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The integrated utilization of satellite images in Hungary: operational applications from crop monitoring to ragweed control

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ABSTRACT: In Hungary, the foundation of systems based on remote sensing goes back to 1980, when the Remote Sensing Centre (RSC) of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI) was established and started the research and development and later the operational applications. The National Crop Monitoring and Production Forecast Program (CROPMON, 1997-2003) has been the flagship product for several years. It provided area assessment and yield prediction for the 8 main crops grown in Hungary, at county and country level. The integration of ‘‘traditional’’ low, medium and high resolution images served as the best basis to carry out the CROPMON operational project.

The research and technological basis of CROPMON made it possible to establish several further operational projects. Land Parcel Identification System (LPIS) provides a unified reference for the farmers’ area-based agricultural subsidy claims and the control procedure. Remote sensing is a legally established, widely applied method for the subsidy control. The determination of crops within the control and the confirmation of land use in LPIS is carried out with high resolution image series. However, in the past years the importance of very high resolution (VHR) images has grown in parallel with the regulatory changes that has made the control stricter and more precise.

In 2005, a special operational endeavour has put the focus again on the medium and high resolution images: the ragweed monitoring and control. In Hungary, some 500 000 – 700 000 hectares was estimated to be covered by ragweed. About 80% of that area can theoretically be pinpointed by HR remote sensing on arable land. Some 28 – 40 M € / year is spent for medication and medical visits, tests because of the allergenic effect of the ragweed. Public movement for pushing back the encroachment of the ragweed resulted in legal actions. To adjust to the nature of the quick ragweed development the amendment of the plant protection law is revolutionary. It authorizes the government for elimination of ragweed spots almost immediately after their detection. FÖMI RSC has been operating a complex yet efficient control system using remote sensing. This system requires only the fraction of the medical costs for its operation. In 2005, the control system consisted of a retrospective analysis for 2004, the detection of non-cultivated

arable spots and the inspection of cereal stubble. The remote sensing identification of the areas contaminated with ragweed is far harder that that of crops. The detailed description of temporal progress plays an essential role in the detection. The survey is carried out with the simultaneous usage of medium (IRS AWiFS) and high resolution (Landsat TM) images. Our experience justified that remote sensing can drive an efficient ragweed control system.

1 INTRODUCTION

In Hungary, Remote Sensing Centre of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI) plays central role in the research and the operational applications related to remote sensing. FÖMI is the research background institute of the Ministry of Agriculture and Rural Development. Beside the management and support of land survey tasks, its most important task is currently the remote sensing support of EU-financed agricultural subsidies. In this article, we will introduce the projects that served as the basis of all other remote sensing applications, and we will show an innovative example of how remote sensing and geographical information systems support the society in fighting against an aggressive allergenic weed. We will see how the knowledge, the experience and the technology gained in a project can be used in other operational applications.

2 THE OPERATIONAL CROP MONITORING AND PRODUCTION FORECAST PROGRAM

In Hungary, the foundation of systems based on remote sensing goes back to 1980, when the Remote Sensing Centre (RSC) of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI) was established and started the research and development, which provided the basis for the operational applications later. The direction of the development was always determined by the demands in the agriculture. The Hungarian Agricultural Remote Sensing Program (HARSP, 1980-) provided the basis for the introduction of remote sensing to support the agro-information system in Hungary. On the basis of HARSP, applications turned into operational phase in 1997, when the National Crop Monitoring and Production Forecast Program started. It used the classification and quantitative evaluation methods developed by FÖMI, under the years of HARSP. The task of CROPMON was to support the economical decisions via providing data on the agricultural production. It provided area assessment and yield prediction for the most important crops (winter wheat, winter barley, spring barley, maize, silage maize, sunflower, sugar beet, alfalfa). The output consisted of maps and tabular data. The evaluation provided data at country level and for the whole country, by a schedule in line with the existing production forecast system.

CROPMON was an integrated system in which both the crop mapping and the development monitoring was carried out with purely remote sensing, instead of e.g. an agro-meteorological model. The usage of traditional ground methods was limited to the preparation of the framework (for example, in the determination of regions that were the basic units of processing) and in reference data collection (limited to 2-4% of the whole examined area).

The crop area assessment provided two kinds of output: crop maps and total areas of the main crops. These were the results of the quantitative analysis of high resolution images (Landsat TM/ETM+, IRS LISS, SPOT XS/Xi) acquired at appropriate dates. We used the methodology to produce results for the counties and for the country—the precision and the robustness of the method on these units of areas were excellent. The main data source of the crop mapping was the Landsat TM/ETM+ images that were subscribed for the whole vegetation period. Beside the crop mapping subsystem of CROPMON, this data set was also the basis of other projects. Beyond the direct usage of the high resolution images, some projects used also the output results of it: the crop maps were also used as an auxiliary data source in the remote sensing control of agricultural subsidies, providing an aid to the operators in their parcel-level decisions.

The crop development assessment and the yield forecasting are tasks where the temporal parameters of input data source are even more important than in the case of crop mapping. For this purpose, NOAA AVHRR image time series were used beside high resolution images, that is, low and high resolution images were utilized in an integrated way. Although the AVHRR images' spatial resolution is coarser, we have usually one image per day, which makes AVHRR images suitable for the purpose of the monitoring of the status of the crops. After the starting of CROPMON project, in 1998 an AVHRR receiving station was installed in FÖMI RSC, which has been providing real time AVHRR data. Again, this set of data is not only an invaluable input of CROPMON, but it is continually used in other monitoring projects. The yield forecasting methodology also provided reliable results for the main crops at county and country level. The output of yield forecasting also consisted of numerical and map data – the latter mean yield spatial distribution maps, with the elementary mapping unit of about 5000 ha.

The research, technology and the data sets in CROPMON have laid the foundation for other remote sensing applications.

3 OTHER REMOTE SENSING APPLICATIONS ON THE CROPMON BASIS

The earliest group of applications based on the CROPMON technology is disaster monitoring. Since the end of the 90's, it is usual that some kind of natural disaster happen in Hungary due to the extreme weather. Flood, waterlog and drought can be effectively monitored with remote sensing, utilizing the advantages of different kinds of optical images used also in CROPMON as well as radar images.

In Hungary, 95% of surface water flows in from abroad, which makes flood monitoring and prevention an important, but difficult task. It is vital to have real time data, as the survival and the rescue of humans may depend on the actions based on timely information. The real time monitoring of the extent of inundation and the forecast of its progress can be achieved with the usage of practically all the available low, medium and high resolution satellite images. In FÖMI RSC, operational flood monitoring was carried out in several years since 2000. In contrast with CROPMON, the method here was mainly visual evaluation, this is the most effective way if even fractions of hours may have significance. To fulfill the requirements of real time monitoring, frequent acquisitions are needed, and the images shall be available in very short time after the acquisition. We can state that among the disaster monitoring projects, the time dimension is the most important in the flood monitoring.

Drought monitoring was also carried out several times in the previous years. Among the disaster monitoring tasks, the presence of the numeric, quantitative methods is the strongest in the drought monitoring. This task resembles to the yield forecasting in CROPMON: the physical background and the remote sensing implementation is rather similar to that of crop development monitoring. But the ‘‘scale’’ of drought monitoring is larger, in several senses. While the yield forecasting model makes distinction among individual crop species, the drought monitoring shows the general status of vegetation. The elementary mapping unit is usually larger in case of drought monitoring. In yield forecasting, usually the values of all the individual daily measurements are used, while in drought monitoring the values belonging to a longer time period (some days, e.g., a week or a decade) are treated together. This process is often a retrospective analysis, not a forecasting. To accomplish this task, series of medium and low resolution satellite images are used. Occasionally several different kinds of images are used within one year’s campaign. In the case of crop development assessment and drought monitoring, the methods are rather sensitive to the proper knowledge of the correspondence between physical properties of vegetation and the digital values stored in the images. This is particularly true when different kinds of images are used simultaneously. The derivation of compatible data sets from different sensors is referred to as inter-calibration. With this pre-processing step we can extend the data set available as input, which improves the quality of monitoring within a year and helps in the comparison among several years.

Beside the ‘‘classical’’ types of satellite images known from CROPMON, images from additional sensors are also drawn into the monitoring applications. The aim of the FÖMI-ESA Prodex (2000–2004) and the PECS (2004–2007) project was the introduction of images acquired by the sensors of ENVISAT satellite—namely, MERIS and ASAR—into the disaster monitoring. These projects are coordinated by the European Space Agency (ESA), which is also responsible for the operation of the ENVISAT satellite.

4 EU MEMBER STATE REQUIREMENTS: LPIS AND ITS MANAGEMENT

Nowadays, the most important remote sensing applications are the implementation and the operation of systems that are necessary to manage the Common Agricultural Policy (CAP) of the EU. The largest part of the financial support that is provided by EU to the member states is related to agriculture. The appropriate management of agricultural production and the distribution of financial sources are controlled by the Common Agricultural Policy. The Integrated Administration and Control System (IACS) is the framework for managing the normative area-based applications, area-related animal payments and rural development claims, financed by the European Agricultural Guidance and Guarantee Fund (EAGGF). IACS is operated by the paying agency, which is the Agricultural and Rural Development Agency (ARDA) in Hungary.

Regarding the area-based agricultural subsidies, the Land Parcel Identification System (LPIS, or MePAR in Hungarian) serves as the reference system for claiming and controlling all the agricultural parcels in a country. In Hungary, the reference units of LPIS are physical blocks.

A physical block is an area that is steady with respect to the agricultural cultivation, it has boundaries that can be clearly identified in the field (e.g., road, railway, canal, ditch, forest fringe), and its land use is homogeneous. A block may contain several agricultural parcels, possibly cultivated by different farmers. Inside the blocks, the so-called ineligible areas (i.e., areas for which no area-based subsidies can be paid) are explicitly delimited. The exact delimitation of block boundaries and ineligible areas are a crucial point due to the strict regulation of the subsidies: the official eligible area of a block is the one determined from the geographical delimitation. The geographical database of LPIS contains spatial data and several attributes for each physical block. Approximately 300 000 physical blocks cover the country, providing a wall-to-wall coverage (covering not only the agricultural areas). The average size of blocks is 32 ha.

In Hungary, we are beyond the second full-country LPIS survey. The fundamental data source for the delineation of blocks is the digital ortho-photo coverage. The aerial photographs that served as the basis for the ortho-photos used in the building up of LPIS were acquired in 2000 for the majority of the country, and in 2003 for some smaller parts. The ortho-photo production for the entire country was accomplished by June 2003. The creation of the LPIS database started in October 2002, and was finished by September 2003. The operational usage of LPIS started in 2004, the year of the EU accession. After creating partial aerial photo coverages in the subsequent years, the second full-countrty survey took place in 2005. After the ortho-photo creation, the updating of the nationwide LPIS database started in the autumn of 2005, and finished by the claim submission period of 2006.

To correctly determine the boundaries and the attributes, beside the ortho-photos several image and map data sources were used for LPIS creation and updating. Topographic maps helped in defining stable elements. Multi-annual high resolution multispectral satellite image series were essential in the checking of the land use categories and the permanent boundaries. To further improve the area delimitation inside the blocks during the building up, a data fusion procedure was applied for the year 2000 high resolution images. Their spatial resolution was improved with 5 m panchromatic (IRS PAN) images, which were available for almost the whole area of the country. During the updating in 2006, image data sources were complemented by ‘‘classical’’ on-the-spot measurements.

5 EU MEMBER STATE REQUIREMENTS: REMOTE SENSING CONTROL OF AGRICULTURAL SUBSIDIES

The farmers’ area-based subsidy claims are systematically checked in order to avoid unjustified payments. Administrative checks are applied for all the submitted claims, and a sample of them is the subject of on-the-spot controls. Depending on the meteorological characteristics and certain organizational aspects of the country, on-the-spot controls are carried out either with ‘‘classical’’ field inspection or with remote sensing. Remote sensing is a legally established, widely applied method for these controls. The determination of crops in remote sensing control is carried out with high resolution image series. In the past years the importance of very high resolution (VHR) images has grown in parallel with the regulatory changes that has made the control stricter and more precise.

In Hungary, area-based subsidies exist since the end of the 90's, within national framework. Their introduction served as a preparation to the EU subsidies. After a pilot project for a small sample, FÖMI has been operationally carrying out the Control with Remote Sensing of Area-based Subsidies (CwRS) program since 2000. From 2000 to 2003, within the national framework the subsidy system, including the control, was gradually developed so that it meets the EU regulations and specifications.

Since the EU accession in 2004, a substantial part of the area-based subsidies is financed by the European Agricultural Guidance and Guarantee Fund (EAGGF). The national regulations have to follow the EU legislation. The payments are managed within the Integrated Administration and Control System (IACS). While the regulatory background is the responsibility of the Directorate-General for Agriculture and Rural Development (DG AGRI), the technical specifications of on-the-spot control, and especially, remote sensing control, are managed by the Directorate-General Joint Research Centre. In Hungary, the management of subsidy system belongs to the Ministry of Agriculture and Rural Development (MARD) and the Agricultural and Rural Development Agency (ARDA). Administrative checks and classical field controls are the responsibility of ARDA, while FÖMI carries out the remote sensing controls as a delegated task.

In the EU system, the applications for area-based agricultural subsidies consist of tabular forms and block maps with the drawing of agricultural parcels inside the physical blocks. Block maps are printed uniquely to each farmer. Scanning of the claims and alphanumerical data input is carried out by ARDA. The remote sensing control of the selected claims (dossiers) is the task of FÖMI. This task can be subdivided into two major parts: the digitization of parcel drawings into GIS and the actual remote sensing control using satellite images—the latter is called Computer-Aided Photo-Interpretation (CAPI). The aim of CAPI is to answer two questions for every declared parcel: whether the declared crop can be observed in the parcel, and whether the declared area is correct. High resolution (HR) image time series are used to determine crops, while exact area measurement is done using very high resolution (VHR) images. The fulfillment of Good Agricultural and Environmental Conditions (GAEC) are also checked. After these decisions at parcel level, results are aggregated to the complete dossiers. The results of control are delivered to ARDA in digital and paper form, this consists of tabular and geographical data. The number of dossiers controlled with remote sensing was about 8500 in 2004, it grew to over 11000 in 2005, and somewhat more can be expected in 2006—this sample is considered a rather big sample among the EU states.

The basic data for the crop identification is high resolution image series (Landsat TM/ETM + , IRS LISS-III and SPOT XS/Xi). The Commission gives financial support to the satellite images used for the control. Regarding the high resolution data, they primarily provide SPOT images, these constitute the standard image set of the control. As in Hungary the number of crop species is relatively high, it is useful to complement the standard images with additional ones—this need is usually covered by the subscribed Landsat images mentioned earlier. As an indirect supply derived from the HR images, the crop map generated in the CROPMON project was also used, when it was available. We used this crop map in CAPI as an auxiliary data, but no automatic classification was carried out for the RS control.

Images used in crop identification have a pixel size of about 20–30 m, but for area measurement we need images with higher spatial resolution. From 2000 to 2003, FÖMI used IRS PAN merged data in CAPI for the better measurement accuracy, if PAN data was available. The rules with the new technical tolerances valid since 2004 cannot be satisfied with using solely with HR and PAN merges. The adequate area measurement can be carried out only with VHR images, having pixel size of 0.5–1 m.

Although we have used VHR (Ikonos and QuickBird) images since 2001, their ‘‘real’’ operational application started in 2003. In the frame of the CwRS Pilot Project, DG JRC provided QuickBird images for the pilot site, which was one of the 13 sites of the operational CwRS campaign. Since 2004, FÖMI has been using VHR (Ikonos or QuickBird) images for all the control sites.

To fully utilize the spatial and spectral characteristics of the VHR images, a fusion procedure is applied for them, which means we merge the respective panchromatic and multispectral images, and the merged images are used for CAPI. Because the multispectral and panchromatic images are acquired in the same satellite pass, there is no risk of the anomalies that could arise with the usage of pan and multi images with different dates.

The most obvious advantage of VHR's over (merged) HR's is shown in the exact parcel delimitation and area measurement, which is made possible by the precise spatial resolution. This is really important in the areas where small land parcels are dominant. Regarding the crop identification, VHR images have both advantages and drawbacks. With their usage, the possibility and importance of pattern (texture) analysis have increased, making easier the decision in a significant amount of cases.

Beyond the crop identification and area measurement, HR and VHR images can also be effectively used in the checking of two issues within the Good Agricultural and Environmental Conditions (GAEC), namely ‘‘keep arable land in good agricultural condition, avoid weed infestation’’ and ‘‘avoid the encroachment of scrubs on grassland’’. It is well recognisable on high and very high resolution images whether a crop is developing squared and maintained continually on a weed-proof way.

To conclude, we can state that the applied image data sources complement each other very effectively; each of them has its specific role. The number of applications using VHR data is expected to increase in the following years, this is imposed by the trends in the regulatory changes.

6 A SPECIAL OPERATIONAL CHALLENGE: RAGWEED MONITORING AND CONTROL

In the recent years the number of people suffering from pollen allergy has incredibly grown in Hungary. Some 28 – 40 M € / year is spent for medication and medical visits, tests because of the allergenic effect of ragweed. There is a serious need from the society to push back the encroachment of ragweed, and this resulted in legal actions. To adjust to the nature of quick ragweed development the amendment of the plant protection law was revolutionary. It authorizes the government for the elimination of ragweed spots almost immediately after their detection. To manage the activities carried out against ragweed, the National Ragweed Exemption Program has started. It involves several governmental participants. FÖMI developed the methodology and the technological background of exploring the contaminated areas using remote sensing and GIS.

From the experience gained in the CROPMON project, between 2002 and 2004 FÖMI made a survey on some agricultural parcels to examine whether fields infected by weed could be separated from not infected areas based on their spectral characteristics, with special attention to ragweed. The result of the examination was positive which means we could monitor and separate with remote sensing fields that are contaminated with weed from the not infected ones.

This project is more difficult than crop identification. The evolution of weeds is not so regular in time as that crops. Weeds usually do not cover the whole agricultural parcel and in most cases weeds are grown sporadically in the crops. In this method the temporal progress has fundamental importance. For the effective exemption it is vital to prevent the pollen scattering. For the monitoring of weed's evolution we need more dense time series than for crop identification and this makes the task more difficult. If just the time resolution was considered, the AVHRR images would have been appropriate because they are available very often. But in this case the spatial resolution of these images is not enough.

This method is suited for areas greater than 0.8 hectare due to the resolution of satellite images and the characteristics of weed's evolution. It seems this value make a constraint but the majority of pollen strain comes from rural lands from large parcels, this is why this spatial resolution is appropriate. During the monitoring process medium resolution (IRS AWIFS) and high resolution (Landsat TM) satellite images were used simultaneously. We made the classification with methodology that fits to the spectral characteristic of the used satellite images. We used a kind of vegetation index indicating the crop growth.

In 2005 ragweed risk maps were made several times. The first risk map was the result of a retrospective analysis of the year 2004, based on data from National Plant Protection and Soil Conservation Service (NTSZ) and satellite images from the previous year. NTSZ participates in the prevention. They make a procedure and impose a fine against who have not done the weed exemption. As from the second risk map the operational ragweed monitoring was started examining the current (2005) status. These risk maps were the result of detecting and surveying of non-cultivated arable spots, the stubble-fields of cereals and sunflower fields where ragweed infection occurred. Most spots infected by ragweed were found on stubble-fields of cereals: altogether on country level FÖMI detected 20 000 spots on 60 000 hectares for the year 2005.

The resulting ragweed risk map was used by the Land Offices. The Land Offices watched the fields, and if they found ragweed infection, they had to measure it. They used GPS and PDA for the measurement of contaminated area. Based on these digital data files that contain the contaminated spots in GIS, NTSZ started a procedure against the owner or the user of the area and executed the ragweed exemption. The authorities that is, Land Offices, NTSZ and FÖMI are the network of MARD. Land Offices plan and optimise the route of their on the spot checks based on ragweed risk maps, control the risky areas, and they send their feedbacks to FÖMI. These feedbacks are built in the method as ground (reference) data, and are used for making more precise ragweed risk map.

For this procedure it is vital that information like spots with ragweed infection, their attributes and remotely sensed risky spots arrive to the authorities as fast as possible. To achieve this, FÖMI has established the Central Ragweed Server and Information System. This server is a GIS database, which ensure data flow among the participant authorities. For the year 2006, FÖMI further developed the functionality the Ragweed Server and is carrying of a training course for the participants of the exemption program.

The result of the exemption program, settlement and physical block level ragweed maps are available via the web site of FÖMI. The maps are based on remote sensing and the Land Office's on the spot checks.

7 CONCLUSION

Through the introduction of the projects of FÖMI RSC, it was illustrated how a sophisticated knowledge base and technological background can be used to carry out various tasks related either strictly to agriculture or to the general status of the Earth's surface. Beyond the proper knowledge and utilization of the general methods of digital image processing and remote sensing, one always has to take into consideration the local environmental and cultivation conditions and the organizational and society requirements to carry out successful agricultural monitoring projects.