Earth Observation based Crisis Information – Emergency mapping services and recent operational developments

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***Abstract* — Over the last years, geospatial and Earth Observation technologies have become essential tools to support the Civil Protection and Disaster Management community by providing value-added crisis information. Several emergency mapping mechanisms have been established at different (inter)national levels. The Center for Satellite Based Crisis Information (ZKI) at the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR) is involved in several services and research projects focusing on the development of the operational services, methods, and products to ensure a continuous improvement. In this paper, an overview of emergency mapping, its services, and recent ZKI developments for Earth Observation based crisis information e.g. 3D mapping and real-time provision of aerial images - tested in an exercise on flood mapping and used for situational awareness during a major event are presented.**

Keywords — Earth Observation, remote sensing, 3D mapping, satellite imagery, aerial imagery, crisis, disaster management

I. INTRODUCTION TO EARTH OBSERVATION BASED CRISIS INFORMATION

Within the last 15 to 20 years, geospatial and Earth Observation technologies have become essential tools to support the Civil Protection and Disaster Management community by providing value-added crisis information derived from satellite imagery [1]. For the Civil Protection and Disaster Management community, area-wide satellite based crisis information can be of great benefit. Nevertheless, decision makers or relief workers cannot work with raw satellite imagery. For this reason, situation maps, reports or statistics, which can be read and understood by non-satellite expert users are necessary.

In order to provide up-to-date and relevant satellite-based crisis information and situation analysis, it is necessary to establish efficient and operational data flow lines between satellite operators, receiving stations, and distribution networks on the one hand, and the decision makers and relief workers on the other hand. Service lines and feedback loops have been created to allow best possible data and information provision, as well as optimized decision support. In order to meet user demands and service requirements in crisis situations, different emergency mapping services as described below have been set up their own rapid mapping standards to ensure fast access to available, reliable, and affordable crisis information worldwide [2].

The German Center for Satellite Based Crisis Information (ZKI) established ISO standards for its rapid mapping workflow covering the full cycle from the emergency call (mobilization phase), satellite tasking (data acquisition), pre-processing, analysis and interpretation, map production and data/information provision to the end-user as fast as possible. (Fig. 1).

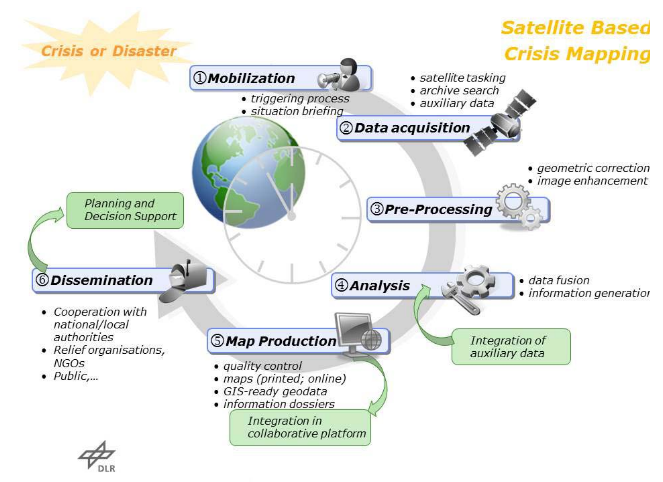

Fig. 1. Emergency mapping workflow

The first step is to clearly define the task and information needed by the user and then to decide whether satellite analysis is appropriate for the respective crisis or not. In order to carry out change detection analysis, pre-disaster satellite imagery needs to be acquired. Besides the procurement of satellite data, supplementary geodata such as population and infrastructure data, road network, contour lines, and administrative boundaries must be made available. Incorporating user's knowledge about the field, e.g. location names or already

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located damages increases the quality of satellite data analysis significantly.

After receiving the archived and recently acquired satellite imagery, essential pre-processing has to be done. This includes geo- and ortho-rectification as well as radiometric corrections and data format conversions. Depending on user's needs, crisis type and extent, different analysis process chains have to be applied.

Derivation of water surfaces or general damage assessment is dependent on input data type, scale, and possible availability of archived satellite imagery. Comparing pre- and post-disaster images allows for the quantification of affected areas. This change detection method can either be applied for optical or radar imagery in order to detect areas where significant changes occured. Furthermore, general image classification and differencing methods allows to quantify flooded areas, fire scars or damaged areas.

Situation and damage maps are generated in order to translate complex satellite information in readable and coherent crisis information. A settled quality control process takes place after each single product generation step as well as before publishing.

Delivery is accomplished via Internet, intranet, ftp, e-mail or satellite communication. Furthermore, printed and laminated maps can be sent via express delivery on request. Maps are updated when new and improved data are available.

II. Emergency Mapping Mechanisms

Several relevant emergency mapping mechanisms have established similar emergency mapping procedures at different (inter)national levels:

(1) In 1999, the **International Charter 'Space and Major Disasters'** [3] was established as a globally functioning mechanism to provide a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through authorized users at international level. Each of the 16 agency members (current as of August 2017) has committed resources to support the Charter and is thus helping to mitigate the effects of disasters on human life and property.

(2) **UNOSAT** is the United Nations Institute for Training and Research (UNITAR) Operational Satellite Applications Programme which was created in 2000 [4]. In 2003 UNOSAT launched a rapid mapping service. Through the use of Geographic Information Systems (GIS) and satellite imagery, UNOSAT provides timely and high-quality geo-spatial information to UN decision makers, member states, international organizations, and non-governmental organizations.

(3) In 2004, DLR was one of the first institutions which set up a dedicated service. The Center for Satellite Based Crisis Information (**ZKI**) facilitates the use of DLR's Earth Observation capacities in the services of national and international response to disaster situations [5]. ZKI's main function is the rapid acquisition, processing, and analysis of satellite data as well as the provision of satellite-based information products. Analyses are tailored to meet the specific requirements of national and international political decision makers, governmental authorities or humanitarian relief organizations. First emergency mapping activities already started in 1999.

(4) **SERVIR** is a joint development initiative of National Aeronautics and Space Administration (NASA) and United States Agency for International Development (USAID). Since 2004, it works globally to help developing countries in Africa, Hindu Kush-Himalaya, and Lower Mekong using information provided by Earth observing satellites and geospatial technologies for managing climate risks and land use [6]. SERVIR is a multi-agency and multi-government mechanism with over 30 partners and collaborators and is endorsed by national governments.

(5) **Sentinel Asia** has a regional focus and was established in 2005, as a collaboration between regional space agencies and disaster management agencies, applying remote sensing and Web-GIS technologies to assist in disaster management in the Asia-Pacific region [7]. Until today, multiple national agencies of about 25 countries in the region have joined and benefited from the disaster support services provided by Sentinel Asia.

(6) For China, the **National Disaster Reduction Centre of China** (NDRCC) [8] is the most important institution, with the International Charter 'Space and Major Disasters' complementing NDRCC capacities on space based crisis information. The agency was established in 2002 to provide information and technological support, including a national disaster database which local civil affairs departments can access to receive details about disasters. Since 2008, satellite based crisis information has also been provided for major disasters.

(7) the **Copernicus Emergency Management Service** (Copernicus EMS) [9, 10] provides information for emergency response in relation to different types of disasters, including natural or man-made disasters and other humanitarian disasters as well as prevention, preparedness, response and recovery activities at EU level. Three modules constitute the Copernicus EMS: Copernicus EMS – Mapping, the European Flood Awareness System (EFAS), the European Forest Fire Information System (EFFIS). Information derived by satellite imagery and geospatial data forms the basis for all three service modules. The services started in 2012 resulting from several previous GMES research projects.

(8) Since 2013, ZKI at DLR operates the **German ZKI-DE** [11] service which allows Federal Agencies to acquire up-to-date geo-information and derived analysis products at German national level in case of disaster or crisis situations as in support of the civil security. Moreover, aiming at a better and more customized use of the products by public authorities, the service includes also user trainings, a consulting service, and continuous further developments based on user requirements and new technical capabilities [10].

In the last years, industry actors such as Digital Globe, Planet Labs, Google or ESRI have been acquiring and providing space based disaster information, too. Moreover, actors based on volunteers like Map Action or crowdsourcing initiatives like Open Street Map – have contributed considerably.

III. CENTER FOR SATELLITE BASED CRISIS INFORMATION (ZKI) - EVOLUTION

ZKI is active in the (1) International Charter 'Space and Major Disasters', (3) the Copernicus EMS – Mapping Service, and (7) the German ZKI-DE service. Additionally, ZKI is involved in several research projects focusing on the development of the operational services, methods, and products to ensure a continuous improvement.

Over the last years, ZKI's main focus was on establishing the aforementioned emergency mapping mechanisms at different international and national levels and standardizing the rapid mapping workflow (section III). In the first years of ZKI, most of the emergency mapping activations supported the work of relief units in different kinds of natural disasters. Over time, ZKI has also increasingly provided Earth Observation based information for planning purposes before and during major events, e.g. the German Unity Day, for maritime surveillance, and police investigations. In total, since 1999 ZKI was activated more than 200 times and produced more than 1000 products - mostly in case of flood events and in support for police inquiries (Fig. 2).

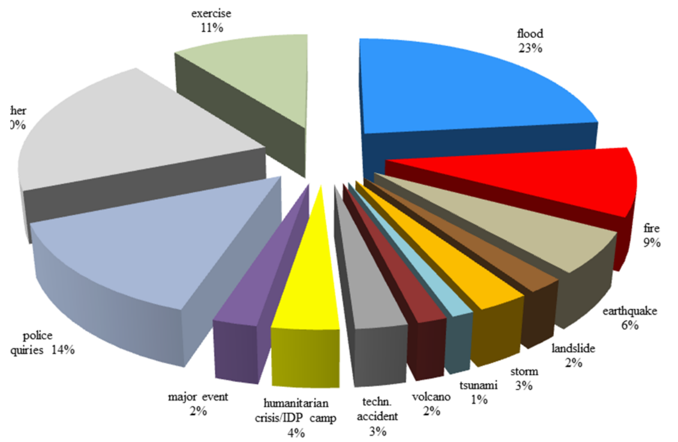

Fig. 2. Thematic categorization of ZKI activations since 1999 (without Charter data provision and maritime surveillance), as at 07/07/2017.

Nowadays, the ZKI service as well as the other (inter)national services are running on a high operational level. However, service evolution is a critical ingredient of the service lifecycle. Thus, efforts are made on permanently improving the services by implementing innovative technologies. Research is concentrating on the use of new sensors, the development of new methodologies and advanced products, or the incorporation and fusion of different data.

While ZKI's operation routines and rapid mapping workflow has constantly been refined, satellite technology improved likewise and led to better emergency mapping products and to more precise Earth Observation based crisis information. In particular the geometric resolution of optical satellites enhanced from meters to sub-meters up to currently 30 cm ground resolution. By using aerial imagery, the geometric resolution can even be higher (10-20 cm) which is beneficial for the assessment of disaster situations or planning purposes. In the coming years, more dynamic drone data will become an important source for emergency mapping purposes [12, 13]. The enhanced geometric resolution and the dynamic monitoring allow a further detailed assessment of small scale damages, e.g. damaged or destroyed houses, or other important disaster or planning information, e.g. barriers, streams of visitors. This requirement has been stated by the users consistently.

Apart from the improved geometric resolution, the availability of up-to-date satellite imagery has increased dramatically since many more satellites are up in space. In the beginning of emergency mapping, the challenge was to receive or acquire an adequate satellite image within a short timeframe. Currently, in most cases the regions of interest are covered by up-to-date satellite imagery.

Regarding the analysis methods within ZKI (semi-)automated processes - in particular for flood and fire assessment - have been developed [14, 15]. Methods are permanently refined and moved forward in order to transfer processing chains into operational workflows.

In addition to increasing availability of image sources and analysis methods, product types have also been redesigned and improved according to ZKI users' requirements. Starting with standard maps in different resolutions and formats, the portfolio was soon extended by including kmz/kml files, information dossiers, and the provision of the extracted information layers for the users' individual purposes, e.g. integration of layers in their own geoinformation systems. In recent times, dynamic GeoPDFs as well as dynamic web services became more important as users can change views easily and add own information. Currently, 3D products are increasingly generated mainly from stereo very high resolved (VHR) satellite imagery, aerial or UAV data and applied for disaster situations or major events. But in the field of crisis and disaster management, 3D mappings are still in an early stage of operational use [16, 17].

In the following two mappings of the ZKI are presented, in which aerial photographs were acquired and analysed near-real time and 3D products were created from them. Both examples - a flood scenario and a major event - are typical fields of application for ZKI products and further developments to support the operational forces.

IV. SUPPORTING RELIEF UNITS WITH 3D MAPPING PRODUCTS

In case of floods, practitioners of a relief unit have to perform a variety of tasks. Many of them involve some form of logistics – whether it is pulling together units from different parts of a region/country, organizing and transporting sandbags or directing crisis management units to a scene of operation. New techniques can provide support to crisis managers in performing these tasks.

Fig. 3. 2D flood map produced by ZKI during the flood event in Magdeburg, Germany on 10/06/2013 enriched with information derived during the DRIVER tabletop experiment simulation.

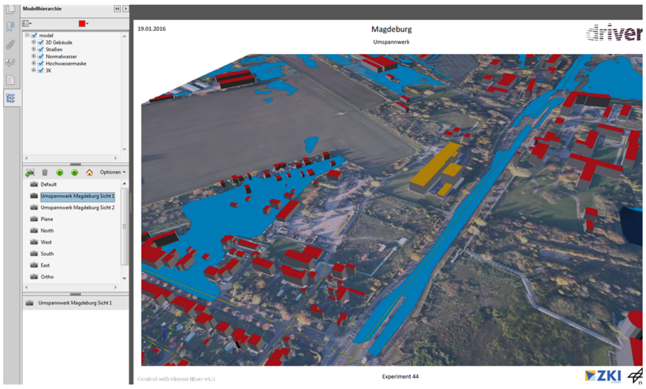

Fig. 4. 3D geopdf generated during the DRIVER experiment.

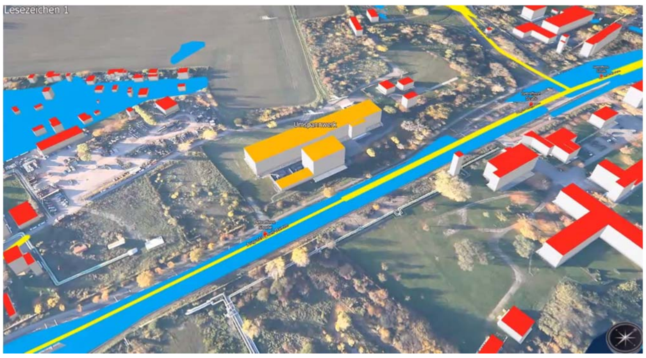

Fig. 5. Screenshot from a 3D video animation produced in the frame of the DRIVER experiment.

Within the EU funded DRIVER project [18], different innovative technologies are being tested in experiments and trials together with partners of the Civil Protection community in order to achieve the maximum benefit for Crisis Management. In the DRIVER tabletop experiment 'Transport and logistic support', a flood scenario was simulated in Magdeburg, Germany in 2016. It was conducted on a national level with Germany's disaster relief organization, the Federal Agency for Technical Relief (THW, Bundesanstalt Technisches Hilfswerk). Aerial images recorded in advance by a plane, operated by DLR, were fed into a DLR-developed traffic management system which allowed crisis managers to receive an overview of the affected area [19].

In addition, crisis relevant information was generated by ZKI to provide situational awareness, support damage and needs assessment, and to facilitate decision making processes. Flooded areas, critical infrastructure such as roads or the affected transformer station were detected using airborne and satellite imagery [20, 21]. This information was disseminated via traditional 2D and new interactive 3D geographical mapping products (compare Fig. 3-5). In addition, a terrain model and buildings in form of block models were included in the 3D map products in order to be able to measure the size and height of buildings as well as the distance to risk / flooded areas.

There are several requirements of THW when responding to a flood disaster. One of them is to get a situational overview of the affected region as realistic as possible. For this reason, 3D situational awareness products in addition to 2D satellite based maps were requested. A video animation was provided by ZKI in order to get a realistic impression of the area, designed in particular for relief workers that have never been in the affected region before. In addition to this general situational awareness, the main requirements referred to transport and logistic support in order to receive information on:

- Flooded areas
- Affected critical infrastructure
  - in this scenario: inundated roads and the transformer substation
- Altitude of affected buildings or buildings in flood risk areas
- Distances / size of areas affected by flood
  - in this scenario: estimating the amount of sandbags needed
- Flood depth
  - in this scenario: identifying potential passages for emergency vehicles.

TABLE I. ZKI PRODUCTS COVERING THW'S REQUIREMENTS REGARDING TRANSPORT AND LOGISTIC SUPPORT IN A FLOOD SCENARIO

THW's requirements	**ZKI product type**		
	2D map	***3D geopdf***	***Fly through video animation***
General situation awareness	✓	✓	✓
Virtual impression of affected region	✗	✓	✓
Flooded area	✓	✓	✓
Inundated roads	✓	✓	✓
Transformer substation	✓	✓	✓
Altitude of affected buildings	✗	✓ (measurement possible)	✓
Distances / size of areas	✓	✓ (measurement possible)	✓
Flood depth	✗	✗	✗

To cover all requirements, different mapping products were generated: (a) 2D situation map, (b) interactive 3D pdf showing the different layers and being able to perform measurements as well as (c) a fly through video animation over the affected area. The different products covered all needs (Tab. 1), especially the 3D products provided a realistic impression of the scenario and supported measuring distances and altitudes of buildings. The derivation of flood depths remains a challenge which has not been satisfactorily solved yet. A precise terrain model before and during the flooding situation is important for this purpose, in order to be able to calculate the flood depth as accurately as possible. Nevertheless, it is difficult to make accurate statements in cm, as objects / obstacles under the water surface can also be detected and included. ZKI is currently putting effort in this research topic.

Furthermore, ZKI increases its operational applications of stereo data from VHR satellite imagery, aerial and also UAV data. As described above, these techniques are still capable of development in the field of crisis and disaster management, but already show promising results.

V. Near-Real Time Situational Awareness with Aerial Imagery

For major events new possibilities exist for delivering situation information based on aerial imagery. About 100.000 people joined the 36th German Protestant Church Conference in Wittenberg on 28th May, 2017. DLR supported the traffic and security management of the festive major event in two different ways: (1) Within the DLR's project VABENE++ [22] aerial imagery was acquired in near-real-time and traffic flows around the festive venue were analyzed [23]; (2) the ZKI-DE service analyzed the acquired aerial imagery as well as satellite imagery before and during the Church Conference in order to monitor the festival grounds and the surrounding infrastructure and generated up-to-date situation maps (Fig. 6). DLR used its own innovative aerial camera system. A 4 band camera with three optical bands and one near infrared band (4K camera) on a research helicopter (Eurocopter EC135) for acquiring ortho-ready aerial imagery in near-real time with a geometric resolution of 10 cm [24]. By using this system, it is possible to generate in short time valuable information for larger regions (e.g. the city of Wittenberg and surroundings) at very high spatial resolution. In addition, the helicopter is very flexible in its operation regarding time and space, meaning that in consultation with task forces in field, areas of interest can be re-defined on call or can be monitored at different times.

Automatically derived traffic flows [25] as well as information about critical infrastructure such as police and fire stations, hospitals, train stations, parking places or assembly areas were combined and provided in up-to-date situational awareness maps and web services.

The involved operational forces and relief units could use the provided information as a support in coordinating their activities and in comparing the pre- and post-event-situation. Main users of DLR's aerial and satellite based information were the event management, the Johanniter, the THW, the state administration of Saxony-Anhalt as well as the police of the German state of Saxony-Anhalt.

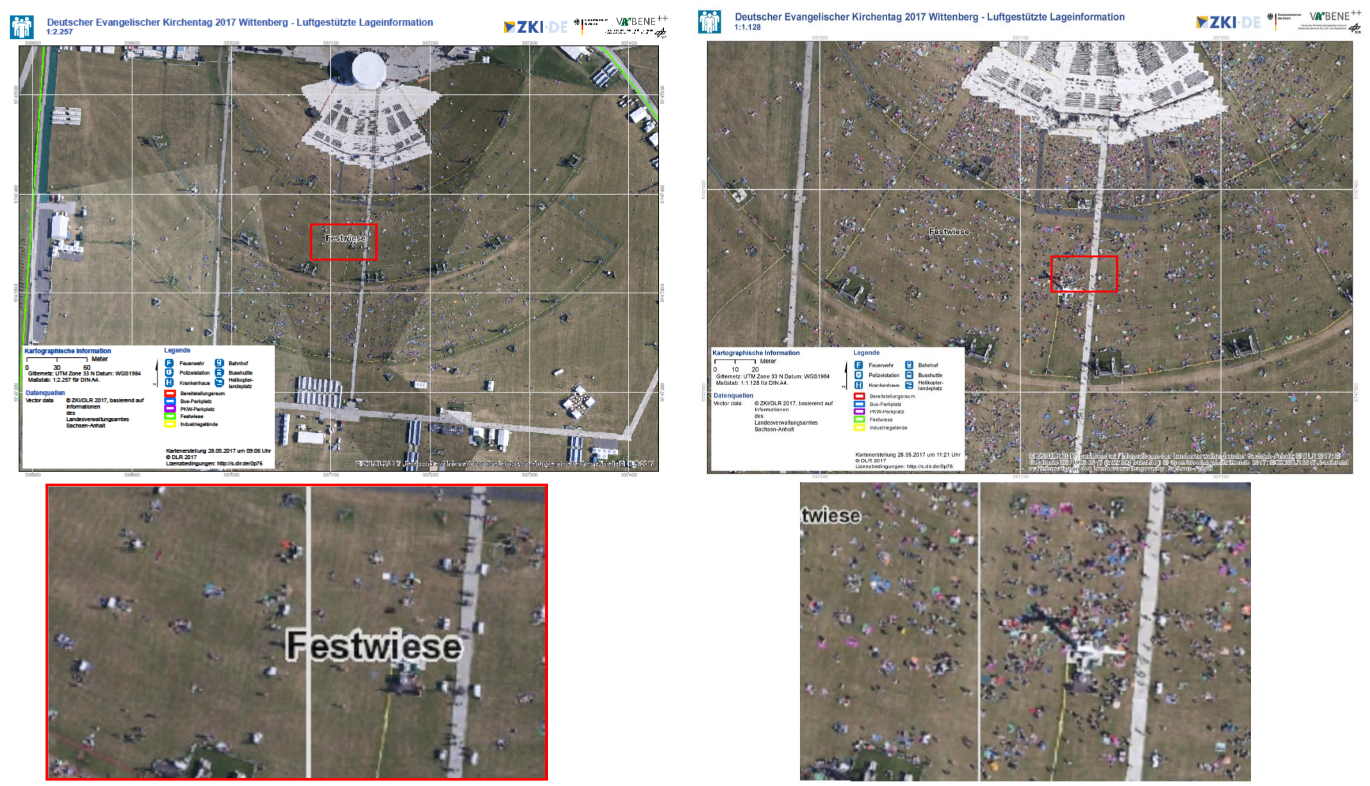

Fig. 6. Detailed situation maps of Wittenberg on 24/05/2017 at 09:06 a.m. (with zoom-in, left side) and at 11:15 a.m. (with zoom-in, right-side)

VI. Conclusions and Outlook

Over the last years, the provision of Earth Observation-based disaster information has improved and operationalized enormously. Rapid Mapping Procedures have been standardized and many Earth Observation based emergency mapping services at different (inter)national levels have been established. Accordingly, Earth Observation technology plays an important role in disaster management, especially during the preparedness and response phase.

Nevertheless, existing operational services have to be permanently improved by (1) using imagery derived from new sensors and by combining different imagery types, e.g. UAV data, near-real-time provision of aerial imagery or microsatellites like Planetscope, (2) the development of new methodologies and their operationalization in the context of emergency mapping, e.g. 3D mappings, and (3) the generation of an extended emergency mapping product portfolio, e.g. 3D products, augmented/virtual reality products or advanced web mapping services, or (4) the incorporation and fusion of other data, e.g. coming from social media.

In the case studies presented in this paper, new developments of Earth Observation based emergency mapping were taken into account by using 3D mapping, aerial imagery as well as near-real time delivery of crisis information in an operational mode. These techniques can be used not only for the aforementioned case studies to support the emergency services in flood management and planning / monitoring of major events, but are also conceivable for many other deployment scenarios. Especially in the area of ad-hoc situational awareness in crisis management of any disaster or major events, e. g. in the case of fire or storm damage, technical accidents or in the case of relieved disaster locations, the new emergency mapping developments presented can provide useful support.

Further research and development will focus on bringing more valuable Earth Observation based crisis information into operational application taking into account the demands of the different users.

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References

[1] S. Voigt, F. Giulio-Tonolo, J. Lyons, J. Kucera, B. Jones, T. Schneiderhan, G. Platzeck, K. Kaku, M. K. Hazarika, L. Czaran, S. Li, W. Pedersen, J. K. Godstime, C. Proy, D. M. Muthike, J. Bequignon, D. Guha-Sapir, "Global trends in satellite-based emergency mapping,". Science, 353 (6296), pp. 247-252, July 2016.

[2] M. Gähler, „Remote Sensing for Natural or Man-Made Disasters and Environmental Changes", Environmental Applications of Remote Sensing, Prof. Maged Marghany (Ed.), InTech, pp. 309-338, 2016.

[3] B. K. Jones, T. S. Striker, A. Mahmood, G. R. Platzeck, "The International Charter 'Space and Major Disasters'," in Time-Sensitive Remote Sensing, Eds. New York: Springer Verlag, pp. 79-89, June 2015.

[4] UNITAR's Operational Satellite Applications Programme – UNOSAT Webpage, http://www.unitar.org/unosat/, accessed July 17, 2017.

[5] S. Voigt, T. Kemper, T. Riedlinger, R. Kiefl, K. Scholte, H. Mehl, "Satellite image analysis for disaster and crisis-management support", IEEE Transactions on Geoscience and Remote Sensing, vol. 45(6), pp. 1520–1528, 2007.

[6] NASA-SERVIR Global Webpage, https://www.servirglobal.net, accessed July 17, 2017.

[7] K. Kaku, H. Held, "Sentinel Asia: A space-based disaster management support system in the Asia-Pacific region", International Journal of Disaster Risk Reduction, pp. 1–17, June 2013.

[8] China National Commission for Disaster Reduction – NDRCC Webpage, http://www.jianzai.gov.cn/DRpublish/ywzsy/00010023-1.html, accessed July 17, 2017.

[9] T. Schneiderhan, M. Gähler, O. Kranz, S. Voigt, "Insights into the emergency mapping service within the GMES project SAFER - Highlights, main achievements and challenges", Proceedings of the ESA Living Planet Symposium, pp. 1-5, June 2010.

[10] European Commission, "Copernicus Emergency Management Service Mapping - Manual of Operatinal Procedures", vol. 1.1, p. 62, 2015.

[11] Center for Satellite Based Crisis Information for Federal Agencies (ZKI-DE) Webpage, https://www.zki.dlr.de/de/services/zki-de, accessed July 17, 2017.

[12] F. Nex, F. Remondino. "UAV for 3D mapping applications: a review.", Applied Geomatics, vol. 6.1, pp. 1-15, 2014.

[13] C. Gomez, H. Purdie, „UAV-based Photogrammetry and Geocomputing for Hazards and Disaster Risk Monitoring–A Review." Geoenvironmental Disasters, vol. 3(1), p. 23, 2016.

[14] S. Plank, E.-M. Fuchs, C. Frey, "A Fully Automatic Instantaneous Fire Hotspot Detection Processor Based on AVHRR Imagery—A TIMELINE Thematic Processor", Remote Sensing, vol. 9 (30), pp. 1-22, 2017.

[15] A. Twele, W. Cao, S. Plank, S. Martinis, "Sentinel-1-based flood mapping: a fully automated processing chain", International Journal of Remote Sensing, vol. 37 (13), pp. 2990-3004, 2016.

[16] S. Martinis, S. Clandillon, A. Twele, C. Huber, S. Plank, J. Maxant, W. Cao, M. Caspard, S. May, "Improving the extraction of crisis information in the context of flood, fire, and landslide rapid mapping using SAR and optical remote sensing data.", EGU General Assembly Conference Abstracts, vol. 18, p. 4928, April 2016.

[17] D. Hein, S. Bayer, R. Berger, T. Kraft, D. Lesmeister, „An Integrated Rapid Mapping System for Disaster Management.", International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives, vol. 42(W1), pp. 499-504, 2017.

[18] DRIVER, "Innovation in crisis management", Crisis Response Journal 11, p. 86, March 2016.

[19] S. Detzer, G. Gurczik, A. Widera, A. Nitschke. „Assessment of Logistic and Traffic Management Tool-Suites for Crisis Management", European Transport Conference, October 2016.

[20] S. Martinis, J. Kersten, A. Twele. A fully automated TerraSAR-X based flood service. ISPRS Journal of Photogrammetry and Remote Sensing, 104, pp. 203-212, 2015.

[21] C. Huber, S. Clandillon, S. Martinis, A. Twele, S. Plank, J. Maxant, W. Cao, S. Haouet, H. Yesou, S. May. Improving the extraction of crisis information in the context of flood, landslide, and fire rapid mapping using SAR and optical remote sensing data. IGARSS, Peking, China, 2016.

[22] V. Gstaiger, R. Nippold, R. Kiefl, „Forschungsprojekt VABENE++: Verkehrsmanagement bei Großereignissen und Katastrophen", Im Einsatz (6), pp. 34-36, December 2016.

[23] V. Gstaiger, H. Römer, D. Rosenbaum, F. Henkel. Airborne Camera System for Real-Time Applications - Support of a National Civil Protection Exercise. In: Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., pp. 1189-1194. May 2015.

[24] F. Kurz, D. Rosenbaum, O. Meynberg, G. Mattyus. Real-time mapping from a helicopter with a new optical sensor system. In: Publikationen der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation e.V., vol. 23, pp. 1-8, March 2014.

[25] S. Detzer, Y.-P. Flötteröd, R. Nippold, E. Melde. Transport and logistic Support for crisis Management decision. SUMO User Conference 2016 - Traffic, Mobility, and Logistics, May 2016.