AGRICAB

A framework for enhancing EO capacity for agriculture and forest management in Africa

FINAL PUBLISHABLE SUMMARY REPORT

Developing increased EO capacity

for better agriculture and forestry management in Africa

Final Publishable Summary Report

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EXECUTIVE SUMMARY

The project entitled "A FRAMEWORK FOR ENHANCING EO CAPACITY FOR AGRICULTURE AND FOREST MANAGEMENT IN AFRICA, AS A CONTRIBUTION TO GEOSS", or AGRICAB in short, aimed at bringing together relevant European and African institutions, in innovative partnerships, to build a sustainable and comprehensive framework with the following objectives:

- To assure **sustained provision & availability of Earth Observation (EO) satellite data** and further facilitate their exploitation through **free software** and direct user support.
- To develop **integrated applications** with monitoring and predictive models on crop production, livestock and forest systems.
- To stimulate the wider uptake of these EO techniques.

The continued **reliable and low cost delivery of EO data** and derived products was achieved through online platforms and GEONETCast, targeting different sectors (public, academic & private) and thematic fields (meteorology, agriculture, environment) on the African continent. The successful uptake of part of AGRICAB's data flow into the flagship EU programme on Earth Observation, Copernicus, and its operational Global Land service, further ensures sustainability. AGRICAB supported the expansion of the network of GEONETCast ground reception stations with installations in Tunisia, Kenya and Burkina Faso. For the extension of related **free software**, efforts were dedicated to facilitating the data-exchanges between them, to the automated processing of time series and to updating the tools to new satellites & sensors (e.g. PROBA-V, Landsat8, Meteosat10) and data sources.

In addition to dedicated web portal for openly sharing training materials, a **time series viewer** web service was developed for demonstration purposes. This web service relied on a prototype platform that uses novel Big Data techniques to digest large sets of EO data, developed by VITO with funding from the European Space Agency. This viewer not only drew particular attention, it is also set to be further developed into a fully operational service, allowing the visualization and presentation of the maps and charts on a user-customizable web page.

The majority of AGRICAB's efforts were devoted to the research and implementation of applications (called use cases) at national levels. On **rain fed crops** in Kenya, Mozambique & Senegal, these use cases focused on crop modelling and yield forecasting, early warning and crop mapping and on agricultural statistics. For **irrigated crops** in Tunisia and its neighbours Algeria and Libya, EO was used for better quantification of irrigated perimeters and for water balance modelling. In Niger, Senegal and Kenya, with the latter extending into the Greater Horn of Africa, the **livestock** use cases concentrated on the estimation of fodder biomass production and on the prediction of, and insurance against, livestock mortality. Last but not least, the **forest & fire management** use cases in South Africa, with extensions into the wider Southern African Development Community (SADC) region, dealt with mapping woody cover and biomass in savannahs and woodlands and understanding fire regimes in these biomes. African ownership of the developed solutions, with the uptake in the Senegalese ministry of Agriculture as prime example, was the objective.

During the AGRICAB project implementation, a total of **47 hands-on training workshops** were organized, with focussed national or broad international scopes. These workshops, along with a dozen stakeholder consultation meetings, helped to enhance the existing scientific and technical capabilities of local experts and institutions, to raise the awareness of decision makers on the potential added value of EO and to ensure that the applications met actual needs in sustainable management of agriculture and forest resources (for e.g. food security).

The institutional impact of AGRICAB is most visible in the form of improved national structures, networks or partnerships and the increase of African involvement in AfriGEOSS – the pan-African coordination initiative of the global Group on Earth Observation (GEO).

The results of the AGRICAB project were presented at approximately 40 conferences and seminars, taken up in higher education and discussed in a handful briefing meetings with African Union policy officials. In total eight (8) peer-reviewed publications were published or are in press, with at least five (5) more under review. This leaves the partnerships, developed within this project, hungry for exploring new horizons.

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ACRONYMS

AARSE	African Association of Remote Sensing of the Environment
ACF	Action Contre la Faim
AMESD	African Monitoring of the Environment for Sustainable Development
ANPP	Aboveground Net Primary Productivity
AU	African Union
CAAPD	Comprehensive Africa Agricultural Development Programme of NEPAD
CGMS	Crop Growth Monitoring system
CST	CGMS Statistical Tool
CV	Coefficient of Variation
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EDF	European Development Fund
EO	Earth Observation
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAO	United Nations Food and Agriculture Organisation
fAPAR	Fraction of Absorbed Photosynthetically Absorbed Radiation
FP	Framework Programme
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GIS	Geographical Information System
GMFS	Global Monitoring for Food Security project
IBLI	Index Based Livestock Insurance
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IGARSS	International Geoscience and Remote Sensing Symposium
IGAD	Intergovernmental Authority on Development
JAXA	Japanese Space Agency
JRC	European Commission's Directorate General Joint Research Centre
LAI	Leaf Area Index
LiDAR	Light Detection And Ranging
LULC	Land Use/Land Cover
MARS	Monitoring Agricultural ResourceS unit of the JRC
MESA	Monitoring of Environment and Security in Africa
MODIS	MODerate resolution Imaging Spectroradiometer
MSG	Meteosat Second Generation
NDVI	Normalized Difference Vegetation Index
NEPAD	African Union's New Partnership for Africa's Development
NGO	Non-Governmental Organization
NWSAS	North-Western Sahara Acquifer System
OGC	Open Geospatial Consortium
PROBA	PRoject for On-Board Autonomy
RMSE	Root Mean Square Error
SADC	Southern African Development Community
SAFNet	Southern African Fire Network
SAR	Synthetic Aperture Radar
SDI	Spatial Data Infrastructure
SPIRITS	Software for the Processing and Interpretation of Remotely Sensed Image Time Series
SPOT	Système Pour l'Observation de la Terre
TAMSAT	Tropical Applications of Meteorology using SATellite
UN	United Nations
UN-ECA	UN Economic Commission for Africa
VCF	Vegetation Continuous Field
VGT	Vegetation instrument
WFP	United Nations World Food Programme
WOFOST	WOrld FOod STudies

1 AGRICAB context and objectives

1.1 Context

With ever increasing global demands on the Earth's resources, a greater ability to understand global change and to predict how natural systems will respond to human activities and management decisions becomes more vital every day. This is particularly the case for many countries in Africa, where more than 60% of the people still depend on very diverse, mostly small-scale agriculture for their livelihood. The impact of recent food crisis has underlined this vulnerability, with large price volatility in small import-dependent countries, in particular in sub-Saharan Africa. Climate change will have important impacts, with expected rising temperatures and variability in rainfall, likely to cause many regions in the continent to suffer from droughts and floods with greater frequency and intensity, reducing the yields of primary crops (e.g. corn, wheat and rice) and affecting food security. On the other hand, tree cover plays an important role in a wide range of ecological processes and also has strong implications for biodiversity conservation, energy security, food security, and climate change in Africa. The effects of human activities (e.g. biomass burning) in savannah and woodland are likewise insufficiently understood, while it is clearly essential for carbon storage.

Sustainable management of agriculture and forests in Africa requires information that is both reliable and fit-for-purpose. Earth Observation (EO) is an important tool to better monitor, understand and manage these natural resources, as it can provide large-scale, recurrent information on current vegetation conditions and dynamics (for monitoring and early warning), map tree cover and crop areas and forecast crop and forage biomass yields through advanced models. The advent of new platforms and sensors, with challenges in ever increasing data volumes and access, innovative software tools and advances in analysis and modelling techniques, are all clear indications of the need to continuously reinforce capacities. For sustainability and effective use of the monitoring and forecasting techniques, it is vital that African institutes improve their existing capacities in integrating EO into their own daily work in order to, in turn, adequately support the management and policy actions in their countries.

The focus of the AGRICAB project entitled **'A Framework for enhancing earth observation capacity for agriculture and forest management in Africa as a contribution to GEOSS'**, was therefore to integrate European and African research capacity in the use of EO technology for agriculture and forestry. Apart from the sustained provision of EO data and derived information, AGRICAB aimed at a continued and better exploitation of remotely sensed data. Innovative partnerships between African and European institutes were set up in order to integrate EO, agricultural statistics and predictive modelling in agriculture and forest management in several focus countries.

1.2 Objectives

The AGRICAB project aimed at building a sustainable framework for enhancing the already existing African capacities in the use of EO for improved management of agriculture and forest resources, as a contribution to the global Group on Earth Observation's System of Systems (GEOSS).

To achieve this, the project brought together relevant national and international organizations, such as satellite data providers, research institutions, capacity builders, operational practitioners and governmental decision makers, in innovative partnerships.

To ensure sustainability of the reinforced infrastructure, human and institutional capacities, AGRICAB focused on the uptake and African ownership of the developed applications, with extensive consultation of national stakeholders and open collaboration with many other initiatives.

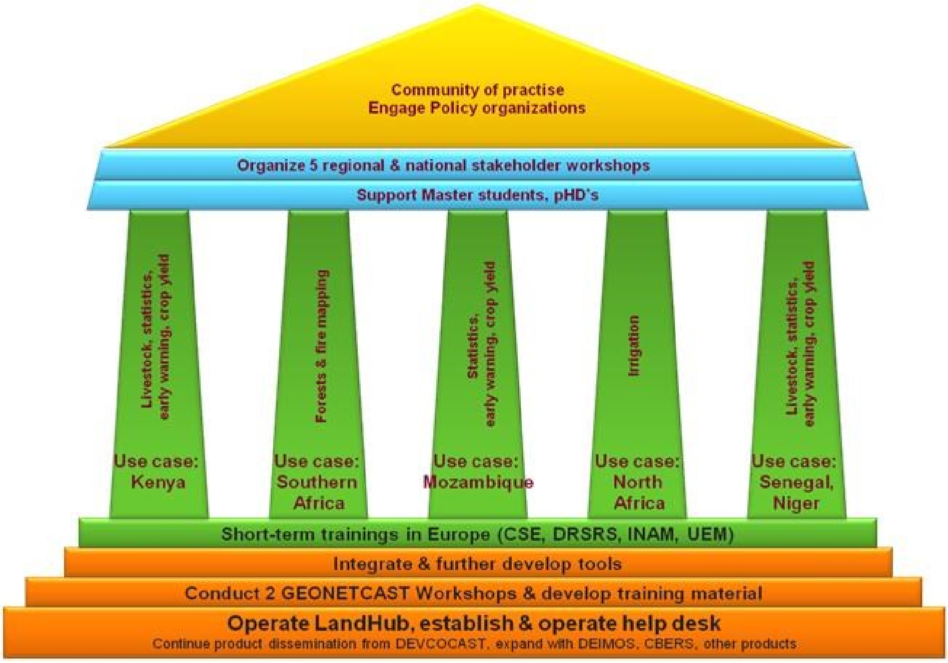


Figure 1-1 The AGRICAB concept with data flow and tools as foundation

The AGRICAB framework was built around the following components and objectives (Figure 1-1):

A. To **assure sustained provision & availability of EO satellite data** and facilitating their exploitation through free & open source software solutions:
   - Following the evolutions in satellites, sensors (e.g. PROBA-V, Landsat-8) and data production services (e.g. Copernicus).
   - Relying further on GEONETCast satellite broadcast and online data access, combined with access to local data source (e.g. official crop statistics, meteorological data).
   - Bringing existing free software together in a comprehensive set, focussing on simplifying the data exchange between them and the exploitation of time series.

B. To develop **nationally-focussed, integrated "use cases"** or thematic applications, with monitoring and predictive models on both rain-fed and irrigated crop production (status, yield, and area), livestock and forest (incl. fire) systems and adapted to local conditions.
   - Emphasis on the exchange of knowledge in bilateral (twinning) partnerships and African ownership at national level.

C. To **stimulate the wider uptake** of EO techniques by organizing a large number of workshops and establishing a pan-African "community of practice"
   - Aligned with national stakeholder needs and train national teams, engaging policy and supporting higher education (for sustainability)
   - Ensuring uptake and outreach of the national efforts to wider regional and continental levels and finally, the global GEO community.

1.3 A growing global partnership

Initially, AGRICAB was inspired by earlier successes of GEONETCast, the global broadcast and exchange of EO data via telecommunication satellite, and EUMETCast, the EUMETSAT-operated component of GEONETCast covering Europe, Africa and the Americas. African examples include:

- PUMA (2001-2005), with pilots in the use of meteorological satellites, and its successors AMESD (2007-2013) and MESA (2013-2017) respectively adding environmental and climate services, each relying on EDF development funding, that pave the way for the GMES and Africa initiative.
- The R&D funded FP6-VGT4Africa project (2005-2007), that can be considered as one of the pioneers of the extension of GEONETCast to vegetation, agriculture and food security domains through the dissemination of SPOT-VEGETATION data and FP7-DevCoCast project (2008-2011) that focused on reinforced GEONETCast-related capacities on three continents (Africa, South America and Asia) and underlined the versatility of GEONETCast (adding e.g. African data sources).

The project was furthermore rooted in the ESA-funded Global Monitoring for Food Security (GMFS, http://www.gmfs.info) project, with strong focus on operational food security applications in support of national agriculture policy.

In addition to GMFS, AMESD and MESA, which partly ran in parallel to AGRICAB, the project collaborated with many national and international organizations, projects and initiatives. A few examples:

- Various national ministries and departments in agriculture, forestry and environment, acting as key stakeholders providing requirements and framing, as well as directly participating in the implementation of AGRICAB's applications and training.
- The sister projects E-AGRI (http://www.e-agri.info) and SIGMA (http://www.geoglam-sigma.info), both funded through EU-FP7 and the latter being the main European contribution to the Global Agriculture Monitoring of GEO, called GEOGLAM.
- The North West Sahara Acquifer System coordination mechanism (NWSAS)
- The South African Fire (GOFC-GOLD's SAFNET), LULC and SA-GEO networks
- The European Commission's Joint Research Centre, in particular its unit on agriculture monitoring with remote sensing (MARS), for supply of advice, data and software tools
- The Copernicus Global Land Service (http://land.copernicus.eu/global) for close collaboration on the distribution of SPOT-VEGETATION and PROBA-V products and related support to African users.
- Colorado State and Cornell universities in the US, for collaboration on the livestock work
- The GEO Secretariat, EUMETSAT, ESA and the South African Department of Science and Technology for advice
- A cluster of FP7 research projects on Africa, for development of a low cost video

On top of this rich heritage and open cooperation, the AGRICAB consortium combined the expertise of 17 partners from 12 countries in a global partnership (Figure 1-2, Table 1-1) with focus on: (i) GEONETCast, tools and data dissemination (ITC, VITO, INPE); (ii) image acquisitions (DEIMOS, INPE); (iii) crop production systems (Alterra, VITO, ITA, OSS); (iv) livestock systems (ILRI, ULG); (v) forest systems (CSIR); (vi) agrometeorology, crop and livestock monitoring in Senegal, Kenya, Mozambique and North Africa (CSE, DRSRS, INAM, UEM, OSS); (vii) trainings, workshops and outreach (RCMRD, AGRHYMET, OSS, ITC, GEOSAS).

Figure 1-2 Overview of the AGRICAB partners and use case countries

Table 1-1 List of AGRICAB beneficiaries

Acronym	Beneficiary's full name	Country
VITO	Vlaamse Instelling voor Technologisch Onderzoek / Flemish Institute for Technological Research	Belgium
ILRI	International Livestock Research Institute	Kenya
ULG	Université de Liège / University of Liège	Belgium
RCMRD	Regional Centre for Mapping of Resources for Development	Kenya
ITC	Universiteit Twente - University of Twente. Faculty of Geo-Information Science and Earth Observation.	The Netherlands
INAM	Instituto Nacional de Meteorologia / National Meteorological Institute	Mozambique
AGRHYMET	Centre Régional AGRHYMET / AGRHYMET Regional centre	Niger
ITA	Consorzio Italiano per il Telerilevamento dell'Ambiente e dell'Agricoltura	Italy
Alterra	Alterra, Wageningen Unversity	The Netherlands
CSE	Centre de Suivi Ecologique / Centre for Ecological Monitoring	Senegal
DRSRS	Ministry of Environment, Water and Natural Resources - Department of Resource Surveys and Remote Sensing	Kenya
UEM	Universidade Eduardo Mondlane / Eduardo Mondlane University	Mozambique

Acronym	Beneficiary's full name	Country
OSS	Observatoire du Sahara et du Sahel / Sahara and Sahel Observatory	Tunisia
CSIR	Council for Scientific and Industrial Research	South-Africa
GeoSAS	GeoSAS Consulting Services PLC	Ethiopia
INPE	Instituto Nactional de Pesquisas Espaciais / National Institute for Space Research	Brazil
DEIMOS	Elecnor Deimos-Imaging	Spain

2 Main results of AGRICAB

2.1 Sustained provision of EO data and tools

Continuing the efforts of the previous "GEONETCast for and by Developing Countries" (DevCoCast) project, one of the first tasks of AGRICAB was to continue the reliable and low cost delivery of, products derived from low resolution, EO sensors through the existing online platforms and the EUMETCast satellite broadcast, the EUMETSAT-operated regional component of the global GEONETCast infrastructure. This continued the supply of data and support to hundreds of users across different sectors (public, academic & private) and thematic fields (meteorology, agriculture and environment), in nearly all countries on the African continent.

The data provision needed to keep up with the evolution in EO satellites and sensors such as Landsat-8, launched February/2013, and PROBA-V, launched May/2013, related production and delivery services and data access. During the course of the project, the Global component of the Land service of the European Copernicus programme (former GMES) started. While focused on operational production and delivery of core data, this "Global Land Service" collaborated closely with the AGRICAB team to partially take over the broadcast of the SPOT-VEGETATION derived products. This helped ensuring continuity beyond FP7 research context and to accommodate the transition to PROBA-V. AGRICAB's contributions thereto included regular reporting to the Copernicus programme and the European Commission on the data availability and support to African users, as well as two updates to the VGTExtract software to support the new Copernicus products.

Seeking to strengthen the data provision with additional EO data, in particular on the use case study areas, AGRICAB supported the dissemination of outputs from the EDF-funded African Monitoring of Environment for Sustainable Development (AMESD) regional services, effectively contributing to the Monitoring for Environment and Security in Africa (MESA) initiative. Following a demonstration broadcast of Landsat in a training workshop, AGRICAB requested routine delivery of imagery from the new Landsat-8 mission. Accompanying the use case field work, radar (SAR) and high/very high resolution optical imagery (e.g. DEIMOS and RapidEye) were also acquired.

On the software side, AGRICAB efforts focused on the extension of free software, aiming in particular to facilitate the data-exchange between them, so that users can benefit from each tools' strengths, and automating the processing of time series. This combined the comprehensive ILWIS and its toolbox extensions for GEONETCast & online data access, time series processing tools including the SPIRITS software, developed by VITO for the European Commission's Joint Research Centre, and a new time series data conversion utility and INPE's Terra software family (TerraLib, TerraView, etc) with its extensions that are well-known from forest applications (GeoDMA).

AGRICAB supported the expansion of the network of GEONETCast ground reception stations. The first two GEONETCast receivers were installed in the Tsavo national Park in Kenya (Figure 2-1a), and at the International Institute for Water and Environment Engineering in Burkina Faso (Figure 2-1b). After being used as demonstration instruments during international training workshops on GEONETCast, data access and related free software tools, these low cost stations were purchased locally and handed over to the local organizations. A third GEONETCast station was set up at the headquarters of the OSS regional centre in Tunisia in order to support the North Africa use case on the monitoring of irrigated agriculture (Figure 2-1c) and inspiring OSS to re-distribute received data across its member states. This station ran in operation since April 2014 and was demonstrated during the two international workshops hosted by OSS in the context of AGRICAB and the North West Sahara Aquifer System (NWSAS) coordination mechanism between Algeria, Tunisia and Libya.

Through the support of training participants and site visits, AGRICAB furthermore supported a few GEONETCast station installations in Ethiopia (Figure 2-1d), in conjunction with an UN-World Food Programme activity, and in Ivory Coast.

Several sources of meteorological data were evaluated and integrated into the software tools. This finally led to a recommendation to JRC-MARS to share the daily ECMWF-based meteorological dataset (specifically temperature, radiation, evapotranspiration). With MARS' agreement on this, this data can now be used operationally in crop growth models, for which AGRICAB developed prototypes, starting with Senegal.

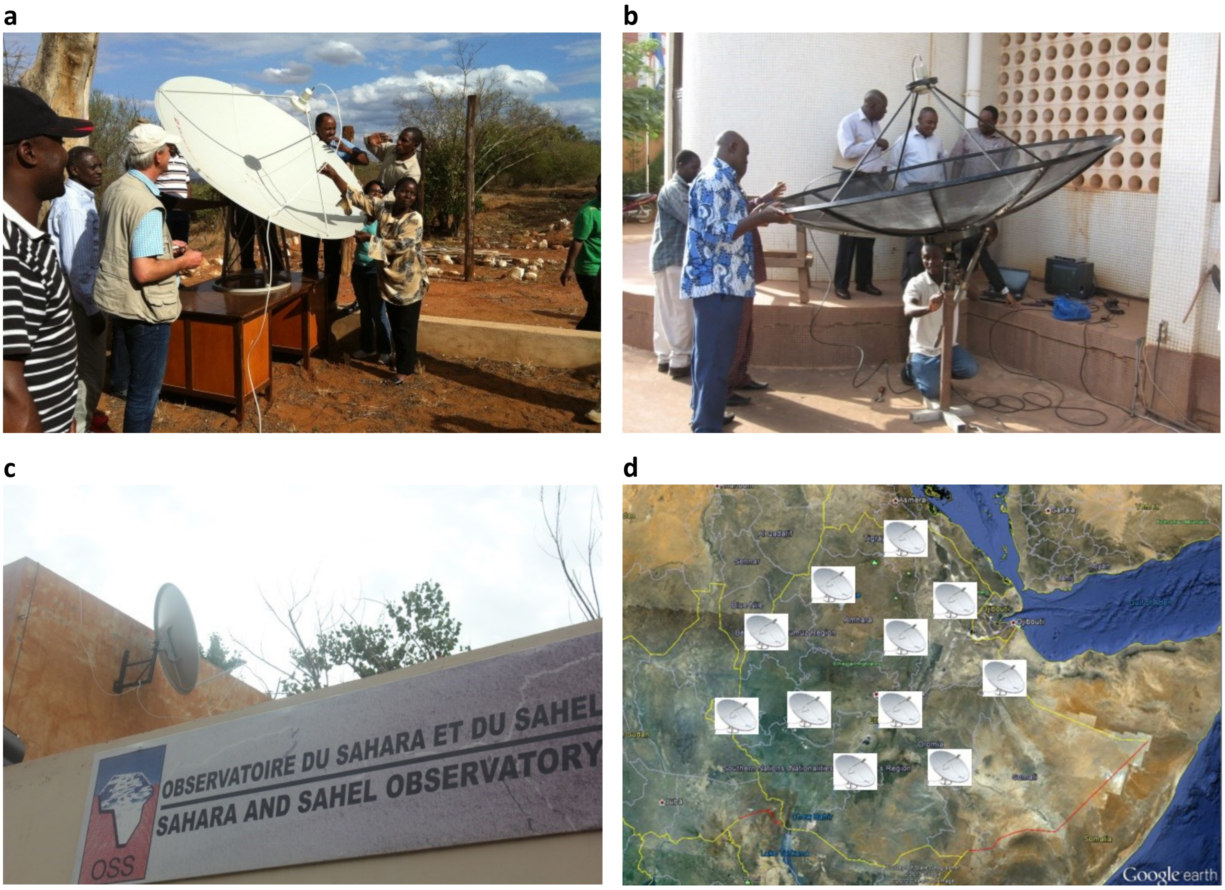


Figure 2-1 a. Receiving station for Kenya Wildlife Service, set up during the GEONETCast workshop in Kenya, b. Establishing temporary reception station for the Ouagadougou workshop, c. GEONETCast station hosted at the OSS headquarters, d. GEONETCast ground reception infrastructure in Ethiopia by the National Meteorological Agency

2.2 Crop production systems

2.2.1 Starting point

Remote sensing, in combination with agro-meteorological modelling, can provide support to monitoring agricultural production with a perspective of food security. Table 2-1 summarizes the main challenges of crop production monitoring using remote sensing in Africa. The green shaded cells in the table were identified as focus areas in the development of AGRICAB's crop applications. Reliable early warning of extreme growing conditions and accurate estimations of crop areas and yields, within and shortly after the growing season, are of high importance. Such information must be processed and presented in a way that stakeholders can use it effectively in the broader context of national food security.

Table 2-1 Challenges of crop production monitoring using remote sensing. Green shaded boxes were focus areas for AGRICAB's work on rain-fed crops.

	Crop area	Crop yield
Forecasting		Occasionally quantitative yield forecasting methods exist but are weakly developed. There is a need for a better conceptual framework, identification of explanatory indicators (e.g. provided by crop models), archive of quality checked yield statistics and supporting tools.
Mapping and monitoring	Solid methods exist for agricultural mapping, but are not often applied in an operational framework. Major challenges still exist for crop specific mapping and further research is necessary.	Operational systems on qualitative yield monitoring exist, mainly related to regional or continental-wide early warning systems. Research could lead to improved methods and enhanced analysis, especially at national level.
Official statistics	Solid methods exist, but are rarely applied in an operational framework. Cost-efficiency is a problem and needs to be investigated.	Few attempts have been made. Official yield statistics available are often based on (too) few ground measurements.

The application of remote sensing on agriculture is rapidly growing because of its (cost) effectiveness. At the start of AGRICAB, however, no large-scale operational service was available in Africa, which combined the advantages of process-based crop growth models and cost–efficient EO-data sets to monitor and forecast yields. Agro-meteorological models can estimate agricultural production as a function of weather and soil conditions as well as crop management information (e.g. planting date).

These models can deliver relevant indicators or explanatory variables for crop yield forecasting. With proper calibration, they have the advantages of being crop specific, providing a faster response on changing weather conditions (especially in combination with short-term weather forecasts) and more detailed indication on crop phenology. In addition to their use in early warning and crop yield forecasting services, the deterministic nature of these models makes them very useful in studies on land and water management scenarios, adaptation to climate change and the exploration of the reasons behind a gap between actual and potential yields. While African institutes show clear interest and growing capacities, it was clear that more is needed for them to take up and manage operational systems based on remote sensing.

As cropland maps are crucial for monitoring of crop development using time series of low spatial resolution vegetation indicators, agricultural masks are a key baseline input for crop monitoring and early warning. The detection of cropland in Africa from EO data can however be very difficult: agricultural areas are often highly fragmented and heterogeneous. The low intensification level of agriculture further increases mixture with other vegetation such as grasslands or shrub lands. Finally, in terms of spectral or temporal properties of vegetation coverage during the growing season, differences in crop cycles are large and climatic events cause high inter-annual variability.

The availability of reliable agricultural statistics of crop production is another key factor in crop monitoring. Sub-Saharan Africa countries face huge needs in this domain. Technologies based on EO can help them to fill, at least partially, this gap.

On the area of agriculture relying on irrigation, the North-Western Sahara Aquifer System (NWSAS) extends over a total area of more than one million km², covers three countries (Algeria, Libya and Tunisia) and is the main resource for irrigated agriculture in arid zones. Groundwater withdrawals have remarkably increased over the last 50 years, with agriculture accounting for about 90% of the total withdrawals.. Intensified water abstraction has led to serious problems: regular lowering of the water level, increased cost of pumping, reduction in artesianism, drying up of natural outlets, poor water quality due to salinization etc. There is a growing need to set up new approaches to promote a sustainable management of the (non-renewable) NWSAS water resources. In order to provide water management institutions with efficient tools to manage this resource, OSS, together with other international partners, initiated a set of methodologies based on hydrogeological models and EO based services.

2.2.2 Crop growth modelling and yield forecasting

Three use cases were developed, in Kenya, Senegal and Mozambique. The crop growth simulation model WOFOST and its regional implementation called CGMS-WOFOST were selected for implementation. The main purpose of CGMS-WOFOST is to estimate the weather impact on crop growth and yield on regional scale (Figure 2-2a)., Simulated crop indicators generated by the CGMS-WOFOST model can be used to predict crop yields within the growing season by explaining the inter-annual variability of crop yields (regression analysis) or by identifying historic years that are similar to the current year in terms of agro-climatic conditions (similarity analysis). The CST (CGMS Statistical Tool) crop yield forecasting module was introduced to streamline the process of estimation and forecasting.

Although capacity on the setup and use of crop models was lacking at the start of the project, and in most cases skills in data processing and analysis were limited, use case partners collaborated in the definition and setup prototypes, adapted to the local climatic and cropping conditions.

All adapted CGMS-WOFOST prototypes were extremely helpful in demonstrating possible applications and to trigger discussions on data inputs, schematization, calibration and validation. Setup and maintenance of the CGMS-WOFOST database for regional crop modelling is rather complicated and requires in-depth knowledge of database management, meteorological, geographical and soil sciences. For all use case countries, this needs an involvement and follow-up of specialized institutes having detailed knowledge and experience in these scientific areas, particularly in meteorology. It was also acknowledged that the prototypes need further adaptation according to more detailed local crop calendars and crop masks. Possibly a better location to run such applications would be the regional RS centres in Africa such as AGRHYMET or RCMRD, as these regional centres have a vast capacity both in agronomy and the ICT domain.

Using the CST tool and its underlying CST database for crop yield forecasting is relatively easy, and can be performed independently from a CGMS-WOFOST database. All use case partners have been sufficiently trained on this subject. Key issues are the preparation of proper indicators and the availability of accurate yield statistics. As the reliability of crop yield forecasts highly depends on the quality of these statistics, a critical review of the official yield statistics in terms of consistency is recommended. Inter-comparisons with other data sets are often useful.

In summary, the organizations with the mandate of crop monitoring and crop yield forecasting in the use case countries (Kenya, Senegal and Mozambique), are now better informed and trained on future information systems for the mentioned applications.

2.2.3 Early warning and crop mapping

During the collection and assessment of requirements at the start of AGRICAB, a strong need was identified for more detailed training in the use of software specifically designed for time series analysis and for crop mapping. The focus was set on time efficiency, reliability and quality of the output products.

For the early warning use cases, four important components were therefore defined: (1) sustainable, near-real time and free access to time series data; (2) appropriate, sustainable, free and user friendly tools for time series analysis; (3) analysis protocols to standardize analysis and facilitate operational monitoring; and (4) capacity building on the three previous components. While operational systems on qualitative yield monitoring exist, mainly at regional or continental-level, AGRICAB focused on research towards improved methods and enhanced analysis, especially at national level.

One of the main objectives was to strengthen the awareness on application potential of remote sensing techniques in agriculture, especially the use of time series of remotely sensed indices for crop condition monitoring and image analysis for crop mapping. A large number of institutes and professionals were reached and made aware of new developments regarding the use of time series analysis, including the newly developed SPIRITS software (officially launched around project mid-term), and crop mapping. Time series analysis of vegetation indices in combination with remote sensing derived rainfall estimates has proven its usefulness and strengths in all three use case countries, in most cases with the objective of drought monitoring, but also for monitoring the effect of floods in Mozambique.

In Senegal, project partner CSE has taken up the improved analysis protocols on operational basis, thereby providing derived information and products that were subsequently included in the regularly published food security bulletins (Figure 2-2b).

The crop yield forecasting method based on the similarity analysis, included in SPIRITS, has proven its relevance for early warning purposes. In coordination with the work on crop modelling and yield forecasting, an import routine was created by Alterra to link the SPIRITS and CST software tools, in order to improve statistical yield forecasting based on the time series analysis outputs. Finally, for the Mozambique use case, different satellite based rainfall estimate products, that are frequently used as input for drought and/or flood monitoring, were validated against rain gauge data.

Next to the early warning use cases, the suitability of crop mapping methodologies was tested. In this respect, the field campaigns performed in specific study areas for the agricultural statistics tasks provided an interesting opportunity and synergy to test different methodologies, as useful ground truth data were collected and made available. The crop mapping use cases confirmed the major issues related to crop specific mapping or even detection of cropland in Africa. Especially in Senegal and Mozambique, there were major constraints due to persistent cloud cover and none or very few successful high to medium spatial resolution image acquisitions. The results of the integration of different datasets (from field surveys, aerial campaigns, sporadic very high resolution imagery to periodic images with low spatial resolution) look promising, but further research will be necessary before these approaches can be adopted in an operational workflow.

2.2.4 Agricultural statistics

Within AGRICAB, modern methods for agricultural statistics that were developed in Europe over the last years, have been adapted and transferred, to three use case countries (Senegal, Kenya and Mozambique). The transfer was preceded by a detailed analysis of the existing statistical systems, as well as the capability of remote sensing application in the country. The methods were developed and transferred to the public administrations of these countries (mainly Ministries of Agriculture and national statistical institutes), through a large number of technical workshops. Methodologies and procedures related mainly to: the construction of the sampling frame through analysis of satellite images freely available on Google Earth (Figure 2-2c); the preparation of the necessary materials to realize a ground survey on the sampling units; its execution by government staff involved in the project after several training sessions; quality control applied in all the steps leading to the creation of products; and finally the statistical treatment of the data collected during the ground survey in order to prepare, for each study area, the statistics of the surfaces of the typical crops of the same area, each labelled with their statistical precision expressed by the coefficient of variation (CV).

When available, these statistics were compared with those obtained for the same areas through existing systems, even though for the latter, the statistical accuracy is almost never documented. All the data of the statistical systems developed in the three countries were stored into Geographical Information Systems (GIS) to facilitate their management and processing.

The accuracies of the crop acreage estimates is higher than those obtained with the traditional systems (list survey) used in the three countries. The reliability of the statistics produced with this new approach was demonstrated and the project objectives were largely achieved, allowing the full transfer of the methods and procedures to the organizations involved. However, a complete and conscious autonomy at an operational level can only be achieved by repetition of operation.

2.2.5 Irrigation agriculture

In order to acquire a better understanding of the stakeholders and partners' requirements in the application of remote sensing in irrigated agriculture, particularly in terms of EO data type and format and the most suitable study areas, members of the African remote-sensing community in the NWSAS member states (Algeria, Libya and Tunisia) were invited to take part in a survey organized by the OSS. The survey provided useful insights into the research orientation for OSS to meet needs and expectations in this field.

Progress was achieved on several domains related to irrigation agriculture. Firstly, Land Use and Land Cover (LULC) mapping was performed at different scales: (i) over the entire NSWAS region using MODIS NDVI time series data, with the objective to study the vegetation patterns and evolution and to enable a better quantification of the total area of irrigated perimeters; and (ii) over three pilot sites using very high resolution satellite imagery and field data (Figure 2-2d).

A water balance model was developed to estimate water withdrawal using remotely sensed data. Since water points are not equipped with meters, approximate water volumes are indirectly estimated using survey collection techniques based on information provided by water users. This was the subject of a PhD research project. In addition, the Simple Surface Energy Balance (SSEB) model was implemented using Landsat 8 data (thermal and optical bands) to assess water use at the field level.

A GEONETCast data reception station was setup at the OSS in 2013, and is regularly receiving data since April 2014. A first use of GEONETCast consisted of vegetation anomalies monitoring using NDVI time series. Now, OSS is updating the processing chain with the PROBA-V data to assure continuity of monitoring operation. In addition, synergies were created with other projects managed by OSS, where SPOT/VGT NDVI time series data and TAMSAT rainfall estimates are provided, as well as the anomaly indicators. This new reception capability has also provided a new impulse to OSS' role as data provider for their member states, in the form of a first data requirements survey.

In order to train national technical services in charge of water resources abstraction and recharge assessment and land use cover mapping, with open source tools and software as well as free data, OSS has organized two regional workshops attended by about 20 participants from Morocco, Algeria, Tunisia, Libya, Egypt and Mali. Participants were mostly senior staff members of different organizations, including OSS as the host institute, its regional partners in the NWSAS coordination and some staff members from the Tunisian Ministry of Agriculture. The first regional workshop on water withdrawal estimates "Open Tools and Data for Water Resources Abstraction and Recharge Assessment" was organized in Tunis in October 2013. The second regional workshop on irrigated agriculture with a specific focus on LULC mapping using low, medium and high spatial resolution imagery, building on the achievements of the 2013 edition, was held in Tunis, on August 25th -29th 2014.

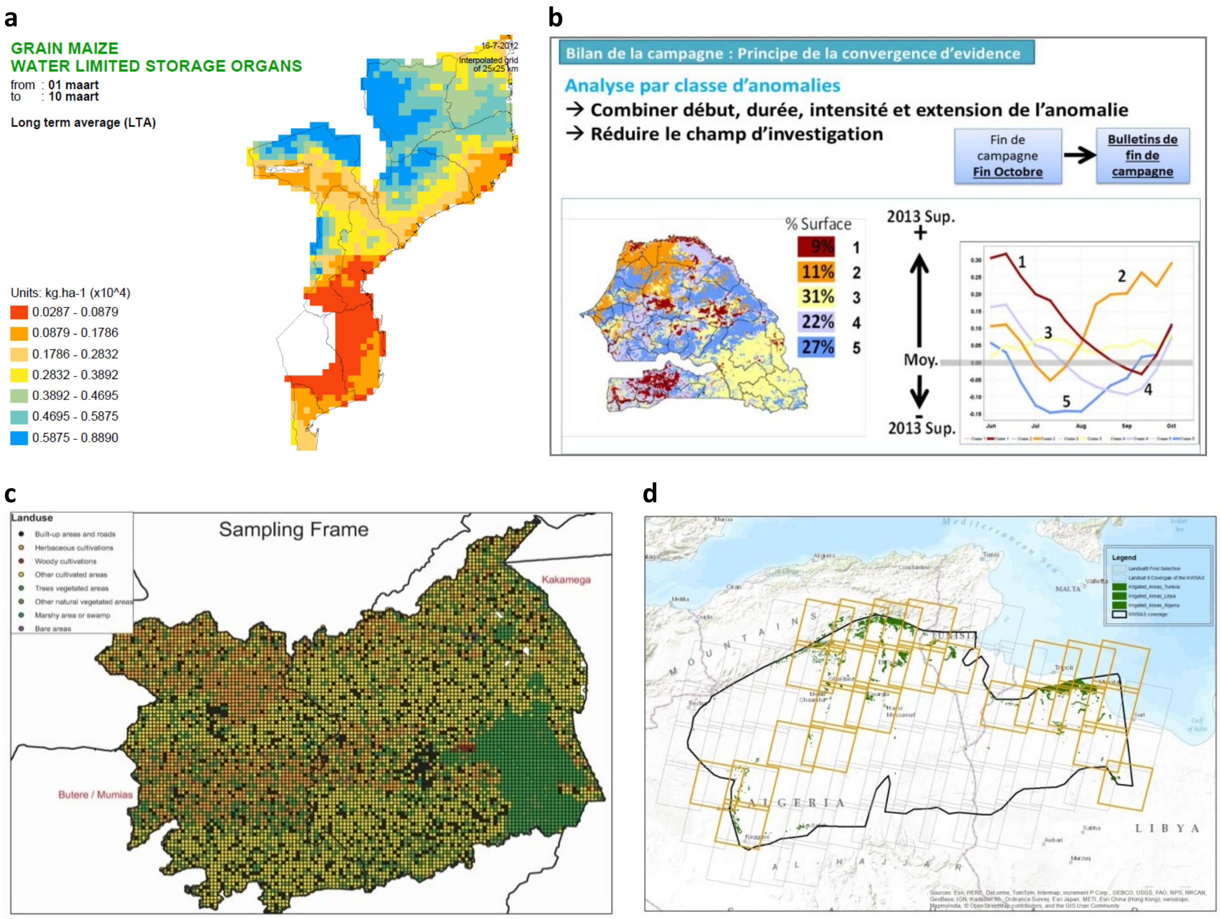


Figure 2-2 Crop production systems use cases: a. Long term average simulated grain maize yields at the end of the season in Mozambique under rain fed conditions; b. Analysis of timing, duration, intensity and extent of vegetation growth anomalies in Senegal based on cluster analysis for the end-of-season bulletin; c. Sampling frame for agricultural statistics in the Butere/Mumias District, Kenya; d. Landsat 8 coverage of the NWSAS

2.3 Livestock systems

2.3.1 Starting point

Livestock herding is a key agricultural activity in the Sahel. Livestock productivity, largely relying on pastoralism in rangelands, is closely linked to fodder biomass production. In that respect, remote sensing can help to evaluate and monitor the state of vegetation and to estimate biomass production in rangelands. Monitoring vegetation state through satellite imagery is often performed using vegetation indices such as the NDVI (Normalized Difference Vegetation Index), fAPAR (fraction of Absorbed Photosynthetically Absorbed Radiation) or LAI (Leaf Area Index). Satellite imagery must be available at a sufficient temporal resolution (~ few days) and at a reasonable spatial resolution (100 m – 1 km).

Existing techniques for estimating biomass production (e.g., in Senegal and Niger) are usually based on empirical relationships between remotely sensed indices and biomass yields collected on the ground sites each year. However, these methods have a large number of constraints: the high cost of ground observations, the long time between the collection and publication of results and low model accuracy.

Drought is the greatest cause of livestock mortality in sub-Saharan African arid and semi-arid lands. An example is northern Kenya, where more than 3 million pastoralist households are regularly hit by increasingly severe droughts. For livelihoods relying solely or largely on livestock, the resulting high mortality rates have devastating effects, rendering these pastoralists amongst the most vulnerable populations in the country. As the consequences of climate change unfold, the link between drought risk, vulnerability and poverty may become significantly stronger. In the case of weather shock in arid and semi-arid lands, a traditional insurance system for farmers becomes less suitable, and a new type of insurance system was developed to better fit the situation (covariate risk such as weather shocks, lots of remote, small farms) and the needs of rural poor populations. This insurance system is known as index-based: payments are made when an objectively measured index reaches a pre-defined trigger level within a pre-defined area and time period. Such an index-based insurance program was launched as a pilot program conducted by the International Livestock Research Institute (ILRI) in the Marsabit District, Northern Kenya in 2010.

The objectives of the livestock use cases within AGRICAB were thus twofold: (i) to implement fodder biomass production models based on remote sensing indicators in the Sahel, through case studies in three African countries (Senegal and Niger) and a larger-scale use case using the global G-range ecosystem model (covering the Greater Horn of Africa region), and (ii) to study index-based livestock insurance (IBLI) schemes in Kenya with the objective of insuring pastoralists during drought periods.

2.3.2 Forage biomass production and prediction of livestock mortality

AGRICAB's work on the livestock use cases was achieved through three supported PhD research projects for the Niger and Senegal biomass fodder production model research and the Kenyan livestock mortality insurance study. The G-range model development activities were carried out by one post-doc researcher involved in the project, in a collaboration between ILRI and Colorado State University in the US, as well as two Sudanese experts who received extensive training.

The outcomes of the calibration and improvement of fodder production models using field data and remote sensing indicators in Senegal and Niger allows for operational implementation of forage biomass models (Figure 2-3a). Operational networks for data collection on forage resources are already in place in both countries. The refined models of biomass prediction can be technically implemented by the livestock department unit of the AGRHYMET Regional Centre. For Senegal, it was shown that simple linear regression models for fodder production were outperformed by power and exponential models, leading to more consistency. Multi-linear regression approaches also improve the prediction performance, using phenological parameters derived from remote sensing. Lastly, the analyses conducted both in Senegal and Niger showed that a regional zoning by pheno-climatic characteristics (eco-regions) increased the prediction performance of models.

To improve the prediction of livestock mortality with remotely sensed biomass indices (Figure 2-3b) in Kenya, multiple linear regressions and generalized linear models were tested. Research within the AGRICAB project also focused on consideration of other remotely sensed biomass indicators (fAPAR, DMP, etc.), other types of meteorological and agro-meteorological indices as well as meteorological time series (rainfall, rainfall distribution, etc.) and field information. Relatively low model performance could be attributed to incorrect delineation of grazing areas in the data, and migration of pastoralists in case of severe conditions, leading to low mortality values while severe conditions do occur. The predictive power of the models could be improved by taken into account geographical patterns.

The G-Range ecosystem model was applied with the objective of quantifying forage availability in the Greater Horn of Africa, in order to inform drought preparation and response policies of the IGAD regional government. Site-scale and regional validation efforts showed encouraging results, in particular for Aboveground Net Primary Productivity (ANPP), the total annual production of aboveground biomass available as forage (herbaceous) and browse (woody).

Two modeling analyses, one on global forecasting of change in ecosystem processes to 2070, and the other on forecasting forage and browse production to 2045 for the Greater Horn of Africa will be concluded and published in near future. These include various scenarios of management (business as usual and improved browse utilization), representative carbon pathways (RCP) for global CO2 emissions and general circulation models (GCMs).

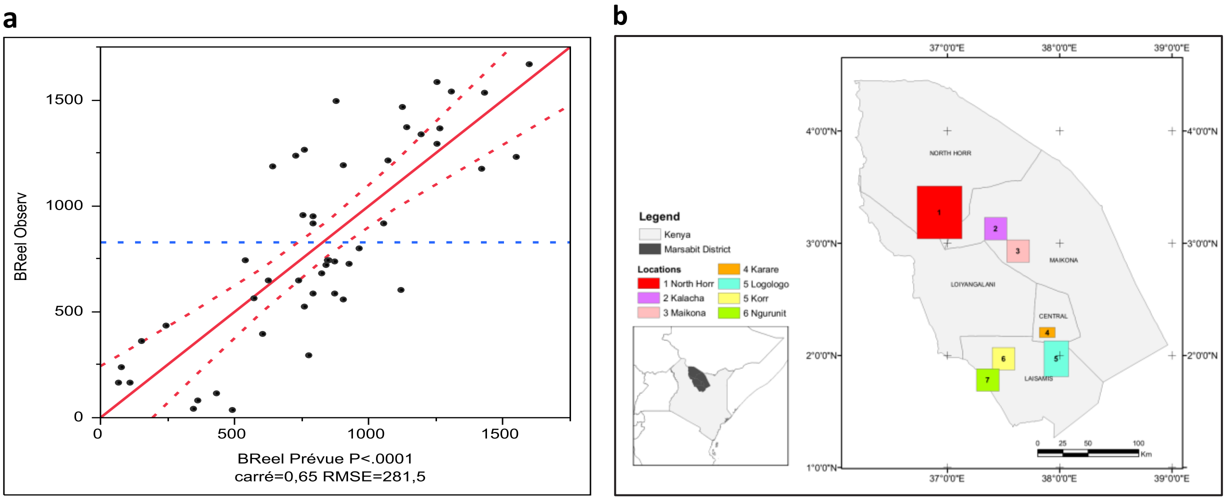


Figure 2-3 Livestock systems use cases: a. Comparison of predicted biomass prediction and observed values, Manga, Niger; b. Study area of IBLI, Northern Kenya

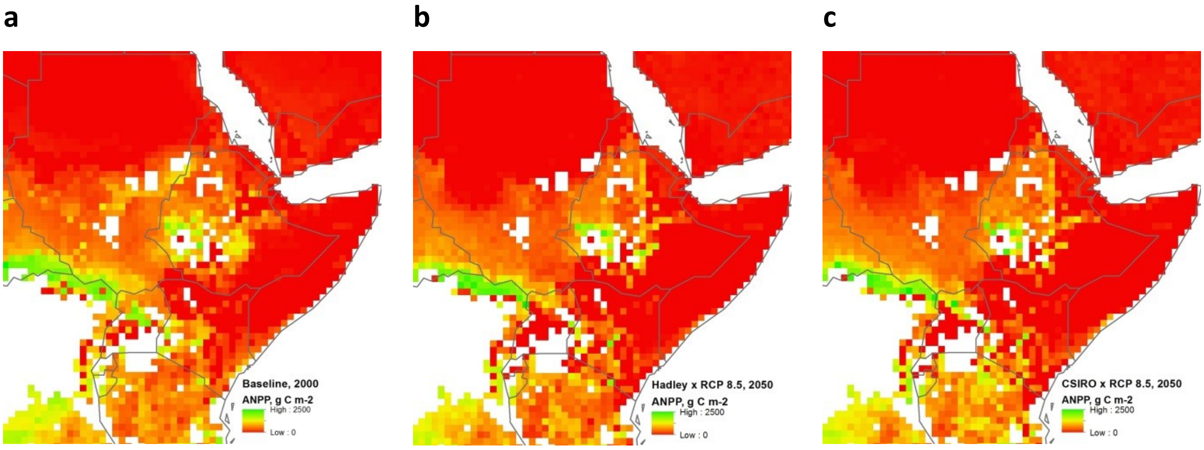


Figure 2-4 ANPP, in g C m^{-2} yr^{-1}, in the Greater Horn of Africa region, for the Baseline simulation (no climate change) in 2000 (a), versus for the Hadley (b) and CSIRO (c) General Circulation Models under Representative Carbon Pathway 8.5 (high CO2) in 2050.

2.4 Forest systems

2.4.1 Starting point

Half of the land surface in sub-Saharan Africa is covered by dry and moist savannahs. Savannahs and woodlands are open canopy forests (10-50% tree cover) made of mixed layers of grass and woody plants. A large proportion of the African rural communities, generally the poorest ones, relies extensively on these ecosystems for e.g. fuelwood, timber and grazing resources. These heterogeneous savannah and woodland landscapes are highly dynamic under the combined effects of fire, human, and wildlife disturbances, which provide feedback loops that in turn influence ecosystem service provision and management.

Mapping of savannahs and woodlands, in particular the woody cover, as well as the understanding of fire regimes in this biome using existing regional EO-based fire datasets were the main focus of the forest systems work in AGRICAB.

In general, very limited spatial data are available on the distribution and dynamic of savannah and woodland resources in southern Africa, thereby limiting sustainable management and policy development for a resource which provides valuable goods and services for the rural poor. In South Africa, legal regular reporting on the status and dynamic of savannahs and woodlands is based on fragmented and mostly non-spatial data.

The generation of tree cover maps for savannah and woodland landscapes is commonly based on EO technologies combining field data, airborne Light Detection And Ranging (LiDAR), and satellite Synthetic Aperture Radar (SAR) imagery. Satellite-based EO provides the only tool for monitoring woodlands over the 30 million hectares they cover in South Africa. The capacity to monitor woody cover over wide area is essential to provide timely information for decision making in managing these resources and to improve the understanding of the drivers controlling changes. However, the use of LiDAR and SAR EO technologies are still in their infancy in South Africa and southern Africa in general, especially for vegetation studies.

Today, there is limited spatial information on tree cover at all scales in the region. The only tree cover product available is the vegetation continuous field (VCF) products developed at continental (and global) scale using 500 m MODIS imagery (MOD44B). This product is too coarse to capture adequately landscape scale variations in open forest, and it remains to be validated in most African savannahs and woodlands.

Initial assessments made in AGRICAB showed that the product does capture dense forests well, such as plantation and indigenous forest, but fails in the savannah biome, and is highly variable from one year to another due to rainfall-driven phenological variability. More recently, a Forest / Non Forest global product derived from the global HH/HV ALOS PALSAR mosaic at a resolution of 25 m was released by the Japanese Space Agency JAXA. The product is designed to monitor change of forests over time but it does not provide qualitative woody cover values. Similarly to the MOD44B products, our assessment showed that the product fails to capture most open forests (low density) in Southern Africa.

On the fire side, we had a good understanding of how fire affects tree cover and woody biomass in these savannah and woodland systems at the beginning of AGRICAB. What was lacking was an understanding of how humans interact with fire and affect biomass burning in Africa. The effect of human activities on fire regimes is essential for accurate information on current carbon storage capacity and future changes to this. AGRICAB therefore aimed to fill some of these gaps, to allow for better predictions of the consequences of human land use and population changes in African environments. This required both the development of innovative new data products (based on available remotely-sensed fire data), as well as detailed information on current population trends and national land use strategies. From the outset, AGRICAB focussed on community engagement with these issues – because it was recognized that there were a range of opinions about how fire is used in rural areas in Africa, which sometimes were totally contradictory. With the renewed interest in the potential carbon-storage opportunities in African landscapes, and the changing political landscapes in many African countries, it has become more important than ever to try to resolve some of these conflicts.

2.4.2 Tree cover mapping

The tree cover mapping task developed and applied EO technology, in particular airborne LiDAR and SAR imagery, to generate tree cover maps in southern African savannahs (Figure 2-5a). These technologies were chosen, in part, because of their high suitability to 3D sensing and forest mapping, as well as their lack of sensitivity to clouds.

The work relied on state-of-the-art SAR technology, and investigated the potential for deriving calibrated tree cover maps at two scales, medium to high resolution (ALOS PalSAR, TerraSAR-X, Radarsat-2) and coarse resolution (ASAR historical dataset in prevision of the Copernicus Sentinel-1 platform). Active microwaves interact with the vertical woody profile and thus are better suited to capture the vegetation structure than optical frequencies. SAR has an all-weather capacity facilitating the constitution of comprehensive time series. Access to SAR datasets is however limited, especially in Africa, and SAR data processing requires advanced stand-alone and often expensive software. Limited expertise is available in South Africa on the use of SAR data and processing in general, and for vegetation in particular.

In addition, the use of airborne LiDAR technology was assessed and demonstrated with the objective of mapping local attributes of open forests (woody height, cover, and biomass) as well as changes in the context of sustainable use of natural resources (e.g. fuel wood, biodiversity). LiDAR were used as extensive and highly accurate reference datasets to train, model, upscale and validate woody cover maps at wider scale using satellite SAR imagery. A number of scenarios and approaches were assessed: image season, predicting model (parametric vs. non parametric), polarization (including polarimetric decomposition), frequency (X-, C-and L-band), fusion with Landsat optical data, scale (high / medium resolution vs high resolution), and hypertemporal time series. The research demonstrated and documented various options for mapping woody cover in southern Africa, and documented achievable accuracies. Overall, dry season L-band imagery (ALOS PALSAR) combined with machine learning algorithms (Random Forest) was found to be the most appropriate approach for mapping tree cover at landscape scale (< 1 ha minimum mapping unit) with good accuracies ($R^2 \geq 0.8$, RMSE ≈ 10%). Hypertemporal time series (more than 6-8 images) of C-band ENVISAT ASAR images also provided a good performance ($R^2 \geq 0.7$, RMSE ≈ 9%), which is encouraging considering the recent launch of the European Sentinel-1 C-band satellite. The combined assessment of SAR datasets with optical Landsat imagery confirmed that the most important dataset is the SAR L-band in southern African landscapes, in contrast to national cover mapping programs based on Landsat in Australia (Australian State-wide Landcover and Trees Study) and in the USA (LandSAT Ecosystem Disturbance Adaptive Processing System). When using Landsat TM only datasets, the best performance was found during the summer and autumn seasons. The latter performance was significantly lower ($R^2 < 0.6$, RMSE ≈ 13%) compared to the L-band SAR only performance. Combined optical and SAR datasets produced a moderate improvement ($R^2 = 0.85$, RMSE ≈ 7%, improvement of ~5%) compared to SAR only datasets. The poorer performance of Landsat in South African savannahs and woodlands was attributed to the fact that the grass versus tree phenology did not allow to capture efficiently the optimal contrast between green tree canopy and dry grasses. AGRICAB thus contributed in producing the knowledge required for moving toward the development of locally calibrated and validated regional maps of woody cover.

In addition, the project contributed to the development of advanced skills through the support of two PhD, one MSc thesis, and two BSc Honors degrees, thereby supporting the need of qualified scientists in the field of remote sensing in the country. Capacity and expertise was built for processing LiDAR and SAR data, which is an important outcome in the southern African context where both of these EO data types are rarely used for vegetation mapping. Through this gain of experience, AGRICAB provided an essential foundation for moving toward the integration of this technology in the local workflows, with the ultimate goal being the operational mapping of national and regional forest resources and woody cover using locally calibrated and validated datasets. Technical expertise was also built for processing large datasets of LiDAR and SAR imagery, and for various SAR sensors (Radarsat-2, ALOS PALSAR, TerraSAR-X, ENVISAT ASAR, and now Sentinel-1 and ALOS PALSAR-2). The state-of-the-art GAMMA software was acquired and is maintained via co-funding resource for the project (Department of Science and Technology, South Africa).

Although not yet at an operational level, a major outcome is that the AGRICAB project allowed the completion of a first unique detailed 1 ha map of woody cover at national scale using ALOS PALSAR mosaic combined with extensive LiDAR tracks. The product was presented at the recent international conference from the African Association of Remote Sensing of the Environment (AARSE, Johannesburg, September 2014) during a special event sponsored by AGRICAB. This product is currently improved by incorporating additional LiDAR datasets when they become available from various stakeholders such as electricity utility ESKOM, national and provincial parks or commercial plantation companies. Products have started to be used by local stakeholders such as the Department of Environmental Affairs and the South African National Parks for e.g. alien species mapping, carbon accounting, fuelwood mapping, and wetland mapping.

The main impact produced by the tree cover mapping task relates to the dissemination of knowledge and the presence of Africa in the regional and global arena of forest mapping using SAR technology. This includes four published peer-reviewed publications, and three papers in review or in preparation. The work was also presented at a large number communications in various international conferences and symposia.

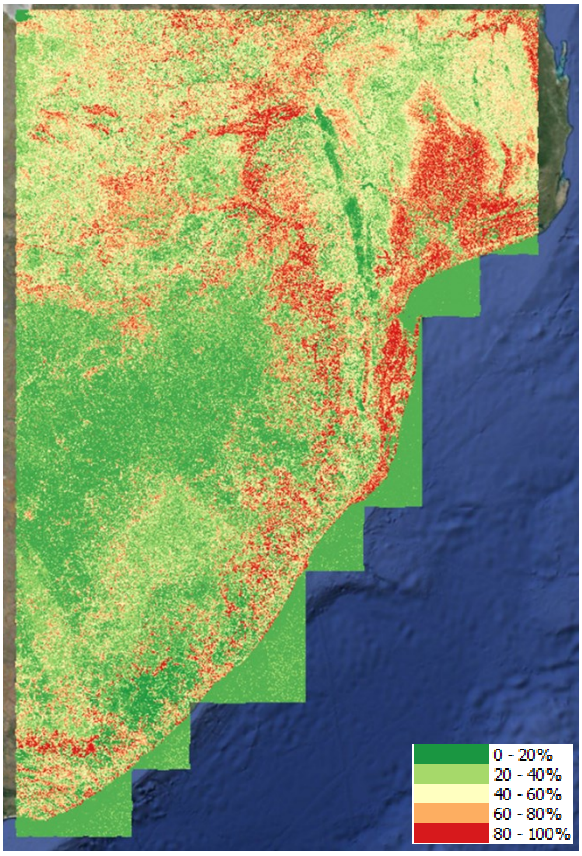
2.4.3 Fire mapping

The objective of the fire mapping task was to increase the knowledge on the effect of human activities on fire regimes, with the aim of being able to predict the impact of future changes in land use and rural development. Fire regimes, linked to human activities, have an impact on the mix of woody and grass layers of these ecosystems, hence the capacity of monitoring and understanding tree cover changes (EO tree cover mapping) and drivers of changes (EO-based fire products) is interrelated and an important need in the African continent. Considering the geographical scope of this task (Southern Africa) and existing regional EO-based fire datasets (e.g. AMESD-MESA SADC Thema), the focus was on several countries of Southern Africa which are dominated by savannahs and woodlands - South Africa, Zambia, Zimbabwe, and Mozambique - therefore excluding dense forests (i.e. tropical belt). When it comes to fire, the rural landscapes of these countries have all changed in very different ways over the last decade: in Mozambique the rural landscape is being re-populated after a devastating war; in Zimbabwe previously commercial farms are now being managed communally, or not managed at all; in Zambia, commercial farming is taking off; and finally, in South Africa, peri-urban development is expanding into previously rural areas. We hypothesized that these differences in political landscape in different southern African countries would impact patterns of fire.

The fire mapping task contributed to expand capacity in fire research globally, and in Africa in particular. New spatial datasets were developed, enabling enhanced understanding of human impacts on fire regimes, facilitating our understanding of the important role that people play in mediating earth system processes like fire (Figure 2-5b). The regional-scale insights that we derived on the role of people in fire management in Africa supported a continued and expanded interaction with policy makers, allowing the former to feed into conservation policy, and contribute towards adaptive land management. In turn, these interactions were critical in informing the science agenda from management practice and experience. African researchers, land managers, students, and policy makers were trained at post-graduate and undergraduate level and in workshops and interactive activities. This work continues beyond the AGRICAB project as part of our continued interaction with South Africa Fire Network (SAFNet) and the Miombo Network that the AGRICAB project made possible. In addition, the project contributed to the development of advanced skills through the support of one PhD and one MSc theses. Within the scope of an international collaboration, the project also trained two German internships on analysis of remotely sensed fire data, and one US internships on the processing of LiDAR data for tree cover mapping.

In South Africa the activities of the Land Cover Change Consortium (LCCC) have been greatly enhanced by the interactions and training we have provided, and this dynamic inter-disciplinary group continues to have fire and human fire management as a focus.

Similarly, the regional-scale insights that we derived on the role of people in fire management in Africa continue to feed into conservation policy: the South African National Parks (SANParks) is currently revising its fire management plan to better represent fire size, frequency, and seasonal aspects of fire that occur outside its eastern boundaries in Mozambique. This represents a dramatic move towards continued recognition that humans and fire in Africa have a long history, and cannot be disconnected. Our continued and expanded interactions with policy makers and the forestry departments in Tanzania and Zambia that were enabled by AGRICAB promise to produce similar insights in both directions (science both learning from management, and contributing towards adaptive land management).



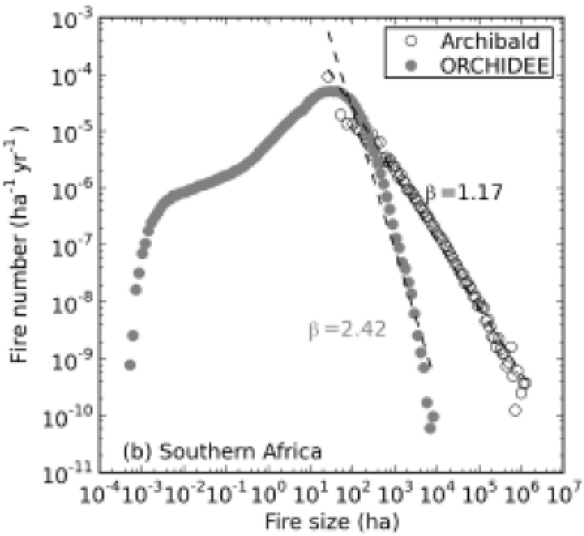


Figure 2-5 Forest systems use cases: a. Map of total canopy cover derived from ALOS PalSAR, Eastern forest belt, South Africa; b. Validation of fire size data against measured and modelled values.

2.5 Innovative web portals to stimulate wider uptake

Next to the thematic applications, with mostly national focus, and broad-scale EO data access and software tool developments, AGRICAB's third pillar of activities was to stimulate the wider use of those EO techniques. Here, the idea was to allow a wide range of communities be exposed to, discover and even experience the EO techniques, as shown in the figure below.

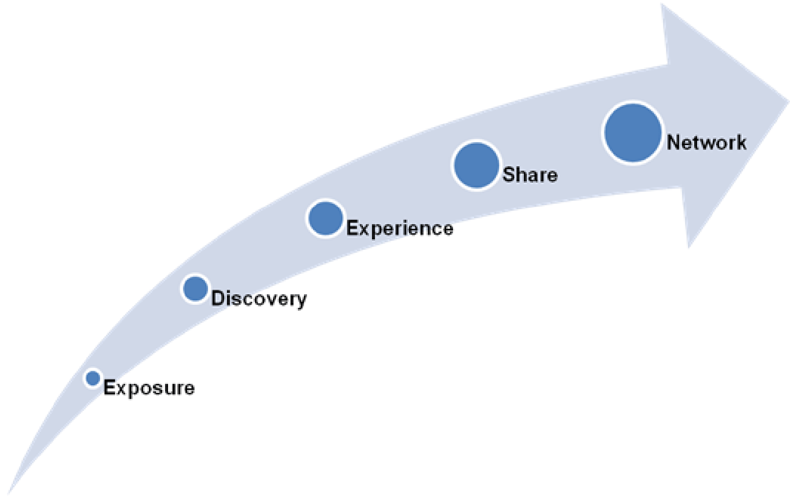


Figure 2-6 AGRICAB's interconnected activities to stimulate EO uptake

The underlying ambition was to work towards a pan-African Community of Practice (CoP): a user-led community of stakeholders with a common interest, for instance on the use of EO for agriculture. Such a CoP would need to span across existing networks and communities, bringing toghether EO data providers, scientists (e.g. CGIAR centres of excellence), capacity builders and education, policy and so on. It is crucial that this CoP is an initiative owned and led by African users.

While such a network-of-networks is clearly a long-term effort, important progress could be made in the development of one or more web portals to support this CoP, in particular in the 'Share' activity: to provide links to relevant EO data sources, (free) software tools and training resources, knowledge (e.g. case study reports) and to add an open forum for discussion using social media.

As a prototype of such a portal, and in addition to the project's main website, VITO developed its "Africa portal for Knowledge and Data sharing on Earth Observation", or "Africa portal" in short, available at http://rs.vito.be/africa. It provided an entrypoint to EO data sources, free software tools, upcoming and past training workshops (incl. reports) and case study documents collected from a range of R&D projects that VITO and its partners conducted in Africa over the last 10-15 years, i.e. part of AGRICAB's history.

Figure 2-7 VITO's Africa portal, http://rs.vito.be/africa

For the data sharing component of the CoP portal and favouring of course data shared openly according to GEO's data sharing principles, the next step would be to develop a traditional Spatial Data Infrastructure (SDI) with a complement of standardized web services (catalogue for data discovery and search, web map viewing and so on). With the advent of new data access portals (called PDF) for EO data produced by VITO (e.g. from PROBA-V mission's ground segment), AGRICAB could shift its focus to on (i) the evaluation of the new data access portals from African-user perspective and (ii) the development of a time series viewer web portal for vegetation (and agriculture) monitoring in Africa.

This evaluation of the PDF through an online survey directed at a small group of users was successful and demonstrated that this portal is a workable solution for African users and a clear recommendation to further elaborate the portal and simplify its usage. Meanwhile, the Copernicus Global Land Service adopted a similar product access portal for the derived or added-value products, superseding the old DevCoCast portal that AGRICAB was using.

The bulk of this effort was however dedicated to making a first release of a new time series viewer (http://tsviewer.vito-eodata.be), a portal for viewing the multiyear time series of EO datasets, in a range of charts and maps and aggregated to administrative units (not image pixels), across the globe and along with data from other web services such as UN-FAO's official crop yield statistics. This viewer was based on a prototype processing platform, under development by VITO in an ESA-funded project, which pushes the use of Big Data processing techniques (e.g. Apache Hadoop, Mondrian OLAP, MonetDB) and paves the way for real on-demand web processing in future.

By ensuring the quality of the visualized data, improving the web interface and navigation for easier use, changing the datasets to those commonly and globally usable for agriculture management users, like those addressed by AGRICAB in Africa, the time series portal was successfully demonstrated in an AGRICAB-sponsored session at mid-term (Nov/2013) and launched in a first, demonstration version in June/2014.

In fact, from its introduction, the time series viewer clearly drew the attention of important international stakeholders such as the Copernicus unit of the European Commission and UN-FAO. The take-up in the sister-project FP7-SIGMA and in the Copernicus Global Land Service, which will bring the viewer to full operation by Q1 2016, but also the fact that the maps and graphs can be integrated into popular web content and collaboration platforms (e.g. Drupal), help to ensure sustainability of this pilot effort. These could for instance allow African national experts to organize the visualization components, each updated with the latest vegetation and rainfall indicators, on a single web page along with their own quick analysis, drawing upon local field knowledge, in a country 'dashboard'.

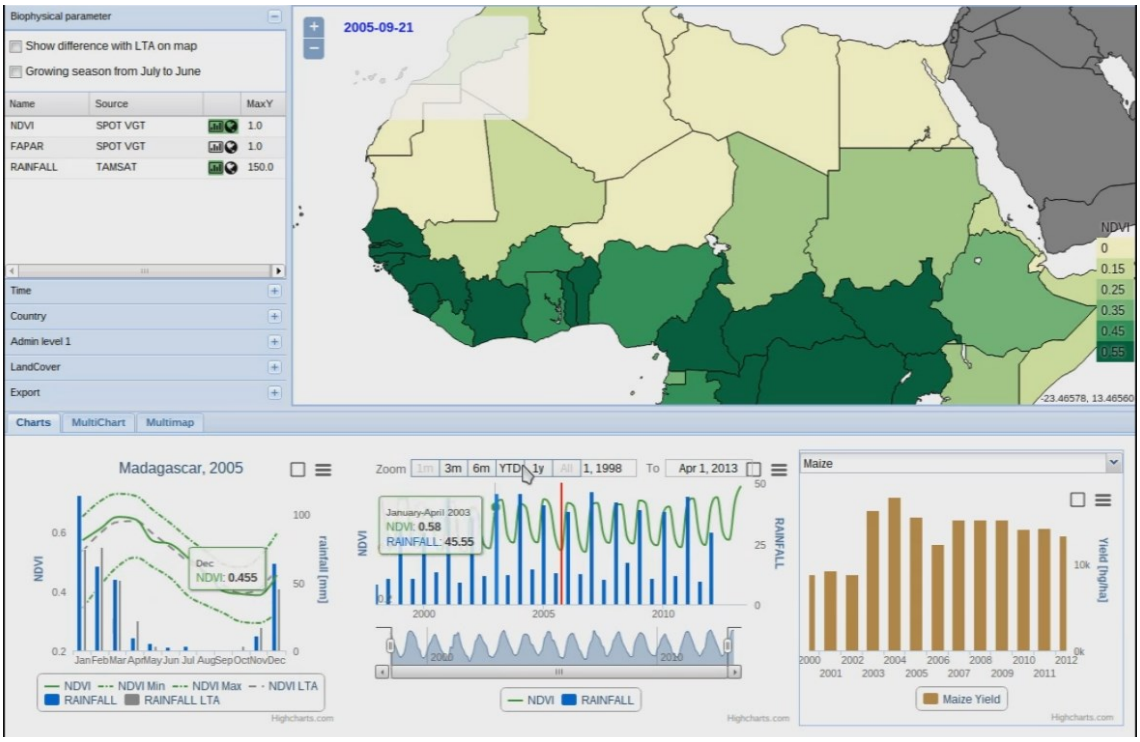


Figure 2-8 VITO's Time Series Viewer demonstration portal, http://tsviewer.vito-eodata.be

For the training component of the envisaged CoP portal, the University of Twente (ITC) set up a dedicated portal using the free Moodle Learning Management System, for openly sharing some of AGRICAB's training materials (incl. sample data), using a Creative Commons license model that allows further distribution. This portal is available at http://eo-cbportal.itc.utwente.nl:100 and currently contains materials from five international workshops as well as resources on crop yield modelling and crop yield forecasting (provided by Alterra) and on the G-range ecosystem model (provided by ILRI and Colorado State University). The commitment to further maintain the EO-CB portal and the fact that this Moodle experience could be replicated, at larger scale, for MESA, is a useful outcome, even though AGRICAB and MESA training materials are developed separately.

Users were furthermore encouraged to use the EO Community portal on the 52North website (http://52north.org/communities/earth-observation) with updated material on GEONETCast and online data access and related software tools.

In addition, AGRICAB organized several discussions with, among others EUMETSAT and JRC-MARS to enhance the collaboration on training and develop the concept for distribution of training material via the GEONETCast satellite broadcast. These however remain to take a more concrete form – a clear opportunity to be addressed in follow-on activities – with the first stepping stone being a joint calendar or system for announcing workshops.

A revised structure for the training modules, following end-to-end application flows, was proposed as well.

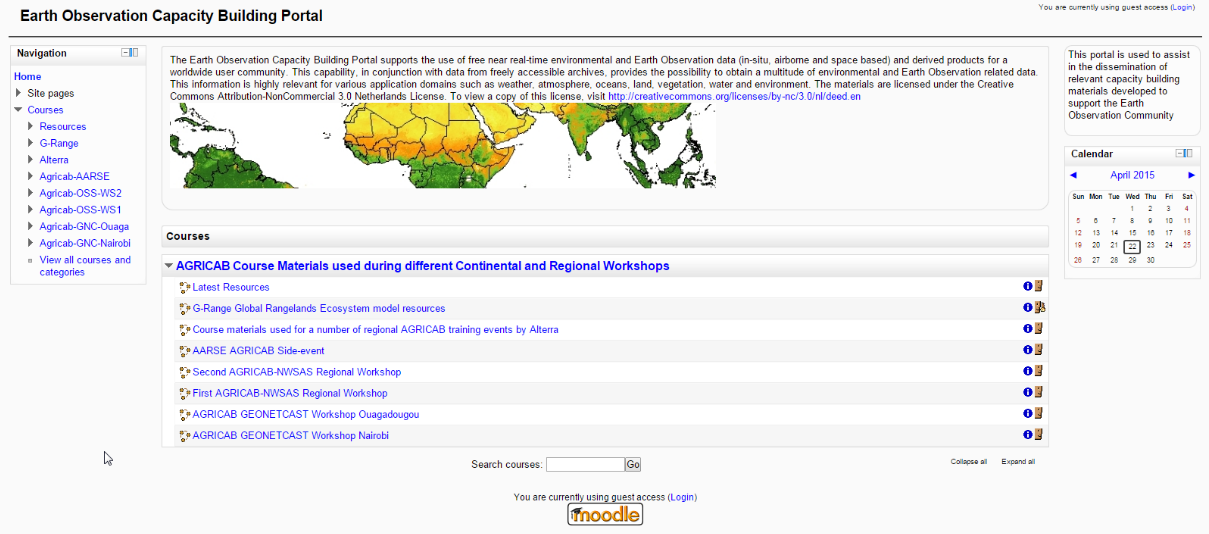


Figure 2-9 ITC's EO Capacity Building Portal, http://eo-cbportal.itc.utwente.nl:100

Regarding the networking aspects of the CoP portal, the efforts to engage in particular the CGIAR agricultural research network or local farmers via community radio did not succeed, leaving a second gap to be filled in future.

3 Impact, main dissemination activities and further exploitation of project results

3.1 Impact

The impact of the AGRICAB's efforts to strengthen existing African capacities can be analysed and described in three pillars: (i) the impact on the institutional domain, (ii) the impact on the human capacity domain (knowledge sharing, training, education), and (iii) improved technical/infrastructure capacity.

3.1.1 Impact on institutional capacities

The institutional impact of AGRICAB is most visible in the form of new or improved national structures, networks or partnerships, set up to stimulate the uptake of EO techniques and support the country's policy making.

In the framework of AGRICAB, ample exchange, interaction and networking took place between national stakeholders –although they were not always official partners in the project– which were actively involved in use case implementation and training activities. Coordination and cooperation between these different stakeholders are a key element of success in integrated modelling and analysis of agricultural production, since the combination of expertise (remote sensing, meteorology, agronomy, and statistics) leads to comprehensive and multi-disciplinary outcome.

Especially in Senegal, AGRICAB's impact on institutional capabilities was notable. Thanks to a successful cooperation and strong efforts by local partner CSE, the Department of Agricultural Statistics in the Ministry of Agriculture (DAPSA) signed a new partnership agreement with CSE and established a remote sensing cell for an efficient coordination role on the use of remote sensing for agricultural monitoring. On the other hand, AGRICAB reinforced the Multi-disciplinary Working Group (GTP), which advises and coordinates the national early warning system and food security policy across several ministries and governmental agencies, and regularly publishes crop growth monitoring bulletins.

In Kenya, the implementation of the AGRICAB project enabled first steps in exchange and collaboration between different governmental departments. In the domain of data sharing, the DRSRS signed a draft of Memorandum of Understanding with the Kenyan Meteorological Service (KMS). DRSRS also contacted the Ministry of Agriculture to harmonize statistical data and information on agriculture.

At same time, AGRICAB stimulated national institutes to join international Earth Observation efforts. For instance, when Senegal officially became member of the Group on Earth Observations (GEO), local partner CSE was assigned as GEO Principal – the focal point for all GEO matters in the country. Following the launch of AfriGEOSS, the pan-African coordination initiative developed in the framework of GEO, and using the synergy with the AGRICAB project implementation, the representatives of the CSE took up an active role in AfriGEOSS activities since 2013. Today, Senegal is one of the six members of the steering committee of the AfriGEOSS, representing western Africa.

In an attempt to further increase GEO memberships of African countries, Kenyan partner DRSRS submitted GEO enrolment documents to the GEO Secretariat. AfriGEOSS is sharing EO data with the DRSRS on a regular basis, and a representative from the DRSRS was invited to the GEO Plenary (November/2015) to achieve more close connection with GEO and AfriGEOSS activities.

The creation of a new multi-disciplinary network for western Africa, called GeosNet-Africa, at one of the workshops conducted by Africa was a relevant result as well.

3.1.2 Impact on human capacities

During the AGRICAB project implementation, a total of 47 hands-on training workshops were organized, with focussed national or broad international scopes and participation. These workshops, along with a dozen stakeholder consultation meetings, helped to enhance the existing scientific and technical capabilities of local experts and institutions, to raise the awareness of decision makers (mainly national policy makers) on the potential added value of EO and to ensure that the applications met actual needs in sustainable management of agriculture and forest resources.

These trainings and workshops were aligned the sustained data flow via GEONETCast and image processing software to build the use cases in the focus countries, before exposing their outcome and multiplying the impact on the regional and pan-African levels, with two GEO workshops organized in Africa and raising awareness to AU policy makers.

For instance, the open, international workshops, first on GEONETCast, data access and software tools, later on sharing the experience of the use case developments at regional levels, were organized with a balanced mix of academia and operational institutes, favouring the project's focus countries and accounting for experience by the regional training hosts – OSS, AGHRYMET and RCMRD and working language of the participants. The participation was particularly extended to representatives of existing networks, for instance from AMESD/MESA SADC Thema, the international NGO Action Contre La Faim (ACF, Action Against Hunger) or the OSFAC forest observatory for central African countries, to inspire further replication.

On the other hand, the training for crop use case developments started off with six weeks of intensive technical training, only for the project partners, in Europe. This was then followed by a number of workshops for relatively small, preferably multi-disciplinary groups.

In addition, the project greatly benefited from previous projects and training experiences in which methods, protocols, GEONETCast data access and software were developed like those from JRC's MARS unit or ESA-funded GMFS and EU-funded FP6-VGT4Africa and FP7-DevCoCast projects.

The common denominator in the training concept being the very hands-on practice, centered around the development of use cases, using local datasets and answering specific issues that the use case countries face.

Finally, AGRICAB achieved impact on higher education. AGRICAB partner UEM was able to integrate components of time series analysis of EO data for early warning and agricultural monitoring into the curriculum of their MSc in Geography. The project furthermore contributed directly to the financial, technical and scientific support of three PhD, and two MSc theses on forestry monitoring and three PhD fellowships and one post-doc on livestock monitoring.

3.1.3 Impact on infrastructure capacities

The infrastructure capacity was strengthened by installing and expanding the GEONETCAST ground reception station network and acquisition of ICT equipment for e.g. fieldwork. AGRICAB installed stations in Kenya, Burkina Faso and Tunisia and supported existing installations in Ethiopia and Ivory Coast (see section 2.1). From data availability point of view, the technical and infrastructure capacity was also enhanced by availing daily meteorological data from European MARS programme.

3.2 Main dissemination and outreach activities

3.2.1 Attendance at workshops, conferences and meetings

Results of the AGRICAB project were presented at a large number of conferences, seminars and meetings as well as dedicated briefings to African Union policy officials. An overview is provided in Table 3-1.

Table 3-1 Conferences and meetings at which the AGRICAB project was presented

Title	Location	Date (dd/mm/yyyy)
European Geosciences Union 2012	Vienna, Austria	23-27/04/2012
Sentinel-2 preparatory symposium	Frascati, Italy	23-27/04/2012
6th EU GEO European Project's Workshop (GEPW6)	Rome, Italy	7-8/05/2012
1st SA GEO symposium	Cape Town, South Africa	11-12/09/2012
IEEE IGARSS 2012	Munich, Germany	22-27/07/2012
10th EUMETSAT User Forum in Africa	Addis Ababa, Ethiopia	1-5/10/2012
AARSE 2012	El Jadida, Morocco	29/10-2/11/2012
7th EU GEO Projects Workshop (GEPW)	Barcelona, Spain	15-16/04/2013
35th International Symposium on Remote Sensing of the Environment (ISRSE)	Beijing, China	22-26/04/2013
GEO Work Plan Symposium	Geneva, Switzerland	4-6/05/2013
Conference on food security of University Gaston Berger of Saint-Louis	Saint-Louis, Senegal	1-5/06/2013
EARSeL 5th Workshop on Remote Sensing for Developing Countries	Matera, Italy	5/06/2013
MultiTemp 2013	Banff, Canada	25-27/06/2013
Probing Vegetation conference	Antwerp, Belgium	4-5/07/2013
Scientific & technical research seminar on livestock and food security - University Abdou Moumouni	Niamey, Niger	2-4/09/2013
2nd annual SA-GEO Symposium	Fort Hare University, South Africa	10-12/09/2013
International Alumni Expert Seminar	Siegen, Germany	15-21/09/2013
EUMETSAT - AMS conference	Vienna, Austria	16-20/09/2013
AfricaGIS 2013 - GSDI 14 Global Geospatial Conference	Addis Ababa, Ethiopia	4-8/11/2013
Colloque Internationale Geographie	Abidjan, Ivory Coast	11-16/11/2013
be-troplive conference 'Pastoralism - Where does it go in an ever changing context?'	Brussels, Belgium	14/11/2013
International Meeting on Food Security, Earth Observation and Agricultural Monitoring	Brussels, Belgium	21/11/2013
JAXA Kyoto & Carbon Scientific Team Meeting 3rd phase	Tokyo, Japan	4-6/12/2013 1
GEO X Week	Geneva, Switzerland	12-17/01/2014
Global Vegetation Monitoring and Modelling (GV2M)	Avignon, France	3-7/02/2014
8th European GEO Projects Workshops (GEPW8)	Athens, Greece	12-13/06/2014
XXVIIe Colloque de l'Association Internationale de Climatologie	Dijon, France	2-5/07/2014

Title	Location	Date (dd/mm/yyyy)
IEEE IGARSS 2014	Quebec City, Canada	14-18/07/2014
11th EUMETSAT User Forum in Africa	Johannesburg, South Africa	8-12/09/2014
Information for Meeting Africa's Agricultural Transformation and Food Security Goals (IMAAFS)	Addis Ababa, Ethiopia	1-3/10/2014
EAU4Food seminar	Brussels, Belgium	1/10/2014
AARSE 2014	Johannesburg, South Africa	27-31/10/2014
GEO XI Plenary	Geneva, Switzerland	13-14/11/2014
JAXA Kyoto & Carbon Scientific Team Meeting 4th phase	Kyoto, Japan	3-5/12/2014
Meeting with NEPAD and CAAPD	Addis Ababa, Ethiopia	29/01/2015
AGRICAB Final meeting	Antwerp, Belgium	23/03/2015
8th Joint Annual Meetings of the African Union Specialized Technical Committee on Finance, Monetary Affairs, Economic Planning and Integration and the ECA Conference of African Ministers of Finance, Planning and Economic Development	Addis Ababa, Ethiopia	25-31/03/2015
UN-ECA High Level Conference on Data Revolution	Addis Ababa, Ethiopia	27-29/03/2015
Gender & Climate Change Agriculture Support Programme meeting	Addis Ababa, Ethiopia	29/03/2015
10th International Conference on ICT for development, education and training: eLearning Africa	Addis Ababa, Ethiopia	20/05/2015
9th EU GEO Projects Workshop	Kopenhagen, Denmark	16/6/2015
GEO XII Plenary and Ministerial	Mexico City	9/11/2015

3.2.2 Publications and outreach materials

a. Peer-reviewed publications

In total eight (8) AGRICAB-related peer-reviewed publications were published or are in press, and at least five (5) more are currently being reviewed. These were of course complemented by a number of presentations, posters and papers for conference proceedings. Please see the related Plan for Use and Dissemination or the project website for more details on those.

- Archibald S, Lehmann CER, Gómez-Dans JL, Bradstock RA (2013). Defining pyromes and global syndromes of fire regimes. *Proceedings of the National Academy of Sciences of the USA*, 110(16), pp.6442–6447.
- Fisher J, Witkowski E, Erasmus B, Mograbi P, Asner G, van Aardt J, Wessels K, Mathieu R (in press). What lies beneath: Detecting sub-canopy changes in savanna woodlands using a 3D classification method. Applied Vegetation Science. *Applied vegetation Science*. DOI: 10.1111/avsc.12160.
- Mathieu R, Naidoo L, Cho M, Leblon B, Main R, Wessels K, Asner G, Buckley J, Van Aardt J, Erasmus B, Smit I (2013). Structural assessment of semi-arid African savannahs and woodlands: the potential of multitemporal polarimetric RADARSAT-2 fine beam images. *Remote Sensing of Environment*, 138, pp.215-231.
- McGlinchy J, van Aardt J, Rhody H, Kerekes J, Ientiluci E, Erasmus BNF, Asner GP, Mathieu R, Wessels W, Knapp D, Kennedy-Bowdoin T, Wu J, Sarrazin D (2014). Extracting structural vegetation components from small-footprint waveform LiDAR for biomass estimation in savannah ecosystems. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 7(2), pp.480-490.

- Mograbi, PJ et al. (In Review). Biomass increases go under cover: Woody vegetation dynamics in South African rangelands. *PLOS One*.
- Naidoo L, Mathieu R, Main R, Kleynhans W, Wessels KJ, Asner G, Leblon B (In Review). Savannah woody structure modelling and mapping using multi-frequency (X-, C- and L-band) Synthetic Aperture Radar remote sensing datasets. *ISPRS Journal of Photogrammetry and Remote Sensing*.
- Naidoo L, Mathieu R, Main R, Wessels KJ, Asner G (In Review). Integration of Optical and L-band Synthetic Aperture Radar (SAR) datasets for the regional assessment of woody fractional cover in the Greater Kruger National Park region. *ISPRS Journal of Photogrammetry and Remote Sensing*.
- Sircely, J (In review). Accuracy and reliability of biomass harvest methods for net primary production in grasslands. *Ecosystems*.
- Toté C, Patricio D, Boogaard H, van der Wijngaart R, Tarnavsky E, Funk C (2015). Evaluation of satellite rainfall estimates for drought and flood monitoring in Mozambique. *Remote Sensing*, 7, 1758–1776.
- Urbazaev M, Thiel C, Schmullius C, Mathieu R, Naidoo L, Levick S, Smit IPJ, Asner G (In Review). Mapping of fractional woody cover using ALOS PALSAR L-band backscatter in the Kruger National Park region, SA. *Remote Sensing of Environment*.
- Wessels KJ, Colgan MS, Erasmus BFN, Asner GP, Twine WC, Mathieu R, van Aardt JAN, Fisher J, Smit IPJ (2013). Unsustainable fuelwood extraction from South African savannahs. *Environmental Research Letters*, 8(1) 014007, 10pp.
- Wessels KJ, Erasmus BFN, Colgan M, Asner GP, Mathieu R, Twine W, Van Aardt JAN, Smit I. Impacts of communal fuelwood extraction on LiDAR-estimated biomass patterns of savanna woodlands. *IGARSS 2012, IEEE, July 22-27 2012, Munich, Germany*. ISBN 978-1-4673-1160-1.
- Yue C, Ciais P, Cadule P, Thonick K, Archibald S et al. (2014) Modelling fires in the terrestrial carbon balance by incorporating SPITFIRE into the global vegetation model ORCHIDEE - Part 1: Simulating historical global burned area and fire regime. *Geoscientific Model Development Discussions*, 7, pp. 2377-2427.

b. Videos

AGRICAB produced or contributed to three low-cost videos.

The first one focuses on the use of remote sensing for improved food security (Figure 3-1a). It shows in particular the collaboration with AGRICAB partners in Senegal (CSE) and Mozambique (INAM and UEM), the time series analysis software (SPIRITS) that was used in several training workshops and crop application efforts and finally the time series viewer demonstration portal.

Secondly, to illustrate on-going partnerships between European and African scientists and stakeholders, the European Commission and a number of its Africa-related FP7 projects jointly developed a set of documentaries, produced by the non-profit Africa Turns Green (http://www.africaturnsgreen.org). One of the documentaries (Figure 3-1b) includes a Kenyan example of AGRICAB's efforts to strengthen capacities in the use of EO for agriculture management. It also nicely captures the added value of remote sensing as a technology for Africa's sustainable development.

Finally, on behalf of AGRICAB project, VITO joined efforts with the GEO Secretariat, the Fraunhofer Institute, the Open Geospatial Consortium (OGC), EUMETSAT and the South African Department of Science and Technology in collecting inputs for the production of a GEO showcase video. This resulted from a selection process between 20+ proposals. Further contributions came from CSIR's Meraka institute, the UN Economic Commission for Africa (UN-ECA) and the European Commission. The video was one of the five GEO showcase videos that were put together for the GEO Plenary and Ministerial Summit in January 2014 (Figure 3-1a). The other videos are available on the GEO website (http://www.earthobservations.org).

a

b

c

Figure 3-1 Three videos that AGRICAB produced or contributed to (available online at http://www.agricab.info/video): a. Video on 'Remote sensing for improving food security over the globe', b. Documentary 'Agriculture, Water and Climate Change in Africa!', and c. 'GEOSS in Africa: building on success'

c. Brochures, press releases and non-scientific publications

The project partners published the following brochures:

- GEO and AfriGEOSS showcase brochure on Senegal entitled 'Strengthening Earth Observation capacities to support Senegal's agriculture policy', which was published on the project and GEO web sites in April 2015.
- Brochure on the 'Africa Platform for Knowledge & Data sharing on EO'
- Project factsheet, finalized in March 2012.

Further contributions were made to two brochures and one other publication from the European Commission in 2013 and 2014, highlighting the European Capacity Building efforts in contribution to GEOSS, from EUMETSAT on its African activities and on GEONETCast and two brochures from the GEO Secretariat (see also http://www.earthobservations.org/documents.php).

The following press releases were disseminated:

- '*How should we burn our landscapes?: The question of fire abatement programmes for Africa*', at the occasion of the 9th SAFNet Meeting in Tanzania (February/2013).
- Announcement of the project's final meeting, published in March/2015 and copied also to a few web sites of the European Commission.
- Release of the demonstration version of the Time Series Viewer portal via social media.
- Water bodies post on social media in relation to World Water Day (March/2014).

The following newsletter articles were published:

- '*The AGRICAB project: Developing increased Earth Observation capacity for better agriculture and forestry management in Africa*', published in the EARSeL newsletter 89, March/2012.
- '*AGRICAB – Developing increased EO capacity for better agriculture and forestry management*', published in the EISAfrica newsletter edition 126 in January/2013.
- '*Developing increased EO capacity for better agriculture and forestry management in Africa*', published in SDI-Africa newsletter volume 12, number 3, in March/2013.

In addition to 13 posters for scientific conferences, the project partners created the following posters for outreach purposes:

- '*Improving agriculture and forest management capacities in Africa: the AGRICAB project*', prepared by VITO for the EU GEO Projects workshop in Italy, in May/2012
- '*Crop monitoring & early warning in Kenya using EO data*' prepared by DRSRS for the GEO XI Plenary in Switzerland, in November/2014
- '*The georeferenced sampling approach in Senegal's agricultural statistics*' prepared by CSE around the end of the project, for future outreach purposes.

3.3 Exploitation of results

The principal objective of this AGRICAB project was to strengthen the existing Earth Observation capability of the partner countries in Africa, especially with the applications in the domains of agriculture and forestry. This strengthening of capability was most visible on the aspects of knowledge transfer and infrastructure built-up.

At the end of the project implementation in March 2015, most technological components developed in this project can be run at pilot or prototype level. Some monitoring activities can even run at operational level such as the crop growth monitoring and crop area assessment in Senegal.

A further exploitation of the results needs the support and involvement of local and/or international institutions, in particular to address the identified gaps in phenological and meteorological data sharing, the collaboration on training, the involvement of the CGIAR network or the further elaboration of a true pan-African Community of Practice.

On the other hand, the project's results paved a solid way for a further multi-disciplinary agricultural monitoring based on the agro-meteorological modelling, remote sensing and a modern agricultural statistics application.

In the domain of livestock and based on the results obtained in AGRICAB, further study can be performed leading to a complete agricultural insurance product adapted to the local pastoral situation or improvements to operational biomass estimation.

Regarding the woody cover and biomass monitoring in southern Africa, the results obtained in the project will be further fed into conservation policy and planning (for instance for invasive alien plant removal), carbon stock assessment, and contribute towards adaptive land management, especially on the fire management plan to better represent fire size, frequency, and seasonal aspects of fire. On the other hand, further research based on these results will enable us to strengthen our collaboration with the specialized institutions and networks including South Africa Fire Network (SAFNet) and the Miombo Network.

Finally, it can be noted that several components and experiences have already been continued in various programmes and projects such as the Copernicus Global Land Service (time series viewer portal), MESA (Moodle experience and sharing training material via GEONETCast) or FP7-SIGMA (jointly developed procedures in early warning, crop modelling and yield forecasting) or the Germany-supported Southern African Science Centre for Climate Change and Adaptive Land Management (SASSCAL).

While scattered, it is clear that the work and the innovative, equal parternship between African and European institutes are set to continue, with AGRICAB's partners eager to team up again in order to contribute to the next 10 years of GEO.

4 Website and contact

The website of the AGRICAB project, hosted by VITO, can be reached at http://www.agricab.info.

For more information on the project and its activities, please address VITO as overall coordinator via:

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