Agricultural Drought Monitoring Using Satellite-Based Products in Romania

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Abstract: In Romania, the complex agricultural drought is a climatic hazard inducing the worst consequences ever occurred in agriculture. The paper presents the results of recent studies developed in the National Meteorological Administration, in the framework of national and European R&D projects, regarding the use of satellite-derived products for agricultural drought monitoring. In this respect, different vegetation indices, biophysical parameters and physically-based vegetation state indicators have been used and tested in study areas over Romania, in order to monitor and assess the drought impact on crops, at different phenological dates. The main sources of satellite data and related products were provided by TERRA/AQUA-Modis, SPOT-Vegetation and Landsat TM/ETM+. By examining spatial and temporal patterns of satellite-derived products and comparing/correlating with the field conditions measured on site, it was determined that the NDVI, NDWI and NDDI vegetation indices, the leaf area index (LAI) and the fraction of absorbed photosynthetical active radiation (fAPAR) proved to be good indicators of the vegetation condition and relevant for the settlement, duration and intensity of the agricultural drought.

1 INTRODUCTION

Among the problems Europe is facing at the beginning of the third millennium, the reduction of water resources, their degrading quality and the occurrence of ever more severe and frequent droughts are of crucial importance.

In Romania, the complex agricultural drought is a climatic hazard phenomenon inducing the worst consequences ever occurred in agriculture.

The most frequent, the agricultural areas in Romania are affected by drought (7 mil. ha), water erosion and landslides (6.4 mil. ha), temporary water excess (4 mil. ha.) and compaction (2.8 mil. ha). Drought is the limiting factor affecting the widest surface as regards the crops. The area subjected to desertification, characterized by an arid, semi-arid or dry sub humid climate is around 30% of the total surface of Romania, being mostly situated in the South-Eastern (Dobrogea), Eastern (Moldavia), Southern parts of the Romanian Plain and in the Western Plain. These areas are prevailingly used for agriculture (around 80% of the total, 60% of which is arable land) (Romanian Ministry of Agriculture and Rural Development, 2008).

In the extremely droughty years the drought phenomenon may engulf the whole Romania's territory, as it happened more recently in 2000, 2003 and 2007. Large precipitation deficits were recorded in 1907, 1924, 1928, 1934, 1945, 1946, 1948, 1953, 1982 and 1983, then in 1992 and 1993 and more recently in 2000, 2001, 2003, 2007, 2009 and 2011.

In Romania, the use of remote sensing data in agriculture is a quickly developing and promising trend. For a better operative surveillance of the agricultural areas, starting with 2005, the Romanian National Meteorological Administration has implemented a dedicated service based on satellite-derived products. The satellite geoinformation products, elaborated by the Remote Sensing and GIS Lab, are included and analysed in the weekly Agrometeorological Bulletin issued by the Agrometeorological Laboratory.

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2 SATELLITE DATA USED

The main sources of satellite data which have been used are TERRA/AQUA-Modis, SPOT-Vegetation and Landsat TM/ETM+. Due to cloudiness, most of the satellite products are averaged in time, producing composites based on data from periods of 8-16 days.

The MODIS instrument is one a key instruments onboard the US satellites of the EOS series (Terra and Aqua). The bands most applicable for rangeland studies are bands 1-7 that gather data in the visible and infrared range at a 250 m and 500 m spatial resolution.

The SPOT VEGETATION S10 product (ten days synthesis) with 1 km- resolution is composed by merging atmospherically corrected segments (data strips) acquired over a ten days interval. All the segments of this period (decade) are compared again pixel by pixel to pick out the 'best' ground reflectance values.

PROBA-V is a new ESA satellite mission, launched in May 2013, with the main task of mapping land cover and vegetation growth across the Earth every two days. This mission is extending the data set of the long-established SPOT Vegetation, but with an improved 350m spatial resolution.

The LANDSAT TM/ETM+ imagery is a unique resource for global change research and applications in agriculture. The main ETM+ image features are: a panchromatic band with a 15 m-spatial resolution (band 8); visible (reflected light) bands in the spectrum of blue, green, red, near-infrared (NIR), and mid-infrared (MIR) with a 30 m-spatial resolution (bands 1-5, 7); a thermal infrared channel with a 60 m-spatial resolution (band 6).

3 AGRICULTURAL DROUGHT MONITORING USING SATELLITE-BASED RODUCTS

3.1 The vegetation indices

The vegetation indices (VIs) are among the most commonly used satellite data products for the evaluation, monitoring, and measurement of vegetation cover, condition, biophysical processes, and change. They have been used for over last decades in a broad variety of applications, including monitoring the effects of drought over regional, national, and even multinational areas (Basso et al., 2004). The VIs are an important tool for drought monitoring and evaluation because of the accurate discrimination of vegetation and correlations with biophysical parameters which determine the vegetation state.

The most important VIs for vegetation monitoring include the "broadband greenness" category (e.g.: Normalized Difference Vegetation Index - NDVI, Soil Adjusted Vegetative Index - SAVI, Enhanced Vegetation Index - EVI, etc) and the "canopy water content" category (e.g.: Normalized Difference Water Index - NDWI, Normalized Difference Drought Index – NDDI, etc) (Gu et al., 2007; Huete, 1997; Penuelas, 1995).

3.1.1 The Normalized Difference Vegetation Index (NDVI)

The NDVI is one of the most well known and most frequently used vegetation indices, being considered as a measure of the amount and vigour of vegetation. The combination of its normalized difference formulation and use of the highest absorption and reflectance regions of chlorophyll make it robust over a wide range of conditions (GU et Al., 2007; Peters et al., 2002). The value of NDVI ranges from -1 to 1. The common range for green vegetation is 0.2 to 0.8.

The NDVI values have been used in correlations with various meteorological parameters. For example, figure 1 shows a good correlation between the SPOT Vegetation 10 days synthesis NDVI values and the precipitation, over the study area situated in the lower basin of the Mures River, located in the Western part of Romania (Pecica agricultural area). In this agricultural area the sun flower and oats crops were identified on the Landsat ETM+ satellite image (and validated by GPS ground measurements); the precipitation values were recorded at Arad weather station, the closest to the study area. The analysis covers periods from March to June 2011.

Figure 2 reveals that in the period 6.03 - 6.04.2003, the NDVI values were lower, compared to the rest, mainly because of the lack of precipitation in March which have caused a delay of the vegetation season start. The NDVI time series analysis is very important for the crop state monitoring. Such a complex analysis was made using MODIS/TERRA NDVI products (MOD13A1) for the following years: 2000 and 2003 (as drought years), 2005 (as normal year) and 2010 (as rainy year) and for different vegetation phases. The year 2010, on the other hand, presents greater NDVI values due to high amount of precipitation. The

NDVI maps show a rather equal set of values between the four years, with a slight grow in 2005 and 2010 compared to 2000 and 2003 for the periods: from the 7th of April to the 8th of May and from the 9th of May to the 9th of June.

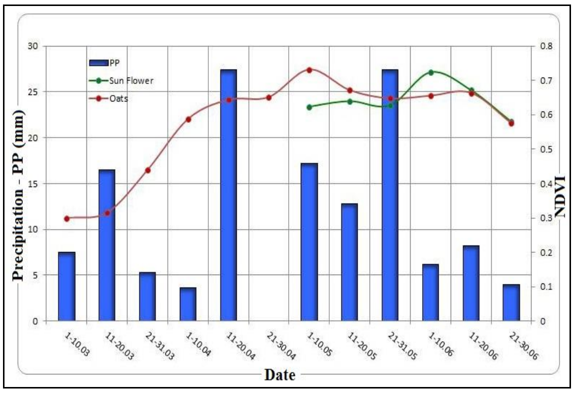
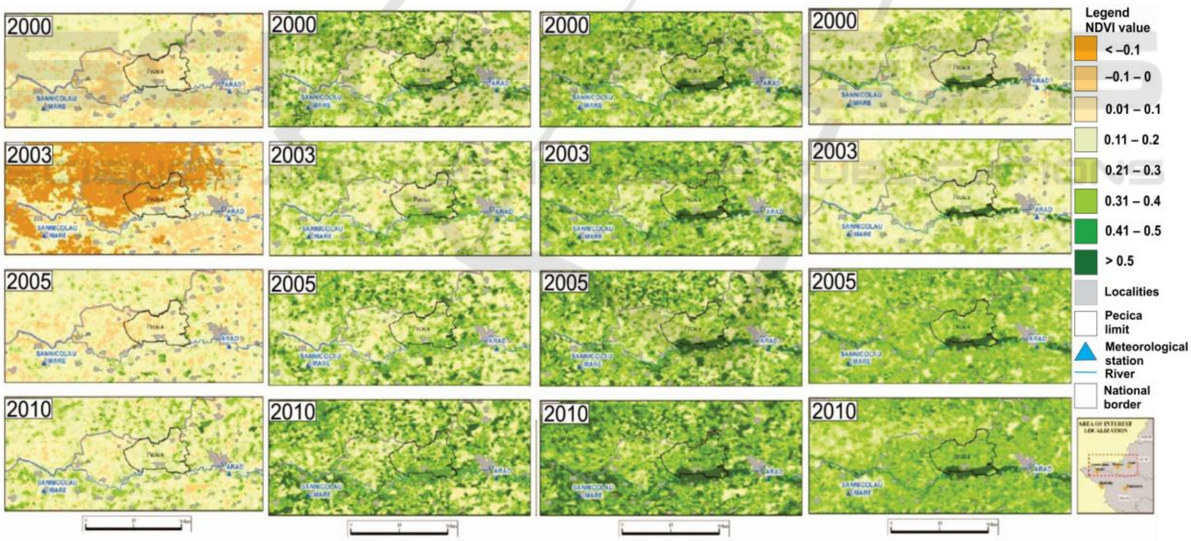


Figure 1: The correlation between NDVI (extracted from SPOT Vegetation) and precipitation (recorded at Arad weather station) for the sun flower and oats crops, in the study area situated in the lower basin of the Mures River, in the Western part of Romania.

Only during the last vegetation phenological phase a visible difference occurs between 2000 and 2003 on one hand, and between 2005 and 2010 on the other hand. The analysis clearly shows the effect of low precipitation and high temperatures in 2000 and 2003 (very droughty years) over the agricultural areas.

The NDVI-based analysis for crop state monitoring was also performed using high-resolution satellite images, such as LANDSAT TM/ETM+ data (Jackson, 2007). Figure 3 presents an example of using LANDSAT TM/ETM+ data for 14.08.2003, 22.08.2006 and 17.08.2010, in the same study area, located in the Western part of Romania.

The figure 3a shows a “hot-spot” area, associated with very low NDVI values (pixels in orange and red), in the central-eastern part of the image acquired on 14.08.2003 (up left image) and normal NDVI values in the other 2 images acquired on 22.08.2006 and on 17.08.2010, respectively. In order to isolate only the parts affected by drought a “low-vegetation” NDVI threshold was applied to highlight only two classes (figure 3b).



a) b) c) d)

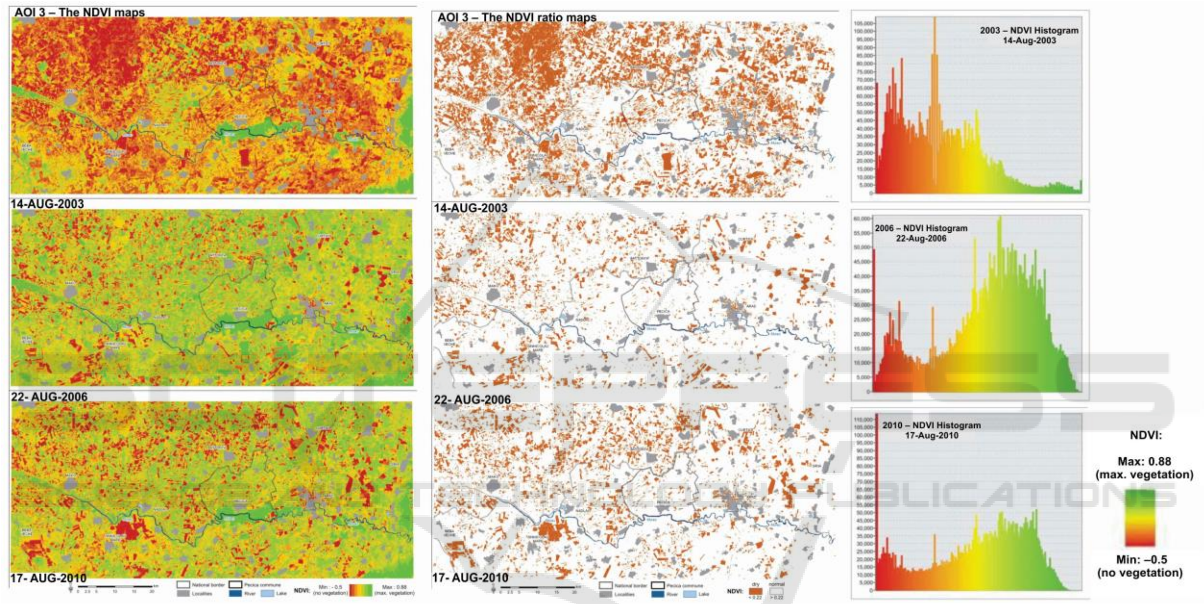
Figure 2: Spatial variation of average NDVI values:)a – in the period 6.03 - 6.04; b) – in the period 7.04 - 8.05; c) – in the period 9.05 - 9.06; d) – in the period 10.06 - 28.08.

The threshold value able to separate the dry and normal conditions was set up using the NDVI histograms (figure 3c). For this study, an NDVI value of 0.22 was used as “drought threshold“. These two classes representation excludes the “normal” NDVI values while keeping the low ones. Areas represented in brown in figure 5b can be therefore associated with dry areas.

3.1.2 The Normalized Difference Water Index (NDWI)

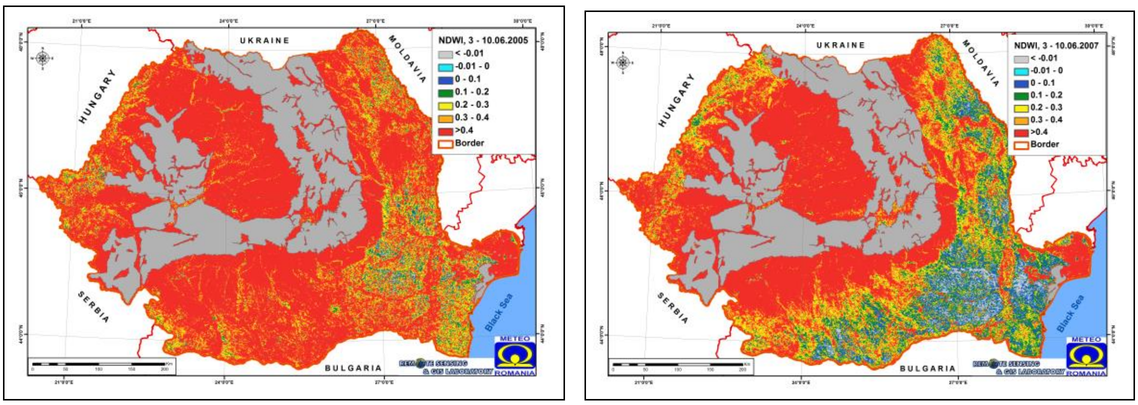
The NDWI is a satellite-derived index from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) reflectance channels (Gao, 1996). The SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. NDWI holds considerable potential for drought monitoring because the two spectral bands used for its calculation are responsive to changes in the water content (SWIR band). This index increases with vegetation water content or from dry soil to free water (Chen et al., 2005; Gu et al., 2007). The NDWI value ranges from –1 to 1. The common range for green vegetation is –0.1 to 0.4.

Figure 4 presents an example for NDWI maps over Romania, obtained from MOD09A1 products (8-day composite) for 2005 – rainy year (figure 4.a) and for 2007 – droughty year (figure 4.b).



a) b) c)

Figure 3: a) – The NDVI maps extracted from LANDSAT data; b) – The two classes NDVI maps obtained by applying a "low-vegetation" NDVI threshold; c) – NDVI histograms.



a) b)

Figure 4: NDWI maps over Romania, obtained from MOD09A1 products (8-day composite): for 03-10.06.2005 (a) and 03-10.06.2007 (b).

The figure clearly emphasized the large areas affected by drought in 2007, in the Eastern, South-eastern and Western agricultural regions of Romania.

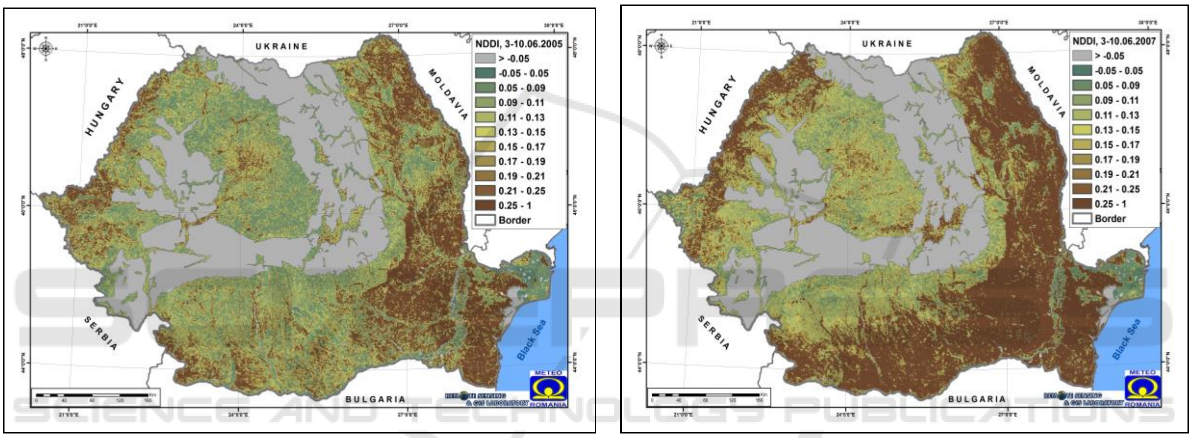
3.1.3 The Normalized Difference Drought Index (NDDI)

The NDDI is a satellite-derived index defined by the equation:

$$NDDI = (NDVI - NDWI) / (NDVI + NDWI) \qquad (1)$$

The NDDI can offer an appropriate measure of the dryness of a particular area, because it combines information on both vegetation and water. The NDDI has a stronger response to summer drought conditions than a simple difference between NDVI and NDWI, and is therefore, a more sensitive indicator of drought. In case of common range of values for vegetation moniotoring the NDDI values vary between 0.33 to 3, a higher range indicating more severe drought. This index can be an optimal complement to in-situ based indicators or for other indicators based on remote sensing data (Gu et al., 2007).

The figure 5 shows the NDDI over Romania, obtained from MODIS MOD09A1 products (8-day composite) for 2005 (rainy year) and 2007 (droughty year). The figure also highlights the areas affected by drought in 2007, especially the Eastern, South-eastern and Southern agricultural regions of Romania.



a) b)

Figure 5: NDDI maps over Romania, obtained from MOD09A1 products (8-day composite): for 03-10.06.2005 (a) and 03-10.06.2007 (b).

3.2 The biophysical parameters and physically-based vegetation state indicators

3.2.1 The Leaf Area Index (LAI)

The LAI, defined, as half the total leaf area per unit ground surface area, is a key biophysical canopy indicator, which play a major role in vegetation physiological processes and ecosystem functioning. Assessment of crop LAI and its spatial distribution are of importance for crop growth monitoring, vegetation stress, crop forecasting, yield predictions, management practices, and climate simulations. Along with the fAPAR, the LAI is a biophysical variable describing canopy structure and are closely related to the rate of energy consumed in the functional processes and exchange mass. Drought monitoring, corresponding to the state and dynamics of vegetation, in a given time may be accounting for LAI values derived from satellite data.

The algorithm for generating the MODIS LAI products uses surface reflectance (MOD09) and land cover (MOD12) products. The MODIS LAI algorithm is based on the analysis of multispectral and multidirectional surface reflectance signatures of vegetation elements. The figures 6 (a, b) show the spatial evolution of average LAI values, as well as the deviation from the multi-annual average (2000 – 2009) for the years 2000, 2003 (dry years) and 2005, 2010 (rainy ones), in the study area located in the Western part of Romania.

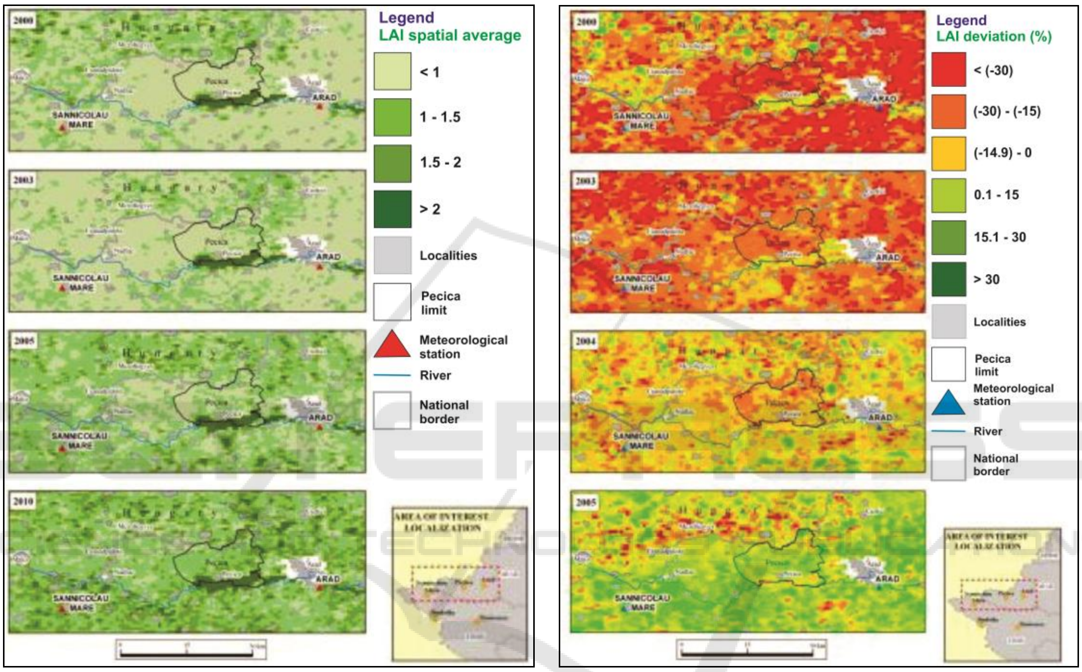
4 CONCLUSIONS

Remote sensing techniques could enhance and improve the crop vegetation state monitoring and the drought analysis, especially considering the limited availability of ground measured agrometeorological data. The use of remote sensing data in agrometeorology is a quickly developing and promising trend.

The main sources of satellite data for crop vegetation state studies and monitoring are the TERRA/AQUA – MODIS, LANDSAT-TM/ETM+ and SPOT-Vegetation archives. The satellite-derived vegetation indices data and biophysical parameters prouved to be good indicators of vegetation condition and relevant for the installation, duration and intensity of the agricultural drought.

The MODIS imagery still represents one of the most important type of satellite data available free of charge and can be successfully used in determining the vegetation status at one point or to predict the changes that may appear in plants activity.

By examining the spatial and temporal patterns of vegetation indices and comparing/correlating with the field conditions measured on site, it was determined that NDVI, NDWI and NDDI, are more suitable for agricultural drought characteristics monitoring.



a) b)

Figure 6: a - Spatial variation of average LAI values (from the 6th of March to the 28th of August); b - The LAI deviation from the multi-annual average (2000 – 2009) (from 6 March to 28 August).

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