*"To provide earth observation based services and encourage partnerships in monitoring Global Food Security and related environmental processes, by concerting efforts to bring data and information providers together, in order to assist stakeholders, nations and international organizations to better implement their policies towards sustainable development"*

# GMFS Final Report
# Stage 1 and Stage 2

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# Contents

# EXECUTIVE SUMMARY

Global Monitoring for Food Security (GMFS) is a Global Monitoring for Environment and Security (GMES) Service Element (GSE) project, part of the European Space Agency (ESA) contribution to the European Union (EU) /ESA GMES Programme. GMFS aims to establish an operational service for crop monitoring in support of Food Security Monitoring to serve policy makers and operational users.

The GMFS project started in March 2003 as part of Stage 1 of the ESA Earthwatch GMES services Element "Service Consolidation Actions", and was continued in October 2005 as part of the Stage 2 of the ESA Earth watch GMES services Element – "Scaling Up Consolidated GMES Services".

In this document an overview is given of the work done throughout the previous six years.

GMFS aimed at monitoring crop state /vegetation condition at continental and national scale. Low resolution Earth Observation (EO) data was used for monitoring purposes at continental scale, while at national scale products were based upon medium and high resolution data, field work and agro-meteorological models. The project was guided by a project strategy group with members from the United States Agency for International Development - Famine Early Warning System Network (USAID-FEWSNET), Directorate General for Development (DG-DEV), Consultative Group on International Agricultural Research - International Wheat Improvement Center (CGIAR-CIMMYT), European Commission Joint Research Center (EC-JRC), United Nations World Food Programme (WFP) and United Nations Food and Agricultural Organisation (FAO).

The goal of the project in Stage 1 (March 2003 –November 2004) was to consolidate an early warning system for food security. This started off by an intensive literature review and setting up an initial service for the Centre de Suivi Ecologique (CSE) in Dakar Senegal. In the second Phase of Stage 1 activities focussed more on the actual service delivery and setting up activities with users. Those activities included the monitoring agricultural production for Senegal, monitoring agriculture in Malawi and giving support to the Crop and Food Supply Assessment Mission (CFSAM) of FAO /WFP. Additionally, services were set up for the centre Agro-Hydro-Météorologique (AGRHYMET) as a result of a meeting between AGHRYMET and Vlaamse Instelling voor Technologisch Onderzoek (VITO).

During 2005 the early warning service was continued to support GMFS users although there was at that time no formal contract to do so.

At the start of the Second Stage, in October 2005, a GMFS user executive board, consisting of one representative from: EC-JRC, FAO, WFP, Southern Africa Development Community Regional Remote Sensing Unit (SADC-RRSU), Regional Centre for Mapping of Resources for Development (RCMRD) and AGRHYMET, was set up to support the consortium in defining the correct services and to review the work. Since the focus for the Second Stage was on up scaling the consolidated services, it was decided that the early warning service and support to the CFSAM were to be continued, the agricultural mapping service was to be expanded to more countries - namely, Senegal, Sudan, Ethiopia, Malawi and Zimbabwe - and extra services on yield modeling using remote sensing and agro-meteorological models were to be provided. During the second year of this stage, the services were even more extended with, support to the Ministry of Agriculture and Meteorological Department in Mozambique, extra activities in Ethiopia and Sudan and support to the regional centers on operational use of the ESA Data Dissemination System (DDS).

Throughout the project user involvement and user contacts grew continuously. The GMFS partnership secured very good relations at regional level with the AGRHYMET centre in Niamey, RCMRD in Nairobi and the SADC-RRSU in Gaborone. At the national level very close working relations were established with the CSE in Senegal, Ministry of Agriculture and Rural Development (MoARD) in Ethiopia, Ministry of Agriculture (MINAG) and Instituto National de Meteorologia (INAM) in Mozambique, Ministry of Agriculture, Irrigation and Food Security

(MoAFS) in Malawi, Federal Ministry of Agriculture and Forestry (FMoAF) in Sudan and national offices of WFP and FAO in Sudan and Zimbabwe. These relations were strengthened by the fact that the GMFS partnership had opted to have local experts as national GMFS representatives to support the consortium with its user liaison and implementation of GMFS services.

The major achievement of GMFS at national level was the introduction of remote sensing based services fitting into the common work flows. GMFS was able to deliver demonstration cases and identify bottlenecks for operational remotes sensing applications for agricultural monitoring. The achievements at regional level were mainly related to the provision of the necessary reliable access to early warning data sets and capacity building to support the national early warning units. GMFS also supported the regional centers to built operational monitoring tools based on the data send through the ESA DDS system.

For the Early Warning services about 30 million km² were covered with indicators on a 10 daily basis, serving 8 regions of interest and 11 user organizations.

Agricultural mapping products were provided to 5 countries; Senegal, Ethiopia, Sudan, Malawi and Zimbabwe, addressing the needs of respective Ministries of Agriculture. Throughout the 6 years of GMFS operations, Malawi and Senegal were mapped 5 times and Ethiopia and Sudan were mapped twice. In other words 4.1 million km² were mapped at medium resolution and about 1 million km² was mapped with high resolution images.

Validation of these products was done based upon fieldwork. In collaboration with local experts and integrated in already existing national surveys, a total of nine fieldwork campaign were executed.

Agro-meteorological departments in Senegal and Malawi were supported with yield estimates. These yield estimates were provided at least twice per year and covered at least the most important regions in the country.

For the support to the FAO /WFP CFSAM, inputs were provided for missions in Zimbabwe, Ethiopia, Sudan, Malawi, CILSS, Mauritania, Senegal, Gambia, Guinea – Bissau, Mali, Niger and Chad.

Over the past 6 years 30 training session were provided to a total of around 200 national, regional and international experts. Training sessions covered all aspects of GMFS:

- Field data collection
- Validation procedures
- Early Warning indicators
- High resolution SAR data and medium resolution optical data for agricultural mapping
- GMFS support to CFSAM methodology
- Agro-meteorological Yield forecasting
- ESA DDS

As a results of these achievements the consortium received clear request from several users to continue with the services after Stage 2.

# INTRODUCTION

Global Monitoring for Food Security (GMFS) is a Global Monitoring for Environment and Security (GMES) Service Element (GSE) project, part of the European Space Agency (ESA) contribution to the European Union (EU) /ESA GMES Programme. GMFS aims to establish an operational service for crop monitoring in support of Food Security Monitoring to serve policy makers and operational users.

GMFS started in March 2003 as part of the Stage 1 of the ESA Earth watch GMES services Element "Service Consolidation Actions", and was continued in October 2005 as part of the Stage 2 of the ESA Earth watch GMES services Element – "Scaling Up Consolidated GMES Services". The Second Stage was scheduled to run for 3 years (September 2008) but was extended up to March 2009 to provide extra services in Eastern Africa.

GMFS aimed at monitoring crop state /vegetation condition at continental and national scale. Low resolution Earth Observation (EO) data was used for monitoring purposes at continental scale, while at national scale products were based upon medium and high resolution data, field work and agro-meteorological models.

Stage 1 consisted of two phase of 10 months

- Phase 1: Services Consolidation up to Mid-Term service Review
- Phase 2: Services Consolidation after mid-term review.

During Stage 1 services were delivered to Southern Africa Development Community Regional Remote Sensing Unit (SADC-RRSU), centre Agro-Hydro-Météorologique (AGRHYMET), Centre de Suivi Ecologique (CSE) Senegal, Ministry of Agriculture, Irrigation and Food Security (MoAFS) Malawi, United Nations Food and Agricultural Organisation (FAO) and United Nations World Food Programme (WFP). This process was guided by the GMFS strategy group, consisting of members from: Directorate General for Development (DG-DEV), FAO, European Commission - Joint Research Center (EC-JRC) and Consultative Group on International Agricultural Research - International Wheat Improvement Center (CGIAR-CIMMYT).

For Stage 2 the project was split into 3 equal phases of 12 months each.

- Phase 1: network set-up and service delivery to first-year service review (6 October 2005 – 30 September 2006)
- Phase 2: service scaling-up to second-year service review (1 October 2006 – 30 September 2007)
- Phase 3: service sustainability demonstration to third-year service review (1 October 2007 – 30 September 2008 and extended to 31 March 2009)

The determination of the service portfolio specifications for Stage 2 was guided by the GMFS user executive body, consisting of 1 representative from the following institutes: EC-JRC, FAO, WFP, SADC-RRSU, Regional Centre for Mapping of Resources for Development (RCMRD) and AGRHYMET. As such the services were expanded to RCMRD, EC-JRC, FMoAF (Federal Ministry of Agriculture and Forestry) in Sudan, MINAG (Ministry of Agriculture) and INAM (Instituto National de Meteorologia) in Mozambique, MoARD (Ministry of Agriculture and Rural Development) and CSA (Central Statistical Agency) and FAO in Ethiopia, CSO (Central Statistics Office) and FAO in Zimbabwe.

Furthermore the project was guided, as for Stage 1, by a service strategy group consisting of 1 representative from EC-JRC, FAO, WFP and United States Agency for International Development Famine Early Warning System Network (USAID-FEWSNet).
After each phase, the project activities and achievements were critically reviewed during the mid-term reviews.

This report describes the activities carried out by the consortium during Stage 1 and Stage 2.

# 1. POLICIES REVIEW

## 1.1. International policies

In recent years, an increasing number of conventions, treaties, international mechanisms and conferences have recognized the necessity of using the human rights framework to alleviate poverty and promote food security. In effect, amongst them, the Agenda 21, the World Food Summits, the UN (United Nations) Millennium Declaration, the World Declaration on Nutrition, the Food Aid Convention, and the UN Convention to Combat Desertification illustrate international concerns for food security. In particular:

- **Agenda 21** states that to meet food security challenges, major adjustments are needed in agricultural, environmental and macro-economic policy, at both national and international levels, in developed as well as developing countries, to create the conditions for sustainable agriculture and rural development.
- The 1996 **World Food Summit** sets forth seven commitments which laid the basis for achieving sustainable food security for all, and a Plan of Action spelling out the objectives and actions relevant for practical implementation of these seven commitments. In endorsing these seven commitments, Heads of State and Government signed to reduce the number of undernourished people to half their present level no later than 2015. They also recognized GMES Service Element Policy Foundations Review that sustainable progress in poverty eradication would be critical to improve access to food as well as the containment of conflicts, terrorism, corruption and environmental degradation, which also contribute significantly to food insecurity. These commitments were renewed in 2002 at the World Food Summit: Five Years Later, as progresses towards meeting the goals of the 1996 World Food Summit remained disappointingly slow.
- The **United Nations Millennium Declaration** again sets forth the commitment of 188 member states of the United Nations to halve, by the year 2015, the proportion of the world’s people whose income is less than one dollar a day and the proportion of people who suffer from hunger and, by the same year, to halve the proportion of people who are unable to reach or to afford safe drinking water. These goals establish yardsticks for measuring results not just for developing countries, but also for the rich countries that help to fund development programs through bilateral aid programs and for the multilateral institutions, such as the World Bank, Regional development Banks, and UN Specialized Institutions, that help countries implement them.
- The **Food Aid Convention** is a legal international agreement established in 1967 that lays down minimum annual food aid commitments, donor by donor, either in terms of total tonnage or market value and regulates food aid donations of individual EU member countries plus Argentina, Australia, Canada, Japan, Norway, Switzerland and the United States.
- The "bottom-up" approach of **UN Convention to Combat Desertification**, is focused both combating desertification and land degradation worldwide and improving the living conditions of the most vulnerable segments of the population. The reason behind this dual approach is that desertification causes quite a large number of socio-economic disruptions, which are directly or indirectly linked to food insecurity and poverty.
- The **Comprehensive Africa Agriculture Development Programme (CAADP)** from the New Partnership for Africa’s Development (NEPAD), is anchored on the determination of Africans to extricate themselves and the continent from the malaise of underdevelopment and exclusion in a globalising world. The agriculture programme is open to continuing improvement and should be adapted to each of Africa's sub-regions in order to best address that continent's diversity.
- The **declaration of the Abuja Food Security Summit** in December 2006 renewed the commitment of the African union to combat poverty and food and nutrition insecurity in

Africa, and directed the attention to a few key decisions to eradicate hunger by 2030. African union website

## 1.2. European policies

The European Commission (EC) completely revised its food security programme in 1996. **Regulation (EC) No 1292 /96 defined the legal framework of the Commission's food security strategy.** It acknowledged the multidimensional nature of food security and the fight against poverty. It incorporated food security into policies for sustainable development and poverty reduction, since the fight against food insecurity is one of the main strategies for poverty reduction. Reducing the vulnerability of poor population groups involved identifying them properly and having a better understanding of the strategies used by them to confront food crisis. Furthermore, the Regulation identified three main types of aid related to food security: first, food aid, mainly short-term operations; second, operations in support of food security, which include long-term operations designed to ensure sustainable food security; and third, operations to improve early warning systems and storage programmes. EC activities related to food aid and food security are currently administered by both European Commission Humanitarian Aid (**ECHO)** and **EuropeAid** (food security). In addition, the Commission introduced the concept of **Linking Relief, Rehabilitation and Development (LRRD)**.

For implementation of the European Food Aid and Food Security policy, timely information is needed by ECHO and EuropeAid on the food and crop situation, notably in countries stricken by food shortage, wars, natural disasters or other factors leading to food insecurity. To respond to this need, the JRC **MARS** is organising a system for monitoring and forecasting crop prospects in different parts of the world in the framework of the GMES initiative. Data from satellite (SPOT-VGT) and Global Meteorological Models are already processed on a regular basis and advanced tools and models for crop yield monitoring and forecasting were being developed.

This work was done in close collaboration with European partners and FAO. The MARS Unit mainly provided technical support to the Agriculture DG, the Enlargement DG, the External Relations DG and the Europe AID Co-Operation office (AIDCO) and to the Member States.

The cooperation of Europe and Africa on Earth Observation (EO) for food security was confirmed on several occasions. The **EU-Africa Strategy** in 2005 mentioned a specific action on enhancing cooperation in the use of space technology. In the **Maputo Declaration** of October 2006, an extension of the GMES Europe initiative to Africa GMES was planned. This included an extensive operational use of EO technologies for sustainable management of African environment whereby regional, national and local policies should be provided with data and tools needed. The **Lisbon Declaration** on GMES-Africa in December 2007 called for the first draft of an action plan for establishing the partnership between GMES and Africa to be submitted to EU and African constituencies by the end of 2008.

# 2. USER SEGMENTS: USER NEEDS & EXPECTED BENEFITS

GMFS services were tailored to three different user communities, international, regional and national, each with specific activities and responsibilities in the field of crop monitoring. The user needs and their expected benefits as analysed at the start of Stage 1 and Stage 2 are described below.

## 2.1. User communities

On overview of GMFS Stage 1 and Stage 2 users is provided in table 1.

*Table 1: GMFS Stage 1-2 overview*

| | | |
|---|---|---|
| **International Users** | • EC-JRC MARS FOODSEC<br>• FAO-GIEWS (Global Information and Early Warning System)<br>• WFP-VAM (Vulnerability Analysis and Mapping) | |
| **Regional Users** | • RCMRD<br>• AGRHYMET<br>• SADC-RRSU | |
| **National Users** | West Africa | • CSE (Senegal)<br>• Direction de l'Analyse, de la Prévision et des Statistics (DAPS) (Senegal) |
| | Southern Africa | • Ministry of Agriculture and Food Security (MoAFS), Malawi<br>• Ministry of Agriculture (MoA), Zimbabwe<br>• central Statistics office (CSO), Zimbabwe<br>• Instituto National de Meteorlogia (INAM), Mozambique<br>• Ministry of Agriculture (MINAG), Mozambique |
| | East African users | • Central Statistical Agency (CSA), Ethiopa<br>• Ministry of Agriculture and Rural Development (MoARD), Ethiopia<br>• Federal Ministry of Agriculture and Forestry (FMoAF), Sudan |

| | | |
|---|---|---|
| **Indirect National Users** | Southern Africa | • FAO Zimbabwe<br>• Scientific and Industrial Research and development centre – Environment and Remote sensing Instite (SIRDC-ERSI), Zimbabwe<br>• FAO/ WFP Malawi |
| | East Africa | • Ethiopian mapping Authority (EMA), Ethiopia<br>• Sudanese Meteorological Authority (SMA), Sudan<br>• Remote Sensing Authority Sudan (RSA), Sudan<br>• Sudanese National Mapping Authority (SNSA), Sudan |

In total there were 3 international users, 3 regional users and 10 direct national beneficiaries.

## 2.2. User needs

### 2.2.1. International user needs

In many drought-prone countries, particularly in sub-Saharan Africa, there is a lack of continuous, reliable information on weather and crop conditions. For this reason, FAO, WFP and JRC have established different crop monitoring systems using near real-time satellite images.
Data from satellite systems are used to monitor the various crop seasons through out the world. To enhance their operational power at continental scale FAO-GIEWS and WFP-VAM are interested in:

- Rainfall estimates
- Relative evapotranspiration estimates
- Crop yield estimates
- Improved methods for monitoring crops, agricultures

Besides this need for information on crop growing conditions and forecasted yield, there is also a strong need for information on planted area.

### 2.2.2. Regional user needs

Although regional centres (AGHRYMET, RCMRD, and SADC-RRSU) already make use of remotely sensed images (e.g. Cold Cloud Duration (CCD) and Normalized Difference vegetation Index (NDVI)), to support and verify the ground observations, they expressed the need to have support in understanding these RS based indicators for food security and disaster management.

Furthermore they would like to demonstrate the member states (see boxes in Figure 1) that satellite RS techniques could help to cut down both cost and time that would otherwise be spent for collecting or generating information that is often not or rarely documented and validated. They want to sensitise decision makers on the importance of the enhanced Geo Information in support of their decision making.

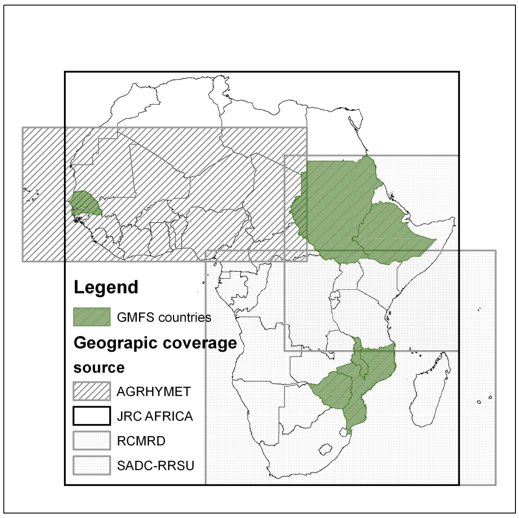


**Figure 1**: GMFS Regional and national approach

Their specific information needs are related to:

- Prediction of frequent droughts
- Measure and estimate the trends and magnitude of the droughts and desertification from systematic assessments and monitoring
- Food supply information
- Calibration of satellite-based climatic data (rainfall, temperature, etc.) with ground data
- Modern methodologies /technologies that focus on more precise crop yield estimation
- Availability of timely and unbiased crop production statistics
- Free access to the European /ESA satellite data.
- Production statistics by main crops and by administrative level

These users also asked for training workshops covering:

- Optical RS
- Radar RS
- Product validation (field work)
- Distribution of indicators in a smooth way to member states

### 2.2.3. National users

Although there are differences in needs between the national users of GMFS (indicated in green on Figure 1), in general it can be said that national user needs are:

- Accurate and reliable crop production information on specific reporting levels, e.g. state or district level
- Spatial distribution of cultivated area
- Crop growth modeling
- Availability of timely and unbiased crop production information on main crops per administrative level
- Availability of timely satellite data
- Improved meteorological data
- Timely delivery of EO imagery /products

- Capacity building to enable the correct use and integration of GMFS products and service outputs.

Specifically, users requested training to cover the following topics:
- Optical RS
- Radar RS
- Agro-meteorological modelling
- Food Security Information Systems
- Product validation (field work)

The broad range of user needs scaling from national authorities, regional institutions, up to the UN level were reflected in specific solutions regarding the thematic, spatial and temporal resolution of GMFS services (see Figure. 2).

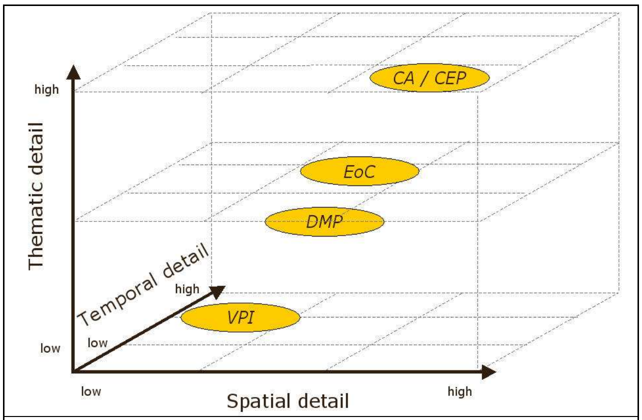



**Figure 2:** Advanced multi scale crop information services (GMFS services, CA = Cultivated Area; CEP = Crop Emergence Period; EoC = Extent of Cultivation; DMP = Dry Matter Productivity; VPI = Vegetation Productivity Indicator).

These multi scale services were developed in intensive exchange and under permanent review with core user organisations in the GMFS countries.

## 2.3. Expected benefits

The benefit analysis from Stage 1 indicated that the reduction in costs involved with traditional in-field data collection would be one of the major benefits from EO food security monitoring services. During stage 2 a number of national users confirmed that the major benefit was to have consistent data over larger areas. In some cases, no other data sources were available other than RS derived data.

### 2.3.1. International users

For the international user cost reduction by use of RS is not a major issue, since they are already working with RS data in their systems. The expected benefit is to improve their EWS. This can be done with new methodologies, other indicators and or new user contacts.
GMFS data may also help to plan and optimize crop assessment missions by providing timely spatially distributed information on expected crop yields. It may also provide crop yield information on non-emergency neighbouring countries, thus adding to an early insight in regional market conditions.

### 2.3.2. Regional users

At a regional level the cost reduction factor plays a bigger role. Use of satellite RS techniques helps to cut down both cost and time that would otherwise be spent in collecting information, for which the regional centres are dependant of the national level. Next to the impact on the timeliness of the products at regional level one also needs to consider that data collected at the national level might be prone to subjectivity and might be based upon different standards and methodologies.
Although it is considered that GMFS products are of potential benefit to solve these issues at the regional centres it is believed that the agricultural mapping and crop yield products can only be of significant benefit when local expertise is involved in the final generation these services. The potential cost-saving and performance improvement of activities at the regional centres lies in the close partnership between international expertise (on RS, image processing and archiving systems) and local expertise (fine-tuning these products to local conditions). In this respect it is a major benefit for the regional centres to directly access technology networks to built expertise at the centres and to play an active role in ensuring the know how transfer to the respective countries in their region.

### 2.3.3. National users

From the user needs it is clear that national users want to develop an operational system to monitor crop conditions and estimate the agricultural area.
GMFS can contribute to stakeholders frameworks with the introduction and the integration of crop monitoring services into the common work flows. GMFS products at national level are tailored to these needs, e.g. EWS improves accessibility to the data and provides a reliable dissemination and training. Thus the benefit of GMFS services for national institutions is the availability of solutions addressed to their needs, which were neither operational before or are lacking alternative approaches.

# 3. SERVICE NETWORK APPROACH

The GMFS service network has been working together over the past six years. The members were selected based upon their complementary skills and activities and were managed based upon the open partnership protocol. The Service Partnership protocol defined the rules for cooperation and operation between GMFS partners. The main principle that underpinned the GMFS service partnership was the commitment of all partners to always maintain the required capacity and constantly look for improving the existing capability by bringing in additional or new expertise, expand the portfolio, look for complementarities, and access new markets. In doing so, the partners were committed to the idea of "open service partnership" principle. The Partnership Protocol is designed in such a way that another party may join the network when agreeing to the partnership principles. Throughout the 6 years of GMFS services and depending of the Stage and phase, the service network consisted of, Sarmap (CH), Consortia ITA (I), IBIMET (I), EFTAS (D), Synoptics (Vexcel /Microsoft) (NL), EARS (NL), Esys (UK), Avia-GIS (B), GIM (B), Trasys (B), ULg (B) and VITO (B).

## 3.1. User-driven approach

GMFS services were user driven, in other words GMFS services could only start once the consortium had a formal agreement with a user. This formal agreement was put into a service level agreement (SLA). Each Service Level Agreement specified the quality, quantity and terms of access for Service-Portfolio items to be delivered by the service provider to an end-user organisations.
This SLA was the start of the yearly iterative step. Based on the SLA, services were provided for one year, after which services were validated and the utility was discussed with users during a

user evaluation meeting. If necessary, updates were made to the products and /or SLA and a new service year was started, in which the complete cycle was repeated (see also Figure 4).
A list of all SLA for Stage 1 and Stage 2 can be found in table 2.

Table 2. Service Level Agreements & signature dates

| User | Period | What? |
|---|---|---|
| **Stage 1** | | |
| SADC-RRSU | 2003 – 2004 | ▪ Vegetation indices: NDVI<br>▪ Trend analysis (difference maps)<br>▪ Agro-classification maps<br>▪ EO based yield (DMP) maps<br>▪ Yield (DMP) statistics by administrative level<br>▪ Rainfall, evapotranspiration maps (METEOSAT)<br>▪ Crop yield forecasting (METEOSAT based) |
| CSE, Senegal | 2003 | ▪ Vegetation indices: NDVI<br>▪ Trend analysis (difference maps - VPI)<br>▪ Agro-classification maps<br>▪ EO based yield (DMP) maps<br>▪ Yield (DMP) statistics by administrative level<br>▪ Rainfall, evapotranspiration maps (METEOSAT)<br>▪ Crop yield forecasting (METEOSAT based)<br>▪ Agro Meteorological Modeling (AMM) yield<br>▪ AMM productivity maps |
| MoA Malawi | 2004 | ▪ Agro-classification maps<br>▪ EO based yield (DMP) maps<br>▪ Yield (DMP) statistics by administrative level<br>▪ Crop yield forecasting (METEOSAT based)<br>▪ AMM yield<br>▪ AMM productivity maps |
| FAO /WFP | March 2004 – December 2004 | ▪ Rainfall<br>▪ Relative Evapotranspiration<br>▪ Relative evapotransp. Diff 5yr<br>▪ Crop yield deviation 5yr avg<br>▪ National maps of crop yield deviation from 5 yr avg<br>▪ Tabulated provincial data of crop yield deviation from 5 yr average |
| AGRHYMET | July 2004 – December 2004 | ▪ Vegetation indices: NDVI<br>▪ Trend analysis (difference maps - VPI)<br>▪ EO based yield (DMP) maps<br>▪ Yield (DMP) statistics by administrative level<br>▪ Rainfall, evapotranspiration maps (METEOSAT)<br>▪ Crop yield forecasting (METEOSAT based) |
| **Stage 2** | | ▪ |
| FAO | June 0§- June 08 | ▪ All products of Stage 2 |
| WFP | July 07 – Sept 08 | ▪ All products of Stage 2 |
| EC-JRC | Oct 05 –Sept 08 | ▪ Early warning |
| RCMRD | May 06 – Feb 09 | ▪ Early Warning<br>▪ DDS<br>▪ Sudan and Ethiopia products |
| SADC-RRSU | Nov 06 – Feb 09 | ▪ Early Warning<br>▪ DDS<br>▪ Malawi, Zimbabwe and Mozambique products |
| AGRHYMET | June 06 – Feb 09 | ▪ Early Warning<br>▪ DDS |
| CSE Senegal | Apr 06 – Apr 08 | ▪ Early Warning<br>▪ Agricultural Mapping<br>▪ Crop Yield assessment |
| MoAFS Malawi | Sept 07 – Sept 08 | ▪ Agricultural Mapping<br>▪ Crop Yield assessment |
| FMoAF Sudan | July 07 – Mar 09 | ▪ Early Warning<br>▪ Agricultural Mapping |
| WFP Khartoum | July 06 – Sept 07 | ▪ Early Warning<br>▪ Agricultural mapping |

| User | Period | What? |
|---|---|---|
| INAM Mozambique | July 06 – Sept 08 | ▪ Special support to SADC,<br>▪ integration of early warning activities |
| MINAG Mozambique | Sept 07 – Sept 08 | ▪ Special support to SADC<br>▪ Integration of early warning activities |
| MoA Zimbabwe | Sept 07 – Sept 09 | ▪ Agricultural Mapping |
| CSA Ethiopia | Sept 07 – March 09 | ▪ Agricultural Mapping |
| MoARD Ethiopia | May 09 – May 11 | ▪ Early Warning |

### 3.1.1. User board and strategy group

Throughout Stage 1 and Stage 2 the GMFS consortium was guided by a **Strategy Group** (SG), providing overall, independent guidance to the partnership. The SG advised and informed the partners on relevant initiatives and developments in global and regional food security related policies and of progress in related fields of science. It also facilitated international and cross-disciplinary coordination.

In both Stage 1 and Stage 2, two SG meetings were held.

The first SG meeting of Stage 1 was held in Brussels in July 2003 and was attended by Henri Josserand (FAO), Amos Tincani (DG-DEV), Jaques Delincé (EC-JRC) and Masa Iwanaga (CGIAR-CIMMYT). The second strategy group meeting was held in Frascati early 2005 and was attended by Paola DeSalvo (WFP-VAM), Harry De Backer (DG-DEV), Jaques Delincé (EC-JRC), Dave Hodson (CGIAR-CIMMYT) and Henri Josserand (FAO).

The first SG meeting of Stage 2 was held in Mol (April 2006) and the second was held in May 2007 in Washington. The SG members in Stage 2 came from the following institutes: EC-JRC FOODSEC, FAO-GIEWS, WFP-VAM and USAID-FEWSNet

In order to have more user involvement, a GMFS **User Board** (UB) was established at the start of Stage 2. Throughout the project, the UB convened once or twice a year during which time an assessment was made to what extent the existing GMFS services fulfilled the users' expectations and how they could be improved to better support their needs. The user board meetings were attended by representatives from WFP, FAO, JRC, RCMRD, AGRHYMET, SADC-RRSU.

- User Board 1, Rome, 9 Sept 2005
- User Board 2, Rome, 14-15 March 2006
- User Board 3, WFP, Rome, 3-4 Oct 2006
- User Board 4, Mol, 20-22 June 2007
- User Board 5, Frascati, 26-28 Sept 2007
- User Board 6, FAO, Rome 24-25 Sept 2009

At the first UB the baseline services and countries of interest for GMFS Stage 2 were defined. It was also highlighted that capacity building is of major importance and that GMFS should train regional and local users to enable them to understand and /or produce their own versions of the GMFS products. Training should target a number of personnel in the relevant end-user government departments as to make sure that the information produced by GMFS is utilised by the real end users in the Ministries of Agriculture.
In the following UB meetings, use cases of the activities and results from GMFS products were presented and discussed. Based on this review, recommendations were formulated to be implemented in the next period.

Most actions taken during the course of GMFS were a direct response to the demands of the UB. Some examples are:

- In order not to supply the products as 'black boxes', without understanding of how they are produced, a product **metadata sheet** and **operations report** are made available.
- **Product sheets** were created to accompany the quick looks of early warning products send to the user.

- The users also asked to extent the **capacity building** to also address improved access to ESA data, such as via the **ESA / DDS satcom system**.

## 3.2. Technology driven approach

In the mid 1990s, there were rapid parallel developments in telecommunications and information technology. This resulted in a technological revision of the currently used approaches for food security information services, which were at that time primarily based upon ground based surveys.

### Early warning

Thanks to its large coverage and its frequent availability low resolution (1km) – and to a lesser extent also medium resolution (250-500m) – satellite imagery is widely used for monitoring the state of the vegetation in an operational way. The NDVI is one of the most robust of many attempts to simply and quickly identify vegetated areas and their condition. However, in recent years, more advanced algorithms are being developed to estimate directly the biophysical variables of interest such as fAPAR (fraction of Absorbed Photosynthetically Absorbed Radiation) or LAI (Leaf Area Index), taking advantage of the enhanced performance and characteristics of recent sensors.
Within the GMFS consortium these vegetation indices are distributed to the end users using an FTP service or the ESA DDS.
During Stage 1 the EWS was mainly based upon actual indicators derived from METEOSAT and SPOT-VGT data whereas during Stage 2 MERIS-RR products were introduced, as well as more complex indicators based upon the comparison of the actual value of an indicator with the historical average.

### Crop mapping

Using RS to make a land cover classification is a common practice in EO. The different land cover types are recognized based on their spectral characteristics and its changes over time. Different types of imagery can be used, ranging from optical to radar and from high resolution (HR) to low resolution (LR).
During Stage 1 crop mapping products were mainly based upon ASAR images and MODIS images.
In order to improve the crop mapping service and after an internal agricultural mapping workshop, two types of crop maps were provided in Stage 2.

The high resolution product called Cultivated Area (CA) was based upon the integration of SAR and high resolution optical data.

The medium resolution product based upon the integration of the CA product and medium resolution MERIS-FR data. Initially these products were generated using MODIS, MERIS-FR, ENVISAT ASAR-AP /WS, and Landsat TM /ETM+ data.

Later on when more high resolution data became available thanks to ESA third party mission agreements, SPOT-4, FORMOSAT, KOMPSAT, DMC, IRS-AWIFS and ALOS PALSAR data were operationally embedded in the existing processing chain.

### Crop modelling

Agricultural yields are traditionally estimated using Crop Growth Models or Agro-Meteorological Models (AMM) with different levels of complexity. Crop modelling has successfully been used as a powerful tool in agricultural decision making and as input for early warning systems.
Today, these crop growth models can be improved and also simplified by using RS data. RS data can be combined or can even replace intermediate model outputs like; LAI, FC, etc..
Most models can use RS data as input in various stages of the modelling process (parameters, input or driving variable) and it has been demonstrated that the performance of these models can be improved when RS data is used in the process.

In Stage 1 yield modelling was mainly done based upon RS data whereas in Stage 2, at the request of the user board, the approach was based upon a combination of traditional crop modelling and RS.

## 3.3. Validation methodology

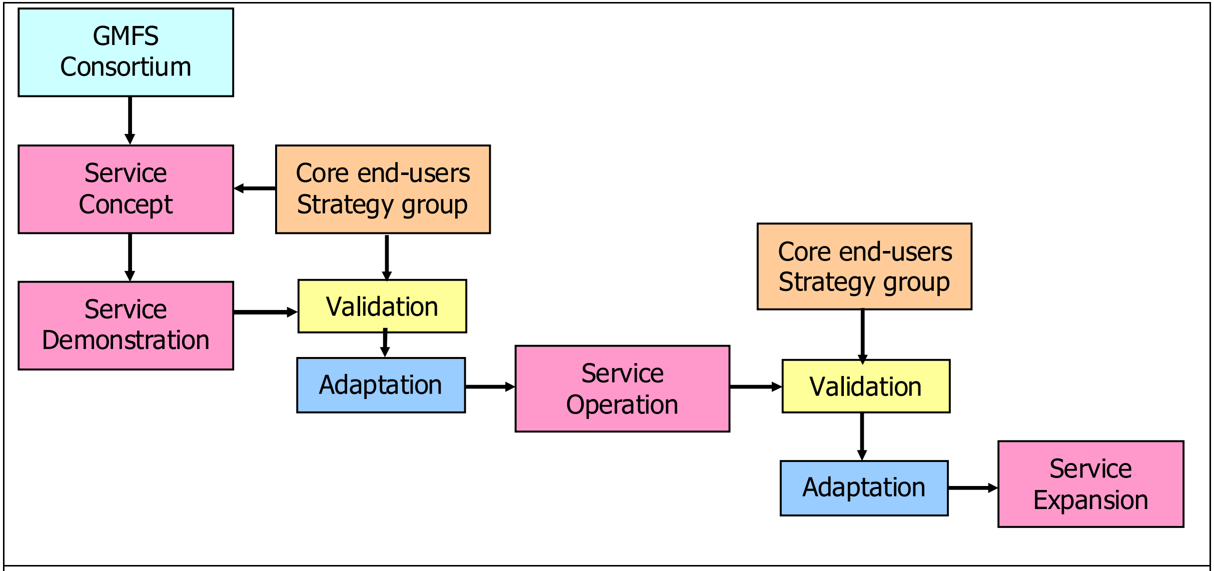



**Figure 3**: Validation sequence of the GMFS service

The goal of the GMFS project is to set up operational, continuous and reliable services. This can only be achieved if the user community gains confidence in the information products provided. This requirement can be met by imposing quality standards and providing reliable validation information for all GMFS products.

In general, the main objectives of validation are:

- Provide a clear accuracy assessment
- Guarantee the highest coherence possible among related products
- Monitor other aspects linked to the quality of service

Validation was set up as an iterative process, whereby the service as validated and adapted several times, so that the overall quality increased. Figure 3 shows this iterative process.

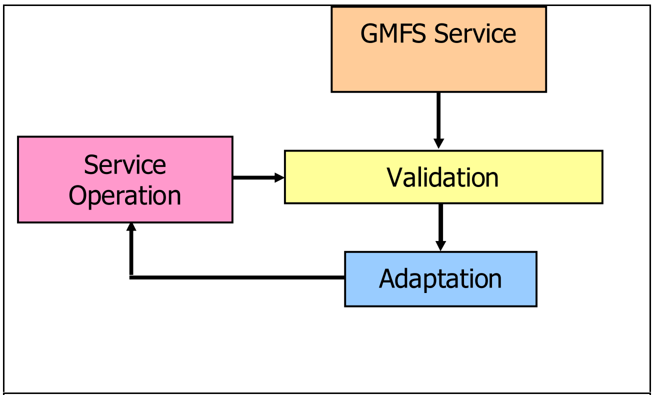



**Figure 4**: Service validation on the long term as a continuous process throughout the cropping seasons.

During the First Stage of the GMFS project, the Service had been defined, demonstrated and validated. A revised validation methodology was defined following the user's feedback.

In the Second Stage, the revised validation methodology was tested, so that the validation could be incorporated as a standard aspect of the service (Figure 4). Within the designed framework, the amount of fieldwork to be collected for validation, was adjusted during each cropping season according to the previous results and local (regional, national, sub-national) user needs.

Validation ideally exists of 3 components. Though, often it was not possible to perform them all due to lack of independent data.

1. **Accuracy assessment**

The accuracy assessment is a quantitative measure of accuracy based on independent (external) data. GMFS designed a random sampling fieldwork approach to collect this data on the ground. The field data were compared to the corresponding classified pixels of the GMFS crop /Landcover maps.
Depending on the results and data availability, a more specific analysis was performed within the same approach. For example, accuracy assessment at more detailed spatial level (districts, peculiar zones) or a deeper analysis of classification errors by exploiting the ground data nomenclature.

2. **Evaluation**

Evaluation is defined as the final quantitative or semi-quantitative assessment of product's accuracy using any kind of external data and user appraisal. Evaluation can integrate a formal accuracy measure for some products or be the only validation process for others, due to the unavailability of proper data sources.
In general, evaluation consisted of the comparison of descriptive statistics (counts, totals, averages) calculated both on the product and on the reference dataset at various levels of spatial aggregation (administrative levels, AOI sub-sections, regular grids), in order to detect possible under /over estimation. Results were summarised and presented in many numeric and graphical formats (scatter-plots, tables, maps), considering both absolute and relative differences.
A product could also be compared with a related product of the same season (e.g. Extent of Cultivation and Cultivated Area) or the same one from a previous season.

3. **Other quality indicators**

Accuracy of the information products was not the only aspect considered in the validation of GMFS services. To obtain a complete view on the product's value for the user, the following elements were assessed as well:

**Accessibility** refers to the physical conditions in which users can obtain data. All GMFS products were made available through the internet (GMFS portal, ftp sites, DDS). Alternative delivery mechanisms could be provided (e.g. DVD) if requested.

To ensure product reliability, **availability** of information products needs to be compliant with delivery plan. A detailed delivery plan indicating the release dates, with reference to crop harvest, or frequency for the products was discussed with all users.

Information products have to **meet users' needs**. Direct feedback from users revealed over /under estimation of their real needs.

## 3.4. Service evolution

During the First Stage of the GMFS project, the Services had been defined, demonstrated, validated and adapted for the regions West Africa (Senegal), Southern Africa (Malawi), and for the international users FAO and WFP.
At the start of Stage 2 a new set of services was proposed based upon the lessons learned during Stage 1, direct user feedback and inputs of the GMFS user executive board. The proposed changes included an expansion of the agricultural mapping service to new countries: Sudan, Ethiopia in East Africa, Zimbabwe in Southern Africa.
An other factor that influenced service evolution was the change in service providers for some service (e.g. Support to the CFSAM).

Throughout the live span of the project, al services evolved based upon the yearly iterative process (see figure 4). User requirements, validation reports, user utility reports and ongoing research were the basis for the adaptations.
A detailed description of service delivery and service evolution can be found in section 5.

# 4. SERVICE PORTFOLIO

## 4.1. Service List

In Stage 2, GMFS provided four different types of services which were (i) Early Warning Activities, (ii) Agricultural mapping, (iii) Crop yield assessments and (iv) support to FAO /WFP CFSAM.

*Table 3: Overview of GMFS services*

| Service | Product Name |
|---|---|
| Early warning | Vegetation Productivity Indicator (VPI) |
| | Fraction of Absorbed Photo synthetically Active radiation (fAPAR) |
| | Dry Matter Productivity (DMP) |
| Agricultural mapping (Agro - Environmental Assessment) | Crop emergence period (CEP) |
| | Cultivated area (CA) |
| | Extent of cultivation (EoC) |
| | Agricultural productivity (AP) |
| Crop Yield assessment | Crop Yield (CY) |
| Support to CFSAM | GMFS Support Kit for FAO /WFP CFSAM missions (SK) |

As can be seen in table 3, the agricultural mapping service consisted of four products: the CEP, the CA, the EoC and the AP. During Progress Meeting 8, which took place in October 2007 in Frascati (Italy) it had been decided that the CEP product was more a research product than an operational service and that it would not be delivered to the end users. Furthermore, since the AP product could easily be produced by the end users by combining the VPI with the EoC products, this product was also excluded as a service.

## 4.2. Service Description

### 4.2.1. Early Warning

GMFS early warning products are considered those that:

- Give a qualitative assessment of parameters affecting crop growth such as vegetation Indicators and climatic parameters
- Have a high temporal frequency
- Allow to identify anomalies in vegetation development or extreme climatic events

While many of those indicators existed already, GMFS focused on the following indicators:

- VPI based upon SPOT-VGT
- fAPAR indicators based upon MERIS-RR
- DMP based upon SPOT-VGT
- MSG derived indicators such as
    - LAI,
    - fCOVER,
    - Daily Temperature (Minimum, maximum, mean)
    - Global Radiation
    - Sunshine duration
    - Albedo

Note: Only VPI was included in the SLA. The other indicators were provided to end users as test case.

#### Vegetation Productivity Indicator (VPI)

The Vegetation Productivity Indicator is used to assess the overal vegetation condition and is a categorical type of difference vegetation index. The VPI method is a statistical distribution of the NDVI for each 10-day period of the year by applying techniques commonly used in hydrology for the prediction of extreme events.

#### Fraction of photosynthetic active radiation (fAPAR)

fAPAR is a parameter which is commonly used in crop yield models and is also used as an indicator for vegetation growth and health. MERIS-RR fAPAR 10-daily composites have been operationally produced during Phase 2. The calculation is based on the method of Gobron et al.

#### Dry matter productivity (DMP)

The Dry Matter Productivity measures the vegetation growth rate. When vegetation (crops or natural vegetation) is healthy and water and nutrients are not limiting, DMP is proportional with the amount of light intercepted by a crop canopy. Estimates of the productivity of terrestrial vegetation can be made by combining RS imagery with meteorological data (solar radiation and temperature information). The calculation is based on the classical Monteith (1972) approach

#### MSG indicators

Through an agreement with WFP-Sudan, Landsaf and JRC, Sudan could experiment in Phase 2 with MSG derived indicators prepared for JRC. An extension for this service to other countries (e.g. Mozambique) already started in agreement with JRC and Landsaf. Currently indicators are distributed to the AGRHYMET regional centre and the RCMRD making use of ESA’s DDS system.

### 4.2.2. Agricultural mapping

#### Cultivated Area

The aim of this product was to map cultivated area from local to national level, by mid or end of the crop season, at 20m resolution. It was derived from ENVISAT ASAR-AP, ALOS PALSAR FM starting from November 2006, Landsat TM /ETM+ and SPOT-4 /5. The production was done on a yearly basis.

#### Extent of Cultivation

The Extent of Cultivation (EoC) product intended to map cropped areas at country level. The EoC product was repetitive, as it was generated every growing season. It was based upon multi-temporal medium resolution MERIS-FR fAPAR images (pixel size 250m - 300m), and the CA product or other high resolution classification. The product was based upon the multi-temporal characteristics of vegetation, and specific changes of agricultural land during the growing season (field clearance, sowing, senescence, harvesting, etc.). This required repetitive acquisitions of satellite data during the growing season, typically once every 10 days.

### 4.2.3. Crop yield assessment

Crop yield assessment was based upon proven methods (based on the FAO agrometshell software), integrated with RS products.

### 4.2.4. Support to Crop and Food Supply Assessment Mission

Support Kits for CFSAM missions were produced upon ad hoc requests of FAO and WFP and could address any country in Sub-Saharan Africa. Given these missions are based upon request of the government and depend upon the ongoing growing season, it was not known up front which countries would request a CFSAM and the time to provide these documents was very short.

In general the reports intended to provide spatial information on potential anomalies in crop production or yield and consisted of 2-3 major parts.

The first part was a hot spot analysis of the start of the growing season and of the ongoing growing season based upon SPOT-VGT VPI data.
The second part was a yield prediction based upon the calibration of historical NDVI /VPI data versus FAO yield statistics (or other if available).
The third section was strongly depending upon the available RS data, when HR data was available, maps of specific agricultural areas in the country of interest were made.

Potential data sources included SPOT-VGT, ASAR-AP, MERIS-RR and MERIS-FR, other available remotely sensed data (e.g. SPOT-4 data) and input from local GMFS partners, agricultural map products, vegetation state indicators.

## 4.3. Service Production Chain

### 4.3.1. Early warning products

#### Production of VPI product

The VPI method is a statistical distribution of the NDVI for each 10-day period of the year by applying techniques commonly used in hydrology for the prediction of extreme events.

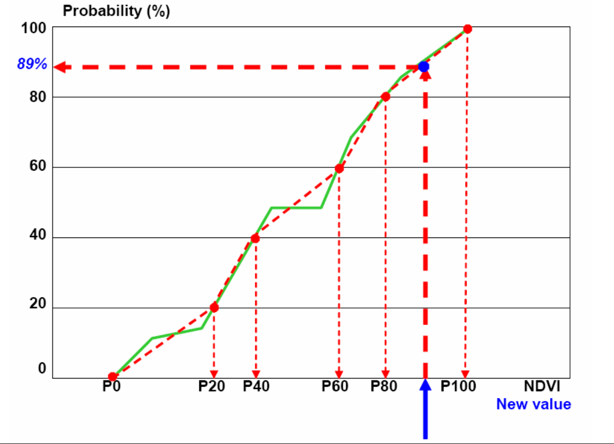



**Figure 5**: Example of cumulative curve used to calculate VPI

VPI-maps were created as follows for every decade:

- For each pixel, the NDVI-percentile was read from the 6 percentile images of the historical year (0%, 20%, 40%, 60%, 80% and 100%).
- By comparing the pixel's actual NDVI-value with these percentiles, it was assigned to one of the five percentile groups ("productivity classes").

The principle of VPI is explained in Figure 5. The green line represents the cumulative histogram, which is derived from the historical values available for the considered period. The red line, which connects the selected set of percentiles, forms an approximation of the true histogram. Figure 6 summarizes how the product was made.

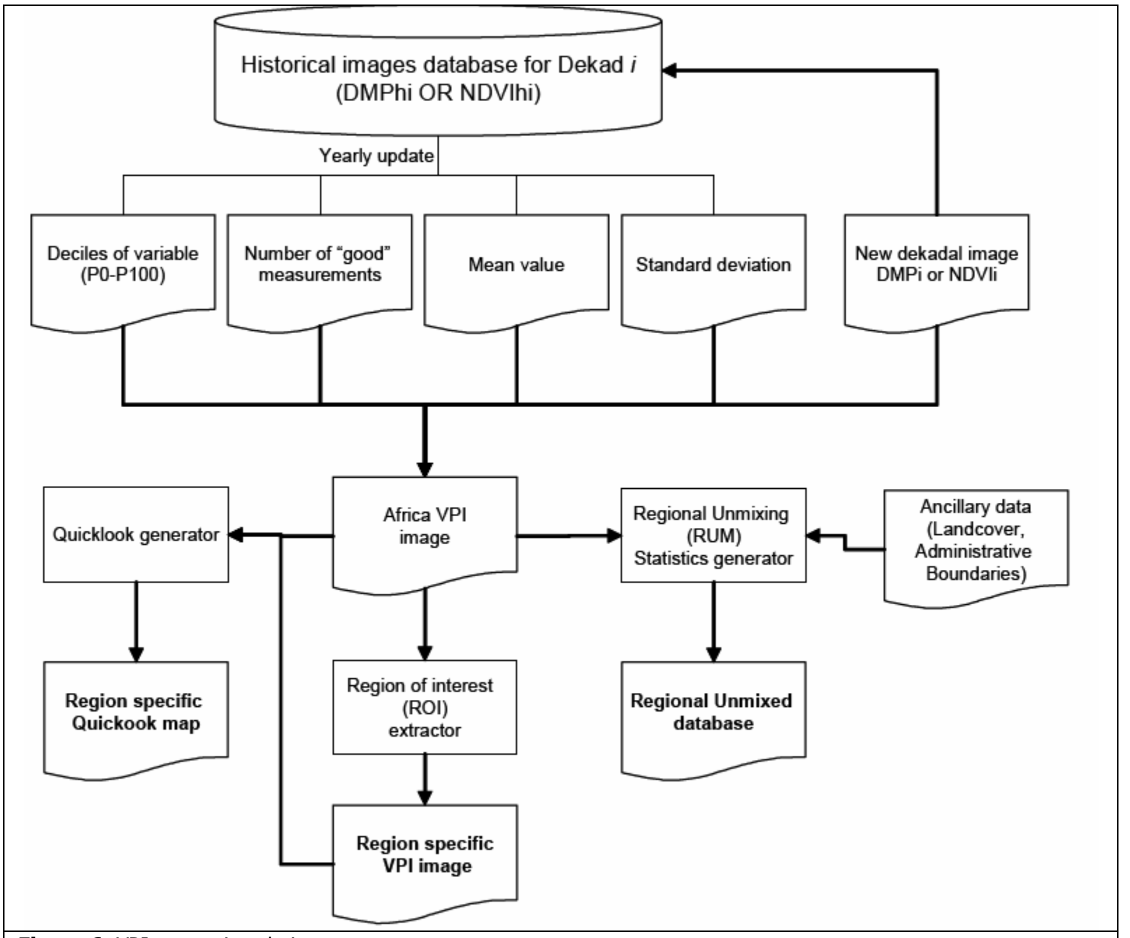



**Figure 6**: VPI processing chain

### Production of fAPAR

The fAPAR images were based upon the MERIS-FR sensor on board of ENVISAT. The data acquisition cycle is > 3 days. MERIS-FR Level 1 input images were ordered in bulk for all regions of interest of GMFS and images were directly retrieved from a dedicated FTP server at ESA.
Based on the method of Gobron *et al.* fAPAR values were calculated for every retrieved scene. For every decade and for every month, composites were made using a maximum value compositing step. The overall processing scheme is shown in Figure 7.

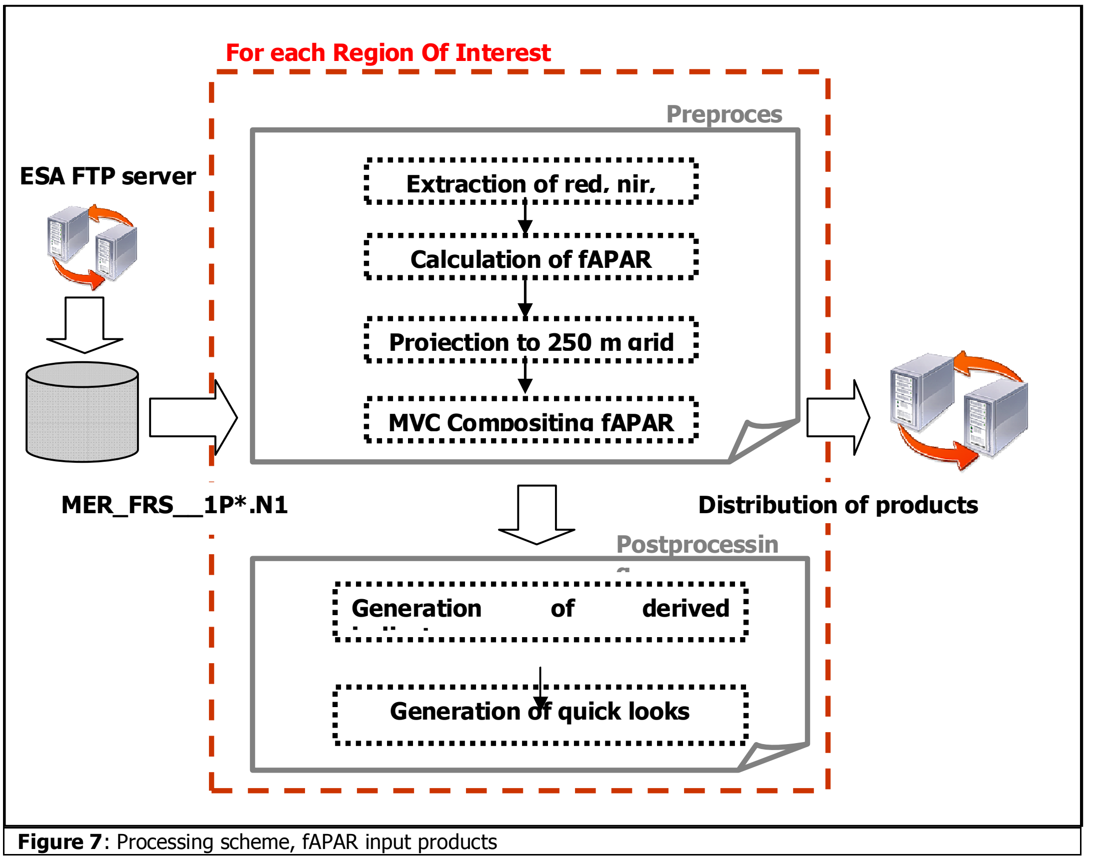



**Figure 7**: Processing scheme, fAPAR input products

### 4.3.2. Agricultural mapping

#### Cultivated area

Figure 8 illustrates the applied methodology for mapping CA. Two complementary parts should be distinguished, namely the optical and the SAR one. Key features derived from these independent sources were integrated in an deterministic-probabilistic (hence hybrid) classifier. While Optical features are primarily related to spectral based behaviour inferred from single acquisitions (in the best case from bi-temporal acquisitions enabling also the generation of thematic classes), SAR time-series allow the derivation of temporal based features, which are characteristic for cultivated areas.

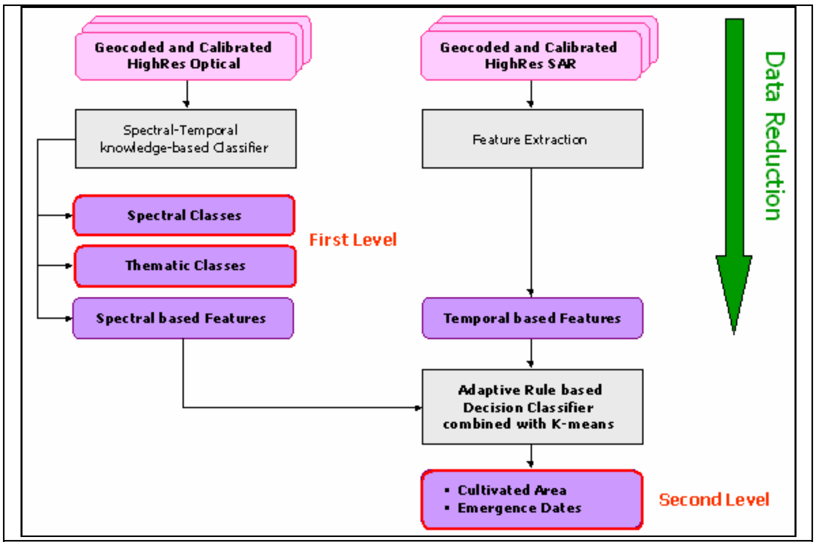



**Figure 8**: Overview of the CA processing chain

Spectral and temporal based features and spectral classes constituted the fundamental input parameters (which may vary from country to country) of the hybrid classifier. This was essentially composed by two complementary parts, namely the deterministic one, whose general rules are applicable in most of the cases. In this part, the first level products (spectral and thematic classes) were taken into account with the most significant features. The probabilistic part of the classifier – which was not mandatory and is applied only to the unclassified areas –wais constituted by a K-means classifier.

### Extent of Cultivation

The EoC and AFI (Area Fraction Image) were national scale products. The EoC presented the two classes "cultivated land" and "non-cultivated land". The AFI estimated the amount of agriculture per pixel. Both EoC and AFI were provided at national scale with a resolution of 250m. The products were repetitively generated every growing season.

The method applied was called an 'up scaling method'. A high resolution classification (e.g. CA product) of a number of small areas was used to train a neural network for sub-pixel classification of a time series of medium resolution imagery (MERIS-FR). The neural network was then applied to the MERIS images, extrapolating the information of the selected areas to the national scale.

Figure 9 gives the different steps to produce the EoC.

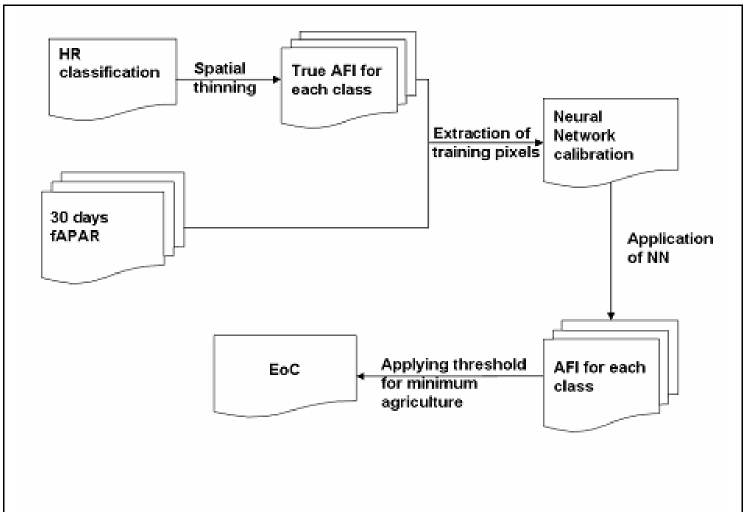



**Figure 9**: Processing sequence of the development of the EoC product

In a first step the high resolution classification was transformed to 'True Area Fraction Images', one for each class, with the same resolution as the MERIS fAPAR. The pixel of an AFI of a certain class contains the fraction of that class within the pixel (sub-pixel level). There were as many AFI's as there were classes under consideration. Ideally, the high resolution classification existed of the CA map. If this product was not (yet) available, a classification was made from optical data combined with field data.

Subsequently the neural network was trained. The input data basically existed of monthly fAPAR products, but could be completed with other data, such as a digital elevation model.
Once the network was trained, it could use its knowledge to produce AFI's covering the whole region of interest. The 'cultivated' AFI was transformed to the EoC with two classes "cultivated land" and "non-cultivated land". The software used for the processing is GLIMPSE (Global Imaging Processing SoftwarE), which is developed by Vito.

### 4.3.3. Crop yield forecasting

The crop yield was calculated at departmental level for each crop and then aggregated at national level. The calculation at departmental scale was realized by studying the correlation between historical yield data and a set of yield explanatory variables. There were 3 sources (figure 10) of explanatory variables: meteorological (actual rainfall), phenological (Agrometshell outputs) and remotely sensed variables.

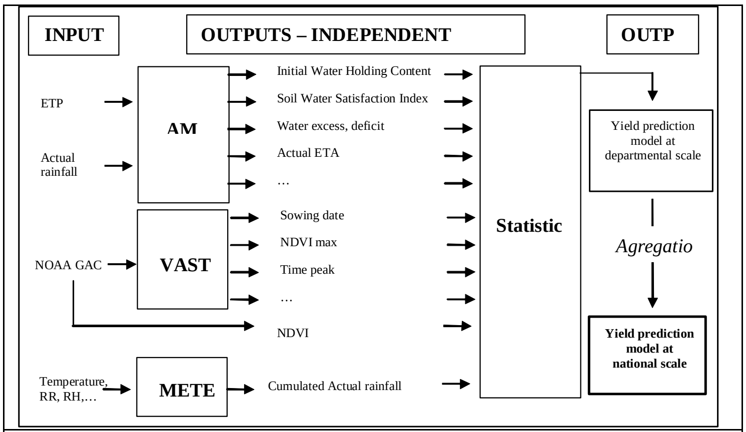



**Figure 10**: Yield prediction methodology

For each department and crop type a multiple linear regression model was fitted:

$$Y_{dep} = a + \sum_{i=1}^{n} b_i * x_i \qquad (1)$$

With, $Y_{dep}$, the predicted yield at departmental level (kg /ha)
a, the intercept
$b_i$, the coefficient regression for the variable $x_i$
xi, the explanatory variable i
n, the number of explicative variables (varies from 2 to 4)

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i \cdot X_i + \varepsilon$$

Model selection was realized in the following steps:

- Computation of correlation matrices to analyze relationships between variables
- Identification of a first subset of models through exhaustive search (up to 3 explanatory variables) and ranking with summary goodness of fit statistics (adjusted R2 , BIC)
- Selection of 3-4 models to be compared by leave-one-out cross validation
- Final choice of the model with best cross validation statistics (adjusted R2–cv, RMSE-cv)

For each crop and for each department, a yield forecast model was made. Only the departments where the amount of historical yield data was sufficient were included into the analysis. The calibration set for each model contains all data available at the time of forecasting.

In order to aggregate the predicted yield at national level, a set of departments were selected after a trial and error analysis on historical yield data that allows recovering the best yield forecasting.

## 4.4. Service Validation

### 4.4.1. Validation data

a) For the EWS and the crop yield estimation, the products were validated by comparison with reference statistics and reports. Timeliness, reliability and accessibility were also used as an indicator for the validation of this service.

**Figure 11**: Field survey training in Addis Ababa, September 2007

b) The agricultural mapping products were validated by means of field data. A number of local experts were trained by GMFS to perform field surveys according to the field survey methodology described below.

The sampling units existed of points, grouped in clusters on a regular grid. A cluster is composed of 16 points arranged at 250m distance and the distance between the clusters is 15km. From all possible clusters, a subset was selected to be visited in the field. The subset was created in two steps. First those clusters located in non cropped areas were eliminated. The land cover classes were determined by means of photo interpretation of HR satellite data or land cover maps. Only mixed or agriculture clusters were retained. Afterwards clusters that could not be easily reached, were excluded from the selection. An example of the selection procedure is shown in Figure 13.

By means of a GPS, the surveyors could retrieve the sampling points in the field (Figure 14). They record the land cover or crop type at that location, as well as the fractions of land cover within a 15m radius (to validate the 15m resolution CA) and 125m (to validate the 250m resolution EoC and AFI). Reference pictures were taken at the point and in North, South, East and West direction. The data was entered with an interactive software application (figure 15). After returning from the field, the field form data, GPS data and the photos taken were examined for completeness and coherence.

The following field surveys were performed:

- 2004: Malawi
- 2005: Malawi
- 2006: Malawi, Senegal
- 2007: Malawi, Senegal, Zimbabwe, Ethiopia, Sudan

In some countries the data collection was more straightforward than in others. In Malawi each year 90% of the points were reachable. In 2005, 1040 sampling points were visited. The next two years, the points of the previous year were revisited and additional points were added to the sampling scheme. In 2007, the database contained 1776 points. In most other countries, the surveys went more difficult. In Ethiopia, Sudan and Zimbabwe, the local conditions required more preparatory work. The field surveys only succeeded in the last year, but they yielded an accurate and extensive database (576 points in Sudan and 1008 points in Zimbabwe). In the case of Ethiopia, accessibility was an issue. The relief and the less dense road network – sometimes in bad conditions due to flooding - only allowed to reach 282 from the 1109 surveyed points.

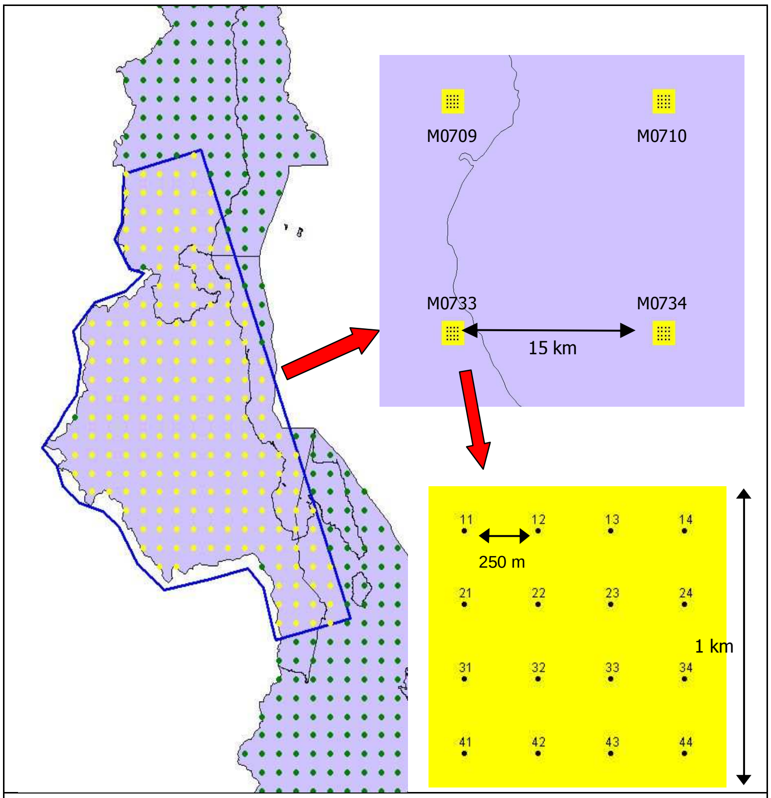



**Figure 12**: Sampling design: systematic grid of clustered points.

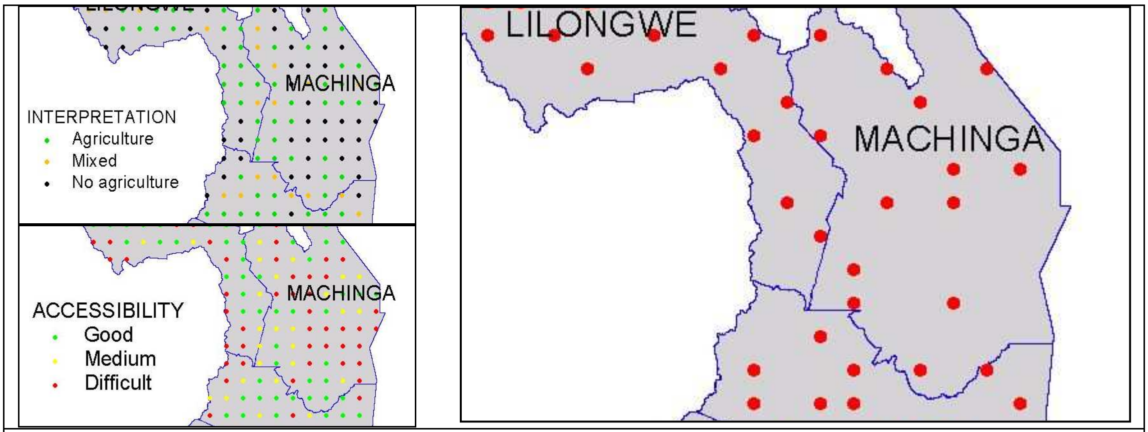



**Figure 13**: Clusters classification by photo interpretation and accessibility (left).and final selection (right) for part of Malawi.

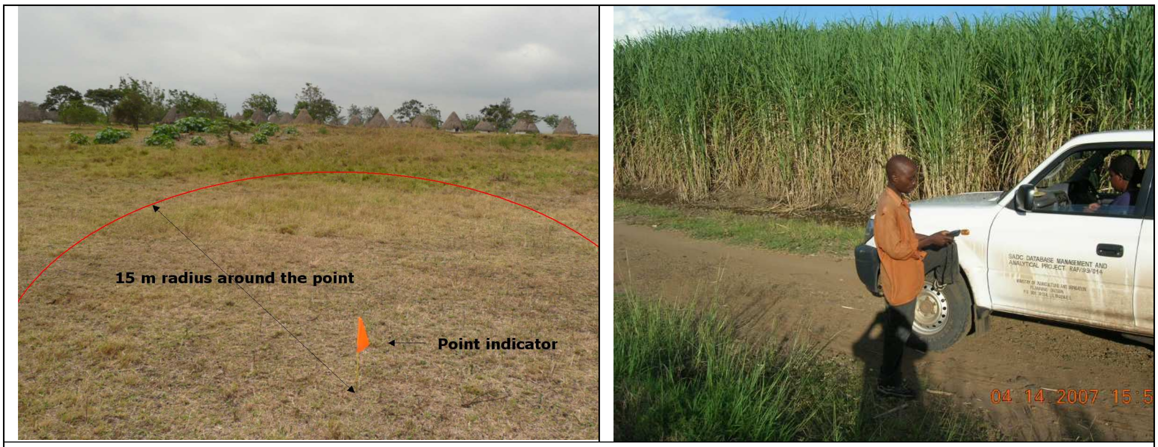



**Figure 14**: Surveyors in a large sugarcane estate in Malawi looking for the next point

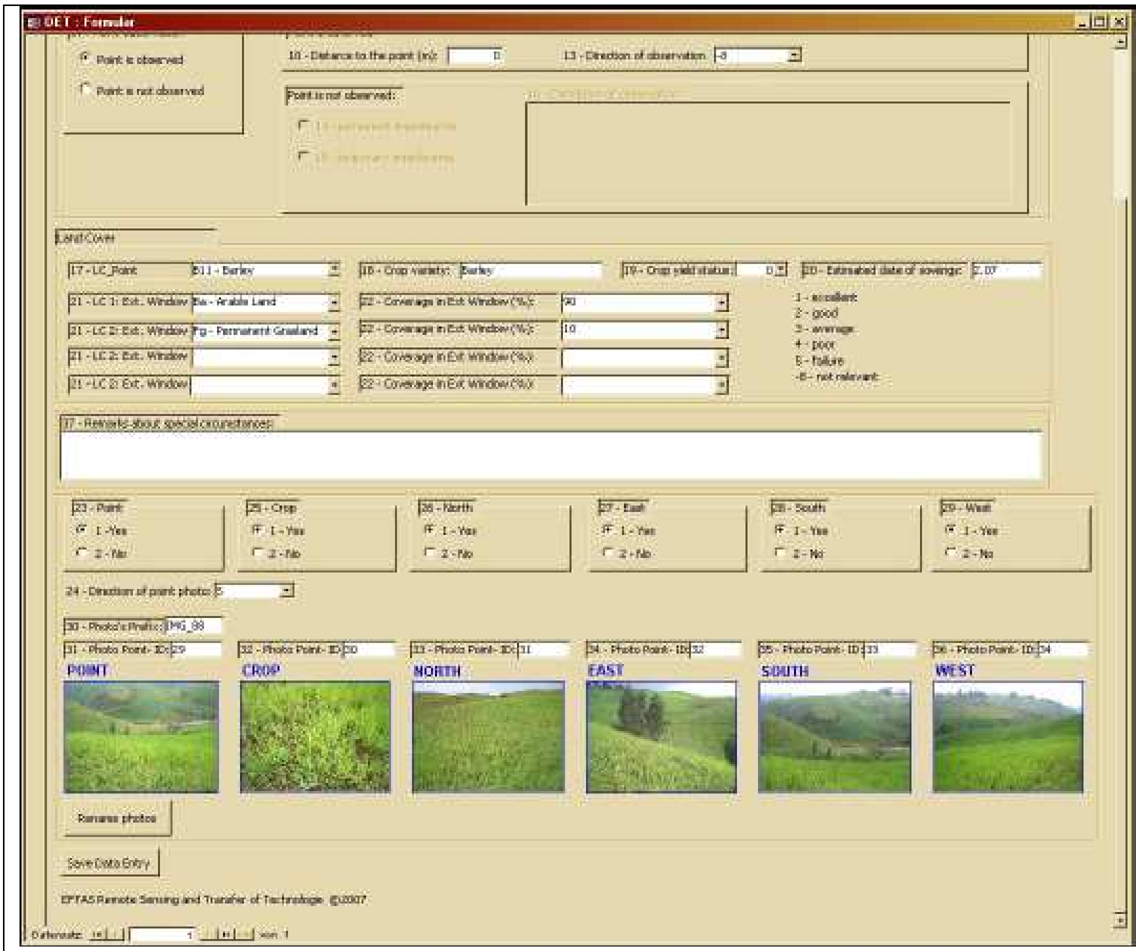



**Figure 15:** Software for field data collection.

**Figure 16:** Examples for inaccessibility of sample points during the 2007 field work campaign in Ethiopia

In Senegal, the methodology was slightly adapted to be integrated in the annual 'enquête agricole permanente' (EPER). In stead of a grid based sampling scheme, the field points were located on the fields visited for the EPER.

If no field survey was performed or insufficient points were collected, the backup procedure for data acquisition was followed, based on photo interpretation of high resolution images of the current season.

### 4.4.2. Validation procedure

For the accuracy assessment of the agricultural maps, only 2 classes were taken into account: cultivated and other land cover. Therefore all crops were grouped into one class and the remainder into a second class. The validation was done by overlaying the clusters with buffer (15 or 250m) on the agricultural maps and comparing the field observation with the classified values. This resulted in fractions in stead of absolute values for two reasons:

1) The field observations mostly existed of a mixture between cultivated and other land cover in stead of a pure class
2) The buffer overlaid on the map intersected several pixels.

In the validation, either the dominant class (Figure 17) or the fractions (Figure 18) were taken into account.

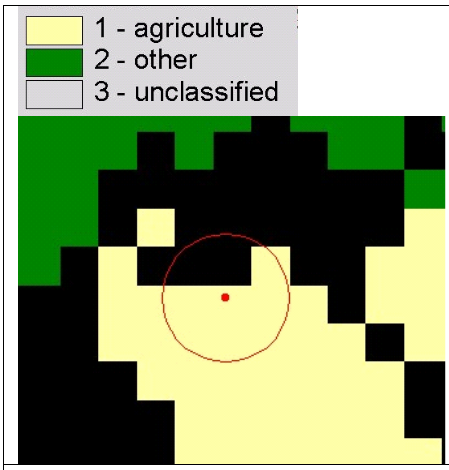



**Figure 17**: Example of CA data extraction in correspondence of a fieldwork sampling point. Dominant cover in a 25m buffer is agriculture.

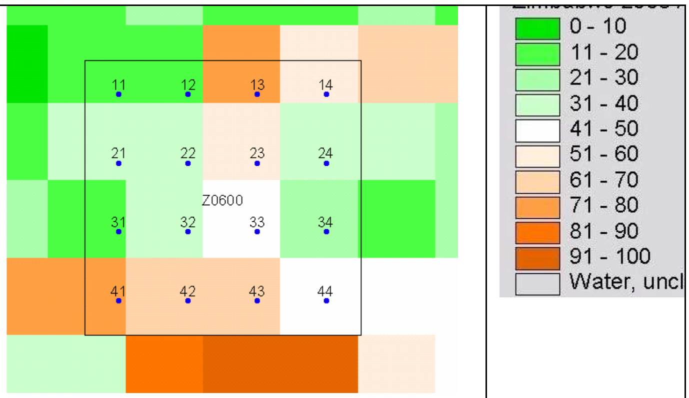



**Figure 18**: Example of classification frequencies extraction at cluster level for AFI: crop=0.44, other=0.56

The comparison resulted in a confusion matrix. Several accuracy assessment indicators were derived from this matrix:

- Omission error: it gives the portion of each class not recognised by the classification (its complement is the producer's accuracy)
- Commission error: it gives the portion wrongly assigned to each class (its complement is the reliability, or user's accuracy)
- Overall accuracy
- Kappa coefficient: an overall accuracy index that takes into account the off-diagonal elements.

An example of such confusion matrix is given in table 4.

*Table 4: CA-Fieldwork confusion matrix for land cover in the point (unit: point; points where dominant class covers less than 2 /3 of the buffer have been excluded; unclassified pixels considered as "other land covers")*

| | Cultivated Area | | | |
|---|---|---|---|---|
| Fieldwork | Crop | Other | Total | Omission error |
| Crop | 271 | 128 | 399 | 32% |
| Other land covers | 103 | 549 | 652 | 16% |
| Total | 374 | 677 | 1051 | K = 0.83 |
| Commission error | 28% | 19% | Accuracy = 78% | |

If the validation results for the latest maps of each country are compared, it appears that the highest overall accuracies for the CA are obtained in Malawi growing season 2007-'08 (78%) and Senegal growing season 2007 (80%) and the lowest value in Ethiopia growing season 2007 (63%). The EoC yielded best results in Malawi growing season 2007-'08 (81%) and was least accurate in Ethiopia growing season 2007 (65%) and Senegal growing season 2007 (63%). Obviously the completeness of the validation dataset has an influence on the validation result. In Ethiopia, e.g., less than half of the surveyed points could be accessed.

Comparing the results from Malawi, where a sound field survey was carried out during the three subsequent growing seasons, it appears that the methodology to produce the maps has improved considerably over the years. Between 2005-'06 and 2006-'07 the overall accuracy of the CA increased with 4% and with 16% for the EoC. For the, 2007-'08 growing season, the overall accuracy of the CA was again 6% higher and the EoC 10%.

## 4.5. Level of Service Maturity

### 4.5.1. Early Warning Service (EWS)

This service is considered fully operational. Early warning indicators were delivered automatically every 10 days to the interested end users.

The VPI was seen by end users as a powerful, very frequent and fully operational product (Service Utility Report Senegal 2007). As an example, in Senegal CSE has integrated it in their food security bulletin and distributed to the GTP partners. They considered it to be complementary to the indicators they developed themselves.

### 4.5.2. Agricultural mapping (AM)

**Cultivated area (CA)**

Most users considered this as a research product and less as an operational product (Malawi, Sudan, Senegal Service Utility Reports). The implementation as part of the local food security decision making chain was hampered by two factors: (1) the timely delivery of raw data, and (2) due to its technical complexity and hardware (CSE, Senegal user evaluation).

**Extent Of Cultivation (EoC)**

The advantage over the CA for the end users was the fact that EoC covers the entire country, but accuracies need to be improved. Since EoC was based upon CA and as such improvements in CA will have influence on the accuracy of this product. The most important impact, would have been achieved with a pre-harvest delivery, but this timelines is difficult to achieve (Service Utility Report Sudan 2008).

### 4.5.3. Crop yield forecasting

The crop yield forecast was considered as fully operational by users in Senegal and Malawi. Presently the crop yield forecasting approach is ready for operational running in Senegal and Malawi.

# 5. SERVICE DELIVERIES

Per country a customized package of services was delivered, depending on the user needs. It was investigated for each user, which was the most efficient delivery mechanism. Per service, one provider was assigned who was responsible for the successful receipt of the products by the users

## 5.1. List of Service Providers per product type

*Table 5: Overview of Service providers*

| Service | Product Name | Provider |
|---|---|---|
| Early warning | Vegetation Productivity Indicator (VPI) | VITO |
| | Fraction of Absorbed Photo synthetically Active radiation (fAPAR) | VITO |
| | Dry Matter Productivity (DMP) | VITO |
| Agricultural mapping (Agro -Environmental Assessment) | Crop Emergence Period (CEP) | SARMAP |
| | Cultivated area (CA) | SARMAP |
| | Extent of cultivation (EoC) | VITO |
| | Agricultural productivity (AP) | VITO |
| Crop Yield assessment | Crop Yield (CY) | ULG (West African region)<br>ITA (South African region) |
| Support to CFSAM | GMFS Support Kit for FAO /WFP CFSAM missions (SK) | VITO |

## 5.2. Services at regional or continental level

The EWS are produced at continental scale and distributed at regional and national level.

In Stage 1 these regional services were provided to the SADC-RSSU and to AGRHYMET.

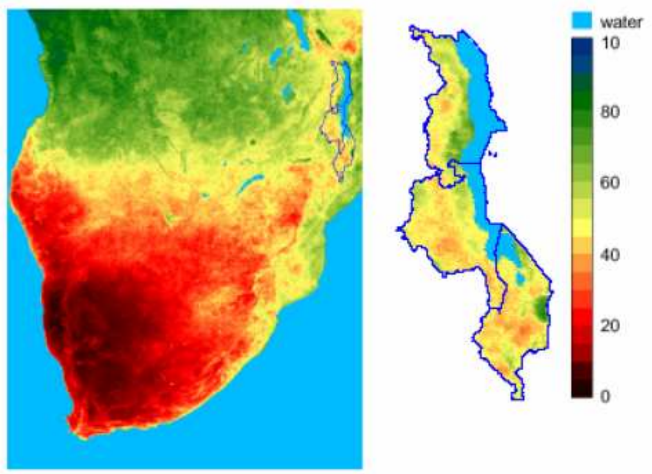
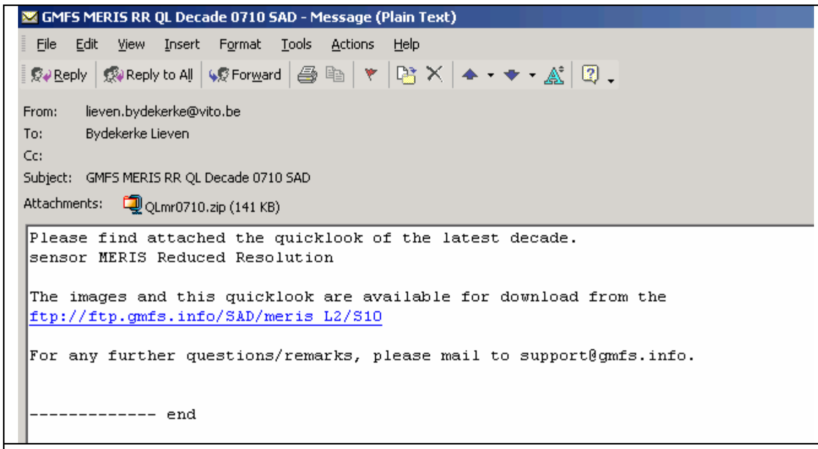



**Figure 19**: relative evapotranspiration during growing season expressed in percentage

The early warning products were produced by EARS. These included drought monitoring and crop yield forecasting based on visual and thermal infrared data from meteorological satellites. Products were delivered for West and Southern Africa mainly by ftp service. An example is given in Figure 19.

During Stage 2 these products were replaced by the VPI based upon SPOT-VEGETATION sensor and fAPAR based upon the MERIS RR sensor. The distribution of this type of indicators was completely automated. The VPI and fAPAR products were provided to the users on a 10-daily basis. Once the raw segments were received from the data provider, the processing chains were automatically activated and the production of the Vegetation Productivity Indicator and the fAPAR started.

The data for the 8 regions of interest were uploaded to the GMFS ftp site and 11 user organisations were notified by email (Figure 20). The email message contained a link to the gmfs ftp site were the data could be downloaded and a quick look (Figure 21) to allow a quick inspection of the product. The quick look was produced as a low resolution /sized image so the email inboxes of the various partners were not blocked. For Senegal, Mozambique and Sudan, some additional products were supplied for testing purposes, including MSG derived products (since July 2006) and VCI (Vegetation Condition Index) product (since June 2006). The MSG products consist of mean daily sunshine duration; mean daily incoming solar radiation, mean, maximum and minimum daily temperature, leaf area index, fraction of vegetation cover and albedo.


GMFS MERIS RR QL Decade 0710 SAD - Message (Plain Text)
File Edit View Insert Format Tools Actions Help
Reply | Reply to All | Forward

From: lieven.bydekerke@vito.be
To: Bydekerke Lieven
Cc:
Subject: GMFS MERIS RR QL Decade 0710 SAD
Attachments: QLmr0710.zip (141 KB)

Please find attached the quicklook of the latest decade.
sensor MERIS Reduced Resolution

The images and this quicklook are available for download from the
ftp://ftp.gmfs.info/SAD/meris L2/S10

For any further questions/remarks, please mail to support@gmfs.info.

------------- end

**Figure 20:** Automated message, announcing the data is ready for download

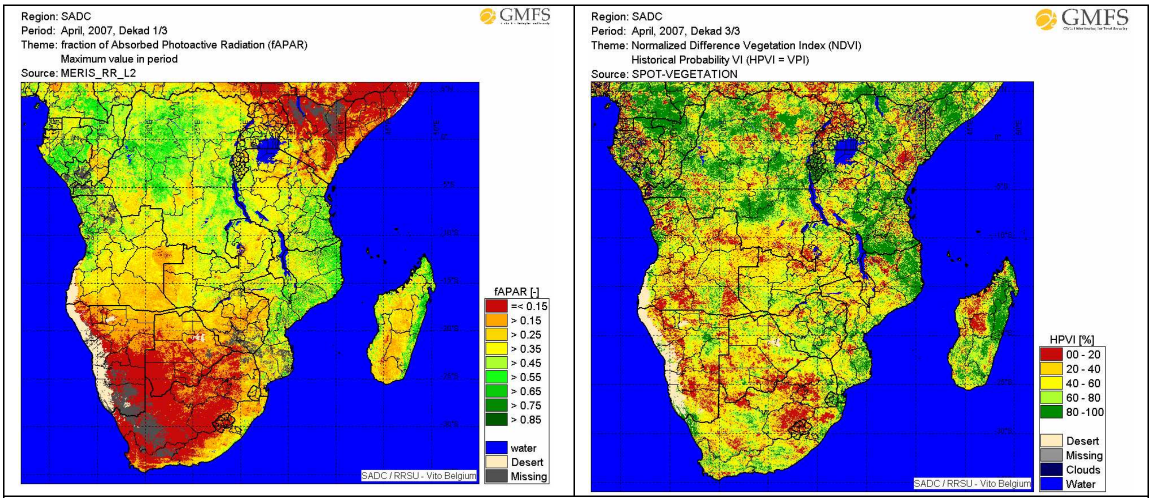


**Figure 21**: Quick look included in the email message. Left fAPAR. Right VPI

## 5.3. Services at national level

Depending on the needs of the countries, different types of services were delivered: Agricultural mapping (CA and EoC), yield estimation and report on early warning.
The services were made available by ftp and DVD in the middle or the end of the crop season.

**SENEGAL**

Senegal was one of the countries where several studies were conducted during the First Stage of GMFS to develop the service portfolio.

During Phase 1 of Stage 1, 13 districts in Senegal were monitored, upon request of the CSE and DAPS the area covered was extended to the whole country during the 2004 growing season. This was done using medium resolution data (250 m) and using ASAR WS data (150 m resolution). Additionally, one site was mapped at 15m resolution.
The delivered products were:

- Kaolack: cropped areas for 2003 and 2004 season (15m resolution)
- Senegal: cropped areas for 2003 and 2004 season
- Agro-meteorological model yield forecast results for Kaolack (2003) and entire country (2004) (yield forecasts for peanuts, maize and millet).
- DMP images at 10-day interval from June to November 2004
- DMP statistics, updated every 10 days from June to November 2004
- NDVI images at 10-day interval from June to November 2004
- VPI images at 10-day interval from June to November 2004
- Crop yield forecasts (METEOSAT based)
- Evapotranspiration, rainfall maps (METEOSAT based)

During Stage 2 the production of the CA, EoC and CY, was well established and was repeated for the growing season of 2005, 2006 and 2007.

Concerning the CA, it was only feasible to cover two third of Senegal with high resolution radar. It was decided to focus the CA on the Central and Western part of the country, including the 'Basin d'Arrachidier', the major agricultural region . The Eastern part of the country, which was not enclosed, exists for a large part mainly of pasture instead of cultivated land.

In Stage 2 Phase 1 the **high resolution agricultural map**, the Cultivated Area (CA) map, was produced as a land cover classification (Figure 22). In the course of the Second Phase this land cover map was changed into a probability map. (Figure 23). Areas defined as "high probability" agriculture are those areas that were classified as agriculture in the previous growing season and are displaying the same temporal profile in the current growing season, "medium probability" agriculture have the same temporal profile as for the high probability areas but were not classified as agriculture in the previous year. The "low probability" agriculture, was classified as agriculture in the previous growing season, but the temporal profile of the current growing season does not correspond with an agricultural profile. The "other vegetation" class groups areas with a non agricultural profile in the current and the previous growing season.

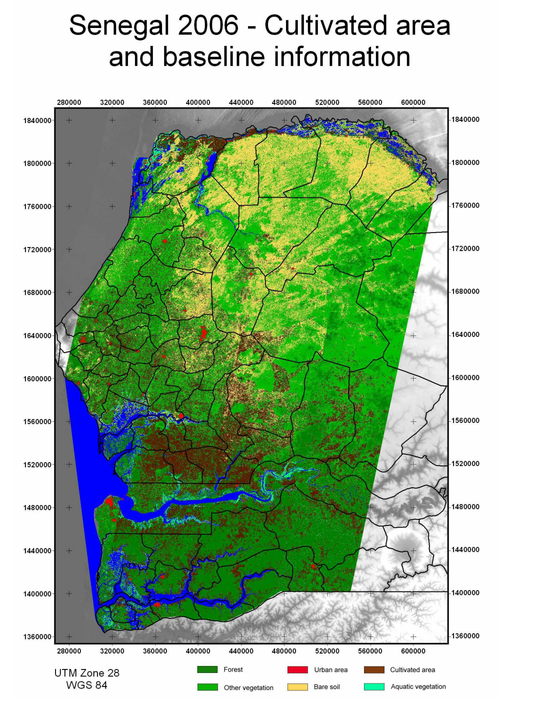



Figure 22: CA Land cover map Senegal 2006

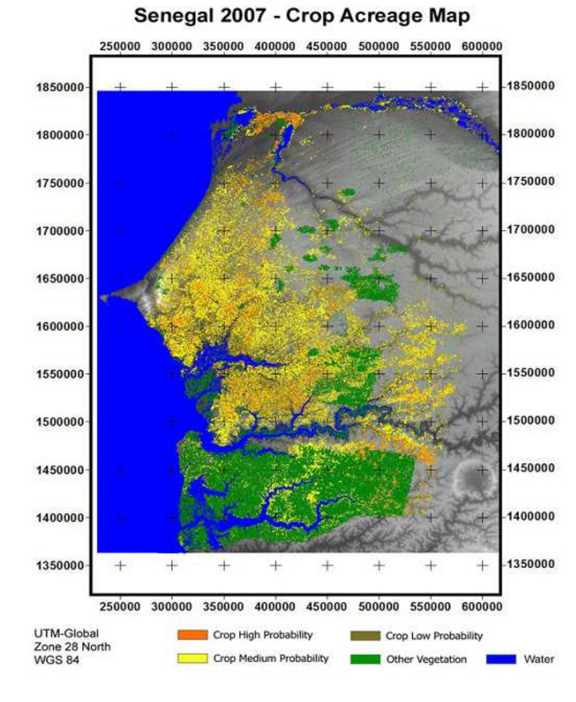



**Figure 23**: CA probability map Senegal 2007

The EoC (Figure 24) and AFI (Figure 25) cover the complete country.

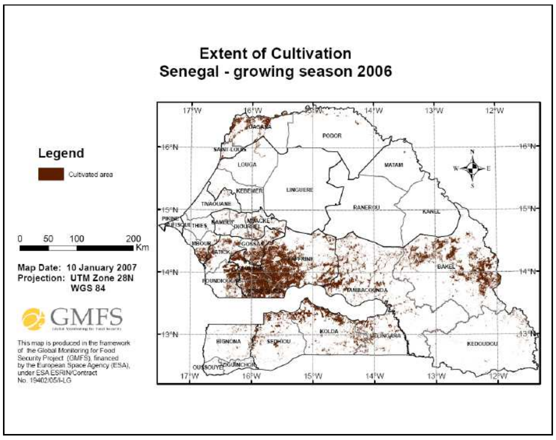



**Figure 24**: Extent of cultivation for the cultivated area in Malawi for the growing season 2006-'07.

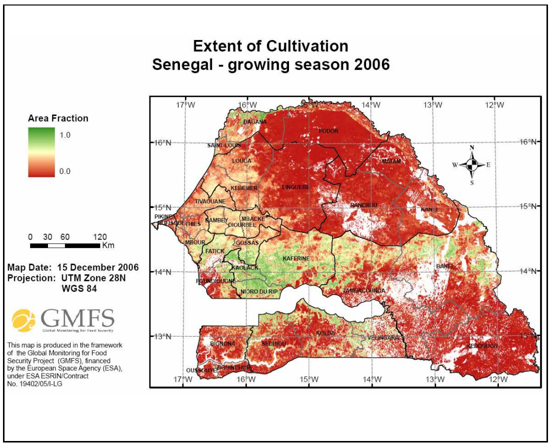



**Figure 25**: Estimated Area Fraction Image for the cultivated area in Senegal for the growing season 2006.

In 2005, yield was estimated for millet near the end of the season. In 2006 and 2007, a first forecast for millet was done end of August, and a second forecast for millet and other main crops (ground nut, sorghum, etc.) in October.
In 2007, training was given on crop yield estimation to allow the Senegalese users in the future to make their own yield predictions with support of GMFS. As such they would no longer entirely

depend upon the delivery of the results. *Table 6* shows an example of the yield estimation for groundnut in 2007.

*Table 6: Yield estimation for groundnut per department in Senegal for growing season of 2007.*

| Département | Rendement estimé (kg /ha) | Rendement moyen DAPS 1986-2004 (kg /ha) | Différence (%) | Superficie moyenne emblavée DAPS 1986-2004 (%) |
|---|---|---|---|---|
| Bambey | 597 | 597 | 0 | 3 |
| Fatick | 694 | 692 | 0.4 | 4 |
| Gossas | 28 | 644 | -96 | 5 |
| Kébémer | 501 | 481 | 4 | 5 |
| Mbacké | 561 | 559 | 0.4 | 4 |
| Mbour | 400 | 499 | -20 | 3 |
| Tambacounda | 1085 | 1085 | 0 | 7 |
| Tivaouane | 307 | 547 | -44 | 5 |

**MALAWI**

In the 2003-'04 growing season, 3 sites were mapped with 15m resolution data. Those are: Mzimba, Ntchisi and Zomba, respectively in the northern, central and southern part of the country. Next to this the entire country was mapped at 250m resolution.
The delivered products for Stage 1 were:

- Mzimba, zomba, Ntchisi: cropped areas for 2004 growing season (15m resolution)
- Malawi: Cropped areas for 2003-'04 growing season
- Dry matter productivity images at 10-day interval from October 2003 to June 2004
- VPI images at 10-day interval from October 2003 to June 2004
- Agro-meteorological model yield forecast results for entire country (2003-'04).
- Crop yield forecasts (METEOSAT based)
- Evapotranspiration, rainfall maps (METEOSAT based)

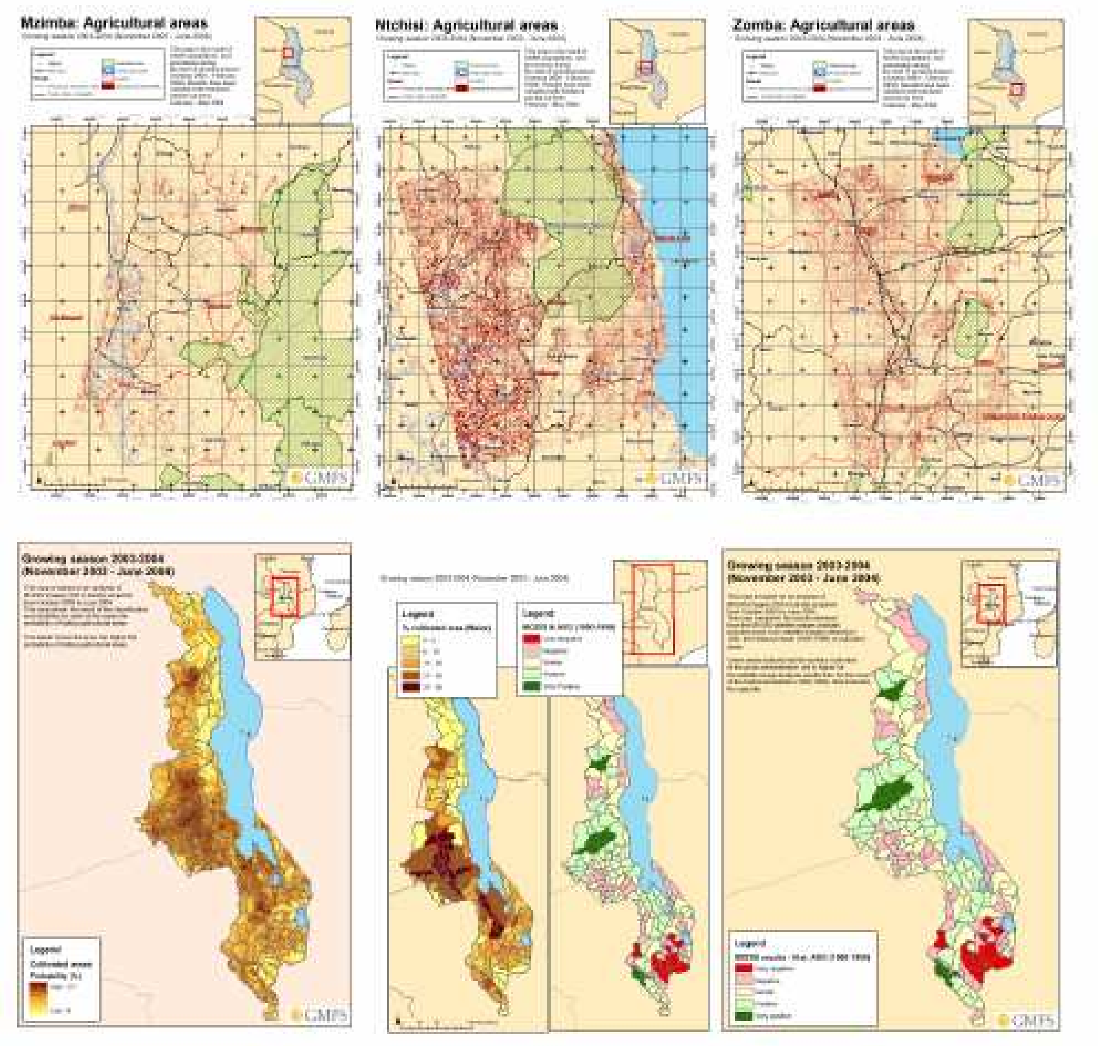



**Figure 26**: Agricultural Mapping products for Malawi 2004

For Stage 2 the 2005-‘06, 2006-‘07 and 2007-‘08 growing season CA, EoC and maize yield prediction were delivered to the end users in Malawi near the end of the growing season (see Figure 27-32).

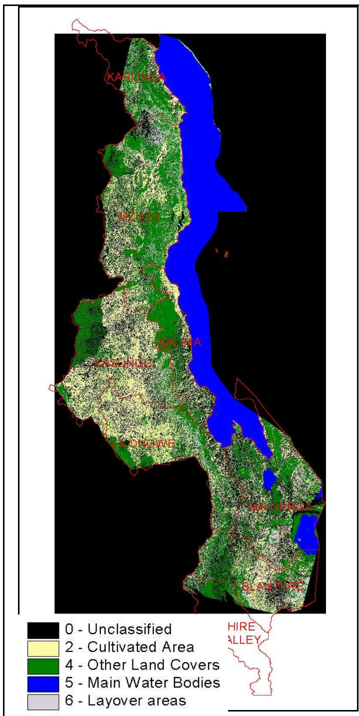



**Figure 27**: Cultivated Product for Malawi for the growing season 2007-‘08

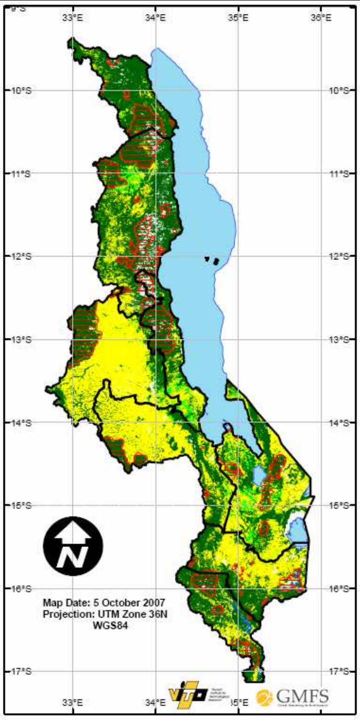



**Figure 28**: Extent of cultivation for the cultivated area in Malawi for the growing season 2006-‘07.

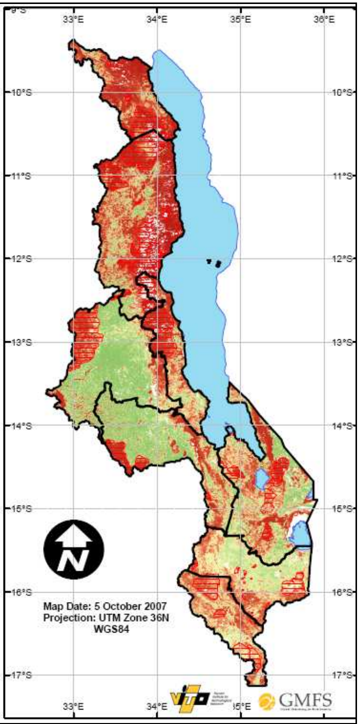



**Figure 29**: Estimated Area Fraction Image for the cultivated area in Malawi for the growing season 2007-‘08.

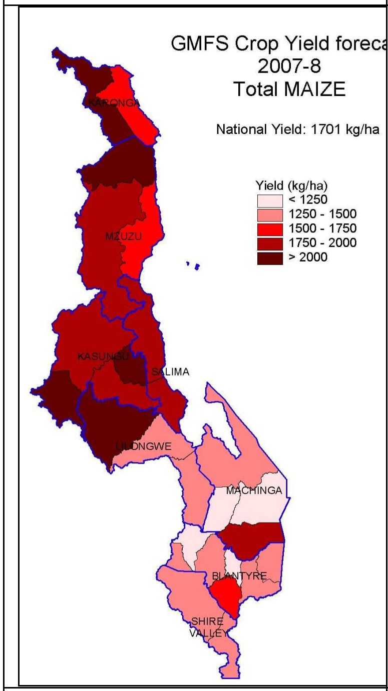



**Figure 30**: Maize 2007-‘08 yield forecasts, RDP and national level.

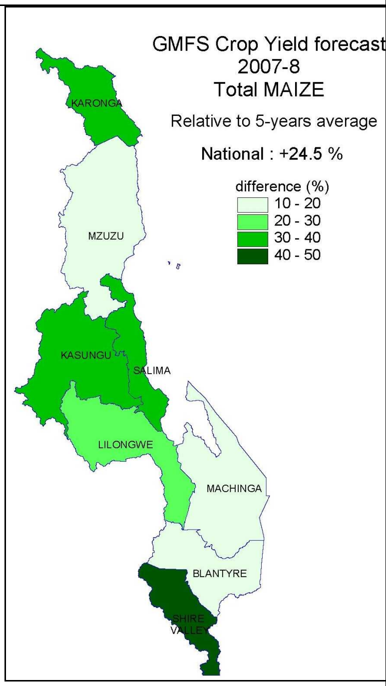



**Figure 31**: Maize 2007-‘08 yield forecasts, ADD and national level: relative difference (%) with 5-years average

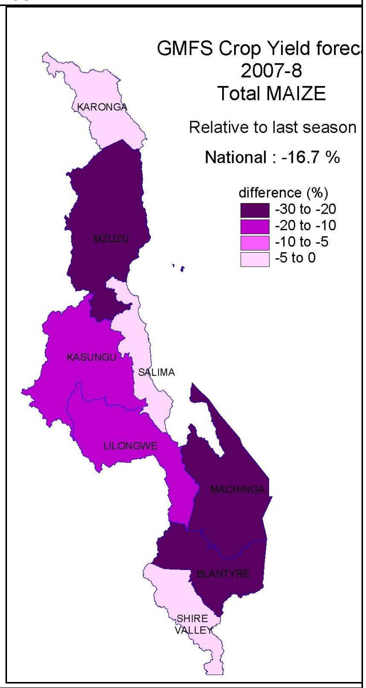



**Figure 32**: Maize 2007-‘08 yield forecasts, ADD and national level: relative difference (%) last season

## SUDAN

Upon agreement with the FMoAF in Khartoum the CA sites focussed on traditional rain fed agriculture. Thus the initial selection, coming from a discussion with the WFP and the Sudanese Meteorological Authority (SMA), with priority to West Darfur, North Darfur, Warab, Kordofan and Gedaref was switched to test sites in West Darfur, Kordofan and Gedaref. The first year (2005) West Darfur and Gedaref were covered. There was a strong delay in the delivery of the product due to, amongst others, late availability of the radar data and unavailability of the field data. In 2006 and 2007 Kordofan was also included and maps were delivered as agreed shortly after the growing season (see Figures 33-35)
In 2009 an improved methodology was tested by reprocessing the Kordofan product of 2007. This reprocessing was also used as an opportunity for knowledge transfer and demonstration of the analysis to the users.

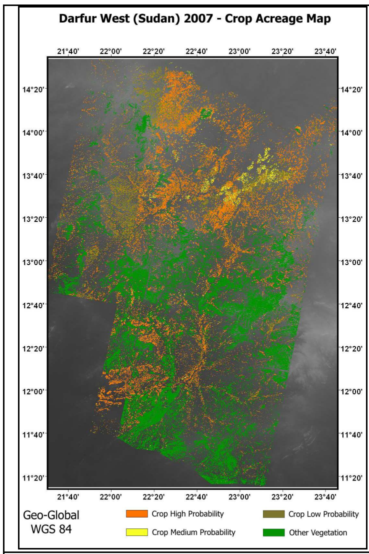



**Figure 33**: Cultivated Area Product for West Darfur for the growing season 2007

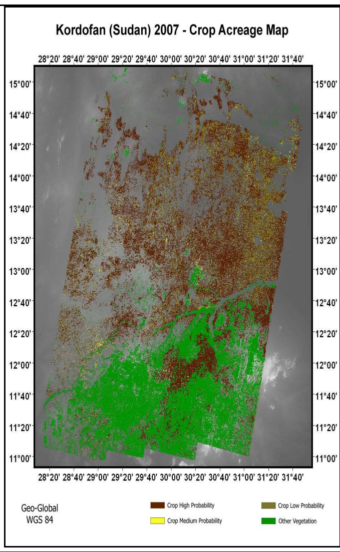



**Figure 34**: Cultivated Area Product for Kordofan for the growing season 2007

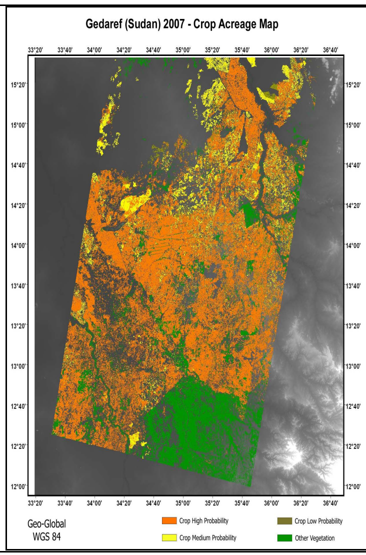



**Figure 35**: Cultivated Area Product for Malawi for the growing season 2007-’08

For this purpose the already produced maps were reclassified and the different results were compared by the end users (see Figure 36).

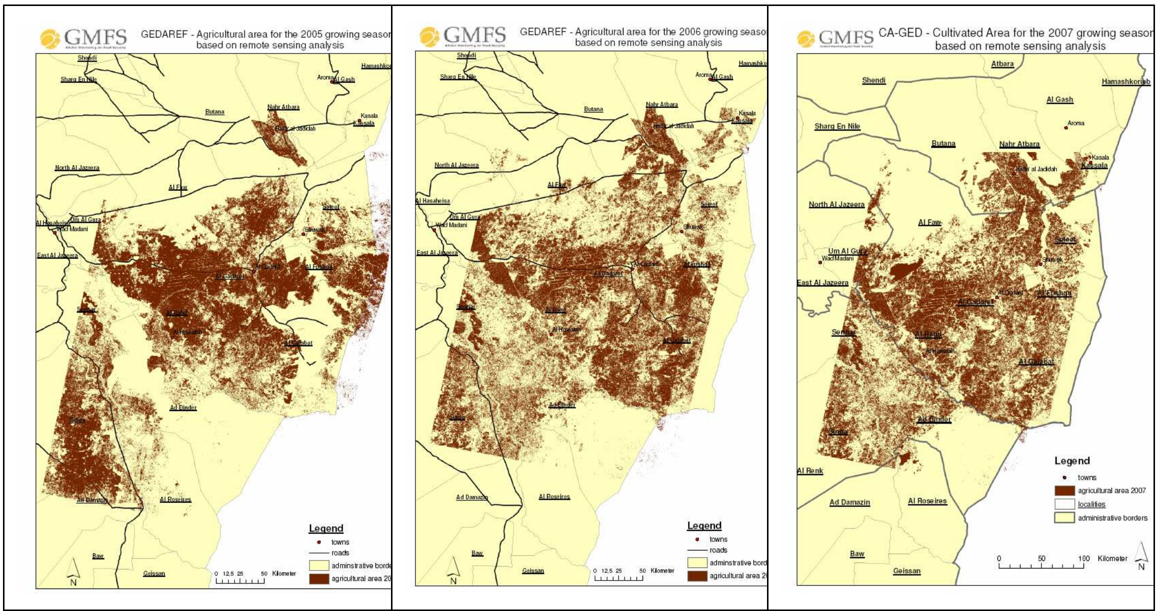



**Figure 36**: CA for 2005-'06-'07 adapted for comparison by end users in Sudan

In 2005, the medium resolution agricultural products (EoC, AFI) were delivered to the Sudanese users. In 2006 the products were delivered at country level. Upon the specific requirements of the Federal Ministry of Agriculture and Forestry in Khartoum, it was decided to focus on the central and northern areas of the country. Therefore in 2007, it was only made for the North of Sudan except the desert (Figure 37 and Figure 38), which covers the major production belt for traditional rain fed agriculture as well as the mechanized schemes in central eastern Sudan.

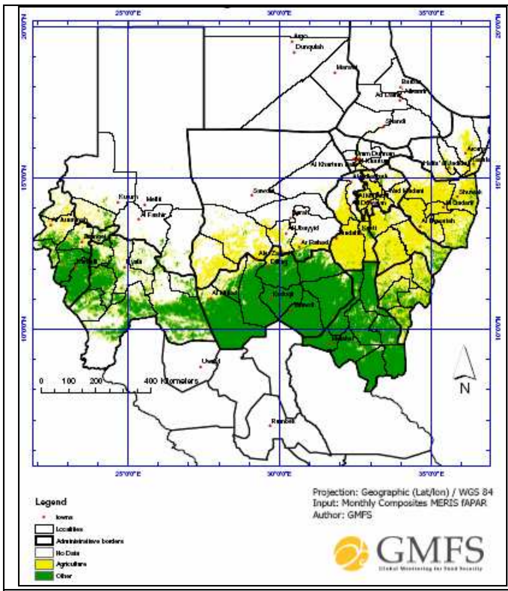



**Figure 37**: Extent of cultivation for the cultivated area in Sudan for the growing season of 2007.

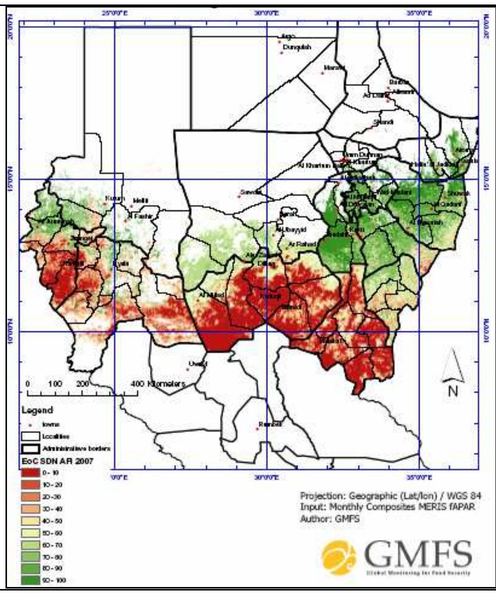



**Figure 38**: Estimated Area Fraction Image for the cultivated area in Sudan for the growing season of 2007

## ETHIOPIA

The CSA requested the GMFS consortium to conduct a feasibility study on agricultural mapping with RS. The delivery of the products was planned for the end of growing season. Figure 39 and Figure 40 show the draft CA for one of the study areas and the draft AFI for selected parts.

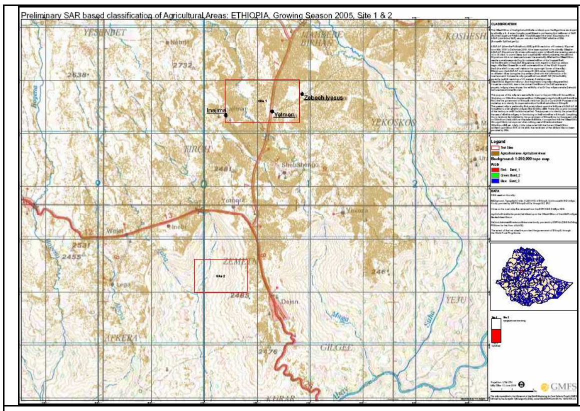



**Figure 39:** Draft cultivated area map for Ethiopia, site 1 & 2.

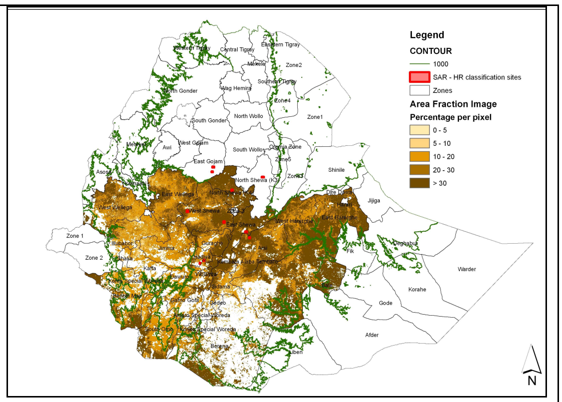



**Figure 40:** Estimated Area Fraction Image for the cultivated area, Examples of selected parts of Ethiopia 2005

To align the project with FAO efforts in Ethiopia, 2006 production was skipped and production of CA, EoC and AFI was restarted for the 2007 growing season.

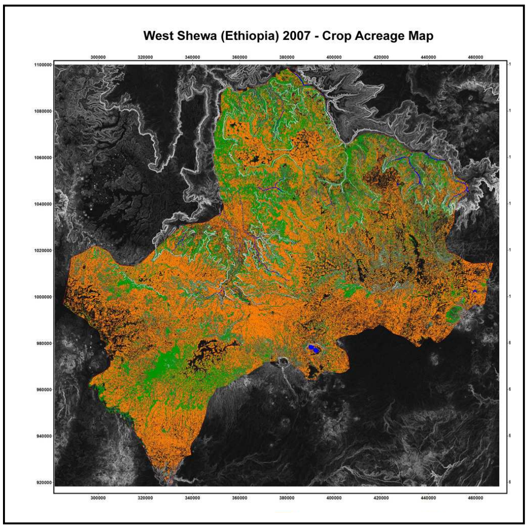



**Figure 41**: Cultivated Area Product for West Shewa for the growing season 2007

During the evaluation meeting early 2008, it became clear that these self-standing RS products could not generate area statistics with the necessary accuracies as desired by CSA. Therefore, it was agreed to deliver to the CSA in 2008 instead of new mapping products, an assessment report on the correlation between GMFS products 2007 and Woreda statistics 2007. Furthermore it was decided to focus the attention of the GMFS partnership on the support of the early warning system at the Disaster Risk Management and Food Security Sector (DRMFSS) of the Ministry of Agriculture and Rural Development (MoARD) of Ethiopia. The following services were provided to the DRMFSS:

- Set up of an operational system to provide DRMFSS with EW data through the standard ftp and email quick look system.
- The historical archive of SPOT indicators and MERIS-FR data were delivered and stored on the server at DRMFSS and computers of the local experts. In order to accommodate users at the regional ministries of agriculture (BoARD), DVDs with the same data were provided to the regional representatives attending the training. During the training the data were also installed at the servers of the National Meteorological Agency (NMA).
- A training was organized to help Ethiopian users understand GMFS EWS and basic data handling.

- An EW Report was compiled, giving an overview to the local experts of possible applications of the low resolution products in support of an operational early warning system.

One of the applications of the LR products for EW was the VPI anomaly analysis. Figure 43 shows the anomaly analysis for the beginning of the growing season 2008.

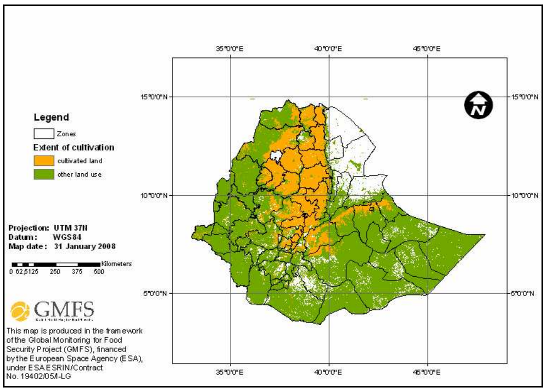



**Figure 42**: Estimated Extent of Cultivation in Ethiopia for the growing season of 2007

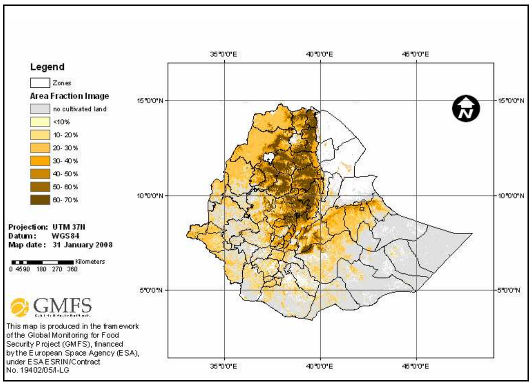



**Figure 43**: Estimated Are Fraction Image for the cultivated area in Ethiopia for the growing season of 2007

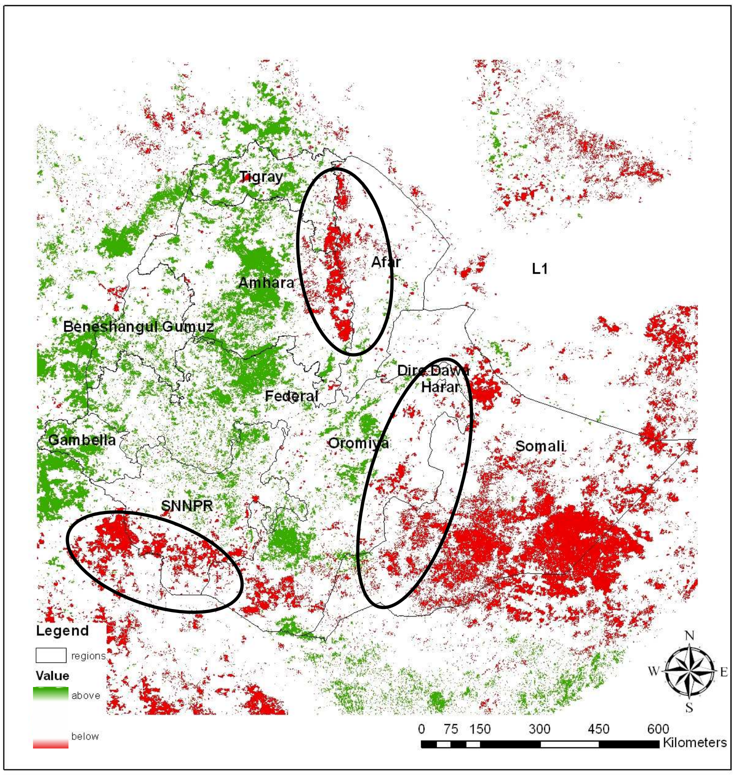



**Figure 44**: Average VPI values for decades 17 18 19 of 2008 for Ethiopia (no agricultural mask or crop mask has been used). Red areas highlight potential late start of the Meher growing season

**MOZAMBIQUE**

The Mozambique services was one of the extension services which started during phase two of the Second Stage. This service was mainly oriented towards Early Warning.

At the start of the service (2007), a preliminary bulletin was made, which contained a number of analyses relating the RS indicators to the ongoing growing season.

After discussion with end users and SADC-RRSU expert during a user meeting /training the report was adjusted in 2008. It contained the following analysis components:

1. Qualitative analysis of the growing season using NDVI /VPI
   - start of the season
   - entire season
2. Mapping start of season by district
3. Analyzing the seasonal behavior of water bodies
4. production estimates using NDVI and /or VPI

Figures 45 to 47 illustrate one of the analyses based on RS indicators: productions estimations.

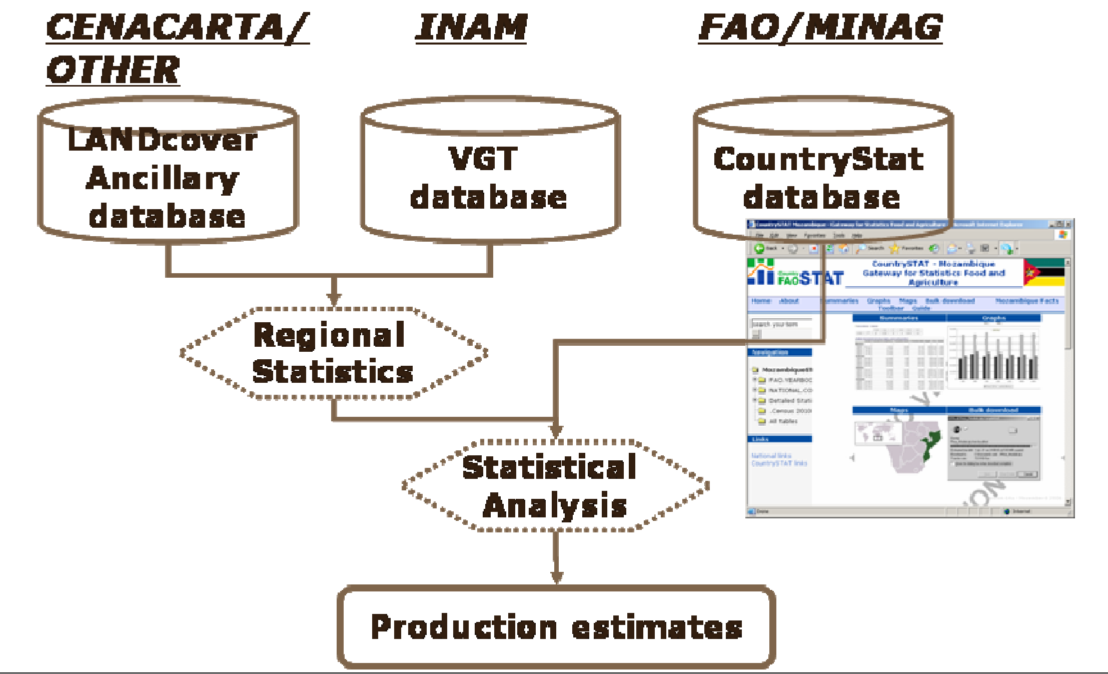



**Figure 45**: Workflow diagram illustrating different steps how production estimates were generated

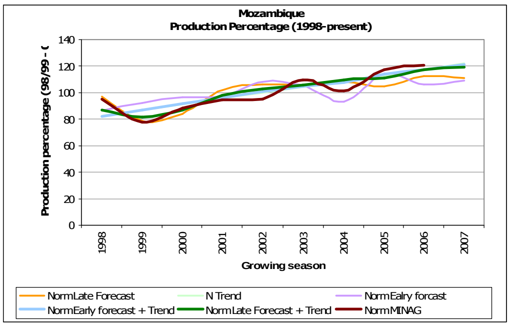


**Figure 46**: Normalized production vs RS estimates

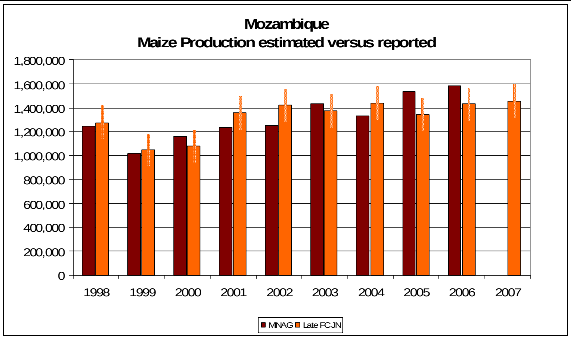


**Figure 47**: RS based Maize production Estimation vs MINAG stats

## Zimbabwe

In Zimbabwe the focus was on agricultural mapping. In the first year (2005-'06), there was a delivery problem with the RS data (MERIS-FR and ASAR WS /AP). Due to this the CA product was not made and EoC was delivered with delays. In 2006-'07, a CA was made for Mashonaland West, Mashonaland Central & East, and Masvingo (Figures 48 and 49). The AFI and EoC were produced at country level (Figure 49 and Figure 50). In 2007-'08 only the medium resolution maps, the EoC and AFI were made.

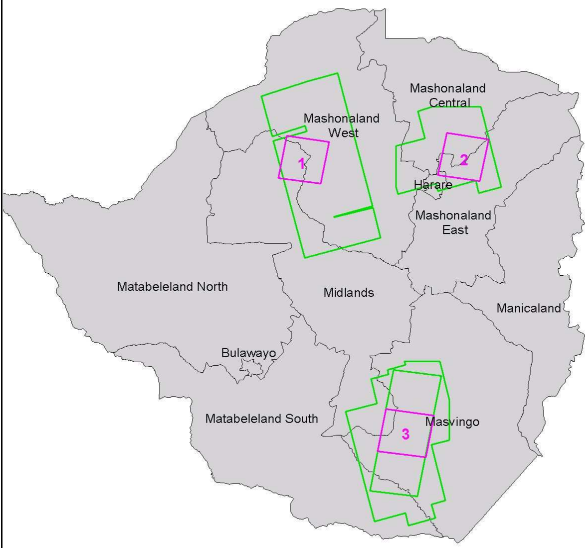



**Figure 48**: Overview of areas in Zimbabwe where high resolution data was acquired for 2006-'07 (SAR – green and SPOT-4 – red)

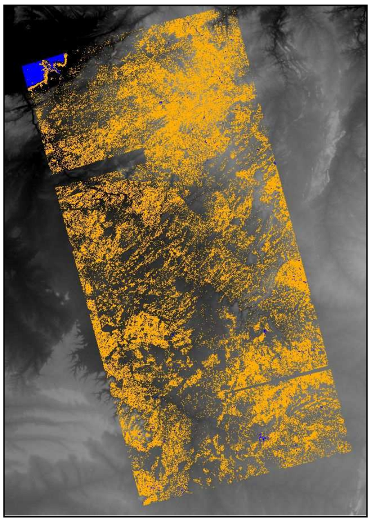


**Figure 49**: Cultivated Area Product for Mashonaland West for the growing season 2006-'07

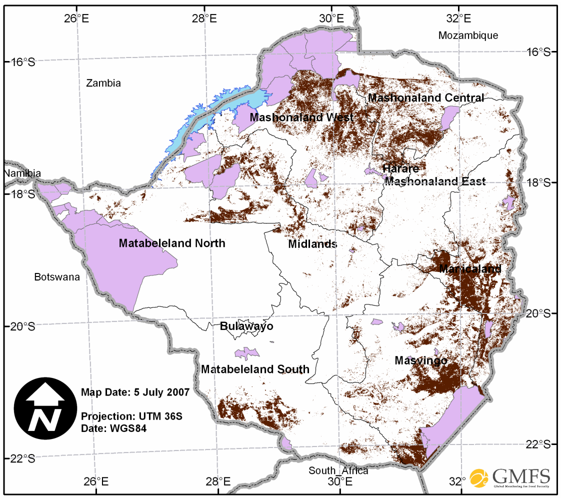



**Figure 50**: Estimated Extent of Cultivation in Zimbabwe for the growing season of 2006-'07.

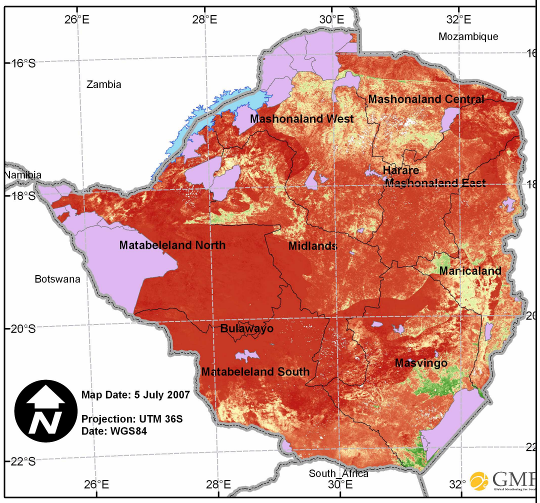


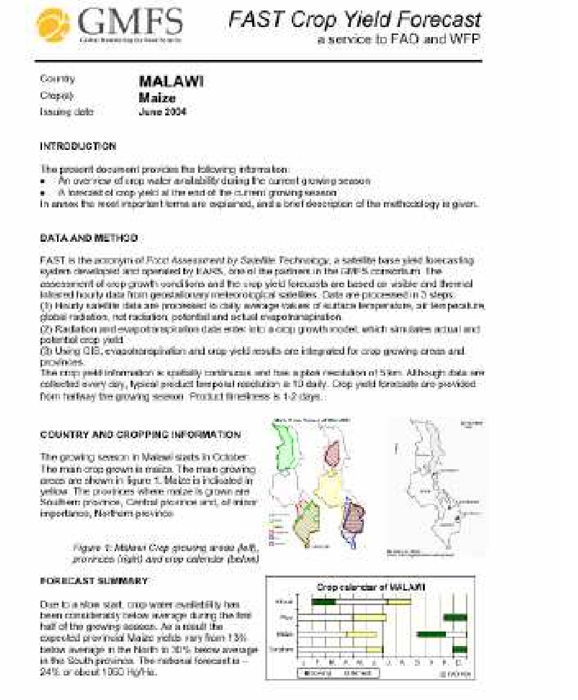

**Figure 51** Estimated Are Fraction Image for the cultivated area in Zimbabwe for the growing season of 2006-'07

## 5.4. Support to Crop and Food Supply Assessment Mission (CFSAM)

CFSAM are carried out by FAO and WFP experts upon the request of countries which face local food emergencies. In most cases there are only 1 or 2 weeks between the decision to undertake a CFSAM and the actual mission. In this very short time span, a support package was delivered to FAO. The content depended on the needs of FAO /WFP and data availability on the country. In most cases the support kit contains geographical information on vegetation status, crop yield forecasts, problem areas, etc.

During Stage 1 bulletins for Zimbabwe, Malawi, CILSS, Mauritania, Senegal, Gambia, Guinea – Bissau, Mali, Niger and Chad were produced based upon MSG data. They included:

- Rainfall
- Relative Evapotranspiration
- Relative evapotranspiration Difference 5 year
- Crop yield deviation 5 year average
- National maps of crop yield deviation from 5 year average
- Tabulated provincial data of crop yield deviation from 5 year average


GMFS

*FAST Crop Yield Forecast*
a service to FAO and WFP

Country **MALAWI**
Crop(s) **Maize**
Issuing date **June 2004**

INTRODUCTION

The present document provides the following information:
- An overview of crop water availability during the current growing season
- A forecast of crop yield at the end of the current growing season

In annex the most important terms are explained, and a brief description of the methodology is given.

DATA AND METHOD

COUNTRY AND CROPPING INFORMATION

FORECAST SUMMARY



**Figure 52:** Report for FAO / WFP on Maize in Malawi

The bulletin for Malawi in June 2004 is shown as example in figure 52.

As from Stage 2 on, the package contained a compilation of geographic information on vegetation status, crop yield forecasting, production data, overall environmental conditions and problem areas, as per best information available at the time of writing. During Stage 2 reports were delivered for Zimbabwe, Malawi, Sudan, Ethiopia, Lesotho and Bolivia. The figure below (Figure 52) is an example of a map produced for the CFSAM in Zimbabwe.

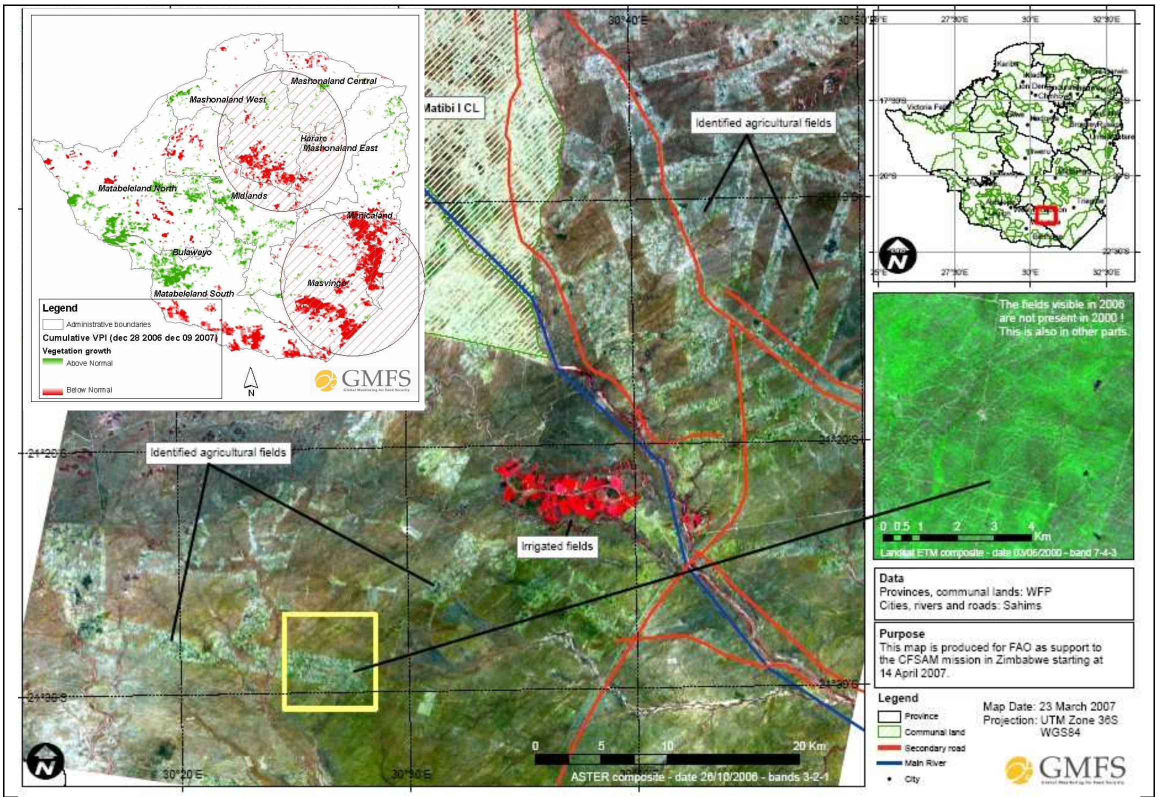



**Figure 52**: GMFS map for as part of the CFSAM package for Zimbabwe. The map consists of a VPI hot spot analysis of the growing season in Zimbawe and compares a high resolution ASTER image of 2006 with a LANDSAT image of 2000 in order to detect new or lost agricultural areas.

# 6. USER ASSESSMENT

## 6.1. Actual Benefits of GMFS products and services

### 6.1.1. International users

International users were mainly involved in the EWS. The VPI and fAPAR information was not integrated in their services as such, but was compared with other approaches to provide an overall assessment of the productivity throughout the season. EWS products were analysed to serve as input for the planning phase of the CFSAM. Although the products were not used in the CFSAM reports as such, CFSAM experts expressed their appreciation of the products.

### 6.1.2. Regional centres

As for the international users, the main impact of the EWS was to provide a alternative to other sources. In this sense it increased confidence in the final assessment. This was very important as the results went into reports which were used to support decision making processes. It is very difficult to say how critical the GMFS inputs were in terms of the end results.

AGHRYMET noticed that, for the Sahel, the product was more appropriate when the crops were already well developed. For next year, AGHRYMET is planning to assess the accuracy of diverse vegetation indices including VPI, for coastal humid countries in West Africa, by collecting field data.

### 6.1.3. National users

In all countries the close relationship between the end users and the GMFS consortium was considered as a direct benefit. The fact that during Stage 2 the consortium subcontracted local staff in the countries or at the regional centres improved this relationship. Through these contacts the consortium was able to meet user demands even more. As an example the director of CSE put forward the positive impact of GMFS on the role of CSE in the framework of Food Security Monitoring in Senegal. Delivery of RS data over the weekend done by the GMFS consortium strengthened the position of CSE in Senegal as a leading trustworthy and efficient Food Security agency enabling to bridge the gap between decision makers and farmers. It also clearly demonstrated the added value of GMFS.
Thanks to the efforts of the regional coordinator at the SADC-RRSU it became possible to perform fieldwork in Zimbabwe and organize several user meetings in Lilongwe, Malawi. Presentations during these meetings triggered discussions about problem solving, complementarity, integration and resulted in a series of recommendations to improve GMFS services and products and their integration as part of the national food security assessment activities.

## 6.2. User Statements

- The approach of GMFS is a demonstration of the precision and timeliness of forecasting that can be achieved with minimal input. The timeliness of the forecast of national cereal production is unrivalled by any of the other currently implemented approaches. (*Review of support to food security systems in Ethiopia 2008 by Wolfgang Göbel)*
- GMFS is about enriching current information sources by using a variety of sources and getting timely information for a better early warning system to better manage cultivated areas. *(FAO)*
- GMFS provides us with a series of products which enable us to compare and validate other existing CSE products. As a result the tool "Suivi de la Campagne Agricole (SCA)", developed by CSE to monitor Food Security in Senegal now is more robust. *(CSE, Senegal)*
- The funding of a national GMFS expert based at CSE and working in close collaboration with the regional GMFS officer enabled to significantly improve (a) integrative activities at CSE, and (b) the development of derived products. *(CSE, Senegal)*
- Knowledge transfer through training and capacity building (workshops and "on the job") enabled us to contribute to producing the CY product and will allow us in future to locally produce the EoC and VPI product. *(CSE, Senegal)*
- It is acknowledged that GMFS products have a potential for cost-cutting in activities of crop monitoring, but there is a need to put monetary figures on the differences between GMFS crop assessment techniques and traditional crop assessment methodologies to show the advantages. *(MoA, Zimbabwe)*
- The VPI and agricultural mapping products are value added information products used by WFP amongst other currently available information products, which WFP strive to bring together, usually in a qualitative manner, through the "convergence of evidence" process *(WFP Zimbabwe).*

- The "convergence of evidence" principle was made possible due to the variety of information sources available including GMFS. This is an important impact of GMFS. It is recognised as a key aspect to evaluate the growing season. This nevertheless requires additional planning and coordination of the agriculture information efforts throughout the season. Resources need to be allocated to achieve this. *(MoA, Zimbawe)*
- We have a good perception of the potential of GMFS products and how they can contribute to improve cost-effectively existing FS assessments, nevertheless it is strongly felt that currently not enough capacity is present (GIS and RS) to properly use the GMFS products. *(FMoAF, Sudan)*
- The impact of GMFS products and other EO products for monitoring agriculture would improve if the MoAFS is convinced to set up a budget to implement the use of these products nationally beyond GMFS and other technical projects support. *(MoAFS, Malawi)*
- RS is a wide and important subject, so that it is not possible to cover the subject in a week. Thanks to the workshop, we are now familiarized with the subject. *(MoARD, Ethiopia)*
- The training is directly related with my present task. I am now working as a crop specialist. It will help me for strengthening my work. It is a major input for Early Warning activities. *(MoARD, Ethiopia)*
- Although data is not yet fully used in the day to day operational systems it has been used as a reference tool. In order to proceed from being a reference tool to an operational tool, transfer of transparent methods for analyzing the growing season is crucial. *(INAM, Mozambique)*

# 7. SATELLITE DATA

## 7.1. Type of Satellite data used for each type of services

*Table 7: Overview of RS data for GMFS services.*

| Service | Country | 2003-2009 |
|---|---|---|
| **Early Warning** | | |
| | **Africa** | - SPOT-VGT 10-daily NDVI images since 1998<br>- MERIS Reduced Resolution 10-daily and monthly (RR) (since 2006) |
| **CFSAM** | | |
| | **Malawi, Mozambique, Zambia; Swaziland; Zimbabwe; Ethiopia; Sudan; Mali; Niger and Bolivia.** | - SPOT-VGT 10-daily NDVI images since 1998 (for the SK and VPI product)<br>- daily METEOSAT images, 30 min interval (2000-'05, FAST DATA)<br>- 5 Aster Data over Zimbabwe<br>- SPOT 4 HR data for Zimbabwe<br>MERIS Full Resolution imagery monthly composites for Sudan. |
| **Agricultural Mapping** | | |
| | **Ethiopia** | - ASAR data WS, IM and AP<br>- ALOS PALSAR (coherence)<br>- MERIS-FR composites<br>- MODIS 16 day composites<br>- SPOT-2 /4 data<br>- AWIFS scenes<br>- LISS-III |
| | **Malawi** | - ASAR-AP and IM data<br>- ALOS PALSAR<br>- MERIS-FR composites<br>- SPOT-2 /4 data<br>- ALOS PALSAR Fine Beam Single Polarisation frames |
| | **Sudan** | - ASAR-AP /IM<br>- MERIS-FR data<br>- SPOT-4 data<br>- ASTER scenes |
| | **Senegal** | - ASAR data WS and AP<br>- MERIS-FR composites<br>- SPOT-4 data- |
| | **Zimbabwe** | - monthly fAPAR MERIS-FR composites<br>- FORMOSAT scenes |
| **Yield Estimates** | | |
| | **Malawi** | - NOAAGAC NDVI data, obtained from FAO<br>- SPOT-VGT, VPI<br>- MERIS-RR |

| | | |
|---|---|---|
| | **Senegal** | - NOAA GAC data, obtained from FAO<br>- SPOT-VGT |

- Additionally Landsat 5 TM and Landsat 7 ETM+ multispectral archive images acquired between year 1999 and year 2000 were used to produce a baseline for the CA product.
- Each MERIS composite used around 18 MERIS-FR Scene

## 7.2. Links to sentinels

One of the risks for GMFS services is the unavailability of RS data. In order to reduce this potential risk as much as possible the service are developed to be able to support alternative data sources. This sensor independent approach will assure the integration of future missions and systems like Sentinel and PROBA-V.

Sentinel-1 and -2 will provide part of the SAR and multi-spectral data required for crop mapping. It is expected that these sensors will improve the reliability of the maps, because the sensor's constellation will strongly increase the temporal and spatial resolution. Potentially solving some of the problems agricultural mapping is currently facing. The low resolution Sentinel-3 can fulfil part of the data requirements for the EWS, with its frequent revisiting time.

# 8. MAJOR ACHIEVEMENTS

During the two stages of GMFS the value of RS information on continental and regional scale for crop monitoring was demonstrated.

Thanks to the EWS good working relations were established with the regional centers. This service provided the centers the necessary reliable access to early warning data sets and capacity building, to support their decision makers and the national early warning units.

Throughout the project this relationship was strengthened through various other services and the submission of joint proposals.

One of those extra services was the support to set up operational EW processing chains based upon the ESA DDS. In the three regional centers ESA installed a DDS whereas the consortium provided the necessary training and tools to maintain the DSS in an operational way.

At national level GMFS contributed to stakeholders frameworks with the introduction and the integration of services into the common work flows. GMFS was able to deliver demonstration cases and identify bottlenecks and weaknesses of RS for agricultural applications.

## 8.1. East Africa

GMFS services in East Africa were implemented in Sudan and Ethiopia.

In Sudan initial contacts were established in 2005 with the WFP-VAM unit in Khartoum. In July 2007 a Memorandum of Understanding was signed between GMFS and the Undersecretary of the FMoAF, lasting until March 2009.

For Ethiopia GMFS executed, in collaboration with FAO and the CSA, a pilot study in the 2005-'06 growing season. This collaboration continued as part of the GCP /ETH /71 Support to Food Security Information System (SIFSIS) project of FAO and EC in 2007 and 2008. In 2009 an SLA was signed with the newly formed DRMFS, part of the MoARD.

Between 2005 and 2009 both countries were at least completely mapped twice with the medium resolution EoC product. About 650.000 km² in Sudan and Ethiopia were mapped with the high resolution CA product. For the processing of these Agricultural Mapping products several hundreds of satellite data have been processed, geo located and analyzed. As one of the biggest satellite data processors during the past years GMFS contributed to strengthen the integration of RS and GIS at the mentioned government institutions.

In addition to the continuously production and provision of the EWS GMFS provided advanced training for ground truthing field work, GMFS- and satellite data handling and the integration of those products into the daily work of up to 60 Ethiopian and Sudanese government experts. GMFS also established an extensive data cataloguing and dissemination infrastructure by means of GeoNetwork, internet, ftp transmission and ESA DDS system.

## 8.2. Southern Africa

In Southern Africa GMFS services were provided to stakeholders in Malawi, Zimbabwe and Mozambique.

The Malawi service already started in 2004. For 2004, 2005, 2006 and 2007 agricultural mapping products covering almost the complete country were made. At first these were based upon SAR data, later on, a combination of field work, HR SAR, HR optical and MR data. The field work started off to collect data in the central part of Malawi but was extended to the whole country. As such the Consortium now has a very good dataset to support future analyses.

The delivery of the 2007-'08 yield forecast /estimates before the last round of production estimates in Malawi, was highly appreciated by the department of Meteorological Services in Malawi..

In close collaboration with the SADC-RRSU two early warning training sessions were held in Mozambique to support the MINAG and INAM experts. During these sessions it became clear that there was a great demand and interest in the RS based yield prediction methodology. For 2007 a report based upon this method was provided to the local experts and it was used in support of national yield predictions.

In Zimbabwe the execution of the field survey and the provision of an EoC product triggered the request of the local FAO office in Harare for more collaboration and knowledge transfer.

## 8.3. West Africa

West African services were mainly focused on Senegal, and as for Malawi the good relationship with the local partner in Senegal was already established during the First Stage of GMFS. Throughout the two stages of GMFS EWS and agricultural mapping services were provided to the stakeholders in Senegal.

With respect to the EWS, the VPI is currently being used by CSE as a cross comparison for the VCI. The data is merged into bulletins which are used to support decisions made during the decadal meetings to follow the growing season. Jointly with the regional coordinator for West Africa a method was developed to use VPI for the timely assessment of specific risks related to the three subsequent crop growing stages.

For 2005-'06-'07 agricultural mapping products covering almost the whole of Senegal were validated based upon field work campaigns and provided to the stakeholders. CSE wants to elaborate further on this approach and as such have requested for further support and knowledge transfer on the agricultural mapping product.

# 9. FUTURE OUTLOOK

The present GMFS framework was and is focusing 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 is aiming at establishing services 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.

Policy makers and operational users at the various administrative levels do need reliable and continuous information sources. Advanced crop information derived from EO data does contribute to their need for information on the production, management and distribution of agriculture.

To reach the ultimate goal to identify and assess food insecure areas and populations and to quantify their level of vulnerability with particular emphasis on food security, does need more than only innovative and robust processing chains. Assessing the information needs, being able to develop a technological solution and providing services is a first step, the second step is ensuring know how transfer, following up the actual integration of the services into the day-to-day frameworks and being fully involved into the institutional networks. This is a necessity to really bring the solutions to the user institutions.

In this respect the particular emphasis of GMFS Stage 3 is to transfer the elaborated GMFS service portfolio to a fully sustainable operational context and to:

## 9.1. Transfer services to operational structures

Future GMFS services will be focussing on integration of the services in the users operational structure and knowledge transfer.
The GMFS partnership already initiated the process of involving more and more the African partner institutions. The active role of the regional centres (RCMRD, AGRHYMET, SADC-RRSU) in Stage 2, established formal collaborations with the relevant legally mandated organizations, will be strengthened and there will be more emphasis put on knowledge transfer in support of the service..

## 9.2. Maintain services and benefits to users

This requires a revision of the given capacities and infrastructures at the user institutions on the one hand and a revision of the appropriateness and usability of the services on the other hand. On basis of the lessons learned, Stage 3 will better address the actual requirements, strengthen systematic know how transfer and link up with complementary development initiatives.

## 9.3. Set up access mechanisms for operational EO data provision structures

During GMFS Stage 2, ESA DDS network and the UN GeoNetwork nodes were used in support of the services. This needs to be enhanced further into a more dense network of nodes in Africa. Another important aspect is to arrange access to other data centres and providers. As various GMFS partners do maintain agreements with international EO data providers the GMFS framework should benefit from this relations.

## 9.4. Achieve sustainability via access to operational funding

Beyond the principle requirements of robustness of the processing technology, reliability of data acquisitions, accurateness of the products and timeliness of the output information, another basic requirement for operationability is the insurance of financial continuity.

GMFS services are targeting institutional users in developing countries. Since these users are mainly supported by development aid, it is currently highly unlikely that they will be able to finance the service (through normal service contracts) at the end of the project.
As such the consortium will need to look for relevant international, European, national and local budget lines to ensure future production of the users services.

Due to the non-commercial nature of the GMFS services, commercial continuation of the activities, were commercial companies provide the core funding, is highly unlikely.

However, the insurance and re-insurance sector might be potentially a funding source for GMFS alike services. Currently there is a trend ongoing whereby larger agencies such as the World Bank, USAID and the World Food Programme finance indicator-based services to speed up the compensation payments for farmers in case of calamities. WFP's Hunger Insurance project and ILRI's Livestock Insurance Programme (funded by USAID) fall under this category. In Europe there is quite some scepticism on this indices based insurance due to the uncertainties associated with the remote sensing methods. Potentially the re-insurance sector might be prepared to pay for this type of service given it requires information which is more generic in nature. The partnership will investigate these possibilities by contacting and meeting with the relevant organizations.

Next to this the GMFS partnership will actively contact and build awareness with the potential funding agencies. Examples are: the World Bank, The African Development bank, the EC AIDCO and AGRI, JRC (intermediate to AIDCO and DG-AGRI), the national development agencies (Flemish/Belgian cooperation, GTZ, SDC, Italian development cooperation), the UN system (IFAD, IFPRI and others).

Continuity of parts of the GMFS activities might also be possible through the following opportunities:

**EC National delegations and financing**: In specific cases, and on a country-by–country basis, the EC finances food security monitoring activities. For example the EC delegation in Ethiopia will start up a project called "Support to Food Security Information System". The project is implemented by the FAO country office for Ethiopia with which GMFS worked closely together. Similar programmes are implemented in other countries. GMFS potentially could contribute to these projects.

The **GMES Global Component** may provide another opportunity for sustaining the 'core' services of GMFS. The GMES initiative aims at establishing a European Capacity for Monitoring Environment and Security. Within its global component Food security, crop and agricultural monitoring is listed as one of the priorities. In addition, the Lisbon process started in 1997, aims at setting up a GMES for Africa Initiative which should be driven by the African Stakeholders. AMESD (African Monitoring for Environment and Sustainable Development) is said to be a precursor of the GMES for Africa initiative. The current time table for GMES Africa aims at having the principle of GMES Africa approved during the Sirte Summit end of 2010. The partnership will closely follow-up the process and closely link with the AMESD teams.

**ACP funding.** Various funding opportunities through the ACP (African, Caribbean and Pacific Group of States) secretariat will come-up. In the AU-EU framework of cooperation, joint proposals will be formulated.

**EC core and downstream services:** What concerns the current LMCS and ERCS it is understood that the first operational funding for the core services may be forthcoming in 2014. Some GMFS services could be part of the ERCS (in terms of monitoring products for of slow onset disaster) or LMCS (in terms of crop yield and areas estimates, as is currently subject of the GEOLAND-2 Crop-CIS, which is said to be a precursor of LMCS). Both pathways will be explored and examined.