BACKGROUNDS: AGRICULTURE IN THE EU & THE MARS PROJECT

Given the post-war food scarcities, agriculture has always been a major focal point of the European Union. DG-AGRI, the European Ministry or "Directorate General" (DG) of Agriculture, is responsible for the definition and realisation of a Common Agricultural Policy (CAP) amongst all the EU Member States. To take adequate and fair decisions, DG-AGRI has to dispose of reliable agro-statistics, acquired in a uniform and timely way over the different EU member states. EUROSTAT (Luxembourg) is responsible for the collection, final approval and distribution of all EU-statistics. But in the agricultural domain, these "official data" generally become available with a delay of at least one year. Often too late to take urgent ("within season") decisions on commodity trades, farmer support, indemnifications for natural hazards, etc.

In this context, the EU started the MARS project (*Monitoring Agriculture by Remote Sensing*) in the year 1988. The project co-ordination was given to the DG-JRC (Joint Research Centre), hosted in Ispra, Italy. Over the years, JRC had to face many challenges:

- Around 1988, each member state still followed its own agro-statistical approach, largely based on traditional methods (paper, farm enquiries,...). Primary target of the MARS project was to harmonize the methodologies amongst member states and to promote new approaches such as the use of computers, GIS, GPS, Remote Sensing (RS), enhanced agro-statistical analysis methods, etc. One of the goals was to obtain better insights in the evolution of the crops and pre-harvest estimates of the final yields – earlier than EUROSTAT. This modernisation is still going on. But as the contribution of RS is now generally acknowledged, the acronym MARS has been re-baptized into "*Monitoring Agricultural ResourceS*".
- Whereas in 1988 there were only 12 member states (EU12), over time the EU expanded towards 28 countries (EU28). Austria, Finland and Sweden entered in 1995. Ten other countries (from Cyprus to Slovenia) came in in 2004. Bulgaria and Rumania joined the EU in 2007, Croatia in 2013. Nowadays, one state wants to leave the union... That always asked for new efforts and adaptations.
- The initial focus was on the provision of data over the EU Member States to DG-AGRI and EUROSTAT. But already in the previous century, it was steadily extended to other countries (Eastern Europe, Maghreb, main food producing countries,...) and even to the entire globe. Thereby providing essential information to other EU-Ministries such as DG-AIDCO (International Co-operation and Development) and DG-ECHO (Humanitarian Aid).

Actually, amongst all other policies (work, health, environment, migration,...), agriculture is the only one which is almost entirely covered by the EU budget. In other words, the national expenditures are largely replaced by the EU-contributions. This justifies the relatively high share of agriculture in the EU-budget. In 2017, the total EU-budget amounted to 158 G€, which on the average corresponds to 1% of the GDP of all involved 28 member states. But the share of agriculture systematically declined over the years. From 70% in 1985, it decreased to 30% of the budget in 2013. Plus 9% for rural development, which earmarks the shift in focus towards greener and more sustainable policies. See more on: https://europa.eu/european-union/about-eu/money/expenditure_en.

THE EU-MARS PROJECT IN PRACTICE

Omitting the important animal sector and focusing on cropland, JRC-MARS has different focal points:

1. **Crop mapping and area estimation**: Initially, JRC launched some isolated projects to reveal the per-annual areas of the different major crops within the EU. They used field surveys, based on segment or point-based sampling methods.
   But this all changed in 1992. Until then, the EU had a system of guaranteed minimum prices per crop, with internal storages and taxes on imports and exports. But under impulse of WTO this system had to be abandoned and replaced with the introduction of the new CAP (McSharry-plan), where farmers started to receive area-based primes (for instance around 400€/ha for cereals in Belgium). To receive these primes, since then all farmers annually provide a map of their fields (plus the concerned crops) to their national ministries. In this new approach JRC has different roles:

   - Promotion of new GIS techniques to acquire and manage all data at national level.
   - Overall control on consistency in a spatial and temporal sense: overlap of declared parcels, improbable changes, etc. High-resolution remote sensing images are used to check the declared parcel boundaries and crops.
   - Setup of an overall database (per country and for the entire EU), with all parcel information. Somewhat blandly, it is called IACS (Integrated Agricultural Information System).

   Since a few years the area-based primes are also diversified, depending on environmental measures (non-cultivated field edges, pasture cutting times,...) and this policy will even be enforced in the future CAP.
2. **Pre-harvest monitoring of the crop state and yield estimation**: As mentioned, EUROSTAT is late in the provision of yield numbers. Within-season yield estimates are of crucial importance for the world trade of food commodities. JRC-MARS nowadays provides the requested information (European or global), via a combination of different resources: meteo-data, crop growth modelling, remote sensing, etc. The results are carried over to EUROSTAT and DG-AGRI but downstream as well to many global players such as the International Grain Council. All these organisations have a direct impact on food prices, local and global.
3. **Derived actions**: These use the results of the previous activities (areas, yields), possibly with other contributions (modelling, climatological scenarios, ...) to enter other domains, such as the setup of crop insurances, environmental issues such as biodiversity in the agro-domain and the effects of climate change on crop production.

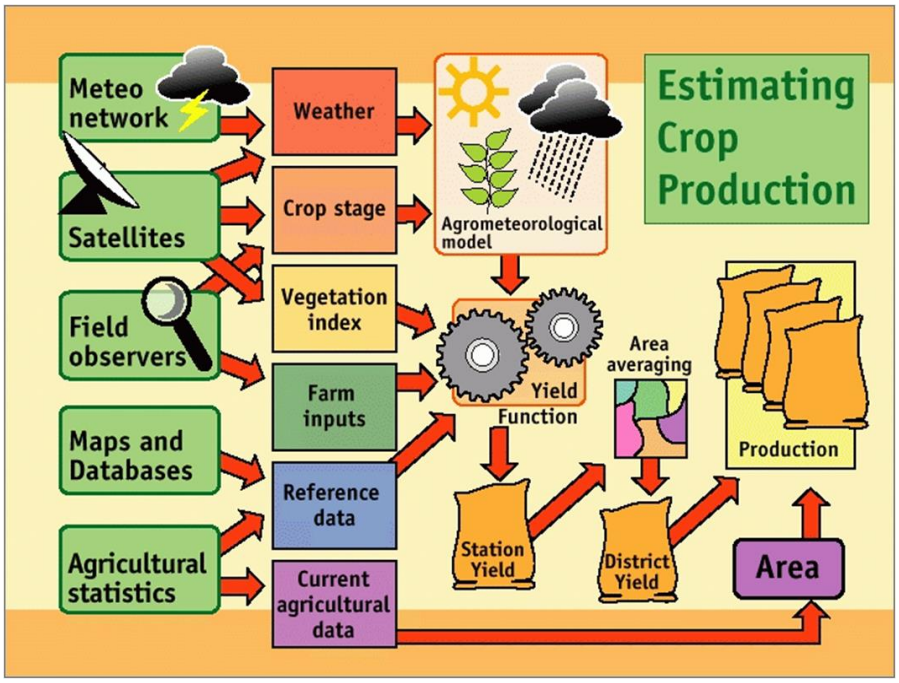
YIELD ESTIMATION VIA THE MARSOP-CONTRACTS

VITO-TAP is active in the above three domains. But this document specifically deals with our MARS actions in the context of the pre-harvest monitoring of the crop state and yield estimations (see point 2 above). The general approach is outlined in the figure below (from René Gommes, ex-FAO).

According to EU-legislation, since 2000 this activity has been outsourced via the so-called "MARSOP" contracts to a consortium of different partners, each providing the following information (for Europe and the globe):

- Meteo-Group (Berlin): Daily information on the most relevant AgroMet variables.
- VITO: Ten-daily image data (per dekad), derived from different satellites (see further below).
- Alterra-NL: Yield estimates (per crop and administrative region), derived by means of the CGMS-model (a spatialized version of the well-known WOFOST crop growth model).

But at the end all these data arrive at JRC, and it is JRC-MARS who compiles them into final yield estimates (per crop and region). Nowadays, JRC-MARS produces agro-meteorological bulletins on a monthly basis for Europe, and for other regions in the world as to the needs.



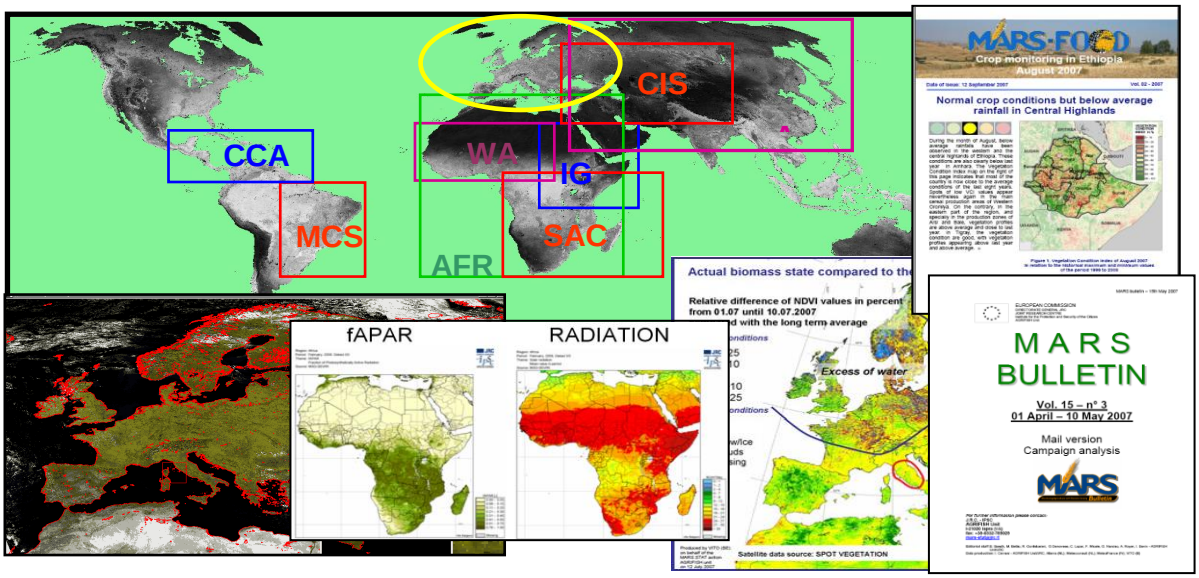
VITO'S ROLE IN JRC-MARSOP

VITO entered into the project around 2001, and today we are still part of the game. Within the yield forecasting segment of JRC-MARS, VITO is responsible for the remote sensing component (RS). In this context, JRC always asked for synoptic imagery with rather coarse resolution (250m to 5km) but with broad coverage and sufficiently high (10-daily) frequency to monitor the vegetation dynamics. Below we summarize the major realisations, omitting all details (the last 17 years were spread over four different MARSOP-contracts, each with varying contents):

- Data collection from different sensors:
  - Global at 1km resolution: SPOT-VGT, PROBA-V and METOP-AVHRR. Nowadays, the focus is shifting towards the improved imagery provided by the Copernicus Global Land Service.

- Europe: NOAA-AVHRR (1km), TERRA-MODIS (250m), MSG-SEVIRI (5km).

- The focus has always been on ten-daily composite images (S10). For VGT, PROBA and Copernicus, these were delivered internally by VITO-colleagues (TAP-CVB), but for the other satellites (NOAA, METOP, MODIS, MSG) similar pre-processing chains had to be developed to collect the raw data and transform them into S10-images. This was always realised in collaboration with CVB.
- In addition to the classical NDVI (Normalised Difference Vegetation Index), more advanced vegetation indicators were developed:
  - FAPAR, FCOVER and LAI, derived via Neural Networks from the original observations (reflectances, sun/view angles).
  - Model-based indices which combine the RS-information (FAPAR) with meteorological data in order to estimate "Dry Matter Productivity" (DMP). In many cases, this DMP appeared to be better correlated with "official yields" than NDVI or FAPAR.
  - Long-Term Statistics (LTS) computed per dekad over the years, and "anomalies", which compare a current dekad with its LTS-analogue. These anomaly maps clearly show the spatial extent of the problematic regions with growth retardation.
  - Unmixing methods which provide per dekad a RUM-file (Regional Unmixed Means), with the mean of the concerned variable (NDVI, DMP,...) over all pixels in a given region, dominated by a given land use type or crop.
- Every dekad, all the new data for the different sensors, regions, indicators and formats (images, quick-look maps, RUM-files) must be quality-checked and delivered in "near-real time" to JRC, for ingestion in the overall MARSOP database and website. And every year in January, all the long-term statistics must be re-computed as well as all the derived anomalies.



The JRC-MARS unit in Ispra-Italy collects all the information (weather data from Meteo-Group, RS-images from VITO, CGMS-based estimates from Alterra) and then applies a range of statistical methods (trend analysis, regression, scenario analysis, ...) to estimate the final yields per crop and

per administrative unit. This process is systematically repeated in the course of the season. The resulting pre-harvest estimates are always sent to DG-AGRI and EUROSTAT and published in the agro-meteorological bulletins.

Some more clarifications:

- Obviously, within the context of these MARSOP projects VITO does not directly deliver yield estimates, only 10-daily "yield indicators" such as NDVI, FAPAR, DMP, etc.
- In a spatial sense, JRC-MARS provides yield estimates for the three highest levels of "administrative units", included in the EU NUTS maps (Nomenclature des Unités Territoriales Statistiques): countries (NUTS1), provinces (NUTS2), districts (NUTS3). The project does not attempt to retrieve information at the more detailed pixel or parcel levels.
- As a consequence, JRC-MARS is not really interested in the more recent type of RS-imagery with higher resolution such as Proba-100m and Sentinel2-10m. The more because these data sets lack long-term series and would involve extra costs (storage, setup of new processing chains, etc.). JRC-MARS is a client which remains satisfied with 1km data.
- All agro-statistics are collected, prepared and reported per crop and per administrative region. This information is typically stored in databases. Hence, JRC-MARS is mostly interested in our RUM-files (see above), and far less in the underlying images. At most, the latter are sometimes used as illustrations in the agromet bulletins. On the other hand, the complete RUM-information (sensors *x* indicators *x* regions *x* crops, all per dekad) is stored in a dedicated Oracle database, from which it can be analysed together with the other resources (weather, CGMS).
- But why remote sensing? The core of the JRC-MARS yield forecasting system is based on "models": crop growth models or statistical methods. Both have the tendency to narrow down on the "normal behaviour", but they often fail in the case of exceptional events. JRC has always emphasized that the "objective observations" of RS can significantly improve the final results.

CONCLUSIONS: VITO'S PROFITS, SPIN-OFFS AND FUTURE

The core MARSOP contracts covering the period 2001-2017 sufficed to fulfil all contractual requirements, but they also provided opportunities to write scientific papers and to start new collaborations, projects, researches and software developments.

MARSOP always had an important R&D component. This resulted in new methods for data smoothing, extraction of phenological parameters (start/end of season), image classification, yield estimation via similarity analysis, and many more.

MARSOP also instigated many other VITO-projects and collaborations, for instance:

- With JRC: RNA (reprocessing of NOAA-archive), METAMP (documentation of MARS-history), AseMARS (inclusion of MODIS and MSG), etc.
- Without JRC (only recent years):
  - ASIS: Set-up of a METOP-based global drought monitoring system for FAO-GIEWS.
  - FRAME: Idem but more detailed over Africa.
  - Copernicus: Regular delivery of 10-daily DMP images.

- Projects with partners in other countries such as Morocco (INRA, CRTS), Senegal (IFAD), China (Harbin, Asia-ITC).
- Free data delivery to the OGN “Acción contra el Hambre” (Madrid) over the Sahel region.
- Etc.

As to the software, we already mentioned the new pre-processing chains for NOAA, METOP, MODIS and MSG. But these Linux-based procedures remain “in-house”, maintained by CVB. Apart from that two Windows software packages should be mentioned, which rather focus on the further post-processing of dekadal S10 time series:

- GLIMPSE: From the very beginning (2001), it was attempted to program all MARSOP procedures in a most generic way. That means: operational for any sensor, resolution, indicator, etc. Over the years this resulted in a set of ANSI-C programs called GLIMPSE (GLobal IMage Processing SoftwarE), all working in Command Line mode (alias DOS), which facilitates their incorporation into “scripts” and the setup of automated processing chains. Nowadays, GLIMPSE is also used in many other projects (at VITO and JRC).
- SPIRITS: This is a Graphical User Interface (GUI) which allows to run the majority of the GLIMPSE modules in a standard Windows-based environment. In addition, it provides a lot of other functionalities such as format conversions, vector rastering, graphical analysis tools, etc. The SPIRITS software is developed by VITO on behalf of JRC-MARS. It is freely available and its latest version can always be downloaded (together with manual, tutorials and test data) from http://spirits.jrc.ec.europa.eu/. SPIRITS is used by many offices around the world to prepare agro-meteorological bulletins.

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