USE OF SPOT/VEGETATION IN DIFFERENT VERSIONS OF THE EUROPEAN CROP GROWTH MONITORING SYSTEM

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ABSTRACT

The Crop Growth Monitoring System (CGMS) is a GIS-application, developed and operated since 1989 by the MARS-unit of the EU Joint Research Centre. The primary objective is the timely forecasting of the yields of the main crops on the Pan-European continent. To reach this goal, CGMS combines all available (historical and actual) resources: official crop statistics, daily meteorological data, specific crop and soil parameters, the predictions of the (spatialized) crop growth model WOFOST, and the 10-daily composite images of NOAA-AVHRR and SPOT-VEGETATION. In recent years CGMS has been implemented in different regions of the world, also beyond Europe. This paper gives a brief overview of some of these applications, with emphasis on the remote sensing component, especially SPOT-VEGETATION.

In 2000, JRC outsourced the practical operation of CGMS to a consortium composed by Alterra (main tasks, agrometeorological model), MeteoConsult (meteo-provider) and VITO (remote sensing). MARS-STAT delivers the European yield forecasts to the EU statistical office EUROSTAT, in view of the follow-up of market prices and the achievement of the CAP-regulations. MARS-FOOD particularly deals with important food producing areas (Russia, Mercosur) and famine-threatened zones in Africa (IGAD-zone). The long-term goal is to steadily fill the actual data gaps (crop areas, parameters, meteo,...) so that, in time, the full CGMS (incl. the model) could be applied on these areas (or even globally).

Specific versions of CGMS emerged in different countries (Finland, Spain, Kazakhstan,...), running with more detailed input data. One example is the so-called B-CGMS which has been operating since 1998 on behalf of the Belgian ministry of agriculture, in a collaboration between ULg-Arlon, CRA-Gembloux and VITO. Since 2002, the B-CGMS group publishes monthly bulletins with forecasts on crop yields, areas and productions. The areas are delivered by the IACS (annually updated GIS of all crop parcels, maintained for the EU-CAP). Together with local partners, the same Belgian group is now implementing CGMS in China's north-eastern province Heilongjiang, part of former Manchuria and China's main producer of soybean, maize and single-cropped rice. Special attention is being paid to the steady drying-out of this region, which 50 years ago was mainly covered by wetlands and forests. Climate change and mismanaged paddy irrigation are leading to a dramatic lowering of the water tables.

Technically, this paper will focus on the main deliverables derived from NOAA-AVHRR and SPOT-VEGETATION. This includes pre/post-processing, extraction of biophysical vegetation state parameters (NDVI, SAVI, fAPAR, Dry Matter Productivity), differences with regard to the historical year (VCI, VPI, etc.), quicklooks, etc. Of most concern however is the "unmixing" approach, which attempts to conform the remote sensing data (image format, 1 km-pixels, different crops mixed) to the CGMS-standards (databases with district/crop as spatial/thematic units). If the low/medium resolution sensors (AVHRR, VEGETATION, MODIS, MERIS,..) want to maintain their role in this agricultural domain, this problem has to be solved. Otherwise, the floor is open for new, revolutionary initiatives such as DMC (Disaster Monitoring Constellation: daily global coverage at 32m resolution).

Keywords: Remote sensing, agriculture, yield forecasting, global processing.

1. INTRODUCTION

The Crop Growth Monitoring System (CGMS) is a GIS-application, developed and operated since 1989 by the MARS-unit of the EU Joint Research Centre [1].

The primary objective is the timely forecasting of the yields of the main crops on the Pan-European continent. To reach this goal, CGMS combines all available (historical and actual) resources: official crop statistics, daily meteorological data, specific crop and soil parameters, the predictions of the (spatialized) crop growth model WOFOST, and the 10-daily composite images of NOAA-AVHRR and SPOT-VEGETATION (see Fig. 1). By combining these yield figures (ton/ha) with acreage estimates (ha) productions (ton) can be determined. In recent years CGMS has been implemented in different regions of the world, also beyond Europe.

In 2000, JRC-MARS outsourced the practical operation of CGMS to a consortium composed by Alterra (main tasks, agrometeorological model), MeteoConsult (meteo-provider) and VITO (remote sensing). MARS-STAT delivers the European yield forecasts to the EU statistical office EUROSTAT, in view of the follow-up of market prices and the achievement of the CAP-regulations. MARS-FOOD particularly deals with important food producing areas (Russia, Mercosur) and famine-threatened zones in Africa (IGAD-zone). The long-term goal is to steadily fill the actual data gaps (crop areas, parameters, meteo,...) so that, in time, the full CGMS (incl. the model) could be applied on these areas (or even globally).

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This paper gives a brief overview of some of these applications, with emphasis on the remote sensing component, especially SPOT-VEGETATION (VGT).

2. YIELD INDICATORS

2.1 Basic inputs

Basic inputs are SPOT-VGT and NOAA-AVHRR syntheses.

SPOT-VGT S10-products are processed by the CTIV, located at VITO. These 10-daily global VGT-products, including a NDVI-layer, are delivered in Plate Carré projection and have a resolution of 1/112°.

NOAA-AVHHR data over Europe are captured by FU Berlin. After conversion to the classical Level1B-format they are delivered to VITO where they are further processed with JRC's SpacePC software into daily composites. Finally dekadal S10-synthetic images are created based on the Maximum Value criterion.

To enable uniform, standardized processing, all images are converted to a single and widely accepted image format: ENVI, though with "enriched header information". All (input and derived) images are stored in flat, binary files (X.IMG) without header/trailer bytes, while the annotation (geo-referencing, decoding of the values,....) is described in associated ASCII HDR-files with the same basic name (X.HDR). To save disk space, most images are stored in the most compact Byte data type (1 byte per pixel). In principle only two main projection systems are used: INSPIRE-LAEA for Europe and Geographic Lon/Lat for all other areas.

All processing steps (pre-processing, calculation of indictors...) are performed with VITO's GLIMPSE (Global Image Processing SoftwarE), a standardized set of programs which could be regarded as an extension of the ENVI-software (also compatible with IDRISI and ArcView).

2.2 Pre-processing: data compression

The original VGT-S10 syntheses, as delivered by CTIV, have some important drawbacks: they are stored in non-standard HDF-format and occupy large disk space amounts (10 Gb/dekad), mainly because of the redundant sea pixels (75%, no data) and the extremely precise 16-bit Integer data type of some information layers. The conversion to “pseudo-images” (PI) eliminates these drawbacks: all 11 VGT-layers are compressed to 8-bit Byte and all sea pixels are excluded, so that these PI’s only occupy 22% of the original space. Another advantage is that data errors (bits 7-4 in the CTIV status map (SM)) are hard-flagged in the PI-images. In the output SM, only 3 of the 8 bits are used (0/1) to label measurements with snow/ice, cloud and cloud shadow. Further, a 12th PI-layer, is added, containing the NDVI but with hard-coded flags and with GLC2000 functioning as land mask (to remove the sea pixels along the coasts included in CTIV mask, and to distinguish sea from boreal/polar land pixels in dark winter months). Whereas the original PI with the NDVI still contains measurements for SM-labeled pixels (snow/ice, cloud, cloud shadow), in the new version, these pixels are marked with dedicated flags (which erases the original measurements). All PI’s are stored in ENVI/GLIMPSE-format. Although these PI-images no longer have spatial coherence (Fig. 2), it is obvious that they can be reconverted to the normal image format at any moment.

All VGT-S10 syntheses of the past (since April 1998) and a number of external datasets (GLC2000, GTOPO30…) were processed in this way. The majority of the calculations (e.g. DMP) can directly be performed on this PI-archive, which saves a lot of processing time. It also allows us to extract at any moment all the original VGT-S10 information for any region of interest (ROI), reconverted to the normal image format and (optionally) even in any other map projection system.

2.3 Derived products

Table 1 gives an overview of the NOAA-AVHRR and/or SPOT-VGT derived products. A number of products are discussed below in detail.

FULL RESOLUTION IMAGES
1. Actual, 10-daily State Indicators: X=NDVI, SAVI, DMP, LST, NDWI
2. Monthly Indicators (S30) and Cumulative Sums (since start of year).
3. Long-Term Averages (Historical year):

For any X and dekad:
    - Percentiles P0 (Min), P10,…, P50 (Median), …, P90, P100 (Max)
    - Mean μ, standard deviation σ, Nr. of cloudfree observations

4. Difference Images:

For any X and Dekad:
    - With regard to Previous year
    - With regard to Historical year (incl. VCI, VPI, …)

QUICKLOOKS
    - Reduced resolution
    - Added: Legend, grid, vectors,…

UNMIXED INDICATORS: DATABASES WITH REGIONAL MEAN VALUES
    - For any X and Dekad
    - Optionally “UNMIXED” ’ Regional Means per Crop or Land Cover Class
    - Required for compatibility with other CGMS-Inputs/outputs

Table 1. *Overview of NOAA-AVHRR and SPOT-VGT derived products*

2.3.1 Actual vegetation indices

The “Soil Adjusted Vegetation Index” or SAVI was first proposed by Huete [4] as an alternative for NDVI, because it is less sensitive to variations in the reflectance σ of the soil background (which are irrelevant for the estimation of the state of the vegetation itself).

The SAVI combines the best of two things: just like NDVI it can easily be computed from the RED and NIR reflectances without too much external information, and on the other hand, in the NIR vs. RED diagram the SAVI-isolines follow a configuration which closely ressembles the one of the LAI-isolines, as predicted by complicated canopy reflectance models.

In other words, without aiming to quantify the vegetation state (LAI, soil cover or fAPAR), SAVI is better correlated with the vegetation state than NDVI.

"Land Surface Temperatures" (LST) are computed for NOAA-AVHRR with the simple method of Price [5], based on the brightness temperatures of channel 4 and 5.

"Dry Matter Productivity" (DMP, in kg/ha/day, Fig. 3) or the increase in dry matter biomass on a daily basis is calculated following the approach of Monteith [6].

$$DMP_1 = R_1 \cdot 0.48 \cdot fAPAR_1 \cdot \varepsilon(T_{12}, T_{24})$$

R1 is the incoming shortwave solar radiation which on average comprises 48% of PAR (Photosynthetically Active Radiation) and fAPAR1 is the PAR-fraction absorbed by the green vegetation.

The efficiency-term is function of two components ($\varepsilon = \varepsilon_1 . \varepsilon_2$): photosynthetic efficiency e1 and autotrophic respiration ε_2. Whereas e1 depends on T_{12} (day), ε_2 depends on T_{24} (day+night), which is generally lower.

These parameters are computed as follows: $T_{12}=T_{min}+ 0.75*(T_{max} - T_{min})$ and $T_{24}=0.50*(T_{min} + T_{max})$.

The practical implementation goes as follows:

- Step 1: "External" meteo-data is converted to image format. The resulting images follow the standard ENVI/GLIMPSE format and are (basically) projected in their native map system. But with some precautions, the data can simultaneously be reprojected as well. In practice, we only convert the 3 variables, requested for the computation of DMP: T_{min}, T_{max} and Solar Radiation.

- Step 2: The basic Monteith-approach is implemented on the daily meteo-images, which have a "very low resolution" (VLR) as compared to the "low resolution" (LR) VGT/AVHRR data. This results in a new, VLR and INTEGER image, called $DMP_{max,1}$, which contains the DMP valid for the case where fAPAR=1.

- Step 3: All DMPmax,1 scenes of a certain dekad are then composited with a mean filter to a new dekadal image $DMP_{max,10}$.

- Step 4: The final DMP-image (LR, Integer, S10) is computed:
  First input is the LR remote sensing image with fAPAR (or NDVI from which fAPAR is derived) Second input is the VLR $DMP_{max,10}$ – which at first is upgraded to the LR resolution by means of bilinear interpolation (this removes "squares" caused by gridded input). All that needs to be done is a simple multiplication: $DMP_{10} = fAPAR * DMP_{max,10}$.
  The output image is spatially conform to the LR remote sensing image.

2.3.2 Difference products

Difference images are computed for different ROI's, sensors (VGT, AVHRR), variables (NDVI, SAVI, DMP, LST), periods (S10, S30) and with different references (previous year, historical year) and operators (absolute, relative, ...).

An overview of these difference products is given in Table 2.

REFERENCE	FORMULATION
Previous Year	ADp(y,p) = X(y,p) - X(y-1,p)
	RDp(y,p) = [X(y,p) - X(y-1,p)] / X(y-1,p)
Historical Year	ADVI(y,p) = X(y,p) - μ(p)
	RDVI(y,p) = [X(y,p) - μ(p)] / μ(p)
	SDVI(y,p) = [X(y,p) - μ(p)] / σ(p)
	RRVI(y,p) = [X(y,p) - MIN(p)] / [MAX(p) - MIN(p)]
	HPVI(y,p) = Historical Probability of X(y,p) [0% for MIN(p), ..., 100% for MAX(p)]
	HCVI(y,p) = HPVI(y,p) classified in 5 or 10 probability classes

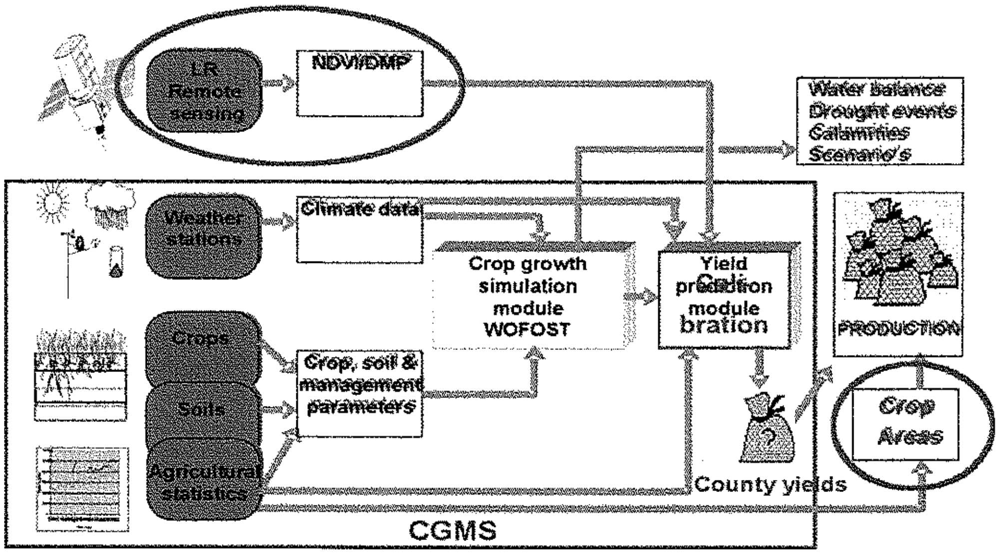

Fig. 1. European Crop Growth Monitoring System (modified version of the FAO-scheme)

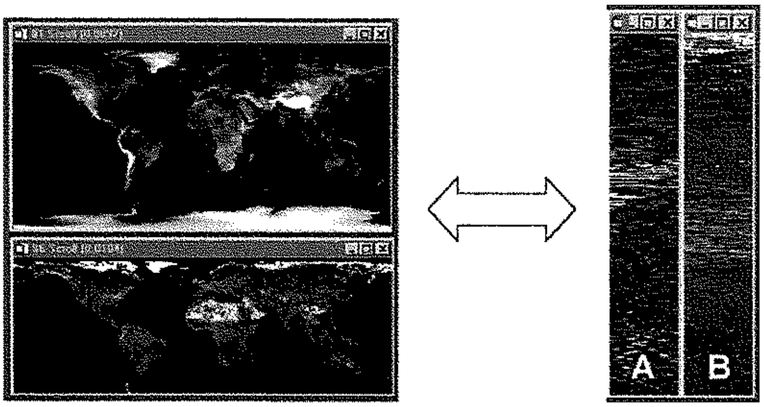

Fig. 2. (A) GTOPO30 map and (B) VGT-S10 synthesis: "normal" images (left) vs. "pseudo-images" (right)

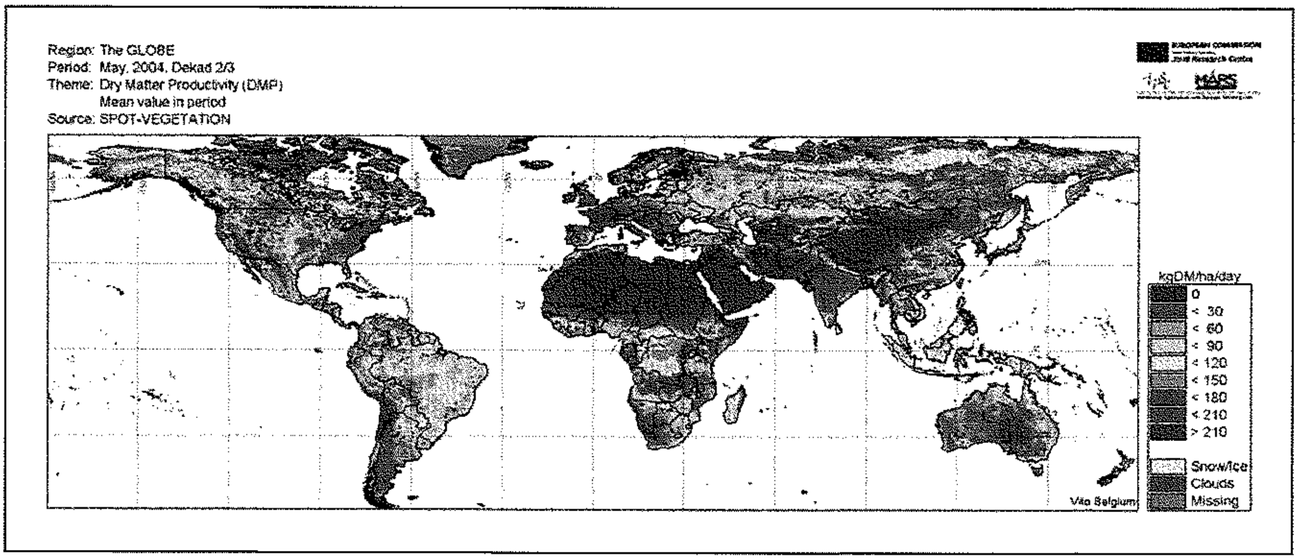

Fig. 3: *Global Dry Matter Productivity (DMP in kg/ha/day) for the second Dekad of May 2004. When applied to NDVI, the RRVI (Relative Range Vegetation Index) corresponds with the VCI (Vegetation Condition Index; Kogan [7]), and the HCVI with the VPI (Vegetation Productivity Index; Sannier et al. [8]). The principle of HPVI/VPI is explained in Fig. 4, for the case of NDVI.*

The green line represents the cumulative histogram, which is derived from the historical values available for the considered period. The red line, which connects the selected set of percentiles, forms an approximation of the true histogram. The figure only shows 6 deciles (P0, P20,..., P100), but in fact we work with 11 deciles (P0, P10,...). New observations are referenced to this (approximative) histogram, which allows to derive their historical probability. The example (blue point) has a relatively high NDVI and hence a high probability (89%). Sannier et al. immediately classified the probabilities in 5 groups (HCVI: 0-20%,..., 80-100%). We however keep the original probabilities (BYTE: in steps of 0.5%). The classification is only performed at the level of the QuickLooks.

2.3.3. Unmixing

Official agro-statistics as well as the CGMS-simulated forecasts are provided in the form of databases which contain the concerned information (acreages or yields) per region and per crop. In low resolution imagery however, the spatial unit is formed by the 1km-pixels which are "mixed" by definition (covered by different land use types or crops). In view of compatibility, it is thus necessary to extract databases with the mean image value for each agro-statistical region (county). At the same time, efforts can be made to make the regional means also "crop-specific". Applied techniques in this context are the CNDVI-technique (based on CORINE landcover maps) of the European MARS-project and the Linear Unmixing approach.

The CNDVI-method developed by Genovese et al. [9] computes regional NDVI-means, weighted according to each pixel's acreage covered by the landcover class of interest (e.g. agricultural arable land: percentages are stored per pixel: "Area Fraction Image"). Fraction thresholds can be specified per land cover type: pixels for which the fraction covered by this land cover type falls below this threshold (e.g. 20%) will not be included in the computation. At the European level the CORINE land cover map is used to determine the area fractions per landcover type, for Belgium the IACS data set was used (Fig. 5 – left graph). Another variant of the CNDVI-technique uses the GLC 2000 classification for unmixing purposes at global scale. In this case the regional means are not weighted (only 0 or 100% belonging to a certain crop type). Of course, this "CNDVI"-method is also applicable for other indices like DMP, SAVI, TS, etc.

The method of linear unmixing assumes that the optical signal yp, registered for the mixed 1km_-pixel p, is equal to the weighted average of the pure signals xk of the Nk individual terrain classes/crops, with the sub-pixel surface fractions fpk as weights (yp = Sfpk.xk). For a homogeneous area of Np pixels one obtains a system of Np equations, from which the pure signals xk (regional means) can be retrieved with a simple matrix inversion. In this case, for Belgium (Fig. 5 – right graph), the required surface fractions fpk were extracted from the IACS data set.

While the image products (especially quicklook images) are mainly used for qualitative crop monitoring (detection of problem areas, comparison with the previous year or with the long term average…), regional unmixed indicators can be used in a quantitative way. They are combined with historical yield statistics, weather indicators, simulated crop indicators to forecast crop yield (see also Fig. 1).

3. ACREAGE ASSESSMENT

Agro-statisticians are mainly interested in the total production (kg) per crop. These are not only determined by the mean yield levels (kg/ha), but also by the cultivated areas (ha).

The classical methodology for detailed crop mapping and subsequent acreage assessment is based on the segmentation and "hard" classification of high resolution imagery of Landsat-TM/ETM+ like sensors (resolution of 30m for the multispectral image layers, 15m for the panchromatic band, which corresponds more or less with the minimum field size in most areas). This approach is demonstrated for the Chinese province Heilongjiang on two predominantly agricultural test areas, which correspond with full Landsat-frames (about 185x185km^2): the Songnen plain in the north of Harbin and the Sanjiang plain (or Three River plain) in the northeast against the Russian border (Fig. 6).

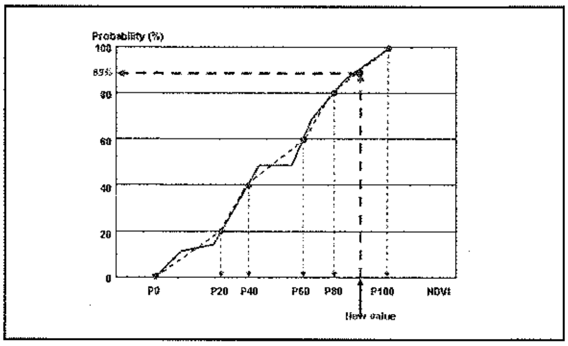

Fig. 4: Principle of the HPVI (or VPI when applied on NDVI)

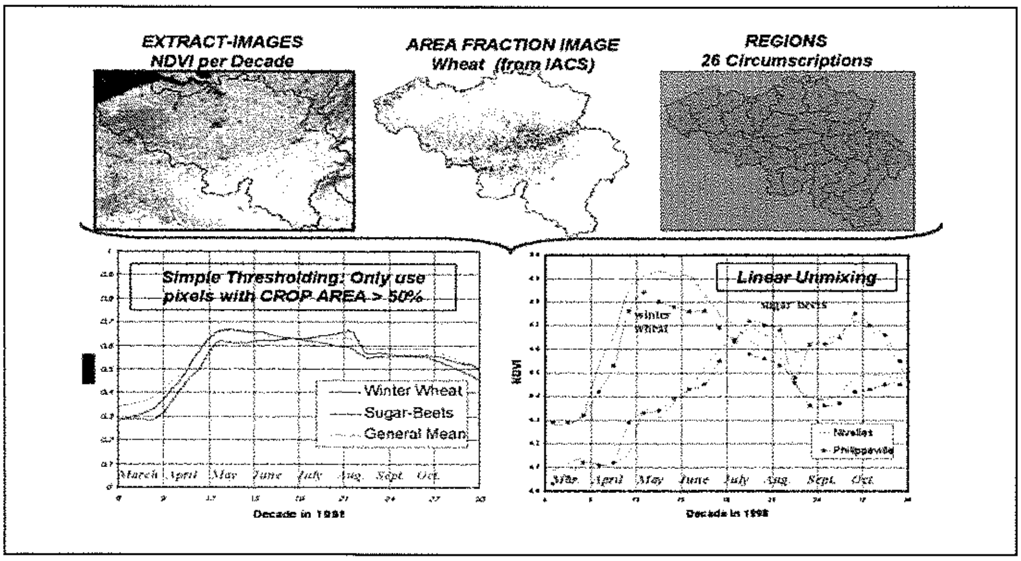

Fig. 5: Regional unmixing for Belgium. Input = VGT-S10 NDVI image, crop type: IACS-derived AFIs, administrative regions: agro-statistical circumscriptions. Left graph: result of the Simple Thresholding approach; Right graph: result of Linear Unmixing approach

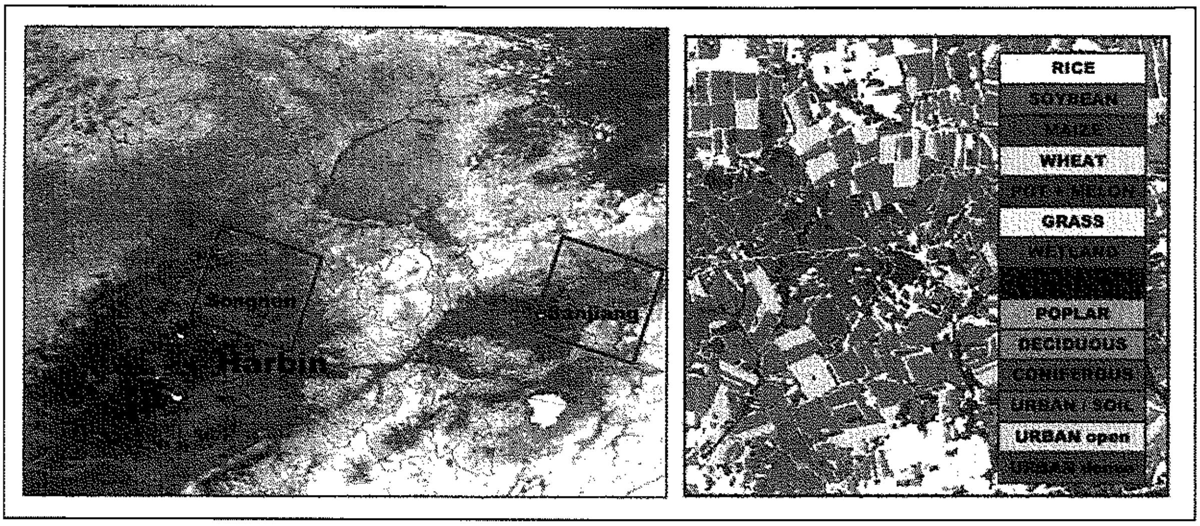

Fig. 6: Left: Heilongjiang Province: Songnen and Sanjiang testsites for high resolution classification; Right: Extract of the high resolution classification for the Sanjiang testsite in 2002 with Landsat-ETM+

Disadvantages of this method are the high costs for image acquisition and field surveys (to collect ground truth data), which make it difficult to apply this approach to large areas. Another drawback is the low temporal frequency of the high resolution image acquisitions, resulting in a low number of available, unclouded registrations over the growing season. In this context, new initiatives as DMC (Disaster Monitoring Constellation), a constellation of 5 microsatellites that will provide global images at 32m resolution on a daily basis and free of charge, could become interesting.

"Hard" classification of low resolution images gives less interesting results for agricultural applications, because a low resolution pixel (1x1km) most often contains mixed culture types. The "hard" legend will thus contain a number of mixed classes (ecosystems). However, the advantage of using low resolution images is that they are freely available, they cover large areas and have a high temporal frequency. As a solution, "soft" or sub-pixel classification methods have been developed for 10-daily (or monthly) low resolution images from the AVHRR and VEGETATION sensors. Just like the "hard" classification methods, the "soft" approach considers two steps: Extrapolation: The application of soft, sub-pixel classification procedures, e.g. neural networks (NN), on the low resolution image set results in a set of "Area Fraction Images" (AFI), one for each of the N considered classes/legend units. These AFIs have the same spatial resolution as the underlying input image sets (low resolution) and give for each pixel the area fraction occupied by the considered class (sum of this fractions per pixel equals 1 or 100%). Prior calibration: All procedures must be calibrated (the weights of the NN have to be determined) using ground truth provided by high resolution classification, covering part of the considered area. To that end, the high resolution classification maps are spatially degraded and converted to AFIs, compatible with the low resolution images to be classified.

Fig. 7 shows AFIs of (part of) Heilongjiang for broadleaf forest, soybeans and wetland. These AFIs are derived by extrapolation of high resolution classification results of the Sanjiang test site over the entire province using monthly SPOT-VGT data. The AFI for soybeans shows that this crop is only cultivated on the Chinese side of the border (the upper red line in Fig. 7 (at the right) indicates the Russian-Chinese border), while on the Russian side the main area is occupied by wetlands, which corresponds with the local field survey observations.

The AFIs will not show as many details as the high resolution classifications and the individual parcels will not be distinguishable anymore. However, the regional area statistics per agro-statistical district and per crop can be derived, just as reliable as in the high resolution mapping. It suffices for each agro-statistical district and crop to make the sum of the concerned pixel fractions. This approach is an interesting and more cost-effective alternative for hard classification and allows large scale extrapolation of costly knowledge, gathered with a limited number of high resolution frames.

4. CONCLUSIONS

The CGMS provides more precise and earlier information about yield and acreages than classical methods (e.g. official statistics). This is shown in Fig. 8, where the monthly RMSE of the MARS yield estimates for barley (in the UK) and the corresponding RMSE of the official EUROSTAT (ex-post observed) yield figures are compared over the season.

Imagery of SPOT-VGT contains useful information on the actual state and final yield of crops, in spite of its low resolution and mixed signal (Fig. 8). Most often, image-derived indicators significantly improve the statistical calibration. Therefore it is important to assure the future of operational "agricultural" sensors as VGT.

This paper discussed a number of image-derived yield indicators, but obviously this list is not limited. Better indicators could be added, e.g. indicators as soil cover or fAPAR derived from canopy reflectance models.

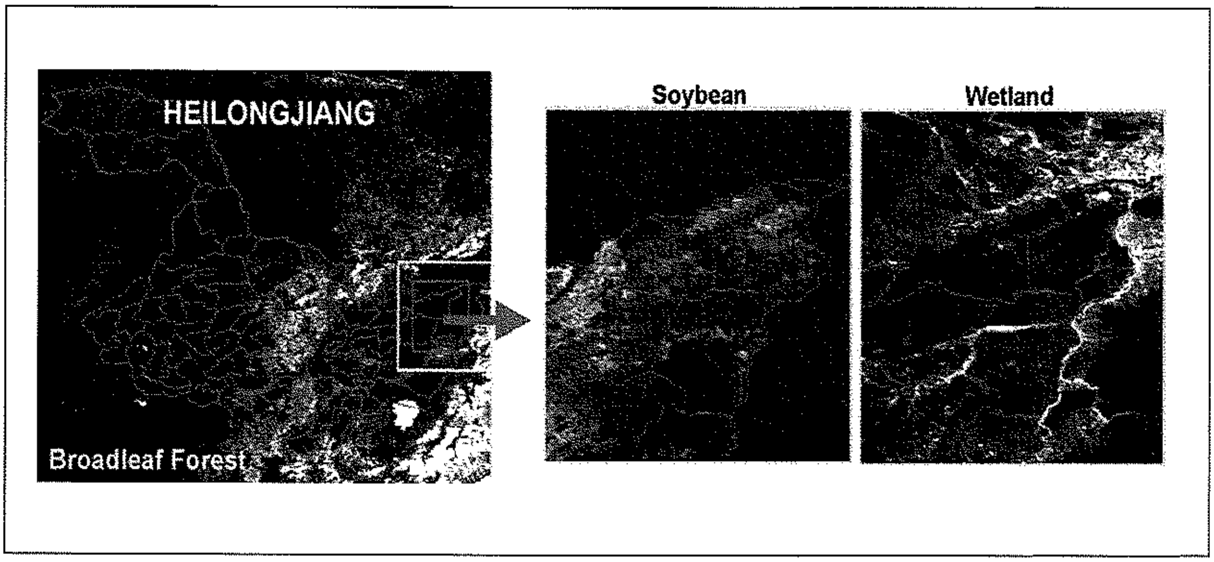

Fig. 7: Area Fraction images for the Chinese province Heilongjiang (left) and the Sanjiang Plain (right): extrapolation of the high resolution classification results of the Sanjiang Plain (2002) over the entire province with monthly SPOT-VGT data.

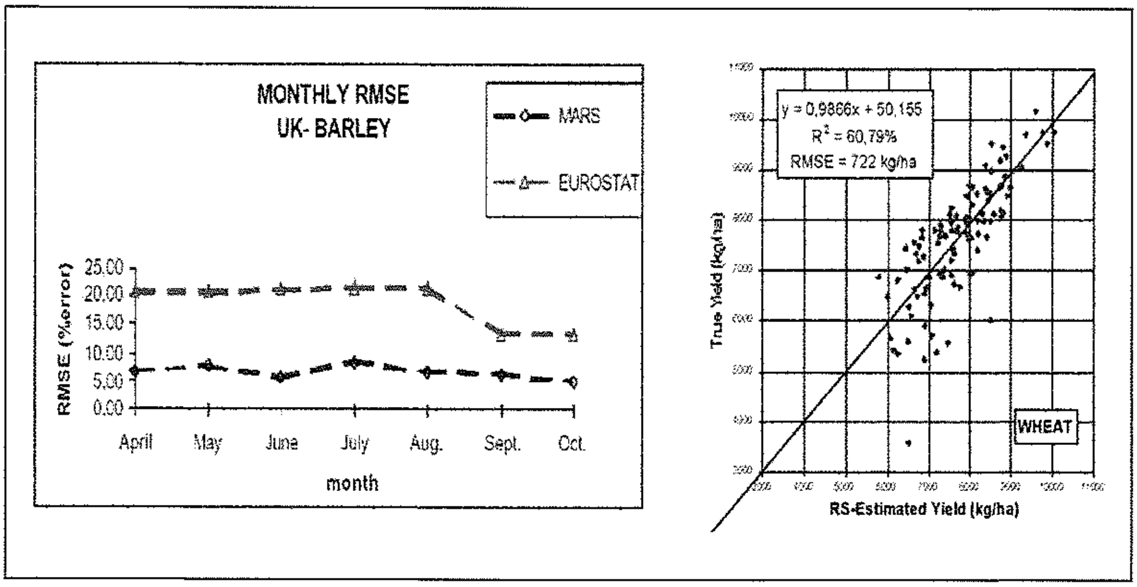

Fig. 8: Comparison of Eurostat and MARS statistics: monthly RMSE for barley, UK (left – source: MARS-STAT) and comparison of true yield and yield estimated with remote sensing: winter wheat, Belgium (right)

5. REFERENCES

1. Boogaard, H., Eerens, H., Supit, I., Diepen, C. van, Piccard, I. and Kempeneers, P., (2002). Description of the MARS Crop Yield Forecasting System (MCYFS). METAMP-report 1/3, Alterra, Supit Consultancy and VITO, JRC-contract 19226-2002-02-F1FED ISP NL.

2. Flores, L., Marin, C., (2003). The use of CGMS for climate change impacts and risk assessments at regional and farm levels in Spanish agriculture. Proceedings of the CGMS Expert Meeting, Ispra, Italy, 30/9-1/10/2002.

3. Tychon, B., Ozer, P., Pecheur, C., Oger, R., Decrem, M., Buffet, D., Leteinturier, B., Eerens, H., Dong, Q., (2003). Application of the European Crop Growth Monitoring System (CGMS) in Belgium and in China's North-eastern province Heilongjiang. Proceedings of the CGMS Expert Meeting, Ispra, Italy, 30/9-1/10/2002.

4. Huete, A., (1988). A soil-adjusted vegetation index (SAVI). Remote Sensing of Environment, 25:295-309.

5. Price, J., (1984). Land surface temperature measurements from the split window channels of the NOAA 7 Advanced Very High Resolution Radiometer. J. Geophys. Res., 89: 7231-7237.

6. Monteith, J., (1972). Solar radiation and productivity in tropical ecosystems. Journal of Applied Ecology, 9: 747-766.

7. Kogan, F., (1990). Remote Sensing of weather impacts on vegetation in non-homogeneous areas. Int. J. Remote Sensing, 11, 1405-1411.

8. Sannier, C., Taylor, J., Du Plessis, W., Campbell, K., (1998). Real-time vegetation monitoring with NOAA-AVHRR in Southern Africa for wildlife management and food security assessment, Int. J. Remote Sensing, 19: 4, 621-639.

9. Genovese, G., Vignolles, C., Nègre, T. and Passera, G., (1999). NOAA-AVHRR/NDVI-profiling on CORI NE land cover classes. Proc. IGARSS-Conf., Hamburg, Germany, 28/06-02/07/1999, 3pp.