The AGRICAB project: Developing increased Earth observation capacity for better agriculture and forestry management in Africa

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Abstract

This paper gives an overview of the upcoming efforts and activities in the recently started AGRICAB project 'A Framework for enhancing earth observation capacity for agriculture and forest management in Africa as a contribution to GEOSS', which main focus is to integrate European and African research capacity and advances in the use of Earth observation technology for agriculture and forestry. One of the key challenges in the future is to enhance scientific and remote sensing capacity in Africa to enable African institutes to independently monitor and generate information on their natural resources to adequately support management and policy actions. Apart from the sustained provision of (derived) EO data, the project aims at a continued and better exploitation of and access to satellite data. Twinning partnerships between African and European institutes are being set up in order to integrate EO and predictive modeling in agriculture and forest management in different themes: yield forecasting for food crops, early warning and agricultural mapping of food crops, agricultural statistics, livestock and rangeland monitoring, and forest and forest fire monitoring. For more information: www.agricab.info and agricab@vito.be.

Résumé

Cette publication décrit les futurs efforts et activités du projet AGRICAB qui a démarré récemment. AGRICAB est 'Une structure pour le renforcement de la capacité d'observation terrestre pour la gestion de l'agriculture et de la forêt en Afrique comme contribution à GEOSS' dont le but principal est d'intégrer les capacités de recherche et les progrès européens et africains dans l'utilisation des technologies d'observation de la Terre pour l'agriculture et la sylviculture. Un des principaux défis pour l'avenir est de renforcer les capacités scientifiques et de la télédétection en Afrique pour permettre aux instituts africains de surveiller de manière indépendante et générer des informations sur leurs ressources naturelles pour soutenir la gestion et les actions politiques. Outre la livraison soutenue des données d'OT (dérivés), le projet vise à mieux exploiter et améliorer l'accès continu aux données satellitaires. Le partenariat entre les instituts africains et européens sont mis en place afin d'intégrer l'OT et la modélisation prédictive de l'agriculture et de la gestion forestière dans les différentes thématiques: les prévisions de rendement pour les récoltes, l'alerte rapide et la cartographie agricole, les statistiques agricoles, le suivi du bétail, la surveillance des pâturages, des forêts et des incendies. Pour plus d'informations: www.agricab.info et agricab@vito.be.

Keywords: Africa, agriculture, forest, Earth observation, capacity building, GEONETCast

1. Introduction

Science plays a key role in understanding the dynamics of agricultural and forest resources. As humanity places ever greater demands on the Earth's resources, a greater ability to understand global change and predict how natural systems will respond to human activities and policies becomes more vital every day (GEO, 2010). An important tool in this respect is remote sensing, which provides recurrent information on natural resources. The Global Earth Observation system of Systems (GEOSS) provides decision-support tools to a wide variety of users. Nevertheless, training programs are essential for building capacity in Earth observation (EO) and geo-information sciences, particularly in developing countries. A key challenge is to enhance scientific and remote sensing capacity in Africa to enable African institutes to independently monitor and generate information on agricultural and forest resources to adequately support management and policy actions.

The main focus of the recently started AGRICAB project entitled 'A Framework for enhancing earth observation capacity for agriculture and forest management in Africa as a contribution to GEOSS', funded by EC-FP7, is to integrate European and African research capacity and advances in the use of EO technology for agriculture and forestry. The project consortium consists of 17 partners located in 12 different countries (5 in Europe, 10 in Africa and 1 in South America, see Table I).

Table I The AGRICAB consortium

Name	Country	Website
Flemish Institute for Technological Research (VITO)	Belgium	www.vito.be
International Livestock Research Institute (ILRI)	Kenya	www.ilri.org
University of Liege (ULG)	Belgium	www.ulg.be
Regional Centre for Mapping of Resources for Development (RCMRD)	Kenya	www.rcmrd.org
ITC, University of Twente	The Netherlands	www.itc.nl
Instituto Nacional de Meteorologia (INAM)	Mozambique	www.inam.gov.mz
Centre Regional AGRHYMET	Niger	www.agrhymet.ne
Consorzio ITA	Italy	www.itacon.it
Alterra	The Netherlands	www.alterra.wur.nl
Centre de Suivi Ecologique (CSE)	Senegal	www.cse.sn
Department of Resource Surveys and Remote Sensing (DRSRS)	Kenya	www.environment.go.ke
Universidade Eduardo Mondlane (UEM)	Mozambique	www.uem.mz
Observatoire du Sahara et du Sahel (OSS)	Tunisia	www.oss-online.org
Council for Scientific and Industrial Research (CSIR)	South Africa	www.csir.co.za
GeoSAS	Ethiopia	www.geosas.net
Instituto Nacional de Pesquisas Espaciais (INPE)	Brazil	www.inpe.br
DEIMOS Imaging	Spain	www.deimos-imaging.com

Apart from the sustained provision of (derived) EO data, the project aims at a continued and better exploitation of and access to satellite data. Twinning partnerships between African and European institutes are being set up in order to integrate EO and predictive modeling in agriculture and forest management in different themes: (i) yield forecasting for food crops, (ii) early warning and agricultural mapping of food crops, (iii) agricultural statistics, (iv) livestock and rangeland monitoring, and (v) forest and forest fire monitoring.

The rapid expansion of EO based information services to society requires continuous knowledge gain and scientific know-how expansion by various user communities. The concept of AGRICAB is to enhance local capacity and knowledge transfer for developing a sustainable data and information management capacity. AGRICAB intends to allow African partners: (i) to get exposed to state-of-the art techniques and models for agricultural and forest monitoring, (ii) to discover these techniques and models through workshops and dedicated training, (iii) to gain experience in the application of these techniques and models on the local conditions in various use cases, and finally, (iv) to adapt appropriate models for integration in the local operational workflows (Figure 1). Through different use cases, located in North-Africa, Senegal, Kenya, Niger, Mozambique and South Africa, specific methodologies will be adapted to local conditions and demonstrated in different agro-meteorological conditions. In the coming years, a series of national and regional training workshops will be organized in Tunisia, Niger, Senegal, Kenya, Mozambique and South-Africa to diffuse the outcomes of these use cases to a wide user community.

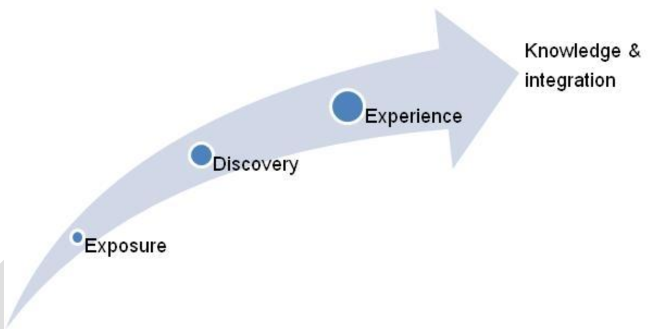

Figure 1 Framework for increasing capacity through AGRICAB

This paper aims to give an overview of the upcoming efforts and activities in the AGRICAB project, and to provide the reader with the necessary links to get further informed about the progress and results of AGRICAB and the workshops organized within the frame of the project. In the following chapters, this article focuses on the main tasks of the project: data provision, software development, the use cases in Africa, and training and outreach.

2. Data provision

Reliable access to environmental data is critical for decision making (GEO, 2010). As often heard in stakeholder feedback and recommendations, the appropriate use of EO data and service development requires the open sharing and availability – at no or low cost to the user – of timely and continuous EO data and derived information products, as well as efficient and state-of-the-art data management, analysis and processing tools and techniques.

GEONETCast is a global, near-real time, environmental data dissemination system in support of the GEOSS (Jungbluth et al., 2011). The system is an interconnected global network of regional dissemination systems (Wolf and Williams, 2008) and has proven successful as a central, reliable technology for data sharing, since it is a low-cost information delivery system that transmits satellite and in-situ data, products and services from data providers to users through commercial communication satellites. The required reception systems are based on off-the-shelf low-cost components and are typically not more expensive than 1400 euro (Wolf and Williams, 2008).

One of the objectives of AGRICAB is therefore to sustain and expand the provision of EO data and derived information products through GEONETCast, the complementary ESA Data Dissemination System (DDS, Badessi et al., 2002) which currently disseminates the products that are used for the Global Monitoring for Food Security service (Bydekerke et al., 2007). This includes a continuation of the hub concept which was set up in the frame of the DevCoCast project and is meant for central data gathering, prioritizing and scheduling as add-on to the Euro-African regional GEONETCast Networking Centre (EUMETCast service) operated by EUMETSAT. The following datasets are foreseen to be fed into the GEONETCast system: SPOT-Vegetation data and derived indicators, Landsat data, CBERS data, DEIMOS-1 data, AGRHYMET data, and possibly newly developed products. For more information on GEONETCast reception in Africa, consult www.eumetsat.int.

3. Software development

The provision of EO data and services requires appropriate tools to ensure that the received products are properly ingested, managed and used. Another objective of AGRICAB is therefore to continue providing and improving direct user support and free software to efficiently manage and use the shared EO products. For this purpose, the project builds on the GEONETCast Toolbox extensions of ILWIS (Mannaerts et al., 2009) and the GEONETCast Data Manager, the Spring, TerraLib (Camara et al., 2008) and SigmaCast software developed by INPE, and state-of-the-art analysis tools such as VGTExtract, Glimpse and SPIRITS developed by VITO. In addition, continuous user support to a growing user community will be ensured, by means of training workshops and freely available training material, help desks and user forums.

4. Use cases in Africa

Even further than the sustained provision of data and user support regarding data reception and software and tools, AGRICAB aims at improving and sustaining the capacity for early warning, agricultural mapping, agro-meteorological modeling, agricultural statistics, livestock monitoring and forest mapping. These components are developed through specific case studies in North Africa, Senegal, Mozambique, Kenya, Niger and South Africa. Although the use cases are based upon current challenges the local partners and end users face, the country cases are developed in a regional context whereby the developed methods are applicable at a regional scale. The following sub-chapters give an overview of the themes treated in the use cases and the general objectives and methodologies that will be applied.

4.1 Early warning for agricultural monitoring

Food insecurity, a condition in which a population does not have access to sufficient safe and nutritious food over a given period to meet its dietary needs, persists in many parts of the world, although Africa is the continent most affected by famines and hunger. Remote sensing is particularly of use in the monitoring of the physical environment, climatic conditions and food production in the context of famine early warning systems. Food production is only one factor of food security, but it is recognized as an important parameter to assess food availability (Bydekerke et al., 2007). According to Justice and Becker-Reshef (2007) and the GEO, an operational system for monitoring global agriculture should encompass a component of effective early warning of famine, enabling the timely mobilization of an international response in food aid. Improved environmental monitoring and prediction systems (see also §4.3) can provide more effective early warnings, which may help governments to enhance agricultural development programs (Brown and Funk, 2008).

In the use case countries for early warning (Senegal, Kenya and Mozambique) staple food crops such as sorghum, grain maize, millet are mainly produced under rain fed conditions. Due to the irregularity of rainfall, crop production can be threatened by droughts and flooding. Early warning systems, operated by organizations like USAID (FEWSNET), FAO (GIEWS), AGRHYMET, SADC and RCMRD, monitor the production focusing on basic weather elements and vegetation related indices, in many cases with support from the ESA-funded Global Monitoring for Food Security project (Haub and Gilliams, 2010; Gilliams et al., 2011). Within the AGRICAB project, specific tools will be used to enable the local partner to perform or to improve their early warning activities, by using time series of satellite derived vegetation indicators and rainfall estimates.

4.2 Agricultural mapping

Crop masks and agricultural maps are a key baseline input for crop monitoring, early warning and agricultural statistics. Knowledge on the spatial distribution of agriculture allows to better stratify, an indispensible part of the agricultural statistics methodology (see also §4.4), and to focus crop monitoring and early warning activities. In specific case study areas, located in Senegal, Kenya and Mozambique, the suitability of different crop mapping methodologies will be tested based on a combination of very high resolution (VHR, e.g. 5m), high resolution (HR, e.g. 30m) and medium/low resolution (MR/LR, 250m – 1km). In many tropical areas with small scale farming, the main bottlenecks of the classification of distinct crop types are the small parcel size, the mixture with other land cover types, and the lower crop performance, which hampers the distinction between crops and the surrounding sparse vegetation (Delrue et al., in review). The advantage of VHR images is the spatial resolution, although the small scene size impedes regional crop mapping, whereas the HR images often have a large swath and a more frequent revisit time, which makes them appropriate to evaluate phenological development, in addition to spectral signatures of the different crop types. The relative advantage of MR/LR imagery is the high repeat frequency, which allows to use the phenological development to monitor crops (e.g. Eerens and Dong, 2005). Neural network sub-pixel classification techniques might be used to extrapolate the VHR information to HR images (Delrue et al., in review) or MR/LR images (Verbeiren et al., 2008). Within AGRICAB, local partners will be trained in classification techniques and field collection methods for agricultural mapping, using local datasets and data available through GEONETCast and other sources.

4.3 Agro-meteorological modeling for crop monitoring and yield forecasting

Crop production in the use case countries for agro-meteorological modeling (Senegal, Kenya and Mozambique) can suffer from droughts and flooding due to irregular rainfall. However, there is no operational service that combines the advantages of deterministic crop growth models and available EO-data sets to monitor and forecast the yield of rain fed arable crops. The objective within AGRICAB is to integrate basic input data in a deterministic crop model, calibrate and validate it for local conditions, and to model crop growth in a realistic way. A modeling solution based on the WOFOST model (Boogaard et al., 2011) will be adapted to the local needs and conditions, while focusing on large scale rain fed arable crops. The simulated crop indicators can then be entered in a statistical framework for crop yield forecast, based on the MARS Crop Yield Forecasting System (MCYFS) of the European Commission (Genovese and Bettio, 2004; Lazar and Genovese, 2004). Within AGRICAB, the local partners will be trained on the principles of crop modeling and selection and building of EO-based data infrastructures needed to run the crop growth model. The final goal is to demonstrate the operational crop monitoring service to a wide community of end users.

4.4 Agricultural statistics

In AGRICAB, satellite images will also be used to suggest improvements, at various levels, to the existing agricultural statistical systems in Kenya, Mozambique and Senegal, with focus on crop area statistics. In order to correctly introduce the use of satellite images in an existing agricultural statistical system, it is necessary to look at experiences from other countries where difficulties have been analyzed and solved for different landscapes, agricultural characteristics and climate conditions. On the application of remote sensing for area frame surveys, see for instance Gallego et al. (2008) and Benedetti et al. (2010). In addition, institutions and approaches currently applied to agricultural statistics in the countries selected for the use cases should be analyzed. An area sampling frame will be developed for small test areas in each country, and the use of satellite products will be tested as part of the proposed procedure. Once the sampling frame has been built, a ground survey will be executed, confirming the crops cultivated in each area sampling unit. The performance of the proposed improvements to the agricultural statistics system will then be tested and evaluated for the different components envisaged: sampling frame characterization for stratification purposes, sample extraction through appropriate statistical models (in accordance with the sampling frame characteristics and the available budget for the ground survey), ground survey carried out during the growing season by means of qualified surveyors, and final crop area estimates. The application of satellite imagery takes place at different stages: in the characterization of the sampling frame through visual interpretation of VHR images, in the preparation and execution of the ground survey as well as in the final estimation of the crop area, where classified images can be used as auxiliary variables for improving the precision of the estimates.

4.5 Irrigation agriculture monitoring in Northern Africa

Due to a rapid increase of ground water use for irrigated agriculture in arid zones, Algeria, Libya and Tunisia face the challenge to set-up an agriculture development action plan taking into account the sustainability of the unique water resource available which is shared by these three countries: the North Western Sahara Aquifer System (NWSAS). Within the ESA/AQUIFER and AfDB/GeoAquifer projects, national institutes in Algeria, Tunisia and Libya were supported in the use of satellite data, and the value of Earth observation in providing valuable information on deep groundwater resources through land cover and land use maps, vegetation monitoring and services related to withdrawal estimates was demonstrated. However, these projects could not fully meet the needs identified at country level, especially in terms of data accessibility, models and methodologies and capacity building. National services face difficulties to manage their water withdrawal databases due to illegal drilling. The objective of AGRICAB is to continue the previous efforts and elaborate on the use of remote sensing to address these challenges, through capacity building, implementation of land cover/land use mapping in 6 pilot areas (Figure 2), exploration of water balance models in order to monitor water abstraction at basin scale, and the application of a monitoring system within the national water services involved in the NSWAS consultation mechanism.

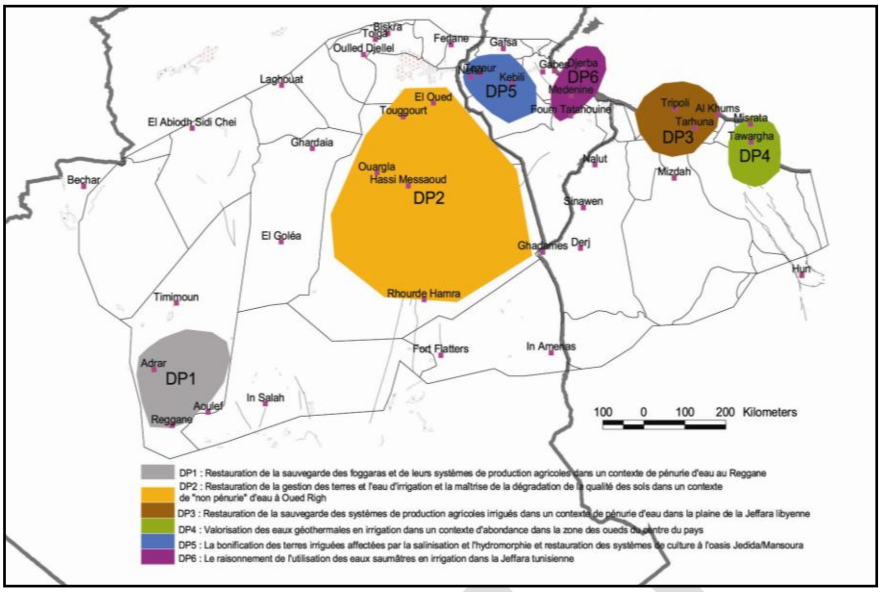

Figure 2 Location and thematic focus of the 6 pilot zones in North Africa (OSS/North-Western Sahara Aquifer System, phase 3 program)

4.6 Livestock monitoring

AGRICAB also focuses on livestock monitoring, and will develop use cases in Niger, Senegal and Kenya. Rangeland assessment and livestock monitoring can be improved by the calibration of the Dry Matter Productivity product (DMP, Veroustraete et al., 2002) derived from satellite observations and the integration of this product into early warning systems by coupling it with thematic data on livestock (Figure 3). Field campaigns will be organized to collect rangeland data, in order to calibrate the DMP product. Livestock early warning indicators can then be developed, integrating DMP, livestock productivity, livestock density and rangeland production field data.

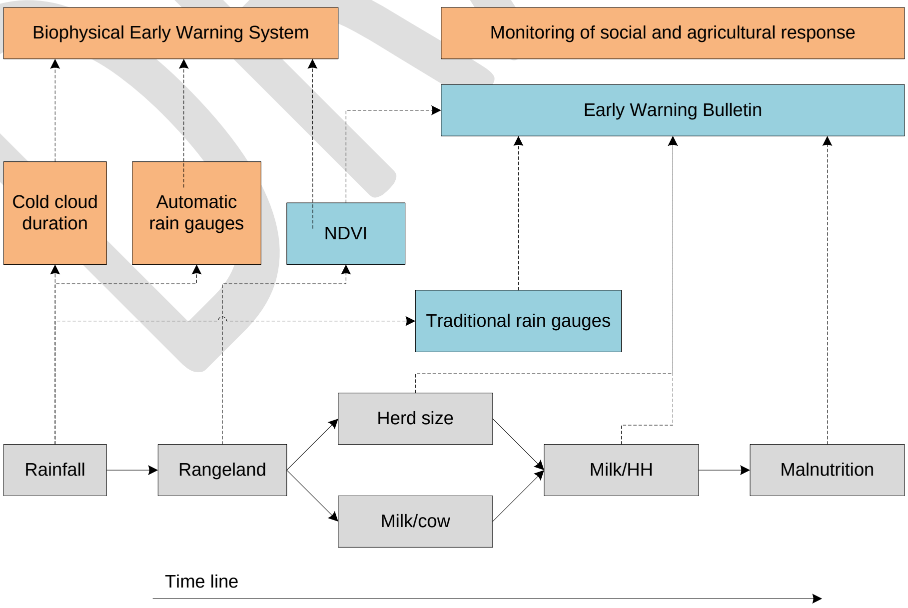

Figure 3 Rangeland biomass and livestock productivity for a complete livestock early warning system showing linkages and time delays between rainfall, rangeland greenness and productivity, livestock condition and productivity, and malnutrition indicators (adapted from Zwaagstra et al., 2010)

4.7 Forest mapping and forest fire monitoring

Tree cover information is essential for the sustainable management of vegetation resources, amongst which food security (bush encroachment and range productivity) and energy security (fuel wood and charcoal) are key components. Nevertheless, tree cover maps are lacking in many African countries, including South Africa, even at the local scale. Within AGRICAB, the aim is to develop EO technology to generate tree cover maps for savannas and woodlands – the most widely distributed biome in sub-Saharan Africa – with a focus on South Africa. The proposed approach relies on state-of-the-art non weather-dependent SAR technology. The task will undertake multi-scale assessment of techniques and models for tree cover measurement, including ground techniques, high resolution airborne LiDAR and optical approaches, and up-scaling to multi-frequency satellite borne SAR imagery.

In addition, the effect of human activities on fire regimes is not well understood in Africa. AGRICAB will help to increase this knowledge with the aim of being able to predict the consequences of future changes in land use and rural population densities. The objective is to enhance the use of existing EO products by promoting further applications. The historical and current burned area and active fire data will be mined to create more informative data products on fire return periods and fire size (Archibald et al., 2010) and the effect of different land management policies will be investigated.

5. Training and outreach

African policy and other decision-makers are increasingly faced with complex choices as to where and how action should be occurring to appropriately respond to global change. EO products present a powerful tool and information source on environmental and climate challenges in support of decision-making and awareness raising. While the status of use of EO products is variable in Africa, exposure to such products is not altogether new to individuals in these roles. Unfortunately, the understanding of EO products, and the analyses, observations and limitations that go into EO is sometimes limited. Consequently, the power of EO products and their ability to inform evidence-based policy development and implementation is severely hampered. While this gap between research output and evidence-based action is a significant challenge everywhere, it is especially pronounced in Africa. The AGRICAB project is tailored to build research application capacities in Africa, to enhance capacity building as well as to secure overall sharing and wider dissemination of results.

One of the objectives of AGRICAB is therefore to share information and to build capacity at different levels, namely local communities, government and multi-lateral institutions, and educational institutions. In the first stage of the project, tailored trainings will be organized for the African AGRICAB partners. Secondly, national stakeholder workshops and meetings will be organized in Senegal, Kenya, South Africa and Mozambique. The defined use cases involve a large number of national organizations. Throughout the duration of the project, multiple workshops and meetings will ensure active participation into the project. Thirdly, regional training workshops will be organized by the 3 regional partners in the project (AGRHYMET, RCMRD and OSS) specifically addressing use of EO to support agriculture and forest management. The trainings will be actively build around the use cases developed as described above, GEONETCast, and the tools and data made available. These workshops are intended to further trigger capacity across Africa and generate a multiplier effect. In addition to the workshops, web-based open access site for GEONETCast toolbox components, training material and user interaction is foreseen.

Enhancing capacity also means generating awareness of the capacity of EO based techniques to support agriculture and forest management. The activities within AGRICAB relate to developing a community of practice for Africa as an African contribution to the GEO agriculture community of practice. It will therefore be important for AGRICAB to integrate with already existing networks on agricultural research and policy.

6. Conclusion

The societal challenges to GEONETCast's success are centered on educating new user groups in the utility and possibilities of the system, including generating concrete user requirements and raising awareness and capacity to utilize Earth observation information among new target populations (Jungbluth et al., 2011). The activities within the AGRICAB project are designed to reinforce the GEONETCast system as a key component of the GEOSS data sharing framework by feeding the system with added value products based on high and low resolution imagery, and to bring the data closer to management information requirements by enhancing observations through predictive models. AGRICAB thereby focuses on five aspects which impact on food security: crop monitoring and yield forecasting, agricultural mapping and early warning, agricultural statistics, livestock monitoring resources and forest resources. Knowledge will be exchanged and capacity will be reinforced and sustained through dedicated training workshops in Europe and Africa, national and regional workshops and forums, with the final objective to increase awareness amongst the management and policy community. This paper gives an overview of the upcoming challenges for the AGRICAB consortium in the following years. For more information: www.agricab.info and agricab@vito.be.

References

Archibald, S., Scholes, R., Roy, D., Roberts, G., Boschetti, L., (2010). Southern African fire regimes as revealed by remote sensing. International Journal of Wildland Fire, vol.19, N°7, pp. 861-878.

Badessi, S., Moeller, H., Viau, P., Castrovillari, D., Collini-Nicker, B., 2002. The Envisat Data Dissemination System, ESA Bulletin 109, pp. 8.

Benedetti, R., Piersimoni, F., Bee, M., Espa, G. (Eds.), 2010. Agricultural Survey Methods. John Wiley and Sons.

Boogaard, H., De Wit, A., te Roller, J., Van Diepen, C., 2011. User Guide for the WOFOST Control Centre 1.8 and WOFOST 7.1.3 crop growth simulation model, Alterra, Wagening University & Research Centre, pp. 137.

Brown, M., Funk, C., (2008). Food security under climate change. Science, vol.319, pp. 580-581.

Bydekerke, L., Holecz, F., Haub, C., Tychon, B., Ragni, P., Vignaroli, P., Hendrickx, G., Heylen, C., 2007. The Global Monitoring for Food Security project: using ENVISAT MERIS and ASAR for monitoring agriculture in Africa, Envisat Symposium, Montreux, Switzerland, 23-27 April 2007.

Camara, G., Vinhas, L., Reis, K., Ribeiro, G., de Souza, R., Vieira, A., de Carvalho, M., Casanova, M., Moura, U., 2008. TerraLib: An Open Source GIS Library for Large-Scale Environmental and Socio-Economic Applications. In: G. Hall, M. Leahy (Eds.), Open Source Approaches in Spatial Data Handling. Advances in Geographic Information Science 2. Springer-Verlag Berlin Heidelberg, pp. 247-270.

Delrue, J., Bydekerke, L., Eerens, H., Gilliams, S., Piccard, I., Swinnen, E., (in review). Crop mapping in countries with small-scale farming: a case study for West Shewa, Ethiopia. International Journal of Remote Sensing, pp.

Eerens, H., Dong, Q., 2005. Monitoring crop yields and areas in Heilongjiang with 10-daily composites of SPOT-VEGETATION, Final meeting on Development of an Agri-environmental monitoring system for the Chinese province Heilongjiang, 1-2 June, 2005.

Gallego, J., Craig, M., Michaelsen, J., Bossyns, B., Fritz, S. (Eds.), 2008. Best practices for crop area estimation with Remote Sensing. JRC Scientific and Technical Reports.

Genovese, G., Bettio, M., (2004). Methodology of the MARS Crop Yield Forecasting System. Vol 4. Statistical data collection, processing and analysis. European Communities

GEO, 2010. Report on progress - Beijing Ministerial Summit - Observe, share, inform, GEO Secretariat, Geneva, Switzerland, pp. 147.

Gilliams, S., Bydekerke, L., Delrue, J., Haub, C., Brockmann, J., Tychon, B., Barbieri, M., Hoecz, F., Luccarini, F., Ragni, P., 2011. Global Monitoring for Food Security - Final Report stage 1 & 2, pp. 55.

Haub, C., Gilliams, S., 2010. GMFS service integration and know how transfer to Africa, ESA Living Planet Symposium, 28 June - 2 July 2010, Bergen, Norway.

Jungbluth, G., Fulton, R., Moodie, L., Seymour, P., Williams, M., Wolf, L., Zhang, J., 2011. In: A. Sinha, D. Arctur, I. Jackson, L. Gundersen (Eds.), Societal Challenges and Geoinformatics (Special Paper 482). The Geological Society of America Inc., pp. 77-85.

Justice, C., Becker-Reshef, I., 2007. Report from the Workshop on Developing a Strategy for Global Agricultural Monitoring in the framework of Group on Earth Observations (GEO), 16-18 July 2007, FAO, Rome, Geography Dept., University of Maryland, pp. 66.

Lazar, C., Genovese, G., (2004). Agrometeorological data collection, processing and analysis. Methodology of the MARS Crop Yield Forecasting System. Vol 2. Agrometeorological data collection, processing and analysis. European Communities

Mannaerts, C., Maathuis, B., Molenaar, M., Lemmens, R., 2009. The ITC GEONETCast Toolbox: a GEO capacity building component for education and training in global Earth Observation & Geo Information provision to society, IGARSS2009, South Africa, pp. V385-V388.

Verbeiren, S., Eerens, H., Piccard, I., Bauwens, I., Van Orshoven, J., (2008). Sub-pixel classification of SPOT-VEGETATION time series for the assessment of regional crop areas in Belgium. International Journal of Applied Earth Observation and Geoinformation, vol.10, N°4, pp. 486-497.

Veroustraete, F., Sabbe, H., Eerens, H., (2002). Estimation of carbon mass fluxes over Europe using the C-Fix model and Euroflux data. Remote Sensing of Environment, vol.83, pp. 376-399.

Wolf, L., Williams, M., (2008). GEONETCast - Delivering environmental data to users worldwide (September 2007). IEEE Systems Journal, vol.2, N°3, pp. 401-405.

Zwaagstra, L., Sharif, Z., Wambile, A., de Leeuw, J., Said, M., Johnson, N., Njuki, J., Ericksen, P., Herrero, M., 2010. An assessment of the response to the 2008-2009 drought in Kenya. a report to the European Union Delegation to the Republic of Kenya, ILRI, Nairobi, Kenya, pp. 108.