PFG 2013 / 3, 0185–0195
Stuttgart, June 2013

Article

Automated Analysis of Satellite Imagery to provide Information Products for Humanitarian Relief Operations in Refugee Camps – from Scientific Development towards Operational Services

Dirk Tiede, Petra Füreder, Stefan Lang, Daniel Hölbling & Peter Zeil, Salzburg, Austria

Keywords: object-based image analysis, refugee and IDP camps, GMES, knowledge-based rule-sets, information products, conditioned information

Summary: Assistance to displaced people in crisis situations requires coordinated and timely action. The latest generation of very high resolution satellite imagery, previously limited in terms of availability and/or resolution, has opened new possibilities for aid organisations to enhance their own reconnaissance. This paper documents the development of algorithms for automated satellite imagery based analysis of refugee and IDP (internally displaced people) camps, and their application over several years under varying conditions, i.e. different sensors and different areas. At fourteen sites VHR (very high resolution) satellite data of four different sensors were used to analyse camps by applying automated dwelling extraction including dwelling differentiation, dwelling density calculation and camp outline estimations, as well as camp monitoring over time. Ranging from experimental stage research, over real-time and benchmarking exercises to pre-operational information provision, the OBIA (object-based image analysis) processing routines greatly matured in terms of transferability, usability and operability.

Zusammenfassung: *Automatische Auswertung von Satellitenbilddaten zur Bereitstellung von Informationen zur Unterstützung von humanitären Hilfsaktionen in Flüchtlingslagern – von wissenschaftlicher Entwicklung bis hin zu funktionsfähigen Diensten.* Die Versorgung von Flüchtlingen in Krisensituationen erfordert koordinierte und zeitkritische Hilfsmaßnahmen. Die Fernerkundung als Quelle zeitnaher, flächendeckender und unverfälschter Primärdaten eignet sich insbesondere seit dem Zeitalter der höchstauflösenden optischen Daten zum Monitoring und zur Folgenabschätzung von Bevölkerungsbewegungen in Krisensituationen, insbesondere von Flüchtlings- bzw. Vertriebenenlagern in schwer erreichbaren oder nicht zugänglichen Gebieten. In diesem Beitrag werden die Entwicklung von Algorithmen zur automatisierten Analyse von Satellitenbilddaten im Bereich von Flüchtlingslagern und deren praktische Anwendungen über einen mehrjährigen Zeitraum und unter verschiedenen Bedingungen beschrieben. Die Anwendungen umfassen bisher insgesamt 14 unterschiedliche Gebiete unter Nutzung von vier unterschiedlichen Sensoren zur Extraktion von Behausungsstrukturen inklusive unterschiedlicher Behausungstypen, Analyse der Ausdehnung der Flüchtlings-/Vertriebenenlager, aber auch zum Monitoring über einen längeren Zeitraum hinweg. Angefangen von ersten experimentellen Entwicklungen über Echtzeit- bzw. Validierungsübungen bis hin zur operationellen Anwendung wird die Verbesserung der auf objektbasierter Bildanalyse (object-based image analysis OBIA) beruhenden Algorithmen hinsichtlich Übertragbarkeit, Verwendbarkeit und Funktionsfähigkeit gezeigt.

DOI: 10.1127/1432-8364/2013/0169 1432-8364/13/0169 $ 2.75

1 Introduction

By the end of 2011, 42.5 million people worldwide were forcibly displaced (UNHCR 2012). That means that the number of affected people exceeded 42 million for the fifth consecutive year, a result of persistent and new conflicts in different parts of the world (UNHCR 2012). The highest number since the mid-1990s occurred at the end of 2010, when an estimated 43.3 million people were forcibly displaced due to conflict and persecution (UNHCR 2011). The usefulness of Earth Observation (EO) data to provide important information which may assist in planning and monitoring the activities in refugee and IDP camps, where field assessments are not possible, is widely recognized (Bouchardy 1995, UNHCR 2000, Bjørgo 1999 and 2000). Previously thought to be only at the disposal of military users, the advent of commercial very high resolution (VHR) satellite imagery opened new possibilities for aid organisations to enhance their own reconnaissance. Humanitarian actions that try to relief the life of displaced people often take place in difficult environments. The location of the affected group is often not precisely known. Civil conflicts prohibit the access to those areas: In the case of internally displaced people (IDP), local authorities are not supportive. The location and the number of refugees may change quickly. Under these circumstances aid agencies, especially NGOs (non-governmental organization), require independent information sources to safeguard their personnel and operations. Accuracy and timeliness of information products are essential requirements.

Some few approaches for the automated extraction of dwellings from satellite imagery are documented in the literature. Giada et al. (2003), Lang et al. (2006a), Laneve et al. (2006) and Kemper et al. (2011) showed research applications for automated extraction of dwellings, while Lang et al. (2010) focused on the transfer of such routines for (retrospective) time-series analysis on camp evolution. For the operational and more sustainable usage of such automated algorithms, continuous improvement is required, especially with respect to:

(1) Transfer of algorithms (different sensors, different areas).
(2) Implementation and performance in real-world and real-time scenarios.
(3) Validation of results, especially reflecting end-users' needs.

This article summarizes previous efforts from initial research to pre-operational service development which have been composed into an efficient processing chain. The applied research was done at the Interfaculty Department of Geoinformatics – Z_GIS (University of Salzburg) and embedded in a series of EU FP (framework programme) 6/7 research projects and institutional research support. In 2003, the European Security Policy 'A secure Europe in a better world' (European Council 2003) broadened security from an exclusive concern regarding the security of the state towards a concern regarding also the security of the citizens. Instead of traditional warfare, e.g. tanks, barracks in national security, objects such as the status of the infrastructure, migration routes, as well as population monitoring became the objects for observation under 'human security'. The challenge of defining and developing methodologies and tools to serve the observational needs emerging from the new definition of security was taken up by the Network of Excellence GMOSS (Global Monitoring for Security and Stability, 2004–2008) in the early stages of the Global Monitoring for Environment and Security GMES (Jasani et al. 2009). During this research effort and the subsequent pre-operational service development projects LIMES (Land and Sea Integrated Monitoring for European Security, 2006–2010) and G-MOSAIC (GMES services for Management of Operations, Situation Awareness and Intelligence for regional Crises, 2009–2012), methodologies and workflows for refugee and IDP camp monitoring using EO data were developed and tested.

Building on this experience, Z_GIS recently entered into an operational commitment with humanitarian aid organizations, whereby the provided services reached a high level of independency from EC funding. This fully supports the GMES idea of establishing self-sustaining services in specific application domains. Recently, GMES was renamed to Co-

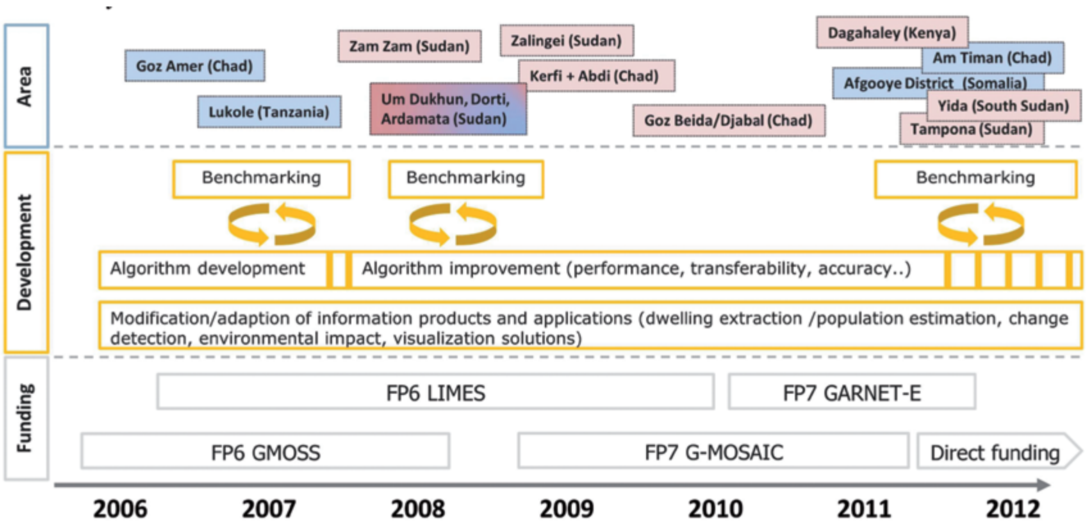

Fig. 1: Overview of the algorithm development since 2006 and the mapped sites (blue: test areas for algorithm development and benchmarking of results, red: pre-operational application areas, red/blue: combined test area (algorithm development and pre-operational application)). The lower part (grey) indicates the research projects/research cooperation supporting the continuous developments, FP = framework programme, LIMES = Land and Sea Integrated Monitoring for European Security, GARNET-E = GMES and Africa: Regional Network for Information Exchange and Training in Emergencies, GMOSS = Global Monitoring for Security and Stability, G-MOSAIC = GMES Services for Management of Operations, Situation Awareness and Intelligence for regional Crises.

pernicus, the European Earth observation programme.

Fig. 1 shows an overview of the research environment for a permanent development and improvement of the algorithms showing also the test areas and benchmarking activities from 2006 until today.

2 Algorithm Development and Improvements

The core algorithm for automated dwelling extraction was developed and improved over several years. Early developments (Lang et al. 2006a and 2006b) were conducted within the FP-6 funded Network of Excellence (GMOSS).

The algorithm relies on object-based image analysis (OBIA) as a methodological framework, which offers the possibility to address complex information classes, defined by spectral, spatial, contextual, as well as hierarchical properties (Lang 2008, Blaschke 2010). Expert knowledge is represented through rule-sets developed within eCognition (Trimble Geospatial Imaging), which offers a modular programming language (CNL, Cognition Network Language) for (image-)object handling (Tiede et al. 2011). Further developments and improvements of the initial algorithms were based on four main pillars:

(1) The development of so called master rule-sets (Tiede et al. 2010): These are generic rule-sets to reduce the time needed for the adaptation of rule-sets if transferred to other camps or other time intervals. To reach this, initial rule-sets are designed where all fixed thresholds, e.g. spectral thresholds, class definitions, are defined as initial variables. This is similar to classical software development and allows the encapsulation of the rule-sets in combination with a graphical user interface (GUI) for parameter adaptation.

(2) Adapted segmentation techniques (Lang et al. 2010, Tiede et al. 2010): Since standard segmentation techniques were not sufficient to achieve a satisfactory delineation of dwelling structures (especially in complex areas), an adapted approach incorporating edge filtering

algorithms as additional parameters for class descriptions of anthropogenic elements (De Kok & Wezyk 2008) was developed. An initial classification of objects at a coarser scale level based on the underlying edge detection layer leads to a better identification of refugee camp areas while minimizing false positives outside of the camp areas at the same time. In addition, class modelling techniques are applied such as cyclic object combination, building on an initial segmentation, and stepwise classification based on parameterized regionalization techniques. These class modelling techniques lead to improved delineations of single dwelling structures.

(3) Improvement of the transferability by reducing absolute thresholds: The classification of dwelling structures builds to a certain degree on relative differences regarding spectral information and spatial characteristics (Tiede et al. 2010). Spatial characteristics such as size, shape and arrangement of the dwelling structures are combined with relative spectral differences between the objects. For example, the identification of a bright dwelling structure is defined relative to darker neighbours, or dark fence structures can be distinguished through shape descriptors from dark round huts. Therefore, fixed spectral thresholds could be significantly reduced in the classification process. Some thresholds like an NDVI threshold and separation values between the main dwelling structures still need to be set. Using sensors such as WorldView-2 with eight spectral bands, the adaptation of rule-sets requires additional expert override, but has the advantage of an improved feature extraction due to the extended spectral information.

(4) Performance improvements: High (timely) performance is one main asset of automated approaches compared to manual image interpretation. In this respect the algorithm was successfully tested in distributed computing environments (Tiede & Lang 2008). New 64 bit based software versions are also leading to performance gains. An entire VHR satellite scene can now be analysed without using distributed computing in acceptable timeframes, i.e. < 4 hours computing time after the adaptation of the rule-sets for an IKONOS scene on a standard PC.

Degree of automation and required accuracies

Ideally, the geometric and thematic accuracy of an automated camp analysis should be comparable to the results of a visual interpretation. In such an ideal situation the automated approach is faster and leads to more detailed results in some areas, as for example the extraction of dwellings as polygons with a measurable size accounts for more accurate population estimations. The degree of automation depends mainly on specific conditions such as complex versus simpler camp structures and the quality of the image data. Complex situations are e. g. caused by cloud shadows within the camp areas, camp locations in very densely vegetated areas or a large variety of building material used for shelters. In contrast, simpler situations for example exist in camps composed of predominantly uniform tent types or huts with corrugated iron roofs. These factors directly influence the adaptation efforts of the master rule-sets. Most of the applications (Tab. 1) make use of satellite imagery such as QuickBird or IKONOS with four spectral bands. The resolution of IKONOS (1 m panchromatic, 4 m multispectral) is the lower limit for single dwelling detection; higher spatial resolutions are preferred (0.5 m in the panchromatic band is at the moment the

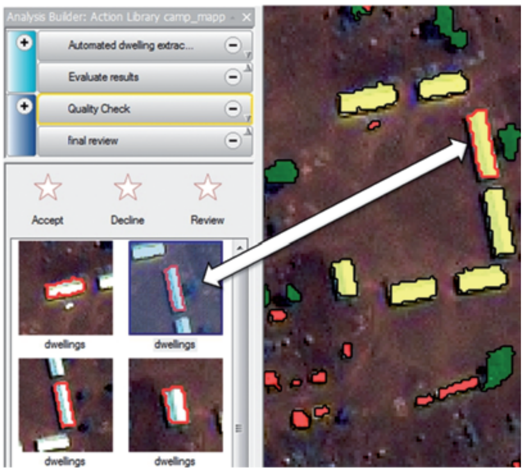

Fig. 2: Hybrid solution for a combined automated and manual analysis and quality check, programmed in eCognition Architect. Extracted dwellings are visualized as thumbnails for an easier post-processing and editable as well as linked to the object in the image scene.

limit, at least for non-US Government customers). Through the availability of new sensors like WorldView-2 with eight spectral bands, improved feature extraction is possible, but the additional bands have to be addressed in the expert rule-set. This increases usually the time for the master rule-set adaptation.

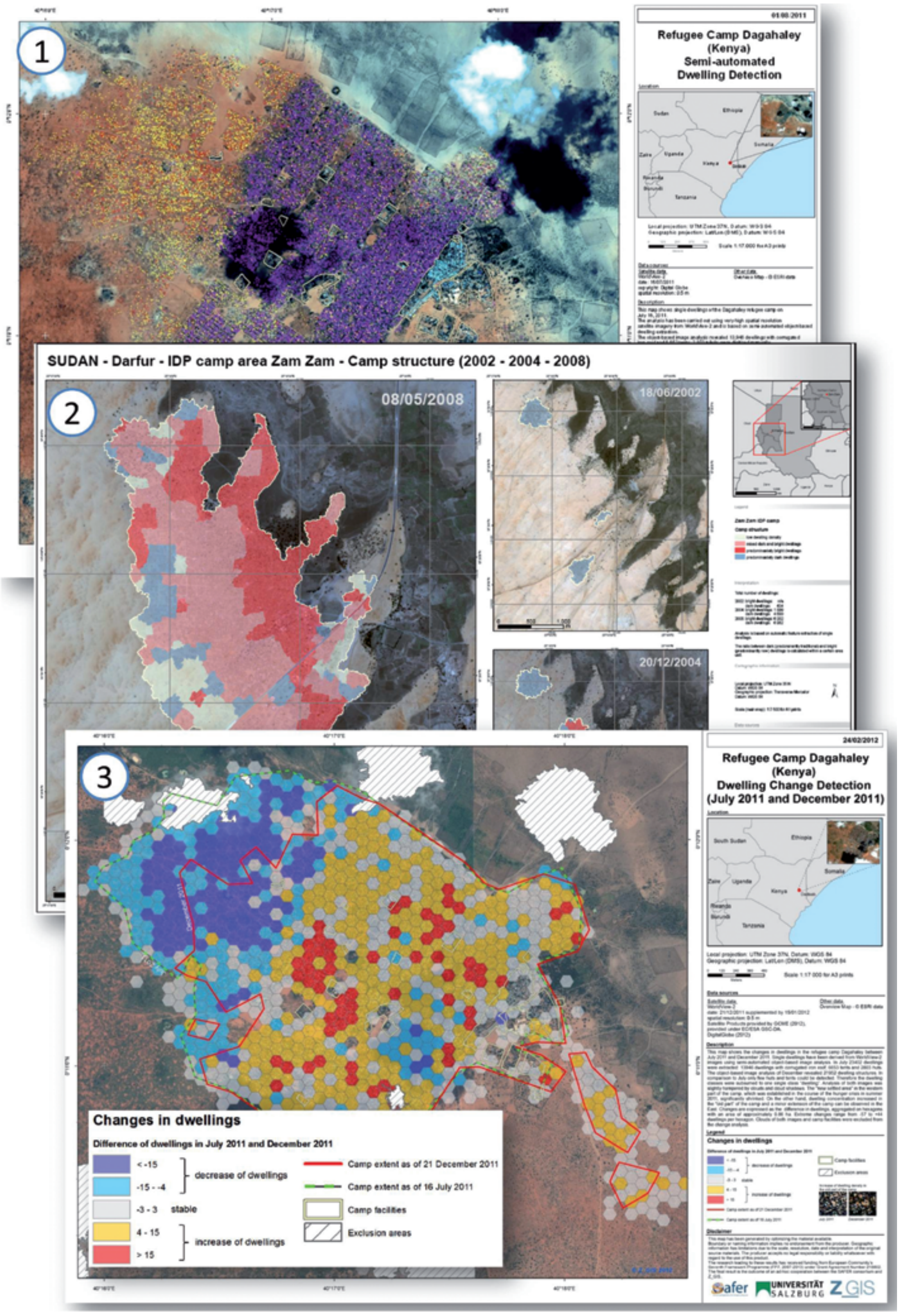

Fig. 3: Examples for products derived from the automated dwelling extraction: (1) single dwelling extraction with different dwelling types (Dagahaley refugee camp, Kenya); (2) camp structure analysis based on dwelling type distributions (IDP camp evolution based on three time slices in Zam Zam, Sudan); (3) change detection analysis and camp outline estimation based on single extracted dwellings aggregated to hexagonal units (Dagahaley refugee camp, Kenya, two time slices) (Füreder et al. 2012).

Under very complex conditions, so called hybrid solutions are applied. They combine automated object detection and manual interpretation in a synergetic manner. Fig. 2 shows such a user interface which supports editing, in order to achieve acceptable accuracies in less favourable environments. The graphical user interfaces and the routines for quality check and analysis are programmed in eCognition Architect.

3 Accuracy Assessment, Benchmarking Exercises and User Validation

Accuracy assessment is very important for the evaluation of the reliability of information products, but in the case of refugee and IDP camps one faces the problem that the products are mostly requested and required in areas where field data is not available or very limited. Only in rare cases real and usable in-situ data are available. Most studies for the development of automated approaches are therefore comparing the results with visual, and in the best case independent, image interpretations (e.g. Giada et al. 2003 and Kemper et al. 2011). For our approach the classification accuracy differs – as mentioned before – due to situation complexity between different camps. More than 90 % classification accuracy could be reached for some camps dominated by dwellings with corrugated iron roofs and/or bright tent types (Lang et al. 2010, Tiede & Lang 2008), whereas around 80 % overall classification accuracy could be reached for mixed structures (Lang et al. 2006a). It dropped partly below 60 % for specific situations like for example dwelling structures which are not easily distinguishable from the surrounding area such as traditional huts and dust or sand covered tents (Lang et al. 2010, Tiede et al. 2010). These figures reflect the results before a potential manual improvement using the described hybrid solutions is applied.

The approach underwent several benchmarking exercises (Fig. 1) in order to calibrate the algorithms and improve the accuracy estimations. This comprised comparisons with automated approaches from other institutions and independent manual interpretation. Results of the benchmarking exercises are documented in the literature (Lang et al. 2006b, Kranz et al. 2010a, Kranz et al. 2010b) and seem promising in terms of accuracy and timeliness, but also reveal the limitations caused by the absence of ground truth, since independent visual interpretations by experts vary a lot.

Building on these experiences a validation study (Grundy et al. 2012) jointly performed with the London School of Hygiene and Tropical Medicine (LSHTM), the Manson Unit – MSF-UK and MSF-OCA (Chad) aimed at the validation of the population estimations derived from two independent manual image interpretations and our automated approach. The results were compared with a population survey carried out by a ground survey of a test area in Am Timan, Chad. For the population survey the quadrat method was used, i.e. sample squares (quadrats) from an overlaying grid of constant size were randomly selected and the ground survey was performed within each of the sampled squares. The resulting estimation of the population density for the samples is then multiplied by the total surface area to compute a population estimate for the whole area. Despite of a general compliance between the methods – with differences mainly in dwelling structure type rather than in total count – it proved the automated method to have its advantages for large areas with less complex structures and recursive analysis (monitoring) over time. The information delivery process can be subdivided in two domains: (1) the user domain addressing relevance and impact, and (2) the information provider domain comprising the translation of the user's request into a service or product regarding demand, thematic information, spatial resolution, and others. The validation of the process and its outputs can then be split in user validation, i.e. feedback by users on relevance and impact of the information product, and technical validation, i.e. effectiveness, efficiency. The latter is a subject well attended by the scientific community (Zeil & Lang 2009).

4 Information Products and Information Delivery

Fig. 3 shows a summary of information products originating from an automated analysis. The base information is the amount of single dwellings distinguished between different dwelling types, e.g. tents, round huts, and camp facility structures. Based on this, the population can be estimated if average occupancy rates per dwelling type are available. Additional information products based on the single dwellings comprise camp structure, e.g. calculated by considering the ratio between tents and huts as an indicator for newly settled areas, and dwelling density measured as dwellings per km² using kernel density methods (Silverman 1986, Lang et al. 2010, Tiede et al. 2010) to provide a better overview on the spatial distribution of the dwellings. Based on the dwelling density, a camp outline can be approximated which is helpful in rapidly expanding camps where the extent can hardly be observed on the ground. The change of camps can be monitored if satellite images of different times are available. Changes of dwellings are visualized using regular shapes, like hexagonal units, or grids, or non-regular features like camp management areas, as reporting units for a fast and easy to grasp overview of the areas undergoing major changes.

All information is delivered to the user as maps in geospatial PDF format, i.e. georeferenced and multi-layer enabled, but also, if requested, as web-services based on Google's KML format or as ArcGIS online Web-

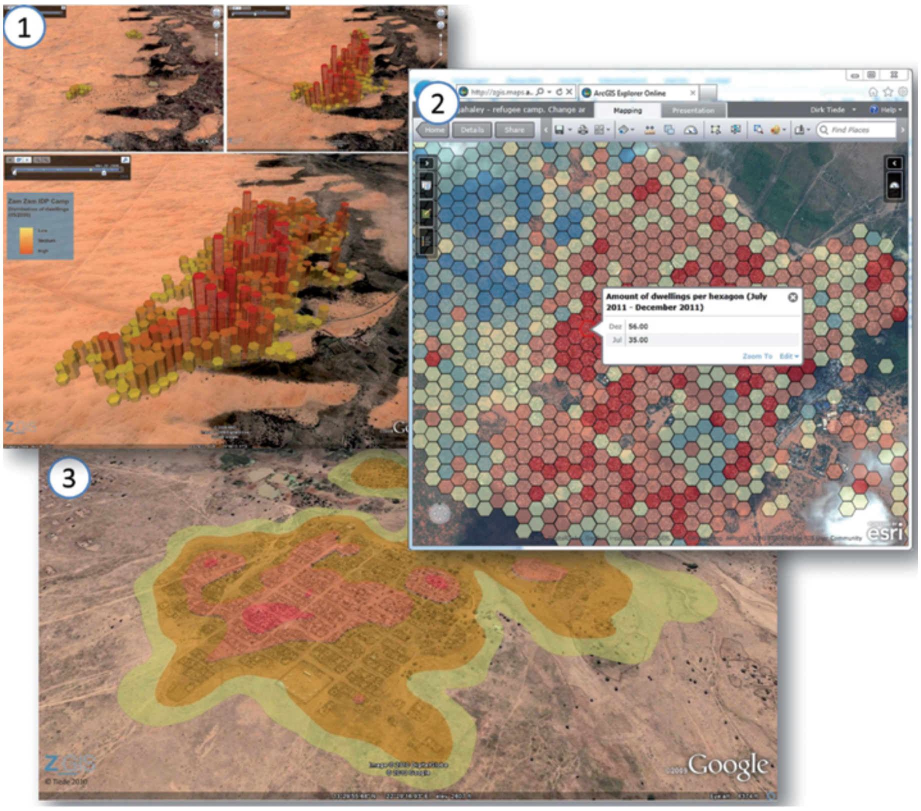

Fig. 4: Web-based visualisations of the information products: (1) Time series of analytical 3D views (Tiede & Lang 2010) in Google Earth showing the development of the IDP camp Zam Zam from 2002 (top left), 2004 (top right) and 2008 (below). Red tones and higher extrusion values of the hexagons indicate higher amounts of automatically extracted dwelling structures (Tiede & Lang 2009); (2) change detection analysis provided via ArcGIS Explorer online, which allows interactive queries; red/yellow tones are indicating increase, blue tones are indicating decrease (Dagahaley refugee camp, Kenya, two time slices); (3) dwelling density analysis, based on kernel density calculations and visualized in Google Earth (IDP camp Dorti, Sudan).

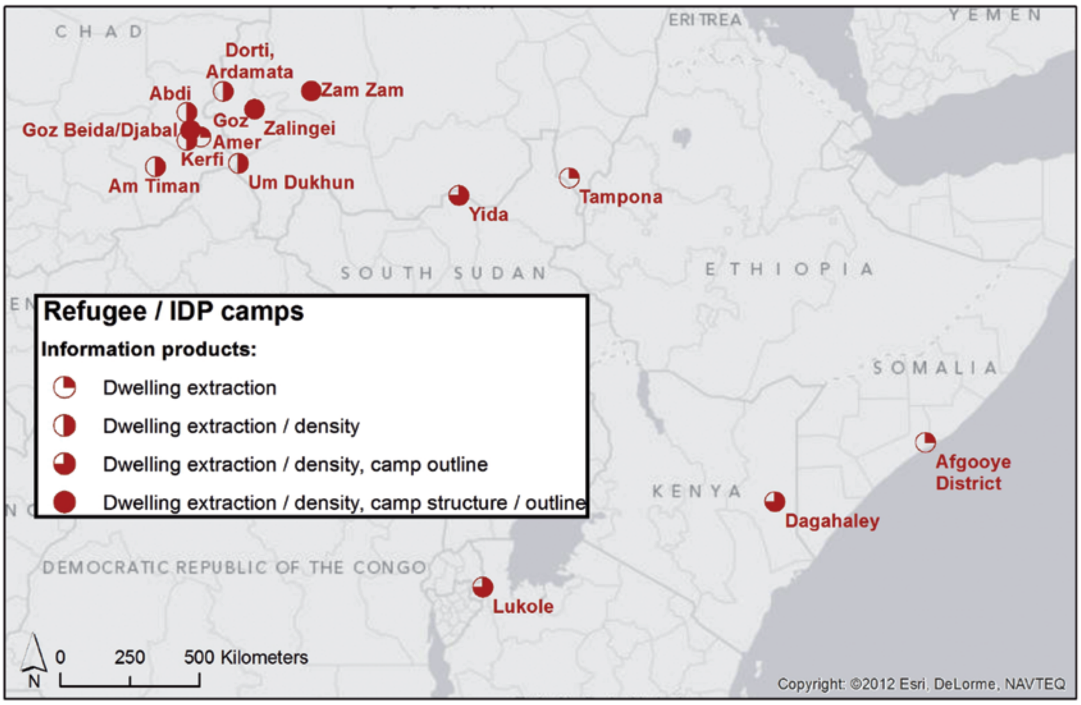

Fig. 5: Overview of the analysed refugee and IDP camps and the provided information products per camp.

Service in conjunction with ArcGIS Server (Fig. 4).

5 Investigated Sites

Fig. 5 shows the location of all refugee and IDP camps which have been analysed since 2006, and the derived products per camp. Tab. 1 indicates the type of analysis (development, benchmarking, real-time exercise/pre-operational application) and the satellite images used. The last column indicates the research project/research cooperation by which the application was co-funded or directly funded. A total of 14 camps were analysed, six of them with more than one time slice, in the case of the IDP camp Zam Zam, even three images were available for retrospective monitoring (Lang et al. 2010). All camps are located in Africa, which limits the experience regarding transferability to certain types of dwelling structures and camp types. Beside emergency shelters, e.g. tents, provided by aid organizations, which are similar in most countries, refugee shelters are often built from local materials and therefore vary from country to country depending on availability, local culture and custom (UNHCR 2007).

6 Discussion and Outlook

The presented applications are the result of a continuous development process, i.e. co-funded research covering more than one funding period, implemented under the GMES/Copernicus framework. Information on the amount and distribution of dwellings can be extracted from VHR imagery in an automated way for inaccessible areas; still, information from the ground is required, e.g. on mean occupancy rates for realistic total population estimations.

We consider the service as still being pre-operational. It requires further research and development as well as frequent applications in order to become fully operational. This is important to improve and test the transferability to other camp structures or types, e.g. on other continents, the overall robustness of the algorithm, and the degree of automation for different sensors. In this respect we need to decide from case to case what degree of "automation" is possible or sensible: Hybrid approaches may be more appropriate to meet the users' need (Füreder et al. 2012) and, where difficult camp structures and data quality issues prevail, they remain the best choice to provide relevant and reliable information most effectively in many cases.

Close cooperation with users, e.g. humanitarian aid organizations, allows a steady improvement of the provided service and the extension of the product portfolio.

Tab. 1: Refugee and IDP camps analysed since 2006 based on the presented workflow (D = Development, B = Benchmarking, RE = Real Time Exercise).

Refugee / IDP Camp	Data	Application Status	Funding
Goz Amer (Chad)	QuickBird 12/2004	D/B	FP6 GMOSS
Lukole (Tanzania)	IKONOS 09/2000	D/B	FP6 GMOSS
Zam Zam (Sudan)	QuickBird 06/2002 12/2004 05/2008	RE	FP6 LIMES
Zalingei (Sudan)	IKONOS 09/2004 QuickBird 07/2008	RE	FP6 LIMES
Dorti, Ardamata (Sudan)	GeoEye-1 05/2009	RE/B	FP6 LIMES
Um Dukhun (Sudan)	GeoEye-1 05/2009	RE/B	FP6 LIMES
Abdi (Chad)	QuickBird 06/2008 10/2008	RE	FP6 LIMES
Kerfi (Chad)	QuickBird 04/.2006 07/2008	RE	FP6 LIMES
Djabal (Chad)	QuickBird 06/2007 GeoEye-1 03/2010	RE	FP7 G-MOSAIC
Afgooye District (Somalia)	GeoEye-1 01/2011	B	FP 7 GARNET-E
Am Timan (Chad)	WorldView-2 12/2011	B	Institutional Funding
Dagahaley (Kenya)	WorldView-2 07/2011 12/2011 01/2012	RE	Institutional Funding
Tampona (Sudan)	WorldView-2 07/2012	RE	Institutional Funding
Yida (South Sudan)	QuickBird 10/2012	RE	Institutional Funding

Summarizing, constant user feedback including a critical reflection on the overall relevance of the provided information products is essential for sustaining such services, also in terms of funding – especially in low-budget domains like humanitarian aid and civilian conflict resolution. As in many other GMES (Copernicus) domains, high-quality and ubiquitous availability of reliable and well tailored geospatial services, whenever and wherever requested, is crucial for a mutually beneficial and sustaining information market.

Acknowledgements

The presented work was co-funded by the European Commission (EC) within the FP6 and FP7 projects GMOSS (contract no: SNE3-CT-2003-503699), LIMES (contract no: 031046), G-MOSAIC (contract no: 218822) and GARNET-E (contract no: 242385). Direct funding has been received by Médecins Sans Frontières (MSF) Austria and the Karl Kahane Foundation.

References

Bjørgo, E., 1999: Very High Resolution Satellites: A New Source of Information in Humanitarian Relief Operations. – Bulletin of the American Society for Information Science **26** (1): 22–24.

Bjørgo, E., 2000: Using very high spatial resolution satellite sensor imagery to monitor refugee camps. – International Journal of Remote Sensing **21** (3): 611–616.

Blaschke, T., 2010: Object based image analysis for remote sensing. – ISPRS Journal of Photogrammetry and Remote Sensing **65:** 2–16.

Bouchardy, J.-Y., 1995: Development of a GIS system in UNHCR for environmental, emergency, logistic, and planning purposes. – Program report. DPOS UNHCR. Geneva, Switzerland, http://repository.forcedmigration.org/show_metadata.jsp?pid=fmo:3246 (6.1.2013).

De Kok, R. & Wezyk, P., 2008: Principles of full autonomy in image interpretation. – The basic architectural design for a sequential process with image objects. – Blaschke T., Lang, S. & Hay, G. (eds.): Object-Based Image Analysis – Spatial concepts for knowledge-driven remote sensing applications: 697–710, Springer, Berlin, Heidelberg.

European Council, 2003: A secure Europe in a better world – The European Security Strategy (Solana Strategy). – www.consilium.europa.eu/uedocs/cmsUpload/78367.pdf (6.1.2013).

Füreder, P., Hölbling, D., Tiede, D., Zeil, P. & Lang, S., 2012: Monitoring refugee camp evolution and population dynamics in Dagahaley, Kenya, based on VHR satellite data. – **9th** International Conference African Association of Remote Sensing of the Environment (AARSE), El Jadida, Morocco, CD-ROM.

Giada, S., De Groeve, T., Ehrlich, D. & Soille, P., 2003: Information extraction from very high resolution satellite imagery over Lukole refugee camp, Tanzania. – International Journal of Remote Sensing **24** (22): 4251–4266.

Grundy, C., Füreder, P., Siddiqui, R., Katsuva Sibongwe, D., Tiede, D., Lang, S. & Checci, F., 2012: Validation of satellite imagery methods to estimate population size. – MSF Scientific Day, 25 May 2012, London, Great Britain.

Hagenlocher, M., Lang, S. & Tiede, D., 2012: Integrated assessment of the environmental impact of an IDP camp in Sudan based on very high resolution multi-temporal satellite imagery. – Remote Sensing of Environment **126:** 27–38.

Jasani, B., Pesaresi, M., Schneiderbauer, S. & Zeug, G. (eds.), 2009: Remote Sensing from Space: Supporting International Peace and Security. – 298 p., Berlin, Springer Netherland.

Kemper, T.M., Jenerowicz, M., Soille, P. & Pesaresi, M., 2011: Enumeration of dwellings in Darfur Camps from GeoEye-1 satellite images using mathematical morphology. – IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing **4** (1): 8–15.

Kranz, O., Lang, S., Tiede, D., Zeug, G., Kemper, T., Caspard, M. & Clandillon, S., 2010a: GMES Services for Conflict Prevention and Mitigation: Support the DG RELEX in Mission Planning. – Konecny, M., Zlatanova, S. & Bandrova, T.L. (eds.): 171–188, Springer, New York.

Kranz, O., Zeug, G., Tiede, D., Clandillon, S., Bruckert, D., Kemper, T., Lang, S. & Caspard, M., 2010b: Monitoring Refugee/IDP camps to Support International Relief Action. – Altan, O., Backhaus, R., Piero Boccardo, P. & Zlatanova, S. (eds.): Joint Board of Geospatial Information Societies (JB GIS), United Nations Office for Outer Space Affairs (UNOOSA).

Laneve, G., Santilli, G. & Lingenfelder, I., 2006: Development of Automatic Techniques for Refugee Camps Monitoring using Very High Spatial Resolution (VHSR) Satellite Imagery. – Geoscience and Remote Sensing Symposium, IGARSS **2006:** 841–845.

LANG, S., TIEDE, D. & HOFER, F., 2006a: Modeling ephemeral settlements using VHSR image data and 3D visualisation – the example of Goz Amer refugee camp in Chad. – PFG – Photogrammetrie, Fernerkundung, Geoinformatik, Special Issue: Urban Remote Sensing **2006** (4): 327–337.

LANG, S., TIEDE, D. & SANTILLI, G., 2006b: Varying sensors and algorithms – an information delivery approach for population estimation in African refugee camps. – **6th** African Association of Remote Sensing of the Environment Conference (AARSE).

LANG, S., 2008: Object-based image analysis for remote sensing applications: modeling reality – dealing with complexity. – BLASCHKE, T., LANG, S. & HAY, G. (eds.): Object-Based Image Analysis – Spatial concepts for knowledge-driven remote sensing applications: 3–27, Springer.

LANG, S., TIEDE, D., HÖLBLING, D., FÜREDER, P. & ZEIL, P., 2010: Earth observation (EO)-based ex post assessment of internally displaced person (IDP) camp evolution and population dynamics in Zam Zam, Darfur. – International Journal of Remote Sensing **31:** 5709–5731.

SILVERMAN, B.W., 1986: Density Estimation for Statistics and Data Analysis. – 175 p., Chapman and Hall, London, New York.

TIEDE, D. & LANG, S., 2008: Distributed computing for accelerated dwelling extraction in refugee camps using VHSR satellite imagery. – CAR, A., GRIESEBNER, G. & STROBL, J. (eds.), Wichmann, Heidelberg.

TIEDE, D. & LANG, S., 2009: IDP camp evolvement analysis in Darfur using VHSR optical satellite image time series and scientific visualization on virtual globes. – GUO, H. & WANG, C. (eds): **Sixth** International Symposium on Digital Earth: Models, Algorithms, and Virtual Reality, SPIE 7840, 78401E, Beijing, China.

TIEDE, D. & LANG, S., 2010: Analytical 3D views and virtual globes – scientific results in a familiar spatial context. – ISPRS Journal of Photogrammetry and Remote Sensing **65:** 300–307.

TIEDE, D., LANG, S., HÖLBLING, D. & FÜREDER, P., 2010: Transferability of OBIA rule-sets for IDP Camp Analysis in Darfur. – ADDINK, E.A. & COILLIE, F.M.B.V. (eds.): ISPRS **XXXVIII-4/C7**, Archives ISSN No 1682–1777.

TIEDE, D., LANG, S., FÜREDER, P., HÖLBLING, D., HOFFMANN, C. & ZEIL, P., 2011: Automated damage indication for rapid geospatial reporting. An operational object-based approach to damage density mapping following the 2010 Haiti earthquake. – Photogrammetric Engineering and Remote Sensing **77:** 933–942.

UNITED NATIONS HIGH COMMISSIONER FOR REFUGEES (UNHCR), 2000: Key Principles for Decision-making. Refugee Operations and Environmental Management. Engineering and Environmental Service Section. – UNHCR. Geneva, Switzerland, http://www.unhcr.org/3b03b24d4.html (6.1.2013).

UNITED NATIONS HIGH COMMISSIONER FOR REFUGEES (UNHCR), 2007: Hand-book for emergencies. – Third edition, http://www.unhcr.org/refworld/docid/46a9e29a2.html (22.2.2013).

UNITED NATIONS HIGH COMMISSIONER FOR REFUGEES (UNHCR). 2011: Statistical Yearbook 2010. Trends in Displacement, Protection and Solutions. – Geneva, Switzerland, http://www.unhcr.org/4ef9cc9c9.html (6.1.2013).

UNITED NATIONS HIGH COMMISSIONER FOR REFUGEES (UNHCR). 2012: Global Trends 2011. A year of crisis. – Geneva, Switzerland, http://www.unhcr.org/4fd6f87f9.html (6.1.2013).

ZEIL, P. & LANG S., 2009: Do have clients a role in validation? – CORBANE, C., BROGLIA, M., CARRION, D., LEMOINE, G. & PESARESI, M. (eds.): Validation of geo-information products for crisis management VALgEO 2009. – European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen: 143–147, Ispra, Italy, http://bookshop.europa.eu/en/valgeo-workshop-proceedings-pbLBNA24082/ (20.2.2013).

Address of the Authors:

Dr. DIRK TIEDE, Mag. PETRA FÜREDER, Mag. Dr. STEFAN LANG, Mag. DANIEL HÖLBLING & Dipl. Geophy. PETER ZEIL, Interfaculty Department of Geoinformatics – Z_GIS, University of Salzburg, A-5020 Salzburg, Austria, e-mail: {dirk.tiede}{petra.fuereder}{stefan.lang}{daniel.hoelbling}{peter.zeil}@sbg.ac.at

Manuskript eingereicht: November 2012
Angenommen: Februar 2013