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APPLICATION OF ENVISAT MERIS, TERRA ASTER AND MODIS DATA FOR CROP YIELD MODELING

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Due to shortage of precipitation in Poland especially during growing season, harsh winters, spring temperature fluctuations and droughts, the yield of many crops varies. The average yield of main crops in Poland is much lower than in majority of West European countries but big areas under cultivation locates Poland on sixth position in Europe in production of wheat, second in production of rye, second in production of potatoes and fourth in production of sugar beet. Because of natural and structural changes in Polish agriculture there is a great need for precision monitoring of crop yield and production. The data used in monitoring of crops development and in modelling of crop yield has most often come from satellites images.

The Remote Sensing Department (OPOLIS) of the Institute of Geodesy and Cartography has carried out programmes on applications of various information derived from satellites data and ground spectral measurements for vegetation monitoring. The specific objectives of the works included validation of data provided by the new scanners installed on ENVISAT and TERRA satellites to describe condition of vegetation and to implement of these data in crop yield model.

SATELLITE DATA

In many projects performed in the Remote Sensing Department of the Institute of Geodesy and Cartography on assessment of vegetation and crop yield prediction, the indices derived from NOAA satellite images have been applied so far. NOAA satellite images have some advantages in application to characteristic of vegetation, but some disadvantages as well. One of them, especially important in the case of Polish agriculture, is a size of pixel. Fragmentation of arable land in Poland makes that one NOAA image pixel covers several arable plots with different crops. That is why images acquired by NOAA satellite have application limited to this part of the country where are small fields.

Application of data provided by new satellites taking high-resolution images seems to be promising for determination of crop structure and crop yield assessment. In the current works performed in the Remote Sensing Department of the Institute of Geodesy and Cartography the images acquired by MERIS on ENVISAT and ASTER and MODIS on EOS-TERRA satellites have been used.

The push broom imaging spectrometer MERIS is a programmable, medium-spectral resolution, imaging instrument operating in the solar reflective spectral range. Fifteen spectral bands can be selected by ground command, each of which has a programmable width and a programmable location in the 390 nm to 1040 nm spectral range. The ground resolution of the images is 300 m.

ASTER and MODIS are scanners installed on EOS-TERRA sun-synchronized satellite. The Advanced Space borne Thermal Emission and Reflection Radiometer ASTER is the only high spatial resolution instrument on the EOS-Terra platform. It obtains high-resolution images of the Earth in 14 different wavelengths of the electromagnetic spectrum, ranging from visible to thermal infrared light. The scanner acquires images in four bands in VNIR with spatial resolution of 15 m, five bands in SWIR of spatial resolution 30 m and five bands in TIR of 90 m resolution. Swath wide of ASTER is 60 km.

The Moderate Resolution Imaging Spectroradiometer MODIS acquires images in 36 spectral bands with ground resolution from 250 to 1000 m. The spectroradiometer acquires images in two bands of VNIR with ground resolution 250 m, five bands in VNIR and SWIR with ground resolution 500 m, and 29 bands in SWIR and TIR with ground resolution of 1000 m. Swath wide of MODIS is 2330 km.

The spectral width of particular bands of these radiometers differs both in bandwidths and the center wavelength (Fig 2). MERIS spectral bands are very narrow. They are located in visible and near infrared part of spectrum. Spectral bands of MODIS are somewhat wider and cover visible, near infrared and short waves infrared part of spectrum. Their location corresponds to the characteristic points of green vegetation reflection curve. Spectral bandwidths of ASTER are much wider. Following the analysis, the particular bands of these three sensors were chosen for classifications of vegetation and for derivation of indices describing vegetation. In this article we are presenting the classification done using ASTER data.

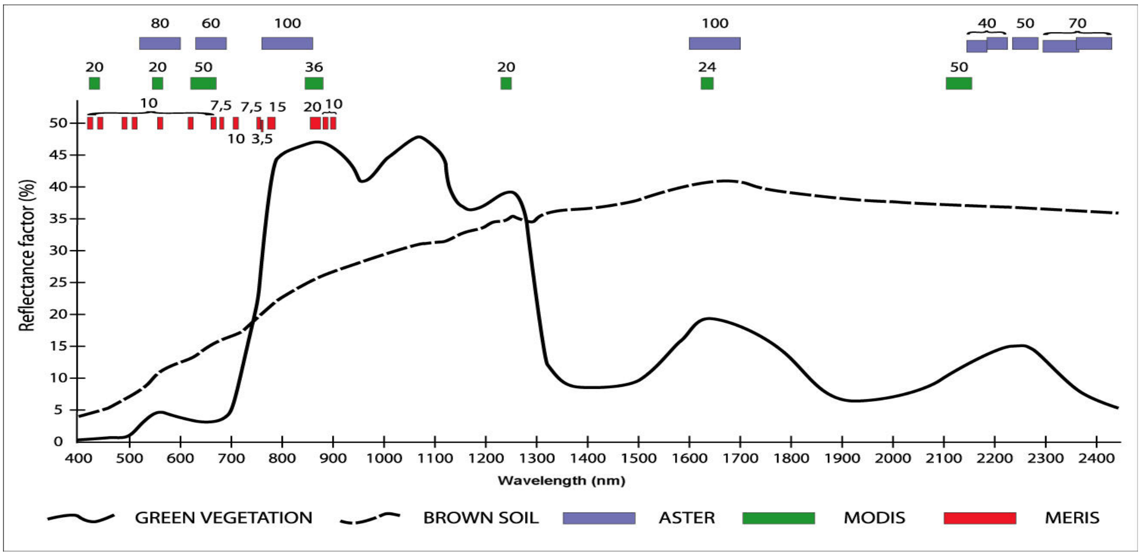

Figure 1: The reflection curve of green vegetation in VNIR and SWIR and distribution of ASTER, MODIS and MERIS spectral bands

The reflectance of crop in particular band from ASTER, MODIS and MERIS presents Fig 2. The reflection registered by three sensors slightly differs. Also, the band center values of particular sensors differ. The early time of acquisition for all three sensors was the 5th of May. At this time the crop conditions slightly varied. However the reflection of grass was always the lowest. This is explained that the grass at this time has lower leaf water content – 73% and lower chlorophyll comparing to winter wheat leaf water content (85%) and rape leaf water content 90%.

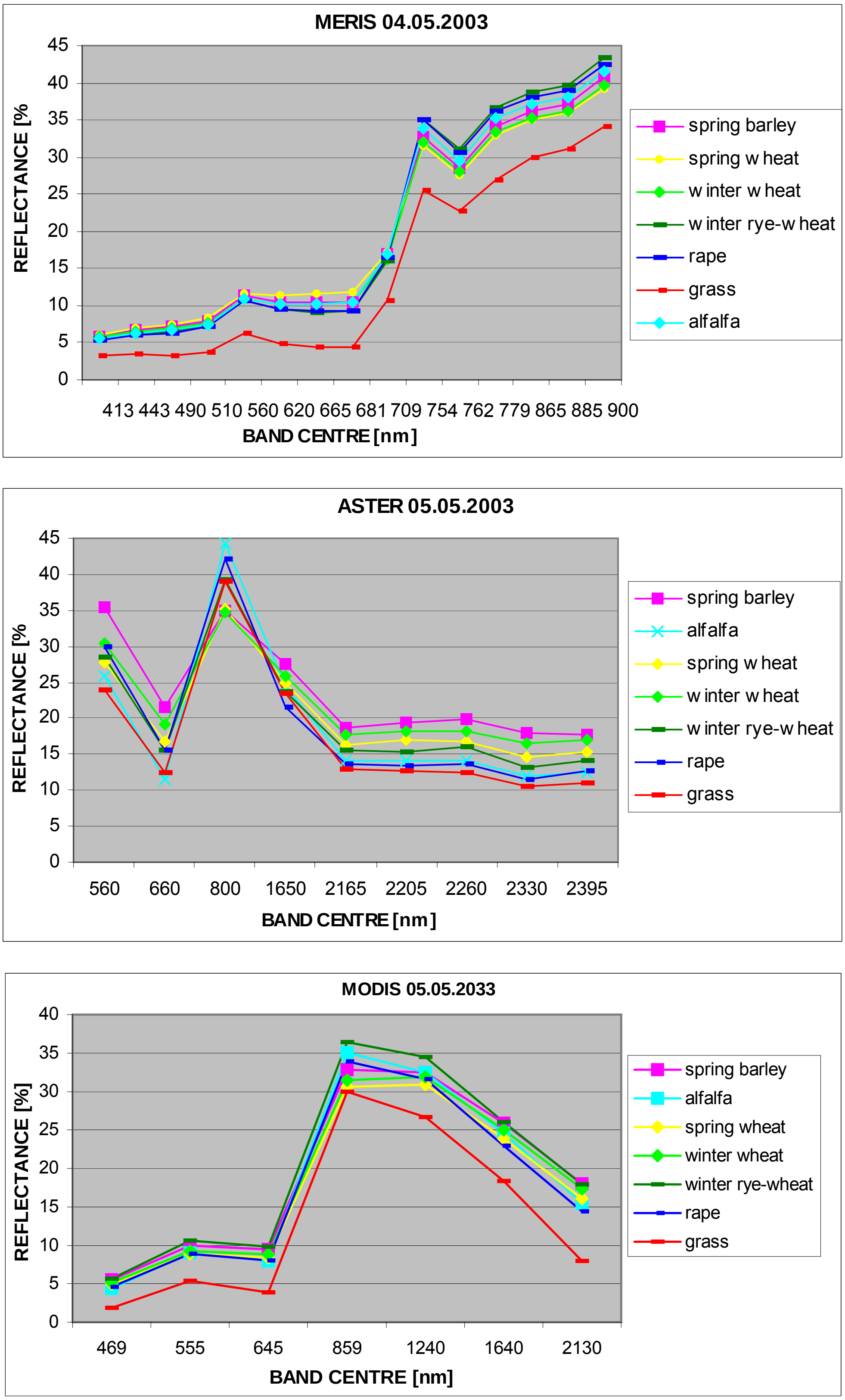

Figure 2: The reflectance of crops in particular band from ASTER, MODIS and MERIS

Crop identification

The test site in western Poland has been chosen for examination of usefulness of images taken by the new sensors in classification of crops. This area was covered by images acquired by ASTER, MODIS and MERIS sensors within a period of April through August 2003 and within growth season of 2004.

The images acquired by ASTER sensor are the images of the high spatial resolution with suitable spectral resolution for vegetation characteristic and that is why these data have been chosen for crop classification in the study area. The cloud free images obtained on 5 May 2003 and 26 September 2003 were used for supervised classification. For these classifications the following channels: 2 (0,63–0,69 μm), 3 (0,78–0,8 μm), 4 (1,60–1,70 μm), 5 (2,14–2,18 μm) and 7 (2,23 – 2,28 μm) were chosen and considered as the best. The resampling procedure to 15 m was done for the bands 4, 5 and 7. Six types of crops: winter barley, other winter cereals, spring cereals, grassland, alfalfa, rape as well as bare soil have been distinguished (fig. 3). Corn and sugar beet soon covered the bare soil. The classification procedure was repeated on the image of ASTER taken on 26 of September 2003 where corn and sugar beet have been identified (fig. 4).

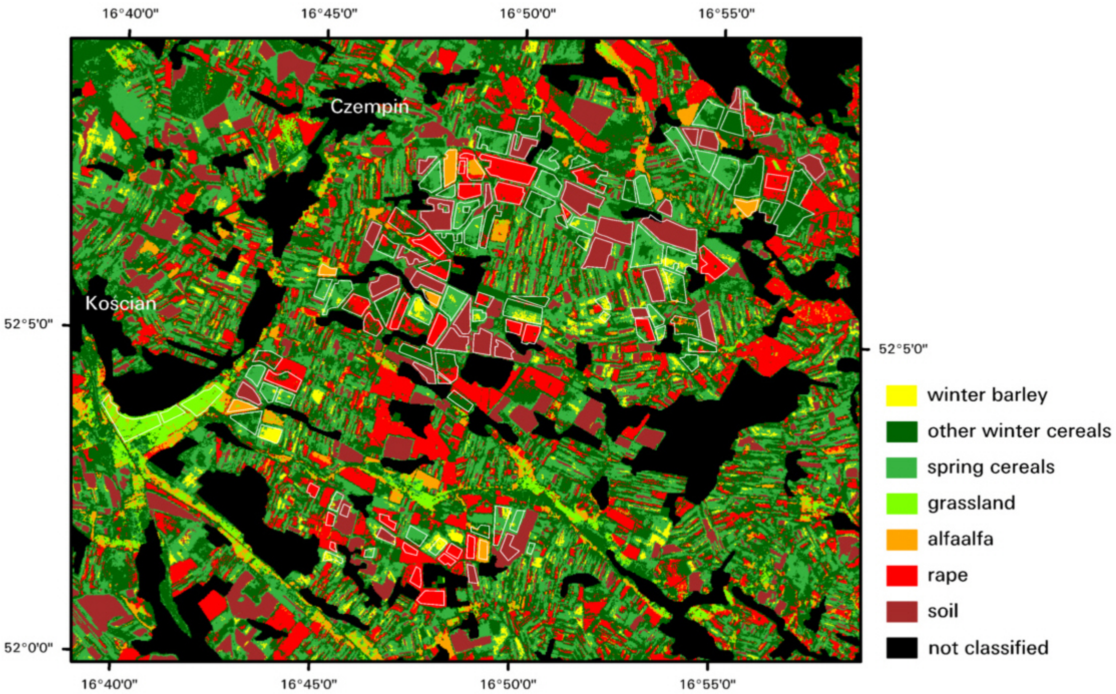

Figure 3: Crop classification based on ASTER image taken on 5 May 2003. The bands 2 and 3 in VNIR as well as bands 4, 5, 7 in SWIR have been used in supervised classification.

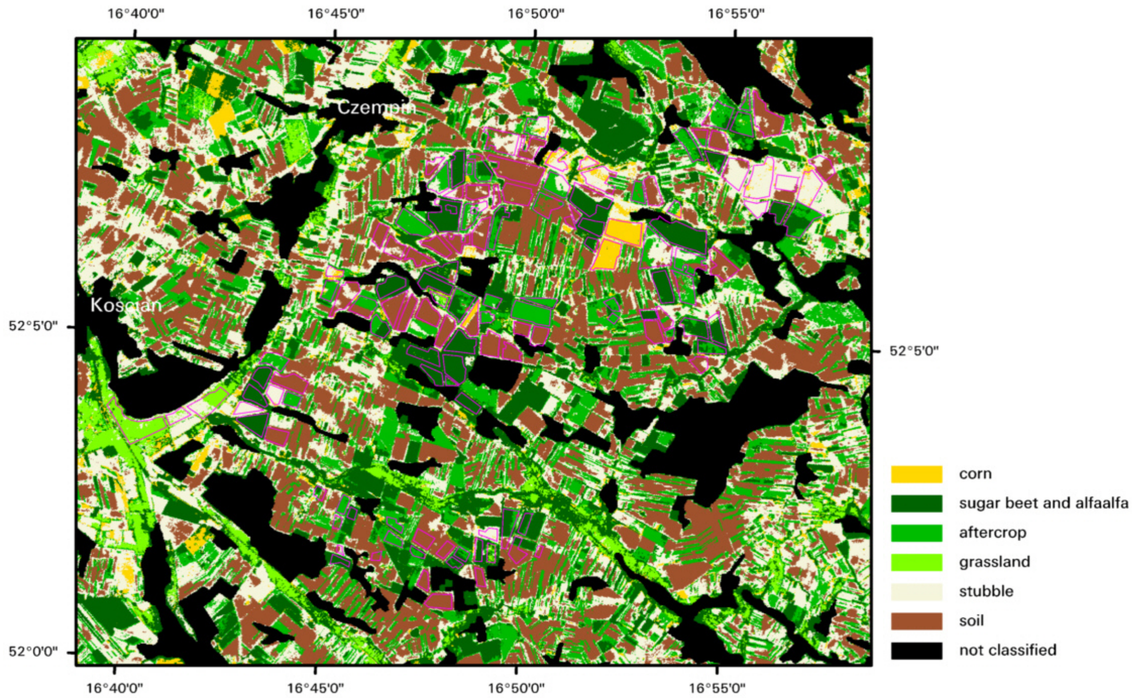

Figure 4: Crop classification based on ASTER image taken on 26 September 2003. The bands 2 and 3 in VNIR as well as bands 4, 5, 8 in SWIR have been used in supervised Classification

Satellite Derived Vegetation Indices

At the time of satellite images acquisitions the extensive field measurements, which included: volumetric soil moisture [%] (bare soil and soil covered by crop), Leaf Area Index, height of the vegetation, wet and dry biomass, vegetation water content (VWC), albedo, amount of ears per m2, amount of seeds in ear, were conducted at the test site. Also, the information concerning the crop type (winter and spring wheat, corn, barley, sugar beet) its actual development stage and growing conditions were recorded. These measurements were needed for statistical analysis of parameters with satellite-derived indices. In this article only data for Leaf Area Index have been used in order to find the relationship between measured and satellite derived indices. The results of meteorological observations stored in the agrometeorological databases have been used in the model for validation of plant growth conditions and net primary production.

The assumption was done that the reflection registered by MODIS in infrared narrow band of 1240 nm combined with reflection registered by MODIS in other narrow bands will be the best data merging for derivation of vegetation index which characterise LAI values.

Therefore the best correlation between LAI and the vegetation index have been examined. For the examination the narrow bandwidth of 50 nm (red); 35 and 20 nm (infrared) were taken. Fig. 5 presents the correlation between Normalized Vegetation Index (NDVI) and LAI.

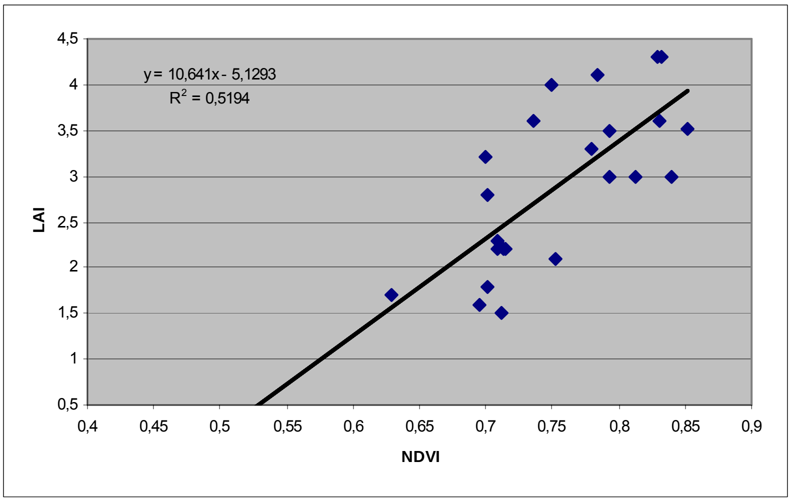

Figure 5: The relationship between NDVI and LAI

The assumption was made that the index representing canopy water content will represent LAI. GAO (1996) applied Normalized Difference Water Index (NDWI) (R860-R1240)/(R860+R1240) where R860 and R1240 is the reflectance in the corresponding wavelength (nm). The reflectance in 860 nm responses for biomass density and reflectance in 1240 nm responses to water absorption. It was proved that Simple Ratio Water Index (SRWI) R860/R1240 responses to leaf structure, dry matter content and LAI (Zarco-Tejada and Ustin 2001).

In this study the index combining NDVI information about the biomass and the index which give information about vegetation–water content was introduced and named Vegetation Water Index (VWI). It was calculated using the formula:

VWI = NDVI/SRWI

The next step was to examine the relationship between VWI and LAI. The Fig. 6 presents the relationship between VWI and LAI.

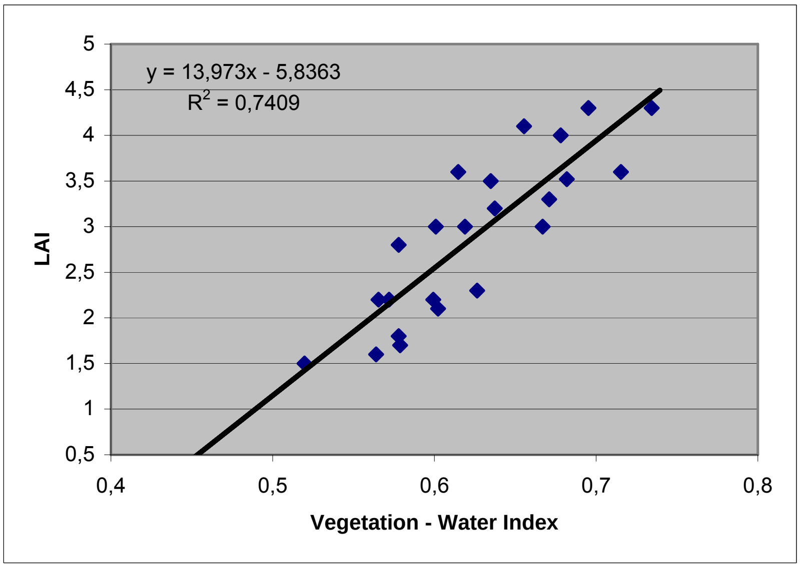

Figure 6: The relationship between Vegetation Water Index and LAI

The precision of LAI calculations is very important in order to obtain precision in crop yield forecast. LAI was calculated using VWI derived from MODIS data obtained from images taken on 5 May 2003 and on 6 June 2003. The values of LAI for winter wheat feeded the model of crop prognosis. The results depend on the precision of LAI calculations. Figure 7. presents the distribution of LAI for classified crop (see Fig 2).

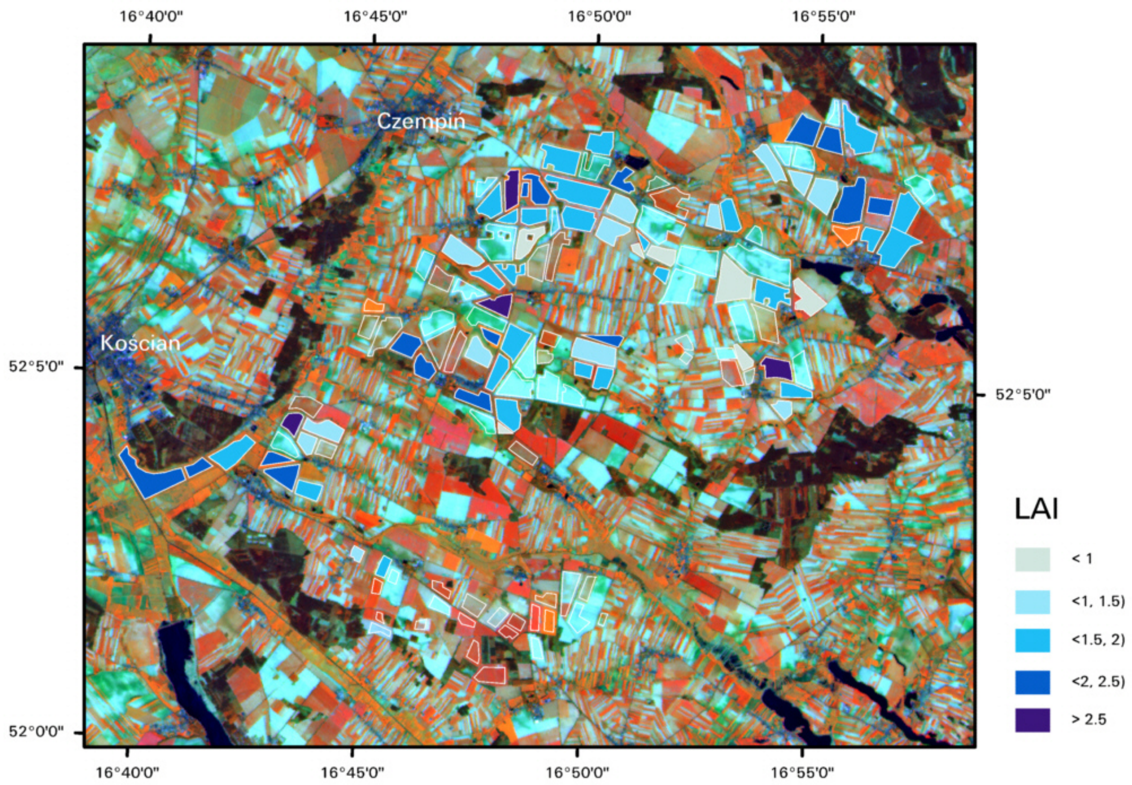

Figure 7: LAI calculated for crops identified on ASTER image

The Crop Prediction Model controlled by remote sensing data

The PROtotype Biomass and Evaporation (PROBE) model was developed for simulation of daily plant growth and evaporation (E) rates in natural and vegetated ecosystems (MAAS et al., 1992). The inputs to the model are basic meteorological information, periodic measurements of Leaf Area Index (LAI) and evapotranspiration (E). The model uses an interactive approach with two sub-models - a vegetation growth (VG) sub-model and soil water balance (SWB) sub-model, where the estimate of LAI from the VG sub-model is used in the SWB sub- model to calculate E. In turn, the estimate of E is used in a rerun of the VG sub- model to refine the estimate of LAI. (Dabrowska–Zielinska et al., 2001). This model was tested on meteorological data as mean daily temperature and total daily solar radiation.

The Fig. 8 presents the model where LAI derived from remote sensing is feeding the model. In this work the evapotranspiration was not calculated.

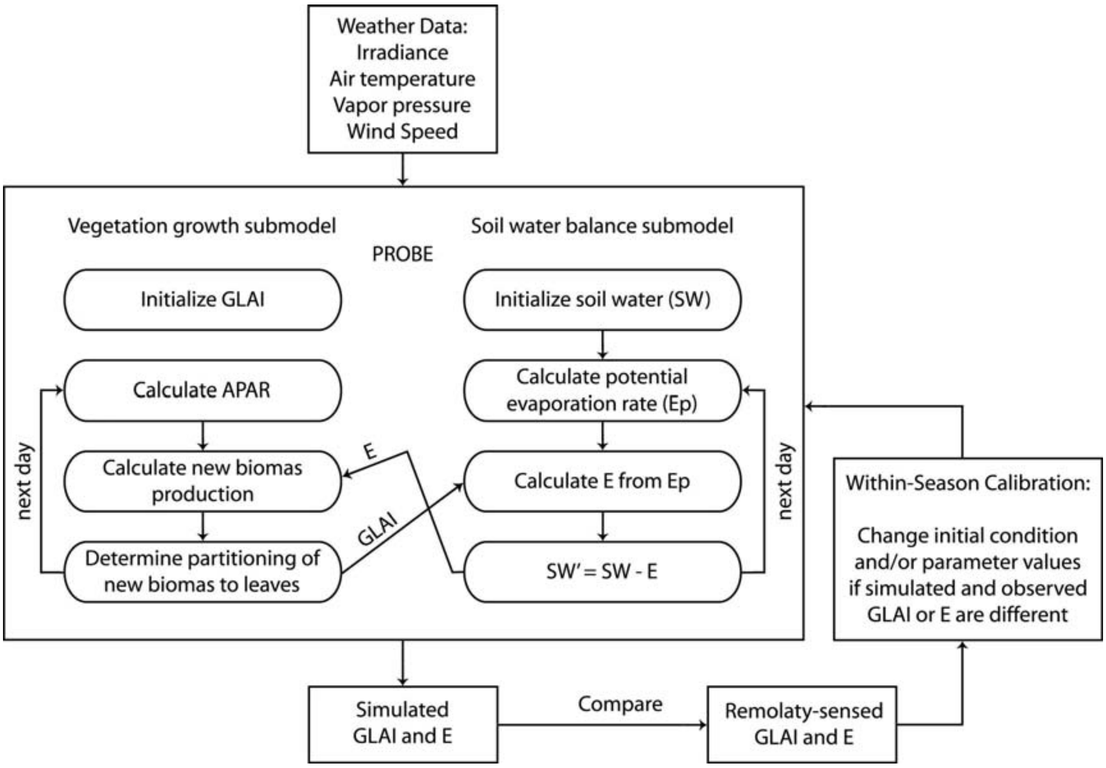

Figure 8. PROBE Simulation Model

Calculated LAI values are included in the simulation model (Fig 9).

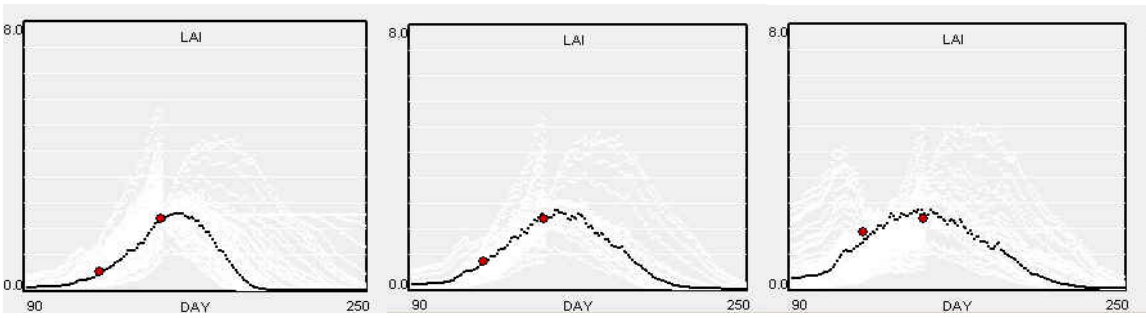

Figure 9. The simulation of LAI values from initialises LAI to harvest for winter wheat

The simulation of LAI values differs (Fig. 9). The assumption was done that the calculated LAI values for the May 5 2003 differed and were 0.5, 0.8, and 1,8 respectively. The simulation of LAI values done by the model for the crop during the growth differed significantly. Therefore, the precision of calculations of LAI has to be high. The winter wheat yield is calculated as a function of accumulated LAI values from initial LAI value to the LAI maximum according to the formula:

$$\text{Yield} = f\left(\sum_{LAI\min}^{LAI\max} LAI \right)$$

CONCLUSIONS

Application of data acquired by different sensors which register reflected radiation in many spectral bands gives a great opportunity to examine vegetation growth conditions and crop yield estimates with a higher accuracy. The registered reflection in narrow bandwidth in infrared spectrum could be used for derivation of new indices, which reflect water content and structure of vegetation. Derived Vegetation Water Index calculated on the basis of MODIS data correlated well with Leaf Area Index.

The model applied for crop yield prediction requires precise information about type of the crops and their specific parameters. One of them is LAI value of particular crops. This parameter was calculated on the basis of data provided by new sensors. Crop classification done on the basis of ASTER 15-m resolution images enabled identification of crops with accuracy sufficient for application in the model.

Due to weather conditions in Poland there are possibility of getting data from MODIS, ASTER or MERIS only few times during the growth season. Therefore application of model that requires only a few data characterising crop conditions is extremely important. Applied model gave the exact information about the yield of particular cereals.

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