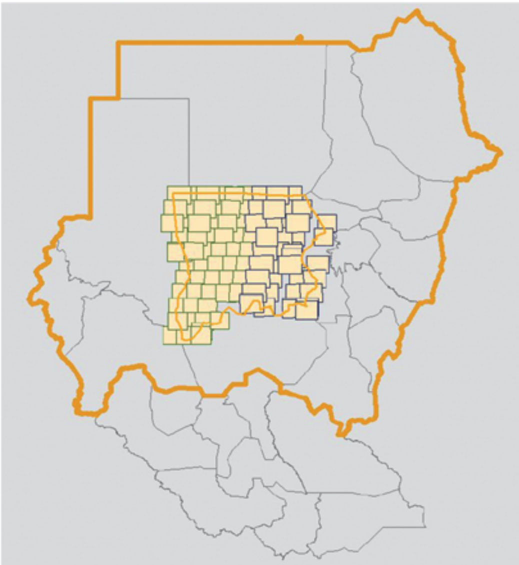

Fig. 7a: Schematic overview of SPOT 4 coverage North Kordofan (early season acquisition window, 6.7.2010).

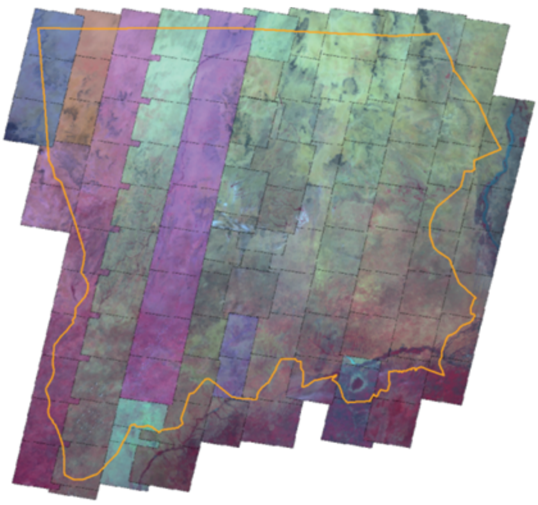

Fig. 7b: SPOT 4 coverage of North Kordofan (June / July & September / October 2010).

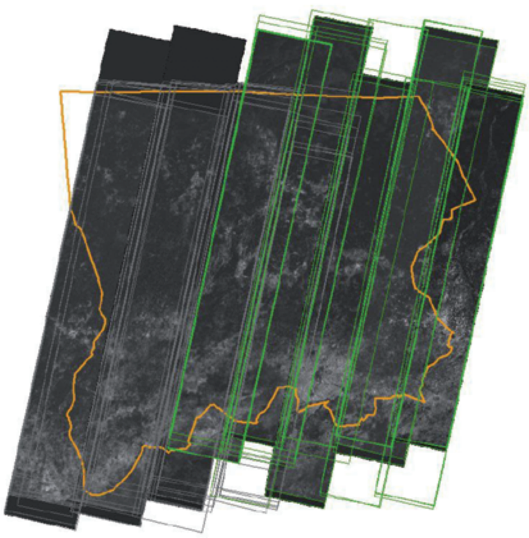

Fig. 8: Radar coverage of North Kordofan by ENVISAT ASAR IM (ASA-IMS 1P, advanced synthetic aperture radar, C-band with choice of five polarisation modes, split into two parts due to capacity limitation of ASAR) grey 2011, green 2010.

The ASAR data were processed with FOODSECURITYscape® software provided by SARMAP in the frame of the GMFS3 project. As SAR input for the classification the Span Ratio between an early (April – May) and late (August – September) ASAR acquisition was used. The Span Ratio represents the ratio calculated between the maximum value and the minimum value of all input data for each pixel. Originally, it was envisaged to generate the maps of Crop Growth Extend by the FOODSECURITYscape® processing (GMFS 2013a). Unfortunately this turned out to be impossible because of unfavourable frequencies and viewing angles of the ASAR sensor. That changed due to an orbital change of the ENVISAT satellite during the peak of the main agricultural season in Sudan in October 2011.

For the generation of the cultivated area product the software ALIS© was used. ALIS© is an EFTAS development using a support vector machine training algorithm with a kernel function that applies a maximum margin hyper plane if linear classification is not possible (SCHÖLKOPF & SMOLA 1999). This tool allows access to advanced remote sensing processing embedded into easy to use interfaces for operators who are no remote sensing experts (KOMP & HAUB 2012).

In a final processing step the classification results of cultivated area were intersected with the Sudan Land Cover Database 2010, a vec-

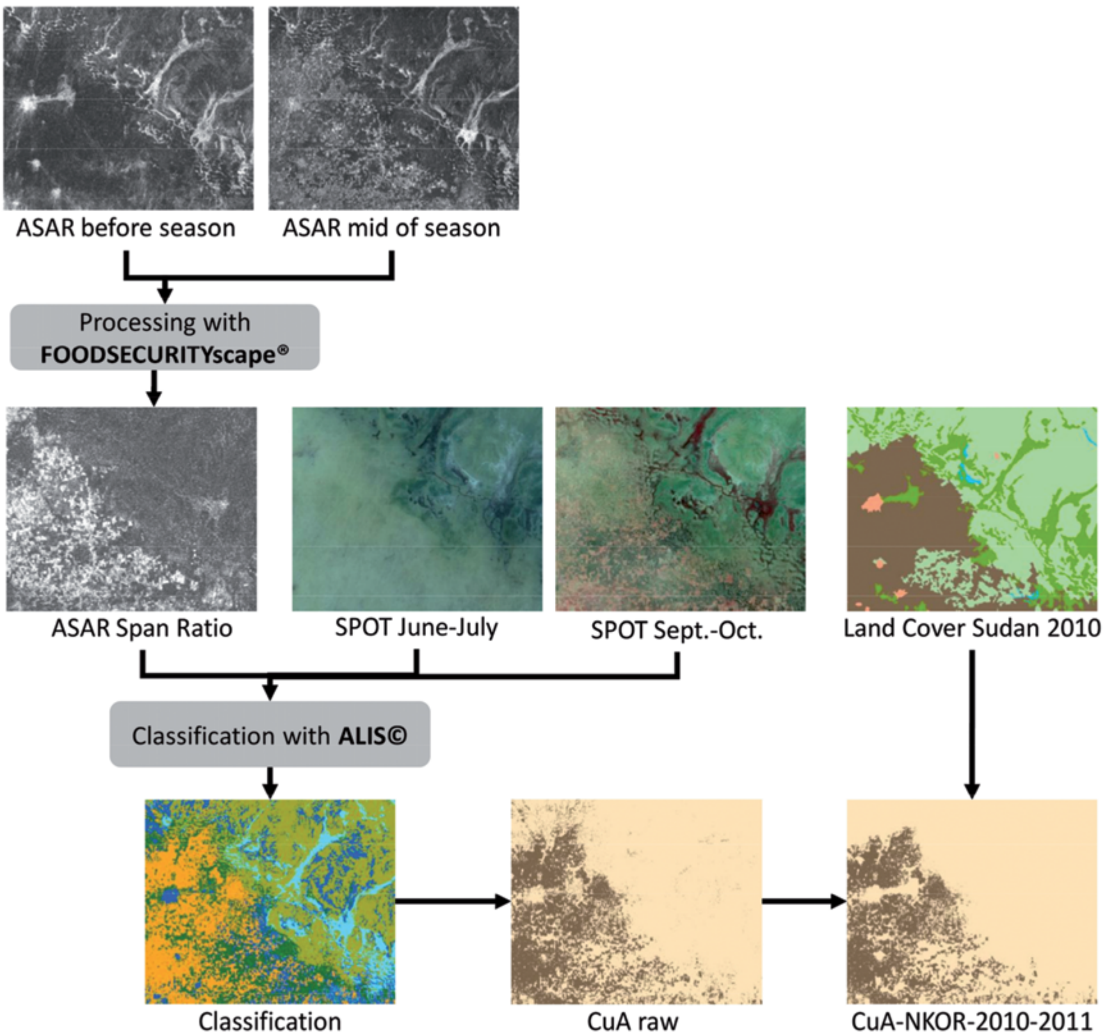

Fig. 9: Work flow to generate maps of cultivated area over North Kordofan (NKOR) by operating ALIS© (ASAR = advanced SAR of ENVISAT, CuA = cultivated area mask).

tor dataset according to the FAO Land Cover Classification System (LCCS) (SIFSIA 2013). The full work flow is shown in a flow chart in Fig. 9 and the final cultivated area map of the agricultural campaign 2010 – 2011 for North Kordofan is shown in Fig. 10. It could be proved that the developed CuA processing chain integrating FOODSECURITYscape® and ALIS© achieved the initial assumptions. Although further efforts are needed to reduce the omission and commission errors the overall accuracy of the final CuA product is close or above the requested 85% (for more detail see GMFS 2013f).

3.3 *Capacity Building*

The ultimate GMFS3 objective in Sudan was to bring the agricultural monitoring services to the FMoAI and to integrate these developments into its actual workflows. Therefore,

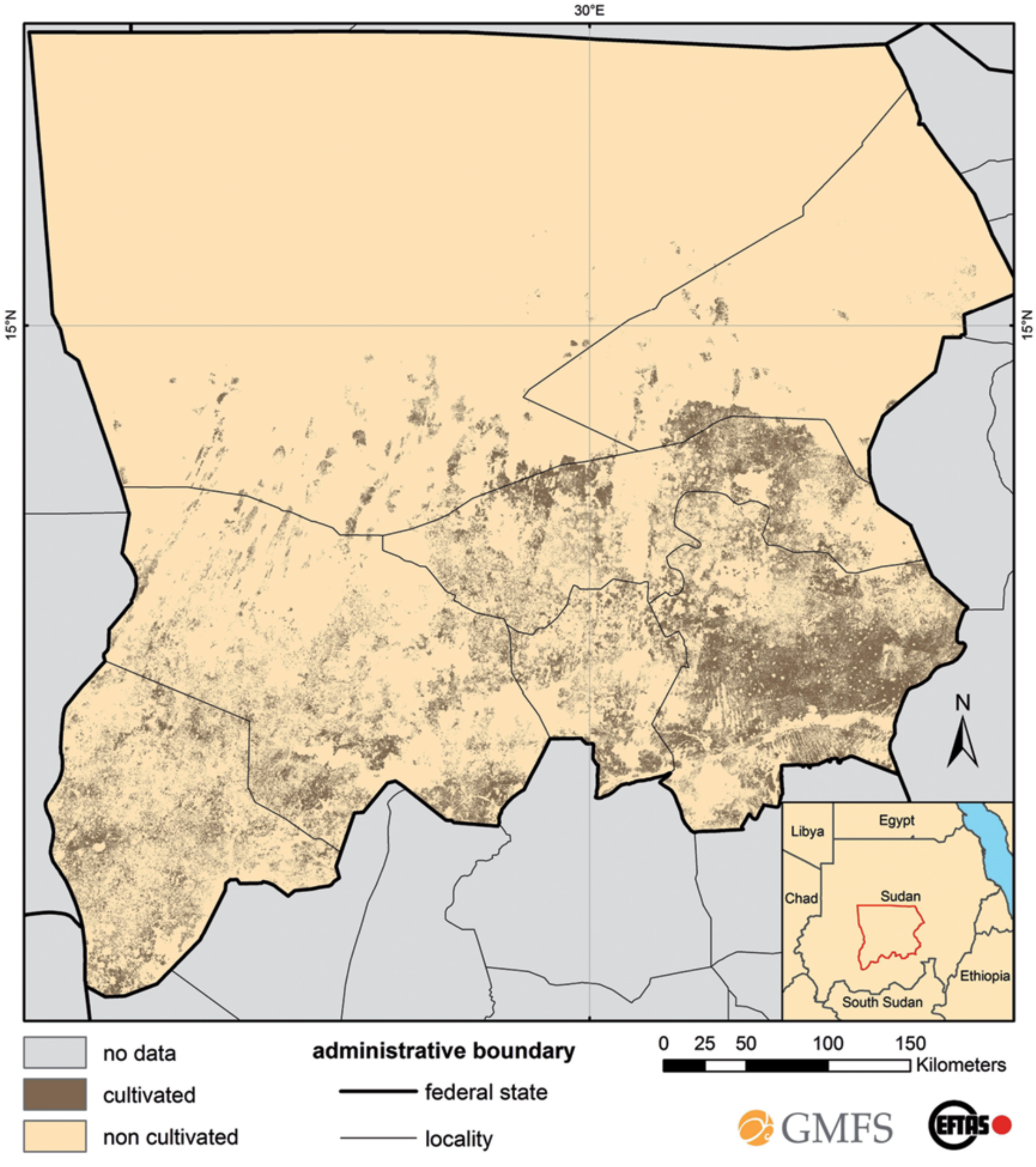

Fig. 10: Cultivated Area in North Kordofan of the campaign 2010 – 2011.

Fig. 11: Training Lab at the FMoAI – Sudan systematically provided with GIS and EO software through EFTAS.

comprehensive training and know how transfer was provided by EFTAS aiming at a sustainable continuation of the methods in Sudan. Beside both mapping components another component on training and consultancy was dedicated to this target and to assist the FMoAI. While implementing and using the above described GMFS mapping products and processing chains, the other component addressed the support and strengthening of the optimisation of agricultural monitoring and surveys, conducted by the regular consultancy missions. Training on geo data handling and field work methodologies had been carried out to a core group of experts at the FMoAI following a "training of trainers" principle.

In this respect a number of training units were realized in Sudan and Germany during the past years. Further to this, the FMoAIs computer-lab, a cluster of server connected GIS working stations and training room with about 50 PCs, was equipped with dedicated open source EO and GIS software packages to access, process and analyse all incoming data. All activities were closely followed up by EFTAS through an intensive exchange and on-the-spot support (Fig. 11).

4 Technology Transfer, Service Outcomes and Integration at the FMoAI Sudan

Almost all initiated service components have been successfully implemented under real conditions during the past years and in close collaboration with and finally taken over by the FMoAI (GMFS 2013c and 2013d). This was a joint effort of the FMoAI and EFTAS together with the capacity building project – Sudan Institutional Capacity Programme: Food Security Information for Action (SIFSIA-N) of the EU and FAO Rome.

Only the high resolution mapping service, which is recently still under development may need more research in order to achieve full integration into the agricultural statistical framework. For the high resolution mapping component it could be proved, that both data availability in terms of optical and SAR coverage as well as the performance of the high resolution processing of cultivated area maps is capable of providing adequate geoinformation at state level in Sudan. With a view to Sentinel-1 and -2 it is expected that both disordered frequencies and viewing angles will be eliminated so that further research can be addressed to improve the accuracy of the products and to optimize the current processing chain.

The medium resolution best suitable for the extend of growth products has been used in a number of applications, such as

- seasonal monitoring on a monthly basis,
- 5 years comparisons in compliance with the standard FMoAI reporting scheme,
- field work routing overlaid with street data,
- independent source for cross verification of field mission results.

All this contributed to the establishment of a GIS & Remote Sensing Unit under the Agricultural Statistics department of the General Administration of Planning & Agricultural Economics of the FMoAI. This unit was established stepwise with substantial support through the ongoing GMFS capacity building since 2006. In particular, the dedicated "hands on" training scheme and consultancy missions conducted by EFTAS on different hierarchical levels had been appreciated by the FMoAI.

Since then this newly founded unit has taken over the GMFS processing, has given training courses using the GIS training lab, has provided presentations to a number of departments within the FMoAI, and has joined international conferences in order to report about the achieved knowledge transfer through GMFS (Khojali 2012, Ismail 2013).

Fig. 12: Customised maps of the Extend of vegetation growth for the official field survey campaign of the FMoAI.

The full impact of the production of the Extend of Growth Map (EoG) and post processing routines were reached for the first time in 2012. The GIS & Remote Sensing Unit took charge to fully organize the preparation of the main official crop and agriculture assessment survey of the Food Security Technical Secretariat of the FMoAI. Dedicated EoG maps were processed, printed and provided to each field team (Fig. 12) and were finally integrated into the final survey report for the state wise comparisons with the information collected in the fields, during experts interviews or extracted from other data, such as rain fall data.

5 Conclusions

The GMFS Agricultural Monitoring Services which were performed in Sudan have been successfully transferred during the past years into the day-to-day work of the FMoAI as the prime user within GMFS. This was achieved in close collaboration with the Remote Sensing Authority in Khartoum, SIFSIA-N, FAO Rome, the Regional Centre for Mapping of Resources for Development, Nairobi, and ESA.

The GMFS partnership consolidated multi-scale agricultural monitoring services by providing spatial information on key variables at dedicated spatial, temporal and thematic resolutions affecting food security in Sudan (GMFS 2013c). GMFS contributes to the development and provision of operational service chains as well as to an improved access to satellite data for the Sudanese government.

The GMFS components for Sudan reached a level on which the FMoAI could take over the established process chains, absorb them into a newly founded GIS&RS unit and supply its departments with recent EO data. With a particular emphasis on the forthcoming ESA Sentinel satellite missions, a long-term service sustainability of those services can be technically ensured until 2020. As such GMFS and ESA have strongly contributed to the geospatial institutional strengthening of the Sudanese Ministry of Agriculture and Irrigation.

In the light of Haub & Gilliams (2010) basic requirements for a successful continuation of these services in Sudan after the project funding period are 1) financial continuity, which the FMoAI is partly taking charge of already but more essential is 2) reliable and efficient access to satellite data.

GMFS Sudan is a successful example for sustainable technology transfer. It demonstrates robustness of the processing technology, reliability of data acquisitions through sensor independency, accurateness of the products, timeliness of the output information, and autonomous processing in the hands of the users. As such GMFS routines have the potential to contribute to the decision making until at least 2020.

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Acknowledgement

Special thanks shall be addressed to the Federal Ministry of Agriculture and Irrigation of Sudan which committed at a high political level over the entire project period and to its involved experts. Without this, the successful and encouraging cooperation would have been impossible. We further appreciate the very fruitful cooperation with the Regional Center for Mapping of Resources for Development, Nairobi, which was the Regional GMFS Coordinator in East Africa in stage 3.

We also thank SARMAP and particularly Francesco Holecz for the great support, provision and customization of FOODSECURITYscape and Peter Haub, dip systems, for the inspiring consultancy on the implementation of HALCON applications. The GMFS Consortium is composed of the following institutions: VITO – Belgium, EFTAS – Germany, SARMAP –Switzerland, University of Liège – Belgium, Conzortio ITA – Italy, EARS – Netherlands and GeoVille – Austria. GMFS was funded by ESA.

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Manuskript eingereicht: Mai 2013
Angenommen: Juli 2013