The System for Early Natural Disasters Monitoring in Agriculture

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Abstract - Droughts and floods are one of the major disasters affecting agriculture production in Poland. Data from optical and microwave satellite images and in-situ measurements of various soil-vegetation parameters have been collected and analyzed to develop the system for early detection of natural disasters, monitor their development and mitigate their impact on the agri-environment. The study include: assessment of crop growth conditions and elaboration of the method for drought detection and its influence on crop yield, detection of flood hazard, and determination of area with excessive moisture. Created system include low spatial but high temporal resolution optical NOAA.AVHRR, TERRA.MODIS, and SPOT.VEGETATION data for drought detection and monitoring, as well as high resolution microwave ERS.SAR and ENVISAT.ASAR data for the assessment of flood extend and the expand of excessive soil moisture. Crop growth conditions were analyzed on the bases of vegetation indices derived from visible and thermal infrared channels.

Keywords: Optical and microwave satellite data, crop growth conditions, drought, flood, excessive soil moisture.

1. INTRODUCTION

The study carried out for Poland covers the period 1997-2010. Poland is situated in the transient oceanic – continental climatic zone what causes the significant weather variation. During the last years frequent weather anomalies caused natural disasters were observed. Discovering areas of drought, floods, and excessive soil moisture expansion has become very important task demanded by farmers and local governments. Remote sensing offers quick, actual, and spatial information on such disasters by monitoring crop growth conditions and yield forecast. The yield and production of crop is being reduced significantly by drought or flood. The great demand of such information caused the development of the system for early natural disasters monitoring in agriculture, which is based on vegetation indices and models derived from optical and microwave satellite data. NOAA.AVHRR, TERRA.MODIS, and SPOT.VEGETATION provide regular repetitive observation in optical spectrum; ERS.SAR, ENVISAT.ASAR and ALOS.PALSAR give information in microwave spectrum. The optical images have been used for developing the threshold for drought detection. The Normalized Vegetation Index (NDVI), Cumulated NDVI (CNDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) have been computed for agriculture area for each ten-day period of the year. The flood extension has been determined using microwave images and the flooded area has been overlaid on land use map in order to calculate the land use category and acreage of flooded area. The difference maps of backscattering coefficient σ° have been composed (each of them from two images of the same period but different year) and applied for the assessment of excessive soil moisture.

2. DROUGHTS

Droughts are one of the major natural disasters affecting agriculture production in Poland. Almost each year the droughts occur, usually in different parts of the vegetation season, and in different locations. The yield reduction due to drought depends on the type of crop and its development stage. In Poland, the losses of agricultural production caused by weather anomalies can reach even 40% of cereals yield. Proper management of agriculture requires rapid data about crops growth conditions and prognosis of yield reduction due to droughts. Remote sensing methods play a significant role, because of spatial and temporal coverage capability. Spectral reflectance signatures taken in the optical spectrum are very useful for such applications, and a variety of information from optical sensors can be applied for estimating vegetation growth conditions. However, the acquisition of optical data is often hampered by unfavourable weather. Composition of indices for every 10 days of vegetation growth diminishes the influence of weather conditions. NDVI, CNDVI, VCI, and TCI indices derived from NOAA AVHRR, TERRA.MODIS, and SPOT.VEGETATION data have been composed for 10-day period of the year for arable land taken from CORINE Land Cover database. It is well known that NDVI fluctuates due to favourable or unfavourable weather and environmental conditions, (Kogan, 1997; Dabrowska–Zielinska et al. 2002a). This variability of NDVI was estimated relative to the maximum and minimum (max/min) intervals of NDVI as the Vegetation Condition Index (VCI):

$$VCI=100[(NDVI-NDVImin)/(NDVImax-NDVImin)] \quad (1)$$

where: NDVI, NDVImax, and NDVImin are decade NDVI, its multi-year absolute maximum, and minimum.
Following the assumption that NDVImin represents poor crop growth conditions and NDVImax represents good crop growth conditions, the high values of VCI represented good conditions while VCI low represented poor, dry conditions.
On the basis of temperature, the index TCI has been calculated from temperature values derived from thermal channels (Kogan, 1997) for each decade for vegetation growth period:

$$TCI=100 (Btmax - BT) / (Btmax - BTmin) \quad (2)$$

where: BT, BTmax and BTmin are the smoothed weekly BT, its multiyear absolute maximum and minimum (respectively) derived from NOAA, channel 4 data.
The high TCI values indicate low temperature and favourable crop growing conditions especially at the second part of the season, while low TCI values indicate dry conditions, unfavourable for development of crops during summer. Low TCI values during the maximum growth of vegetation indicate stress in crop development expressed by high values of BT close to maximum for this period (Dabrowska-Zielinska et al., 2002a).
The CNDVI index was calculated as cumulated values of NDVI.
Figure 1 shows the values of cumulated NDVI at each 10-day period of the year. Cumulating starts since the beginning of April, when vegetation starts to grow. In general, the highest values of CNDVI were at the years: 1998, 2004, and 2009; the lowest at the years: 2003, 2006, and 2000. Every year, time of particular crop phonological stage differs, as the start of vegetation season occurs at the various time.
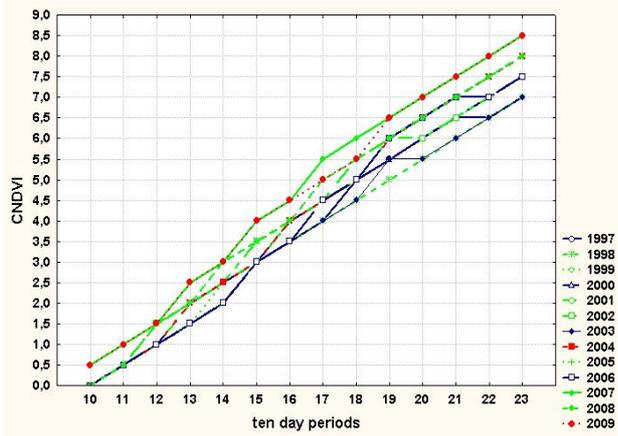
Figure 1. Cumulated values of NDVI – CNDVI versus ten day periods of the years 1997 – 2009.

It was noticed that when crop started to grow, index CNDVI reaches value of 0.5 usually in decade 11, but at the years 2005, 2007, and 2009 vegetation started to grow earlier i.e. at the 10 decade of these years. It was considered that index CNDVI represents the phenological stage of vegetation growth, and conditions of crop growth. Based on this hypothesis it was necessary to consider the crop growth conditions at particular phenological stage instead of taking constant decade of the year. Through modeling, it was proved that crucial time for yield forecast is both, when CNDVI equals to 0.5 (start of vegetation growth) and reach value of 4. As we see in Figure 1 the time when CNDVI reached 4 was in 2009 at the decade 15, in 2000 at 16 and in 2003 at 17. The following model for yield prediction has been elaborated: Model = f(VCIn, TCIn). If CNDVIn >0.5 then VCIn from this 10-day period is taken, if CNDVIn > 4.0 then TCIn from this 10-day period is the input to the model. Index VCI at the beginning of the crop development when CNDVI equals 0.5, characterizes well the vegetation growth. Later, when CNDVI equals to 4, index TCI characterizes well crop-soil conditions as TCI seems to characterize better vegetation water stress. Figure 2 presents distribution of VCI values in particular NUTS3 regions when CNDVI was 0.5 at the years 2003 and 2009. For the year 2009 VCI values were the highest in all NUTS3 regions for the time when CNDVI was 0.5. For the year 2003 VCI values were the lowest at the time when CNDVI was 0.5. Figure 3 presents distribution of TCI values in particular NUTS3 regions when CNDVI was 4 at the years 2003 and 2009. In the year 2003, the TCI values for the time when CNDVI equals to 4 was low (<50) what was reached in decade 17 in most of the regions in the country. In the year 2009 TCI values were high and reached values of 50-80 in decades 16-17 when CNDVI equals to 4. From considered years of investigation (1997-2009), the year 2003 was the driest - TCI values were low and indicated the drought. The vegetation growth conditions for 2009 were good and with sufficient amount of moisture.
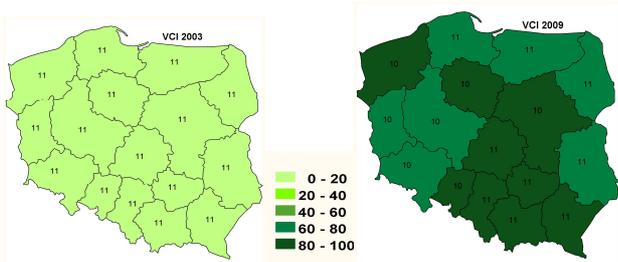

Figure 2. Distribution of VCI values for specific CNDVI=0.5.
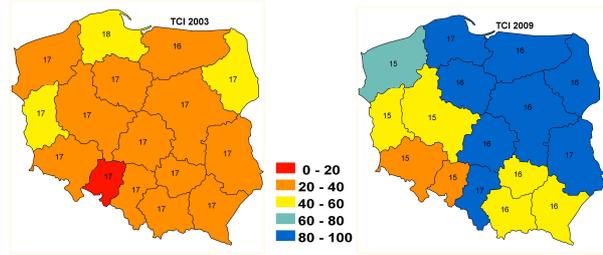

Figure 3. Distribution of TCI values for specific CNDVI=4.

Figures 4-6 present the results of modeling yield reduction (the difference between potential and actual yield) due to drought in 2003. The first prognosis has been done when CNDVI was 0.5, what occurred in April, Figure 4. The next prognosis has been done for decades 16-17 (end of May), Figure 5. Such early prognosis gives possibility to take decisions for mitigation of drought. The third map presents data of yield reduction published by Central Statistical Office (CSO) in October, Figure 6. The remote sensing prognosis of yield reductions in the regions follows CSO information (which in fact is given after the harvest), what is too late for proper management in agriculture.
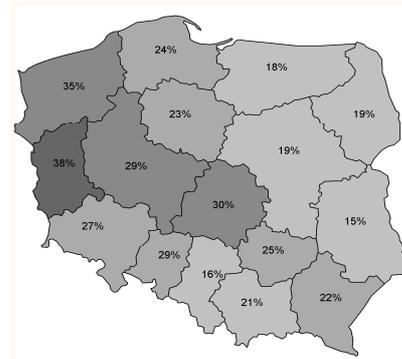

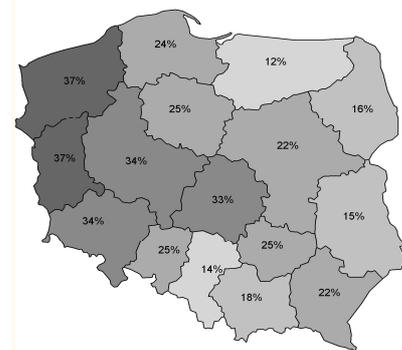Figure 4. Prognosis of yield reduction when CNDVI=0.5

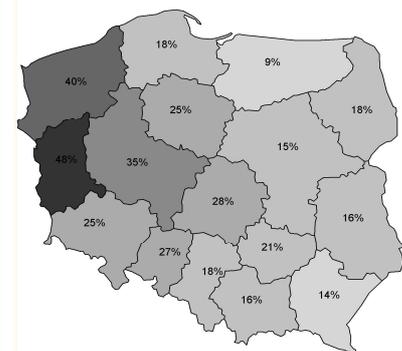Figure 5. Prognosis of yield reduction when CNDVI=4

Figure 6. CSO yield data (September).

3. FLOODS

The floods in 1997 and 2010 have been one of the biggest disasters in Poland in the last two centuries. Flood in July 1997 affected west part of Poland in the Odra Valley, Figure 7. Flood in May and June 2010 affected area along main rivers in Poland - Odra and Vistula. In both years European Space Agency has provided full set of satellite microwave images of ERS-2.SAR over the flooded parts of Poland which have been used for the derivation of flood extend. Classified flooded areas have been combined with CORINE Land Cover database and acreage of particular land cover classes under water has been calculated, Figures 8-9.
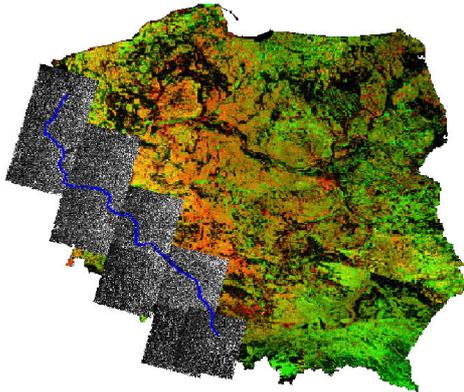

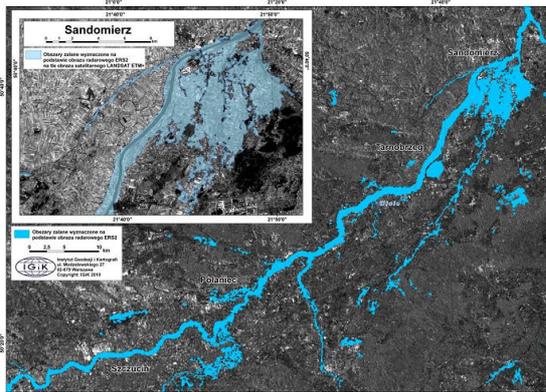Figure 7. Flooded area in July 1977 in Odra Valley derived from ERS-2.SAR images.

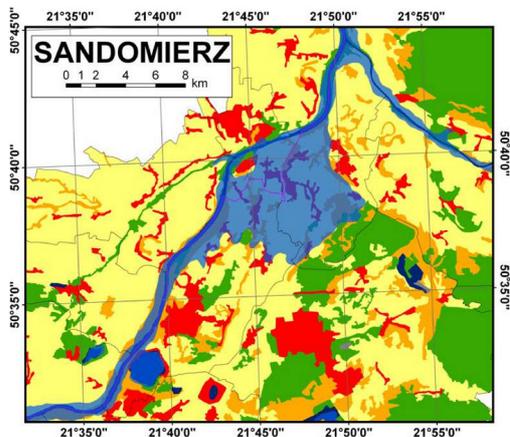Figure 8. Flooded area in May 2010 in Vistula Valley derived from ERS-2.SAR images.

Figure 9. CORINE Land Cover database overlaid with flooded area in May 2010 in Vistula Valley.

4. EXCESSIVE MOISTURE

The same amount of rainfall could not cause flood in the areas where there is the deficit in soil moisture, while in the other areas where soil has already been saturated and the storage capacity has become close to zero the same amount of rainfall causes flood. During the floods some agriculture areas are flooded and in some others soil moisture is very high exceeding the soil capacity. It is known that microwave backscatter is affected by dielectric and geometrical properties of plants Therefore in the study conducted in Odra Valley after flood in 1997 the following procedures have been applied using ERS-2.SAR and in-situ data:

1. Values of soil moisture for 15.07.1997 were calculated based on linear model obtained from the relation between backscattering coefficients ($\sigma°$) and soil moisture (Dabrowska-Zielinska et al., 2002b)

2. The differences between $\sigma°$ calculated for 15.07.1997 and 20.07.1999 (in-situ soil moisture measurements) and the differences between soil moisture for the same dates have been calculated for each of the measurement points (agriculture plots).

3. Obtained differences have been used to develop the method of mapping excessive soil moisture over flooded areas applying ERS-2.SAR images.

The assumption was done that the same type of crop covered agricultural fields in 1997 as in 1999 because of two-year crop rotation. It has been also assumed that the cereals have been in the same stage of development. It was considered that geometrical properties of plants were the same in July 1997 and July 1999. Figure 10 presents the values of soil moisture (% volumetric) calculated for the date 15.07.1997 and measured for the date 20.07.1999 for each of the agriculture plot. Figure 11 presents the values of $\sigma°$ calculated from ERS-2.SAR data for the same dates and plots.
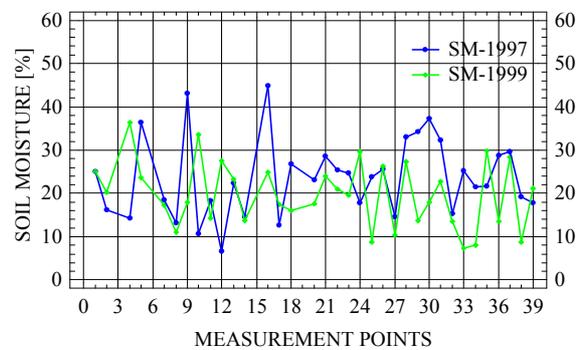

Figure 10. Soil moisture (SM) in the points of measurement for 15.07.1997 and 20.07.1999.
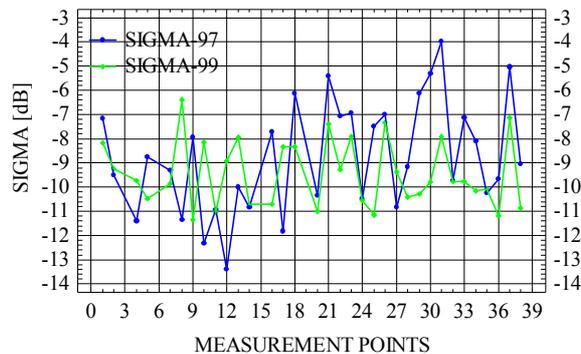

Figure 11. Backscattering coefficient (SIGMA) values in the points of measurement for 15.07.1997 and 20.07.1999.

As we see in Figures 10-11, the difference between σ° obtained from ERS-2.SAR images registered on 15.07.1997 and 20.07.1999 equals to 4 dB refer to the difference between soil moisture obtained from the developed models equals to 30%. These large differences of soil moisture occurred even for the distant areas from the river bed. For the derivation of the area with excessive moisture the assumption was done that changes in soil moisture can be assessed by calculation differences of backscattering coefficients σ° obtained from microwave images of the same region registered in different years at the same time of vegetation development. Figure 12 shows map where the class of excessive soil moisture was created from the differences of σ° (σ°15.07.97 - σ°20.07.99).

This simple method relies on the difference between backscattering coefficients of two microwave images registered in similar periods of vegetation development and has been applied for validation at the other areas to assess the soil moisture changes. The results, showing changes of soil moisture between May 2000 and May 1995 are illustrated in Figure 13. It can be observed that during this five year period in some of the areas the amount of moisture has diminished while in some others has increased.
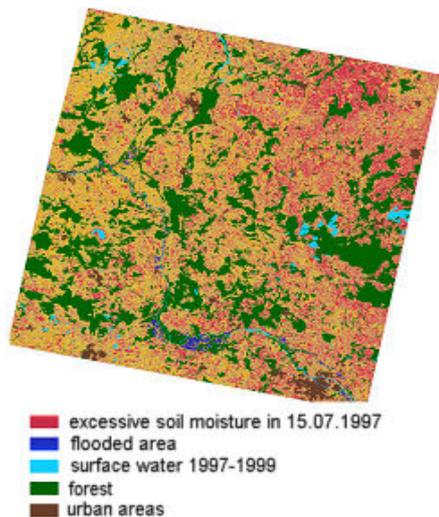

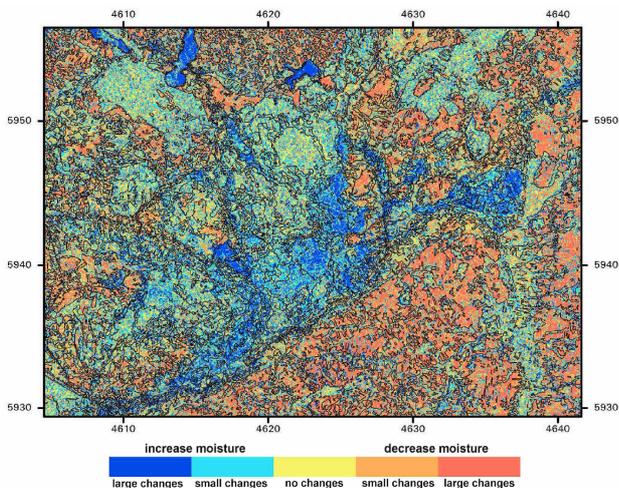Figure 12. Map of excessive soil moisture values close to the flooded areas.

Figure 13. Backscattering coefficient σ° difference map from ERS-2.SAR images showing changes in soil moisture.

5. SYSTEM FOR NATURAL DISASTERS MONITORING

The developed system for early natural disasters detection and monitoring was based on satellite images registered in optical and microwave spectrum and land cover classification. From optical images various indices were calculated and along with land cover database were used in modeling yield reduction due to drought. Results are presented on maps within areas of NUT3 regions or smaller administrative divisions. From microwave images flood extension and areas with excessive soil moisture are distinguished and mapped. Then, acreage of flooded area as well as acreage of particular land use classes taken from land cover database are calculated. The prognosis of crop yield/production reduction due to drought or flood can be assessed. Figure 14 presents flow chart of the developed system which is based only on remote sensed data.
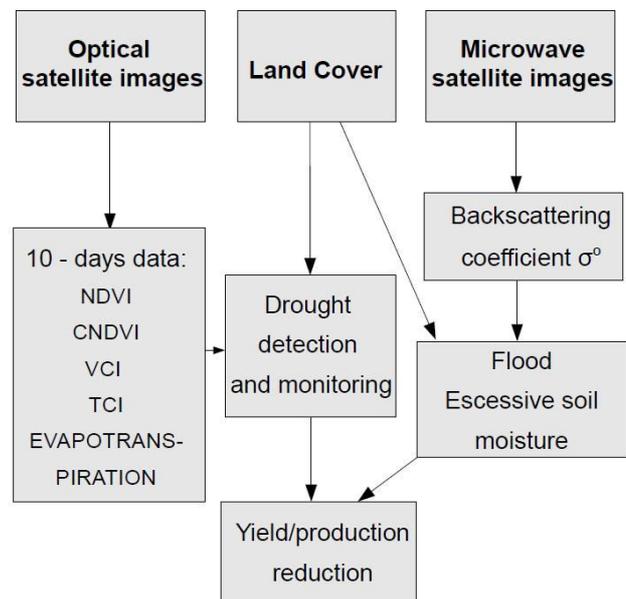

Figure 14. Flow chart of the developed system.

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