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Short communication

Image time series processing for agriculture monitoring☆

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ABSTRACT

Given strong year-to-year variability, increasing competition for natural resources, and climate change impacts on agriculture, monitoring global crop and natural vegetation conditions is highly relevant, particularly in food insecure areas. Data from remote sensing image series at high temporal and low spatial resolution can help to assist in this monitoring as they provide key information in near-real time over large areas. The SPIRITS software, presented in this paper, is a stand-alone toolbox developed for environmental monitoring, particularly to produce clear and evidence-based information for crop production analysts and decision makers. It includes a large number of tools with the main aim of extracting vegetation indicators from image time series, estimating the potential impact of anomalies on crop production and sharing this information with different audiences. SPIRITS offers an integrated and flexible analysis environment with a user-friendly graphical interface, which allows sequential tasking and a high level of automation of processing chains. It is freely distributed for non-commercial use and extensively documented.

Software availability

Software name: SPIRITS (Software for the Processing and Interpretation of Remotely sensed Image Time Series)
Developers: Herman Eerens, Dominique Haesen, Contact address: Boeretang 200, b-2400 Mol, Belgium (herman.eerens@vito.be, dominique.haesen@vito.be)
Year first official release: 2013
Hardware requirements: PC
System requirements: Microsoft Windows (XP or later), Java (version 1.6 or higher)
Program language: C, Java
Program size: 240 MB
Availability: http://spirits.jrc.ec.europa.eu/, https://rs.vito.be/africa/en/software/Pages/Spirits.aspx
License: Free for non-commercial use
Documentation and support for users: Manual, tutorial with test data, training sessions

1. Introduction

The analysis of image time series, particularly those derived from remote sensing, is of increasing relevance for environmental monitoring (e.g. ocean, forests, fires, land use/land cover change, flooded areas, climate change, water bodies, ecology) over large areas, and vegetation and crop monitoring is no exception. In fact, agricultural production depends on a series of factors that are highly variable over space and time. The 2007/2008 food price crisis has brought back to the spotlight the impact of sudden changes in global crop production in a context of growing pressure on natural resources, increasing uncertainty linked to climatic change and high levels of vulnerability to food shortage in politically unstable areas such as the Sahel and the Horn of Africa (FAO, 2009). Remote sensing significantly contributes to agricultural production assessments thanks to its capacity to collect information over large areas and with a high temporal frequency (Atzberger, 2013; Baruth et al., 2008; Zhao et al., 2013). Satellite data made available to users in a timely manner by sensors such as SPOT-Vegetation (VGT) (e.g., Maisongrande et al., 2004), Terra/Aqua MODIS (e.g., Cracknell, 1997), NOAA AVHRR (e.g., Justice et al., 1998), Metop AVHRR (e.g., Eerens et al., 2009) and Meteosat MVIRI/SEVIRI (e.g., Fensholt et al., 2011) play a key role in assessing crop conditions in a qualitative manner and identifying potential production deficits at the end of the cropping season.

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Methodologies have been constantly improved since the 1980's for using satellite derived biophysical indicators directly as proxy for crop yield (Tucker et al., 1980) or as inputs for quantitative crop growth and biomass estimation models (Baret et al., 1989; Delécolle et al., 1992). A review on this evolution has been published by Rembold et al. (2013). However, to transform the data embedded in these images into useful information for decision support, analysts need a software environment able to manage in an integrated way both the spatial and temporal dimensions of the time series (Rasinmäki, 2003).

Most of the available GIS and image processing software packages do not provide a complete range of built-in functionalities to handle time series of images (Babu et al., 2006), and are not optimized for the needs of the crop monitoring community. In the 1990's the Food and Agriculture Organization (FAO) developed the free WinDisp software (http://www.fao.org/giews/english/windisp/), which marked a clear effort in this direction and became a widespread tool in developing countries. Unfortunately the development of WinDisp stopped in 2003 and the tool has become obsolete. Advanced crop monitoring analyses can be conducted with standard image processing software (e.g., IDRISI, http://clarklabs.org/; ENVI, http://www.exelisvis.com/; GRASS, http://grass.osgeo.org/, Neteler et al., 2012), statistical packages (e.g., MATLAB, http://www.mathworks.it/; R http://www.r-project.org/) or spatial databases (e.g., PostgreSQL/PostGIS, http://www.postgresql.org/, http://postgis.refractions.net/). However, these tools are generic in nature and their use for advanced image time series processing requires specific programming skills, remote sensing knowledge and long program development efforts. Such capacities are not always available in institutions dealing with agricultural monitoring and early warning.

Some tools partially address the needs of the agricultural monitoring community, for instance the e-station (http://estation.jrc.ec.europa.eu/, Clerici et al., 2013), which focuses on African conditions, and other online platforms such as the Global Agriculture Monitoring (GLAM) (Becker-Reshef et al., 2010), CropExplorer (http://www.pecad.fas.usda.gov/cropexplorer/), the MARS web viewer (http://www.marsop.info/marsop3/) and the interpretation tools of the United States Geological Survey (USGS) portal ADDS (http://earlywarning.usgs.gov/fews/). All these tools are mainly designed to directly provide users with the standard outputs of remote sensing analyses such as Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1974) and rainfall status, anomaly maps and graphs of temporal profiles. However, they generally do not offer a flexible image processing environment that can be used by technicians and involved institutions to adapt the data analysis steps and generate additional and customized outputs.

Other online applications offer services related to image time series acquisition and processing, but they are designed for either very specific purposes (e.g., fires, Díaz et al., 2013; habitats, Dubois et al., 2013) or are typically generalised (e.g. visualization tools, Blower et al., 2013).

The TIMESAT tool (Jönsson and Eklundh, 2004) is quite flexible but it focuses on the extraction of phenological parameters and it lacks a graphical user interface. TimeStats (Udelhoven, 2011) offers some advanced tools for data mining in long-term remote sensing data archives but is mainly addressed to advanced users (i.e., remote sensing experts). Finally, gro-meteorological modelling packages such as GeoWRSI (FEWSNET, http://chg.geog.ucsb.edu/products/geowrsi/) and AGROMET-SHELL (FAO, http://www.hoefsloot.com/agrometshell.htm) also work with time series of raster data (mainly meteorological data) but they are not optimized for the processing of remote sensing imagery.

We can therefore conclude that none of the existing systems provides in one package the highly specific set of time series processing functions to assess crop and vegetation status, including temporal smoothing, detection of phenological stages, computation of long term averages and anomalies, classification based on vegetation seasonal performance, and production of the outputs traditionally used in crop monitoring bulletins (statistics, maps, graphs). For this reason, a flexible and user-friendly interface, targeting both national and international agriculture and food security experts, is highly desirable (Gommes et al., 2011). There is a clear need for dedicated software with optimized functions to efficiently process and analyse large image archives. This is particularly relevant in view of imminent satellite constellations such as the European Space Agency's (ESA) Sentinel program (Petitjean et al., 2012), which will combine both high spatial and temporal resolution making an improved software approach even more urgent. Finally and especially in developing countries, free software can play an important contribution to capacity building for local institutions, which are the main actors in the design and implementation of prevention and response policies to potential food crises.

SPIRITS is an integrated, modular software platform that aims at answering the requirements outlined above. The software is extensively documented and distributed freely for non-commercial use.

2. SPIRITS: general aspects

SPIRITS is developed in JAVA and runs under Windows. The version currently available (July 2013) is 1.1.1. Originally it was conceived as a graphical user interface (GUI) around a software called GLIMPSE (GLobal IMage Processing SoftwarE), also developed by the Flemish Institute for Technological Research (VITO). GLIMPSE consists of a set of ANSI-C executables performing a wide range of dedicated image processing tasks. The GLIMPSE modules can only be accessed via a command line interface, but they can be scripted to set up complex processing chains. SPIRITS provides a convenient GUI, which enables to guide the GLIMPSE modules via an up-to-date interface and to run them in the background. However, over the years SPIRITS was extended with many (non-GLIMPSE) modules enabling, for example, the import of imagery in external formats, the generation of maps and the extraction of regional databases. To this goal, it makes use of open source libraries such as GDAL (http://www.gdal.org/), FWTools (http://fwtools.maptools.org/) and HSQLDB (http://hsqldb.org/), which are included in the SPIRITS installer.

For each function, SPIRITS provides an adapted GUI that allows users to enter the relevant parameters, assisted by tooltips and an interactive help system. Once the parameters have been set, the tools can be executed for a single input image or in a loop for a complete time series. Extensive error controls provide feedbacks in case of erroneous inputs. Different tasks can be launched and are processed sequentially, whilst a progress bar indicates the evolution of each action. The results of former tasks can be recalled at any time. A typical example of the SPIRITS GUI is shown in Fig. 1.

Settings can be saved and reused in order to automate processes that have to be repeated whenever new images become available. Multiple operations can be performed in a sequential way so that complex, multi-step processing chains can be launched at once as subsequent jobs only start once previous jobs have finished. Statistics can be extracted from the images for different administrative regions and thematic units (typically land cover types). These are stored in an internal database and then used to create graphs. Maps and graphs created for the analysis of a particular variable and region can be saved as templates and easily reused for application on complete time series or sets of regions.