УДК 528.852

Выявление глобального потепления в процессе мониторинга сельскохозяйственных зон с применением многомасштабных методов дистанционного зондирования – Сообщение о ходе выполнения совместного германско-российского научно-исследовательского проекта «Устойчивое землепользование и стратегии адаптации к изменениям климата для сельскохозяйственной зоны Западной Сибири» (SASCHA)

Клаус Комп
EFTAS Remote Sensing Transfer of Technology, Германия, Oststrasse 2-18, 48145 Muenster, доктор наук, президент консультативного комитета, тел: +49-251-13 30 70, факс: +49-251-13 30 733, email:klaus.komp@eftas.com

Карстен Хауб
EFTAS Remote Sensing Transfer of Technology, Германия, Oststrasse 2-18, 48145 Muenster, инженер, руководитель отдела агрономического и ландшафтного мониторинга, тел: +49-251-13 30 70, факс: +49-251-13 30 733, email: carsten.haub@eftas.com

Андреас Фолькер
EFTAS Remote Sensing Transfer of Technology, Германия, Oststrasse 2-18, 48145 Muenster, эколог по ландшафту, руководитель проекта «SASCHA», тел: +49-251-13 30 70, факс: +49-251-13 30 733, email: klaus.komp@eftas.com

Оглядываясь назад на 40-летний период наблюдения Земли из космоса, мы понимаем, насколько нам помогли спутниковые изображения составить карту мира и даже самых отдалённых и сельских районов на всех континентах. Кроме того повторное перекрытие одних и тех же районов позволяют сегодня выявлять и временные изменения, а также выполнять последовательный мониторинг окружающей среды. В наш век глобализации растет спрос на быстрое обновление карт различного назначения, например, сеть автомобильных дорог, железнодорожная инфраструктура и развитие поселков. Но также и воздействие глобального изменения климата требует быстрого обновления пространственной информации по всем природным ресурсам: леса, пустыни, заболоченные территории и сельскохозяйственная деятельность.
На основе данных разработок и научных исследований в рамках проекта по глобальному мониторингу в целях продовольственной безопасности (GMFS), финансируемого Европейским космическим агентством (ESA) больше шести лет, было принято решение использовать ключевые инструментальные средства ALIS © interface для наблюдений за воздействием глобального потепления в сельскохозяйственной зоне Западной Сибири. Это и стало целью совместного германско-российского научно-исследовательского проекта «Устойчивое землепользование и стратегии адаптации к изменениям климата для сельскохозяйственной зоны Западной Сибири» (SASCHA), реализация, которого продолжается вот уже третий год. Вовлечены различные дисциплины и поставлены цели исследований с применением методов дистанционного зондирования Земли для анализа пространственных и временных изменений растительного покрова, создания баз данных ГИС для трех выбранных районов с одинаковым растительным покровом. Многочисленные результаты, включенные в данные ГИС, и карты будут использованы для дальнейшей разработки стратегий адаптации вместе с местными заинтересованными лицами, которые окажут неоценимую помощь экономике сельского хозяйства в выявлении воздействия глобального потепления на местном уровне.
Ключевые слова: глобальное потепление, мониторинг окружающей среды, стратегии по внедрению, многовременное дистанционное зондирование, сельскохозяйственное развитие, продовольственная безопасность, устойчивость.

TRACING GLOBAL WARMING BY AGRICULTURAL MONITORING USING MULTISCALE APPROACHES OF REMOTE SENSING – PROGRESS REPORT FROM THE GERMAN-SIBERIAN RESEARCH PROJECT «SASCHA»

Klaus Komp
EFTAS Remote Sensing Transfer of Technology, Germany,Oststrasse 2-18, 48145 Muenster, Dr., President of the Advisory Board, tel: +49-251-13 30 70, fax: +49-251-13 30 733, klaus.komp@eftas.com

Carsten Haub
EFTAS Remote Sensing Transfer of Technology, Germany,Oststrasse 2-18, 48145 Muenster, Agricultural Engineer, Head of Agronomic and Landscape Monitoring Division, tel: +49-251-13 30 70, fax: +49-251-13 30 733, carsten.haub@eftas.com

Andreas Völker
EFTAS Remote Sensing Transfer of Technology, Germany,Oststrasse 2-18, 48145 Muenster, Landscape Ecologist, Project Leader of «SASCHA», tel: +49-251-13 30 70, fax: +49-251-13 30 733, klaus.komp@eftas.com

1. INTRODUCTION

Remote sensing data from space have sustained worldwide mapping activities since four decades with growing importance. While in the beginning of space born remote sensing there was a strong emphasis on the reduction of unmapped white patches of the planet, the recent developments have allowed to enter into large scale mapping and repeated observation of landscape developments. Recent indicators for climatic change together with worrisome alterations in regional food production versus the constantly increase of human population demand the design and implementation of reliable land management tools which will serve the food security as well as the sustainable use of resources of the ecosystem in its respective regional context.

Around the world there are always the rural areas that suffer from incomplete or inconsistent maps and environmental data. Several studies have been executed by the United Nations which proof that rural areas have been mapped in smaller scales only and have not been updated for many years (e.g. Brandenberger 1987, Konecny 2013). The same applies for environmental data and GIS data bases. Only if we develop methods and operational approaches to monitor the rural environment, which means also the agricultural land use, we will gain spatial information to improve sustainable land management and food security.

The positive responses and convincing results of ESA service elements in the efforts towards food security in several African countries have been the basis for the transfer of the methods into another region, the Western Siberian corn-belt. The large extends of cropping schemes in West Siberia demand advanced remote sensing methods to be applied in order to compare the impacts of climatic change not only on the agricultural production but also on risks for the ecosystem. A multi scale approach of remote sensing methods is introduced in analogy to the African activities. An adopted monitoring concept is developed using a nearly daily product of medium resolution for wide areas, high resolution sensors for stratified sample areas and in-situ observations. Beyond methodological research, the ability of remote sensing is contributing to operational solutions that can ensure the nutritional and ecological future of our planet.

The Global Monitoring for Food Security (GMFS) focuses on those aspects of food security monitoring where satellite derived technology can bring added value. These include monitoring parameters reflecting crop condition, agricultural production and overall vegetation health. For test areas, it has established an operational service for crop monitoring in support of Food Security that can serve policy makers and operational users on various scales by providing spatial information on var-

iables that affect Food Security. In view of the global need for improved food security and sustainable land management schemes, the potential of methodological transfer of the African results into a moderate climate environment is being investigated through SASCHA. The SASCHA project focuses on regional shifts of agricultural production in consequence of changing environmental conditions. The joint reflection of different land management developments in different continents is using comparable methodological tools. The system adapts existing technologies from the Global Monitoring for Environment and Security (GMES) initiative to region-specific LULC classes. Related approaches have been earmarked by the World Bank, from the German Agency for International Cooperation and even the Millennium Challenge Corporation for many years, but without really turning around the situation of rural areas around the world (cf. Falloux 1989). Therefore demand driven approaches using remote sensing tools within processing chains as technology which can be managed in the hands of agronomic experts with local knowledge are the particular focus of GMFS and SASCHA.

2. SUSTAINABLE LAND MANAGEMENT AND LONG TERM FOOD SECURITY

2.1 Reciprocity between Food Security, Land Management and Climate

The impact of land management on food security can easily be illustrated by the following observations: global population passed the 7 billion milestone in 2011 and will reach 10 billion by 2050 (cf. Crossette 2011) on one hand; but already now more than 1 billion people on earth are affected by hunger and more than 30 countries are experiencing food emergencies (cf. FAO 2009). Looking at food emergencies, it seems utmost dangerous that biofuel production has increased sharply in the past few years (cf. Flammini 2008; Godvina 2010). The world is facing an increased crisis potential, as already over the last 60 years 40 % of all internal conflicts have had a link to natural resources (cf. UNEP 2011).

These alarming facts underline the overall significance of a responsible use of natural resources, which demands a monitoring of the current developments, and the research for improved methodological tools to be integrated into operational applications. Although the mapping or monitoring of complex agro ecological aspects by highly specialist remote sensing experts is done far away from the target areas, this innovative approach focuses on bringing adapted but easy to handle processing tools to local experts.

2.2 Operational Remote Sensing Services to Agriculture and Land Tenure

Geographers and other scientists have discussed since more than hundred years the carrying capacity of the earth. Fortunately most of the early figures of the middle of the 20th century have been topped by reality, and still it seems that the end of the fossil resources has not jet come and even the food resources have turned out to be bigger if managed properly. But since the Kyoto Protocol there was a world wired attention raised on the impacts of climate change, disasters and conflicts, soil and land degradation versus the increasing demand on food and energy production and the increasing global population span an area of conflict targeting land as prime ecosystem resource. Therefore it remains one of the challenging research topics, which can be summarized as follows: What potentials can an increased agricultural production provide in order to reduce the conflict between land degradation and land loss and the increasing pressure on the remaining land resources?

Tools to measure, describe, and assess sources and impacts of these land use conflicts request enormous efforts, but given the complexity, they are still not sufficient to provide answers. Although these conflicts have a global dimension their sources and solutions are at a regional or local level. Solutions by means of land resource management systems need to involve the regional and local stakeholders' networks. As such, geospatial information derived from satellite earth observation can contribute to implement structures for sustainable land management systems.

GMFS and SASCHA services are designed to contribute to this. Based on the highly innovative developments at the latest status of research and technologies, stakeholders of various thematic domains can get access to geospatial technologies but without the need to be experts in remote sensing or GIS. The processing tools are designed for experts and operators skilled in the fields of agricultural statistics or nature conservation who are non remote sensing experts. Either through very ro-

bust and clear processing steps (see indicative fAPAR maps processing below) or through advanced software developments which are systematically integrated into platforms, providing instruments with easy to use interfaces, but having access to advanced optical and radar remote sensing processing routines in the background. Specifically the software tools such as ALIS © (see figure 1) will facilitate knowhow and technology transfer and increase the availability and access for up to date remote sensing methodologies to non remote sensing experts, but also contribute to multi-scale geo information systems.
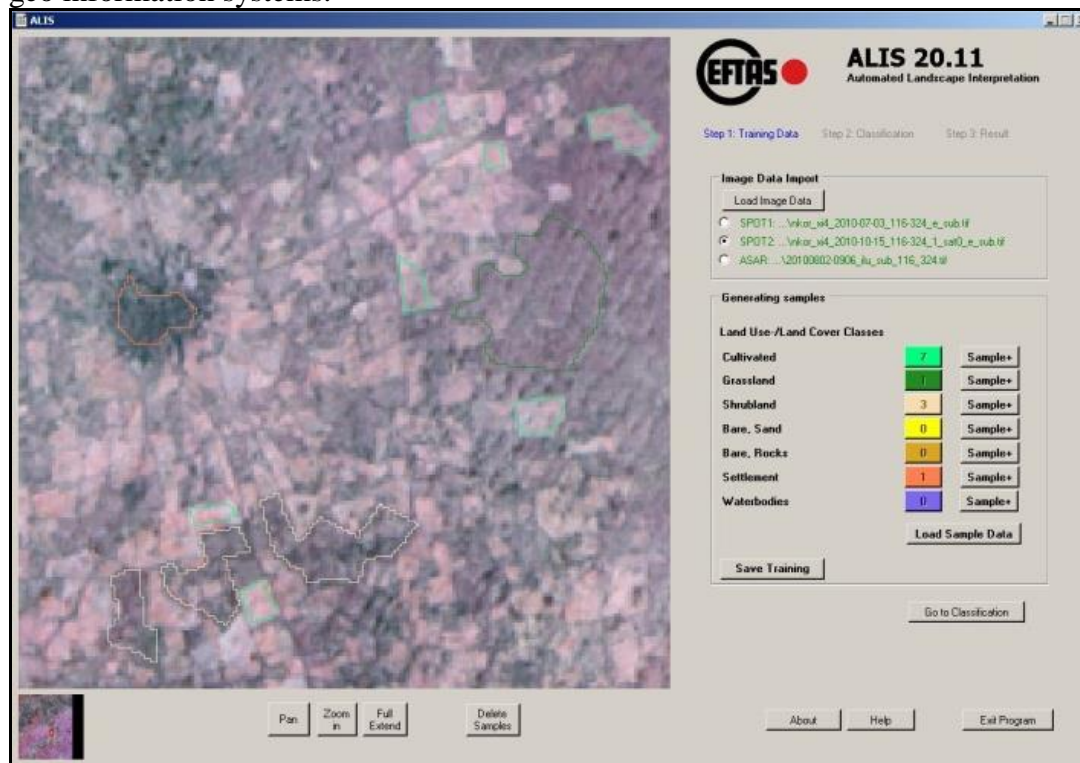

Figure 1: ALIS © interface for the GMFS CuA processing

2.3 Application Sites in the Sudan and beyond

The remote sensing community has developed a bundle of worthy tools for change detection of land cover which have grown beyond academic research into stable and reproducible application instruments. These achievements have been the precondition for the transfer of technology into the regional application in African administrative environments. This transfer was one of the driving goals for the European Space Agency (ESA) to start the project series of "Global Monitoring for Food Security in Africa" (GMFS) ten years ago. GMFS is part of ESAs contribution to the European Union / ESA Global Monitoring for Environment and Security (GMES) programme. It is the main European GMES Service Element in support of food security monitoring systems with remote sensing and GIS applications serving the food security sector in African countries. A consortium of seven European R&D partners lead by VITO (www.gmfs.info) jointly developed technical specifications and methodological improvements in remote sensing applications to early warning, biomass forecast, agricultural mapping, change maps, soil moisture indicators and agro statistical survey. The GMFS Service Portfolio is structured into three top-level service types. The agricultural monitoring service type provides processing routines to assess total planted crop land and its variability from one year to another with specific emphasis on the traditional rain fed agriculture production in Sudan. Agriculture production in Sudan is largely depending on seasonal variability and distribution, intensity, duration and period of rains. Large areas in the central Sudan are depending on traditional rain fed agriculture with the cropping of Sorghum and Millet mainly for personal consumption. This causes high vulnerability of a certain part of the Sudanese population. About 60% of the

Sudanese population are living in rural areas with an average population density of 14-17 people per km².

The creation of the annual cultivated area map uses the ALIS © software interface (figure 1), which is adopted for the application in the FMoA in Sudan in the frame of the GMFS project.
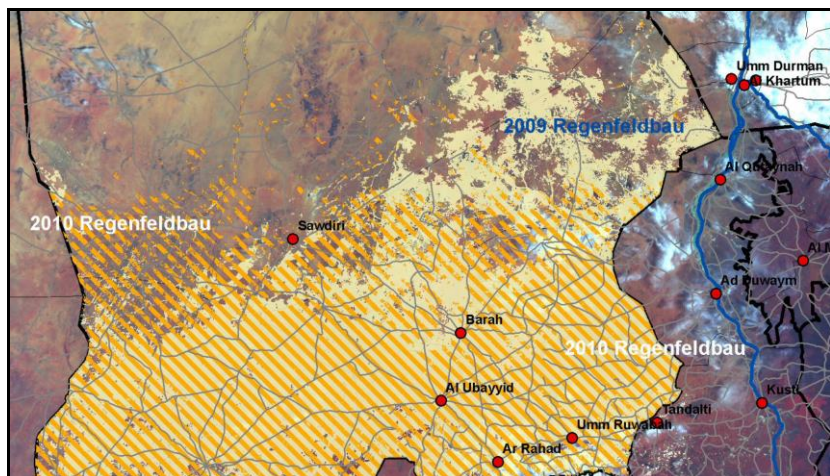

Figure 2: ENVISAT MERIS FR false colour composite (2010-09-12 – bands 13-5-1) overlaid with MERIS FR level 2 fAPAR data from 2009 versus 2010

Figure 2 shows the distribution of potential rain fed areas between the crop seasons 2009 (light yellow) versus 2010 (hatched light brown) in North Kordofan State, Sudan (Brockmann 2011). The thematic overlays show a decrease from North to South of the potentially cultivated area in the Eastern part of the state, while at the same time an increase is observed from the South towards the North in the Western part of the state. Compared to the official statistics of the FMoA, which estimate an increase of 10% of production in North Kordofan for the same period, the satellite data obviously indicate that there is much more spatial differentiation needed. Based on those annual EO application results, the FMoA is now improving its monitoring framework for the benefit of the rural population in the fragile environment of traditional rain fed agriculture.

3. AGRICULTURAL MONITORING SERVING RESEARCH ON CLIMATIC CHANGE
3.1 Project Background for Application Sites in the Western Siberian Corn Belt
The positive responses and convincing results have been the basis for the transfer of the methods into another region, the Western Siberian corn-belt. In a joint programme funded by the German Ministry for Education and Research and the Russian Ministry of Research, the project called "Sustainable Land Management and Adaption Strategies to Climatic Change for the Western Siberian Corn-Belt" (SASCHA) was started one year ago. The large extends of cropping schemes in West Siberia demand advanced remote sensing methods to be applied in order to compare the impacts of climatic change not only on the agricultural production but also on risks for the eco system. The experiences from the African activities will also introduce a multi scale approach of remote sensing data. From a nearly daily product of medium resolution (typically MERIS with 300m GSD) for wide areas, and high resolution sensors for stratified sample areas once per season to very high resolution data for stratified spot observation, the project will develop and establish an adopted monitoring concept.

The project SASCHA investigates interactional effects of climate and land-use change on natural resources and ecosystem functions in the Pre-Taiga and Forest-Steppe ecotone of Western Siberia. The interface between the steppe and the northern forest zone in Western Siberia is of global significance in terms of carbon sequestration, food production, and biodiversity. Affecting all these subject matters, climate change and rapid socio-economic development will trigger fundamental land use changes. The analysis of these former, present and future changes and their implications for es-

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sential ecosystem functions are the focus of the first project phase. Subsequently, sustainable land-use practices and adaption strategies to climate change will be developed. There were three test sites determined in cooperation between the Russian and German partners, all in the Siberian Corn Belt to the South East of the city of Tyumen.
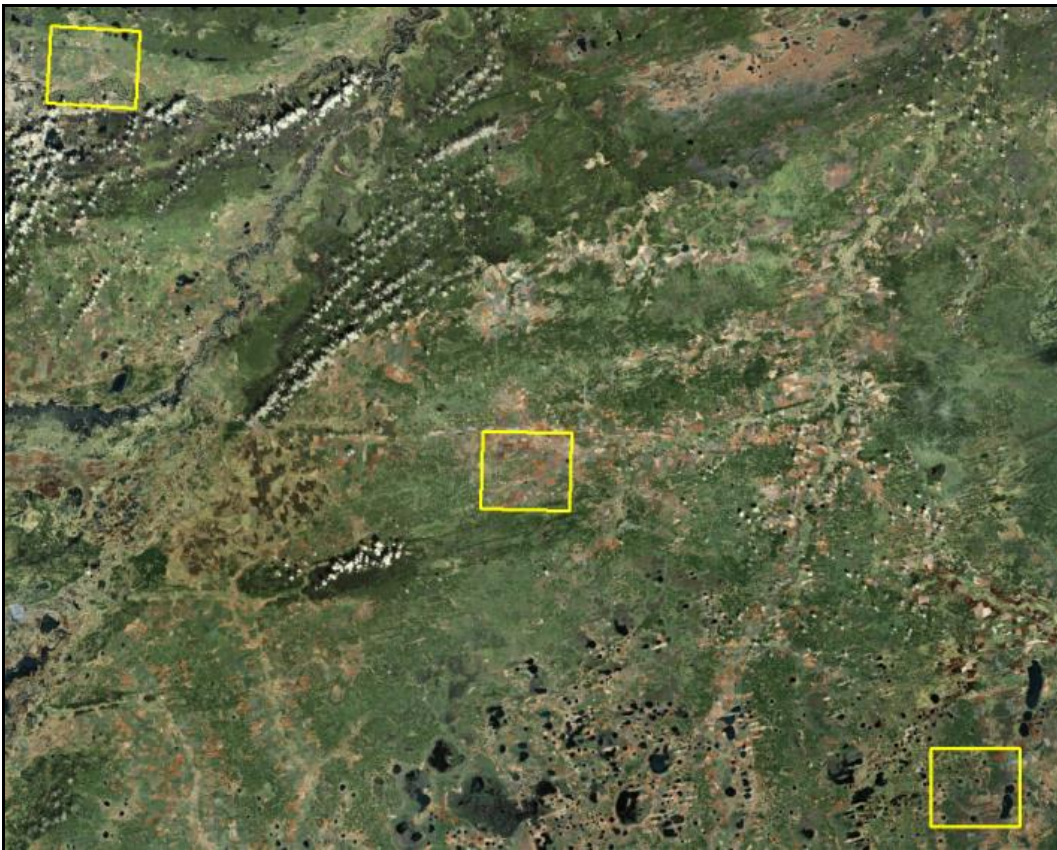

Figure 3: Localization of SASCHA test sites (Western Siberia)
(left: Kaskara, middle: Omutinsky, right: Ishin)

One of the subjects is to adopt, evaluate and implement the ALIS © functionalities and the same know how transfer principles for the extraction of LULC information (land use and land cover) from remote sensing images to local institutions. A core issue is the development of change detection methods and the implementation of adequate image analysis algorithms, especially for agricultural LULC changes, such as the expansion and intensification of arable land. The system adapts existing technologies from the GMES initiative to region-specific LULC classes and aims to enable a (semi-) automatic detection and quantification of future LULC changes. The system development will be driven by user needs collected from stakeholders of the Oblast´s Departments for Environmental Protection and Agriculture.

Although the user demand is of a complete different subject, compared with the use in GMFS, the philosophy of a software interface that is user-friendly and easy to use remains the same principle in order to bring remote sensing solutions to the thematic experts rather than the attempts of the remote sensing community to step into the various mandates of local and regional institutions!

Only with a reliable spatial analysis of the current threats and factors for change will it be possible to develop sustainable land use practices and promising adaption strategies to environmental changes, in cooperation with the regional authorities and stakeholders.

3.2 Monitoring of Changes in Agriculture, Biodiversity and Carbon Stocks for Landscape Planning

The second project phase is dedicated to the implementation of monitoring tools for a wise and sustainable future land use in the region. As already identified by relevant European directives such as INSPIRE (Infrastructure for Spatial Information in Europe), Water-framework directive, and Habitat directive, land use and land cover (LULC) datasets are an indispensible prerequisite for the support of stakeholders in environmental policy.
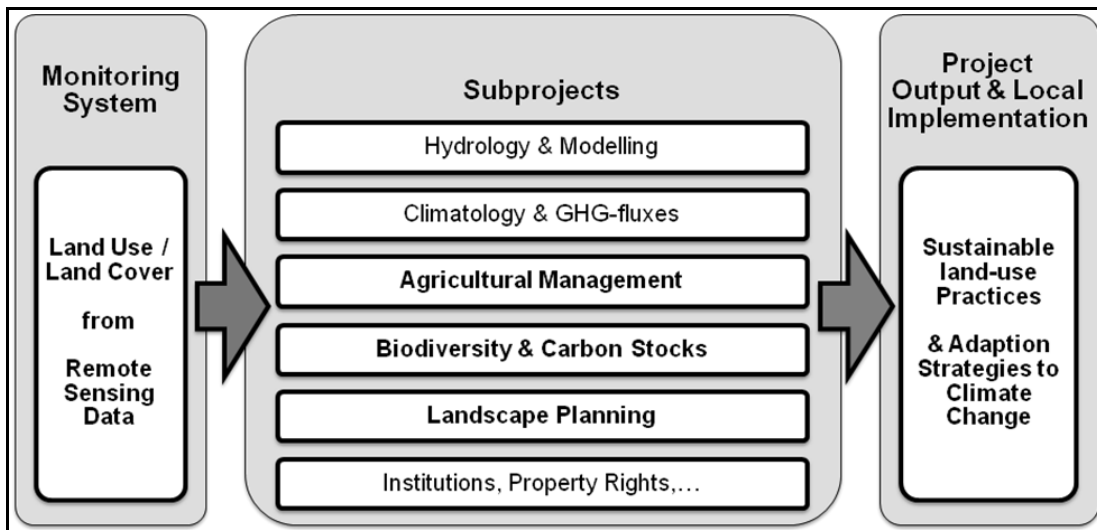

Figure 4: Acquisition of land use changes with remote sensing data
in the SASCHA project

Derived from this experience, the efficient collection of reliable up-to-date LULC data is one major issue in the context of the development and implementation of a sustainable land management system for the pilot region, the Tyumen Oblast. Figure 4 depicts the interoperability of the monitoring system with the planned project results, and the potential for local implementation through the different approaches of the subprojects, all serving the achievement of the common results (cf. Voelker 2011).

The SASCHA subproject 'Analysis and Monitoring of Land Cover and current Land-Use Change' has started to develop, evaluate and implement a prototype system for the extraction of LULC information from remote sensing images. A core issue is the development of change detection methods and the implementation of adequate image analysis algorithms, especially for agricultural LULC changes, such as the expansion and intensification of arable land. The system adapts existing technologies from the Global Monitoring for Environment and Security (GMES) initiative to region-specific LULC classes and aims to enable a (semi-)automatic detection and quantification of future LULC changes with a software interface that is user-friendly and easy to use: the ALIS © interface (cf. fig. 1). The system development will be driven by user needs collected from stakeholders of the Oblast´s Departments for Environmental Protection and Agriculture.
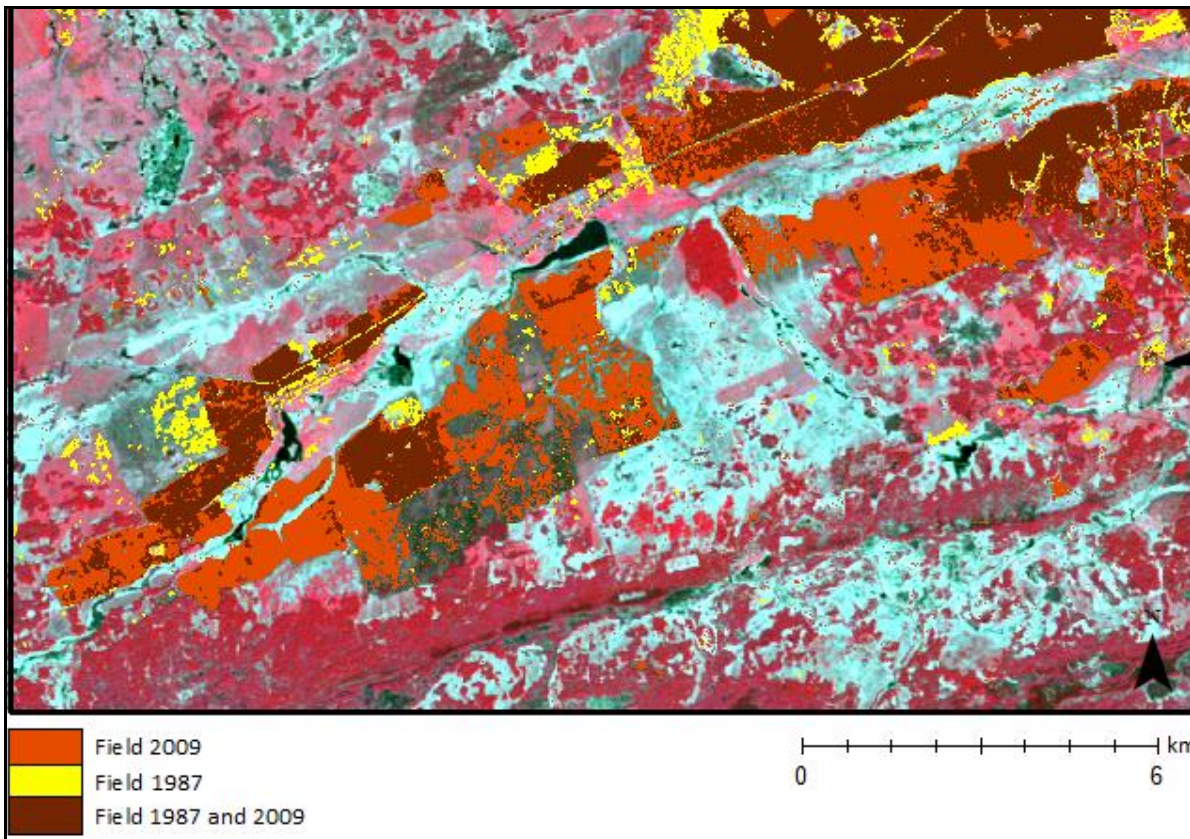
Figure 5: Change detection of agricultural land use in the SASCHA test site of Omutinsky (Tillmann 2012)

To monitor the assumed northward shift of agriculture the technique of remote sensing is considered to be appropriate to the large extend of agricultural schemes in Western Siberia. The first results of the ongoing project are taken from Tillmann 2012 using available archive data from 1987 and 2009 of the Landsat satellites (cf. fig. 5). The land use changes give evidence to a considerable increase of agricultural use and relatively few abandoned sites. Detailed investigations have started and will include additional parameters from the other subprojects in order to detect driving factors for the spatial changes.

3.3 Quantitative Land Cover Changing in the Kaskara Test Area

The project acquired for all three test areas satellite data of three years, approximately with ten years time difference between the acquisition dates. The test area 1, named Kaskara, has been captured by Landsat TM data in 1988, 2001 and 2011. For Omutinsky, the second test area the image data are from 1988, 1998 and 2001 and for the third area, named Ishin, the data were acquired in 1991, 2003 and 2011. Although there are some minor statistical differences, all three test areas show similar tendencies of a decrease of cropland and an increase of grassland and herbaceous wetland.

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Fig 6: Kaskara Test Area, Landsat TM Image
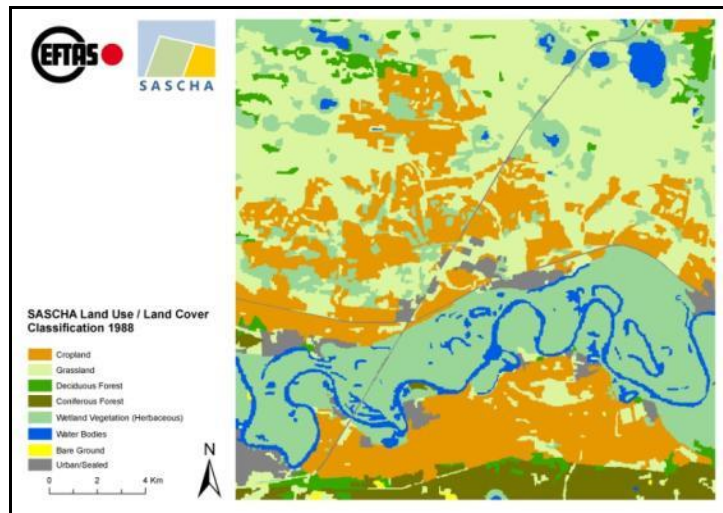acquired June 1988, displayed, RGB = 4-3-2

Fig 7: Kaskara Test Area, Land Cover Classification 1988

For the overview to be presented here, the example of Kaskara may satisfy. Figure 6 shows the data of June 1988 with some partial haze, displayed in the common colour infrared band combination. In the southern part of the area there the Tura River is flowing from East to West, meandering in its three km wide floodplain. Significant is also the mostly straight railway line traversing the area from Tyumen in North-eastern direction towards Tobolsk. The land cover classification map in Figure 7 gives the results of the satellite data processing in eight land cover classes, of which the classes cropland, grassland and wetland cover most of the area.
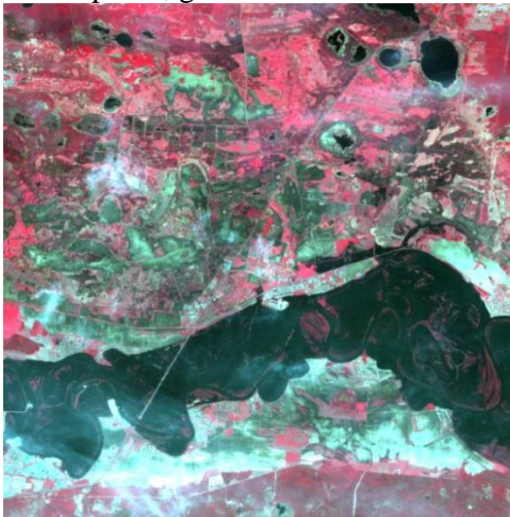

Fig 8: Kaskara Test Area, Landsat TM Image
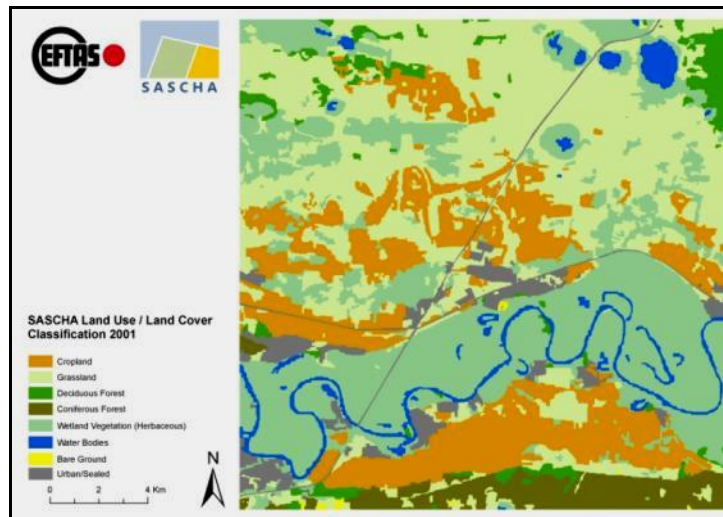acquired 22th May 2001, displayed,
RGB = 4-3-2

Fig 9: Kaskara Test Area, Land Cover Classification 2001

The second image of the time series has been acquired in May 2001 and gives in Figure 8 and 9 the same overview and land cover classification results like before for the 1988 data. From the built-up area of Kaskara in the Northern fringe of the Tura floodplain towards the railway line there are

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some settlement extensions visible. But more interesting are the transitions from cropland into grassland or wetland, especially in the middle northern part.

Fig 10: Kaskara Test Area, Landsat TM Image
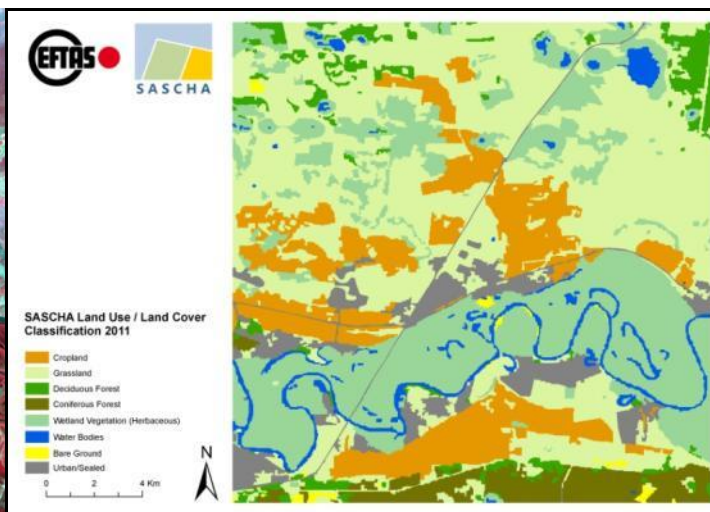acquired 26th May 2011, displayed, RGB = 4-3-2

Fig 11: Kaskara Test Area, Land Cover Classification 2011

Finally the last image of the time series, acquired in May 2011 is presented in Figure 10 again in CIR mode and in Figure 11 with its land cover classification. The settlement area of Kaskara has grown not only in the north but now also on the south banks of the Tura floodplain. The ongoing losses of cropland have resulted since 1988 now into a loss of 40% (cf. Table 1 and Figure 12).

Table 1: Multitemporal Balance of Land Cover in the Kaskara Test Area

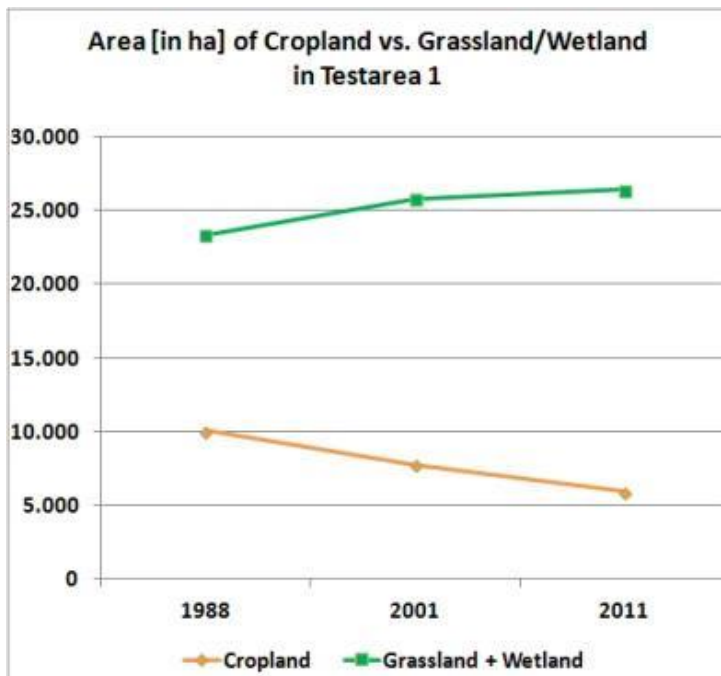| KASKARA	1988		2001		2011	
Class	area	proportion	area	proportion	area	proportion
Bare Ground	40,3 ha	0,1 %	52,4 ha	0,1 %	190,8 ha	0,5 %
Coniferous Forest	1.919,3 ha	4,8 %	1.824,0 ha	4,6 %	1.752,3 ha	4,4 %
Cropland	10.083,8 ha	25,2 %	7.737,5 ha	19,3 %	5.901,0 ha	14,8 %
Deciduous Forest	1.255,6 ha	3,1 %	1.422,7 ha	3,6 %	1.657,3 ha	4,1 %
Grassland	12.698,2 ha	31,7 %	13.152,3 ha	32,9 %	15.702,2 ha	39,3 %
Urban/Sealed	1.434,3 ha	3,6 %	1.826,2 ha	4,6 %	2.696,1 ha	6,7 %
Water Bodies	1.923,6 ha	4,8 %	1.355,9 ha	3,4 %	1.369,6 ha	3,4 %
Wetland (Herbaceous)	10.644,7 ha	26,6 %	12.629,0 ha	31,6 %	10.730,7 ha	26,8 %
Total Test Area 1	40.000,0 ha	100,0 %	40.000,0 ha	100,0 %	40.000,0 ha	100,0 %

Figure 12: Kaskara Test Area, Statistics of
Multitemporal Land Cover Classification Results

While the two other test areas give comparable results regarding cropland and grassland develop-
ment, it has to be stated that there is a statistical significance of decreasing cropland proportion. The
proportions of wetland have some fluctuations with moderate increases. This has to be investigated
still more precisely according to seasonal flooding occurrence or morphological properties of the
terrain.

3.4 Tracking Ecological and Economic Factors for Land Cover Change in the Kaskara Test Area

After having got the first statistical based evidence of land cover changes in the different test areas
over two decades by multitemporal remote sensing, there will be the next step to identify the driv-
ing factors for this development. In order to go into more details, the investigations will focus now
on the seasonal aspects and the local factors triggering a change in land use practise. Since 2009
there is a unique constellation of five satellites on the same orbit operating to deliver repeated satel-
lite observations within the same season: the RapidEye company. The characteristics of the
RapidEye data are a five band sensor, including a red edge band with a ground sampling distance
GSD = 5 m. The campaign in 2012 resulted in four seasonal data, acquired on May 16, May 22,
August 4 and September 5, some of them not covering the total area.

During the growing season of 2012 a ground truth sampling survey has been performed to collect
detailed information on the land cover and the agricultural crop condition (see Figure 13).
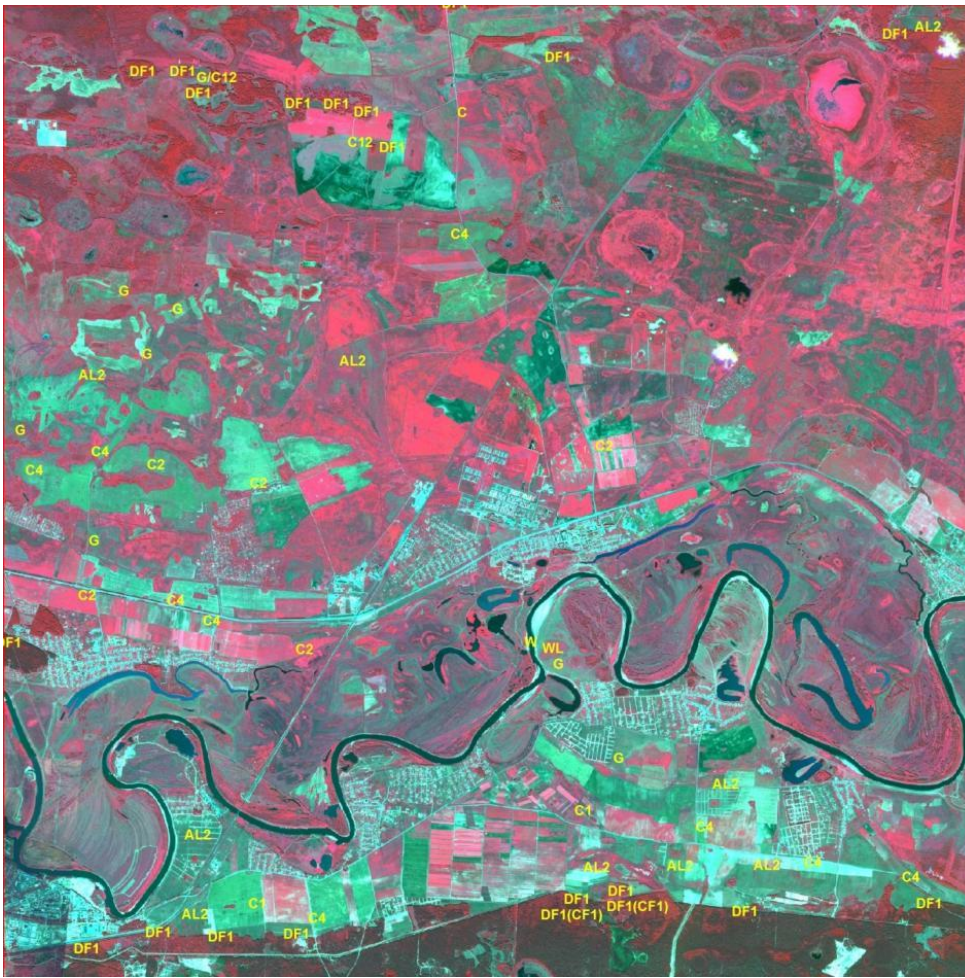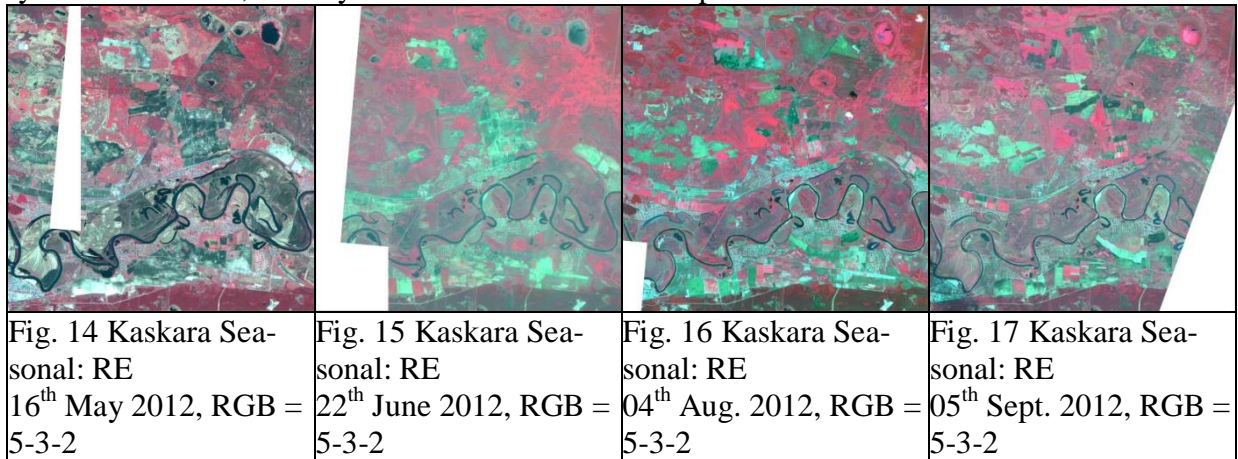
Figure 13: Kaskara Test Area acquired from RapidEye Constellation, composite of 2013 data, displayed RGB = 5-3-2, overlayed with Ground Truth Sample Observations on Land Cover

Fig. 14 Kaskara Seasonal: RE 16th May 2012, RGB = 5-3-2	Fig. 15 Kaskara Seasonal: RE 22th June 2012, RGB = 5-3-2	Fig. 16 Kaskara Seasonal: RE 04th Aug. 2012, RGB = 5-3-2	Fig. 17 Kaskara Seasonal: RE 05th Sept. 2012, RGB = 5-3-2

Figures 14, 15, 16 and 17 show four seasonal different acquisition data from RapidEye throughout the 2012 season. The image from May show the rather humid situation in springtime, after snowmelt but still with a high water content in the soils. The lake in the North-East of the area becomes already shallow in June and dry with herbage during August and September. These traces will be analysed in detail together with morphologists, soil scientists and hydrologists to broaden the knowledge base. First observations lead to the assumption that hydro morphologic conditions cause reduced yield of crops and under economic pressure cause set aside unfavourable crop sites and development of succession sites. The knowledge of ecological and economic factors in their local variations will be necessary to analyse the mitigation and adaption strategies.

Only with a reliable spatial analysis of the current threats and factors for change will it be possible to develop sustainable land use practices and promising adaption strategies to environmental changes, in cooperation with the regional authorities and stakeholders.

3.5 Advances in Remote Sensing Methods and Potentials for Transfer

Advances in remote sensing from related research have been used, improved and incorporated in operational processing chains. The related investigations on this topic from Calvet 2010, Listner 2011 and Mariotto 2011 have been reflected to improve the own knowledge based methodologies, when developing the ALIS © interface, which serves already in different working environments. The close cooperation of universities, R&D companies and administrative users has lead to stable transfers from science to applications, according to the demand of the competent administrations. One of the subjects is to adopt, evaluate and implement the ALIS © functionalities and the same know how transfer principles for the extraction of LULC information from remote sensing images to local institutions. A core issue is the development of change detection methods and the implementation of adequate image analysis algorithms, especially for agricultural LULC changes, such as the expansion and intensification of arable land. The system adapts existing technologies from the GMES initiative to region-specific LULC classes and aims to enable a (semi-) automatic detection and quantification of future LULC changes. The system development will be driven by user needs collected from stakeholders of the Oblast´s Departments for Environmental Protection and Agriculture.

Although the user demand is of a complete different subject, compared with the use in GMFS, the philosophy of a software interface that is user-friendly and easy to use remains the same principle in order to bring remote sensing solutions to the thematic experts rather than the attempts of the remote sensing community to step into the various mandates of local and regional institutions!

3. CONCLUSIONS

The attempt to install synergies between the described research projects with quite different regional, socio-economic and environmental conditions is certainly challenging. On the other hand it is very helpful to experience that despite all the different pre-conditions, there are also some common issues to be found, which threaten the living conditions of the future generations. The world's responsibility for improvements in sustainability of the land management will become the basis for environmental security and food security of our planet. The current investigations show the part remote sensing and GIS play in contributing to the dissemination of better tools for land management and food security in order to ensure the involvement of the regional stakeholders and expertise to reach operability.

This working report from the ongoing SASCHA project shows in its preliminary results that there is a strong need to motivate those responsible, to invest into a sustainable data collection. Even more the situation described give evidence that there is a worldwide need for:

- Implementing EO as a tool for food security
- Land Tenure is the key factor for rural development
- Monitoring Climatic Change needs EO

Remote Sensing & GIS contribute to dissemination of improved tools for land management, food security and sustainable adaption to climate change – so there is no doubt: our planet needs Remote Sensing.

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