Efficiency of SPIRITS (Software for Processing and Interpretation of Remotely Sensed Image Time Serie) to Ecological Modeling: New Functionalities and Use Examples

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Abstract: — We studied the effectiveness of SPIRITS processing software used to monitor drought. In this article, we propose practice steps and we prove that ecological modeling can be available with remote sensing data on a larger scale (for any place in the world) with SPIRITS. The studies summarize some important analyses of remote sensing time series at high temporal and medium spatial resolution. The Software for the Processing and Interpretation of Remotely sensed Image Time Series (SPIRITS) is a stand-alone flexible analysis environment created to facilitate the processing and analysis of large image time series and ultimately for providing clear information about vegetation status in various graphical formats to ecological modeling. The examples of operational analyses are taken from several recent drought monitoring articles. We conclude with considerations on SPIRITS use also in view of data processing requirements imposed by the coming generation of remote sensing products at high spatial and temporal resolution, such as those provided by the Sentinel sensors of the European Copernicus program.

Key-Words: — SPIRITS, Processing and Interpretation, Remote sensing time series, Ecological modeling.

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1 Introduction

In order to perform a perfect statistical analysis, it is essential to ensure the quality of the time series through a careful analysis of the dataset or sample studied. This filtering allows the systematic elimination of possible outliers. However, these outliers do not always have to be eliminated, as in exceptional cases it may be worthwhile to take them into account in certain analyses. Scientific researchers must be open to all new scientific data and software. The research methods are also developing with the advancement of technology (Zbiri and Hachmi [1], 2022, Zbiri et al., 2022 [2], Hachmi et al., 2021 [3]). Similarly, AI integrated with blockchain has been found to positively impact water management and climate control (Lin, Petway [4]). AI can manage and reduce energy consumption within smart cities (Şerban & Lytras, 2020 [5]). Studies have identified that blockchain applications can improve sustainable practices in supply chain management and agricultural practices (Kshetri, 2021 [6]). Similarly, within nano-technology applications, AI has provided benefits through better precision in agricultural water distribution delivering positive impacts on the efficient use of natural resources.

There are many methods of pre-processing data derived from remote sensing. In our study, the processing module is used to transform the spatial and temporal information of the various decadal image input data as required.

Vegetation data is captured during the period February to April, while soil moisture and precipitation data are captured between the months of November to February for a whole decade. For SPIRITS users or analysts who need to use remote sensing software or improve programming efficiency, this is another article about SPIRITS with an extensive collection practical for processing remotely sensed data used for environmental risk modeling.

The first paper was published in 2015 about analysis for crop monitoring with the SPIRITS software (Eerens et al., 2014 [7]).

Despite the high demand for in-house models, this pioneering guidebook is the only complete, focused resource of expert guidance on building and validating accurate, state-of-the-art Environmental risk management models. Written by a proven authorial team with international experience, this hands-on road map can be used such as the fundamentals of processing data using

SPIRITS software. However, many types of indices from 360 to 552 images of a WGS-84 projection are processed with SPIRITS such us: Copernicus Global Land Service (CGLSSWI) soil water data for 2007-2017 version 3 from MetOp-A / ASCAT with a spatial resolution of 11 km and geographic coordinates (Long / Lat) (Wagner et al., 1999 [8], Bauer-Marschallinger et al., 2018 [9]). The Normalized Difference Vegetation Index (NDVI) is calculated from MODIS L1B Terra surface reflectances and corrected using the MODIS algorithms by the United States Land Observation and Resources Center (EROS) to produce NDVI eModis (Tucker, 1979 [10], Jenkerson et al., 2010 [11]). Data of absorbed photosynthetically active radiation and dry matter productivity derived from Copernicus World Terrestrial Service (CGLSFAPAR and CGLSDMP) from 2007 to 2017 version 2 which corresponds to values of reflectance absorbed by canopy and mass flows of carbon (Claverie et al., 2013 [12]).
The European Centre for Medium-Range Weather Forecasting (ECMWF) is one of the best providers of high-quality climate data series at different time scales (Woods, 2006 [13]). The forecast charts are free for anyone to access, redistribute and adapt - even for commercial applications - as part of their open data Strategy for 2021-2030 (https://www.ecmwf.int/ [14]).

The indices averages were obtained by the final processing of the eMODIS-based inputs which consisted of the spatial segmentation of the imageries using a mask surrounding Moroccan rangeland and Global Land Cover 2000 (Mayaux et al., 2004 [15]).

In this paper, we briefly summarize the SPIRITS architecture and main functionalities, and then we present the latest functional developments of the software from 2014 to today. The most commonly used functionalities of the software are illustrated with real case examples. In particular, we focus on the time series analysis performed for the production of drought monitoring on arid land.

2 Remote Sensing Data Analysis

SPIRITS
After the official presentation of SPIRITS (Software for the Processing and Interpretation of Remotely sensed Image Time Series) at the GSDI conference in Addis Ababa in November 2013, the users' community has been rapidly growing and increasingly providing feedback about possible improvements beyond the main functionalities summarized in the following sections. As a result of this interaction with users and developers, new versions, including the upgrades described below, are periodically released. The latest available version is dated March 2015 (version 1.3.0) and is available at http://spirits.jrc.ec.europa.eu. This section provides a detailed list of the new developments included in version 1.3.0 (Eerens et al., 2014 [7]).

SPIRITS is a Windows-based software aiming at the analysis of remotely sensed earth observation data. Although it includes a wide range of general-purpose functionalities, the focus lies on the processing of time series of images, derived from low-resolution sensors such as SPOT VEGETATION, NOAA-AVHRR, METOP-AVHRR, TERRA-MODIS, ENVISAT-MERIS, and MSG-SEVIRI. SPIRITS has been developed by VITO's [1] remote sensing unit on behalf of (and sponsored by) the European Commission's Joint Research Centre (EC[2]-JRC[3]) in Ispra, Italy. The JRC-MARS [4] group (Monitoring Agricultural Resources) continuously supplies the EC directorates with agro-statistical information on crop areas and yields for Europe and the major production areas of the world. SPIRITS is a free software environment for analyzing satellite-derived image time series in crop and vegetation monitoring, available at: https://mars.jrc.ec.europa.eu/asap/.

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 you to guide the GLIMPSE modules via an up-to-date interface and run them in the background. However, gradually, a number of new tools were incorporated without a relationship with GLIMPSE, for example, the import of imagery in external formats, reproject data, adapt metadata of a satellite image HDR, resampling and generation of maps, and the extraction of regional databases (Eerens, Haesen, 2016 [16]).

[1] VITO: Vlaamse Instelling voor Technologisch Onderzoek Flemish Institute for Technological Research.
[2] EC: European Commission.
[3] JRC: Joint Research Center.
[4] MARS: Monitoring of agricultural resources.

Generic Format Image Import

The Generic file format is designed to efficiently store and organize large amounts of numerical data, including satellite images. It is already used for a number of remote sensing data sources (eMODIS-TERRA NDVI (250 m), MetOp-A /ASCAT SWI (12.5 km), SPOT-VEGETATION and Proba-V Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and Dry Matter Productivity (DMP) (11 km) provided through the Copernicus program) and Advanced SCATterometer sensors. The Generic importer makes use of Image TIFF (.tiff) with n resolution for inspecting data and attributes and converting GeoTIFF imagery into SPIRITS format. This tool allows a large set of current and future data sources to be easily integrated into the SPIRITS processing chain. SPIRITS works with a fixed set of input image periodicity, namely: daily, 10-daily, monthly and annual images. The primary global daily datasets of SM2RAIN rainfall (mm/day) employed in this study are acquired from ASCAT at a spatial resolution of 12.5 km (Brocca et al., 2019 [17]). Ten years (from 2007 to 2017) of cumulative value composite of SM2RAIN images at 250-m spatial resolution were exploited for drought monitoring. Simple Python and Matlab codes for the extraction of SM2RAIN-ASCAT rainfall at one or multiple station(s)\location(s) are available at https://zenodo.org/record/3451685. The SM2RAIN code in Python is available at https://zenodo.org/record/2203560.

The SM2RAIN code in Matlab is available at http://hydrology.irpi.cnr.it/download-area/sm2rain-code/. A GeoTIFF version of the SM2RAIN-ASCAT dataset is available at https://zenodo.org/record/3520620.

With this SPIRITS toolbox, we can process and examine time series of low and medium-resolution sensors. It can be used to perform and automatize many spatial and temporal processing steps on time series and to extract spatially aggregated statistics (Table 1). Vegetation indices and their anomalies can be rapidly mapped and statistics can be plotted in seasonal graphs to be shared with analysts and decision-makers (Figures 1 and 2).

Table 1. Main SPIRITS functionalities according to the SPIRITS program menu.

Create location of processed files	Firstly we must activate SPIRITS commanded Windows in 'libs/util' files and Launch GLIMPSE/Setup GLIMPSE in the 'GLIMPSE' file. Start work with SPIRITS Executable Jar File/SPIRITS/General Menu. We can use the File tool to create a new project or to adapt HDR.
Import data (Images)	The first important thing when we import an image from Geotiff to ENVI form is the name of IMG : (prefix_(YYYYMMDDsufix). Exp: NDVI_20210301i/Period (YYYYMMDD).
Rename	Specification: 2001001 = .*. Filename: "africa_north.*.C05.NDVI.MOD44.D16.R000250.MODAPS.v1" - Input pattern: africa_north.*.C05.NDVI.MOD44.D16.R000250.MODAPS.v1* - Output pattern: a_%0i Or - In case the filenames have extensions, Exp: "africa_north.*.C05.NDVI.MOD44.D16.R000250.MODAPS.v1.img" and "africa_north.*.C05.NDVI.MOD44.D16.R000250.MODAPS.v1.hdr" - Input pattern africa_north.*.C05.NDVI.MOD44.D16.R000250.MODAPS.v1.* - Output pattern a_%0i%1
Adapt HDR	Add a date in image HDR without a date or period (YYYYMMDD). We also find the data needed for the map info: Origin = (-2890000.000000000000000,4182500.000000000000000) Pixel Size = (250.000000000000000,-250.000000000000000)
Scaling and Reclassification	Rescale, reclass or modify the original image values, and change the data type. The overlay of the land cover layer data and the corresponding satellite image consists of producing the information contained in each pixel of this image. To extract the values of each pixel, we superimposed a vector file of the pastoral areas on a raster of the rangeland classes studied.
Reprojecting	Using the EPSG (4326) for output we convert the file from the arbitrary spatial reference to the spheroid projection/ or using existing HDR. Using the wkt file we created from the spatial reference set of the original tiff.

Rasterize SHP	The vector shapefile is converted into a raster file while keeping all the significant information such as the different regions and their administrative boundaries in the ten Moroccan pastoral zones. This means that a vector that contains ten areas will be transformed into a ten-area raster for coordinates (X/Y) plus spatial information or metadata of an identical satellite image. The type of input field determines the type of output raster. Rasterize an ESRI shapefile (SHP) into an ENVI raster image file (IMG) while keeping all the significant information. The raster file will be used in classes to create the RUM.
Extract ROI	The zoning corresponds to the division of the territory concerned by the analysis of its contour following a technique of reduction of certain information included in the images. This zoning will make it possible to locate the samples. Two types of zoning are envisaged: one based on the administrative boundaries of the rangelands; and one based on the application of a mask whose vector layer is in raster format. Corresponds to the division of the territory concerned by the analysis of its contour following a technique of reduction of certain information included in the images. ROI will make it possible to locate the samples.
Resampling	he resolution of the image describes its content: the higher the resolution, the more detailed the image content. The resolution of a digital image can be of different types: spatial, spectral, temporal, or radiometric. Our digital images, used in this study, will be in spatial resolution. Modification of the resolution, or resampling of the input data, is necessary for SPIRITS calculations to be performed at the same spatial scale. The resampling method allows having the same spatial information for the input and output images, by changing the resolution in the increasing or decreasing direction.
Extract RUM	Prepare RUM database for the data which will be extracted from input images, using rasterized shp as regions. In this case without distinguishing land-use classes - just extracting overall mean values for the regions.

SPIRITS processing has been carried out for the evaluation of image times series used to study drought in Moroccan rangeland. However, these steps are standard for any issue and area (cropland, forest, water, and ocean). Aside from other programs, this interface helps you to view your images, convert their formats, and change their pixel sizes and projections. Thus, the calculation of an average image of a large series of images is quickly performed by spirits. The current study was taken up to investigate the utility of spatiotemporal analysis established by a multidisciplinary program that can handle enough satellite data processing problems.

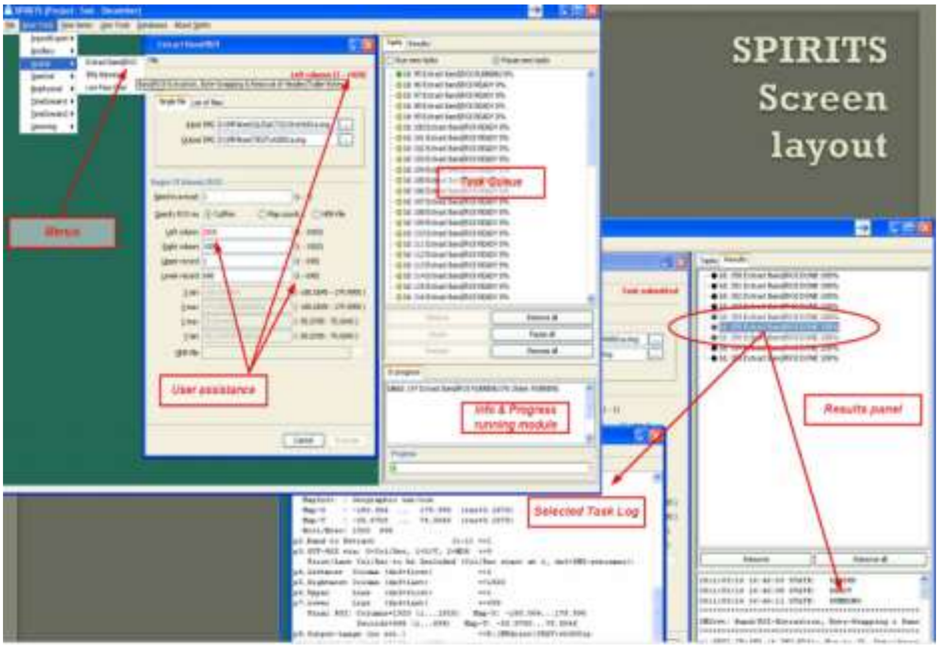


Fig. 1: SPIRITS tasks and results extract from software developers presentation/"VITO_Unesco_Brazil_201607_SPIRITS_Intro".

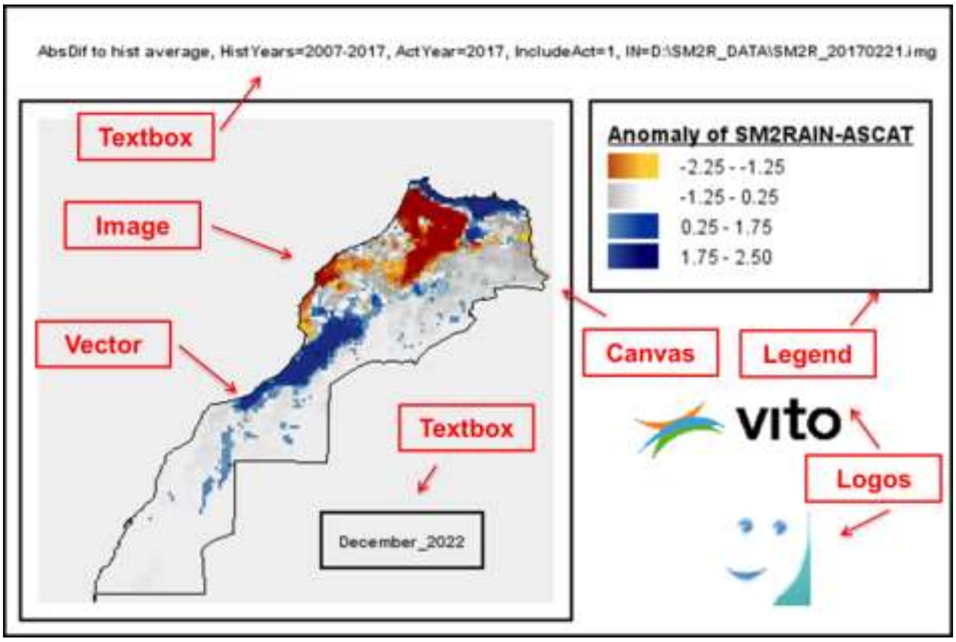


Fig. 2: SPIRITS Quick Look of SM2RAIN anomaly.

3 Results of Data processed by SPIRITS

In the first experiment of drought monitoring using SWI and NDVI, SPIRITS allowed us to extract decadal data from the image series and calculate index averages. Maps are generated easily and on a spatiotemporal scale (Zbiri et al., 2019a [18]).

Then through a second attempt to calibrate the spatial reflectances with the SPIRITS data we were able to create an algorithm for the two phenological indices FAPAR and DMP. FAPAR and DMP data, both from SPOT VEGETATION and PROBA_V, pose estimation problems and therefore their evaluation and validation was essential for further studies (Zbiri et al., 2019b [19]).

Thus, many statistical techniques exist in the identification of outliers in FAPAR and DMP indices. In our study, a methodology for rapid assessment of estimates quality of these indices was used. NDVI values are used to compare FAPAR and DMP values recovered fewer than two assumptions. Once estimation errors found in phenological indices are corrected, the estimation of the productivity of our rangelands is carried out by soil moisture index SWI, for the period before April (spring), from a polynomial regression-based algorithm (Zbiri et al., 2021 [20]).

Over time, however, improvements to instruments and data availability and advancements in algorithms and computation methods allowed for the development of different change-detecting techniques, such as time series analysis and temporal trajectory-based change detection. As a result, the detection of climate–vegetation interactions and land cover classification are no longer implemented as separate and independent activities as was typical in past studies. The problem is the efficiency of these methods and the formulation of an exact response with low errors to manage environmental risk. Processing a time series of images is a fatal step. Once data is reliable study can be completed and the theory's more or less accurate.

With SPIRITS it was possible to model the relationship between European Center for Medium-Range Weather Forecasts dataset and NDVI eMODIS-TERRA.

Most weather forecasts today are based on the output of complex computer programs, known as forecast models, which typically run on supercomputers and provide predictions on many atmospheric variables such as temperature, pressure, wind, and rainfall. A forecaster examines how the features predicted by the computer will interact to produce the day's weather (http://www.atmo.arizona.edu/students/courselinks/spring17/atmo336s2/lectures/sec6/weather_forecast_atmo170.html [21]).

In the last decade, some authors have proposed a completely new approach to using satellite soil moisture for estimating and improving rainfall prediction, doing hydrology backward. The algorithm used for estimating rainfall is called SM2RAIN (Brocca et al., 2014 [22]).

Recently, SPIRITS is used for processing the bottom-up precipitation dataset (SM2RAIN-ASCAT) (Zbiri et al., 2022 [23]). For the majority of the world's land areas, satellite-based precipitation estimates offer the only possible source of near-real-time precipitation accumulation information for operational hydrological applications. However, it is difficult to provide information at more precise levels.

The anomalies were calculated using two methods of the similarity of each type of data used: absolute difference (AbsDif) to the historical average of SM2RAIN and relative difference (RelDif) to the historical average of NDVI (Figure 3).

$ADha\ (y,p) = X(y,p) - MEAN(p)$ (Eq 1),

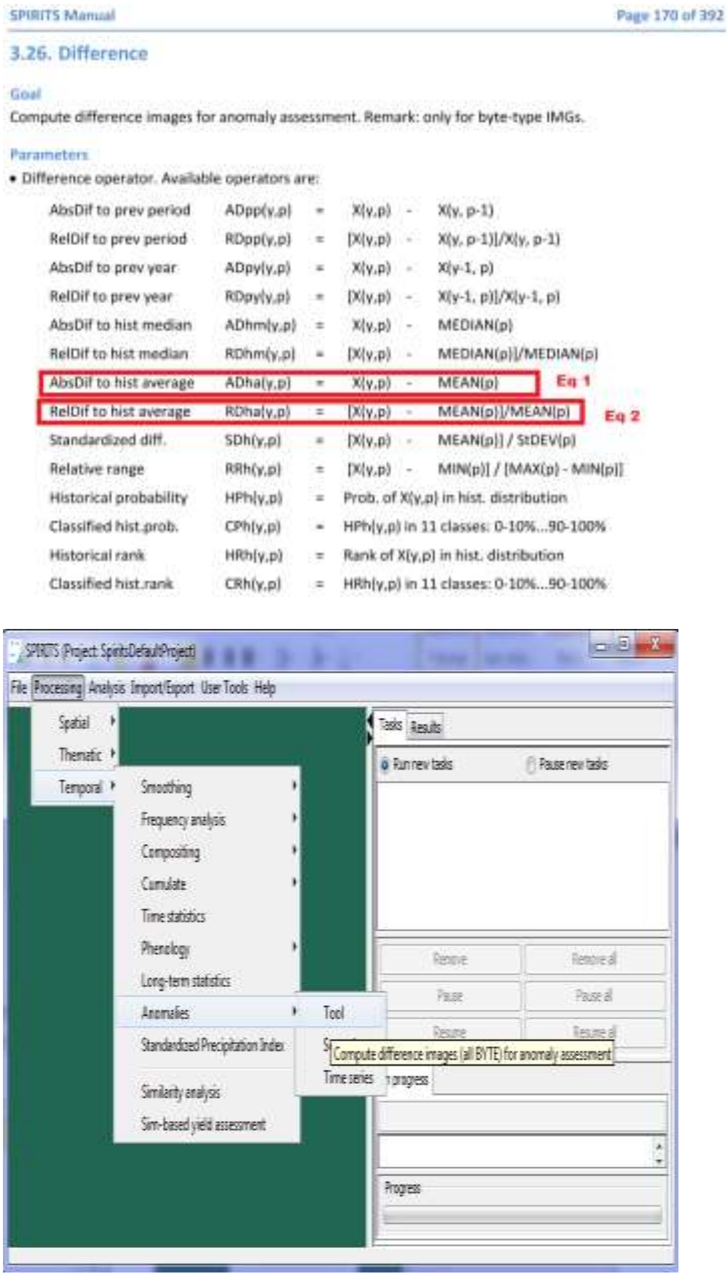
Where X is the SM2RAIN estimate for a given period p (from November to February) and $MEANp$ is the mean value of the SM2RAIN during period p, derived from the previously described 10 years of SM2RAIN time series.

$RDha\ (y,p) = [X(y,p) - MEAN(p)]/MEAN(p)$ (Eq 2),

Where X is the NDVI estimate for a given period p (from February to April) and $MEANp$ is the mean value of the NDVI during period p, derived from the previously described 10 years of NDVI time series.

SM2RAIN rainfall and NDVI anomalies data is a highly innovative idea in hydrological modeling. SM2RAIN rainfall data is another key parameter such as SM for detecting water stress related to a decrease in NDVI. The anomaly was calculated by the formulae shown in equations 1 and 2 with SPIRITS. An anomalies time series of precipitation (SM2RAIN) has been calculated to understand the rangelands' water stress condition and correlate it with a decrease in vegetation indices.

Overall, SM2RAIN-ASCAT rainfall demonstrates efficiency in a new investigation over many arid areas and soil typologies. Using SM2RAIN rainfall in arid and semi-arid areas as a new way of monitoring the yield of vegetation is a new challenge. These products can be effectively used for rainfall estimation on a global scale (Zbiri et al., 2022 [23]).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3.26. Difference

Goal

Compute difference images for anomaly assessment. Remark: only for byte-type IMGs.

Parameters

• Difference operator. Available operators are:

AbsDif to prev period	ADpp(y,p)	=	X(y,p)	-	X(y, p-1)	
RelDif to prev period	RDpp(y,p)	=	[X(y,p)	-	X(y, p-1)]/X(y, p-1)	
AbsDif to prev year	ADpy(y,p)	=	X(y,p)	-	X(y-1, p)	
RelDif to prev year	RDpy(y,p)	=	[X(y,p)	-	X(y-1, p)]/X(y-1, p)	
AbsDif to hist median	ADhm(y,p)	=	X(y,p)	-	MEDIAN(p)	
RelDif to hist median	RDhm(y,p)	=	[X(y,p)	-	MEDIAN(p)]/MEDIAN(p)	
AbsDif to hist average	ADha(y,p)	=	X(y,p)	-	MEAN(p)	Eq 1
RelDif to hist average	RDha(y,p)	=	[X(y,p)	-	MEAN(p)]/MEAN(p)	Eq 2
Standardized diff.	SDh(y,p)	=	[X(y,p)	-	MEAN(p)] / StDEV(p)	
Relative range	RRh(y,p)	=	[X(y,p)	-	MIN(p)] / [MAX(p) - MIN(p)]	
Historical probability	HPh(y,p)	=	Prob. of X(y,p) in hist. distribution			
Classified hist.prob.	CPh(y,p)	=	HPh(y,p) in 11 classes: 0-10%...90-100%			
Historical rank	HRh(y,p)	=	Rank of X(y,p) in hist. distribution			
Classified hist.rank	CRh(y,p)	=	HRh(y,p) in 11 classes: 0-10%...90-100%			

Fig. 3: Temporal functionalities and calculation of dif ferent images for anomaly assessment.

4 Conclusion

Currently, there are no future plans for further updates or maintenance of SPIRITS. The further development of SPIRITS unfortunately has stopped. For educational purposes, the tool can still be used. Actually, that was the main reason for the development of SPIRITS.

The operational processing chains use the underlying executable (GLIMPSE). The most important reason is that during the last few years, researchers are migrating more and more to other technologies. Generally, they tend to write their own scripts, typically in Python or R environments, typically using the gdal and/or geopandas libraries. We would seriously suggest to researchers to have a look at this software.

Sincerely, the satellite image processing software is magic for researchers who use a large amount of data. It was perfectly reliable for our studies described in this article. However, it still needs to be used by the scientific community as a multidisciplinary tool and is very practical for beginners and experts.

Importantly, for any scientific study, SPIRITS is a reliable program for processing different types of data. The results obtained with statistical analysis can be used in assessing and monitoring any ecological problem. However, we encourage researchers to use this excellent tool of ecological modeling.

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The authors would like to thank Eerens Herman and Haesen Dominique who are now retired. We would like to acknowledge VITO for these free software (SPIRITS) and data. We are disappointed that the development of SPIRITS has been halted. But for educational purposes, the tool can still be used. Commonly, all data allow them to be used for scientific purposes and to manage ecological and humanitarian problems (https://mars.jrc.ec.europa.eu/asap/). We thank the editor-in-chief and Assistant Editor of the WSEAS journal and we thank the Reviewers that reviewed the paper.

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