INTEGRATION OF MULTITEMPORAL ERS.2 SAR AND LANDSAT TM DATA FOR SOIL MOISTURE ASSESSMENT

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ABSTRACT

The heavy flood in Poland in 1997 has generated many damages on settlements but also on agriculture area. On the flooded region all crops were damaged - it was short time effect. A lasting soil moisture increasing could be called a long time effect that could change agriculture structure for a long time. A flood monitoring using satellite remote sensing data is not easy to realization mostly because the maximum flood wave is difficult to render. It is caused by term of repetitive coverage imaging cycle of the satellite systems. However, satellite remote sensing methods are promising to monitoring the effects of flood within the agriculture areas. In our research we used multitemporal ERS.2 SAR and LANDSAT TM images. Remote sensing multi sensor data were standardized in spatial and radiometric sense. Especially preprocessing was conducted for radar images because of their noisily speckled effect. Different filtering techniques were tested. Besides Fourier transformation was performed to improve radar image. Next, multitemporal ERS data were compare, to state the influence of the flood on the agricultural area. The third part of the project contained image data processing for soil moisture evaluation. Tasseled cup method, basing on visible and infrared channels of LANDSAT TM was used and wetness was analyzed. The other technique, combining visible and thermal infrared channel, so called thermal inertia method, was implemented. Finally the results of non-radar images processing and radar data were compared.

1 INTRODUCTION

Using remote sensing techniques for soil moisture detection was the subject of number scientific papers and reports published at the last decades. It was soon realized, that remotely sensed data might be able to help to solve the problem faster, low-costs and much more effectively, than traditional methods could do. Traditional methods for measuring soil wetness are essentially point measurements, while remote sensing methods can provide areal measures rather then point data. Remote sensors operating in infrared, thermal infrared and particularly in micro-waves region of electromagnetic spectrum can provide useful information of soil moisture detection and distribution and even for the quantitative measurements. Especially, the radar imagining systems: Synthetic Aperture Radar (SAR) such as ERS, RADARSAT and JRS, are permissible to detect soil moisture differences, because the back-scattering effect is strongly dependent on the soil water content. Also non-imaging radar scatterometers, like the one installed on board European Remote Sensing (ERS) satellites as well as passive microwaves were recently successfully used for the soil moisture assessments (Dubois et al., 1995, Wignerouet al., 1998, Wagner 1998).

The open–water surface strongly reflects the radar beam thus the backscattering signal is very low or even non-registered. The returned radar signal coming from the bare soil surface and the vegetation is less or more scattered depending on the surface roughness, soil permittivity or the dielectric constant. Therefore, the suggested approach is to relate the measured backscattering to the permittivity and later to the soil wetness. It is very difficult task to separate the moisture and roughness components each other, from the backscattering signal. For this purpose the theoretical models were recently developed and the concept of the interferometry was also used for soil moisture monitoring (Wergmuler et al., 1995). The main objective of the study presented was to show the usefulness of multitemporal ERS-2.SAR data for soil moisture detection over the flooded area. A possibility of the thermal inertia modeling of bare soils and using HIS (Hue, Intensity, Saturation) techniques of the LANDSAT TM and ERS-2.SAR imageries to enhance soil-agriculture versus the other land-use/land-cover categories, is also presented.
These research have been conducted within the project No 9 T12E 030 15 financed by the Polish Committee of Scientific Research – “Delimitation of the over-moisture areas on the test field located within the region being flooded in 1997 on the base of the satellite radar images”

2 STUDY AREA AND DATA SETS

In July 1997 the southern part of Poland has been heavily flooded, particularly within the upper and the middle part of the Odra river catchment. As a test site the above parts of the Odra river valley were chosen and for the particular studies the test area covered by the whole scene of ERS-2.SAR image (100x100km) was investigated. Within the test area several little towns, villages and the mostly agriculture land-use type is observed. It consists of about 60% of farmland, 15% of rangeland and the rest of the whole area is covered by forest (deciduous and conifer), surface water (rivers, ponds, lakes) and urban (mostly residential) as well as transportation structures. As the flooding effect the increase of soil water content was observed, even on the areas laying far away from the Odra river valley, because of the heavy rainfalls over this area and high the ground-water table level. In a such situation the surface drainage-pattern as well as underground flow-streams are disturbed and as the result the over-moisture of soils is observed. This is especially important for the agriculture practice because of the long-term water stress affected the cultivated vegetation. Geographical coordinates of the center of study area are 51.75^{o} N and 16.50^{o} E . On the Fig.1a) one can see Radar – ERS2 over study area, recorded in the year 1997 during the big flood in Poland. Open water as a black areas near the river-bed are easy to noticed, even in the small image scale. On the Fig.1b) false color composite from, recorded in year 1999, LANDSAT TM 234 channels of interesting area, are shown.

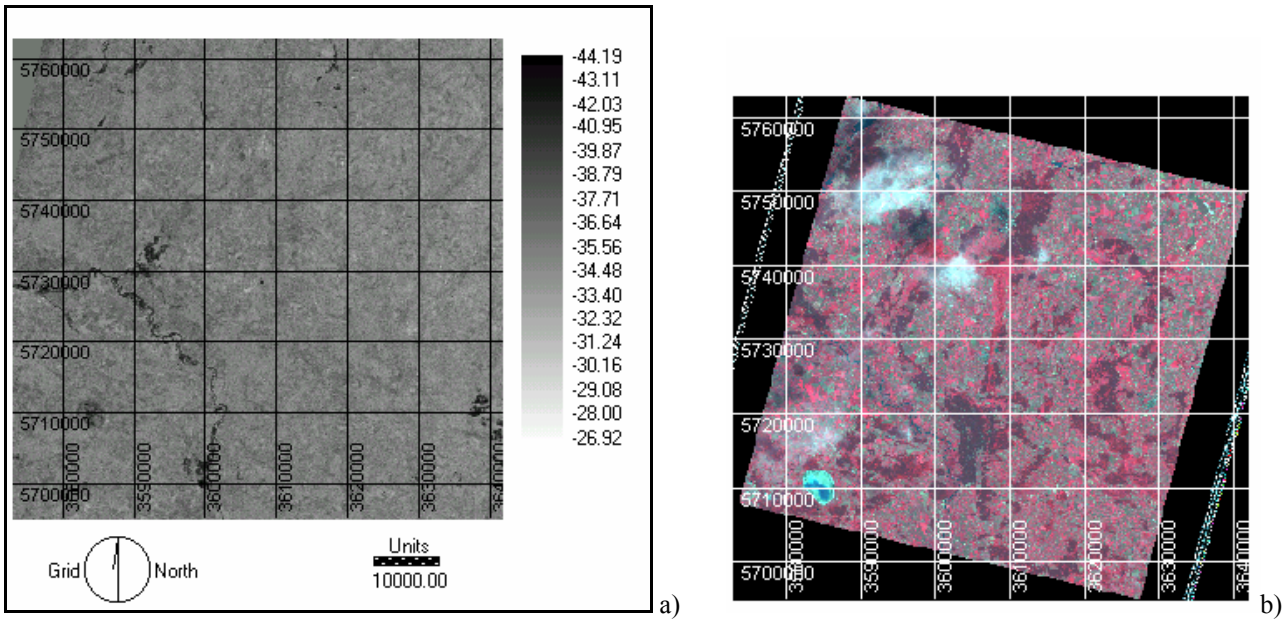


Figure 1. Study area, a) Radar image – ERS2, b) False Color Composite of LANDSAT TM234 bands.

In the research the following data set was analyzed:

- LANDSAT TM (1999.07.05) mini scene ,
- ERS (1996.06.25),
- ERS (1997.07.15),
- ERS (1999.07.20).
- *In situ* measurements of soil moisture on the chosen control fields.

3 DATA PREPROCESSING AND ENHANCEMENT

Remote sensing data were initial pre-processed and enhanced:

- Images were georeferenced to topographic map 1: 200 000: ERS images of about 100 km x 100 km and 9500 columns x 9500 rows, with original pixel resolution 12.5 m (3 x about 180 MB when data are integer binary), LANDSAT TM of about 50km x 50 km and 2300 columns x 2267 rows, with original pixel resolution 30 m, 7 channels each about 1 MB (data in byte binary format).
- ERS images were resampled to LANDSAT resolution (30 m)
- LANDSAT TM was resampled to ERS resolution of 12.5 m for small test area: 12.8 x 12.8 km and 1024x1024 pixels,

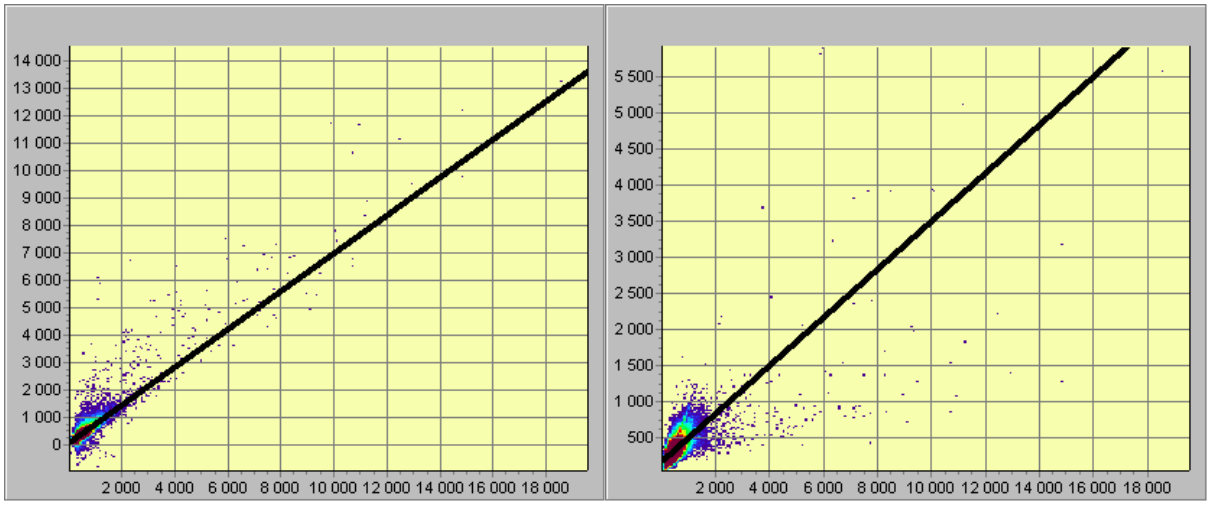
- Different false color composites were tested and visual evaluated – (TM7+TM5+TM4) and (TM7+TM5+TM4) as RGB was chosen for the later processing
- *In situ* control fields were digitized on the LANDSAT (TM7+TM5+TM4) composite.

3.1 INITIAL TRANSFORMATION OF RADAR IMAGE

Different remote sensing techniques were tested for radiometric correction of radar data. Because of time consuming calculation only a part of the radar image was chosen for this purpose: 12.8 km x 12.8 km, 1024x1024 pixels. ERS images were filtered using typical filters. Defining of the best result of filtering depends on the following interpretation purposes: classification, edge detection or change analysis. For our task the median filter performed with kernel 5x5 pixels was the best of the "classic" filters. Besides Fourier transformation was tested as a technique of removal a speckled effect. Spatial domain was converted to power, real and imaginary images. Than different filter was tested, especially low and high pass filter. In the next step inverse Fourier transformation has to be calculate for image in spatial domain. Different cutoff frequency was tried to obtain the best result, the frequencies higher than following were omitted, that is respectively 10% and 5% of overall frequencies of each image:

- ERS (96): f = 85 and f = 205
- ERS (97): f = 86 and f = 209
- ERS (99): f = 100 and f = 212.

We tested also different cutoff frequencies connected to the row size – 1024 : 25, 68 and 128. Frequency of 25 was of course to small and the resulting image was not interpretable. Transformation results were evaluated visually and statistically. Correlations between images before and after filtering were calculated. Image after median filtering with kernel 5x5 pixels and original radar image correlated with r=0.64, Fig 2a). More significant correlation (r=0.83) was obtained for image after Fourier transformation cutting off the highest 5% of frequencies, Fig 2b). Influence of different filtering of radar image can be follow on Fig. 3, b) difference between original ERS(99) and ERS(median5), c) ERS(99) – image after Fourier transformation with cutting off frequencies greater than 100 and d) the same as c) but f=212. The smallest changes of the original radar signal characteristic was obtained after Fourier transformation with cutting off the 5% of the highest frequencies.



a) b)

Figure 2. Correlation between ERS after and before transformation: a) Fourier transformation (f=212), b) median filter 5x5.

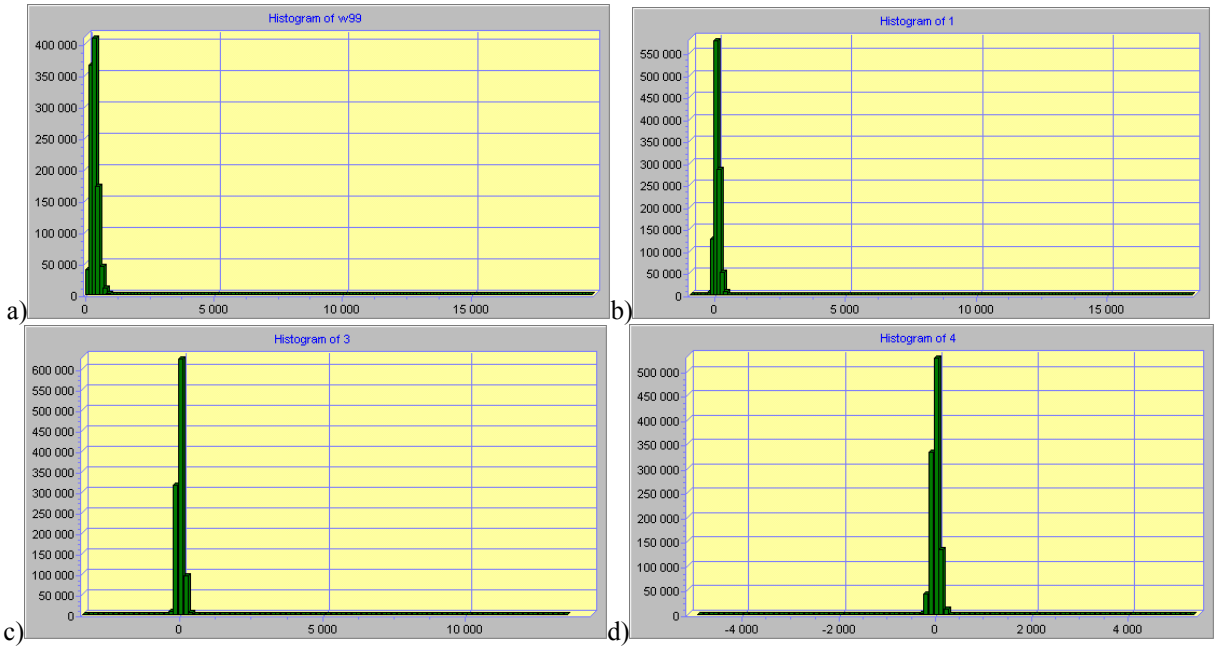


Figure 3. a) Histogram of the original ERS(99); Histograms of differences between original ERS (99) and: b) ERS(99) after median filter 5x5, c) ERS(99) after Fourier transformation with cutting off frequencies greater than 100, d) the same as c) but f = 212.

The final step of radar data preprocessing was transformation to backscattering coefficient (SIGMA) according to the formula:

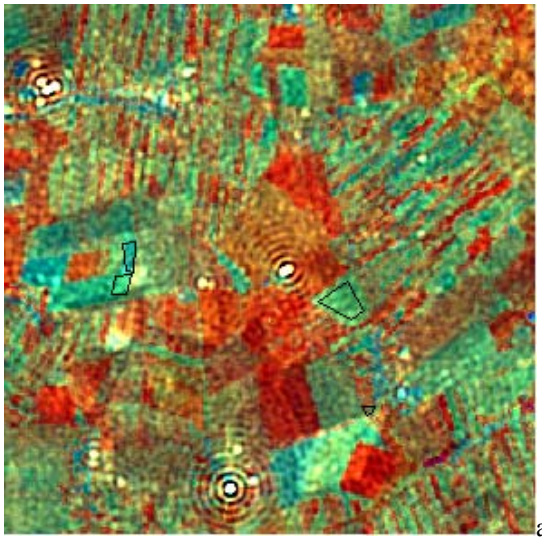
$$SIGMA = 10 * \log_{10} (ERS\_filtered) - K$$

where: K – correction factor.

3.2 MERGING OF LANDSAT TM AND ERS IMAGES

In the next step LANDSAT images, resampled to resolution 12.5 m for the small test sub-area, was merged with ERS (99) using the most popular Hue, Intensity, Saturation (HIS) method. ERS (99) image was substituted as an Intensity input. For the data fusion LANDSAT (754) composition was chosen. Two results of merging are shown on Fig. 4. False color composite calculated from HIS and inputting ERS(99) image after median filtering 5x5 as intensity are on Fig. 4b), and effect of merging using as Intensity ERS(99) after Fourier transformation with cutoff frequency of 128 on Fig.4a).

It can be seen on Fig. 4a) that on the image appeared very light spots with central rings around. The spots, representing corner reflectors coming from man made objects, might be sometimes, when we are not looking for man-made objects, treated as a noise. We tried to remove it during initial preprocessing, using reclassification method assuming overall mean for the values greater then for ex. 1200 (see Fig. 3a). The result of Fourier transformation calculated on the base on reclassified ERS data was significant the worst, not only in contrast sense but also considering the rest of noisy high frequencies. But of course the spots were removed. The problem is how to remove this fanny light spots and leave the advantages of Fourier transformation easy to see on agriculture fields where more details can be delineated (Fig. 4a).


a)

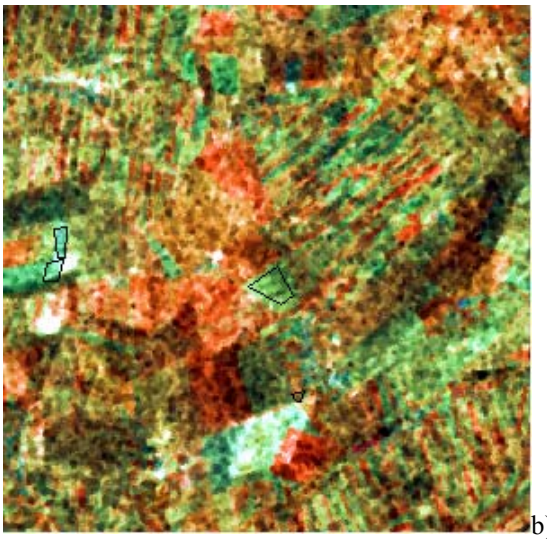
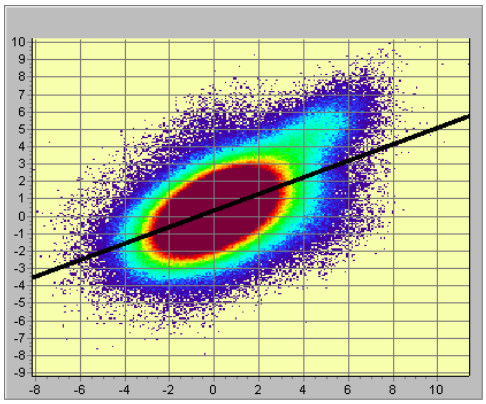

b)

Figure 4. False color composite calculated from HIS, a) I=ERS (99) after median filtering 5x5, b) I=ERS (99) after Fourier transformation using cutoff frequency of 128 on Fig.5b).

4 TIME CHANGES ON RADAR IMAGE

Radar data were collected in summer time of 1996, 1997 and 1999, 25th of June, 15th of July and 20th of July respectively. Stage of vegetation was of course different during the imagery of each image. Crops of 25th of June might be green with rough surface of the field. The same field on 20th of July might be a bare soil after harvest. So the main goal of image processing should be considering the surface roughness. Surface roughness could be estimated from, the images recorded in visible spectrum range: panchromatic or color aerial photographs or satellite images on the one assumption, that they and radar are recorded as simultaneously as possible. Such a data were collected only for year 1999, but we would like to compare the three ERS images in spite of that. We calculated differences between ERS(96)-ERS(97) and ERS(99)-ERS(97) to analyze the influence of the flood in year 1997. On the Fig. 5 regress analyze between the image differences, are shown.



Be aware the influences of surface roughness we would like to calculated also difference ERS (99-96) to see changes on radar data. The changes “in minus” mean that radar signal in year 1999 was greater then in year 1999, changes “in plus” against mean that signal in 1999 was smaller then in year 1996. On each ERS image the roughness was varying depending on field cover. Difference of the images recording date is about 1 month and we assume the similar field roughness for each field on the two ERS images. So the influence of surface roughness could be removed during differencing and the result can be interpreted as an influence of soil moisture.

Figure 5. Regress analyze, ERS (99-97)=0.49 ERS (96-97) + 0.34, r = 0.52.

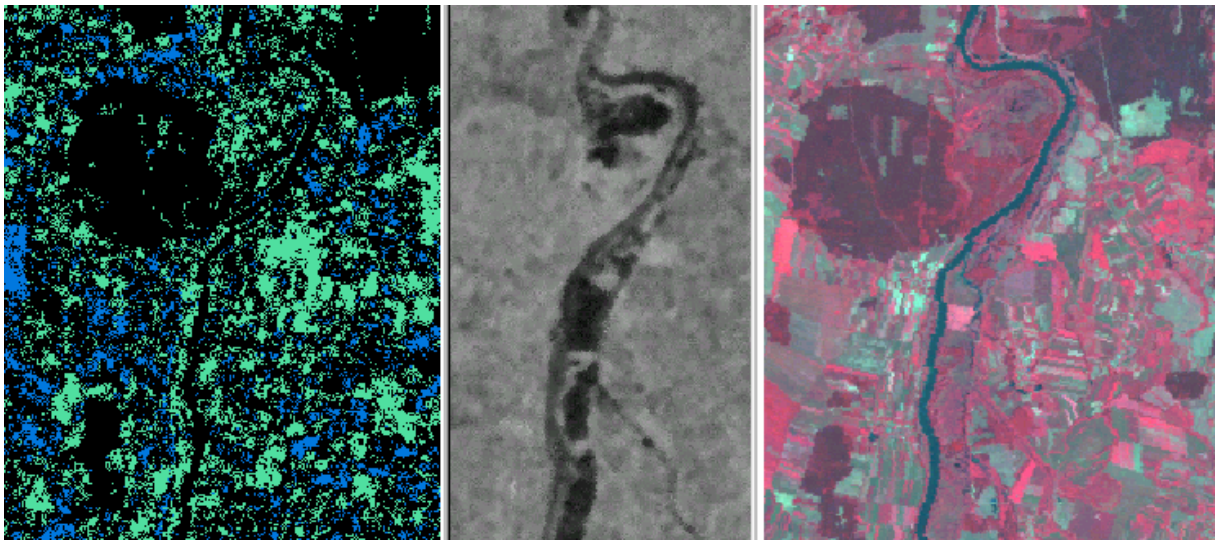


Figure 6a) ERS (99-96), blue-changes “in plus”, cyan – changes “in minus” , b) ERS (97), c) TM234.

5 SOIL MOISTURE DETECTION

Some part of the project contained image data processing for soil moisture evaluation. At the beginning Tasseled cup method, basing on visible and infrared channels of LANDSAT TM was used and so called: *brightness, greenness, wetness* (Fig. 7) images were generated.

Generally, determination of soil moisture is not an easy task. From the literature are known many methods for soil moisture estimation on the base of non radar spectral range. Thermal inertia seems to be a good parameter for wetness assessment. Thermal inertia modeling is a method combining information from visual and thermal infrared spectral range. LANDSAT TM was used as an input data to thermal inertia modeling (Fig. 8). In the thermal inertia model albedo and maximal diurnal temperature difference images are needed. Albedo was calculated from TM 3. Maximum of the diurnal temperature differences was estimated from TM6, converted to temperature values. Because minimum temperature was not possible to obtained (LANDSAT TM from the early morning was not bought) was neglected. In thermal inertia modeling the replacement of maximum diurnal temperature differences by maximum diurnal temperature distribution does not affect the results very much, as we stated in our early research, (Mularz 1995).

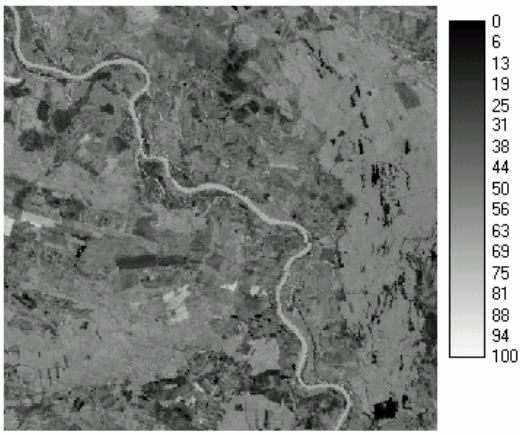


Figure 7 Effect of tasseled cup transformation- *wetness*

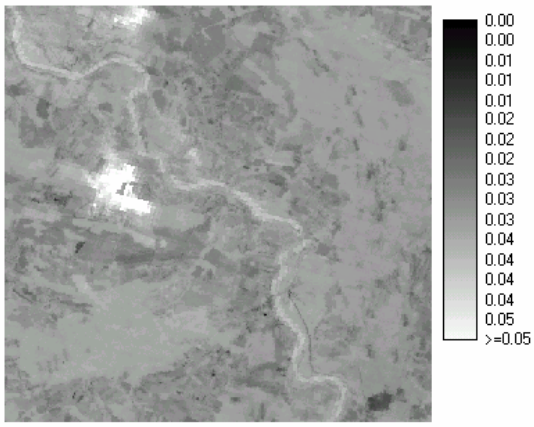
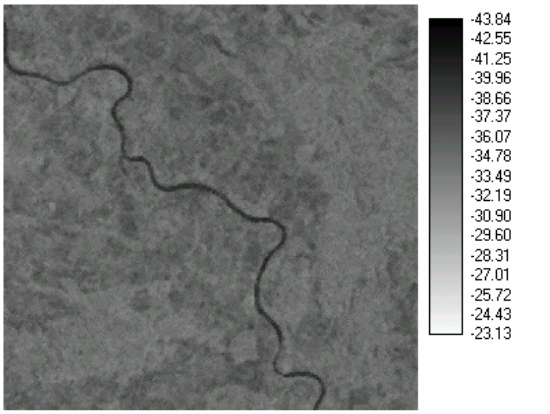


Figure 8 Thermal inertia image.



As one can see on Fig. 7, 8, 9 there are general similarity between value of the images of thermal inertia, wetness and radar. Many details are easy to noticed on the wetness image even that radar image has better resolution. Thermal inertia image is also interpretable but is very influenced by atmospheric conditions for examples clouds (center-left and upper part of Fig. 8). Very light part of the thermal inertia image means not very moist soils but only clouds. It is caused by thermal image, because clouds are very cold. All the three images, are governed by soil moisture but not only. Detailed interpretation could be performed in range of special land cover. Therefore unsupervised classification was made extracting 5 classes: background, crops (1380km^2), rangeland (680km^2), bare soils (500km^2), forest (600 km^2).

Figure 9. ERS (99) calibrated to backscattering values.

The quantity analyze was made for crops and rangeland. About 180 km^2 of rangeland was more wet in year 1999 in compare to year 1996, against 90 km^2 was dryer then before. About 560 km^2 crops fields was more wet in year 1999 in compare to year 1996, 360 km^2 was dryer.

6 COMPARISON BETWEEN REMOTE SENSING DATA AND IN SITU MEASUREMENTS

The last part of our research was concerned to compare *in situ* measurements on the test fields with the remote sensing data. Unfortunately we have only 7 control fields, that is insufficiently to make some statistic analyze. We present the results for visual interpretation as a "tie points". On the Fig.10 on false color composition: TM754 test control field are overlaid, on Fig. 11 the spectral characteristic of the test fields are presented and on Fig. 12 the variation between DN from 7 TM channels with soil moisture are shown. The correlation are generally poor expect channel TM4. Average values of *brightness* and thermal inertia on the area of each test fields were automatically extracted from *brightness* and thermal inertia images. On the Fig 13 correlation between *brightness* and thermal inertia and soil moisture are presented.

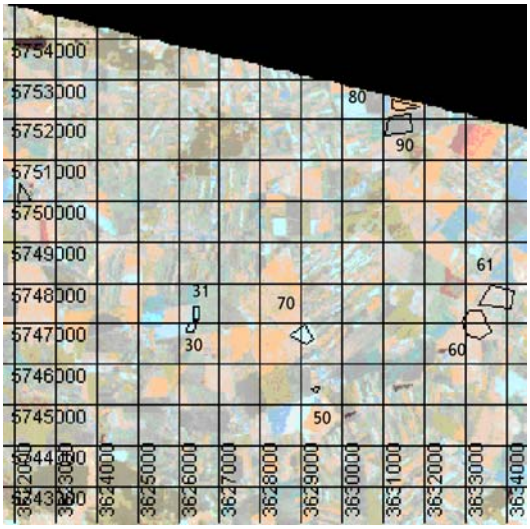


Figure 10 Test control fields on FCC (TM754)

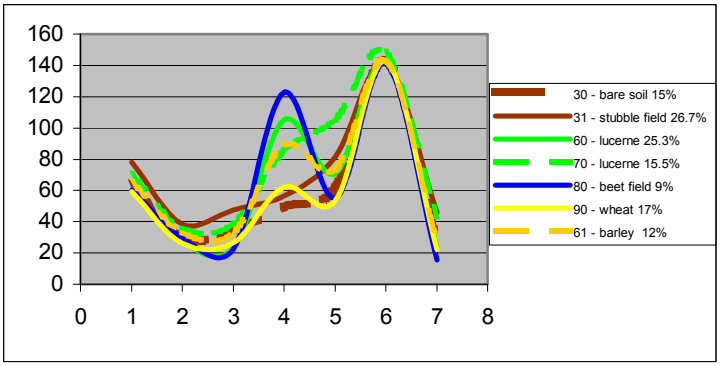


Figure 11 Spectral characteristic of test fields.

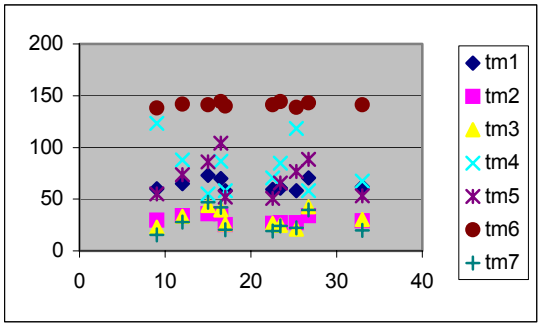
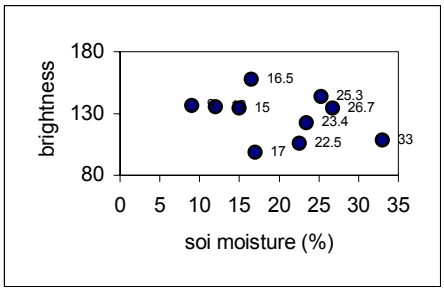
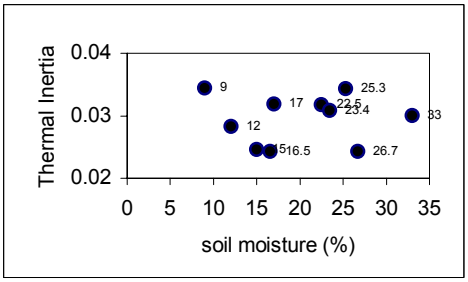


Figure 12 Variation between DN from 7 TM bands with soil moisture (%)



a)



b)

Figure 13 Correlation between *brightness* a) and thermal inertia b) and soil moisture for test fields.

5 CONCLUSIONS

The focus of this study is on processing of the radar multitemporal data for soil moisture assessment over the flooding area. An optical LANDSAT TM imageries could be effectively used to merge the ERS-2.SAR images for enhancement the land-use/land-cover categories and also for the thermal inertia modeling soil-moisture detection of the bare soils based on the TM6 thermal LANDSAT band and *in situ* temperature measurements. Testing of filtering techniques bases on the Fourier analysis of the radar imaging data to remove the speckle noise was special emphasized. The best results was obtained for Fourier transformation cutting 5% of the highest frequencies, but is time consuming method. The influence of the vegetation cover, suppressing the sensitivity of the backscattering signal to soil-moisture is a possible extent ion of the study are presented. The merging method of the LANDSAT TM and ERS.SAR data provide also a good visual interpretability as judges by the authors.

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REFERENENCES

Dubois P.C., J. van Zyl Engmann, 1995. Measuring Soil Moisture with imaging Radars, IEEE Trans. Geosci. Remote Sensing, Vol. 33, No 4, pp 915-926.
Mularz S. 1996. „ Remote sensing monitoring of the open-pit mine area. University research project No. 10.150.92
Mularz S., K. Dąbrowska-Zielińska, M. Gruszczyńska. 2000. Using Radar Satellite images ERS-2 SAR for Soil Moisture Mapping over Flooded Areas. Proceedings 28th international Symposium on Remote Sensing of Environment "Information for sustainable development", 27-31 March 2000, Cape Town, South Africa.
Wagner W., 1998. Soil Moisture Retrieval from ERS Scatterometer Data, Ph. D Thesis, the Wien University of Technology, Austria.
Wegmuller W., C.L. Werner, D. Nuesh, M. Borgeant, 1995. Land-surface analysis using ERS-1 SAR interferometer, ESA-Bulletin, 81.Wigneron J.-P., T. Schmugge, A. Chanzy, Calvet Y.Kerr, 1998. Use of passive remote sensing to monitor soil moisture , Agronomia, Vol. 18, pp.27-43.