DEMONSTRATING AN OPERATIONAL WORKFLOW FOR CRISIS MAPPING BASED ON SATELLITE IMAGERY

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ABSTRACT The advantages and usage of geo-information derived from Earth Observation satellites in time-critical situations have been well proven in recent decades. In particular, in the wake of natural or man-made disasters, the processing and analysing of satellite data using standard techniques can provide fast and synoptic information during the first critical stage of a crisis. At the early stage, when every minute counts, the challenge is to manage the balancing act to supply accurate and reliable information as fast as possible in a very short time frame. When natural disasters, major man-made accidents or other time-critical situations occur, the availability of geo-information is an asset that supports decision-making processes. This paper outlines the challenging organisational and technical aspects from the practitioner's perspective with regard to operational early response in terms of crisis mapping. The goal of this paper is to underline the crucial and critical operational aspect from the service provider's perspective, and to demonstrate a structured and coordinated workflow. Such a workflow has already been implemented with the objective of providing fast and reliable information about the overall impact of an incident to support the Common Operational Picture (COP) within the first hours and days after the occurrence of an incident. The example presented here refers to the industrial accident at the Chenjiagang Chemical Industry Park, Yancheng, China, on 21 March 2019, for which crisis mapping was performed based on Very High Resolution (VHR) satellite sensors. Suitable satellite data was acquired and delivered 3 days after the event and the generation of the corresponding crisis information was finalised within a few hours after reception of the respective satellite data at the service provider's production site. The resulting product was supplied in easy-to-use standard formats. Taking into account the very dynamic current technological evolution, an outlook is also given about the potential regarding satellite based crisis information extraction.

1. INTRODUCTION

1.1 Background

Over the past decades, the use of up-to-date geospatial information extracted and derived from Earth Observation (EO) satellites has accomplished the transition from the research and development stage through the implementation stage and on to the operational phase in the disaster management domain. Looking back at the situation 20 years ago, operational mapping mechanisms and services based on Earth Observation satellites were then in a pre-operational stage. Fully operational services were on the wish list of participants and stakeholders in the natural disaster management domain. At that time, the focus was on research and development, with the goal of evaluating the technical and organisational feasibility and limits, and determining fundamental and robust methodical approaches to meet the requirements. This has been facilitated not only by developments in the EO satellite sector and the emergence of disruptive technologies; a key driver is that the added value provided by time-critical geo-information derived from EO satellites has been recognised and demonstrated by the obvious and tremendous advantages regarding increasing and supporting situational awareness in the wake of natural disasters. The Indian Ocean Tsunami in 2004, with its large and extensive destruction, was a key event in demonstrating the benefits and potential of EO satellite imagery (Voigt et al., 2016). As a consequence, a great deal of effort has been made in this area and impressive progress has been achieved in terms of international cooperation and coordination.

Several international programmes dedicated to the application of EO satellite data primarily in the area of natural disasters are operational, including the International Charter "Space and Major Disasters", which consists of space agencies and satellite providers and became operational in 2000 (Martinis et al., 2017). Its main task is providing access to satellite data. In terms of the Asian region, the Sentinel Asia Program that was created in 2005 focuses on the regional satellite data provider's network and user communities. European research and development programmes have led to the European Copernicus Emergency Service being operational since April 2012. This provides mapping services for each phase in a disaster management cycle, and additionally operates early-warning information systems for fire, flood and drought. The United Nations Operational Satellite Applications Programme (UNOSAT) is dedicated to United Nations entities and international and national NGOs (Gähler, 2016).

A common factor in these international programmes is the provision and usage of both optical and SAR EO satellite data, mainly with a focus on utilising the relevant information to monitor natural disasters and humanitarian impacts. Satellite data are made easily and readily accessible to civil protection authorities, humanitarian relief organisations, first response mission teams and national and international institutions. The data are provided directly in standard product formats or processed, analysed and integrated into a value-added product or a Situational Awareness Information System. The tasks are performed by remote sensing and GIS experts, who extract and visualise the relevant information in the emergency context. Generally, all the phases within a disaster management cycle, from prevention and response through to recovery, are supported by rapidly providing overall and contextual geo-information.

When natural disasters occur, the mitigation of human suffering and prevention of loss of human life are given the highest priority. In addition to the humanitarian considerations, there is also a financial impact, which can have severe and long-term consequences for development and economic growth at the regional and national levels. For example, from 1998 – 2017, it is reported that global economic losses caused by natural disasters amounted to US$ 2.9 billion (CRED/UNISDR, 2018). Earth Observation satellite data can help provide additional updated information in terms of economic and insured loss. In the case of large and serious industrial accidents, geo-information can supply initial insights into where and to what extent the facility or infrastructure has been affected. In addition to a first rough assessment of the level of impact, the information that is derived can be directly linked with demand for the latest information for predictions relating to business interruption and the disruption of supply chains. Information about the economic dimension is increasingly required by the risk intelligence and insurance sectors due to the potential economic loss, and its impact on all associated direct and indirect economic activities (Siebert, 2017). Also, with regard to monitoring sensitive facilities, time-critical geo-information can help agencies react in time in order to avoid potential hazardous situations or circumstances. As an example, the industrial accident in Tianjin in China in August 2015 gained tremendous attention in the insurance industry. The explosions in the Port of Tianjin were the largest ever recorded man-made insured loss event in Asia (Bevere et al., 2017). The accident has resulted in long, drawn-out and complex evaluation and processing activities regarding insurance coverages. In the first hours and days after the technical disaster, a range of data sources were consulted and analysed to provide a first impression of the scale of the accident. These included high and very high pre-event and post-event imagery (Guy Carpenter, 2015). GAF AG's Service-on-Demand-Team was alerted and activated, and produced a first damage assessment data set that gave a rough insight into the extent and degree of destruction (Figure 1).

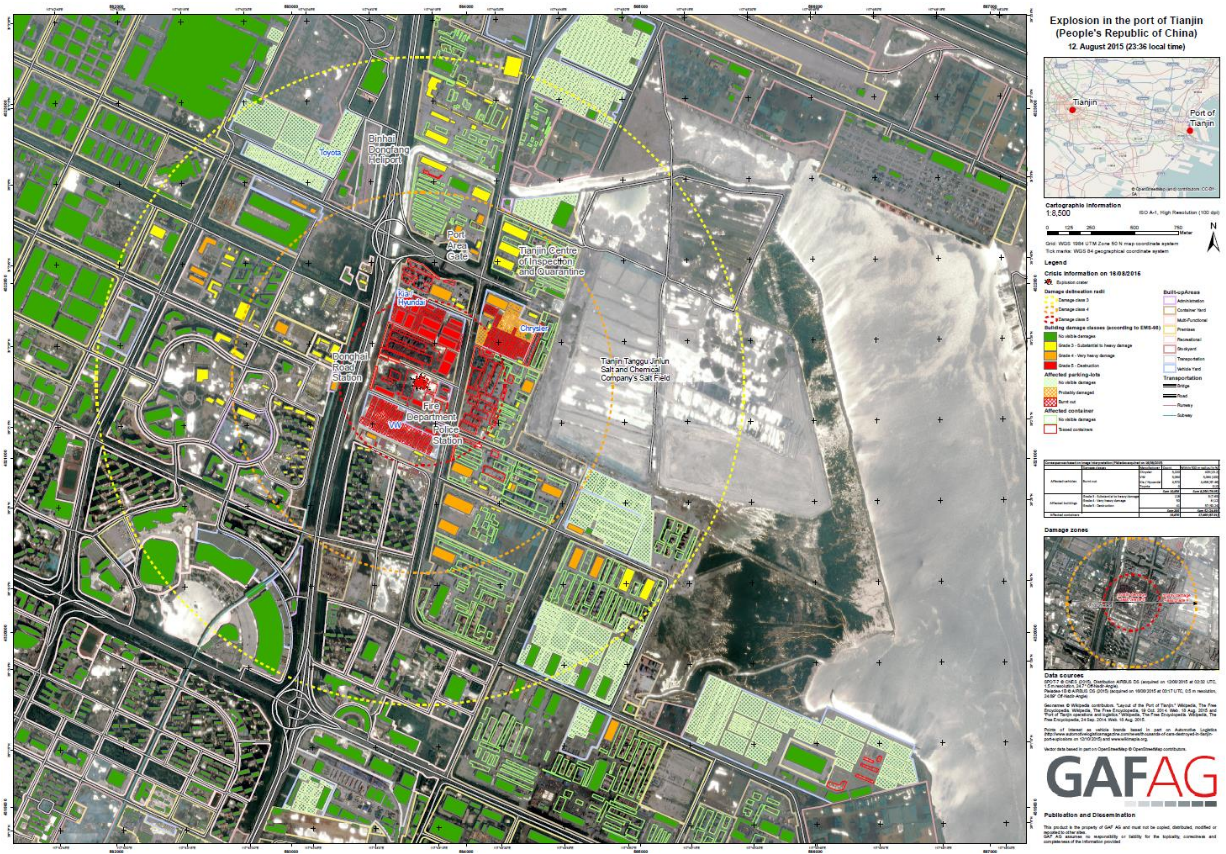

Figure 1: Damage assessment map from Tianjin explosions in August 2015

All initiatives, programmes, services and activities dedicated to emergency and crisis mapping based on satellite data have one major critical common component, which is their timeliness, i.e. the need for rapid provision of the relevant geospatial information to all levels of experts, from the disaster management coordination level to the in-the-field emergency teams. Once an emergency activation has been triggered, the complex and dynamic nature of the events requires a high level of collaboration within a multi-disciplinary context (Sophronides, 2017; Chen, 2014). Therefore, it is an essential requirement that organisational and technical tasks have already been implemented, tested and made operational, to guarantee a smooth processing workflow. This requires the permanent maintaining of a systematic and standardised set-up, and the ready-to-use availability of technical and human resources with comprehensive and dedicated capabilities and capacities. GAF AG, an e-GEOS (ASI/Telespazio) company, located in Munich, Germany, used EO satellite data as far back as 1986, to assess the Chernobyl nuclear accident. Since then, it has continually developed and established dedicated methods and approaches for time-critical applications based on remote sensing technologies. Since 2012, GAF AG has operated a Service-on-Demand team focusing on programmes, projects and products tailored for time-critical applications.

1.2 Event and Location

On 21 March 2019, at around 3:00 am, a destructive and fatal industrial accident occurred at the Chenjiagang Chemical Industry Park in Xiangshui County, in the Jiangsu Province. The blast, at a pesticide chemical plant located at 34°20’36.04’’ North, 119°46’30.05’’ East, triggered a 2.2-magnitude earth tremor. The industrial park is located directly on the Guanhe River, has loading terminals for petrochemical materials (Resilience360, 2019) and covers an area of about 7 square kilometres. The longest distance from the centre of the explosion to the Guanhe River is about 2.3 kilometres, in a westerly direction. To the east and south, there are several small settlements within a distance of about 1.5 kilometres.

Figure 2: Location of the Chenjiagang Chemical Industry Park in Xiangshui County, Yancheng, Jiangsu

2. OPERATIONAL SERVICE ENVIRONMENT

2.1 Operational requirements

In this paper, the term ‘operational’ is defined as being a system or process that is fully functional and ready for use, i.e. communication, coordination and production capacities are made available by service providers in a stand-by mode, which can be triggered at any time from any place in the world. Naturally, in the case of an emergency activation there are numerous providers and stakeholders involved, each of them with different mandates, responsibilities and tasks. For example, in the case of natural disasters, there are usually civil protection or international/national disaster management authorities that issue a request for management support or rescue assistance. Furthermore, other affected parties, such as the supply chain management sector or insurance companies, ask for specific geospatial information, in order to have an additional source of information to complement their overall picture of the crisis situation. Once a request for providing updated geo-information and crisis information has been initiated, a complex processing chain starts. Many different parties are alerted and each of them initiates their specific tasks. Figure 3 schematically illustrates the three main groups that are involved in an activation focusing on providing crisis extraction based on satellite imagery – the end-users, the thematic information service providers and the satellite data operators. The client/end-user asks for reliable, understandable and tailored information provided within a certain time frame, the service and product provider generates and delivers the requested information in the agreed rapid response period, and is also responsible for the procurement and processing of the satellite data. Since all the groups that are involved have different organisational and technical working environments, capabilities and capacities at any given time, the challenge is to coordinate and calibrate all the participants in order to provide a robust and plausible product within the requested time.

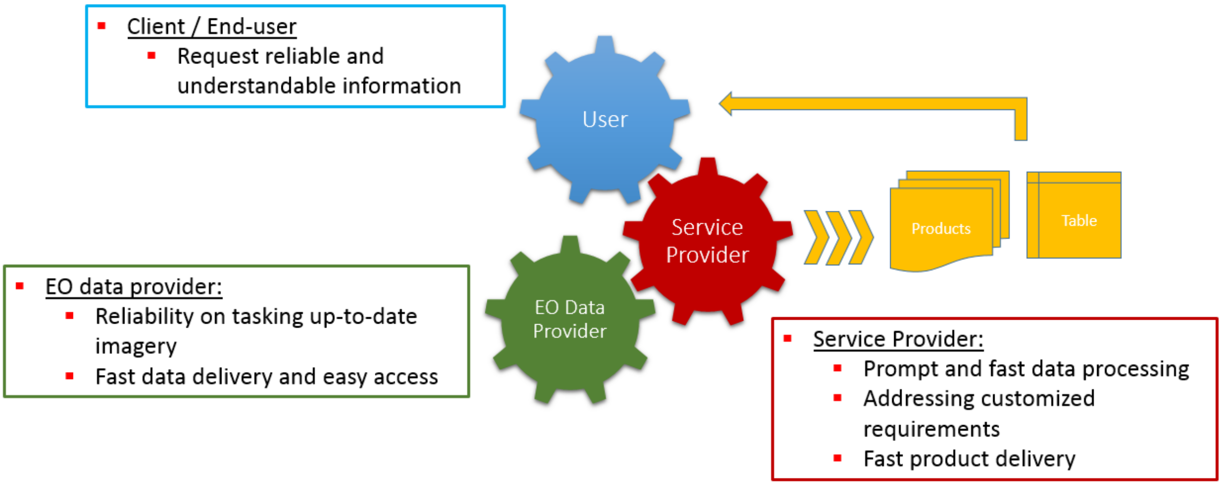

Figure 3: Meshing the tasks and dependencies of participating groups in a time-critical working environment

In general, operational services and activities involve the fulfilment of a minimum set of characteristics:

- Ability to react to global events: natural disasters or man-made accidents can occur at any place around the world.
- Scalable operational mode: crisis events can occur at any time of the day or night. In most cases, fast reaction is required to trigger all follow-up tasks. Consequentially, this can require extended working modes, i.e. 12/7 or 24/7 service.
- Production in rush/priority mode: the requested products contain time-critical information and are therefore classified into priority products.
- Product delivery within hours/days: depending on the severity and the course of an event, the timely availability of the crisis information is essential and crucial.
- Standardised procedures, content and formats: structured procedures and standardisation facilitate coordination and communication throughout the entire workflow

From the service provider's point of view, the operational coordination, consulting, data processing and mapping activities require a dedicated and well-organised working environment. An operational crisis workflow has to build on a predefined set-up of systemised personnel and technical organisational structures, coordinated measures, standardised techniques and actions, and customised tools. Finally, the products that are generated often have to fulfil specific thematic requirements and have to address the multifaceted needs of a broad range of end-users.

2.2 Operational expert resources

While the technical part of the workflow can be automated to a certain extent, the communication and coordination tasks are executed by professionals. Dedicated staff resources and capacities have to be made available during standard working hours or switched to standby mode during weekends or at night. To provide this service, dedicated infrastructure and facilities have to be established and compliance with national laws, regulations and standards has to be ensured. The Service-on-Demand team at the GAF AG premises can allocate three high-level staff per shift within a daily three shift system. The on-duty team consists of one activation and production manager, supported by two technical remote sensing, GIS, and thematic experts. All members of the Contact Point Team are equipped with high performance IT infrastructure, hardware and software packages, and dedicated communication devices that ensure they can be contacted at any time.

Table 1: Roles and tasks of Service-on-Demand team

Role	Tasks	On-duty shift system option
Contact Point team / production manager (5 members including backup /1 per on-duty shift)	• Communication • Organisation • Coordination • Quality assurance	8/5, 12/7, 24/7
Technical expert team (20 members including backup /2 per on-duty shift)	• Image pre-/post processing • Thematic analysis, interpretation • Product generation, delivery	8/5, 12/7, 24/7

2.3 Operational workflow

The workflow starts with the alert or triggering of a crisis mapping request by the client, including a satellite and metadata enquiry, the production set-up request and the definition of dissemination channels. After the initial communication, a well-established mechanism is followed, i.e. understanding the request, searching for and obtaining the necessary data, coordinating and planning the production set-up, and mobilising the on-duty team.

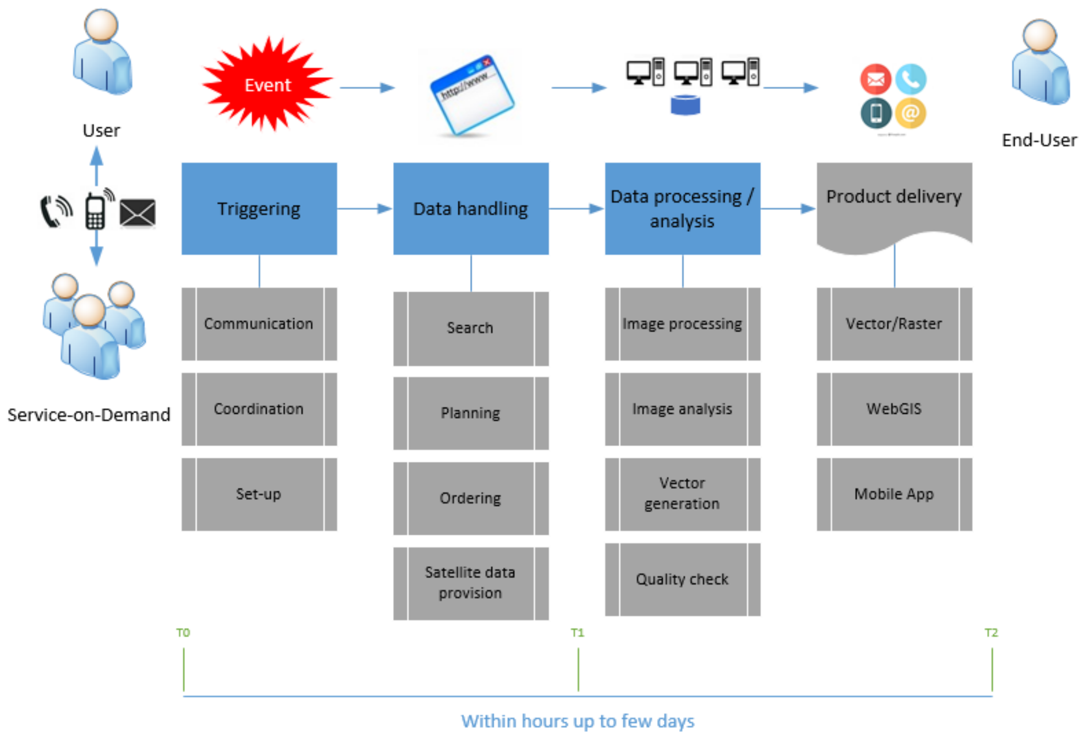

Figure 4: Schematic workflow and sub-tasks during an activation

The main factors that influence the duration of an activation are the type of event, the type of product requested, i.e. whether the request is asking, for example, for a standard crisis extents map or a detailed damage assessment map based on VHR satellite data. One major critical component is the prompt acquisition and provision of the latest post-event satellite data. In the case of SAR imagery, this factor is less critical, but once optical satellite data are required there could be several constraints leading to a delay in image acquisition and delivery. In the Chenjiagang case, optical data acquired shortly after the event was used. Therefore, the required data was available within just a few hours. In Table 2, the timeline for each major working step that is performed is indicated. While the monitoring of the event and activation was continuously maintained from 21 March to 25 March, the data handling activities ended after the reception of the ordered satellite image (March 25). Since the area of interest and image analysis was about 12 square kilometres, the analysis and damage assessment could be finalised within just a few hours on 25 March.

Table 2: Timeline for the Chenjiagang product generation

ID	Working steps	Start	End	Time window	Duration	Mar 2019				
						21	22	23	24	25
1	Event/Monitoring activation	21/03/2019	25/03/2019	5T	Ø 3 hours/day					
2	Data handling	21/03/2019	24/03/2019	4T	Ø 1 hours/day					
3	Data processing/product generation	24/03/2019	25/03/2019	2T	Ø 5 hours/day					
4	Product finalisation	25/03/2019	25/03/2019	1T	3 hours					

2.4 Satellite data search and data mining

One of the first actions to be performed after the triggering of the activation is data mining, in particular, the search for suitable satellite data. Dedicated data query and search tools allow an overview of the data availability to be obtained, both in terms of archive imagery and potential tasking options. In many cases, the exact location and accurate coordinates of the location/area of interest are not yet known in the first hours of the event. Therefore, additional information sources, particularly social media and national/international online news portals, are consulted. In the case of the Chenjiagang incident, the location could be identified without much delay due to breaking news and social media pictures. By default, thermal band information derived from low resolution satellite sensors VIIRS/MODIS Terra/Aqua was retrieved, but due to dense cloud coverage during the event no usable information could be extracted from this source.

On 21 March 2019, when the news about the incident started to be reported, the news channels were monitored continuously, and the satellite data providers' archives were checked periodically for updates (Figure 5). It is well known that satellite providers have an interest in monitoring global disaster and crisis events in order to capture a first image. In relation to possible tasking requests and options, the proprietary satellite acquisition support tool was consulted in order to allow consideration of potential upcoming orbits performed by very high resolution (VHR) satellites (Figure 6).

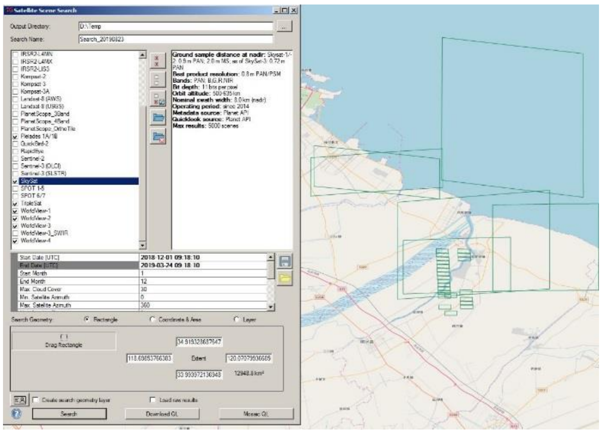

Figure 5: Satellite archive data scene search tool

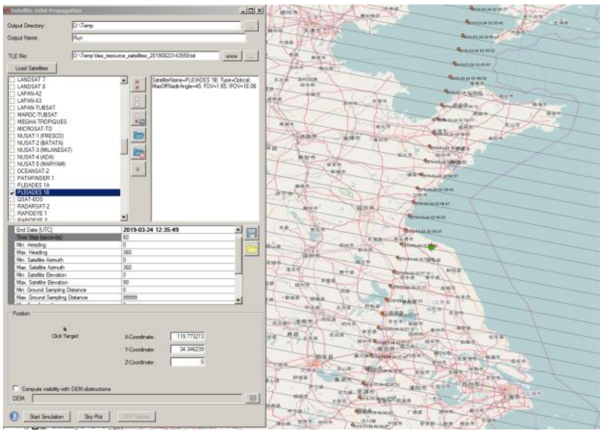

Figure 6: Satellite data acquisition support tool

2.5 Image data selection and ordering

Finally, the proprietary satellite scene search resulted in a cloud-free Pléiades-1B scene acquired on 24 March over the destroyed chemical plant (see Figure 7). Additionally, Figure 7 lists important acquisition parameters from all the retrieved scenes visualised in Figure 8. It is essential to have knowledge of the respective scene characteristics and acquisition parameters, in particular the satellite elevation and azimuth angle, because this helps anticipate possible constraints during the image processing and analysis. For example, a very oblique scene with a low satellite elevation angle acquired in mountainous relief could hamper the analysis and information extraction. Since the area of interest in this case was characterised by flat terrain, there was, however, no need to consider any possible morphological constraints.

	FID	Satellite	ID	StripId	Date	CloudCover	Resolution	SatAz	SatEl	TarAz	OffNadir	SunAz	SunEl
▷	8	PHR1B	DS_PHR1B_201...	DS_PHR1B_201...	2019-03-24 02:5...	0	0.5	213.8	74.3	33.8	14.2	149.7	53.2
	5	KOMPSAT-3A	K3A_201812210...	K3A_201812210...	2018-12-21 05:0...	0	0.55	260	80.7	80	8.6	198	30
	4	KOMPSAT-3A	K3A_201812210...	K3A_201812210...	2018-12-21 05:0...	0	0.55	260	80.7	80	8.6	198	30
	3	KOMPSAT-3A	K3A_201812210...	K3A_201812210...	2018-12-21 05:0...	20	0.55	260	80.7	80	8.6	198	30
	2	KOMPSAT-3A	K3A_201812130...	K3A_201812130...	2018-12-13 04:5...	10	0.55	80	69.9	260	18.5	196	31
	1	KOMPSAT-3A	K3A_201812130...	K3A_201812130...	2018-12-13 04:5...	10	0.55	80	69.9	260	18.5	197	31
	6	PHR1B	DS_PHR1B_201...	DS_PHR1B_201...	2018-12-12 02:4...	2	0.5	129	61.2	309	25.7	160.5	30
	7	PHR1A	DS_PHR1A_201...	DS_PHR1A_201...	2018-12-04 02:5...	27	0.5	190.7	74.7	10.7	13.8	164.4	32

Figure 7: Extract of the attribute table of satellite archive data retrieval listing relevant acquisition parameters

Since, at that time, there were no other post-event images available, the relevant Pléidades-1B scene fulfilled all the technical requirements and was ordered immediately.

Figure 8 also shows VHR pre-event imagery (e.g. KOMPSAT-3A) but these images were not included in the damage assessment procedure as there was no overlap with the selected post-event Pléiades-1B scene. Also, due to the extent and scale of the impact and damage that was expected, it was deemed that no pre-event imagery was explicitly necessary to perform a thorough and detailed comparison of the pre-event and post-event situations.

In general, and independent of the satellite data provider, the ordering procedure should be a standardised process. It is essential that all Contact Points (see Table 1) are familiar with all formal and technical information provided by the satellite data provider in order to speed up the order process. The relevant Pléiades-1B scene was ordered via the AIRBUS Defence & Space GeoStore-Platform with the Ortho-Basic product level. The requested scene was delivered just a few hours after the order was submitted.

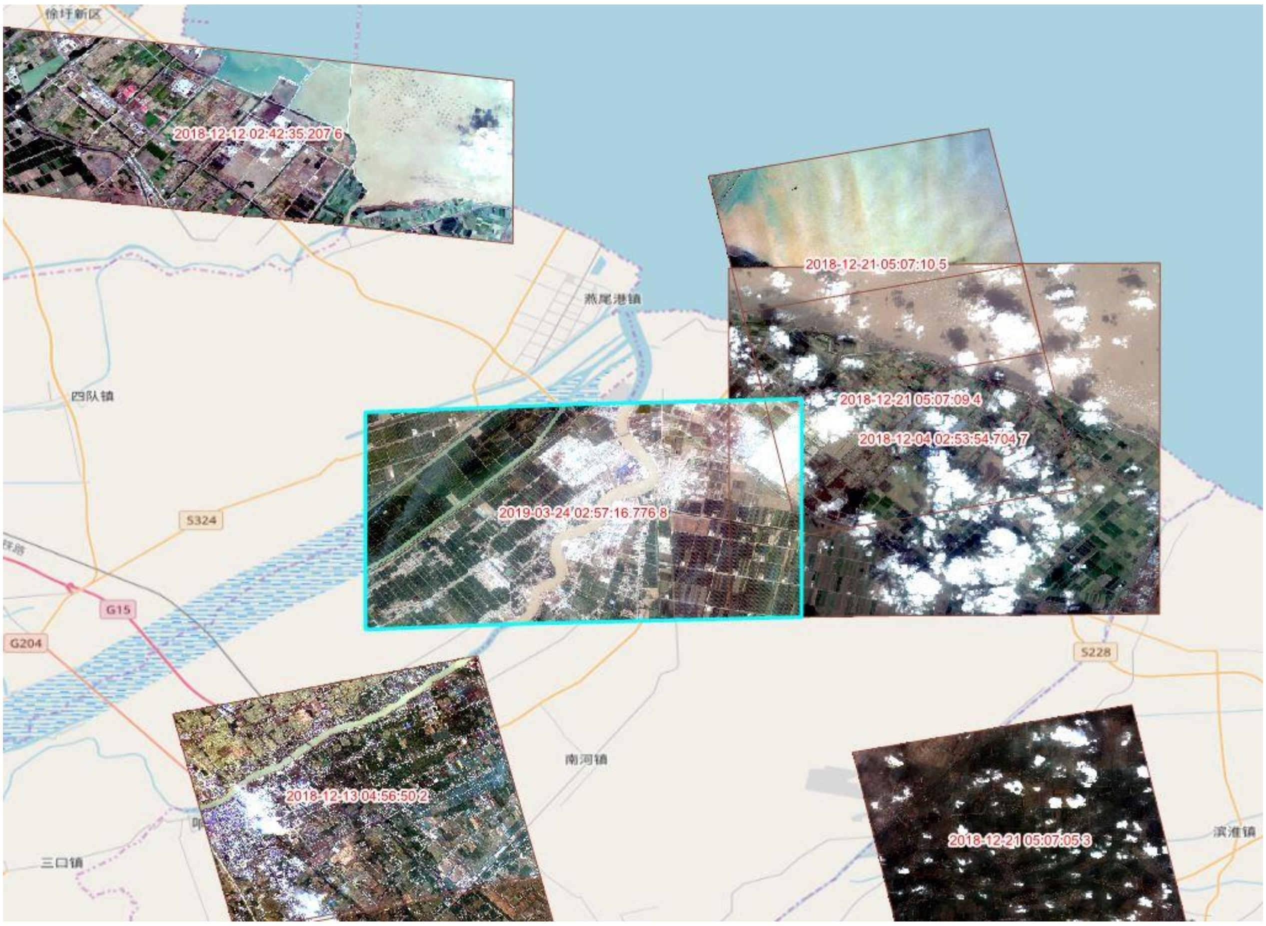

Figure 8: Thumbnails from the satellite archive data search for pre-event and post-event time frames (selected scene outlined in light blue).

2.6 Image data processing

Within the workflow, the image processing step is a highly standardised procedure executed using commercial off-the-shelf (COTS) software packages. However, in order to guarantee a smooth and time-efficient process it is extremely important to have good knowledge about the various access channels, product levels and related specifications, tasking and order mechanisms of the large number of satellite data providers.

The purchased Pléiades-1B scene was ordered as a four spectral band (Blue, Red, Green, Near-Infra-Red) pansharpened Ortho-Basic product with a product resolution of 0.5 metres (nominally 0.7 metres at nadir viewing) based on the provider's post-processed resampling. The Ortho-Basic product allows checking of orthorectification process based on available digital elevation models (DEM) and, if necessary, ground control points. The standard processing steps that are performed are:

- Quality assurance of ordered data (readability, completeness, quality)
- Orthorectification (using global/local DEMs; based on RPC sensor model)
- Radiometric enhancement (optional depending on image quality)
- Quality assurance of orthorectified imagery (geometric accuracy, completeness)

The Pléiades-1B scene was orthorectified based on the sensor RPC model using a 30 metre SRTM digital elevation model. According to the provider's specifications, the Pléiades image location accuracy is 6.5 metres (CE90) for the Pléiades constellation, without control points. The National Imagery Interpretability Rating Scale (NIIRS) class is indicated at 6 (AIRBUS, 2019). Within the rapid damage assessment context, that accuracy is deemed to be sufficient for the envisaged product. A slight radiometric adjustment was performed manually, based on the 12-bit dynamic range. The output projection is UTM Zone 50 N. The image data processing step was completed within one hour.

2.7 Product generation

The product generation started with analysis and interpretation based on all the available spectral bands. The interpretation process consists of detection, identification, damage classification and mapping of relevant features. The goal was to produce a damage assessment map giving an overall picture of the situation on the ground and the extent of the impact around the crater of the destructive blast. The image interpretation and extraction of the relevant features affected by the impact was performed manually and using only the post-event Pléiades scene acquired on 24 March 2019. To support and align the image interpretation process, the building damage assessment guideline published by the International Working Group on Satellite-based Emergency Mapping was consulted (IWG-SEM, 2018). Although the image resolution and quality were very good, the ability to identify small-scale damage was somewhat limited.

Based on longstanding experience in operational crisis damage mapping, and in particular generation of the previous Tianjin damage assessment products provided in 2015, a basic set of relevant features and attributes were defined in a preliminary assessment of the impact: destruction radius, five classes of damage grading, and basic information about the water and canal networks. Subsequently, a rough statistical retrieval of information was performed on the line and polygon features that were extracted, in order to evaluate the extent of the damage. As the interpretation focused on the area of the industrial park, a differentiation into building or facility functionality (e.g. cooling tower, supply network, production hall, storage depot, transformer station) was not made. Additional information from social media and news channels was continuously consulted to support the interpretation and to enhance the thematic accuracy of the graded assets. Additionally, the main drainage network was mapped to provide information on possible contamination and dissemination. A simple statistic query was retrieved from the vector data (Table 3).

Table 3: Overall statistics roughly estimated based on image analysis

Consequences within the AOI based on Pleiades acquired on 24/03/2019									
	Unit of measurement		totally destroyed	heavy damage	light damage	Possibly damaged	Possibly affected	Total affected	Analyzed
Affected area		km2	2,0		7,5			9,5	
Buildings and Facilities	Industrial buildings	No.	187	203	38	186	498	1112	1226
	Residential buildings	No.	0	6	15	0	0	21	21
	Storage Tanks	No.	50	8	0	55	133	246	263
	Chimneys	No.	0	0	0	0	2	0	2

The final product was generated in a standard format package, i.e. raster map as GeoPDF/GeoJPG and vector data in ESRI-shape/Google KML-format, to facilitate integration into GIS/sectorial information systems. Additional dissemination channels e.g. WebGIS and mobile applications, are also available.

Figure 9: Damage assessment map of Chenjiagang Chemical Industry Park based on Péiades-1B satellite acquired on 24/03/2019

It should be highlighted in this regard that although all the processes and procedures were conducted using the best knowledge and ability available at the time, no liability is provided regarding accuracy and comprehensiveness. The information that was extracted in a short time frame was intended as general information and does not constitute an official or authoritative statement.

3. CONCLUSION AND OUTLOOK

The use case presented here is a representative example of providing relevant and up-to-date detailed geospatial information derived from satellite data for crisis management applications. In order to supply the required information to the client or end-user in a time-sensitive situation, a dedicated operational organisational and technical working environment is absolutely mandatory. The dedicated Service-on-Demand mechanism ensures a seamless and smooth service component embedded in an activation workflow that integrates and serves all the relevant participants and stakeholders.

The damage assessment that was performed demonstrates that useful and up-to-date information layers can be created and provided within a few hours or days, in order to support the crisis management tasks throughout the duration of an incident. The semi-automatic and manual procedures that are applied have been proven to be robust, even though there are also potential limits inherent in the process. Given the two most important criteria in the emergency mapping domain, i.e. quality and timeliness, the crux is in many cases the availability and acquisition of adequate satellite imagery. The trend towards an increasing number of available satellite constellations increases the chances of capturing suitable images shortly after an incident, which can subsequently be fed into the operational crisis mapping processing chain. From the processing point of view as well, and given that also large areas can be affected by a widespread disaster, disruptive technologies are increasingly being implemented and are complementing, or even substituting conventional processing techniques and methodologies. These include, to name just a few, big data cloud processing, artificial intelligence and social media. These will increasingly be integrated into relevant stages within a disaster management cycle (ITU 2019). The damage assessment map presented here is only one example of a wide range of possible products. The Service-on-Demand capabilities and capacities can be used to generate any time-critical geospatial information efficiently, e.g. high-level 3D elevation information for Virtual/Augmented Reality (VR/AR) applications and near-real-time simulations and animations.

REFERENCES

AIRBUS Defence and Space, Pléiades Imagery User Guide. Retrieved August 2019, from https://www.intelligence-airbusds.com/optical-and-radar-data

Bevere, L. Sharan, R. and K.S, Vipin. Swiss Re sigma – Natural catastrophes and man-made disasters in 2015. Retrieved February 2017, from https://www.swissre.com/institute/research/sigma-research/sigma-2015-02.html

Centre for Research on the Epidemiology of Disasters (CRED), United Nations Office for Disaster Risk Reduction (UNISDR), 2018. Economic Losses, Poverty & Disasters 1998 – 2017. Retrieved July 2019, from https://www.preventionweb.net

Chen, T. Su, G. and Yuan, H., 2014, Creating common operational pictures for disaster response with collaborative work, WIT Transactions on Information and Communication Technologies, Vol. 47, Risk Analysis IX

Gähler, M., 2016. Remote Sensing for Natural or Man-made Disasters and Environmental Changes. Retrieved July 2019, from http://dx.doi.org/10.5772/62183

Guy Carpenter, Port of Tianjin Explosions 12th August 2015, Retrieved September 2015, https://www.guycarp.com

Resilience360 Special Report, May 14, 2019, Retrieved May 2019, from https://www.resilience360.dhl.com

International Communication Union (ITU), 2019. Disruptive technologies and their use in disaster risk reduction and management. Retrieved July 2019, from https://www.itu.int

International Working Group on Satellite-based Emergency Mapping (IWG-SEM), 2018, Emergency Mapping Guidelines – Building Damage Assessment Chapter, Working paper, Version 1.0, Retrieved August 2019, from http://www.un-spider.org/network/iwg-sem

Hoeppe, P., 2016, Trends in weather related disaster – consequences for insurers and society. Weather and Climate Extremes 11, pp. 70-79.

Martinis, S. Twele, A., Plank, S. et al., 2017, The International Charter 'Space and Major Disasters': DLR's Contributions to Emergency Response Worldwide. Journal of Photogrammetry, Remote Sensing and Geoinformation Science, Volume 85 (5), pp. 317 – 325.

Siebert, A. 2017. MuRE: Geo-Daten und Big-Data-Analysen – Ein Mehrwert im Risikomanagement der Assekuranz? GEOSYSTMES User Group Meeting 2017, Germering, Germany

Sophronides, P., Chrysaida-Aliki, P.; Giaoutzi and M. Scholten, H., 2017. A Common Operational Picture in Support of Situational Awareness for Efficient Emergency Response Operations; from https://www.researchgate.net/publication/316219240

Voigt, S., Giulio-Tonolo, F., Lyons, J. et al., 2016, Global trends in satellite-based emergency mapping. Science Vol. 353 (6296), pp. 247-252.