THE USE OF REMOTE SENSING WITHIN THE MARS CROP YIELD MONITORING SYSTEM OF THE EUROPEAN COMMISSION

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ABSTRACT:

The objective of the Mars Crop Yield Forecasting Systems (MCYFS) is to provide precise, scientific, traceable independent and timely forecasts for the main crops yields at EU level. The forecasts and analysis are used since 2001 as a benchmark by analysts from DG – Agriculture and Rural Development in charge of food balance estimates. The system is supported by the use of Remote Sensing data, namely SPOT-VEGETATION, NOAA-AVHRR, MSG-SEVIRI and MODIS TERRA and in the future METOP AVHRR too. So a broad spectrum from low to medium resolution data at pan-European level is covered and historical time series go back to 1981 for NOAA and 1998 for SPOT VEGETATION. In order to work with the data operationally, processing chains have been set-up to make the data consistent with our requirements concerning near real time delivery (3 days), spatial coverage (pan-Europe), projection and ten day time steps. Moreover tailored indicators like NDVI, fAPAR and DMP are derived. In case of available time-series, difference values of the indicators (e.g. relative or absolute differences) and frequency analysis of the indicators (e.g. position in historical range or distribution) are calculated. The data is explored at full resolution or unmixed related to landcover types and aggregated at administrative NUTS 2 level (profile analysis of time series). Special tools to inspect and distribute the data to external users have been developed as well. Furthermore, it is the objective to develop a strategy for an optimal use of the different sensors and thus derived indicators at different aggregation levels for the ingestion into the MCYFS. As a first step smoothing algorithms have to be applied to the time series to diminish noise effects and to retrieve continuous information. Thus, an algorithm based on Swets et al. (1999) is employed. Thereafter, so-called Chronos Key Indicators are derived from the smoothed time-series. Currently, a study is carried out to establish the link between these indicators and (1) state variables of the crop growth simulation (e.g., development stages), and (2) the forecasted yield/production.

1. INTRODUCTION

The MARS (Monitoring Agriculture with Remote Sensing) project of the AGRI4CAST action at the JRC runs since 1993 an operational activity on the analysis of crop growth condition assessment and crop yield forecasts. The system in place to monitor the agriculture campaign and make quantitative crop forecasts is the so called MARS Crop Growth Monitoring System (CGMS) which is embedded in a series of additional tools and services called MARS Crop Yield Forecasting System (MCYFS).
The CGMS itself consists of three levels:

- weather monitoring (level I),
- crop growth simulation taking into account the actual weather situation (level II) and
- final yield forecasting (level III).

Each level of the system is supported by the operational use of remote sensing data. The use has been currently realized to different extents (Royer and Genovese, 2004). Complete system documentation is also available as hypertext under http://mars.jrc.it/marsstat/Crop_Yield_Forecasting/crop_yield_forecasting_system.htm. Results are regularly published in form of monthly bulletins containing analysis, forecasts and thematic maps on crop yield expectations.

2. REMOTE SENSING DATA IN SUPPORT OF THE MCYFS

Remote sensing data is qualitatively used as an independent source of information to confirm crop growth indicators as well as forecasts, and identify area with anomalies. It is realised by a series of products that are based on the comparison of the various parameters for the current season with the one of historical year, the previous year or exceptional years (e.g. absolute and relative differences, frequency analysis).
Moreover, an integrative approach is followed by direct ingestion of derived parameters into the CGMS at the three levels and thus using remote sensing quantitatively:

- Level I: complement of station weather data (e.g. radiation, temperature, snow cover) by remote sensing parameters
- Level II: calibration or update of state variables of crop growth simulation (e.g. development stages) by the Chronos Key Indicators
- Level III: crop yield/production estimation and forecast by means of scenario and regression analysis from the Chronos Key Indicators

According to the different ingestion levels, the exploitation of the data is performed at full resolution, at grid level the CGMS (50/25 km) (Lazar and Genovese, 2004) or regional unmixed means (C-indicators) are used (see 4.3).

3. DATA REQUIREMENTS AND SENSORS

The use of operational remote sensing data within the MARS Crop Yield Forecasting System for Europe requires a certain number of specificities.

First of all the data should cover the whole Europe at a relevant frequency allowing a synthesis every ten day with a delivery delay of 3 days. Moreover to have a minimum return on investment on any new sensor processing and to develop stable analysis over time, the new system should have a projected minimum lifetime of 8-10 years. To allow us to perform accurate analysis over the European territory with reference to historical data the quality of the sensor measurement should be stable over space/time with a good geolocation at least in relative way (at least half pixel). Despite the geolocation the data processing should include adequate inter sensor radiometric calibration from the historical to the most recent images. Last but not least the sensor should have the necessary bands to get at least vegetation indexes to follow the green vegetation development or to derive meteorological indicators.

A variety of different sensors partly fulfilled these requirements to support the MCYFS. Starting with data from 1981, a time series with almost 27 years of NOAA–AVHRR is retrieved which is the cornerstone of the remote sensing database covering pan-Europe. In addition SPOT-VEGETATION data are available since 1998. New METOP-AVHRR will be include in the system from 2008. The apparent overlap of the two similar sensors increases the chances of permanent data availability, which is an important aspect as we work in an operational context.

The low resolution data with 1 km pixel size are completed by more recent MODIS data at 250 m spatial resolution which are available since 2000. These data should help to solve the unmixing problem and to derive more crop specific information. On the other side as there is no daily European coverage, cloud coverage is a more severe problem reducing data availability.

Furthermore, MSG–SEVIRI data with 5 km spatial resolution are used from 2005.

As a real-time crop monitoring is performed throughout the season, we have high demands concerning the timely availability of the remote sensing data products. Operational chains are put in place to regularly produce 10-daily and monthly vegetation state parameters covering EU 27 and neighbouring countries. Moreover, daily, 10-daily and monthly meteorological products based on MSG-SEVIRI data are available.

All data are mosaicked to a pan-European extent with the same spatial extent and projection. On one hand we are working at pan-European scale, but on the other hand regional analysis is required. This implies a high geometric quality throughout the products, which is not always simple to ensure.

4. VALUE ADDED PRODUCTS

Two categories of value added products with different fields of applications according to the qualitative and quantitative analysis (see 2) can be distinguished.

4.1 Meteorological products

Meteorological products used within the MCYFS are based on MSG-SEVIRI distributed by the LSA SAF and adapted to the MCYFS requirements throughout an operational processing chain. These products comprehend land surface temperature (Trigo, 2005), snow cover (Siljamo & Hyvärinen, 2007), down-welling surface short-wave radiation flux (Geiger, 2005) and sunshine duration. They support the level I of the system.

The default input data for the CGMS model come daily from meteorological stations. Information is gathered and inter-polated to a 50 km * 50 km grid. However, these stations are not always distributed homogeneously, data delivery is not always regular and some inputs like radiation are particularly difficult to acquire. In some regions we even have to face the complete lack of station data.

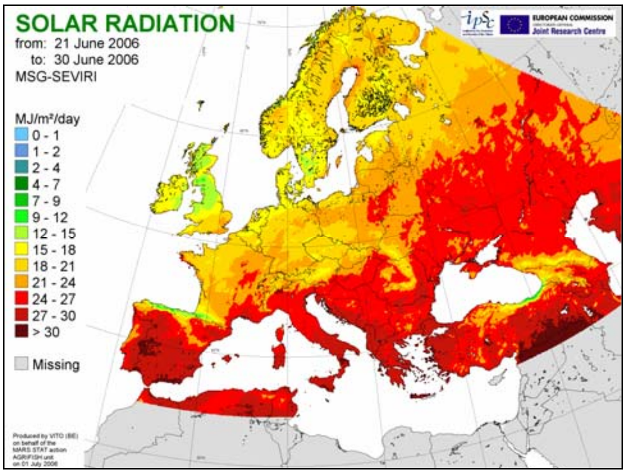

Figure 1: Quicklook example for MSG data produced within the operational processing chains.

The remotely sensed meteorological products delivered by the LSA SAF can be used for the CGMS in two ways:

1. As a complement to the station network: Data that serves to enhance our existing meteorological infrastructure, like land surface temperature. It is a possibility to fill gaps within the station data, to increase the density of the observation network and to perform cross-checking.

2. As an alternative to the station network: data that can be directly ingested into CGMS crop growth model or used to perform cross-checking of the data at station or grid level. This is the case for radiation, sunshine duration and snow presence.

At this stage the different data are evaluated and information content is analyzed with respect to the relevance to our CGMS system and the ingestion possibilities.

4.2 Vegetation state parameters

Vegetation state parameters from NOAA-AVHRR and SPOT-VEGETATION are currently the main remote sensing information used in the context of the MCYFS. They allow interpretation of vegetation conditions, biomass development etc. They are simple to understand and fast computed as often band ratios are used. Their main characteristic is the maintenance of the signal sensitivity to the vegetation while reducing sensitivity to topographic effects, soil background and atmosphere and thus making the interpretation of temporal sequences easier. (Pettorelli, 2005)

Normalized difference vegetation index (NDVI) is computed. The fraction of absorbed photo synthetically active radiation (fAPAR) (Myneni, 1994) is derived by a model based approach after Gobron (2006) for SPOT and based on the CYCLOPES approach (Baret et al., 2007) for NOAA. Using the fAPAR, dry matter productivity (DMP) following the approach from Monteith (1972) is calculated as well.

Thereafter daily values as well as masked cloud and snow cover, are mosaicked to decadal and monthly images using a maximum value compositing approach for NDVI and fAPAR. The DMP product is composited by calculating the mean value).

In addition, the long term average or so called historical year for these state parameters at monthly and decadal steps is computed for the time series of NOAA-AVHRR and SPOT-VEGETATION. The long term average is used to compute difference images with the actual data and to determine the range of the values occurring and their probability respectively. This corresponds to the VCI (Kogan, 1990) and VPI (Sannier et al. 1998) when applied to the NDVI. These products are part of the qualitative analysis. They are widely used by our analysts, as they allow evaluating vegetation condition in a historical context.

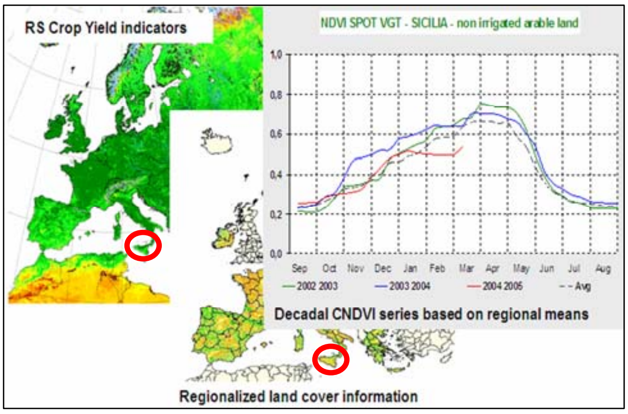

Figure 2: Example for spectral unmixed and weighted NDVI values for the CLC class “non-irrigated arable land” aggregated at NUTS 2 level.

4.3 Extraction of databases with regional and land cover specific means

This procedure is meant to extract landcover /crop specific information, to tailor the remote sensing information to the needs of agro-statistical purposes and to reduce the amount of data.

Based on the landcover information provided by CORINE land cover (CLC) 2000 (De Lima, 2005), landcover class weighted means of the vegetation indicator values per administrative region are derived (Genovese et al., 2001). Figure 2 shows an example of a graphical representation of unmixed NDVI values for the landcover class ”non irrigated arable land” for a NUTS 2 region in Italy

In this way the image data become compatible with the other agro-statistical information (official areas/yields, CGMS-outputs) in a spatial and thematic sense.

5. EXTRACTION OF CHRONOS KEY INDICATIORS

5.1 Definition

The growing season of crops is reflected by the time course of remotely sensed parameters like NDVI and fAPAR. The occurrence of key events in the season like start, maximum and end of the season can be detected and linked to bio-physical parameters of crops like their phenology (Tucker et al. 1979, Xin et al. 2002).

The Chronos Key Indicators are a set of values that characterize the typical seasonal behaviour of the remotely sensed parameters. They consist of:

- Phasing indicators: time (e.g. decades) of key events like start, maximum, half of senescence or end of season
- Intensity indicators: value of the parameter at the key event (e.g. NDVI at start or maximum)
- Duration indicators: time period between two key events (e.g. duration of increase defined as time between start and maximum)
- Slope indicators: slope of parameter between two key events (e.g. slope of increase defined as slope between start and maximum)
- Cumulated indicators: cumulated parameters between two key events (e.g. cumulated NDVI between start and maximum)

These indicators can be used to draw conclusions about the timing of the crop cycle for a specific year (phenology) and about the state of the crop cover for a specific year (yield estimate and forecast).

5.2 Methodology

The products derived for vegetation parameters (see 4.2) still contain missing values related to cloud or snow coverage. Moreover, noise is biasing the data (Pettorelli et al., 2005). Therefore, the missing data are first linearly interpolated resulting in continuous time series of the observed parameter. Afterwards, a modified approach of the weighted linear regression after Swets et al. (1999) is applied for smoothing. This algorithm has been chosen as it keeps a balance between (a) the effort for the historical and near real time operational processing, and (b) the improvements of the time series needed for the extraction of the Chronos Indicators (Klisch et al. 2006).

First, the Chronos timing indicators are detected. For retrieving start and end, the position and length of continuous increases or decreases of the observed parameter are registered within a region specific time window and analysed. The maximum of the growing season is defined as maximum value of the parameter after the start. Half senescence is mathematically defined as the event, when the parameter for the first time after the maximum reaches a threshold. The latter one is calculated as the average of the values at start and maximum. All the other Chronos Indicators can be easily derived from the timing indicators.

The link between physical parameters and the Chronos Indicators is currently analysed at regional level in different countries of Europe. According to the ingestion at the different CGMS levels following ground truth is used:

- Level II: Development stages at field scale for the main crops
- Level III: national yield, area and production statistics at NUTS level 2, 3 or 4

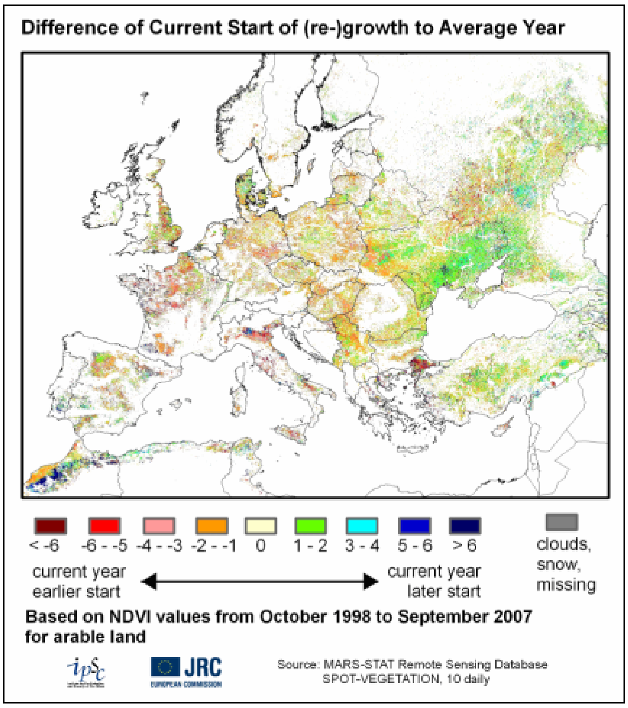

Figure3: example of Chronos Key Indicator products. Difference of current start of (re-)growth to the average year for the season 2007.

6. DATA ACCESS

To facilitate the access to the databases specific tools have been created for internal and external users to follow the vegetation growth development by means of vegetation state parameters over the season and to inspect the meteorological remote sensing data information.

In the first place there is a web application for external users offering a wide variety of information about the current agricultural season in Europe and other important agricultural areas in the world. Available products include not only the remote sensing data but also maps of weather indicators based on observations and numerical weather models and maps and time profiles of crop indicators based on agro-meteorological models. The extranet site can be assessed under http://www.marsop.info/.

For the external users interested in the value added products from remote sensing with full spatial resolution an image server has been set up. The image server allows displaying, printing and downloading of the full resolution remote sensing imagery. It can be found under http://cid.jrc.it/idp/thematic-portals/mars-stat-imageserver..

7. CONCLUSIONS

At present remote sensing information is used operational to monitor crop growth in near real time and to monitor the actual meteorological situation in qualitative way. The data adds valuable information concerning vegetation condition and supports well the CGMS.

But the modelling and analysis of the crop cycle has to be supported by results from vegetation state parameters. So remote sensing is not only an independent source of information but there is also a mutual dependence to deduct the right crop behaviour interpretation.

It is subject of current workings to employ remote sensing data for the quantitative analysis. An extended processing chain will be set-up that contains the operational smoothing of time-series and the extraction of the Chronos Key Indicators. Ground truth in form of development stages and yield statistics is employed to allow the direct ingestion of remote sensing data into the CGMS levels II (crop growth model) and III (statistical crop yield forecasting)

As we are working at pan-European scale the daily coverage provided by sensors like SPOT-VEGETATION and NOAA-AVHHR is a big advantage to ensure a sufficient amount of measurements throughout the ten day period to generate the decadal products. But not only from this point of view it's desirable that there is a continuation of these programs (like AVHRR on METOP), also the longer the time series is the more reliable the interpretation becomes. In addition, remote sensing data could be more easily used for the regression analysis within the level III of the CGMS to do yield forecasting. It should be possible to find more easily similar years to establish relationships with the ongoing season.

Non sufficient spatial coverage is a shortcoming of sensors like MODIS with higher spatial resolution. The ten day products remain rather cloudy and diminish the interpretation possibilities, but have high demands in terms of data storage.

With the available NOAA AVHRR (1981) and SPOT VEGETATION (1998) time series and the derived value added products of pan-European extent the Remote Sensing Infrastructure of the AGRI4CAST action has valuable data sets for the assessment of vegetation conditions.

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