# REMOTE SENSING AS A SERVICE TOOL FOR THE DETECTION OF WATER RESOURCES AND CROP CONDITIONS MONITORING

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***Remote sensing has long been a useful tool in global applications, since it provides physically-based, worldwide and consistent spatial information over space and time. In particular, remote sensing techniques have been used in hydrological and agricultural applications in order to estimate relevant variables such as evapotranspiration, precipitation, soil moisture, land cover type or vegetation indices at different temporal and spatial scales. This paper presents an overview of the potential of using data obtained from remote sensing as a service tool in the field of water management and crop conditions monitoring. Remote sensing methods have been developed for non-destructive monitoring of plant growth and for the detection of many environmental stresses which limit plant productivity. Although, the series of satellite data are difficult to be analyzed, due to the huge amounts of data but also because of certain limitations like the satellite orbit drift, sensors degradation and calibration, and variability of sensor's spectral response in satellite missions, the atmosphere and biosphere can be monitored with the use of satellite-derived information. For biosphere observations with optical sensors an important limiting factor is cloudiness. Monitoring and observing the Earth's water resources and agriculture, needs high volume of satellite data which allow and lead to successful satellite missions. The analysis of the archives of data records developed from operational satellite observations, presents the possibilities of services that can be offered to the end users (customers) in both the public and private sector. Among companies that provide satellite data worldwide there is a great inhomogeneity concerning the spectral, spatial and temporal resolution as well as the levels of data analysis offered, from raw data to ready to be used products. Some of them are currently collecting satellite data for many years and the data records can be useful for climate services. The main variables that are collected in operational way are the land surface temperature, precipitation, soil moisture and vegetation indices. The main types of satellite instruments used for the estimation of the variables in climate and agriculture studies are MODIS on TERRA-AQUA, AVHRR on NOAA, VEGETATION on SPOT, TM/ETM+ on LANDSAT and SEVIRI on METEOSAT series of satellites. Future missions are promising better spatial and temporal resolution data for providing better services. Examples of satellite data service companies are presented.***

***Keywords: Remote sensing, services, agriculture, water***

## INTRODUCTION

Satellite remote sensing is becoming very important tool in climate and agriculture related services due to the unique capacity to provide global data sets continuously and consistently not only on global level, but also on the national and local levels. The instruments on-board satellites allow for determination of many parameters characterising the actual state of the atmosphere and biosphere and spatial and temporal changes that are important in agriculture. Some of these variables are required as inputs to give an immediate view of the status of the conditions of the crops. Spectral reflectance and thermal emittance properties of soils and crops provide a great deal of fundamental information relating to their agronomic and biophysical characteristics. Coupled with rapid advances in computing and position locating technologies, remote sensing from ground-, air-, and space-based platforms is now capable of providing detailed spatial and temporal information on plant response to their local environment that is needed for crop water and agricultural management approaches. Remote sensing plays important role in monitoring of our entire planet in real time and the water cycle related processes are observed by hundreds of space missions. Remote sensing techniques have been used in hydrological applications in order to estimate relevant variables such as evapotranspiration, precipitation, soil moisture, land cover type or vegetation indices at different temporal and spatial scales (Mu et al., 2007; Toulios et al., 2008; Struzik et al., 2010).

The paper presents the potential of using data obtained from remote sensing in the field of crop monitoring as a service tool by the governmental organisations and the private sector. The paper reviews shortly how the spectral data can serve in their operational applications for agriculture and presents the current and future trends of remote sensing technology, with the recent achievements and the contribution of satellite-derived data to offer information regarding crop conditions and the challenges facing remote sensing in the future. Eumetsat climate and land services as well examples of operational agricultural monitoring systems are also presented.

## SPECTRAL DATA SERVICING AGRICULTURE

Remote sensing data can greatly contribute to the monitoring task by providing timely, synoptic, cost efficient and repetitive information about the status of the Earth's surface (Justice et al, 2002). Satellite and airborne images are used as mapping tools to classify crops, examine their health and viability, and monitor farming practices. Agricultural applications of remote sensing include crop type classification, crop condition assessment, crop yield estimation, mapping of soil characteristics, mapping of soil management practices and compliance monitoring.

For monitoring vegetation stress simple vegetation indices based approaches are often not sufficient. The main drawbacks relate to the fact that they often rely only on one parameter and do not consider the persistence of the stress periods (Balint et al., 2011). Hence, in the absence of easy-to-use monitoring tools and methodologies, often rudimentary methodologies are used, like the annual rainfall amount. However, sometimes even a few weeks of unfavorable climate conditions induce already serious plant stress.

Remote sensing offers a synoptic view of the spatial distribution and dynamics of hydrological phenomena, often unattainable by traditional ground surveys. Radar has brought a new dimension to hydrological studies with its active sensing capabilities, allowing the time window of image acquisition to include inclement weather conditions or seasonal or diurnal darkness. The imagery from new satellites avoids to be affected by the diurnal changes in the crop conditions. The optimum time for viewing is about 10:30am for production agriculture because this allows for early morning fog to lift, lets plants reach their normal, unstressed metabolic state, avoids afternoon cloud build-up, and avoids thermal stress which occurs around 6pm on hot days.

## TRENDS OF REMOTE SENSING TECHNOLOGY

In the past, spatial resolutions, spectral content, field-of-view, revisit frequencies, and multi-temporal consistency have only been sufficient for doing “passive observation”. The new systems can enable “active management” of areas in a way that sustainably addresses land, water, food, and natural resource challenges given current population projections over the next thirty years.

Today’s commercial remote sensing industry, especially the satellite industry, is comprised of sources from commercial as well as government, that make the imagery available for public consumption. In the following, the trends of these commercial sensors and their impacts on agriculture are discussed.

### Spatial resolution

Today’s *low* spatial resolution sensors (>30 meters) are typically launched by governments to monitor the environment and global changes in natural resources and agriculture. These sensors typically have large swath widths and provide global coverage on a daily basis. Existing sources of low resolution satellites exceed from 1000 meters (Aqua & Terra) to 30 meters (Landsat & IRS). There are several *medium* resolution sensors (5-30 meters) that are operational today. The operators of these sensors include a wide range of providers from government sources to the commercial industry. The constellation approach of medium resolution satellites offers a unique revisit for broad crop monitoring area on a daily basis. One of the disadvantages with micro satellites is the lack of pointing accuracy that results in poor positional accuracy on the ground. Existing sources of medium resolution satellites comprise SPOT (5, 10, 20 meters) Rapid Eye (6.5 meters), IRS (6 meters), DMC (22 meters), GMES Sentinel-2-a/2b (10-20 meters). *High* resolution imagery providers include a combination of government owned satellites, as well as commercial vendors that provide imagery at multiple resolutions. Sources of high resolution satellites include a fleet of satellites from 1 to 3 meters spatial resolution (Kompsat-1, THEOS, SPOT 5 & 6, Cartosat 1 &2, CBERS-2, Ziyuan-2). The successful launch of Ikonos in 1999 formally signalled the start of the *very high* resolution commercial satellite imagery market at 1 meter resolution or better spatial resolutions (<1 meter). The past decade has seen an increase in satellite spatial resolutions that are positioned to compete with the traditional aerial markets. Today the very high spatial resolution market is primarily serviced by commercial industry, but there are a few government satellites, designed for military applications, that contribute excess capacity. These very high resolution imagery datasets are ideally suited for addressing small holder agriculture problems. In order to impact global agricultural issues, the agriculture industry will benefit from the planned constellations increases that can provide essential global coverage and frequent revisits. Sources of very high resolution satellites comprise Ikonos, QuickBird, WorldView-1, Geoeye-1, WorldView-2, WorldView-3, Pleiades 2A & 2B and Kompsat 3.

Very high resolution imagery from aerial sources is currently being used for precision agriculture applications. These sources are well suited for local and regional agriculture applications. Low cost autonomous drones and remotely-piloted vehicles (RPV) are being tested in a number of application areas. Autonomous drones will have better economics than remotely-piloted vehicles (RPV) that need substantial ground crew involvement for operation. Hand-held devices are already ubiquitous and can take very detailed pictures of agriculture fields. Smart phones enabled with personal navigation can be used to cue humans to very specific locations to then capture sub-millimeter color imagery. Smart phone imagery can then be sent to experts and machines for interpretation and diagnosis.

### Spectral and radiometric properties

Spectral sensors are typically categorized as multi, super or hyper spectral. *Multi*-spectral imagery refers to sensors with less than 10 bands, *super*-spectral resolution include sensors carrying 10-20 bands, and *hyper*-spectral sensors tend to have hundreds of contiguous bands across the visible, VNIR and SWIR parts of the spectrum. The most common spectral bands used are red, green and blue bands in the visible part of sun spectrum followed by a spectral band in the near infra-red region. In addition, most of these systems typically have a high resolution panchromatic band that has a spectral range covering the entire visible part of the spectrum, with some panchromatic bands extending into the NIR spectrum as well.

Landsat multi-spectral satellites carried 8 spectral bands that capture information in the visible, near infra-red, shortwave infra-red, and thermal regions of sun spectrum. Most aerial and UAV platforms carry 4 multi-spectral bands. The SPOT series of satellites carried a broad SWIR band which is now discontinued on the SPOT 6 satellite. DigitalGlobe’s WorldView-2 satellite was designed with eight spectral bands in the VNIR region. The red edge band, yellow band, and additional NIR band were added to traditional 4 bands and are primarily designed for agriculture applications. The new satellites with very high spatial resolution covering visible, NIR, and SWIR parts of the sun spectrum coupled with very high spatial resolution are ideal for addressing small holder farmer applications. The short wave infra-red bands are primarily designed to estimate crop canopy moisture, as well as measure soil residue, moisture content, and organic matter content that can be used for soil mapping as well as other applications. With the exception of a few, special mission hyper-spectral imaging and thermal imaging aerial platforms, most of the satellite, aerial, and UAV platforms are trending towards multi-spectral imagery.

Radiometric properties include radiometric resolution and dynamic range. Radiometric resolution of an imaging system describes its ability to discriminate very slight differences in measured energy. The dynamic range of an imaging system specifies the ratio of the highest energy pixel to the lowest energy pixel that can be captured. The older systems had dynamic range of 256:1, stored as 8-bit data. Modern systems have dynamic ranges between 2.048:1 (11-bits) and 16.384:1 (14-bits). In the case of systems with 11-bits of dynamic range, the effective dynamic range can be on the order of 9-bits (or better) with discernable differences in reflectance of about 0.2% (or smaller), making them ideal for measuring very subtle changes in stress in crops. High effective radiometric resolution is paramount for agriculture applications, especially to accurately model crop vigor and health issues at an early stage, as well as to identify subtle changes on soils for moisture and organic matter mapping. These increased capabilities have resulted in superior information quality of the images and, subsequently, the ability to extract information from them accurately and in an automated fashion.

### Temporal properties and positional accuracy

Temporal resolution is characterized by the revisit frequency of the platforms for a given spot on the earth. Over the last decade, significant progress has been made in developing and launching satellites in constellations that can provide daily revisits across the globe. Large amounts of data are being acquired by these systems globally to include images from newer and more complex platforms such as WorldView-1, WorldView-2, GeoEye-1, and the more recent Pleiades-1A and Pleiades-1B. Currently, the potential global capacity of very high spatial resolution imaging satellites is greater than 1.8 billion square kilometers per year, which corresponds to more than 12 times the land surface area of the earth. This capacity could potentially increase to more than 2.4 billion square kilometers per year (about 16 times the land surface area of the earth) in the near future. Other than the areas that are under permanent cloud belts, commercial remote sensing industry can provide the revisit to support precision agriculture and small holder farmer agriculture practices globally.

Imagery's positional accuracy has been steadily improving from error margins around 23 meters in the early 2000's to less than 3 meters today. Increased accuracy is primarily due to more stable satellite orbits and innovative post-processing techniques that reduce error margins.

## CLIMATE AND LAND SERVICES OF EUMETSAT

Satellite remote sensing has provided major advances in understanding the climate system by quantifying processes and spatio-temporal states of the atmosphere, land and oceans. New insights are made feasible by the unparalleled global and fine scale spatial coverage of satellite observations. Eumetsat (the European Organisation for the Exploitation of Meteorological Satellites) supply weather and climate-related satellite data, images and products (24 hours a day, 365 days a year) to the National Meteorological Services of the Member and Cooperating State in Europe, and other users worldwide. EUMETSAT generates Climate Data Records for NWP (Numerical Weather Prediction) model-based reanalysis, climate system analysis and climate modelling applications. The activities involve the generation of high-quality Fundamental Climate Data Records (FCDR), by recalibration and inter-satellite calibration of historic and current EUMETSAT sensor raw data records. For example, the Meteosat time series already covers more than 30 years and nine different satellites. Differences between instruments need careful consideration to mitigate unwanted, spurious anomalies in the time series, caused by instrument and spacecraft behaviour in space. Data from EUMETSAT can be used to analyse climate variability and change, and support operational climate monitoring activities such as monthly bulletins.

Satellite Climate Data Records generated by the EUMETSAT Satellite Application Facility network provides information on the state of the land and on land processes. This information is of considerable benefit for agriculture and the monitoring of ecological and hydrological systems. The LSA-SAF develops techniques to retrieve products related with land applications, like fire products (SEVIRI, VEGETATION2, MODIS, AVHRR, GOES), land surface temperature products (SEVIRI, AVHRR), snow and ice products (SEVIRI, AVHRR, AMSU-B, VISSR), soil moisture products (ASCAT) and vegetation products (AVHRR, VEGETATION, VEGETATION2, MODIS, SEVIRI, GOES).

## OPERATIONAL AGRICULTURAL MONITORING SYSTEMS

Agricultural monitoring systems should be able to provide timely information on crop production, status and yield in a standardized and regular manner at the regional to the national level. Estimates should be provided as early as possible during the growing season and updated periodically through the season until harvest. Based on the information provided, stakeholders are enabled to take early decisions and identify geographically the areas with large variation in production and productivity. The system should provide homogeneous and interchangeable data sets with statistically valid precision and accuracy. Probably, only satellite remote sensing, combined with sophisticated modeling tools, can provide such information in a timely manner, over large areas, in sufficient spatial detail and with reasonable costs (Atzberger, 2013). Preliminary research and development on satellite monitoring of agriculture started with the Landsat-1 system in the early 1970s. In 1974 the USDA together with NASA and NOAA initiated the Large Area Crop Inventory Experiment (LACIE) to improve crop forecasting methods. With enhancements that became available from the NOAA AVHRR sensor, allowing for daily global monitoring, the AgRISTARS (Agriculture and Resource Inventory Surveys Through Aerospace Remote Sensing) program was initiated in the early 1980s (Becker-Reshef et al., 2010). Through the research conducted in these NASA-USDA joint programs, the considerable potential for use of remotely sensed information for monitoring and management of agricultural lands was identified. One of the most recent efforts that NASA and the USDA Foreign Agricultural Service (FAS) have initiated is the Global Agricultural Monitoring (GLAM) Project (Becker-Reshef et al., 2010). The GLAM project focuses on applying data from NASA's MODIS instrument to feed FAS Decision Support System (DSS) needs (Fig. 1).

There are currently several other regional to global operational agricultural monitoring systems providing critical agricultural information at a range of scales: the USAID Famine Early Warning System (FEWS-NET) (http://fews.net), the UN Food and Agriculture Organization

(FAO) Global Information and Early Warning System (GIEWS) (http://fao.org/giews), the JRC's Monitoring Agricultural ResourceS (MARS) action of the European Commission with two different topics: agricultural production estimates of EU countries (Agri4Cast) and food security assessments in food insecure countries (FoodSec) (http://www.eea.europa.eu/data-and-maps/data/ external/ monitoring-agricultural-resources-mars), the European Union Global Monitoring of Food Security (GMFS) program http://gmfs.info and the Crop Watch Program at the Institute of Remote Sensing Applications (IRSA) of the Chinese Academy of Sciences (CAS) (http://cropwatch.com.cn/en).

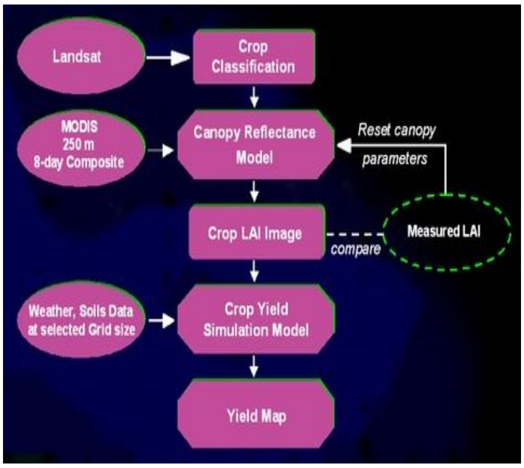


Figure 1. Operational crop condition and yield mapping system (Agriculture Data and Information Services Center (DISC)/NASA)

However, the USDA FAS with its GLAM system is currently the only provider of regular, timely, objective crop production forecasts at a global scale. This unique capability is in part afforded by the USDA's partnership with NASA, providing global coverage of Earth observation data, as well as analysis tools for crop condition monitoring and production assessment at the global scale (Becker-Reshef et al., 2010). At high revisit frequency, the Earth's land surface can currently only be covered by coarse/medium resolution sensors, such as MODIS. Consequently, a monitoring system must heavily rely on time series provided by such sensors. With the upcoming Sentinel's 2 and 3 and Proba-V sensors (http://probav-iuc.org/) a new era of Earth observation will be entered and coarse/medium resolution will increase (e.g., Sentinel 3 providing data at 300 m and Proba-V at 100 m). Even more exciting, Sentinel-2 will provide 10–30 m data at five-day revisit intervals. The Venus sensor will be launched soon with 12 spectral bands (5 m ground resolution) and a two-day's revisiting time. The hyperspectral HyspIRI will be launched between 2013 and 2016 with a spectral resolution of 10 nm, 19-day's revisiting time and a spatial resolution of 60 m. The Landsat data continuity mission (LDCM) is planned for launch very soon. The free data will also include two thermal bands for energy balance calculations.

## CONCLUSION

Recent advances on the resolution and availability of satellite geo-information, coupled with a decrease in its associated costs (most data are free), allow the collection of timely information for vegetation state monitoring. Space-borne sensors can measure at a variety of spatial and temporal scales, which offer synoptic view and regular sampling.

Separate sensor/satellite data are integrated into high-quality climate and biophysical products, useful for crop vigor and drought monitoring and assessment. High-resolution satellite imagery is most useful for assessing within-field vegetation state variability. Images taken during the growing season can be used to monitor crop growing conditions and identify potential problems that could be addressed within the growing season. Because the high resolution satellite repeat cycle may not provide enough time series for crops monitoring and assessment of seasonal vegetation, it is necessary to use also the coarse and mid-resolution satellite data with better temporal frequency (1-2 days). When the satellite-derrived products are combined with climate weather and agro-meteorogical data, a better crop vegetation state monitoring, including the water stress assessment, at the field level can be obtained.

Operational crop condition monitoring and yield mapping systems in conjunction with the new era of the satellite technology are promising more detailed and accurate information from parcel to global range and will open new opportunities for crop monitoring.

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