MONITORING OF THE 2003 SUMMER DROUGHT IN BELGIUM WITH THE NDWI APPLIED ON SPOT-VEGETATION DATA

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ABSTRACT

The summer 2003 was abnormally hot, sunny and dry. The average temperatures from June to August were the highest ever recorded in the Belgian reference meteorological station of Uccle, but also in other countries of western and central Europe such as Portugal, Germany, Switzerland and the United Kingdom. Many human activities were affected by these particular climatic conditions, among which agriculture. The Normalized Difference Water Index (NDWI) applied on ten-daily SPOT-VEGETATION imagery is one of the drought indicators which could serve for the localisation of drought affected areas in Belgium. In this paper preliminary results show that detection of dry events is possible using historical averages of NDWI. Relative NDWI images can be used to monitor the development of the summer drought. These images are computed by the weighted difference between the NDWI values during this summer and its value at the same period in a reference year, which corresponds to a normal year in terms of rainfall availability. Analysis of the relation between NDWI and NDVI behaviours show that the green biomass influences the NDWI value especially during the growing season. More accurate study has to be done to individualize the specific NDWI behaviour during dry events. In perspectives, index validation with meteorological parameters and with the Relative Soil Moisture Index, which is an output of the Belgian Crop Growth Monitoring System, will improve this study.

Keywords: Drought, NDWI, SPOT-VEGETATION S10, summer 2003, Belgium.

1. INTRODUCTION

Europe was dramatically affected by a severe rainfall deficit and an exceptional heat wave during the summer of 2003 [2,10]. The Belgian reference meteorological station of Uccle (near Brussels) also recorded during the summer of 2003 the highest summer average temperatures since the beginning of the instrumental observations (1833). The Royal Meteorological Institute qualifies these summer temperatures as "very exceptional" [13]. In the meantime, the incoming solar radiation in summer 2003 was "very abnormally high" and the frequency of rainy events was "very abnormally low" [13]. In some parts of the country only few days of rain were observed during the months of June, July and August.

In terms of yield losses, the impact differs by region and type of crop. Indeed, crop sensitivity to water stress varies over the growing season. The 2003 summer dry event appeared during the critical water period for maize (around male flowering). At the national scale, a yield reduction of 4,8% for green biomass of maize were recorded by the Belgian National Institute of Statistics (NIS) in comparison with 2002. Losses have reached 7% in the Sandy Region (North Belgium). Fig. 1a represents the evolution in 2000 and in 2003 of the Relative Soil Moisture Index for maize fields in the northern part of Belgium. This index is an output of the Belgian Crop Growth Monitoring System (B-CGMS) [3,11] used to localize potential drought affected areas [1,5] (Fig. 1b). To improve the actual BCGMS and its outputs, new remotely sensed variables are analysed, amongst which the Normalized Difference Water Vegetation Index.

The Normalized Difference Water Vegetation Index, NDWI, is a remotely sensed indicator which combines the near-infrared and short wave infrared bands. Several scientists proposed this index for the estimation of vegetation liquid water by remote sensing [4,7,8,9]. Despite the first results of the NDWI implementation in Belgium

[12] which were not convincing on its capability to monitor drought in Belgium, the behaviour of the NDWI has been analysed during this abnormal climatic event.

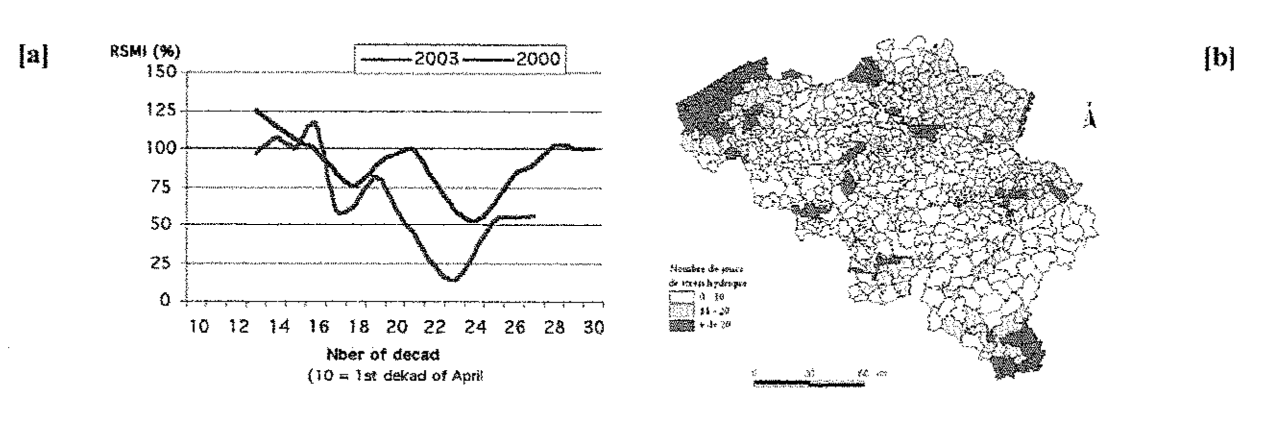

Fig. 1: [a] Evolution of the Relative Soil Moisture in 2000 and in 2003 (Maize field - Agrcultural circumscription of Eeklo). Hatching shows water stress period (RSMI > 50% [5])
[b] Map of water stress in maize field during the critical period (summer) – Legend: Number of water stress days

2. DATA AND METHODOLOGY

For this study, SPOT-VEGETATION data have been acquired for the period April 1998 to October 2003. Original daily images were pre-processed by the Vlaamse Instelling voor Technologisch Onderzoek (VITO) and converted using the Maximum Value Compositing (MVC) into ten-daily composites (VGT-S10). This pre-processing aims to reduce the atmospheric interferences (clouds).

The Near Infrared (NIR) and the Short Wave Infrared (SWIR) were combined to compute the Normalized Difference Water Index, NDWI, according to Equ. 1. The use of SWIR bands implies to work with idle lines (Cf. Fig.4) resulting from blind and/or aberrant SWIR detectors.

$$NDWI = \frac{\rho 3 - \rho 4}{\rho 3 + \rho 4} \qquad (1)$$

Where: ρ 3 is the reflectance in the Near Infrared band
ρ 4 is the reflectance in the Short Wave Infrared band

To reduce the amount of data, mean NDWI-values were computed, both for the 26 agro-statistical circumscriptions and for the 589 Belgian municipalities. The regional averages were only based on the NDWI's values of pixels which were at least covered for 50% by arable crops. The Integrated Administration and Control System (IACS) of the Ministry of Agriculture is used for the unmixing [6].

Ranging from -1 to +1, this index is similar to the NDVI but the particularity of the SWIR band (1,58 μm to 1,75 μm) is to be sensitive to the plant water content and to the soil moisture. It gives us the opportunity to follow up the water status of plants and to detect events of water stresses. The radiation absorption by vegetation in the middle infrared depends on the total amount of water in leaves, which is both a function of the water content of leaves and of leaf layers [10]. Therefore increasing plant water content is recorded as an increasing NDWI value (Fig. 2). Others factors like soil composition (organic matter, iron oxides), snow cover, etc. can influence the signal recorded by the captor in the middle infrared. These potential disturbances must be taken into account in the analysis of the signal.

Using times series of VGT-S10 data, detection of dry event in a region is realized by comparison of NDWI values to NDWI historical averages or to NDWI values of a reference year. Relative images of NDWI are computed according to the Equ. 2. The reference year corresponds to a normal year in terms of rainfall amount and availability [13]. These relative images are useful to detect drought affected areas and to follow their spatio-temporal evolutions.

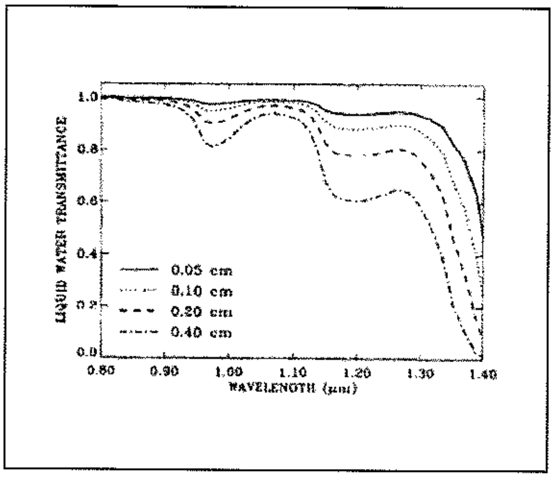

Fig. 2: Liquid water transmittances for water thicknesses of 0.05 cm, 0.1 cm, 0.2 cm, and 0.5 cm (from top to bottom) [9]

$$RelativeNDWI = \frac{NDWIobs - NDWIref}{NDWIref} \qquad (2)$$

Where: NDWIobs is the NDWI image of the current studied period,
NDWIref is the NDWI image of the same period in the reference year.

The last part of the study is focused on the analysis of the NDVI behaviour during dry periods and its comparison to the NDWI evolution. Indeed to consider the NDWI as complementary information to the NDVI, this index should provide during the drought event new or more precise indications on the vegetation stress [9].

3. RESULTS

Fig. 3 shows the evolution of the NDWI and the NDVI during the growing season 2003 for the circumscription of Arlon. Historical averages (mean from 1998 to 2002) are represented in green and hatched areas represent the maximum and minimum values ever observed during 1998-2002. The NDVI curve presents near normal evolution, except in June where values exceed historical maxima. The NDWI behaviour in 2003 clearly differs from the previous years especially during the summer where a remarkable decrease can be observed since June. This situation is more or less generalized in Belgium, even if deviation to historical mean is higher in some part of the country such as in the southern region of Belgium, and in the Sandy Region (northern Belgium). Moreover maximum value of this curve is nearly systematically situated one or two decades earlier in the season, especially in the South of Belgium. This could be related to the phenological advance for maturity stages which were observed in Belgium and also in Luxembourg one or two weeks earlier. Many agronomists consider this advance as a consequence of the heat wave started in June.

Relative NDWI images of the summer 2003 prove to be of high interest for the delineation of the drought affected areas. The relative NDWI images computed during the summer 2003, with a reference year fixed to 2000, are shown in the Figure 4. We can visualize the diachronic development of the drought. On the second decade of July 2003, NDWI values are similar or even higher than the values at same period in 2000. Then, from mid-July, decade after decade, vegetation is affected by drought.

The 2nd decade of August (Fig. 4c) was probably the paroxysm of the drought in Belgium. Nearly the entire territory was affected by this abnormal climatic event. On the relative NDVI image of the same decade (Fig. 4d), smaller decreases are observed. This highlights the difficulties to delimitate drought affected areas. On the contrary the picture presented on the relative NDWI image seems to be more sensitive.

The Jurassic Region (southern part of Belgium) is particularly characterized by low values of relative NDWI, except a small area which corresponds to the Forest of Anlier. The Sandy region and the Eastern regions (around Liège) present also a huge deficit of NDWI with most of pixels values around -30% to -50%. The surrounding countries of France and Luxembourg present also very low values of relative NDWI. This description of the 2003 summer drought in Belgium and in the surrounding countries using the NDWI fit relatively well with the reality. Moreover, main forests in Belgium can be individualized easily such as the green belt of the Ardennes, the Forest of Anlier in the South and the Forest of Soignes close to the capital. Clearly agricultural lands were more affected by the summer drought.

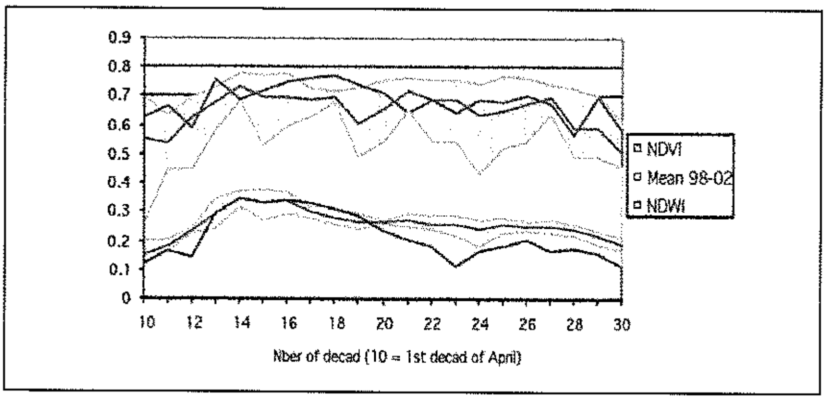

Fig. 3: 10-daily evolution of the NDWI and NDVI averaging values for 2003 (Agricultural circumscription of Arlon). Grey lines are historical means from 1998 to 2002 and hatched areas are statistical ranges

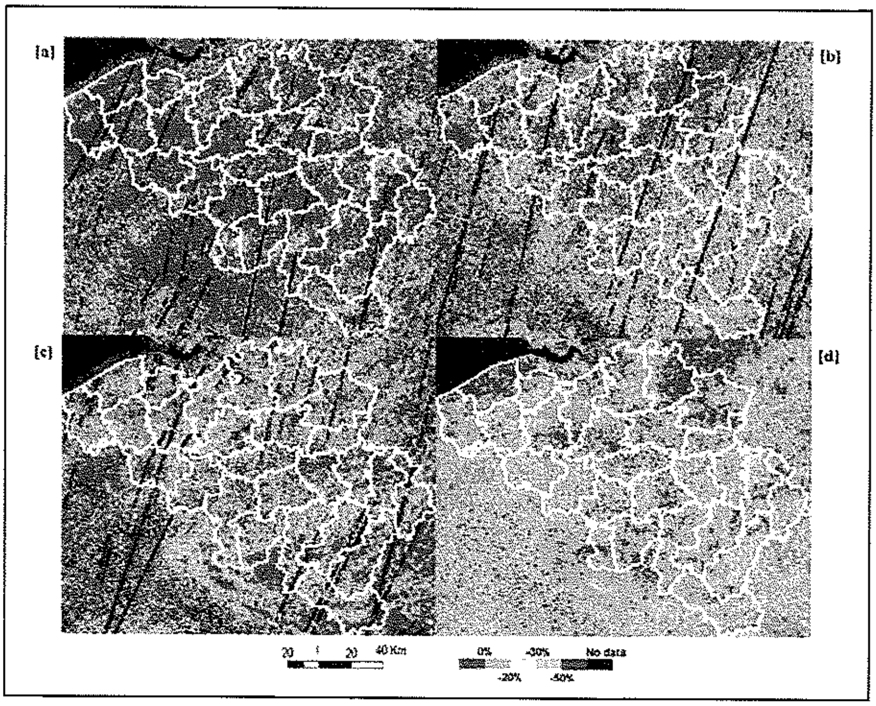

Fig. 4: Relative images of the summer 2003 (Reference year 2000): Relative NDWI of the [a] 2nd decade of July; [b] 3rd decade of July; [c] 2nd decade of August; and [d] Relative NDVI of the 2nd decade of August

4. RELATION BETWEEN NDWI AND NDVI VALUES AT THE SCALE OF MUNICIPALITY

Regressions are realized between regional averaging of the NDWI and the NDVI for 35 Belgian municipalities (Fig. 5). Relationship between these two indexes is positive during the growing season. Values of the resulting coefficients of determination are more or less variable with low values outside of the growing season period (Table 1). Theoretically the best regression should be observed in June or July (important green biomass) but during the summer 2003 low R_ were observed. A hypothesis could be that these low R_ are a signature of the summer drought. The decrease of the NDWI without similar evolution for the NDVI clearly impacts the regressions. The dephasing between NDWI and NDVI will be analysed in a further study to verify this hypothesis.

Number of decade	Period	R^2 in 2003
7	1st decade of March	0,0766
10	1st decade of April	0,5788
13	1st decade of May	0,6045
21	3rd decade of July	0,2437
23	2nd decade of August	0,3419
30	3rd decade of October	0,3783

Table 1. *Coefficients of determination (R^2) resulting of the regressions between NDWI and NDVI values extracted for different decades of the year 2003 (Belgium)*

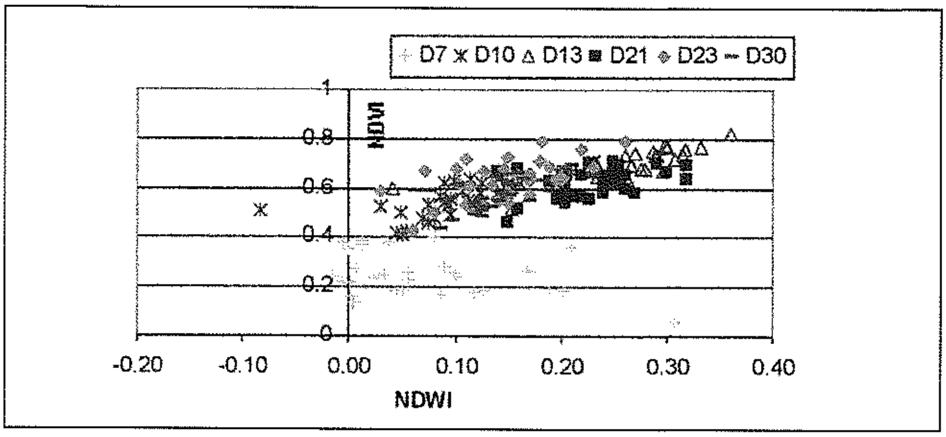

Fig. 5: Regression between the NDWI values and the NDVI values of 35 Belgian municipalities, for different decades in 2003

5. CONCLUSIONS & PERSPECTIVES

These preliminary results show interesting perspectives for the Normalized Difference Water Index computed on 10-daily SPOT-VEGETATION images, even in Belgium during extreme events. The historical values of the NDWI can be useful to detect, delineate and monitor drought impacted areas.

The relation between the NDWI and the NDVI has to be further studied. An analysis of the dephasing between these two indexes will be realized very accurately to detect the starting point of the plant water stress. This analysis should have a huge importance for the monitoring and the prediction of drought in the agricultural sector. Validation of the NDWI results should be realized thanks to the meteorological parameters of the GRID_WEATHER and the Relative Soil Moisture simulated by the Crop Growth Monitoring System (B-CGMS). The implementation of a relevant remotely sensed index to monitor extreme climatic event in Belgium is a great opportunity for BCGMS. Although dry and hot summer events are still currently rare in Belgium, model simulations show that such types of weather could be more and more frequent in the near future [2,10]. Therefore, this index could be integrated as new RS information inside BCGMS and serve for the improvement of crop monitoring.

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