Evaluation of Multi-Frequency and Multi-Polarization Airborne SAR data for Marsh Land and River Dyke Analysis

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ABSTRACT

The flood disasters increasing world-wide represent a challenge at research and technology development. These extreme events have dramatic consequences for humans and environment. Here are both ecological research, and also the advancement of the technical flood protection urgently necessary. The "Oder" flood of 1997 gave the impact for the pilot project SediSAR which uses the characteristics of long-wave, multi-frequent and multi-polarimetric SAR remote sensing (Synthetic Aperture Radar).

This pilot project promoted by the Federal Ministry for education and research (BMBF) is accomplished by the EFTAS Remote Sensing Transfer of Technology GmbH in co-operation with the state geological survey of Brandenburg (LGRB).

The floods of the river "Oder" in 1997 or the river "Elbe" in 2002 have shown that the stability of a dyke at high tide is not only due to the height of the dyke, but it also depends significantly on the nature and type of underground. SediSAR has a very important role to play in the construction of the planning-, security- and sanitation concept in a frame of prophylactic flood protection in river areas.

The results of the project are on future satellite based SAR L- or P-band-systems, e.g. the TerraSAR being transferable.

1. INTRODUCTION

Microwave remote sensing at wavelengths ranging from 1 cm to 1 m has gained a lot in importance over the last decade with the availability of active radar imaging systems for a wide range of scientific applications. Synthetic aperture radars proved to be of great benefit, due to their day and night capabilities and weather independence. In comparison, optical sensors are strongly dependent on weather conditions, where, on average, only 10% of the data collected over Europe throughout a year proves to be usable.

With its potential to acquire subsurface information offers a new dimension to marsh land and River Dyke studies. Furthermore, active microwave sensors are sensitive to parameters such as soil moisture, relief and surface roughness, vegetation coverage and structure. The area wide estimation of these properties would represent a significant contribution to prophylactic flood protection in river areas.

Due to the genesis of the marsh land in which most dykes are, the lying of these things consists of spatially strongly varying substrates with different building ground stability characteristics. The substrates are bound to here formerly the running river branch. On the basis of these former, today covered river courses, with its spatial substrate changes, a susceptibility exists in relation to lateral pressure and thus hydraulic shear failure danger with organic silt and turf in the dyke underground. With sandy underground against it the danger of a dyke under flushing exists in extreme situations. From this fact results the necessity to detect existing substrate differences in the underground of dyke constructions.

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2. TEST AREA AND DATA ACQUISITION

A 140km^2 test area at the German-Polish border in East Germany was selected for this study. Situated approximately 20 km North of Frankfurt/Oder, the Oderbruch is composed of mainly agricultural fields and some forests.

In July 1997, two macro weather situations of the type Vb were formed in Central Europe briefly followed one another. The resulting intense rain during the first week (4 – 7 July) as well as the occurrence of a second episode of strong precipitation between 18 - 21 July, provided the long persistent flood which generated continuous stress on the dykes.

Figure 1: Test area location.

Image acquisition was realized with the airborne sensor system E-SAR (Experimental Synthetic Aperture Radar) mounted on board a Dornier DO228 aircraft. Owned and operated by the DLR (German Aerospace Center), this sensor system operates in the X-, C-, L- and P-band, with selectable vertical or horizontal antenna polarizations (HORN, 1997). The flight campaign was made at an altitude of about 3200m over the catchments with a mean depression angle of approx. 40°. The four campaigns were realized in April 2001/2002 and in August 2001/2002. No big rainfall event had been forecasted for this period. The time delay between both campaigns in each year was scheduled to ensure, which season will be best for SAR campaigns. Besides the flight campaigns, terrains campaigns were schedulded by the LGRB, in order to collect a maximum of soil characteristics.

Additionally are available a Laserscann DGM, orthophotos (1997, 2001), CIR photographs of 1997 and 2002, groundwater level measurements as well as weather data of the German Meteorological Service (DWD - station Manschnow).

3. SYNTHETIC APERTURE RADAR (SAR)

Radar systems are commonly based on the measurement of signal time delays (RADAR = **Ra**dio **D**etection **A**nd **R**anging). In 1951 Carl Wiley announced the illustration of the synthetic array radar (SAR: **S**ynthetic **A**perture **R**adar) to the patent. The side-looking imaging geometry is typical of radar systems. The geometric resolution of SAR systems is defined by the range and the azimuth resolution, measured in the look direction and the flight direction respectively. This is completely different from optical or infrared sensors. Radar systems work within the microwave range with a wavelength of 1 m to 1 cm, this corresponds to a frequency range of 1.2 [GHz] to 0.3 [GHz]. In contrast to it the spectral region of the visible light is illustrated by wavelengths of 0.4 to 0.7 [µm] (e.g. by satellite systems such as Landsat, Aster, IKONOS, Quickbird). The spectral region of the microwaves is divided into so-called "Bands". Their designation originally goes back to one for secrecy reasons selected coding and finds still use today. As an active system, a SAR emits by itself microwave radiation to the ground and measures the electric field backscattered by the illuminated ground patch. The SAR system can perform equally well during day and night. These measurements are transformed into a high resolution image.
Imaging radar systems builds up a two-dimensional image of the surface (CURLANDER & MCDONOUGH, 1991) of the area flown over. Due to their long wavelength, microwaves are capable to penetrate vegetation and even the ground up to a certain depth. The penetration capabilities depend on the wavelength as well as on the complex dielectric constants, conductivities and densities of the observed targets (ULABY, MOORE & FUNG, 1981/82). Shorter wavelengths, like the X-band, show a typical high attenuation and are mainly backscattered on the ground or on the vegetation surface. Consequently, at these wavelengths mainly information about this layer is collected. Longer wavelengths, like L- and P-band, normally penetrate deep into vegetation and often also into the subsurface. The backscattering then contains contributions from the entire volume.
A Synthetic Aperture Radar is designed to achieve high resolutions with small antennas over long distances (CURLANDER & MCDONOUGH, 1991). A SAR system takes advantage of the fact that the response of a scatter on the ground is contained in more than a single radar echo, and shows a typical phase history over the illumination time. An appropriate coherent combination of several pulses leads to the formation of a synthetically enlarged antenna.
In addition to the signal frequency, the signal polarization provides complementary information about the illuminated targets. Polarization defines the orientation of the electric and magnetic fields of the microwave. If the electric field is vertically or horizontally transmitted, it refers to a vertically or horizontally polarized signal (V or H). Thus, there can be four combinations of both transmit and receive polarizations as HH, VV, HV and VH, where HH and VV (commonly called like-polarized signals) produce stronger returns than HV and VH (cross-polarized signals).
Under identical basic conditions (incidence angle and frequency) aimed at radar systems: The rougher the surface, the more diffuse is the backscattering and/or the smoother the surface, the more directional the backscattering. A surface, which appears rough with in short-wave radar (e.g. X-Band), can exhibit characteristics of a smooth surface with in longer wavelengths (e.g. P-Band). The change of the dielectric constant on change of the soil water content leads to a changed backscattering. The large difference of the dielectric constant of water (80) and dry soil (3-5) plays the crucial role. With rising soilmoisture content the dielectric constant increases. The high dielectric constant of water is justified in the easy polarizability of the water dipoles. In the case of change of the electrical field put on (pole reversal) the dipoles align themselves again. Particularly the use of low frequencies (e.g. L- and P-Band) is suitable, in order to detect soilmoisture differences, because the water dipoles have sufficient time to orient again (raised the dielectric constant). The adjustment of the dipoles is crucial for the height of the dielectric constant. The connection of the free water depends on the soil texture and compaction. The free water molecules

cause an ever stronger rise of the dielectric constant. Clayey soils with large specific surface bind larger quantity water firmly at the surface than sandy soils. Generally applies: The longer the wavelength, the smaller the incidence angle and the drier the material, the deeper penetration of the wave into a medium (HAJNSEK, 1999).

4. TERRAIN CAMPAIGNS

Concurrent with imaging campaigns, soil moisture measurements were taken by the LGRB. The gravimetric measurements remain the classical way for soil moisture determination (DIN 18121). In the context of soil moisture measurements, gravimetric measurements consist of taking a soil sample and weighting it before and after a 48 hour drying at 105 °C.
It has been shown that microwaves have the capability of penetrating into the ground and thus providing subsurface information where the surface penetration extent depends on both, sensor and surface properties. For this reason, soil moisture measurements were taken at more than one depth.
The gravimetrical measurements of the soil moisture were taken with a stick cylinder in layers of 0-4 cm and 4-8 cm on several positions per testfield.

Figure 2: Marsh land and Dyke area in the orthophoto of 1997.

5. RADAR IMAGE PREPROCESSING

Prior to image analysis, the data acquired by the E-SAR sensor system had to be processed using several steps. The acqurired short-wave X-band (3.1cm) in the horizontal polarization as well as full-polarized long-wave L- (23.5cm) and P-band (68cm) makes available nine channels and their respective backscattering intensities.
The backscattering intensities were examined for their suitability to the substrate distinction:
X_{HH}, L_{HH}, L_{HV}, L_{VH}, L_{VV}, P_{HH}, P_{HV}, P_{VH}, P_{VV}
P-band imagery could not be exactly calibrated, due to the presence of noise caused by radio interferences in the calibrated scenes. These effects affected particularly the vertically received waves, i.e. VV and HV-bands.
The statistic analysis of the nine single channels showed that the individual volumes differ statistically from each other. Besides it became clear that in each case the two cross polarizations

(HV and VH) exhibit almost identical statistic parameters in L- and P-band. This result could be confirmed by the visual analysis. Due to this reason the respective cross polarization (VH) in L- and P-band results were not selected for consideration.
The computation of coefficient of correlation for the seven remaining channels shows clearly that a small correlation between the X- and L-band as well as between the X- and P-band exists. In them thus the spectral variation is most clearly pronounced. A strong correlation is indicated between L- and P-band. The visual analysis of the seven single channels showed besides that the P-band is characterized by strong noise in the cross polarization and the vertical polarization. The horizontal polarization of the P-band exhibits weaker noise, so that this polarization can be used with restrictions for the further analysis. These disturbances are likely caused by the system noise of the sensor as well as to radio interference in the investigation area.
In the context of the image processing the generation of false colour composites was accomplished to increase the information content of the SAR-data and to consider the color feeling of the human eye.
The following three-channel combinations proved by statistic and visual analysis for the interpretation of existing substrate differences are particularly suitable:
X_{HH}, L_{HH}, P_{HH} (Figure 3 and 4)
L_{VV}, L_{HV}, L_{HH}
L_{VV}, L_{HH}, L_{HV}
L_{VV}, L_{HH}, L_{HK1} (Figure 5 and 6)

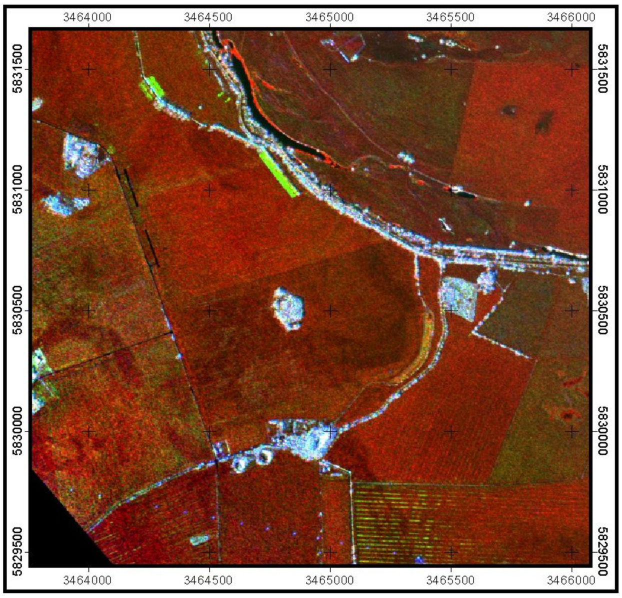

Figure 3: E-SAR false colour composite X_{HH}, L_{HH}, P_{HH} (April 2001).

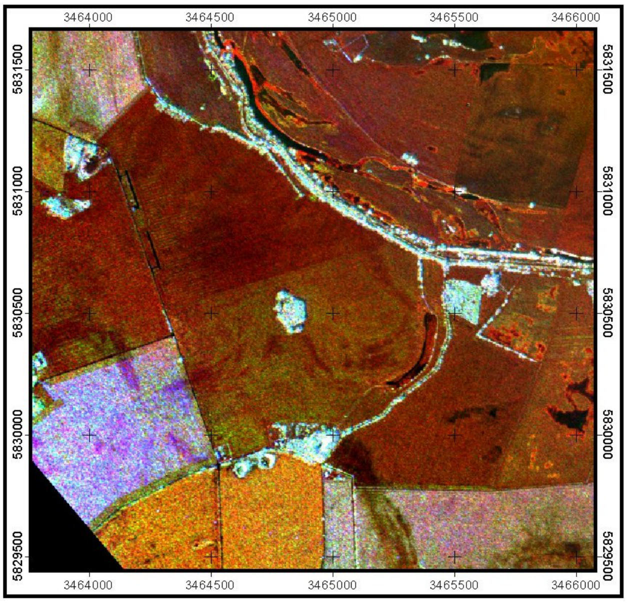

Figure 4: E-SAR false colour composite X_{HH}, L_{HH}, P_{HH} (April 2002).

The evaluation of the data characterises the high sensitivity of soil moisture variations, points to a substrate change in the underground of the long-wave L-band. The backscattering behaviour of the surface and upper bottom set beds differs in the L_{VV} from those in the L_{HH} and L_{HV} by an altogether higher backscatter. The vertical polarization of the L-band is characterised by a smaller influence of the vegetation. Conditionally, L_{VV} penetrates the vegetation layer deeper and supplies more information about dielectric characteristics of the upper bottom set beds.
The cross-polarized L-band shows an altogether lower backscattering, since only the de-polarized radiation is noted.
Principal component analysis (PCA) of the SAR data in different bands was performed for the reduction of the amount of data, since it determines which bands and frequencies contain the most

information (DRURY, 1993). The PCA is a linear combination which rotates the axes of image space along lines of maximum variance. These lines are orthogonal with respect to each other and are called eigenvectors of the covariance matrix generated from the channels. The principal components (PC) with high order show thereby an improvement of the signal-to-noise ratio as well as further radiometric effects (e.g. speckle).
According to visual criteria, 1.PC from the multipolarized L-band data proves as useful for the further analysis of the image data. The first component could be attributed to a combination of the soil texture and the soil moisture influences.

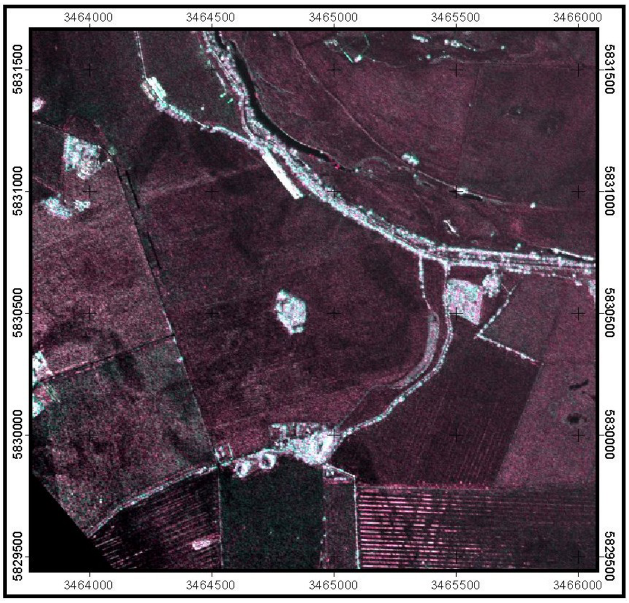

Figure 5: E-SAR false colour composite L_{VV}, L_{HH}, L_{HK1} (April 2001).

Figure 6: E-SAR false colour composite L_{VV}, L_{HH}, L_{HK1} (April 2002).

6. CORRELATION OF PRECIPITATION, GROUNDWATER AND SAR

The comparison between the data of April 2001 and April 2002 shows clear identification of meander like structures in the 2002 data (see Figure 3 to 6).

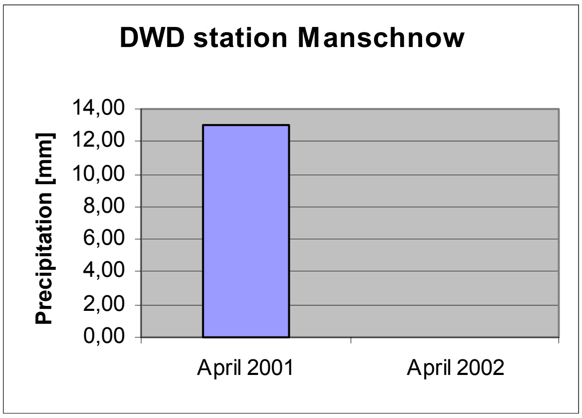

Figure 7: Comparison of the precipitation for April 2001 and 2002.

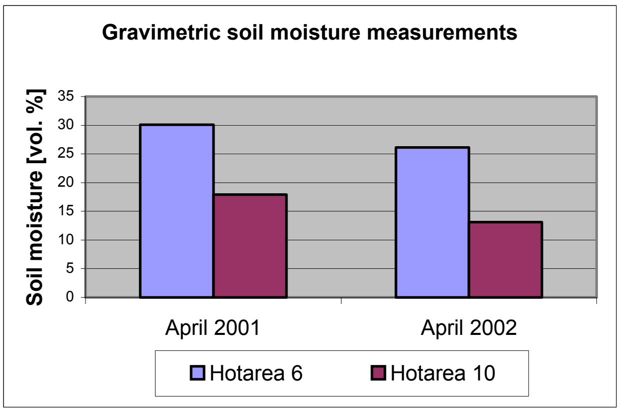

Figure 8: Comparison of the soil moisture for April 2001 and 2002.

For the week before the respective attachment flying campaign a higher amount of precipitation proves the DWD data, for 2001 than for 2002 (Figure 7). This result is reflected also in the gravimetric soil moisture measurements. For 2001 a higher soil moisture is to be determined, than for 2002 (Figure 8). An analysis of the groundwater level measurements for the attachment flying periods does not show a considerable difference in groundwater distance of the upper edge area, so that an influence of the E-SAR data can be excluded by ground-water level fluctuations.

7. SUMMARY

Procedures derived from the radar data detailed above, highlight the suitability for the identification of substrate changes in the upper underground.

From the radar data collated during spring and late summer flying attachments, it is clear to recognise meander like structure; suggesting a former course.

These structures are not illustrated in the official soil estimation map (1: 25 000) of Brandenburg. A mapping of these structures on the basis of the radar data is possible with the help of a visual interpretation. By the consideration of geological knowledge, prompt recognition of the dyke surrounding field weak points can be identified.

The comparison of the prepared radar data with data of optical remote sensing systems shows impressively the advantages of a long-wave multipolarimetric radar system for the collection of substrate changes in the upper underground. The radar data also indicates the ranges of soil moisture variations, indicating a substrate change; where optical remote sensing systems can not (compare Figure 2 with Fig. 3 to 6).

8. REFERENCES

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