MAPPING FLOODED URBAN AND RURAL AREAS IN SLOVENIA

Flood Identification from Radar Imagery

Time series of satellite radar images are very useful for monitoring the extent and dynamics of floods and the devastations caused. A time series of four medium resolution radar images (ENVISAT, RADARSAT-2) captured after heavy rainfalls scourged Slovenia early autumn 2010, revealed overestimations and underestimations of the extent of flooded area in and around Ljubljana, the capital of Slovenia. The authors examined the sources underlying the deficiencies to gain insight into the possibilities of radar imagery for mapping flooded areas covered with a great diversity of land use types.

Between 17th and 19th September 2010, Slovenia endured enormous rainfalls casting about 175mm water over the country within approximately 48 hours; the highest amount in such a short time in the last 60 years. A substantial part of Slovenia was flooded and the Ljubljana territory belonged to the most affected areas (Figure 1). The sparsely settled marshes south of Ljubljana resembled a shallow lake. Houses were submerged to a height up to 1.2m, while crops were flooded to a height up to 1.6m; the last such occurrence took place over one hundred years ago.

Radar Imagery

The International Charter Space and Major Disasters (CSMD) and SAFER (Services and Applications for Emergency Response) monitored the inventory of the extent and devastation of the flood. For Ljubljana and its surroundings, four after-event radar images with 12.5m Ground Sample Distance (GSD) were obtained: one ENVISAT image acquired during the evening of 19th September 2010, a few hours after the heaviest rainfalls came to an end and three RADARSAT-2 images acquired between 23rd and 26th September and on 2nd October. These images form a time series over a period of two weeks and so enabled mapping at a scale of 1:25,000 or less of the flooded area and enabled the study of the flood dynamics in the Ljubljana Marshes.

Satellite radar images are most valued for flood detection purposes because - in contrast to optical imagery - their recording is independent of the availability of sunlight and the microwaves emitted by the system are able to penetrate haze and clouds. On the other hand, understanding and interpretation of radar images is more difficult than interpretation of optical images. Radar captures emitted microwave wavelengths that are bounced back to the antenna. The pixel values represent the intensity of the return signal which depends on roughness and dielectricity of the objects hit, and on their shape and size. The pixel values will be low for flooded areas because microwaves are reflected away from the radar antenna when hitting water bodies and so the return signals from smooth water surface will be very weak. Hence, flooded areas appear dark in radar imagery. However, there are many additional effects which frustrate this general rule. Speckle noise, for example, causes small spots to appear very bright or very dark. Areas which are not accessed by emitted microwaves because the signals are blocked by hills, buildings or other obstructions (radar shadow) appear dark resulting in an overestimation of area covered by water. The presence of trees, shrubs and other objects in or near the water body causes those parts of the inundated areas to appear bright resulting in an underestimation of area covered by water.

Rapid Mapping

The vast extent of floods became clear from applying the semi-automatic technique of thresholding, that is, pixels with a value below a predefined threshold are classified as inundated. The first rapid mapping results, showing the inundated areas, already became available a few hours after the transmission of the radar imagery from the CSMD server. The maps gave an excellent insight into the general extent of the floods and dynamics of water inflow/outflow. Figure 2 depicts how the water was moving back within the first two weeks after the heavy weather: on the eastern part near Ljubljana, which has a natural outflow to the rivers, the flooded areas visible in the ENVISAT image of 19th September no longer pop up in the RADARSAT-2 of the 23rd September image demonstrating that the lowering of the water level went on rather quickly here. In contrast, in the western part the lowering of the water level went on very slowly; the 2nd October RADARSAT-2 image reveals that an extensive area was still inundated two weeks after the downpours. After the above quick analysis a more thorough examination was carried out, which showed that not all inundated areas had been detected from the radar imagery and as a result the flood pattern appeared to be fragmented and the size of the flooded area underestimated. Furthermore, flooded urban sites such as the south-eastern part of Ljubljana were not visible as such in the radar images. To get a grip on these deficiencies field inspections were carried out.

Validation

Comparing the data gathered in the field with the radar maps revealed a number of reasons for the underestimation of flooded areas. Land use in the Ljubljana area is a mixture of urban settlement and farming activities. Houses, traffic lights, trees, corn fields, high-growing reeds and other objects above the water surface cause a part of the radar signal to be reflected back to the satellite radar antenna with high intensity resulting in high pixel values so that the area is not classified as flooded. Furthermore, man-made objects in urban areas may cause total reflection resulting in high reflections from the surrounding objects, including water surfaces. In urban areas shape, size and arrangement of objects influence the radar signals such that they are reflected into another direction or are amplified. This leads to higher intensity values of pixels covering water and hence all urban areas have been classified as non-flooded. This means that radar imagery is not well suited for mapping flooded urban areas. The agricultural area of the Ljubljana Marshes also introduced problems related to the presence of objects. In early autumn, many fields are still covered with crops, especially corn, which are detected as non-flooded areas since the radar signals scatter on stems and leaves. Trees and shrubs pose a similar problem since radar signals do not penetrate dense crops or leaves to reach the water on the ground. An additional problem specific to the Ljubljana Marshes concerns the shape and the size of the agricultural fields which are typically long but narrow (see Figure 1) having a width similar to the GSD of the images (12.5m). Since fields are alternately planted with corn (high) and other plants (low), this causes problems in appropriately detecting shape, size and land cover of agricultural parcels.

Additional Data

Comparing the maps compiled from radar imagery with field survey validation data revealed the causes of overestimation and underestimation of flooded areas. For the needs of rapid mapping, the effects of overestimation can be reduced simply with semi-automatic procedures using a digital elevation model (DEM) and applying contextual classification methods. Areas covered by radar shadow, which are identified as covered by water, can be automatically outlined using the height information present in the DEM combined with the angle of incident of the radar signal. Reducing underestimation is more complicated and cannot be easily performed semi-automatically. For example, masking out of riparian vegetation, which should have been classified as water surface, requires manual interpretation, which is time consuming and labour intensive. Such procedures have a lower potential for implementation in rapid mapping procedures.

Concluding Remarks

Our study confirmed the usefulness of time series of satellite images. The maps derived from radar imagery are not only valuable for analysing the extent and dynamics of floods but also provide important information for improving flood protection and support flood prevention in critical areas in the future. Medium resolution radar imagery can effectively monitor areas on a regional scale, also those which are remote or hardly accessible. However, local scale applications strongly need very high resolution radar imagery. Improving the accuracy of detection remains a challenge.

Further Reading

- Veljanovski, T., Lamovec, P., Pehani, P., Oštir, K., 2011, Comparison of three techniques for detection of flooded areas on ENVISAT and RADARSAT-2 satellite images, Geoinformation for disaster management: Gi4DM 2011.