Abstract: This practical paper gives an overview about the widely unused potential of radar satellite imagery to assist humanitarian action. It briefly introduces the basic differences between optical and radar images and demonstrates the practical use of the latter in different settings based on their information content and their potential for multi-temporal analyses. It gives reading recommendations and closes with suggestions on the practical integration of radar data into humanitarian work.

Keywords: Data collection, remote sensing, refugee camps, humanitarian operations, earth observation, monitoring, emergency response

1 INTRODUCTION

Techniques of earth observation have become increasingly valuable for humanitarian work, because they assist the retrieval of information required for decision making, both in cases of emergencies and for the long-term support of people in need (Lang et al., 2015). They allow to collect consistent data of large areas, which is especially important when the observed phenomena rapidly change over time, and when systematic monitoring and data collection in the field are time-consuming, expensive or even dangerous. But while the visual interpretation and digital analysis of images from optical satellites (as known from Google Earth, for example) is already part of many working routines of humanitarian NGOs, the role of radar images is still neglected (Braun and Hochschild, 2017b). Yet, they offer capabilities which make them attractive for the humanitarian domain. This paper introduces radar images as a potential source of information in this field and gives examples on potential applications to stimulate its uptake into operational routines and to initiate further inter-disciplinary discussions. Each section closes with a short list of references for further reading.

2 BENEFITS OF RADAR IMAGES FOR HUMANITARIAN WORK

One of the main barriers which prevent the transfer of radar data into humanitarian practice so far is the fact that most studies published are technically-oriented and aim at scientific novelty. However, what is needed to highlight their use and applicability are case studies and practical examples. Therefore, the following section will highlight the benefits of radar data for humanitarian work while focusing on the practical use, hopefully creating a basis for conversations and discussions between scientists and experts from the humanitarian field.
2.1 Basic principles and specifications

Radar satellites send signals to the earth’s surface to form an image. These signals consist of microwaves which penetrate cloud cover and are independent from daylight, which allows reliable image acquisition for emergency response and a constant monitoring of an area at regular intervals. However, the images do not show natural colours but the intensity of the returned signal which is determined by the physical characteristics of a surface (i.e. its roughness, moisture, material, size, structure, and orientation). That means radar images can be used to identify structures which are not visible to the human eye or only at little contrast.

Figure 1: Comparison between optical (left) and radar (middle and right) satellite images.

Figure 1 demonstrates how radar images are sensitive to different surface characteristics: It shows the area of Dadaab, Kenya, including the refugee camps of Dagahaley, Ifo and Ifo2, as shown by optical (left) and radar (middle and right) satellites. Both are of the same spatial resolution (pixel size of 10 meter) and freely accessible within the Copernicus Programme of the European Space Agency (Aschbacher, 2017). The built-up areas have similar colour tones as the braided river system in the northeast and the shrublands in the southwest in the optical image (bluish grey), while they are visible more clearly in the radar image (middle) because the horizontal structures of the buildings and their solid construction materials (stone and partly metal) cause high radar backscatter intensity. Furthermore, the open areas in the centre of the scene and the river system reveal more variation in the radar image caused by different levels of soil compaction and moisture. Figure 1 also shows that the building structure of Ifo2 is different, because it consists of light tents with a more regular structure.
The image on the right consists of three images acquired at different times with colours attached to it (red: 2016, green: 2017, blue: 2018). This form of additive colour mixing allows the identification of temporal dynamics within one image (Beatty, 1983). For example, it highlights the camp extension of Dagahaley after 2017 and the increasing soil compaction around Ifo2. How the information content of radar images can contribute to humanitarian work, as well as their potential for temporal analyses, are demonstrated at more detail in the following sections.

As a first reading recommendation, a compact and nicely illustrated introduction to radar remote sensing is given by Moreira et al. (2013). It uses comparably simple language to outline the technique and possible applications.

2.2 Information content

As shown in the previous example, radar images are suitable to highlight buildings and urban structures, for example to estimate the number of people in need. As suggested by the Handbook for Emergencies published by the United Nations High Commissioner for Refugees (UNHCR, 2007) satellite images allow to assess the number of people in need by assessing the areas of their camps or by counting their dwellings. To give another visual example, Figure 2 shows a small part of the area of Kutupalong in Bangladesh in a very high-resolution radar image. It was acquired by the sensor TerraSAR-X at a spatial resolution of around 50 centimetres and impressively illustrates the change in landcover between 30 September and 27 December 2017. During that period, over 650,000 refugees crossed the border to Bangladesh to seek shelter from violent persecution in Myanmar, leading to enormous growth of the camp (UNHCR, 2017).

![Figure 2: Radar image of Kutupalong before (left) and after (right) the arrival of 650,000 refugees.](image)

The maps document the construction of new shelters (rectangular bright shapes) in a previously forest-covered area (darker areas), as well as the development of a network of paths (black lines). However, it also demonstrates the downsides of radar images. The level of detail is often lower than of optical images of same resolution because of noise-like patterns caused by signal
interference (called ‘speckle effect’, Lee et al., 1994). Additionally, white linear features (mostly ranging from north to south) caused by steep slopes can make the visual interpretation difficult for people with little knowledge of the area. Lastly, small dwellings constructed from light or natural materials are sometimes hard to identify because they cause lesser radar backscatter. Still, observations like this contribute to a better understanding of camps and the dynamics of displacement, and help to assess the need for action.

While built-up objects are bright in radar images, water bodies are mostly black because only a small share of the signal is reflected back to the sensor. This is of great advantage for the mapping of surface waters as a resource, but also for the assessment of natural hazards. Figure 3 shows how emergency response can be assisted by radar imagery within a web-based platform. Cyan colours indicate flooded areas derived from Sentinel-1 data. As these images are openly available within a few hours after acquisition, such maps can be utilized for evacuation planning and the management of logistics. This is especially valuable because flooding is generally accompanied by thick cloud cover and optical data cannot be used here.

Figure 3: Identification of flood extents (black and cyan) in Mozambique in March 2019 in an open and web-based image processing platform (Braun, 2019a).

Another example on the increased information content of radar images is given in Figure 4. It shows the nomad city of Kidal in eastern Mali and its surroundings. Many of the landforms and subsurface structures cause variations in backscatter intensity which can then be used to identify structures, such as geological faults (as indicators for groundwater storage in crystalline basements), or buried channels which potentially carry water which can be extracted from more shallow depths. Especially the areas and shapes of the wadis are clearly visible in red. The comparison with the geological map of this area (Figure 4 right) shows that the variations in radar backscatter intensity also correspond to the different geological formations which are furthermore useful for hydrological reconnaissance. These indications were partly provable by in-site geophysical measurements (Vanden Borre, 2011): For instance, different backscatter
mechanisms retrieved from the radar images correlated with the depth of the wadis and the porosity of their sediments. In the shown case study, two areas were suggested (Figure 4 left, green rectangles) as new drilling sites for water extraction based on the analysis of measurements and interpretation of satellite data (Braun, 2019b, chapter 3.3.2). However, it has to be denoted that such recommendations have to be validated in the field. At the time of writing no information was available to the author if drillings were conducted at these locations and if the wells produced the expected amount of water. Only if such information is reported to the analysts, existing approaches can be optimized and transferred into operational routines.

Figure 4: Comparison of optical (left) and radar (middle) image for structural mapping and groundwater exploration.

Reading recommendations:

- Practical aspects on the visual interpretation of radar images of refugee camps were demonstrated in an online document published by Astrium (2011) using the example of Dadaab in Kenya, a region hosting more than 350,000 displaced persons.
- It was shown by Braun (2019b) that freely available Sentinel-1 data can be used to map rural settlements which were required for vaccination campaigns in Guinea. Using radar images resulted in nearly the same number of identified settlements than using optical imagery which is often inconsistent regarding time of acquisition and image quality.
- The capabilities of microwaves to penetrate dry soils were already exploited in a humanitarian setting by Bouchardy (2005) who used radar images to identify moisture variations in sediments in the Darfur crisis to locate water resources, thus directly assisting the UNHCR with their planning and relocation of refugee camps.
- As one of the first, Wegmüller et al. (2002) mention the benefits of radar data for rapid mapping, hazard mapping and thematic mapping in a humanitarian context.
2.3 Data continuity and time-series analyses

Because of their independency from daylight or cloud cover, operational radar satellite missions deliver usable images at constant intervals. This makes them a reliable source of information over longer periods and allows to understand things that happened in the past. Looking back allows to identify the point in time when a specific event happened, for example when a building was demolished (Figure 5) or a certain area was flooded (Figure 6). These sorts of information are important for the management of camps and the planning of their supply and further humanitarian logistics. However, all of these interpretations require a certain amount of on-site validation to ensure that the information which is retrieved for entire camps is not biased by false interpretation of specific patterns. Unfortunately, humanitarian workers engaged in refugee camps are often busy with more important tasks, such as the provision of food and basic medical services (Braun, 2019b). Methods have to be established for continuous and time-effective feedback, for instance facilitated by mobile devices, as proposed by Vinek et al. (2016).

Figure 5: Changes in camp Dagahaley visualized by a colour composite (red: 08 June 2014, green: 30 June 2014, blue: 10 March 2015). Left: Demolished (red and green) and newly constructed (blue) buildings. Middle: Logging of trees outside the camp. Right: Expansion of the camp. (Braun, 2019b).

Another advantage of archived images is the possibility to assess the situation of an area before a disaster has occurred and compare it to a post-disaster image, as it was done in the flood mapping example in Figure 3. This is applicable for natural hazards (earthquakes, floods, landslides), but also to systematically track ecosystem changes related to displaced persons. This is important to estimate the velocity of land degradation, the capacity of ecosystems, and the sustainable development of host communities (Jacobsen, 2002). In the example given in Figure 7 landcover changes were assessed based on radar data at regular intervals for the area of Kutupalong (the case introduced in section 2.1) to measure the expansion of the camp and the retreat of forests. Due to pronounced rainy seasons, such regular time-series analyses are not possible based on optical data. It is therefore important to develop routines based on radar images before an emergency occurs, so that the required information can be extracted within a short time, thus enabling fast response.
Figure 6: Road infrastructure in Gambella region, Ethiopia, as mapped from images of Sentinel-1. Blue areas indicate derived flood extents in May 2016 and September 2017 (Braun, 2019b).

The development of such routines should be undertaken by both scientists or technicians and the users of the products from the humanitarian side to ensure that these products fulfill their exact needs and that they understand the information they contain. Only if a product is useful, reliable, readable and transferable, it can be implemented in operational frameworks (d’Oleire-Oltermanns et al., 2015). This also involves that the data which these routines are based on are freely available and directly accessible, such as the Sentinel-1 mission which delivers new images for most parts of the earth every 6 days which is made available within 24 hours after image acquisition and even within three hours for selected priority areas (Potin et al., 2019).

Frameworks for automated routines could be based on predefined data processors using scripting languages, such as python (Truckenbrodt et al., 2019) or the graph processing tool of the Sentinel Application Platform (SNAP; ESA, 2019) which allow the users to only apply minor adjustments according to the area and purpose. But besides the technical automation, humanitarian organizations also require a knowledge management framework which allows all involved persons to exchange latest findings and data products, and to prioritize among new crises and submitted requests, for example, as proposed by Zhang et al. (2002).

Figure 7: Land-use changes in Kutupalong, Bangladesh, before and after the influx of over 650,000 arrivals, as measured by radar data (selection of three out of eleven analysed dates, Braun et al., 2019)
Reading recommendations:

- Flores-Anderson et al. (2019) published an open-access work on resource monitoring based on radar data with many hands-on examples and practical guidelines.
- The impacts of refugee camps on their environments were analysed in Kenya (Braun et al., 2016), Chad (Braun and Hochschild, 2017a) and Bangladesh (Braun et al., 2019) based on time-series of radar images to assess landscape changes over longer periods.
- Hardy et al. (2019) used time-series of Sentinel-1 images to locate water bodies suitable for breeding habitats of mosquitos to combat the spread of malaria in Zambia.
- Braun (2018) mapped damages on buildings in the city of Raqqa during the Syrian civil war, to assist evacuation and clean-up efforts, but also to record the time and severity of damage for tasks related to human rights protection and advocacy.

3 WHERE TO START?

Radar remote sensing can be difficult to approach, because it is not documented as well as working with optical data. However, large advancements have been made in the last five years regarding data access, processing systems, and their documentation to beginners. But a potential user has to become clear about his or her main intentions: If the visual interpretation of images is sufficient (e.g. for the quick assessment of camp areas, land use, current developments, or the verification of rumors on new displacements), online platforms, such as the EO Browser (Figure 8) allow to search, display and combine data of the most important operational missions (including Sentinel-1) free of charge for non-commercial use, or even to generate time-lapse videos of an area (Sentinel-Hub, 2019). To reduce the risk of misinterpretation capacity building on fundamental principles of radar backscatter and its visual evaluation for humanitarian purposes should be carried out. This knowledge can be acquired within a couple of days when instructed expert within a on-site compact course, for example, accompanied by self-taught learning based on the many tutorials and guidelines available (Betzin et al., 2019; Simms, 2019; Smith, 2012).

More advanced portals allow to apply fully-prepared workflows to user-defined areas. For example, the map in Figure 3 was computed with the Geohazards Thematic Exploitation Platform (Terradue, 2019) within a couple of minutes. These portals are usually well documented and user friendly, and can be used within even shorter time, even by someone with little or no knowledge on data processing. They allow to quickly generate results and share them with colleagues, within hours after an emergency in a web browser. These results should then contain value added information and be understandable by any humanitarian worker in order to avoid misinterpretation of the original radar images.

Users who are technically more experienced can also access and analyse Sentinel-1 data via the Google Earth Engine (Google, 2019) with custom scripts in JavaScript language. All these portals allow to access data without having to download them first, so they are especially useful for workers in the field, as long as a stable internet connection is granted.

On the other hand, the more traditional way to work with satellite images is downloading the data and processing them on local computers. This takes more time but gives more control over the processing and a larger variety of opportunities regarding input data, analysis tools, and the visualization of results. One of the most user-friendly and free of charge software solutions is the Sentinel Application Platform (SNAP; ESA, 2019), accompanied by an up-to-date and plain
tutorial of data sources and their processing techniques given by Meyer (2019). It includes commercial satellite missions and their capabilities regarding revisit time, coverage, and spatial resolution so users can compare and decide for a data source meeting their requirements. To fully understand and exploit the different steps of radar data processing and the parameters used to control the outputs requires more time, routine and experience. Depending on the technical affinity of the user this can range between a couple of weeks and several months.

Figure 8: Online visualization of Kutupalong in Bangladesh in the EO Browser. Left part: optical image; right part: radar image.

Lastly, users from the humanitarian field who are interested in working with radar data are encouraged to get in touch with the authors of the studies provided in this paper. Most researchers are open to new ideas and welcome invitations to discuss or to collaborate. Moreover, science needs information from the user side, especially in application-oriented fields like humanitarian aid. This not only includes feedback on the usability of proposed methods, but also the provision of field data for training and validation purposes (UNHCR, 2007). The sustainable transfer of developed approaches only works if they can be tested and successfully conducted in real use cases. Accordingly, technical innovation alone is not enough; there is a large need for stronger collaboration, inter-disciplinary discussion, and mutual teaching and learning (Braun, 2019b). Especially the risk of misinterpretation has to be mitigated through collaboration and capacity building to avoid improper use or the drawing of false conclusions. Otherwise, the currently observable mistrust towards this comparably unused technique cannot be dismantled. Hopefully, this paper initiates further discussions and contributes to a culture of exchange and data sharing, with solutions jointly-developed by scientists, companies, and humanitarian organizations.
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