MONITORING CROP GROWTH CONDITIONS USING THE GLOBAL WATER SATISFACTION INDEX AND REMOTE SENSING

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ABSTRACT:

Water availability is one of the limiting factors to crop growth in arid and semi-arid zones. Shortages of fresh water become very serious for different regions of the world with important consequences for food security. Early warning systems based on the integrative use of remote sensing observations and crop growth modelling have been developed and implemented for specific regions. The Joint Research Centre, Ispra (Italy) initiated the MARS project (Monitoring Agriculture with Remote Sensing). Nowadays, this system is used operationally to forecast crop yield across Europe.

To produce global real-time water balance calculations and outputs a system has been developed called GWSI[x] (Global Water Satisfaction Index). The GWSI model is based on a simple soil water balance model, which is used to assess the impact of weather conditions on crop growth. The water balance used is known as the FAO Crop Specific Water Balance, CSWB. The system developed delivers actual information on crop growth conditions for the major food crops per country per decade (periods of 10 days) and per 0.1 by 0.1 degree grid cell. It was found that the developed method delivers indications for the occurrence of crop stress.

The spatial distribution of available water and crop development at different scales can also be described by applying remote sensing observations. Quantitative information dealing with space-time distribution of water can be obtained through the mapping of crop surface evapotranspiration. However, application of such an approach at global scale is hardly possible.

NDVI time series as derived from NOAA AVHRR satellite observations have been used extensively to monitor vegetation development at different scales. To assess agricultural crop growth conditions we used the Global Inventory Modelling and Mapping Studies (GIMMS) dataset of the NASA. It contains bimonthly NDVI data in an 8-km global raster as derived from NOAAA AVHRR satellite observations for the period 1982-2002.

Output of the GWSI system has been compared with results obtained through remote sensing. Preliminary results are presented.

1. INTRODUCTION

Availability of fresh water is a crucial factor for the arid and semi-arid regions for food security on the long term. Therefore several initiatives are taken to study the water cycle and water resources at global scale, as a contribution to international or regional policies and initiatives related to water (e.g. WMO, IGOS, GEO). It is important to improve the knowledge and awareness of the meaning of the water cycle to monitor regional drought.

To assess the impact of weather conditions on crop growth we developed the GWSI-system. It is based on a simple water balance, known as the FAO Crop Specific Water Balance (CSWB), available in the Agromet-shell software (AMS). As input 10-days weather data are applied as delivered by ECMWF (European Centre for Medium-range Weather Forecast). With such a model simulated values are obtained dealing with crop growth conditions. Validation of the obtained results is, however, hardly possible.

Since several years remote sensing is applied to acquire data at national, regional and continental scale. Over the last decade, progress on space techniques and earth observation methodologies has opened a wide range of applications for continental hydrology. Methods were developed applying

thermal infrared imagery in combination with meteorological data to map regional evapotranspiration. However, operational application is still hampered due to lack of suitable satellite images at the global scale. Moreover, the developed physically based methods to map crop transpiration are rather complicated.

With thermal images quantitative information about the surface energy balance, and consequently about crop growth conditions, are obtained. Also observations in the shortwave range of the electromagnetic spectrum can be applied to monitor vegetation development. Maps of vegetation indices as derived from multi-spectral images are frequently used. Nowadays historical databases are accessible to perform time series analyses.

In this paper we discuss the use of the GWSI model in combination with remote sensing observations both in the shortwave and thermal range of the electromagnetic spectrum. We especially focus at dry years as indicated through El Niño effects.

2. GLOBAL WATER SATISFACTION INDEX

2.1 Theory

We have set up a system called Global Water Satisfaction Index GWSI to produce global water balance calculations

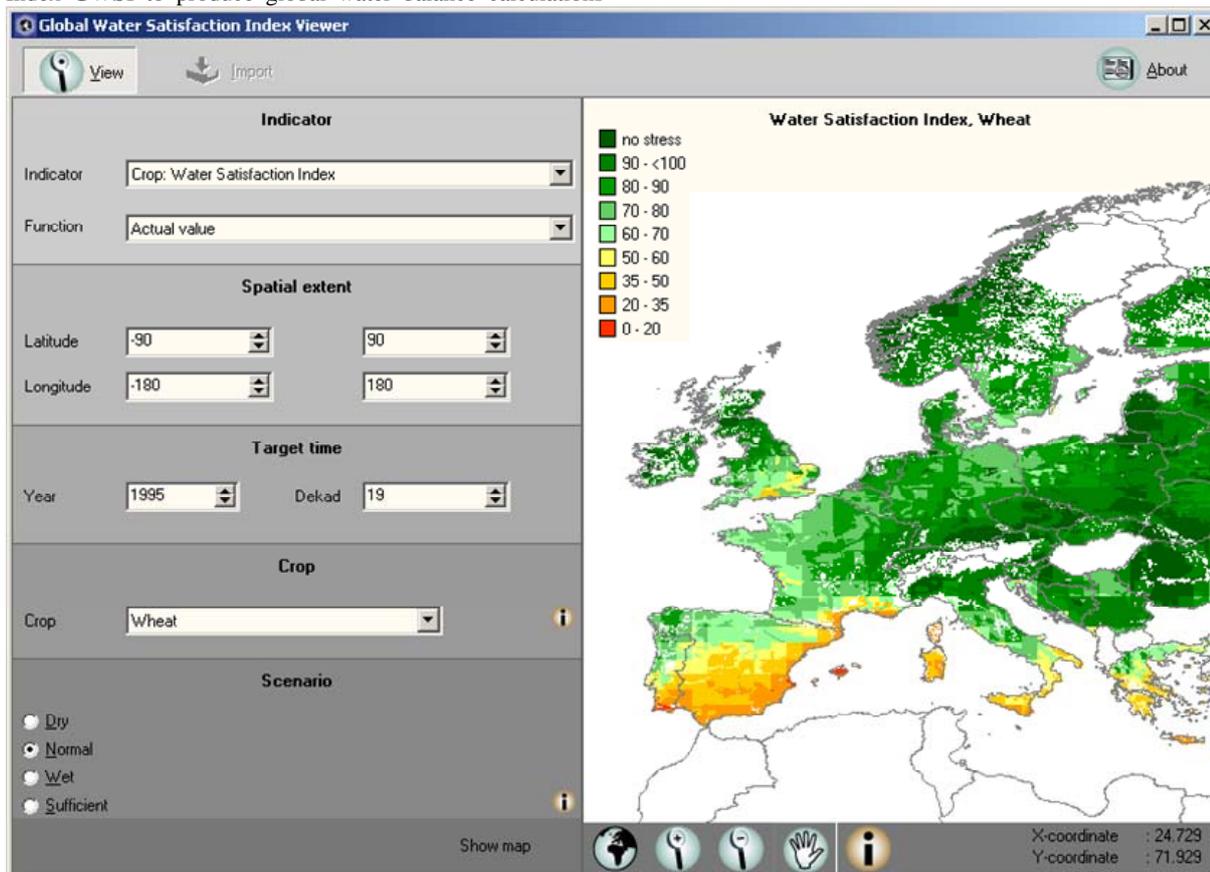and outputs. The water balance used is known as the FAO

Figure 1. Example of a map in the GWSI administrator

Crop Specific Water Balance, CSWB (Frere and Popov, 1986) available in the Agromet-shell software (AMS). It contains a simple soil water balance model which is used to assess the impact of weather conditions on crops. The water balance of the specific crop is calculated in time increments of decades (10-days). The equation of the water balance is:

$$W_t = W_{t-1} + R - ET_m$$
(1)

where W_t= amount of available water stored in the soil at the end of decade t
W_{t-1}= amount of available water stored in the soil at the end of the previous decade (t-1)
R=cumulated rainfall during the decade (mm)
ET_m=cumulated maximum evapotranspiration during the decade for a given crop (mm/decade)

The soil profile functions are considered as a water reservoir, like a bucket. When (R-ET_m) exceeds the storage capacity, the excess rainfall is accounted for as water surplus or deep percolation. Run-off is not taken into account because we assume that 1 by 1 degree ECMWF weather is not suitable (too coarse spatial resolution) to determine local run-off. Therefore on the global level we assume that all rainfall is effective. The storage capacity of the soil profile is the amount of water between field capacity and wilting point taken for the whole rooting depth.

The maximum evapotranspiration is the water requirement for the crop, defined as:

$$ET_m = K_c.ET_0$$
(2)

where K_c=crop coefficient according to Doorenbos and Pruitt
ET_0=potential Evaporation and Transpiration in mm/decade according to Penman-Monteith

2.2 Implementation

The GWSI information system has been made accessible to the world using the MARSOP-2 website (see: www.marsop.info).Through this website maps can be retrieved fast enough to enable on-the-fly-creation of maps. Thus the maps are not pre-processed but following a request from the MARSOP-2 website these maps (PNG-format) are created dynamically. The website offers several navigation options (kind of crop, type of indicator and parameter), resulting in maps with title, legend, units and logos using a HTML template.
Several indicators dealing with historical and actual information about crop growth conditions can be viewed through the 'GWSI administrator' which serves as a viewing tool on the data base. The map format is a georeferenced bitmap. Several functions have been developed to support the MARS-FOOD analyst to explore the data in a user friendly

and fast way. Figure (1) shows an example of a map selected in the 'GWSI administrator'.

2.3 Input data

The input data concern weather data, soil data, crop data and additional data, like administrative boundaries. A special tool has been built to import and check the data for both historic and actual meteorological data. The required soil data are derived from the digital soil map of the world (1:5.000.000) of the FAO (FAO, 1995). The crops taken into consideration are the major food crops within the country. A selection of crops is based on the relative importance of the crop as food crop.
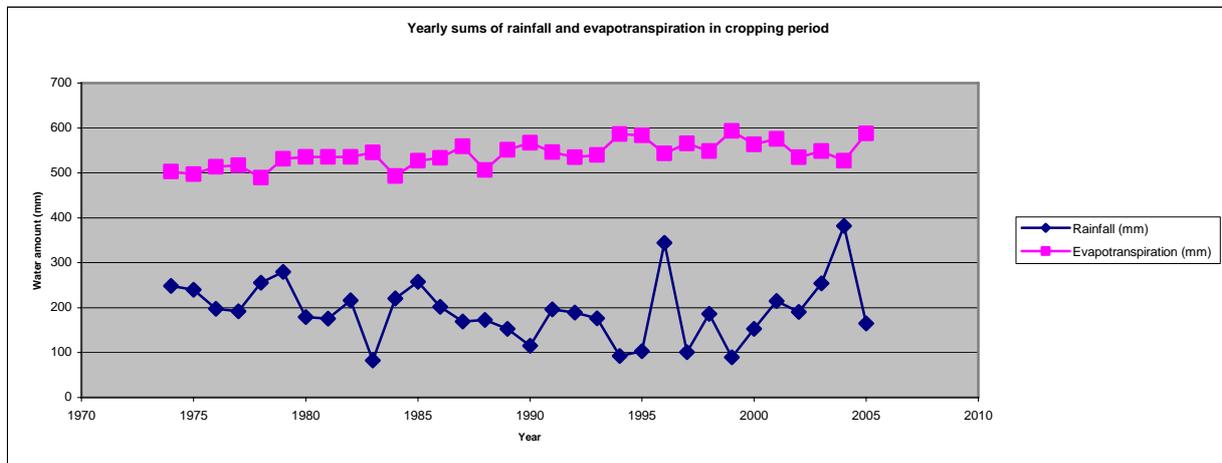

Figure 2. Yearly sum of rainfall and evapotranspiration for the cropping season according to the GWSI model for the research are in southern Spain

3. VALIDATION WITH REMOTE SENSING DATA

3.1 Evapotranspiration mapping with remote sensing

Methods have been developed by applying thermal infrared imagery in combination with meteorological data to map regional evapotranspiration. An example is the SEBS model (Su and Roerink, 2004). Such a model has been used in the EU project ASTIMwR to monitor irrigation efficiency for the Mediterranean region (Somma et al, 1999 and de Zeeuw, 1999). For southern Spain it was found that during the growing season 1994/1995 even for irrigated agriculture there were severe problems with crop water supply, while for 1995/1996 due to higher precipitation rates problems were less. For rainfed agriculture both for 1994/1995 and 1995/1996 the evapotranspiration maps as derived from remote sensing imagery clearly showed problems with crop water supply.

Evapotranspiration maps as derived from remote sensing imagery can be applied to indicate where crop stress conditions occur due to drought. That means that in principle such maps can be used to validate output of the GWSI model. Application at the global scale, however, is hampered by the availability of the required multi-spectral and thermal images from satellites and operational methods to map evapotranspiration globally.

3.2 Vegetation indices

A lot of experience has been obtained monitoring vegetation conditions by mapping vegetation indices as derived from multi-spectral imagery. In the framework of the MARS project Vegetation Indices as derived from data of the VEGETATION instrument of the SPOT 4 satellite are used to monitor vegetation development during the growing season. Especially images showing the difference between the actually observed vegetation index and the long term mean are useful to indicate specific situations dealing with vegetation development. The results are published through the monthly bulletins of the MARS project and they are also available through the web (see: www.marsop.info).

Through the GIMMS database NDVI data are globally available for a period of 21 years. Therefore we investigated if this database could be applied, although the spatial resolution is less in comparison to the VEGETATION data of SPOT 4. The GIMMS dataset contains bimonthly Normalized Difference Vegetation Index (NDVI) data in an 8 km global raster derived from NOAA satellites (Tucker et al., 2003). The NASA GIMMS data set used in this study is currently the longest time series data that can be used detecting long term vegetation changes.

We investigated if the GIMMS data set could be used to validate GWSI model results.

3.3 GWSI and NDVI time series

In this study we analyzed time series for a region in southern Spain, roughly the province of Andalusia. Form the ASTIMwR project, among others, it was known that extreme differences in crop water supply occured in this region due to differences in rainfall. Figure (2) shows the variation in rainfall and evapotranspiration during the growing season for the period 1974-2005. Cumulative rainfall during the growing season varies between 100 and 400 mm. Variation in evapotranspiration is relatively small at a mean level of about 550 mm. That means that low rainfall rates during the growing season results in crop stress conditions if no irrigation is applied due to the high atmospheric demand. So according to the GWSI model in 1983, 1990, 1994, 1995, 1997 and 1999 severe problems with crop water supply are

forecasted. Especially the years 1996 and 2004 are characterized by high precipitation rates.

We compared simulated water deficits during the growing season with observed NDVI values. You may expect that water deficits effect vegetation development with a certain delay. Interactively we found that a time shift of two months gave the best results. So calculated water deficits were related to NDVI rates as derived from the GIMMS database with a delay of two months. Figure (3) shows the results. It was found that with an increase of water deficits NDVI decreases. This means that NDVI as derived from satellite imagery could be applied to validate results of the GWSI model. However, this should be elaborated more systematically for different climatic regions.
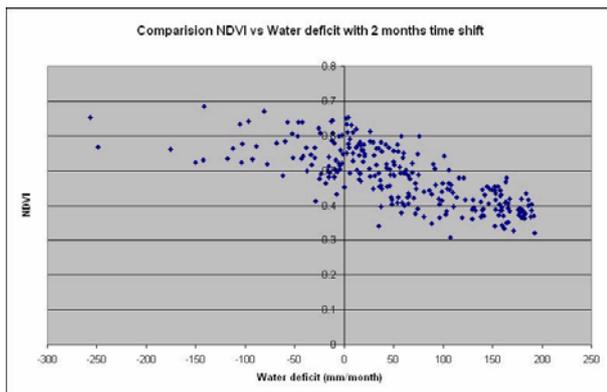

Figure 3. Comparison of NDVI values as derived from the GIMMS data base and simulated water deficit with a time shift of two months for the research area in southern Spain.

4. CONCLUSIONS AND DISCUSSIONS

The developed GWSI model is a user friendly system to forecast water deficits and to monitor crop growth at global scale for local conditions. It supplies information on crop growth conditions concerning the major agricultural crops.

Remote sensing can be used to validate results as obtained with the GWSI model. Both evapotranspiration maps and NDVI time series as derived from satellite imagery are applicable to indicate when and where specific crop growth conditions occur. Application of evapotranspiration maps at global scale is, however, hampered by the availability of suitable satellite images and operational methods to map evapotranspiration globally.

NDVI time series are frequently applied to monitor vegetation conditions. We applied the GIMMS data base to investigate if NDVI time series could be used to validate GWSI model results. The studied time series from 1982-2002 include some extreme dry growing seasons. These years were

clearly indicated by relatively high water deficits according to the GWSI model. Low rainfall rates and consequently high crop water deficits resulted in severe crop stress conditions. Water deficits could be related to observed NDVI values taking into account a delay of about 2 months.

Preliminary results indicate that the GWSI model in combination with NDVI time series might be applied to monitor crop growth conditions at global scale.

In the framework of the MARS project VEGETATION data obtained with SPOT 4 are operationally applied. Vegetation maps as derived from the VEGETATION data show patterns which are related to specific crop growth conditions. Especially difference maps showing the situation for a specific year in comparison to long term mean values are relevant in this context. Therefore in addition to the analysis of observed time series of vegetation index values spatial patterns as shown by satellite derived vegetation maps should be taken into consideration.

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