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From global observations to local information: The Earth Observation Monitor

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KEY WORDS: Web-based geo-processing; Earth Observation; time-series; vegetation analysis; web portal; mobile application; service-based infrastructure

ABSTRACT:

Earth Observation (EO) data are available around the globe and can be used for a range of applications. To support scientists and local stakeholders in the usage of information from space, barriers, especially in data processing, need to be reduced. To meet this need, the software framework "Earth Observation Monitor" provides access and analysis tools for global EO vegetation time-series data based on standard-compliant geo-processing services. Data are automatically downloaded from several data providers, processed, and time-series analysis tools for vegetation analyses extract further information. A web portal and a mobile application have been developed to show the usage of interoperable geospatial web services and to simplify the access and analysis of global EO time-series data. All steps from data download to analysis are automated and provided as operational geo-processing services. Open-source software has been used to develop the services and client applications.

1 Introduction

Information about environmental change is an important component in monitoring study areas on earth. Parameters of vegetation deliver valuable information about land cover and land use. Earth Observation satellites (e.g., Landsat, Terra, and Aqua) provide global datasets that are used for vegetation analysis. Time-series information of vegetation parameters delivers further information about changes, which can be used for new analyses. If the spatial resolution of these global datasets is suitable for local study areas, these datasets can also be used for local applications, giving local stakeholders the possibility of using global Earth Observation data for their specific needs. The transformation of global observations into local information facilitates the use of Earth Observation data for local studies, as well as the subsequent processing into local knowledge by involving stakeholders.

The involvement and consideration of stakeholders is an essential task in current international programs. A program launched in 2012, Future Earth (Future Earth 2013), was founded by international research funding organizations with the aim of supporting interdisciplinary collaborations in the area of global environmental change research, to address critical questions. In addition to questions regarding how the earth is changing, an important 'cross-cutting capability' is the focus on data and on observing systems, with the aims to "make the research more useful and accessible for decision makers" (Future Earth 2013:12) and "[make] research accessible to all parties" (Future Earth 2013:21).

Technical feasibilities are also mentioned in the Future Earth program seeking to determine best practices in integrating user needs and understanding research needs, by, for example "developing and diffusing useful tools for applying knowledge" (Future Earth 2013:21). On a more technical level, the Belmont Forum, a high level group of the world's major and emerging funders of global environmental change research and international science councils, aims to develop capable E-Infrastructures to increase community-level integration and collaboration, and to provide a community-owned global E-Infrastructure and Data Management Strategy and Implementation plan (Allison and Gurney 2014). The Group on Earth Observation (GEO) initiated the Global Earth Observation System of Systems (GEOSS; Group on Earth Observations 2005) with the aim of building a global public infrastructure that generates comprehensive, near-real-time environmental data, information, and analyses. To date, GEOSS has consisted of a metadata registry, a web portal, and a brokering system to tether external metadata catalogues to standard-compliant data services. However, only information can be downloaded from the metadata entries; it is often not possible to retrieve the data directly. Craglia et al. (2008)

published an agenda for the “Next-Generation Digital Earth” stating that multiple connected digital infrastructures and a problem-oriented focus to enable access to data, information, and services are needed, and visualization, open access, and multidisciplinary education and science is supported.

New insights into global environmental change, in focus with the next-generation digital earth, can be realized by making Earth Observation data and methods available with easy-to-use interfaces. An automated processing and analysis of Earth Observation time-series data is needed to fulfill this purpose. At present, many individual steps, such as discovery, download, pre-processing, analysis, post-processing, are needed to derive local information based on Earth Observation data. Only after completing these steps the user can derive the final information based on the outputs of the analysis tool, highlighting the need for ready-to-use derived information based on defined parameters. This can be achieved by operational and automated data processing to ensure easy access to this type of information.

The software framework “Earth Observation Monitor” (EOM) was initiated to provide easy access to Earth Observation time-series data and information from analysis tools, without the need to process data on the user’s computer. The main users are local stakeholders, as well as scientists who need an overview of their area of study. The EOM makes applied analysis methods and tools developed by different research communities online available, in combination with data access tools and web services, all encapsulated within a straightforward web interface. The spatial data infrastructure developed deals with data search, download, and conversion, as well as analysis based on user inputs.

The objective of the present paper is to describe the functional and technical concept of the Earth Observation Monitor, as well as the applications developed. The EOM can be used to explore Earth Observation time-series data based on the following three principles:

- Simple time-series data access and analysis without data processing,
- Making software tools available via web services, and
- Providing simple tools with easy-to-use applications for stakeholders and scientists.

The remaining paper is structured as follows: Background and related work is shown in Section 2 with a focus on geospatial web services, vegetation time-series analysis, and available online tools. The design and implementation of the EOM are explained in Section 3 including data access and processing services as well as web and mobile applications. Finally, a summary and conclusions are given in Section 4 and future work in Section 5.

2 Background and related work

2.1 Geospatial service infrastructure

Modern web technologies facilitate the use of web services and are the basis for interactive and easy-to-use web-based geographic information systems. Using web services also allows the usage from multiple systems (e.g., a web portal, a mobile application, and other software clients). An important consideration in developing web-based geographic information systems is hiding the complexity of data processing techniques from users and providing simple web interfaces. Making desktop software available online relies on web services, which make it possible to execute tasks independently on remote servers. Client applications and service infrastructures can be separated (Figure 1) but interoperability needs to be integrated and provided; external clients can make use of the service infrastructure if access is permitted. Services are provided over the network, and thereby made available for client applications. Two main different architectural styles are available to publish services, service-oriented architecture (SOA; MacKenzie et al. 2006) and resource-oriented architecture (ROA; Overdick 2007). Both of them can also be used for geospatial services. Mazzetti, Nativi, and Caron (2009) have stated that “it is not possible to say that one architecture is better than the other” and that “the selection [...] depends on application requirements.” These authors selected the REST approach for their Earth System Science applications.

In a spatial data infrastructure, services are available for the tasks of visualization, data access, metadata cataloging, and data processing. To provide interoperable services and metadata, the Open Geospatial Consortium (OGC) published several standards and implementation specifications for the geospatial world. Those can be used to establish interoperability on server- and client-side. Automated and operational processing is needed for user-friendly time-series analysis tools, allowing users to perform the tasks of data downloading,

processing, and analysis. The OGC has specified standardized processing services with the Web Processing Service (WPS; Schut 2007). This specification describes service interfaces that can be used to publish processing algorithms and to request their execution on the Web. Within the process algorithm, external software can be made available, for example, by executing software on the command line or through libraries used in programming languages. This allows a wide range of software to be integrated into a web service environment. Several open source software programs exist that meet OGC WPS specifications (an overview is given by Zhao, Foerster, and Yue 2012 or Lopez-Pellicer et al. 2012).

Web Processing Services are widely used in conjunction with spatial data infrastructures when processing methods are available to the user. Several publications also list any usage in research projects, and research has been done in the field regarding distributed processing (Friis-Christensen et al. 2007; Meng, Xie, and Bian 2010; Schaeffer et al. 2012; Foerster et al. 2011), semantic processing (Farnaghi and Mansourian 2013; Wosniok et al. 2014; Vitolo et al. 2015), process orchestration (Nash et al. 2007; Eberle and Strobl 2012; de Jesus et al. 2011; Wu et al. 2014; Meng, Bian, and Xie 2009), processing in the cloud (Sun 2013; Evangelidis et al. 2014), moving code (Müller, Bernard, and Kadner 2013), and modeling (Buytaert et al. 2012; Imran, Zurita-milla, and By 2011; Dubois et al. 2013).

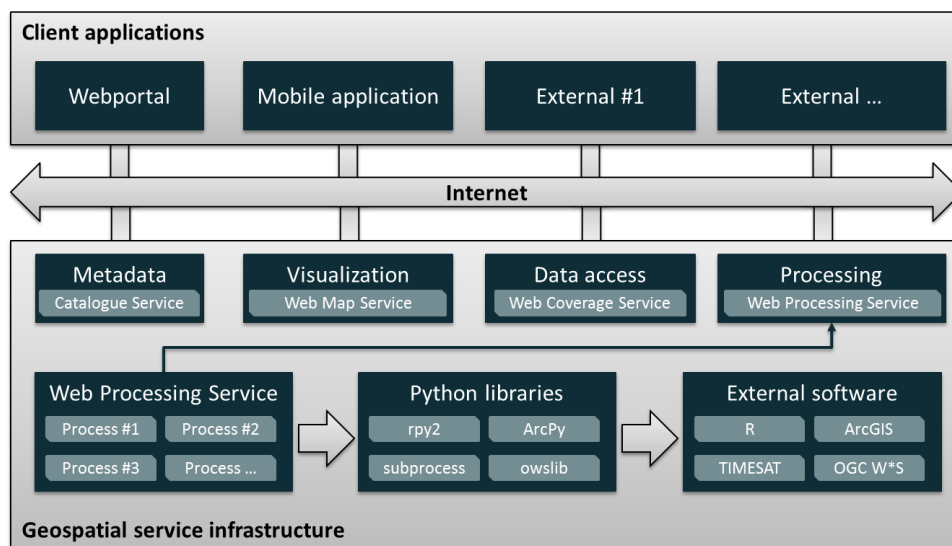


Figure 1: Client applications can connect through the internet to the geospatial service infrastructure that includes processing based on OGC Web Processing Services on Python programming language. Connections to diverse GIS processing software are made either through Python modules (e.g., R, ArcMap, OWS services) or through command line access (e.g., TIMESAT).

2.2 Vegetation time-series analysis

Satellite image time-series of vegetation indices are radiometric measurements of photosynthetically active radiation in the leaves of the vegetation, a proxy for the photosynthetic activity and vitality of plants. Vegetation indices like the Normalized Difference Vegetation Index (NDVI, Tucker 1979) or the Enhanced Vegetation Index (EVI, Huete et al. 2002) have proven to be important data sources for vegetation change and dynamics analyses. Daily to bi-weekly global data with a spatial resolution of 250m using the NDVI and EVI data from the Moderate Resolution Imaging Spectroradiometer (MODIS) allows vegetation analyses from 2000 onwards (Huete et al. 2002).

Evolving methods on vegetation change characterization have been developed by scientists around the world. Recent developments such as the 'Breaks For Additive Seasonal and Trend' (BFAST) method allow users to detect land cover changes by detecting phenological changes in the inter-annual time-series. BFAST integrates the decomposition of time-series into trend, seasonal, and remainder components, and provides the time and number of changes in the time-series. Studies observing increasing or declining net primary productivity of vegetation (Verbesselt, Hyndman, Newnham, et al. 2010; Verbesselt, Hyndman, Zeileis, et al. 2010) fostered the development of statistical tools for detecting trends such as greening or browning. The greenbrown package (Forkel et al. 2013) is a collection of functions designed to analyze trends and trend changes in gridded time-series, like those from satellite observations or climate model simulations. In the Earth Observation community, Greening describes positive trends in vegetation greenness, whereas Browning

indicates negative trends in vegetation greenness. Both methods are provided as tools in the R statistical language. In addition to trend analyses of satellite time-series, the derivation of phenological metrics for vegetation characterization and classification is another important issue. Introduced by Jönsson and Eklundh (2004), the software TIMESAT has been developed for satellite-based phenological analyses based on the seasonality of satellite time-series data and their relationship with the phenological cycling of vegetation. Further on, it enables the extraction of time-related phenological metrics (e.g., start of season, length of season) or biomass-related metrics, such as the integral of the vegetation period.

2.3 Online time-series access and analysis tools

A number of tools for Earth Observation time-series data access and analyses are available online, but they have all specific limitations, described in this chapter. More and more tools allowing time-series extraction and analysis of specific datasets from NASA MODIS sensor are becoming available. Some of these tools are listed in Table 1, and are discussed in the following paragraphs.

The probably best known web-based tool is NASA Giovanni – Interactive Visualization & Analysis (Acker and Leptoukh 2007), which offers a wide range of available MODIS datasets and different time-series extraction and analysis tools. Although NASA Giovanni does provide access to all input data for a given bounding box and time range, these tools are not publicly available as web services to be integrated into external applications. The MODIS Land Subsets tool from the United States' Oak Ridge National Laboratory (ORNL) provides time-series extraction for a bounding box around a selected pixel location. In addition to time-series data access, the tool also visualizes land cover types and provides a phenology time-series plot for vegetation data. A SOA-based MODIS Web Service is publicly available for querying the data catalogue and submitting an order for time-series access and analysis graphs. The Laboratory of Remote Sensing in Agriculture and Forestry of the Brazilian National Institute for Space Research (INPE) developed a tool for MODIS EVI-2 and TRMM precipitation data plotting for South America; an easy-to-use web portal provides time-series data with just one click on the map. The Multi-Sensor Evolution Analysis (MEA) of the EU EarthServer project focuses on the provision of time-series data access, based on OGC-compliant web services. Through the web portal, tools are available for interactive time-series plotting for different pixels and datasets, which can be compared using a chart. Spatial subset plots can also be shown as images or as map-based visualizations. Via the OGC Web Coverage Processing Service (WCPS), the datasets are available in a web service query-processing language.

Table 1: Comparison of web-based time-series data access and analysis tools.

	Outputs / Web Services
NASA Giovanni http://giovanni.gsfc.nasa.gov/ Available portals: Atmospheric, meteorological portals Ocean & hydrology portals	Results as images, GeoTiff files, ASCII text. GeoTiff files can be visualized interactively with an OGC Web Map Service.
MODIS Land Subsets http://daac.ornl.gov/MODIS/ Available MODIS products (excerpt): BRDF, Surface Reflectance Land Surface Temperature Vegetation Indices, Leaf Area Index	Results as interactive and image plots, GeoTiff files, ASCII text. MODIS Web Service based on SOAP for data queries and access (only ordering).
INPE EVI2 tool https://www.dsr.inpe.br/laf/series/en/ Available data: MODIS EVI-2, SRTM, TRMM	Results as interactive plots, CSV export.
Earthserver MEA http://earthserver.services.meeo.it/ Available MODIS products: Atmospheric datasets MOD13Q1 NDVI	Results as interactive plots, XML export. Datasets available as OGC Web Coverage Service (WCS) and Web Coverage Processing Service.

For users focusing on vegetation time-series data, many of the tools described in the preceding paragraphs offer web-based tools for time-series extraction and visualization. However, none of the existing tools can yet be integrated into external applications. The OGC WCPS service from MEA is a good approach to overcome this issue; however, the complete MODIS vegetation datasets with Enhanced Vegetation Index, the Normalized Difference Vegetation Index, and the quality flag datasets are not yet fully available and are not yet updated automatically. Although the MODIS Web Service from ORNL provides users with a way to submit order requests, the resulting data are only available on a website whose link is sent via electronic mail. To sum, service-based access to time-series vegetation data is only available within specific limits. Using OGC Web Processing Services is therefore a good technical solution, allowing users to execute the services directly within other external applications.

From the point of view of an end-user, further information based on the analysis of time-series data is also useful. Some of the scientific algorithms that are currently available can provide information about breakpoints in trends and seasonality that can be used, for example, as indicators for changes in vegetation. A great deal of information can also be retrieved from phenological derivations, like the start and end of a season, seasonal amplitude, and seasonal integral. However, to date, none of this information is available as on-demand processing services in web-based environments.

3 The Earth Observation Monitor

The Earth Observation Monitor (EOM) is a software framework with the aim of ensuring easy access and analysis of spatial time-series data for land monitoring on local scales. Scientists and stakeholders working in local areas need to be able to do time-series analysis without the need to process any data. In this chapter, the concept; technical developments based on automated data access, processing, and analysis; and example client applications are described.

3.1 Concept

The concept behind the EOM combines the advantages of web service-based geoprocessing with user-friendly interfaces; this provides an easy access for users without specific knowledge in data processing. The EOM focuses on hiding existing barriers (e.g., data download, data processing, format conversion), to allow users to focus on the analysis results. As many steps that are needed to produce analysis results from Earth Observation data can be automatized, users can concentrate on the interpretation of the analysis results. Figure 2 illustrates the tasks: The EOM integrates the data for the specified area including quality checks and data clipping. If the analysis method and its parameters are set, the system prepares data needed for the analysis, executes the method, and prepares the results for online visualization and easy-to-use offline usage.

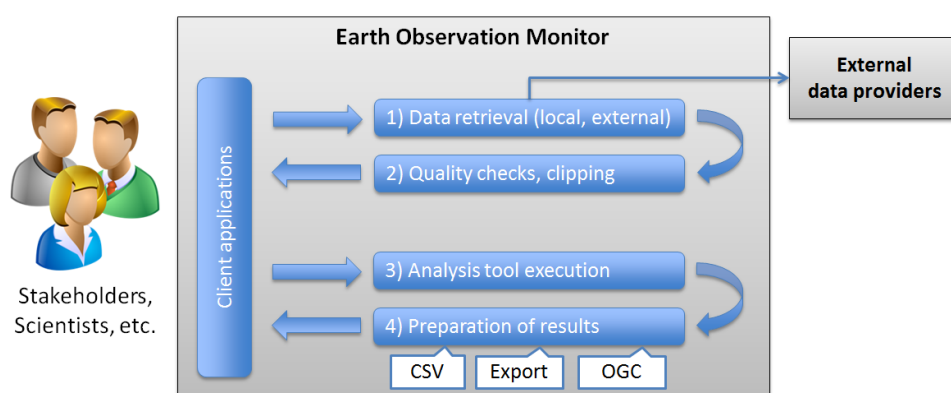


Figure 2: Concept of the Earth Observation Monitor.

3.2 Automated data access

The basis for an automated data processing and analysis tool is operational and automated data access, which is accomplished by introducing a multi-source data processing middleware (Eberle et al. 2013). This middleware (see Figure 3) integrates data from external sources (like NASA, NOAA, Google Earth Engine, and general datasets) on demand. Any integrated dataset is described with metadata and stored as geospatial data in a

common data format. These data are provided to client applications through OGC-compliant web services, the integration is also available as OGC Web Processing Service.

The middleware was developed as a Python library named pyEOM . The aims of the library are (1) to provide access to time-series data as easily as possible and (2) to provide a standard-compliant web service for data access, visualization, processing, and analysis. This library can either be used within a Python script or by the web processing services published by the EOM framework. pyEOM provides access to several external datasets like MODIS and climate station data. Table 2 lists available data sources. Datasets from OGC Web Coverage Services (WCS) and OGC Sensor Observation Services (SOS) can also be integrated into the middleware. Any dataset integrated into the middleware can be visualized with OGC-compliant web services. Point-based time-series data can be published as an OGC SOS; Polygon-based time-series raster data is available as an OGC Web Map Service (WMS) for visualization and as OGC WCS for data download.

Table 2: Datasets connected in the multi-source data processing middleware (adjusted after Eberle et al. 2013).

<i>Dataset</i>	<i>Type</i>	<i>Spatial res.</i>	<i>Temporal</i>	<i>Time range</i>
NASA Land Processes Distributed Active Archive Center (LPDAAC)				
MODIS	Raster	250m – 1km	Daily to Monthly	2000 – now
National Snow and Ice Data Center (NSIDC)				
MODIS	Raster	250m – 1km	Daily to Monthly	2000 – now
NOAA National Climatic Data Center				
GSOD, GHCN	Sensor	-	Daily	1929 – now
Google Earth Engine				
MODIS	Raster	250m – 1km	Daily to Monthly	2000 – now

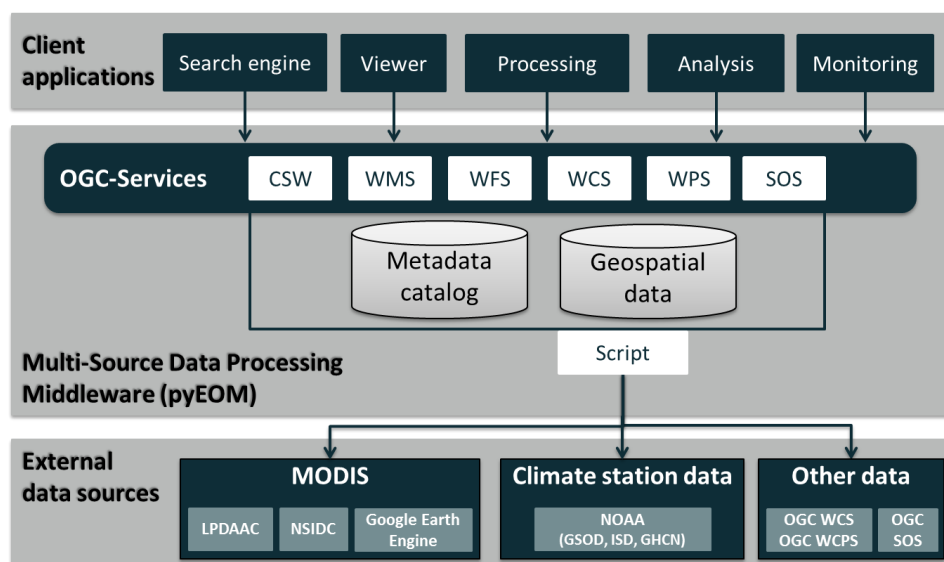


Figure 3: The Multi-Source Data Processing Middleware (updated after Eberle et al. 2013) is connected to external data sources and provides data integrated into the middleware as OGC-compliant web services.

Geospatial data is stored in a common data format, meta

3.3 Automated data processing and analysis

Data processing and analysis need to be available via a web-based system. To make processing and analysis tools automatically available, they must be executable either within a programming language or from the

command line. *PyWPS*³ was used as Python-based open-source software compliant with the OGC Web Processing Service specifications. Ready-to-use Python-libraries, such as *rpy2* for R statistical language or *ArcPy* for ArcMap tools, as well as command line executions (with the Python library subprocess), can be used to run external software for data analysis or data processing (see Figure 1).

The automated workflow can be divided into five steps:

1. Time-series data extraction for a point or polygon selected by the user.
2. Data post-processing for quality checks and interpolation.
3. Data preparation for the individual analysis tool.
4. Execution of the analysis tool.
5. Preparation of analysis results for online visualization and download.

For any processed dataset of a created feature—a point or a polygon—an individual processing directory is created that can be accessed by the user. Within this processing directory, any downloaded and processed data is available for download. Any input data, as well as results for a selected analysis tool, are also stored in this directory (see Figure 4). For example, the user can download the input data to execute the analysis tool offline on the local computer to reproduce the results. The individual steps of the automated geoprocessing services (Figure 4) are described in the sections 3.3.1 and 3.3.2. Appendix B lists all WPS processes that have been developed for data retrieval and data analysis.

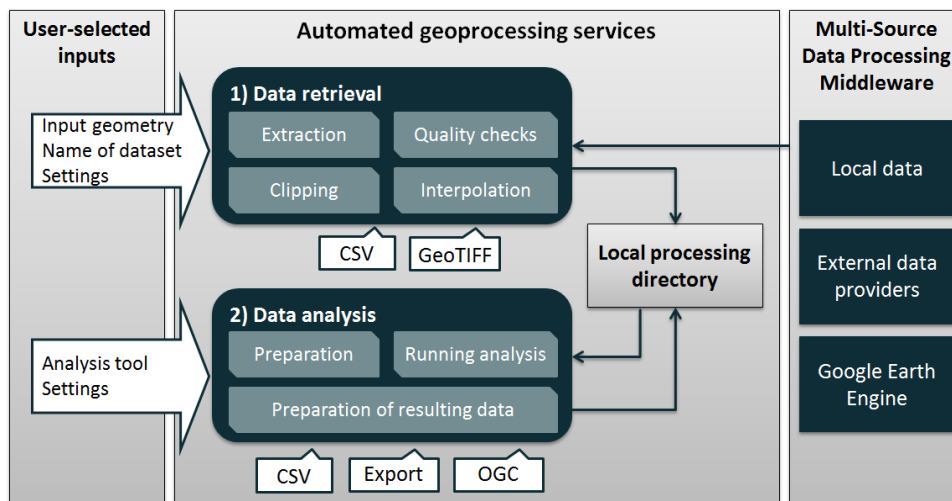


Figure 4: Automated data processing and analysis workflow.

3.3.1 Data retrieval

The retrieval of data is the basis for all further analyses. Dependent on the selected dataset, feature geometry, and source of the dataset, different processing steps have to be conducted. The processing includes the extraction of time-series data from the original dataset, clipping to the feature geometry, quality checks based on user inputs, and linear interpolation to replace `no-data` values from the time-series. To ensure transparency, quality flags and information regarding any interpolated values are stored. The data retrieval has been made available as OGC WPS process to be able to retrieve data within external client applications.

Figure 5 shows an example request for the WPS process to integrate a MODIS MOD13Q1 EVI dataset or a lat/lon coordinate. Further parameters can be set to consider a specific time range and quality flags. The request can be executed synchronously or asynchronously (including the parameters `status` and `storeExecuteResponse`). The resulting output consists of files including data and plots as well as a unique identifier (`uuid`). This identifier is needed afterwards in the execution of analyses processes to reference the data integrated in this step.

³ <http://pywps.org/>


```

http://artemis.geogr.uni-jena.de/cgi-bin/testbox.cgi?
  service=WPS&version=1.0.0&request=Execute&
  identifier=1013_single_ts_plot_point&
  datainputs=[
    datasetName=mod13q1_evi;
    pointX=13.54;
    pointY=52.31
  ]
  &status=true&storeExecuteResponse=true (optional)

```

Figure 5: Request to integrate a MOD13Q1 EVI dataset for a given coordinate.

Extraction & Clipping

In the first step of data retrieval, the required information needs to be extracted out of the raw time-series dataset and clipped to the user's geometry. Dependent on the geometry type (point or polygon), the output of the common data format differs: For points, a CSV file with the time-series information is provided; for polygons, GeoTiff files are stored individually for each timestamp.

Quality checks

Products from MODIS sensor are always delivered with quality flags so that users can decide which data are good enough for their specific application. To give users the opportunity to determine data quality, quality flags have to be processed. Depending on the threshold being used, some data can be declared as having no-data value. The quality flags are also extracted and clipped to the users' geometry. A quality mask is then created for each timestamp, based on the users' quality parameter inputs. These masks are then applied to the corresponding raster data.

Interpolation

For some time-series analysis methods missing data need to be interpolated, if no-data values are present. A linear interpolation is used to overcome this issue in the pre-processing step. Interpolated values are marked in a separate column in the final output CSV file, as well as in the output plot.

3.3.2 Data analysis

The basis for the time-series data analysis is either a CSV file, for point-based analyses, or a multi-band raster image stack, for polygon-based analyses. The following steps concerning data preparation, analysis execution, and preparation of resulting data are mostly individual for each analysis tool; these steps are also different for point-based and polygon-based analyses. As with data retrieval, any processed data is stored in the processing directory that is available to the users, giving them the possibility to download the prepared data for a specific analysis tool and to reproduce the analysis offline on their computers. The OGC WPS processes developed for time-series analysis are listed in Appendix B. Two processes always exist for each analysis method, one for point-based and one for polygon-based analyses.

Figure 6 shows an example request for the WPS process to execute BFAST for a prior integrated dataset. The dataset is specified by the unique identifier (uuid) as output from the data retrieval process. Further optional parameters can be set to adjust the BFAST algorithm. The resulting output consists of several plots and files (see Table 3).

```

http://artemis.geogr.uni-jena.de/cgi-bin/testbox.cgi?
  service=WPS&version=1.0.0&request=Execute&
  identifier=2010_single_ts_bfast_point&
  datainputs=[
    uuid=b5b17389-05d7-4058-9d87-aea05a0234d7
  ]
  &status=true&storeExecuteResponse=true (optional)

```

Figure 6: HTTP request to execute bfast for a prior integrated dataset (defined by the uuid parameter).

Data preparation

The preparation of datasets for specific analysis tools can be automated based on the requirements of the selected tool. For the R-packages ‘BFAST’ and ‘greenbrown’ it is necessary to build a time-series object with a starting date and a frequency parameter to describe the time-series. For polygon-based analyses, both packages need a *raster brick* object that can be created based on the multi-band raster file. Data pre-processing for TIMESAT consists of the creation of a configuration file and the preparation of the input data. For point-based analyses, the input data is a new ASCII text file with data values in a single row. For polygon-based analyses, the data must first be scaled to the original values and converted into the ENVI HDR raster data format, which does not include header information. This is done with the Geospatial Data Abstraction Library (GDAL; (Warmerdam 2008)). Afterwards, a list of files is saved in an ASCII file that is referenced in the TIMESAT configuration file.

Analysis execution

The execution of analysis methods can be done either from the command line or using a Python library. The Python library rpy2⁴ was used as a direct connection to R within Python. With this library it is possible to execute R functions and to exchange variables between both languages. The execution of TIMESAT is done from the command line, which is executed from the subprocess module of Python. In such an automated environment, no command line prompts can occur; rather, the complete execution has to run in a single step. The resulting data need to be stored in files that can be accessed by the Python process after successful execution.

Preparation of analysis results data

The resulting data can then be prepared to ensure easy user access. A graphical figure can be made from the results of any analysis method; several output files are also generated, depending on the feature geometry and the analysis method. Table 3 lists the prepared output files and services. To visualize spatial analyses of feature polygons, OGC Web Map Services (WMS) and OGC Web Feature Services (WFS) are automatically generated from the raster and vector outputs: GeoTiff files are provided as WMS, and shape files as WFS. The shape files show each pixel of the polygon in the map, and come with an attribute table, which gives the statistics of each pixel by analysis method. This attribute table can also be obtained using the OGC WFS GetFeatureInfo request.

Table 3: Generated output files, by feature geometry and analysis method.

	BFAST	greenbrown	TIMESAT
Point	Data (CSV) Statistics (CSV) Plot (PNG)	Data (CSV) Statistics (CSV) Plot (PNG)	Data (CSV) Phenology (CSV) Plot (PNG)
Polygon	Data (GeoTiff) OGC WMS Pixel-Shapefile	Classification, slope, p-Value (GeoTiff, WMS) Shapefile / WFS for slope, p-Value	Data (GeoTiff) OGC WMS Shapefile / OGC WFS for Phenology

3.4 Client applications

The functions of the EOM are available with web services, allowing client applications to make use of these services. Two example clients were developed to show the possibilities of such a service-based infrastructure: A web portal (webEOM) and a mobile application (mobileEOM). Both of these clients use the OGC WPS for data integration and analysis. OGC Web Map and Feature Services for resulting data provide the possibility for direct online visualization.

3.4.1 webEOM

The focus of the web portal is to provide an easy-to-use client, while making it possible to extract time-series data and execute further time-series analysis functions. The webEOM⁵ map (Figure 7) can be used to create the geometry of a study area. Based on this geometry, the system requests a list of available datasets that are registered in the multi-source data processing middleware. When conducting data integration, users can specify different parameters for the selected dataset, such as start and end dates, as well as filtering options. A processing directory for each integrated dataset is available to users, which contains any processed data for both the dataset and the executed analysis tools. A time-series and a decomposition plot are generated automatically

⁴ <http://rpy.sourceforge.net>

⁵ <http://www.earth-observation-monitor.net/map.php>

from the extracted time-series data that are plotted in the web portal. In addition to the images, CSV files are created and available for download. After data integration, users can select an analysis tool for execution, and individual parameters can be set for the selected analysis. The resulting data can either be visualized directly in the web portal or can be downloaded for further usage. Spatial outputs can be interactively explored in the map, and CSV files will be plotted as an interactive chart.

Several open-source libraries were used to develop the web portal (Appendix A): Drupal CMS is used for user registration and authentication, as well as as a registration service for created features. On the frontend interface, the JavaScript library OpenLayers is used as a mapping library; dygraphs are used to generate interactive charts; and jQuery provides standard JavaScript functions.

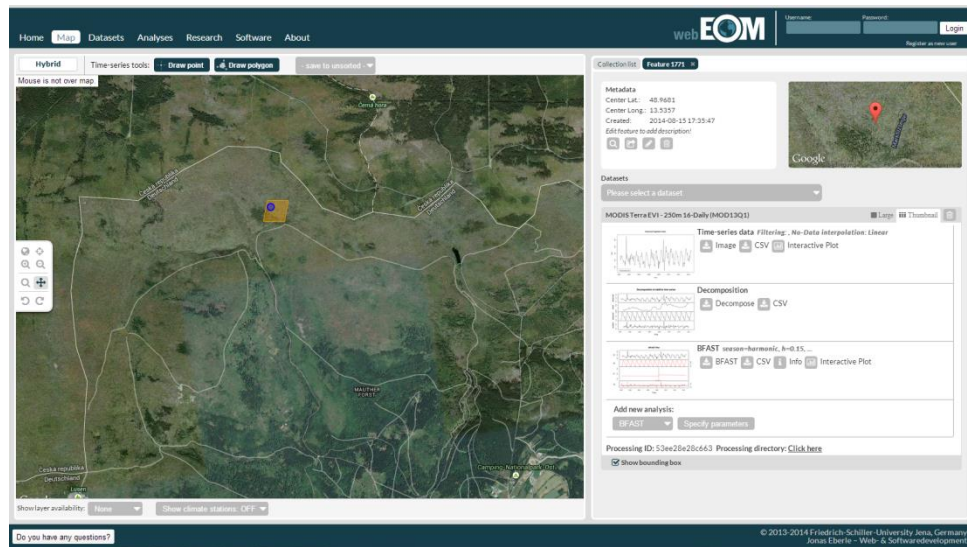


Figure 7: Screenshot of webEOM portal.

3.4.2 mobileEOM

During fieldwork, users cannot use web-based systems developed for desktop computers. A mobile application is therefore needed to foster the use of spatial time-series tools on mobile devices, which can be more easily used during work in the field. With such a mobile application users have access to a wide range of information, because a time-series of several years (15 years for MODIS vegetation data) can tell stories about the changing environment. The combined usage with time-series analysis tools allows identifying breaks in the past and overall trends of the vegetation, while users are in the field.

The mobile application for EOM was developed to provide access to time-series data and derived analyses on mobile devices. Using their current GPS location or a manual set position, users can extract vegetation time-series data, as well as view data plots, trend, and breakpoint analysis plots directly on their mobile devices. An OGC WPS process was developed for the mobile application. This provides all necessary functionalities in a single process, available as web service. This process extracts the data from Google Earth Engine⁶ and plots the time-series and decomposition figure. In a second step, time-series analyses for breakpoint detection (BFAST) and trend calculations (greenbrown) are executed and plotted in a figure. The resulting output is a GeoJSON file containing the values of the analysis tools, as well as links to the generated figures. Figure 8 shows screenshots of the mobile app linked with a chart of the OGC WPS process and how they interact.

⁶ <https://earthengine.google.org/>

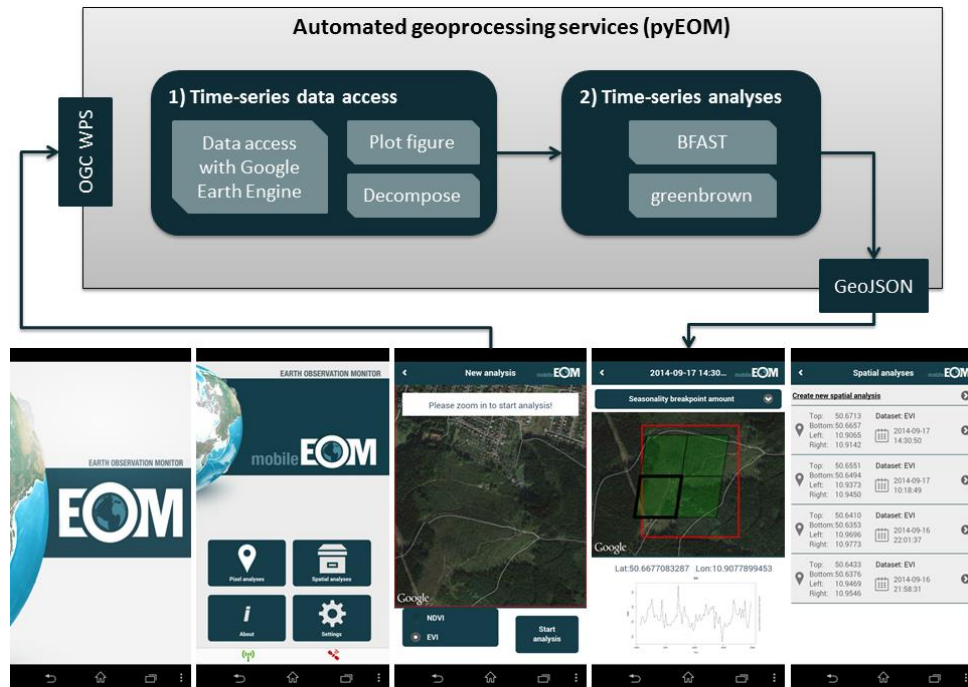


Figure 8: Screenshots of the mobileEOM app and interactions between the app and EOM web services.

The mobile application was developed as hybrid web application. Applications of this type are developed using HTML5, CSS, and JavaScript and then exported as native applications. To access the sensors and functions of the mobile device (e.g., GPS, file storage), the software PhoneGap was integrated and used for native application export. The interface was developed using jQuery Mobile, and the interactive map was integrated with Google Maps API.

4 Summary and conclusions

Based on an infrastructure using standard-compliant geospatial web services, the Earth Observation Monitor (EOM) software framework was introduced to provide global access and analysis tools for NASA MODIS vegetation time-series data, for user-defined points and polygons. A further aim was to make such time-series data and algorithms developed in research projects for data analysis more useful and accessible for users (i.e., scientists, stakeholders, and other decision-makers). Interoperable web-based geoprocessing services have been developed that can be used from external software and linked from data registries and metadata catalogues (e.g., GEOSS portal). Metadata entries can now be linked with such data-access services as provided within the framework of EOM. Two client applications have been developed to show how EOM can provide simple access to these services via a web portal and a mobile application, meaning that users do not need to process any data themselves.

Earth Observation time-series data are now operationally available for a wide range of applications. In many cases, users are interested in information about the change of the environment in their specific area of interest. Valuable information can be derived from time-series data for such user-defined areas, but better tools are needed to extract time-series data and to provide this information. With increasingly large data archives and high volumes of requests for data access, standard-compliant services for data access must be provided. In addition to traditional ways of providing data access services from the Open Geospatial Consortium (OGC), like Web Feature Service and Web Coverage Service, the present article proposes using Web Processing Services (WPS). Individual data integration and processing steps can be realized using WPS, such as applying individual quality masks, sub-setting data to a specific polygon, and providing different output formats. Until today only a few WPS processes are available for data access and processing; these need to be considered also by data providers.

Diverse scientific subjects (e.g., biodiversity monitoring, conservation ecology, and forest management) can benefit from using global Earth Observation time-series data, but data access still remains a complex task (Kuenzer et al. 2014). In addition to needing easier data access, interoperable analyses methods must be integrated to enable further information derivation. Global data can be transformed into locally relevant

information by extracting datasets for local areas and applying algorithms. For time-series data, these algorithms can be land-surface trend calculations, breakpoint detection, or phenological analyses of vegetation data. Providing access to such algorithms—for example, by implementing web services for algorithms that have been developed within research communities—will make this area of research more accessible. This was shown in the present article for vegetation time-series analysis, and led to the Earth Observation Monitor framework.

An ideal way to make data access easier is providing web services, as they can be easily integrated into other applications and used within programming languages. The OGC WPS specification provides a standardized framework for geospatial processing, allowing other external applications to use these services with a common interface. Only at least the name of a dataset and the geometry (point, polygon) are necessary to access the data; the user does not need to know the details in handling specific Earth Observation datasets. As Earth Observation data are mostly provided in diverse data formats, these web services can provide consistent data formats, which are easier for users. In addition to providing easier data access, information based on time-series data must also be made more available. By providing scientific algorithms as web services, both algorithms and time-series data can be linked. This linking then allows users to execute both the integration process for data access and the algorithm process for information extraction. Without needing to do any data processing at all, users can retrieve locally relevant information, such as climate-driven vegetation phenology trends and back-dating of land-cover change events using breakpoints.

Web clients and mobile apps can be used in conjunction with geospatial web services, increasing the effectiveness and interoperability of web services by adding an intuitive frontend interface for different devices. Such an interface can, for example, provide notifications when data are available for analysis. A mobile app gives users direct access to time-series data while they are conducting fieldwork, without requiring a notebook or desktop computer to have access to the time-series data. Such applications can be built on top of the developed web services, and, as they are available over the Internet, can be used from any application that is compliant with the OGC WPS specifications.

5 Future work

Although the technical solutions have shown that geoprocessing services can be used to lower barriers in time-series data access and analysis, there are still some topics that can be considered in the future: The processing services need to be described with metadata and made available in catalogue services and system of systems (e.g., GEOSS). Inputs and outputs of a process need to be semantically described to automatically detect what kind of inputs can be used with a process and to establish automatic connections between processes as workflows. Also the “moving code” (Müller et al. 2013) paradigm needs to be considered further to make it easier to process algorithms on external servers.

The further development of the EOM is concentrates on the usage of distributed processing capabilities to increase the performance and the integration of further high- and medium-resolution satellite sensors, such as the new Copernicus Sentinel satellites or Landsat. Furthermore the web and mobile applications can be optimized in various ways.

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Appendices

A. List of software used for EOM services, webEOM, and mobileEOM

Software	Version	Function
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Drupal CMS	7	Backend
jQuery	1.10.2	JavaScript Frontend Library
OpenLayers	2.12	JavaScript Mapping Library
dygraphs	1.0.1	JavaScript Chart Library
Google Maps API	3	JavaScript Mapping Library
jQuery Mobile	1.3.2	JavaScript Mobile Library
PhoneGap / Cordova	3	Native Mobile Application Framework
MapServer	6	OGC WMS & WFS output layers for time-series analysis results
PyWPS	3.2.2	OGC Web Processing Service
R	3	Time-series analysis (BFAST, greenbrown)
Python	2.7	Libraries such as GDAL, OGR, Pandas
TIMESAT	3.1	Phenological time-series analysis

B. Web processing services for time-series data retrieval and time-series analysis available for EOM: <http://artemis.geogr.uni-jena.de/cgi-bin/testbox.cgi>

Data access for points	
Identifier:	1012_single_ts_plot_point
Inputs:	pointX, pointY, datasetName, dateStart, dateEnd, qualityLimits
Outputs:	pointBBOX, tsCSV, tsPlot, tsDecompose, tsDecomposeCSV, uuid
Data access for polygons	
Identifier:	1012_single_ts_plot_polygon
Inputs:	wkt, datasetName, dateStart, dateEnd, qualityLimits
Outputs:	tsCSV, tsPlot, tsDecompose, tsDecomposeCSV, uuid
Data access for climate stations	
Identifier:	1020_single_ts_plot_climate
Inputs:	station, parameters, dateStart, dateEnd
Outputs:	tsCSV, tsPlot, uuid
Time-series BFAST analysis	
Identifier:	2010_single_ts_bfast_point 2010_single_ts_bfast_polygon
Inputs:	uuid, season, h, maxiter, breaks
Outputs:	Point: seasonalityDates, trendDates, bfastCSV, bfastPlot Polygon: layers, plot
Time-series greenbrown analysis	
Identifier:	3010_single_ts_greenbrown_point _polygon
Inputs:	uuid, method, mosumpval, h, funSeasonalCycle, funAnnual
Outputs:	Point: breakpoint, slopes pvalue, gbCSV, gbPlot, trendCSV Polygon: layers, mac, mac_cl, mac_plot
Time-series TIMESAT analysis	
Identifier:	4010_single_ts_timesat_point _polygon

Inputs:	uuid, fitting, seasonStartMethod, seasonStart, seasonEnd, spikeMethod, spikeValue, adaptionStrenght, windowSize, noIterationsUpperEnvelope
Outputs:	Point: timesatFitCSV, timesatSeasonalityCSV, timesatPlot Polygon: layers, seasonalityParameters, seasons
Data availability	
Identifier:	0020_wps_available_datasets
Inputs:	wkt (Point or Polygon representation as string)
Outputs:	json (list of datasets)
Mobile point-based WPS	
Identifier:	8010_single_ts_mobile
Inputs:	pointX, pointY, qualityLimits, uuid, width
Outputs:	pointBBOX, tsCSV, tsPlot, tsDecompose, tsBfast, tsGreenbrown, uuid
Mobile point-based WPS	
Identifier:	8020_multiple_ts_mobile
Inputs:	bbox_top, bbox_right, bbox_bottom, bbox_left, dataset, width
Outputs:	results, analysis, uuid

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