Sources of remote sensing data used for estimating variables in environmental change studies in agriculture

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Abstract. The paper presents the contribution of satellite-derived data to assess the environmental change impact on agriculture. Satellite remote sensing is becoming very important tool in environmental change related studies due to the unique capacity to provide global data sets continuously and consistently not only on this level, but also on the national and local levels. The instruments on-board meteorological and environmental satellites allow for determination of many parameters characterising the actual state of the biosphere and spatial and temporal changes. Some of these variables are required as inputs to give an immediate view of environmental change impact on the crops. Although, the series of satellite data are difficult to be analyzed, because of certain limitations like the satellite orbit drift, sensors degradation, different methods of sensors calibration, and variability of sensor's spectral response in satellite missions, the environmental change influence on 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 climate and generally the environment, needs high volume of satellite data which allow and lead to successful satellite missions. The analysis and the presentation of the data records which have been developed from operational satellite observations, presents the status of satellite climatic and biophysical data for warning purposes for agriculture, in Europe. Among European countries there is a great inhomogeneity concerning climatic and biophysical data received from satellite sensors or collected as satellite-derived ready products. Some of them are currently collecting satellite data for years and these data records could be useful for models for environmental change impact studies. The main variables that are collected in operational or experimental way are the land surface temperature and the vegetation indices (e.g. NDVI). The main types of satellite instruments used for the estimation of the variables in environmental change studies in agriculture are MODIS on TERRA-AQUA, AVHRR on NOAA, VEGETATION on SPOT, TM/ETM+ on LANDSAT and SEVIRI on METEOSAT.
The study is mainly based on the outcomes of the EU COST 734 "Impacts of Climate Change and Variability on European Agriculture – CLIVAGRI" and COST ES1106: „Assessment of EUROpean AGRIculture WATer use and trade under climate change - EURO-AGRIWAT".

Key words

Environmental change, agriculture, satellite remote sensing.

Introduction

The general trend towards more intensive and industrialised agriculture in Europe has a profound impact on the environment, including emissions to air air and water, quality and quantity of surface water and groundwater, soil erosion, pollution due to large-scale use of pesticides, and loss of biodiversity and habitats.
The major environmental related drivers for European agriculture are: land use change and biodiversity, climate change, water availability and increase demand for water, soil degradation and pollution and the greenhouse emissions to the air (Walls, 2006).
Satellite data offer an unprecedented potential for climate research provided that separate sensor/satellite data are integrated into high-quality, globally-integrated climate products. Also climate change influence on biosphere can be monitored with use of satellite data. Presence of meteorological and environmental satellites in space since the 1960s allows for real environmental studies. The examples of successful use of long time satellite data series and the description of limitations of this technology conclude the main issues that are accuracy and stability of satellite measurements. Actually, not all climatic related variables can be traced with use of satellite sensors due to their not sufficient accuracy. Much improved post-launch calibration of satellite instruments, and intercalibration of similar instruments flying on different satellites is highly required to achieve continuity of observations. This requires overlapping periods of consecutive satellite missions. Other problems concern data management (processing and reprocessing). Rapid development of Earth observations resulted extremely huge volume of satellite data. Regarding future missions, new and more accurate sensors are envisaged (Toulios and Stancalie, 2010).
Recent reviews regarding the methods for retrieving biophysical properties showed that most of radiative transfer inversion techniques are based on iterative optimization or neural network methods. However, the inversion of radiative transfer models is a major problem which may induce significant uncertainties in the biophysical variables estimation when limited information is used. The improvement of the inversion process capabilities requires more information obtained from radiative transfer models, using of proper prior information on the canopy variables distribution and atmosphere variables, and knowledge of uncertainties of the satellite measurements according to spatial and temporal constraints.
Usually, statistical approaches based on vegetation indices

(VI) use only two or three spectral wavebands, whereas parameter retrieval based on canopy reflectance modeling, partial least squares regression (PLS) models or artificial neural networks can use the complete spectral data space provided by the sensor (Dorigo et al., 2007). Consequently, it is important to choose an adequate inversion algorithm and/or merit function due to the fact that representation of bands in spectral ranges with high absolute reflectance may generate the retrieval of only the canopy variables that affect these wavelengths.

There are still a lot of limitations for the use of satellite image data in agrometeorological models, like the lack of short wave IR bands, the reduced availability of on-board storage and data transmission capabilities, the calibration/validation procedures and atmospheric corrections, etc. In this respect the creation of a European Agrisat Constellation, specifically configured for satellite-based agrometeorological applications has to be put into practice as soon as possible (Struzik et al., 2010).

There appear to be very few examples of operational data assimilation methods applied to crop or agrometerological models. Outstanding issues for operationalization include: (i) lack of an appropriate satellite constellation, (ii) lack of knowledge on spatial and temporal variations of cloud cover, (iii) lack of operational approaches for atmospheric correction and (iv), lack of sensors with SWIR wavebands.

Satellite data availability for environmental studies and impacts on agriculture

Today long term satellite archives are freely available to users focusing on original spectral channels of the satellite sensors. In some cases only registration is required. It must be mentioned that this type of data is addressed to experienced users, who are able to deal with further data processing, have knowledge on about data formats and methods for retrieval of indices, which can be used for studies on vegetation state and its temporal and spatial variability. There are many popular archives containing information registered by the satellite sensors in individual spectral channels with an indication of data type, temporal coverage and geographical area, focusing on Europe (Struzik et al., 2010).

For the users who require typical indices retrieved from satellite data it is much easier to use processed data collected in various archives. Access to the archives is available through the Internet. Typical indices related to biosphere monitoring are based on visible/near-infrared spectral channels of satellite sensors like: AVHRR/NOAA and MetOp, MODIS/Terra, Aqua, VGT/SPOT, MERIS/ENVISAT, SEVIRI/MSG and many others (Heute et al., 2004). Available indices cover a wide spectrum of parameters like:

- Albedo and BRDF
- NDVI
- Leaf Area Index (LAI)
- FAPAR
- Vegetation Percentage
- Continuous Fields of Vegetation Cover
- Land Cover Data
- Fire and Burned Area
- Vegetation Anomalies
- Thermal Anomalies
- Vegetation Health Index
- Radiation Balance components and many others

Access to required satellite data and products is less difficult when specialized search engines and selection tools are applied. Administrators of individual archives provide many interesting tools (Table 1) which allow for:

- Product selection from the archive
- Geographical area selection
- Time period selection
- Ordering products or direct connection to FTP site for download
- In some cases also visualization software based on distributed data format is available

The satellite data archives and tools which help with data search and further use of them show that a large variety of information is freely available for the users who would like to study vegetation temporal and spatial changes over the last 10-30 years. The information allows for selection of individual region of interest located in any place on the Globe and to calculate or use available processed indices characterizing the state of vegetation or agrometeorological conditions. Resolutions available start from 250 m (MODIS based) and extend to 16 km (GAC NOAA based).

The most important feature of long term archives is the possibility to obtain or easily calculate anomalies and trends of investigated parameters, which allow for determination of biosphere changes in individual region. Such studies provide an opportunity to analyze possible climate change influences on agriculture.

Based on COST action 734 studies, the climatic and biophysical variables, recorded at least in one country that could be assessed by satellite remote sensing, are presented in Table 2 (Toulios et al., 2008). Enhanced Vegetation Index (EVI) could be also included to the biophysical variables. EVI compared to NDVI better depicts biophysical canopy structural variations, is less prone to saturate in high biomass areas and less influenced by aerosol scaterring and background properties. In Table 3 the type of satellite / instrument used per climate and biophysical product recorded is presented (Toulios et al., 2008). Surface temperature, cloud products, albedo are already available also from AVHRR on MetOp.

Conclusions

Challenges for the application of satellite image data in environmental studies for agriculture

Operational applications of remote sensing data in environmental and agrometeorological studies now require new approaches to collection and analysis. There are probably enough platforms currently in space to collect daily 30m spatial resolution data for the whole of Europe. The collection of such data requires coordinated effort and funding however. The effects of cloud cover need to be quantified and some areas of Europe may be too cloudy (<14% cloud free frequency) to allow weekly observations. Cloud free frequency may be seasonally dependent for some areas, but there is poor information on this from a remote sensing perspective. The most promising solution is to use a constellation of identical satellites in same orbit, and the availability of small satellite technology which can be built and launched at relatively low cost, illustrated by the DMC constellation, opens up the possibility for the development of a dedicated European "AgriSatellite" constellation. The current DMC systems lack wavebands in the short-wave infrared (SWIR) however, which are important for monitoring crop moisture condition; in addition they have limited on-board storage and data transmission capabilities. These technical limitations will be overcome in the next few years and when data from such constellations are coupled with carefully planned and executed calibration and validation activities, the full potential of remote sensing data in environmental and agrometeorological studies in Europe, and in a wide range of other fields, will be fully realised. There are great prospects for improving remote sensing data assimilation into crop models in the future with data form new satellites satellites/sensors with high spatial resolution and high time frequency (e.g. GMES, Sentinel 2, etc) (Danson and Toulios, 2010).

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Table 1: Selected tools helping with satellite products search and retrieval (Struzik et al., 2010).

Service	Internet link	Short description
EUMETSAT Product Navigator	http://navigator.eumetsat.int	Search engine to various satellite products both transmitted in real time and archived
Search and Preview Tool (www.landcover.org)	http://glcfapp.umiacs.umd.edu:8080/esdi/index.isp?productID=19	Search engine to land cover products
USGS Global Visualisation Viewer GloVis	http://glovis.usgs.org	Online search and order tool for selected satellite data. The viewer allows access to all available browse images from the Landsat 7 ETM+, Landsat 4/5 TM, Landsat 1-5 MSS, EO-1 ALI, EO-1 Hyperion, MRLC, and Tri-Decadal data sets, as well as Aster TIR, Aster VNIR and MODIS browse images from the DAAC inventory.
NASA Warehouse Inventory Search Tool (WIST)	http://wist.echo.nasa.gov/~wist/api/imswelcome/	All LP DAAC data holdings available · Search and order earth science data from all NASA data centers · Replacement for EOSDIS Data Gateway (EDG).
LP DAAC MODIS Reprojection Tool on the Web (MRTWeb)	http://mrtweb.cs.usgs.org	Selected MODIS Land Product Tiles · Search, Visualize, Select · Mosaicking, Spatial Subsetting, Band Subsetting, Reprojection, Reformatting.
LP DAAC Data Pool	http://lpdaac.usgs.org/lpdaac/get_data/data_pool	Selected LP DAAC ASTER and MODIS data holdings · Direct FTP access · All data are at no charge.

***Table 2**: Climatic and biophysical variables surveyed in Europe (Toulios et al., 2008)*

Climatic variables	Biophysical variables
Surface temperature	NDVI
Precipitation	MSAVI
Snow cover	LAI
Solar radiation	VCI
Albedo	TCI
Cloud cover and other cloud products	TVDI
SAF products (precipitation, soil moisture, snow)	Soil moisture
Air stability	Vegetation cover
Storm detection	Land cover
Ozone content	Evapotranspiration
Sea ice, sea wind	Degree days
	CCD

***Table 3**: Type of satellite / instrument per climate and biophysical product recorded (Toulios et al., 2008)*

climate and biophysical product	Type of satellite / instrument
NDVI	(MODIS / TERRA-AQUA, AVHRR / NOAA, VEGETATION / SPOT, TM / LANDSAT, SEVIRI / METEOSAT)
Surface temperature	(AVHRR / NOAA, TM / LANDSAT, ASTER / TERRA, MODIS / TERRA-AQUA, SEVIRI / METEOSAT)
LAI	(MODIS / TERRA)
MSAVI	(VEGETATION / SPOT)
Cloud products	(SEVIRI / METEOSAT, NOAA / AVHRR)
Snow cover	(MODIS / TERRA, SEVIRI / METEOSAT)
Radiation	(SEVIRI / METEOSAT)
Vegetation / land cover	(TM-ETM / LANDSAT, ASTER /TERRA, SEVIRI / METEOSAT)
Precipitation	(SEVIRI / METEOSAT, GEO / LEO satellites, TOVS/NOAA)
SAF products	(METEOSAT, NOAA, AQUA)
Air-stability	(SEVERI / METEOSAT)
Storm detection	(SEVERI / METEOSAT)
Ozone	(TOVS / NOAA)
Evapotranspiration	(TM/LANDSAT,ASTER/TERRA, AVHRR/NOAA)
Soil moisture	(ASCAT / METOP)
VCI,TCI,VHI,TVDI	(AVHRR / NOAA)
Degree days	(AVHRR / NOAA)
CCD	(METEOSAT)
Albedo	(SEVIRI / METEOSAT, AVHRR / NOAA)
Sea ice	(AVHRR / NOAA)
Sea wind	(METOP)