Assessing the Feasibility of Using Radar Satellite Data to Detect Flood Extent and Floodplain Structures

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ABSTRACT: River dynamics and hydrological behaviour are strongly influenced by human activities both in the catchment areas and in the floodplains. The knowledge of recent and historical river dynamics and related morphological and structural changes on the land surface (e.g. sedimentation, accumulation, river bed movement) is essential in assessing the flood risk and the vulnerability of human resources and structures. Earth Observation (EO) systems provide data to monitor and to analyse both, the river dynamics and small surface changes. Especially, radar-based systems and interferometric data analysis are of high interest. Along selected sites in the River Odra area, we analysed the potential of radar-based EO-applications for the detection of structural changes, validated by fieldwork.

It is shown that the coherence information is of great significance: On the one hand, it could be used to eliminate misclassifications of the flood extent caused by double bounce scattering, corner reflection or smooth surfaces. On the other hand the production of RGB’s type Interferometric Signatures (coherence, average, difference of tandem pairs) proofed to be a powerful tool to visualise the flood dynamics in space and time but also the morphologic structure in the floodplain. As conclusion, it is shown that the combined analysis of radar backscatter and coherence information will be very useful in the flood application domain, especially with respect to risk assessment and vulnerability mapping. In addition, the methods described will support the collection of relevant base data claimed by the EU water framework directive.

Keywords: Spaceborne Earth Observation, SAR Interferometry, Coherence Analysis, River Dynamics, Flood, Floodplain Structures, Floodplain Management, River Odra

1. INTRODUCTION

The impacts of human activities and water regulation on rivers and floodplains are well known. The more intensive river basins are used by man and the lesser user functions are adapted to natural river characteristics, the bigger the damages will be if a flood crisis happens. Floods of great magnitude cannot be prevented, but flood damages can be limited. In order to take successful measures studies of the spatial and temporal flood distribution are essential. Floodplain management requires also a characterisation of floodplain structures as well as information about flood extent and river dynamics. Remote Sensing and Geographic Information Systems (GIS) are important tools for the analysis and visualisation of geographical entities of river systems and for decision support for management measures [1].

The main aim of the research described in this paper is to assess the feasibility of using radar satellite imagery for the floodplain management. ERS-SAR data and interferometric products were used to document the pattern of floodplain inundation, floodplain structures and morphological changes due to flooding (e.g. erosion, break of a meander). The Odra River basin in Poland and Germany, where large-scale flooding occurred in summer 1997, was chosen as the focus of the study.

The investigation was done subsequently to the Odra flood event. The high data availability, - ERS-1/2 tandem data as well as different GIS-data -, but also the geographic dimension of the flooded areas are important preconditions to study river dynamics with radar EO-methods. Selected sites in the floodplain of the river Odra were analysed regarding the flood risk estimation and the vulnerability of resources and structures.

2. THE REGION OF INTEREST (ROI)

The Odra River with its source in the Czech Republic has a length of 850 km. The river catchment area of about 124.000 km^2 plays an important role for the water economy of the western part of Poland and the northeastern part of Germany.

Due to regulation works, - which started already at the end of the 18th century and continued up to the early decades of the 20th century -, the course of the river Odra was shortened by 154 km [2]. The construction of a regulation infrastructure in the upper, middle and lower course of the Odra has caused large-scale degradation of the river bed (erosion and deepening of the river bed up to 3m) and in some areas a lowering of the ground water table.

On the other hand, recent hydraulic measures were not taken along the Odra. The river has maintained part of its natural, unregulated character, comprising floodplain forests and associated wildlife, mainly in the middle and lower sections of the river. Therefore some authors consider the Odra as the most natural large river in Europe [3].

The greatest flood in the last century caused by the river Odra occurred in summer 1997. After strong rainfall in the middle and upper catchment areas floods appear in summer typically with short and steep flood waves. Exceptionally strong-rain falls, which occurred in three places of origin from 4. -8. July 1997 and from 17. -21. July 1997, brought a huge flood disaster to the Odra and most of its tributaries with extensive flooding. All littoral states along the river Odra were affected by the flood disaster in July/August 1997. The flood was particularly strong in Poland and the Czech Republic. Partially, the flood was influenced by human impact.

Above all, the importance of natural retention areas was shown dramatically: Bursting of dikes in Poland with an overall length of 40 km brought an inundation area of 55000 km^2 but also a noticeable reduction of the flood peak at the German-Polish section of the Odra. As a result of the persistent high water level two breaches in the levees of the German-polish Odra section occurred with a flooded area of 6000 ha in “Ziltendorfer Niederung”. The decline of water from the inundated areas took some weeks.

Fig. 1: Research areas in Poland and Germany

The following test sites were selected do detect different river and floodplain characteristics:

- Floodplain near Krosno Odrańskie (mapping of floodplain structures)
- Ziltendorfer Niederung situated at the German-Polish border south of Frankfurt/Oder (mapping of inundation pattern)
- Odra at the Polish-Czech border (mapping of the breached meander near Chałupki)

This selection was also done in view of the ground resolution of the EO instruments. The phenomena to be analysed must have a minimum spatial dimension in order to make sense of the use of satellite remote sensing methods.

3. EARTH OBSERVATION DATA PROCESSING

3. 1 Floodplain structures

Floodplain structures are important for the potential of flood retention. In the work described, the term floodplain structures is not used in the hydraulical sense but in an geographical sense. Therefore, the structures detection includes different types of land cover like floodplain forests, herbs and bushes, thin woodland vegetation, meadows and agricultural field as well as other flood plain related features such as rivulets, canals, ditches and different types of former river structures.

In the floodplains of River Odra over 15 ecotopes could be distinguished from the Atlas of Odra Floodplain [4]. Because the morphological and vegetative structures of each ecotope is known, these ecotopes can be labelled with a specific hydraulic roughness factor according to the studies of [5] who combine ecological and hydraulic roughness data. The preliminary results provide good perspectives for determining the hydraulic roughness of entire river sections.

The hydraulic characteristics of river sections vary with time. It is laborious and expensive to adequately monitor any changes, which occur in the floodplains by conventional techniques (aerial photographs and field studies). In the future, faster and cheaper and more efficient techniques are needed to monitor abundance and structure of vegetation in large parts of a river basin. Airborne laser-altimetry is used in some studies [6]. However, in this context, a method involving spaceborne radar data also seems promising.

Using the derived data as input for water flow models may provide quick and cheap monitoring of the continuously changing conditions in floodplains, and may enable the river manager to ensure sufficient water flow capacity in a dynamic river bed.

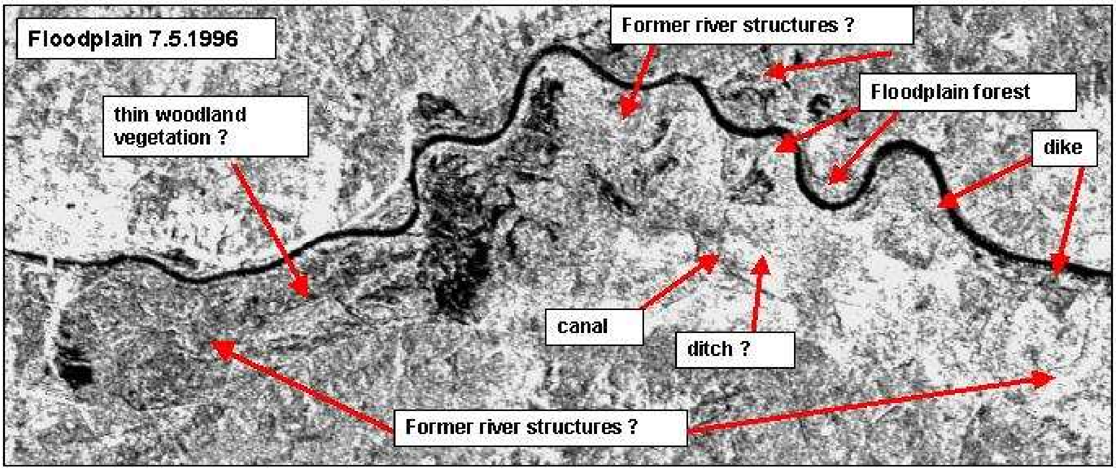

Fig. 2: Floodplain Krosno Odrańskie: normal situation (7.5.1996 ERS-1)

This research makes use of spaceborne radar data, - backscatter & coherence tandem data -, to obtain information on vegetation structure. ERS-1/2 tandem pairs with acquisition dates before and duringe the flood were analysed to determine different structural types. The well structured floodplains of Krosno Odrańskie, Poland served as test site.

A better visibility of such structures was achieved when analysing radar images with an acquisition date during flood events. The reason is that slighthly flooded areas are increasing the contrast of radar backscatter of different land units, for instance . due to double-bounce-scattering. Most of these structures can not be identified when using satellite imagery taken during normal water level.

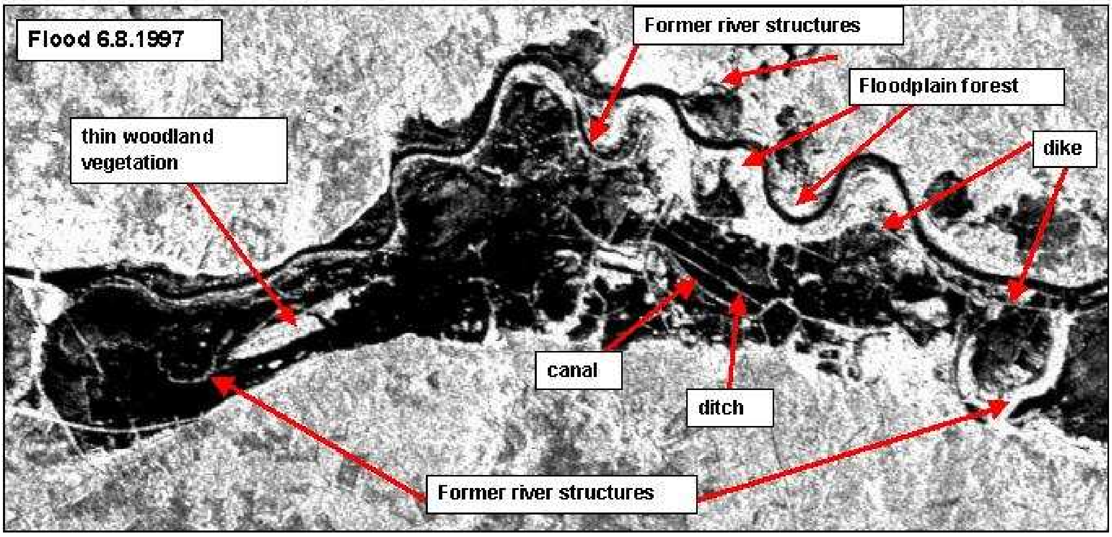

Fig. 3: Floodplain Krosno Odrańskie: flooded (6.8.1997 ERS-2)

Especially the pattern of former river structures, floodplain forest and thin woodland vegetation can be identified much better on the flooded backscatter image.

3. 2 Floodplain inundation pattern

Discussing vulnerability with respect to flood hazards, the first step is the knowledge of the river dynamics, the inundation pattern and the maximum extent of the flood in the affected areas. Therefore, the flood lines were extracted from the images at different acquisitions during the phase of maximum flooding. For this part of the study the "Ziltendorfer Niederung" in, Germany was taken as test site.

Fig. 4: Backscatter information, Ziltendorfer Niederung (Germany, 6.8.1997)

Mapping the flood extent by using only backscatter information can lead to significant misclassifications. At the image shown above, there are streets and settlements with a strong radar return (white pixels) despite the fact that they were flooded the time of image acquisition. Especially flooded tree-lined avenues produce a signal similar to that of a non-flooded situation. This phenomenon is related to an important principle of radar backscatter: the corner reflection and the double-bounce scattering. These misclassifications can cause supply bottlenecks and problems in the decision making process in the flood hazard and crisis management.

Two or three dimensional corner reflection is caused by the existence of buildings. Scattering from a forest canopy or from tree-lined streets can present a complex case of volume scattering. Double-bounce scattering between trunks and the ground is one important effect in volume scattering. This can give a strong return if the ground is covered with water. Buildings and trees are able to redirect a radar beam which was backscattered from a smooth water surface back to the radar sensor. This is why some flooded settlements and tree-lined streets can look even brighter than not flooded areas [7].

Calculating the coherence information of this area (Fig.5) provides additional data about the surface conditions. In this case the coherence map supplied information on flood conditions for the tree-lined avenues and the village.

However, very flat meadows can also be responsible for a wrong assessment of the flood situation. The backscatter signal provides no radar return as meadows react as smooth surfaces like a water body. Water surfaces without waves act as a smooth surface. When the radar sensor transmits a beam of radar energy towards this smooth surface, the result is no backscatter return to the radar sensor but rather the scattering of the radar energy away from the sensor. The meadows areas can not easily be distinguished from flooded areas. The coherence map shows a very high coherence for the meadows, which means that this area was not flooded.

The combination of coherence information derived by tandem radar data with backscatter data can avoid wrong interpretations of the flood situation.

The two examples show that any automated unsupervised classification performed without an additional visual interpretation can result in serious misinformation.

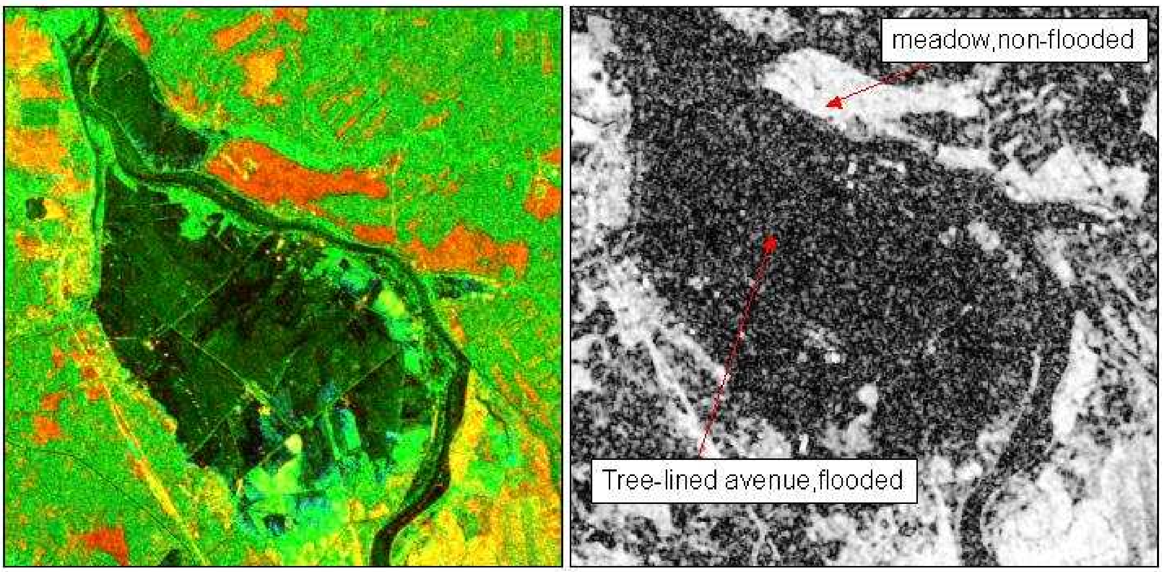

Fig. 5: Coherence information, Ziltendorfer Niederung (Germany, 6.8.1997)

3.3 Flood Dynamics

The detection of morphologic activity, - such as the bursting of a meander -, provides information about the risk and the vulnerability of special sites in the floodplain. Visualising the morphodynamic activity can be done by processing a multitemporal image (RGB), type “Interferometric Signatures” (red = coherence, green = average, blue = difference). RGB images are created with SAR images of the PRI product level.

The multitemporal image is a system of producing colour imagery that is based upon the additive properties of primary colours. The multitemporal technique uses black and white radar images taken at different dates and adds them to the red, green and blue colour channels. The resulting multitemporal image (RGB) reveals changes in the land surface by the presence of colour on the image. The hue of the colour indicates the date of the change and the intensity of the colour the degree of change. The reason for change may be the growth of crops, a change in soil moisture or in soil structure, or the presence of floodwater in one image when it was absent before.

Morphological changes such as the break of a meander can be shown using a multitemporal colour composite with two images taken before and after flood and using coherence, average and difference information of these images. The detection of disturbed radar information requires a validation and specification by fieldwork. In the area of Chałupki the resolution of the ERS-SAR instrument is at its limit; the Odra is only 25m wide.

3.4 Vulnerability Mapping

The basic problem concerning floodplains is the conflict between human uses of river environments on the one hand and floodplain resources and natural functions one the other. All natural and cultural resources and functions of floodplains are subjected to threats, the most significant of which are related to human use and development.

The permanent location of settlements, industrial plants, infrastructures as well as agricultural activities within floodplain are the most common infringements in contemporary times and result annually in ever increasing damages, risk for human life, personal inconveniences, and material loss world-wide, when floodwaters reclaim these lands. Natural hazards are having an increased impact on human settlements, probably because of the greater number of settlements and their increased vulnerability due to their uncontrolled extension to high risk areas. The response and policy options to counteract are wise land use and emergency planning to reduce the impacts of floods and other hazards and their interactions with human activities.

The delineation of floodplains and socio-economic characteristics on maps to derive vulnerability information is a basic necessity for floodplain management.

In the case of the Odra floodplain the information derived by radar satellite data will be integrated with different sources of Geodata to produce maps for the floodplain management.

The derived risk and vulnerability maps will be used for flood risk estimation in sensitive areas. In addition, these maps will yield vital information to support decisions concerning the siting of flood-control works such as reservoirs and levees, or floodplain zoning provisions.

4. CONCLUSIONS

In terms of describing characteristics for floodplain management by using radar satellite imagery the investigations permit the following conclusions:

- Mapping floodplain structures with radar imagery with acquisition data during flood events improve the detection of different structural types, such as former river structures, floodplain forest and thin woodland vegetation.
- Combining backscatter and coherence information improves the mapping of the flood pattern and mitigates the errors derived by double-bounce-scattering and corner-reflection occurring in backscatter data. This improved assessment of the flood situation is important for the decision making process in flood hazard management.
- The detection of morphological changes, - the break of a meander near Chalupki -, was taken at the limits of spatial resolution of ERS-1/2 due to the narrowness of the River Odra of 25 m in this area. For larger rivers it should be possible to map this kind of activity by using RGB type “Interferometric Signatures”. The detection of a morphodynamic process must be verified by field studies.

However, floods are natural events and turn into a threat only through uncontrolled use and settlement in the potentially targeted areas. The vulnerability and risk need to be carefully estimated to optimise future planning of living in floodplains.

There is also a necessity to combine all sources of data available for rivers and floodplains, not only by remotely sensed data but also using other Geodata, to improve floodplain management. Nevertheless, important progress can be achieved through interpreting and estimating existing data sets.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] Leuven, R.S.E.W. & Poudevigne, I. & Teeuw, R.M. [Eds.] (2000): Application of GIS and Remote Sensing in river studies. – Backhuys Publishers, Leiden.

[2] Parzonka, W. & Bartnik, W. (1998): Degradation of Middle Odra caused by regulation works. – In: Gayer, J. & Scheuerlein, H. & Starosolsky, O. [Eds.], Proceed. Intern. Confer. River Development, Budapest, Hungary, April 16-18, 1998, VITUKI, Budapest, pp. 345-352.

[3] Nienhuis, P.H. & Chojnacki, J.C. & Harms, O. & Majewski, W. & Parzonka, W. & Prus, T. (2000): Elbe, Odra and Vistula: Reference Rivers for the restoration of biodiversity and habitat quality. – In: Smits, A.J.M. & Nienhuis, P.H. & Leuven, R.S.E.W. [Eds.]: New Approaches to River Management, Leiden, The Netherlands.

[4] WWF (2000): Der Oder-Auen-Atlas. – Auen-Institut des WWF, Rastatt.

[5] Smits, A.J.M. & Havinga, H. & Marteijn, E.C.L. (2000): New concepts in river and water management in the Rhine river basin: how to live with the unexpected? – In: Smits, A.J.M. & Nienhuis, P.H. & Leuven, R.S.E.W. [Eds.]: New Approaches to River Management, Leiden, The Netherlands.

[6] Asselmann, N. (1999): Laseraltimetrie an vegetatieruwheid. – Report Q2577. WL Delft Hydraulics, Delft.

[7] Halounova, Lena (1998): Integration of various types of remote sensing data for the Morava River catchment evaluation. – In: International Archives of Photogrammetry and Remote Sensing, Vol. 32, Part 7, Budapest.