PRACTICAL PAPER

Space borne radar imagery – An under-utilised source of information for humanitarian relief

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***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 radar images in different settings, based on their information content, and their potential for multi-temporal analyses. The paper gives recommendations on further reading, 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 are increasingly valuable for humanitarian work for assisting 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 the collecting of consistent data for large areas; this is especially important when observed phenomena changes rapidly over time, and when systematic monitoring and data collection in the field are time-consuming, expensive or dangerous. Whilst visual interpretation and digital analysis of images from optical satellites (e.g. Google Earth aerial imagery) is already part of many working routines of humanitarian non-government organisations (NGOs), the role of radar imagery is still neglected (Braun and Hochschild, 2017b). Radar imagery offers capabilities that make them attractive for the humanitarian domain. This paper introduces radar imagery as a potential source of information the humanitarian field and provides examples on potential applications to increase uptake in 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 preventing transfer of radar data into humanitarian practice is that most studies published are technically oriented and aim at scientific novelty. What is needed to highlight the benefits of the use of radar images, are case studies and practical examples. The following section will highlight the benefits of the practical application of radar data for humanitarian work, and in doing so, create 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 that penetrate cloud cover independently from daylight. This allows reliable image acquisition for emergency response, and a constant monitoring of an area at regular intervals. Radar images do not show natural colours; instead the intensity of the returned signal is determined by the physical characteristics of a surface (i.e. roughness, moisture, material, size, structure, and orientation). This means radar images can be used to identify structures that are not visible, or only mildly visible, to the human eye at low contrast.

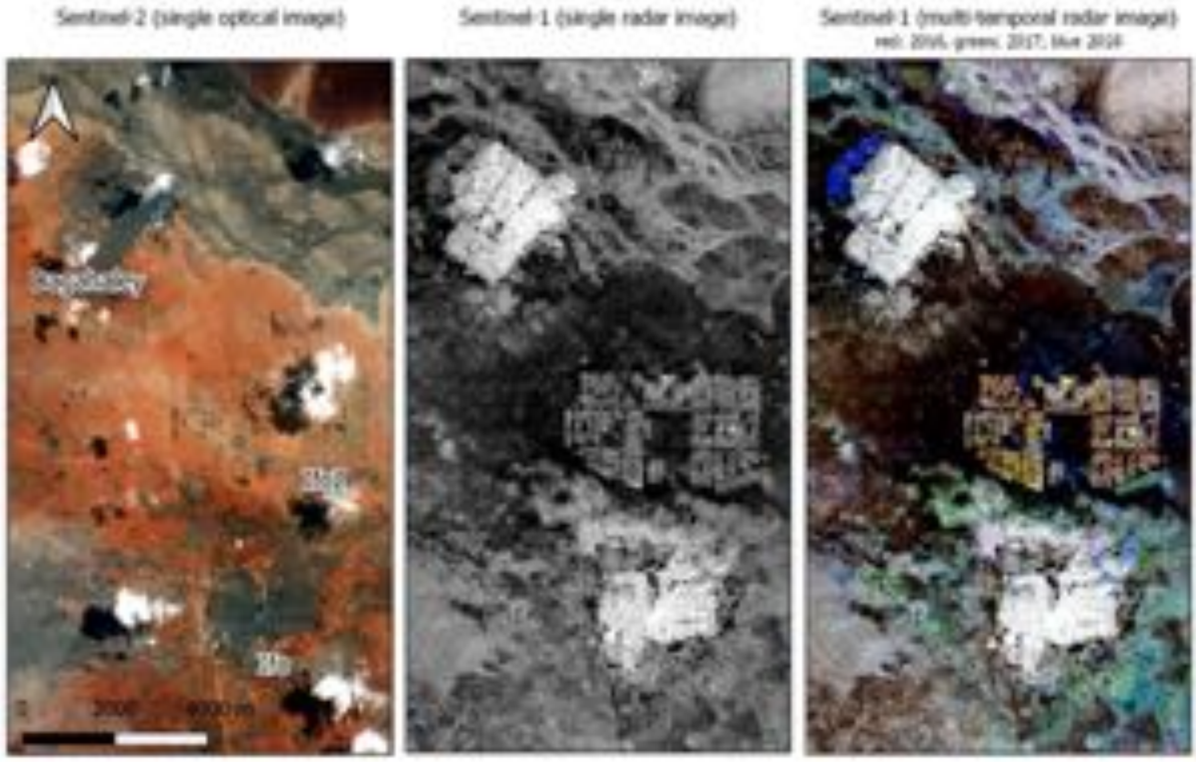

Figure 1: Comparison between optical (left) and radar (middle and right) satellite images.

Figure 1 illustrates the sensitivity of radar imagery to different surface characteristics. Figure 1 displays the area of Dadaab and Kenya (including the refugee camps of Dagahaley, Ifo and Ifo2), depicted through optical (leftmost) and radar (middle and rightmost) satellites. All images are of the same spatial resolution (pixel size of 10 m) and are freely accessible through the Copernicus Programme of the European Space Agency (Aschbacher, 2017).

As can be seen in the optical imagery in Figure 1, the built-up areas have similar bluish grey colour tones as the braided river system in the northeast and the shrublands in the southwest. The built-up areas become more clearly visible in the radar image (middle) as the horizontal structures of the buildings, and their solid construction materials (stone and partly metal), cause high radar backscatter intensity. Furthermore, the radar images (single and multitemporal) reveal more variation in the centre of the images and the river systems due to different levels of soil compaction and moisture. The Figure 1 radar imagery also shows that the building structure of Ifo2 is different, because it consists of light tents with a more regular structure.

The multi-temporal radar image on the right consists of the overlay of three images acquired at different times; the images were coloured to represent the year the image was taken (i.e. red: 2016, green: 2017, blue: 2018). This form of additive colour mixing allows the identification of temporal dynamics of the area over time, represented in a singular image (Beatty, 1983). For example, an extension of camp Dagahaley can be seen to have occurred in 2018 (indicated in blue), whilst Ifo2 experienced increasing soil compaction and vegetation retrogression as visualised by the red tones in the surroundings of Ifo2 which indicate that former volume scattering from plants was successively replaced by simple surface scattering from bare and flat soils. How the information content of radar imagery can contribute to humanitarian work, as well its potential for temporal analyses, is demonstrated in 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 of radar remote sensing, and its 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 as assessment of the numbers 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 land cover 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).

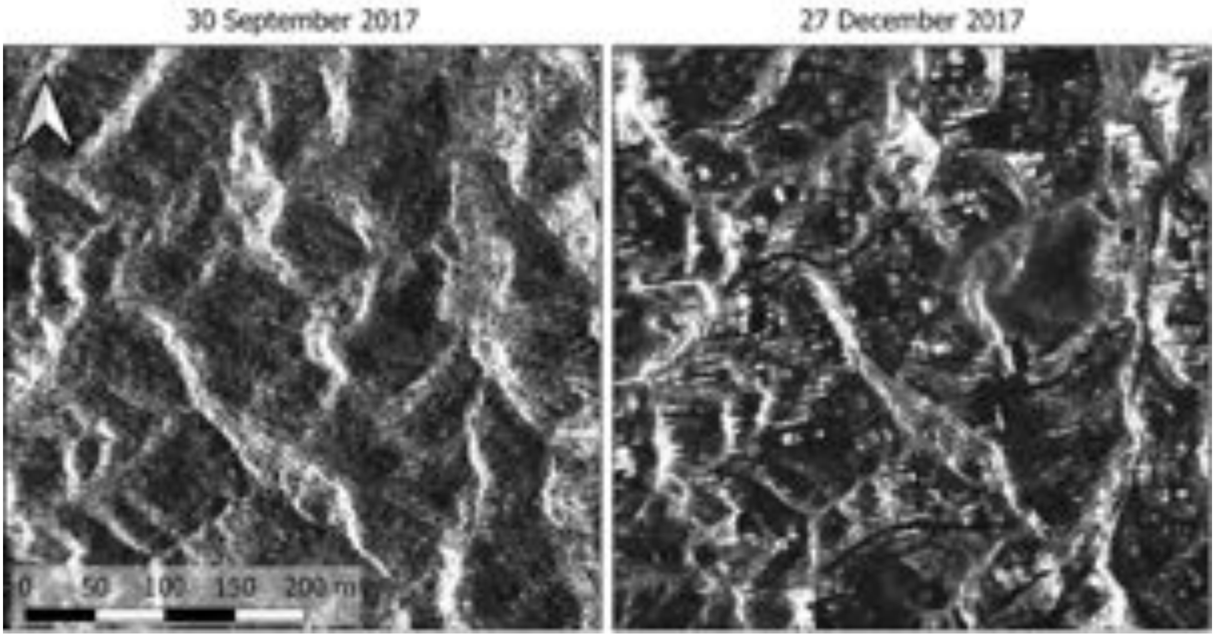

Figure 2: Radar image of Kutupalong before (left) and after (right) the arrival of 650,000 refugees.

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 imagery. The level of detail is often lower than that of optical imagery of the same resolution. This is due to noise-like patterns caused by signal interference or the ‘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 imagery, 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 utilised for evacuation planning and logistics management. This is especially valuable as flooding is generally accompanied by thick cloud cover where optical data cannot be gathered.

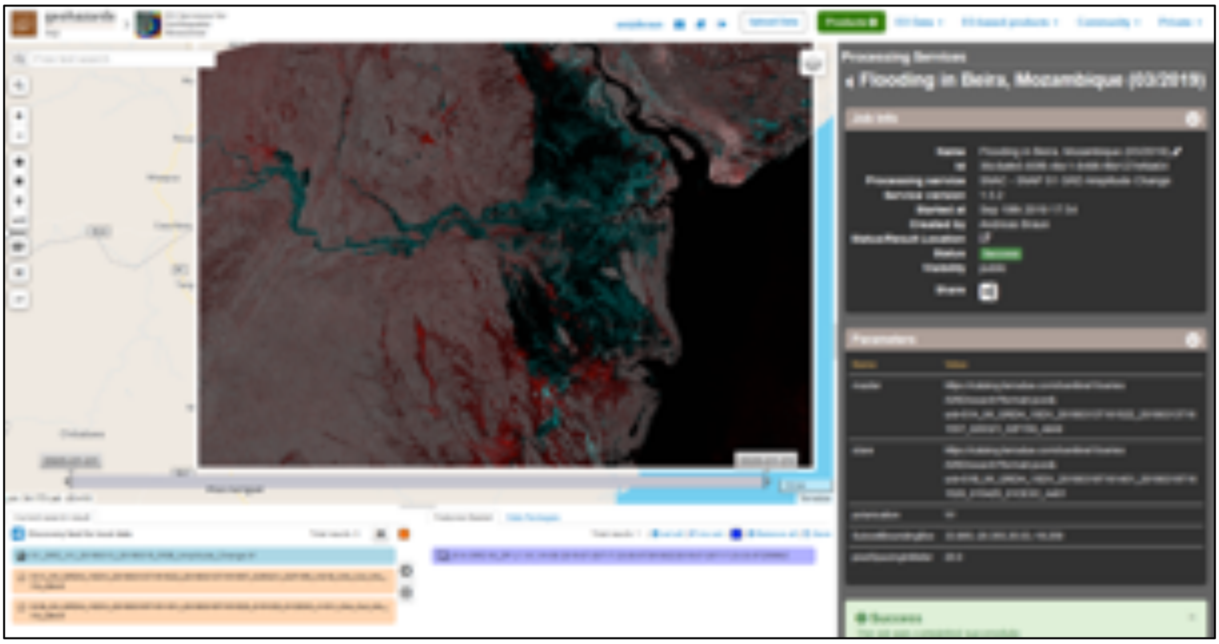

Figure 3: Identification of flood extents (black and cyan) in Mozambique in March 2019 in an open and web-based image processing platform (Braun, 2019a).

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 that can be used to identify structures, such as geological faults (as indicators for groundwater storage in crystalline basements), or buried channels that potentially carry water that can be extracted from 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 that are 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 imagery correlated with the depth of the wadis and the porosity of their sediments. In the 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 noted that such recommendations have to be validated in the field. At the time of writing, no information was available to indicate that drilling was conducted at these locations, and if the wells produced the expected amount of water. Only if such information is reported to the analysts, can existing approaches can be optimised and transferred into operational routines.

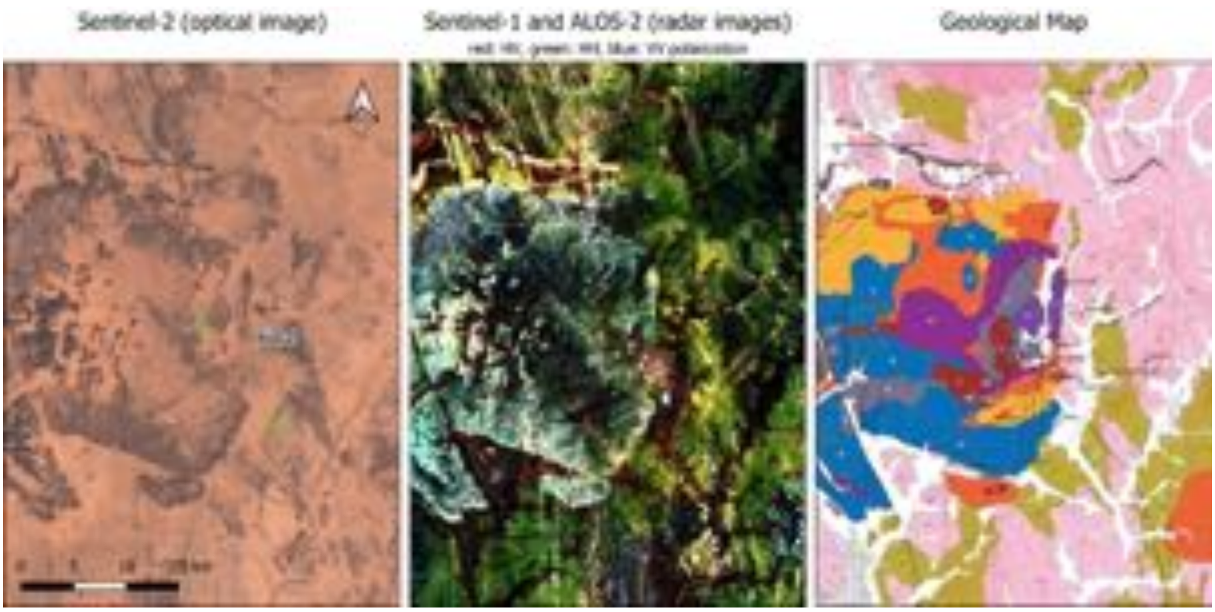

Figure 4: Comparison of optical (left), radar (middle) and geological map (right) images for structural mapping and groundwater exploration.

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 imagery 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 utilised in a humanitarian setting by Bouchardy (2005) who used radar imagery to identify moisture variations in sediments in the Darfur crisis to locate water resources. This

directly assisted the UNHCR with planning and relocation of refugee camps.

- As one of the first researchers, Wegmüller et al. (2002) explain 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

Due to the independency from daylight or cloud cover, operational radar satellite missions deliver usable images at constant intervals. This makes radar satellite missions a reliable source of information over longer periods, and allows an understanding of historical events. Looking at imagery that tracks changes over time, facilitates the ability to identify points in time when specific events have occurred, for example when a building was demolished (Figure 5) or a certain area was flooded (Figure 6). This information is important for the management of camps and the planning of supply and humanitarian logistics. However, the interpretation of radar imagery requires on-site validation to ensure the information 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, such as the use of mobile devices, as proposed by Vinek et al. (2016).

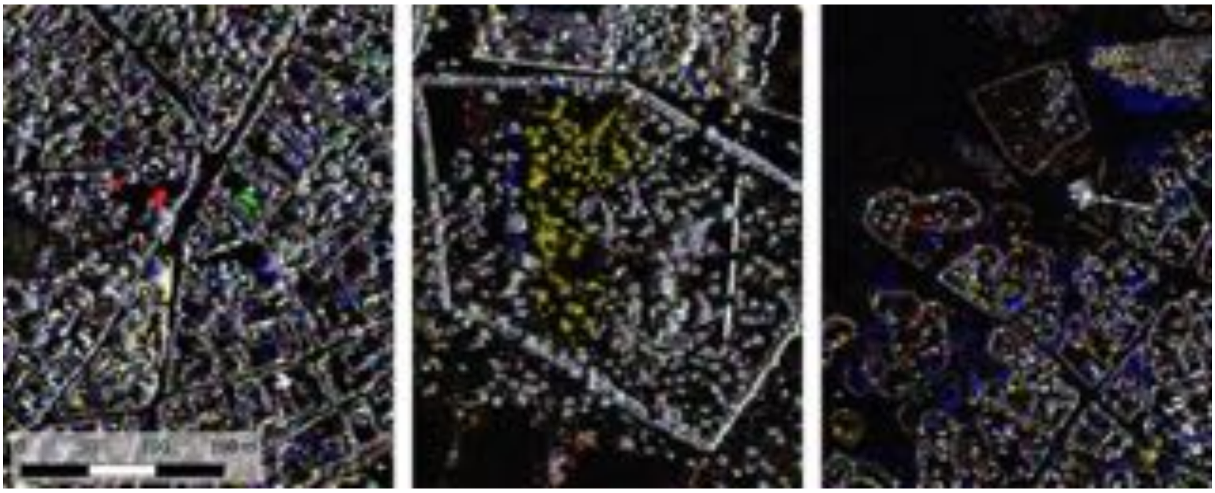

Figure 5: Changes in camp Dagahaley visualised by a colour composite overlay (red: 08 June 2014, green: 30 June 2014, blue: 10 March 2015). Left image: Demolished (red and green) and newly constructed (blue) buildings. Middle: Logging of trees (indicated in yellow). Right: Expansion of the north-western camp outskirts by planting of vegetation around the households (indicated in blue) (Braun, 2019b).

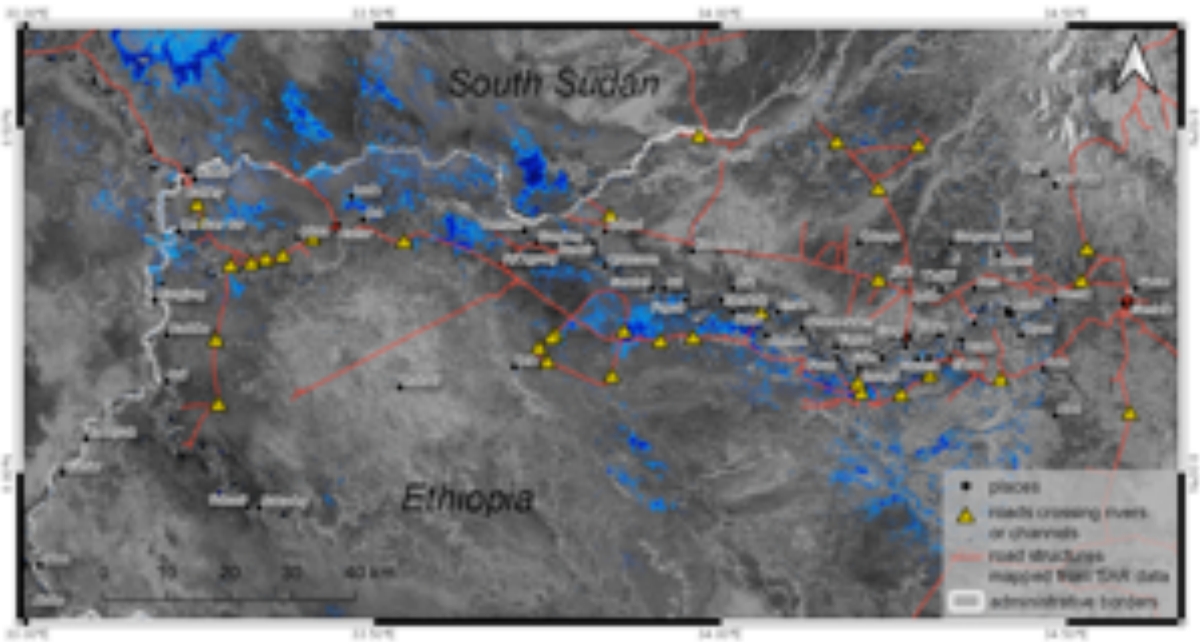

Figure 6: Road infrastructure in Gambella region, Ethiopia, as mapped from images of Sentinel-1. Blue areas indicate derived flood extents in May 2016 and September 2017 (Braun, 2019b).

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 imagery, 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 **Error! Reference source not found.**, land cover 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.

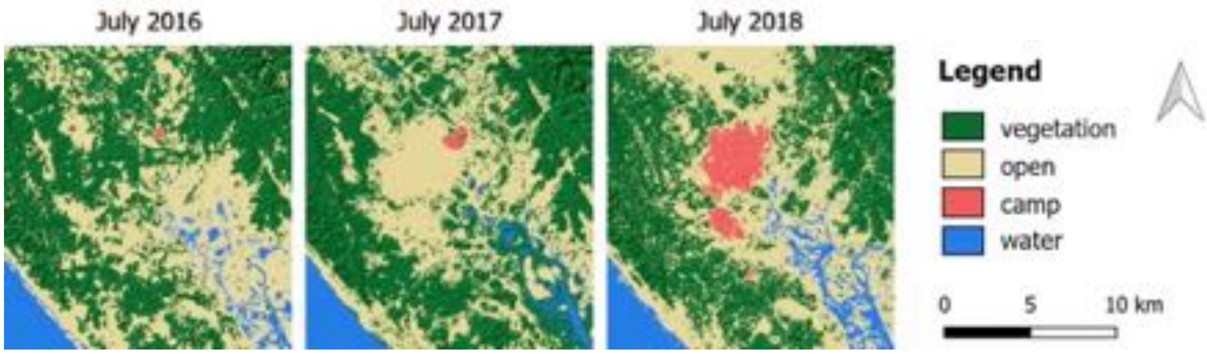

Figure 7: Land-use changes in Kutupalong, Bangladesh, before and after the influx of over 650,000 arrivals, as measured by radar data (selection of three out of eleven analysed dates, Braun et al., 2019)

Due to pronounced rainy seasons, such regular time-series analysis was not possible utilising optical data. It is therefore important to develop routine analysis of radar imagery before emergency situations, such that the required information can be extracted quickly and enable a fast response.

Routine radar imagery analysis should be undertaken by both scientists or technicians and the users of any information products produced from imagery analysis on the humanitarian side. This ensures that the information products generated fulfil their exact needs, and that they understand the information they contain. Only if a product is useful, reliable, readable and transferable, can be implemented in operational frameworks (d'Oleire-Oltmanns et al., 2015). This also requires the data that these analysis routines are based on to be freely available and directly accessible. An example of this is the Sentinel-1 mission that delivers new radar imagery for most parts of the Earth every 6 days. This imagery is made available within 24 hours of general image capture, with priority area imagery being available within three hours post image capture (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 graphic processing tools such as the Sentinel Application Platform (SNAP) which allows the users to apply minor adjustments according to the area and purpose of the captured imagery (ESA, 2019). In addition to technical automation, humanitarian organisations also require a knowledge management framework that allows all persons involved to exchange the latest findings and data products as well as prioritise crises and submitted information requests, as proposed by Zhang et al. (2002).

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) utilised time-series imagery produced by Sentinel-1 to locate water bodies suitable for mosquito breeding habitats in order 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, and to record the time and severity of damage to assist tasks related to human rights protection and advocacy.

3 WHERE TO START?

Radar remote sensing can be difficult to approach, as it is not as well documented as working with optical data. However, large advancements have been made in the last five years regarding data access, processing systems, and user documentation. But a potential user must be 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 new encampments), online platforms such as the EO Browser (**Error! Reference source not found.**) allow for the search, display and combination of data of the most important operational missions (including Sentinel-1) free of charge for non-commercial use. Online platforms also allow for the generation of time-lapse videos of specific areas (Sentinel-Hub, 2019).

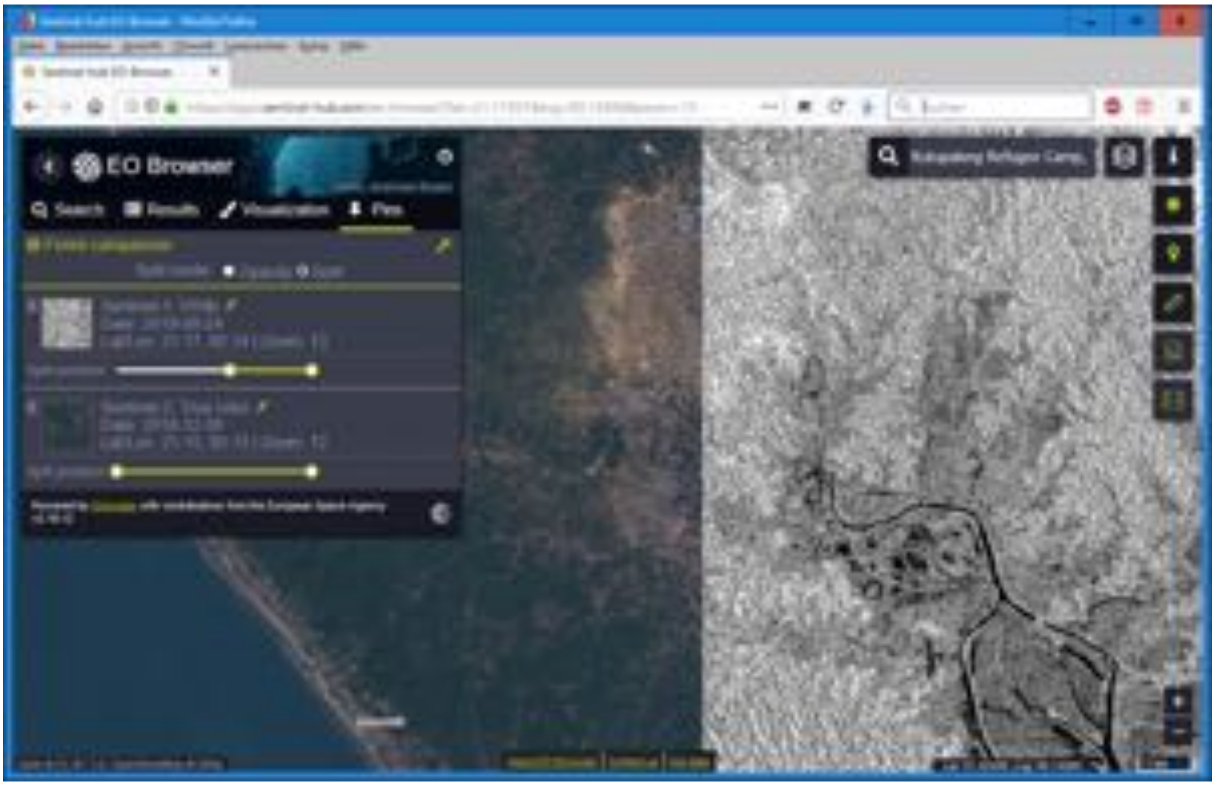

Figure 8: Online visualisation of Kutupalong in Bangladesh in the EO Browser. Optical imagery (left) and radar imagery of the same (right).

To reduce the risk of misinterpretation of the colours and patterns within radar images, it is recommended that the reader of the imagery understands the fundamental principles of radar backscatter mechanisms and its visual evaluation for humanitarian purposes. This fundamental knowledge can be acquired through short online courses on-site with expert instructors accompanied by self-tuition based on the various current tutorials and guidelines available (Betzin et al., 2019; Simms, 2019; Smith, 2012).

More advanced portals allow the application of 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 short time periods by users with little to no experience with data processing. These portals allow for the quick generation of results for sharing with colleagues via web browsers, within hours of an emergency occurring. These results should then contain value added information and be understandable by any humanitarian worker to avoid misinterpretation of the original radar imagery.

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 access to data without having to download the data. This is especially useful for workers in the field, as long as a stable Internet connection can be guaranteed.

The more traditional way to work with satellite imagery is to download the data and process it through local computers. This takes more time but provides more control over the data processing, and greater opportunity of varying input data, analysis tools, and the visualisation of the 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 processing techniques given by Meyer (2019). It includes commercial satellite missions and their capabilities for revisiting time, coverage, and spatial resolution so users can compare and decide on a data source that meets their requirements. To fully understand and utilise the different steps of radar data processing and the output parameters requires more time, routine and experience. Depending on the technical experience of the user, this can range between a couple of weeks to several months.

Lastly, users from in 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 conduced 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 current lack of confidence towards this underutilised methodology cannot be easily reverted. This paper hopes to initiate further discussion and contribution to a culture of exchange and data sharing, with solutions jointly-developed by scientists, companies, and humanitarian organisations.

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