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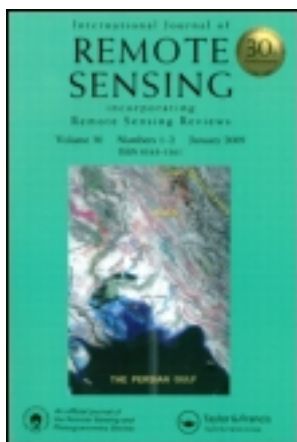
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15 years of processing and dissemination of SPOT-VEGETATION products

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Throughout the VEGETATION programme, the Flemish Institute for Technological Research (VITO) uninterruptedly hosted the prime user segment of both VEGETATION 1 and VEGETATION 2 multispectral instruments on board the Satellite Pour l'Observation de la Terre 4 (SPOT 4) and SPOT 5 satellites. Operational since the launch of SPOT 4 in March 1998, and foreseen to continue at least until the end of the SPOT 5 mission (anticipated in spring 2014), this user segment comprises a processing facility (PF), actively receiving, processing, correcting, archiving, and distributing the VEGETATION data and derived added-value products. First and foremost, the VEGETATION programme has been serving the needs of operational users – both institutional and commercial – requesting data in near-real time. However, scientific and educational users too benefited significantly, in particular from VEGETATION's unique time series of the Earth's land cover, and more specifically the vegetation cover. Over the years, the centralized archive houses processed data covering the equivalent of 11,000 times the Earth's surface, and delivered more than 50 terapixels to around 10,000 users. As such, VEGETATION's mission is a prime example of what Europe wants to achieve through the Global Monitoring for Environment and Security (GMES) initiative: truly operational services providing reliable and up-to-date information.

This article describes the processing facility, the way the data and products are archived, the different dissemination channels as well as the data policy adopted and the users served. One of the recent evolutions, the development of an entirely new product distribution facility (PDF), implemented as part of the Project for On-Board Autonomy – Vegetation (PROBA-V) user segment is discussed.

1. Introduction

We only have one planet – 'Spaceship Earth'. It is our sole heritage ... all we have to pass on to our children. And it deserves to be treated as such. (http://spot4.cnes.fr/spot4_gb/spot4.htm)

In response to this challenge, the VEGETATION programme has been conceived to monitor environmental change – and especially the evolution of the world's vegetation cover – on a global and daily basis. The programme is the fruit of a collaboration between various European partners: Belgium, France, Italy, Sweden, and the European Commission. In 1998, it was grafted onto the Satellite Pour l'Observation de la Terre (SPOT) programme, founded by Belgium, France, and Sweden in 1978. The VEGETATION programme consists of two observation instruments, VEGETATION 1 (VGT 1) and VEGETATION 2 (VGT 2), as well as all necessary ground infrastructures.

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The first of the two instruments in orbit is aboard the SPOT 4 satellite, launched on 24 March 1998 (Henry 1999). The second is aboard SPOT 5, launched on 4 May 2002.

On 29 April 2012, VGT 1 was switched off after more than 14 years of uninterrupted observations. Its platform, SPOT 4, was drifting to a lower orbit and earlier overpass time, while its prime instruments, the two High-Resolution Visible and Infrared (HRVIR) sensors remained active until December 2012. VGT 2 is still active and is planned to continue its observations until 31 May 2014 (Swinnen et al. 2014).

2. The processing facility

Since the launch of SPOT 4 and the subsequent launch of SPOT 5, the processing facility at the Flemish Institute for Technological Research (VITO) (also called CTIV – Centre de Traitement d'Images VEGETATION) in Mol, Belgium, has been processing the daily VEGETATION data stream. The data is sent via X-band from the satellites to the receiving station in Kiruna, Sweden. This station is located at a high latitude, which enables a large number of daily overpasses (owing to the quasi-polar orbit) and thus offers multiple possibilities to download the mass memory. Indeed, the memory capacity corresponds to about 90 minutes of observations and needs 4–5 downloads every day. The data transmission on the ground is carried out through an X-band link (8.2 GHz). A first preprocessing of the data is realized in the receiving station; it consists of the proper recovery of the viewing segments, and in the provision of auxiliary data (orbit, date, satellite attitude data, ...), which are to be used during the processing sequence.

The CTIV is operated by VITO. It receives the data pre-processed by the VEGETATION X-band imagery receiving station in Kiruna through a dedicated high-speed link, which is activated after each data reception by the station.

The role of the CTIV is, on the one hand, to ingest, process, and archive all VEGETATION data (systematic tasks) and, on the other hand, to provide a catalogue, production, and delivery service to the user community. The CTIV is operated seven days a week during regular office hours. A high degree of automation allows the centre to be operational continuously. This includes acceptance, processing, and delivery of user orders (Fierens and Van Speybroeck 2001). The centre is designed to deliver products less than 48 hours after image acquisition, on condition that the user has already 'subscribed' to imagery covering the area of interest. All processing is carried out as soon as the necessary raw image telemetry data and auxiliary data, such as meteo, are available, with as little human intervention as possible.

2.1. The VEGETATION systematic processing chain

Figure 1 provides an overview of the main processing algorithms used in the VEGETATION image processing facility. Starting from the telemetry data received from the receiving station to the final products delivered to the users, the geometric processing, the radiometric corrections, the atmospheric corrections, the synthesis composition, and the product formatting are the main steps of this process. The automated processing chain transforms the incoming VEGETATION raw data into products with added value.

At the end of the processing chain, the following standard VEGETATION products are available to the user community.

- P or Physical products: zone extracted from a single orbit, geometrically and radiometrically corrected.

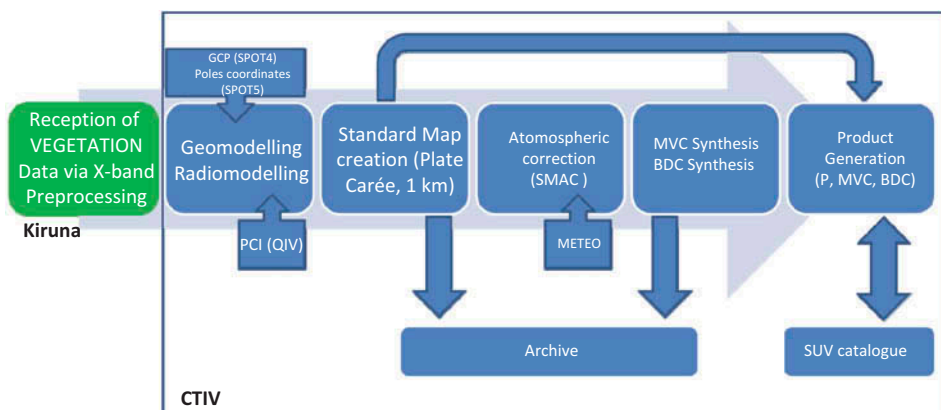


Figure 1. Overview of the SPOT-VEGETATION image processing chain.

- S or Synthesis products:
 - S1 or daily synthesis: synthesis of all data acquired over a 24 hour period.
 - S10 or 10 day synthesis: a result of the merging of data strips from 10 consecutive days.
 - D10: 10 day synthesis based on a bi-directional reflectance distribution function.
 - S-NDVI products: contain only the NDVI (normalized difference vegetation index).
 - S-total products: contain the NDVI, all spectral bands, and acquisition parameters.

2.2. Radiometric calibration

The operational absolute radiometric calibration was originally based on gains and offsets as derived from irradiance measurements of an on-board calibration lamp (Meygret 1998, 2000; Henry and Meygret 2001). Later, owing to degradation of the on-board calibration lamp, the operational radiometric calibration shifted to vicarious in-orbit techniques based on systematic (monthly) acquisitions over radiometrically homogeneous stable desert sites located in the Sahara. The vicarious calibration result thus obtained is regularly validated via the Rayleigh calibration approach and inter-band calibration acquisitions over deep convective clouds and Sun-glinted ocean areas. Dark current calibration is performed by image acquisitions over oceans during the night. This operational calibration procedure is performed by the QIV (the Image Quality Centre at the Centre National d'Etudes Spatiales (CNES) in Toulouse, France), which subsequently provides the CTIV with updated calibration coefficients to be implemented in the VEGETATION processing chains.

2.3. Radiometric recalibration

As explained above, the radiometric calibration depended primarily on on-board calibration devices. In 2006, a cross-calibration campaign (VGT 2 vs. POLDER (Polarization and Directionality of the Earth's Reflectances) 2, POLDER 3, and VGT 1) over deserts indicated that the VGT 2 calibration lamp was not evolving as expected. The inter-comparison showed that the on-board calibration system had systematically overestimated the sensitivity losses in some spectral bands. The VGT 2 calibration coefficients in these bands were therefore lower and the provided reflectance values were higher than they

should have been. Therefore, the complete VGT 2 archive was reprocessed with corrected calibration coefficients based on the vicarious approach. This campaign was completed at the beginning of 2007 (Bartholomé et al. 2006).

During 2009 and 2010, the VGT 1 archive was also reprocessed based on the vicarious approach to maintain consistency over time for all the VGT 1/VGT 2 reflectance data. All P, S1, and S10 products have been recalculated besides part of this campaign.

In March 2012, a harmonization study on processing methods and products revealed an anomaly in the VEGETATION processing chain. This artefact concerns the incorrect implementation of the standardization of solar illumination. This standardization has a direct impact on the values of the top-of-atmosphere reflectance provided in the VGT-P products, as well as secondary effects on the atmospherically corrected S1 and S10 products. The correction of this anomaly will be performed during a reprocessing campaign after the end of the VEGETATION mission, which will last until May 2014. One key objective of this reprocessing operation is ensuring full consistency with the processing chain for Project for On-Board Autonomy – Vegetation (PROBA-V), the VGT successor scheduled for launch in early 2013. The calibration approach for PROBA-V is described in, e.g., Sterckx et al. (2014); a consistent inter-calibration campaign is to be established during the commissioning phase of PROBA-V.

2.4. Geometric calibration

The VEGETATION image geometry is corrected differently for VGT 1 and VGT 2. For the VGT 1 instrument, the correction is implemented in two steps. In a first step, the gyroscopic measurements, which are part of the SPOT 4 telemetry, are converted into corrections for changes in the satellite's attitude (corrections for roll, pitch, and yaw). In a second step, an absolute reference attitude is assigned to the start of each orbit. This is accomplished by comparing discernible reference points in the imagery with a database of ground control points. The correlation of image points and ground control points is used to derive the absolute attitude and position of the satellite at the start of every orbit. The assignment of the absolute satellite attitude, as described, is a semi-automatic process. Operator intervention is still required for selecting an adequate distribution of cloud-free reference points in the imagery. The subsequent correlation and derivation of the corrective parameters are automated processes (Fierens and Van Speybroeck 2001; Sylvander et al. 2000; Passot 2001).

For the VGT 2 instrument on board SPOT 5, a star tracker provides a reliable estimation of the satellite attitude, implying an accurate absolute image location: it is therefore not necessary to further improve VGT 2 imagery using ground control points (Sylvander, Albert-Grousset, and Henry 2003).

2.5. Map projection in Plate-Carrée

The first step of the synthesis processing is transforming all segments to the same cartographic projection. The chosen projection is Plate-Carrée with $1/112^\circ$ per pixel in line and row, which is about 1×1 km at the equator, and 0.5 km wide and 1 km long at 60° latitude. Hence, previously computed geometrical grids are used, related to a digital elevation model (Earth Topography 5-minute (ETOPO5)) to compute the location of the pixels taking into account the relief effects. This is particularly important on the edges of the viewing field; an interpolation is performed between the two location grids at 0 m and 5000 m elevation. To go from the 'system projection' coordinates to the Plate Carrée coordinates, the cartographic coordinates are computed using the Geolib Institut

Géographique National (IGN) library. To calculate the best radiometry of the resulting pixel, a bi-cubic interpolation is performed using a 4×4 window, from the 16 nearest pixels in the raw image. The products resulting from these steps are the so-called VGT-P products. These products are adapted for scientific applications requiring highly accurate physical measurements and contain top-of-atmosphere reflectance (TOA).

2.6. Derivation of ground reflectance

The main objective of the VEGETATION processing chain is providing products from which bio-geophysical parameters can be derived. Therefore, atmospheric influences should be eliminated from the imagery, thus yielding ground reflectance values. The atmospheric corrections applied make use of near-real-time global meteorological data. This global meteorological dataset is generated four times daily. The corrective software used is the Sequential Model-based Algorithm Configuration (SMAC) developed by Rahman and Dedieu (1994), which in turn is based on the 6S model. New algorithms for eliminating the effects of tropospheric aerosols and bi-directional effects (BDC) were introduced in 2000 (Duchemin et al. 2000; Maisongrande et al. 2001; Duchemin et al. 2001; Duchemin and Maisongrande 2002).

Consequently, all segments captured in one day are combined into a world synthesis (S1 product), according to the maximum value compositing principle, i.e. the pixels selected for the synthesis are based on the selection of the maximum NDVI value in all available segments, to ensure coverage of all landmasses worldwide with a minimal effect of cloud cover.

2.7. Cloud screening and filtering

Cloud screening and filtering is performed in two steps. In a first step, a cloud detection algorithm based on the spectral signature of the individual pixels flags them as cloudy, not cloudy, or not sure (Lissens et al. 2000). In a second step, the global S1 datasets of 10 consecutive days are compared pixel by pixel and, based on cloud flags and maximum NDVI value, the least cloudy pixel of these 10 consecutive days is selected and included in a 10-day synthesis dataset (S10). This dataset, consisting of a global 1 km cloud-free atmospherically corrected top-of-canopy reflectance map in the standard VEGETATION projection, is the basis for all VGT-S10-derived user products.

All S1 and S10 products are subject to visual inspection by CTIV operators (e.g. Fierens and Van Speybroeck 2001).

The information content of a standard S10 product is provided in Table 1.

3. The VEGETATION archive

3.1. Archived datasets

All data transmitted by the VEGETATION instruments, i.e. the raw image telemetry, are archived on 'Linear Tape-Open' LTO-3 tapes. The correction parameters as calculated by the CTIV processing chains are stored together with the image data. The corrective parameters include both radiometric and geometric correction factors of the image data. These data are backed up twice on an LTO-3 tape (one archive tape and one clone tape, which is stored at a separate remote location (safeguard)). The corresponding meteorological data are also archived (e.g. Fierens and Van Speybroeck 2001).

Table 1. Content of a standard VEGETATION S10 product.

Acronym	Parameter	Description
PHYS_VOL	Physical volume descriptor	Leader file of the product, containing some basic information and the list of files available in the product
LOG	Logical volume descriptor	Information about <ul style="list-style-type: none"> • map projection information (general information, geodetic system parameters, projection parameters) • cartographic location • geographic location • image coordinates (corresponding to carto- and geographic location) • geometric correction • radiometric correction • orbit parameters • date and time • algorithms references
RIG	Copyright descriptor	Information about the copyright
BO	B0 spectral band	Radiometry data : 0.43–0.47 μm
B2	B2 spectral band	Radiometry data : 0.61–0.68 μm
B3	B3 spectral band	Radiometry data : 0.78–0.89 μm
MIR	MIR spectral band	Radiometry data : 1.58–1.75 μm
NDV	Vegetation index	Normalized difference vegetation index (NDVI)
SM	Status map	Info on radiometric quality of spectral bands, presence of ice/snow, cloud, etc.
VZA	Viewing zenith angle	Data on the satellite zenith angles
VAA	Viewing azimuth angle	Data on the satellite azimuth angles
SZA	Solar zenith angle	Data on the solar zenith angles
SAA	Solar azimuth angle	Data on the solar azimuth angles
TG	Time grid	Each pixel is expressed with a precision of one minute referring to the beginning of the first segment of the synthesis
QL	Quick look	Quick look of one spectral band

The processing facility is equipped with two tape robots (MSL6060). These devices take care of the archiving and cloning of all S10 and D10 products. All these products are backed up on an LTO-3 tape.

The S1 and Free-P archive is an online archive that is regularly backed up on LTO-3 tape. Also here, two copies are made: one archive tape and one clone tape, which is stored at a remote location. The archiving system will regularly back up the online archive of P and S1 products on an LTO-5 tape. This will be an incremental backup and will be preserved for many years. Later on, a second backup process will start in order to have a second copy of the online archive.

Once the mission of SPOT-VEGETATION is over, all VGT data will be stored in the long-term archive of Commvault, to ensure long-term preservation of the data.

3.2. Constant media migration as a strategy

Although small in comparison to other earth observation (EO) data archives, the VEGETATION archive is liable to the typical growing pains inherent to the constant evolution of data storage technology rather than to those inherent to the actual growth of

the archive itself. To cope with this issue, regular migration of storage media is part of the long-term operational strategy of the CTIV. Regular migration of archive media is necessary for various reasons. In the first place, media supports and devices to access these archive media become obsolete over time. This can happen long before degradation of the storage on the support media themselves. Even before device obsolescence becomes an issue, the cost associated with this migration activity is to be balanced against increasing maintenance costs of older hardware, the decreasing costs of modern media and media access devices, and typically the decreasing need for operator intervention while managing modern types of media. A typical example is, for instance, the comparison of the manual handling necessary for computer compatible tapes (CCTs) used in older archives with the automation possible in a Linear Tape-Open (LTO) robotic archive.

An additional benefit of a semi-constant migration strategy is the fact that a migration constitutes an intrinsic test of the integrity of the archive. A strategic approach to archive supports and access devices further reduces and simplifies the level of human expertise needed to guarantee a continued servicing and evolution of the system.

Within its lifetime (15 years of operation), the CTIV archive already migrated from a 35 GB Digital Linear Tape (DLT) robotic system to a 3 TB LTO-5 system and further on to the migration of the archive to online disc-based storage. Although it is nearly impossible to provide an accurate estimation of cost *versus* benefit of these migrations, it is generally felt that the ease of operation gained by these timely migrations outweighs the savings that would have been made by not making these investments (e.g. Fierens and Van Speybroeck 2001).

4. Product dissemination

4.1. Data policy, users, and distribution channels

Since 2001, VITO has been in charge of the worldwide distribution of SPOT-VEGETATION products to the scientific community (Van Speybroeck, Bomans, and Sayag 2005). Since 2007, also the 'commercial' users (requesting near-real-time delivery) have been served by VITO. As shown in Figure 2, around 65 terapixels have been distributed to VEGETATION users. As illustrated in this figure, the distribution policy has been adapted over time, driven by the commitment of the VEGETATION Partnership towards the Global Monitoring for Environment and Security (GMES) initiative. The goals of the renewed policy were two-fold:

- to increase the volume of data distributed to users; and
- to increase the number of users.

A first step towards these objectives was made with the establishment of the internet site <http://free.vgt.vito.be>, going online on 15 October 2001. This service delivered the standard S10 product, in a set of 10 predefined continental-scale coverages, free of charge to all users, but limited to data that are at least three months old. Through this channel, more than 8000 users downloaded thousands of products (see Figure 3).

A second step was taken via the delivery of so-called Free-P products. Since 2004, P products could be freely requested by scientists and programme partners for specific applications. Although designed for and reaching only a limited number of expert users, this Free-P service accounts for an important data volume and a number of downloaded products comparable to the normal CTIV product distribution (see Figure 2). With the

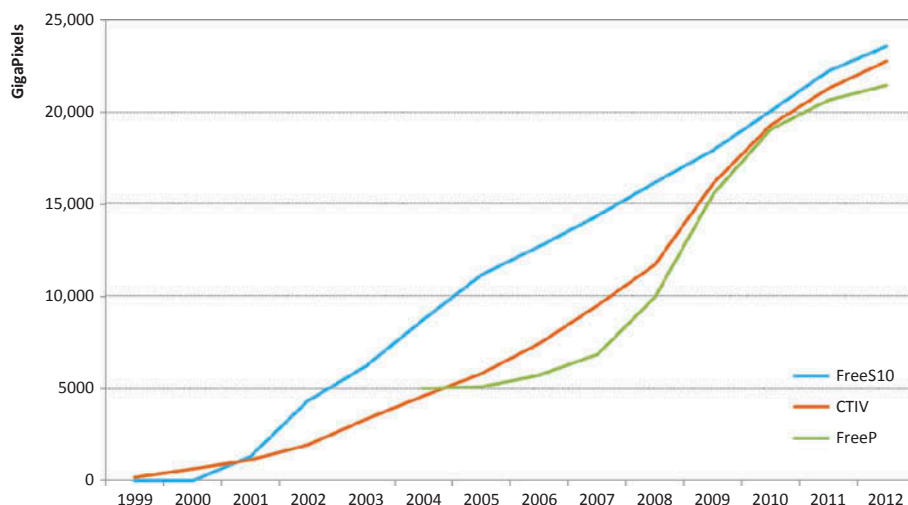


Figure 2. The cumulative evolution of the amount of data (in gigapixels) delivered to the users. 'CTIV' stands for the nominal product distribution via the VGT-portal; 'Free S10' are S10 syntheses that are least three months old and are freely available; 'Free-P' are freely available P products for specific scientific purposes.

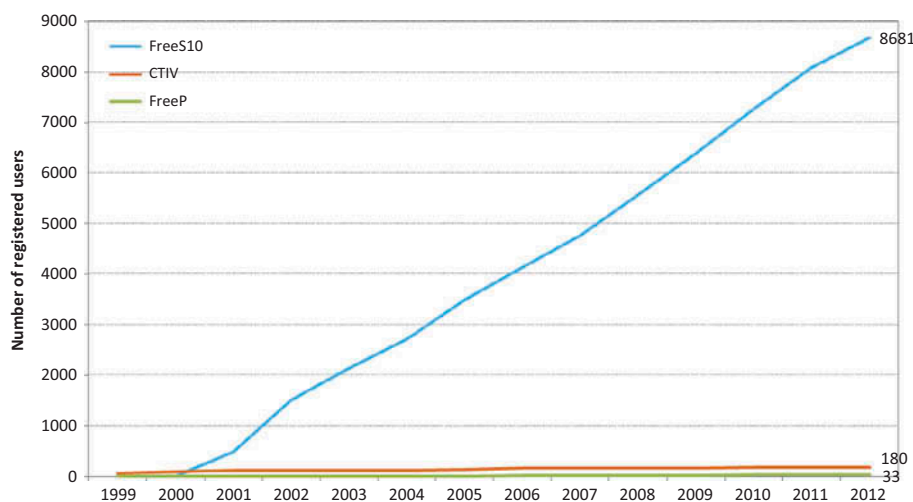


Figure 3. The cumulative number of registered users of free decadal syntheses (Free S10) increased dramatically after the renewed pricing policy adopted in 2001.

inclusion of the SPOT-VEGETATION datasets in the GMES Space Component Data Access (GSCDA) initiative from ESA (<http://gmesdata.esa.int/web/gsc/home>), 2009 witnessed the introduction of new users. Because they request mainly VGT-P products, the amount of data delivered increased significantly.

Typical users of SPOT-VEGETATION products are governmental bodies and agencies, research institutes, and universities, primarily requesting free products. For this user community, the renewed 'free' policy was a prerequisite to access the archive. Figure 4

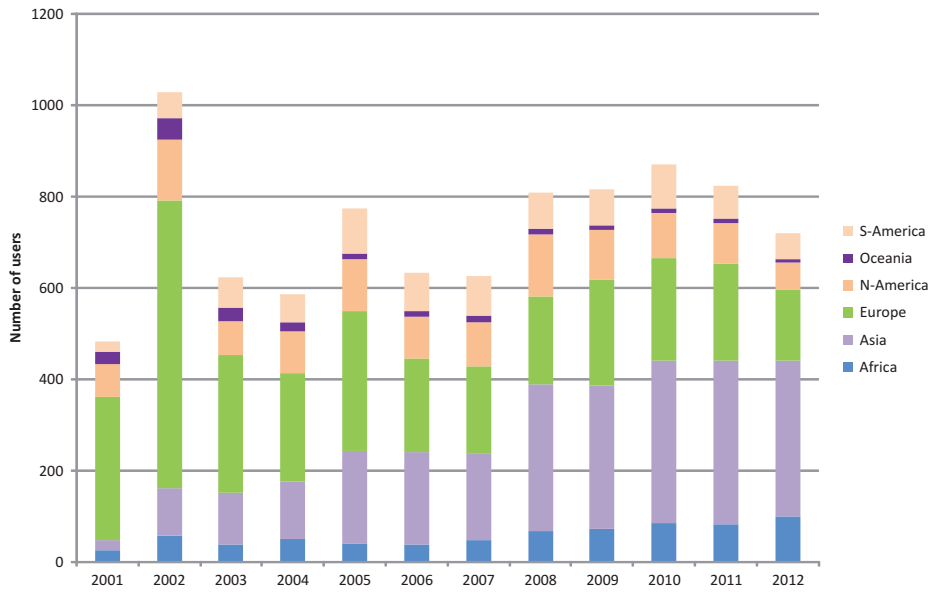


Figure 4. Geographical distribution of yearly registered users of the Free S10 products.

illustrates the geographical distribution of the users of the free services, whereas Figure 5 shows the areas that are mostly downloaded by these users.

During 2001–2003, the majority of users originated clearly from Europe; from 2004 onwards, the number of Asian users rose sharply, whereas the number of European users decreased slightly. The number of US users remained more or less stable over the years. Meanwhile, the number of African users rose slowly but steadily.

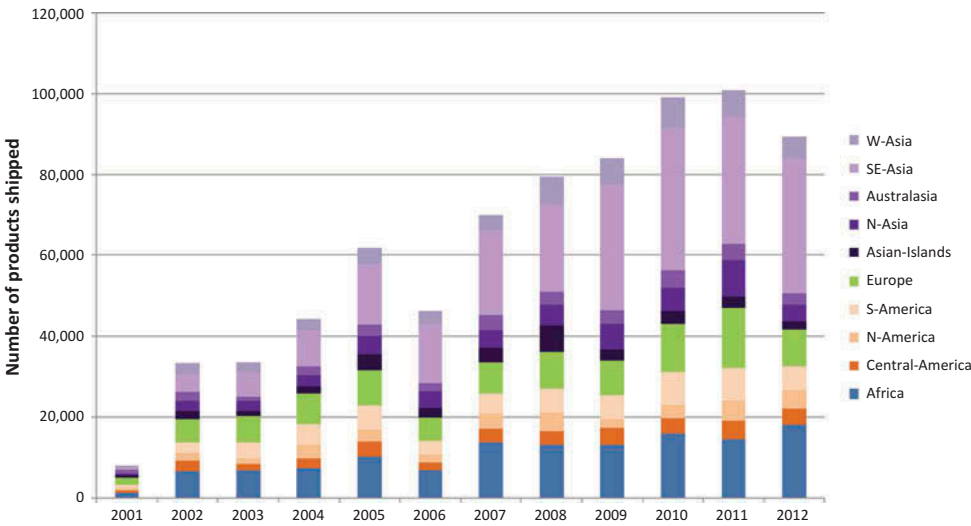


Figure 5. The 10 predefined regions for which Free S10 products are downloaded by the users as a function of time.

As illustrated in [Figure 5](#), the Free S10 products are available in 10 predefined regions. The most striking evolution observed is the increase in products downloaded over Southeast Asia. The number of products acquired covering the other parts of Asia, Europe, and the Americas remained rather stable over the last 10 years. By analogy with the number of users, the amount of products downloaded over Africa increased steadily.

SPOT-VEGETATION users are actively involved in a broad palette of thematic domains such as (non-exhaustive list of subjects): land-cover/use characterization (e.g. Boles et al. [2004](#); Immerzeel, Quiroz, and De Jong [2005](#); Huttich et al. [2007](#); Carreiras, Pereira, and Shimabukuro [2006](#)), burned area and forest fire estimates (e.g. Zhang et al. [2003](#); Lasaponara [2006](#); Telesca et al. [2005](#); Silva, Sa, and Pereira [2005](#); Lhermitte et al. [2011](#)), vegetation status monitoring (e.g. Abuelgasim, Fernandes, and Leblanc [2006](#); Delbart et al. [2006](#); Xiao et al. [2005](#); Fraser et al. [2005](#); Atzberger and Eilers [2011b](#); Fensholt et al. [2009](#)), forest productivity (e.g. Maselli et al. [2006](#)), agricultural monitoring (e.g. Wani, Velmuragan, and Dadhwal [2010](#)), ecological monitoring (e.g. Leitao, Moreira, and Osborne [2010](#); Sun, Chang, and Opp [2010](#)), climate change (e.g. Manjunath et al. [2006](#)), small waterbodies (e.g. Haas, Bartholomé, and Combal [2009](#)), and snow cover/depth and lake ice (e.g. Dankers and De Jong [2004](#); Latifovic and Pouliot [2007](#)).

SPOT-VEGETATION data have also provided the substructure for technological research in algorithm development (e.g. Chen et al. [2004](#); Zhang et al. [2005](#); Atzberger and Eilers [2011a](#); Heremans et al. [2011](#)), or have been used to substantiate policy measures (e.g. Harris, Jenkins, and Pimm [2005](#); Zhou, Van Rompaey, and Wang [2009](#)).

To better serve the needs of the users in developing countries (included in [Figure 4](#)), i.e. to overcome the limited access to the internet in these countries, the European Organisation for the Exploitation of Meteorological Satellites (ECUMESAT) broadcasting system (EUMETCast) services of EUMETSAT were used to broadcast the VEGETATION products to Africa and South and Central America. At the start of this broadcasting activity in 2008, EUMETCast was becoming an important component of the global GEONETCast system, a key infrastructure and early success of the Group on Earth Observations (GEO) System of Systems (GEOSS, 2005–2015) that interlinks EUMETCast with similar systems over Asia (CMACast, operated by the Chinese Meteorological Agency (CMA) and the Americas (GEONETCast-Americas, operated by National Oceanic and Atmospheric Administration (NOAA)).

Actually, this reliable product distribution mechanism to broadcast near-real-time data at low cost to users in the Southern Hemisphere continues to gain importance. This service helps the VEGETATION programme to reach out, the S10 NDVI product being the flagship VEGETATION product delivered via this route.

After the first three years of this type of broadcasting service towards Africa, in March 2008 ([Figure 6\(a\)](#), and Jacobs et al. [2011](#)), the number of registered users and EUMETCast receiving stations was still modest. Key users were Africa's regional centres, as well as African branch offices to the UN Food and Agriculture Organization (FAO) and the UN World Food Programme (WFP), as well as many universities.

Three and a half years later, by September 2011 ([Figure 6\(b\)](#)), the user network in Africa had expanded to include institutes from almost all African countries, tripling the number of registered users (290) and encompassing the first private African companies. Joint European/African Union development initiatives, such as the African Monitoring of Environment for Sustainable Development (AMESD) initiative, helped extend the receiver network to 166 registered receivers.

The start-up of a similar service towards South and Central America, with a still limited number of added value products but including the S10 NDVI product, sparked the interest of 60 registered users in 11 (out of 22) countries and 22 registered EUMETCast receiving

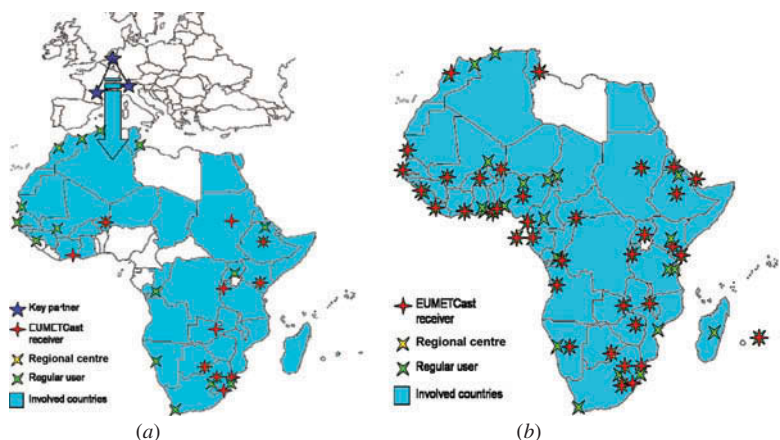


Figure 6. Regular users (via website) and EUMETCast users of the dedicated service towards Africa in 2008 (a) and 2011 (b).

stations. The continued dissemination of the VEGETATION products via EUMETCast has been specifically requested by GMES in the frame of the Global Land component of the GMES Initial Operations phase. This should effectively steer the dissemination to a more tightly controlled operation, adding reliability and decreasing delivery times.

To conclude this section, it should be mentioned that near-real-time VEGETATION products are bought by only a limited number of commercial customers. Among them are private companies, but also international institutions, such as the European Space Agency (ESA), the UN Food & Agricultural Organisation (UN-FAO), the United States Department of Agriculture's Foreign Agricultural Service (USDA-FAS), and non-governmental organizations (NGOs) such as information management and mine action programmes (iMMAPs).

4.2. The new product distribution facility

The existing SPOT-VEGETATION catalogue was developed in the 1990s and is not designed to easily incorporate additional product types (also called collections). Furthermore, different access points exist for the fee-based products (<http://suvweb.vgt.vito.be/suv/index.jsp>) and the free 10-day synthesis products (<http://free.vgt.vito.be/>) and yet others for derived products. To overcome these shortcomings and to distribute the products from the new PROBA-V mission, a state-of-the-art solution had to be designed. Therefore, as one of the subsystems of the PROBA-V User Segment, the product distribution facility (PDF) was developed together with partner TRASYS. The PDF supports the consultation, viewing, download, ordering, subscription, and delivery of the PROBA-V products. The PDF subsystem is designed to distribute also products from other collections: e.g. the AVHRR-METOP (EUMETSAT Polar System, also known as Metop) 10-day syntheses - and ENVISAT-MERIS (Medium Resolution Imaging Spectrometer) 10-day syntheses-derived bio-geophysical parameters, and much more. An administrator can add new collections without new software development and can tailor the Web-based user interface towards the needs of the different collections and user communities.

A high-level component diagram of the PDF is given in Figure 7.

The PDF contains different components, as outlined in the green box in Figure 7. The most important component is of course the product catalogue that contains metadata from

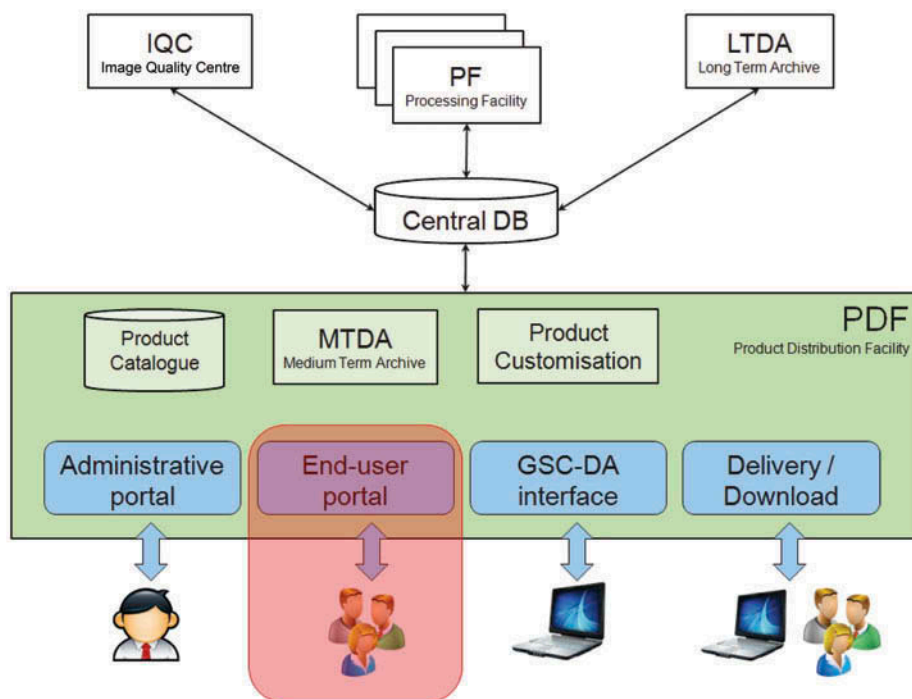


Figure 7. Product distribution facility (PDF) components.

all the products, which can be accessed by the users. All data files from these products are stored on discs in the Medium Term Data Archive (MTDA). This allows a fast delivery of products to the users, as no copy action is required to access the products. For some collections, users are able to request product customizations, e.g. to extract a region of interest, another product format (GeoTIFF, HDF4, HDF5), and a selection of specific bands. The PDF is capable of performing the most common product customizations. The PDF communicates via a central database with other subsystems of the VITO processing centre.

- Multiple processing facilities can be connected to the PDF, which produces SPOT-VEGETATION products, PROBA-V products, higher-level products, etc.
- Other subsystems can also deliver products to be ingested in the PDF. An example is the Image Quality Centre from the PROBA-V user segment, which provides the parameter files for the radiometric and geometric calibration.
- A long-term data archive (LTDA) has the purpose of preserving data, typically on tapes in multiple copies at remote locations, which are still accessible upon request by users.

The PDF offers the following different interfaces (Figure 8) to the users.

- A Web-based end-user portal allows the user to consult, view, and download products. A user can order multiple products within a single order or can subscribe to get products that will become available in the future.

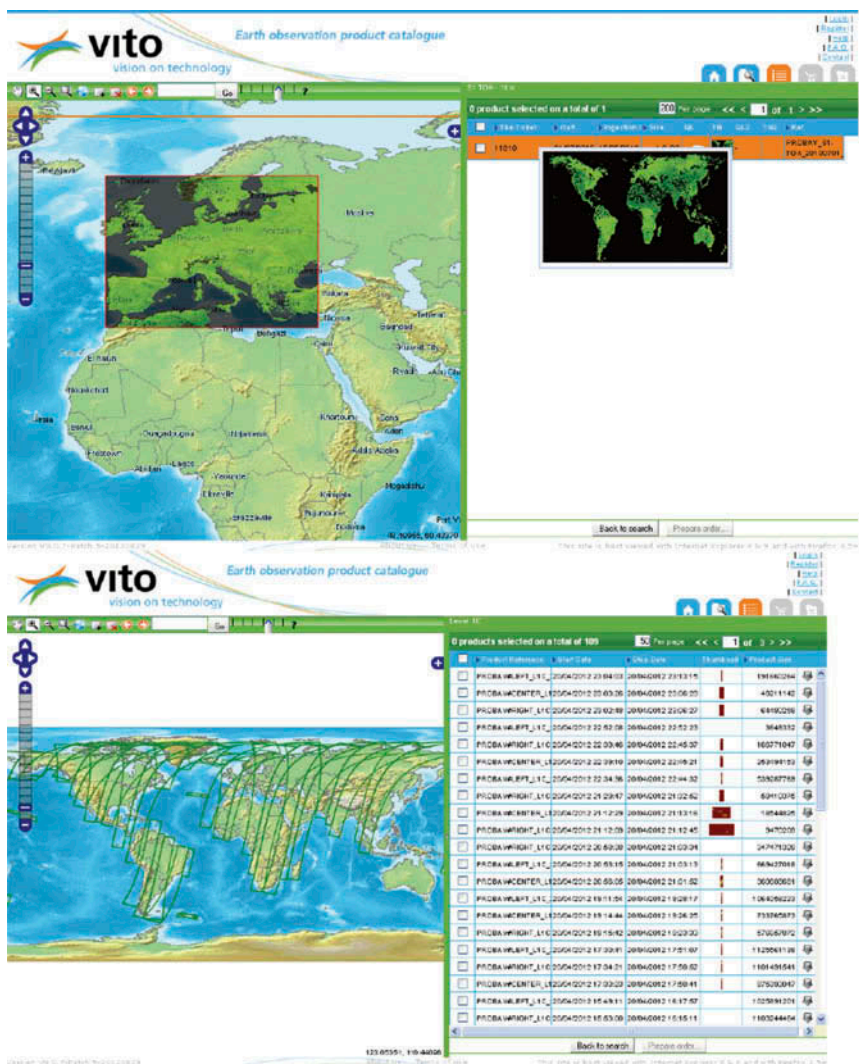


Figure 8. Catalogue search results on the new end-user portal.

- A Web-based administrative portal is available to configure the PDF, e.g. to support new collections, to manage users and access rights, approve orders, etc.
- Users can select different delivery methods such as FTP pull, FTP push, WCS (Web Coverage Service), HTTP URL, etc.
- The GSCDA interface provides catalogue and ordering interfaces towards the GSCDA system at ESA, according to HMA (Heterogeneous Missions Accessibility) open-standards that are mandated by ESA. The GSCDA interface is described in Section 5.

The PDF is a total solution for the dissemination of all EO products available at VITO and will be operational from early 2013 onwards. It is highly configurable and scalable to fulfil the needs of future missions and projects. It will be used to disseminate the products

from the PROBA-V mission but it will also integrate SPOT-VEGETATION products and derived products into one centralized VITO Earth Observation Product Catalogue.

4.3. Processing on demand

VITO's time series of SPOT-VEGETATION products will be continued in the future with data from the PROBA-V mission, as well as from many complementary missions from ESA, NASA (National Aeronautics and Space Administration), and others. Next to these time series of standard EO-products, several time series of derived products, e.g. biogeophysical parameters, are produced in different projects. The analysis of these time series is important for research in many areas (e.g. climate change, land use/cover, crop monitoring); however, the overpowering size of the data archive prevents users from downloading and processing the large amounts of data involved at their own premises. Therefore, next to data delivery services, as presented in the previous section, VITO envisages providing remote data processing and analysis services to users.

The solution needs to address the use cases of the following two communities.

- The **scientific community** has the need to process and analyse extreme amounts of data, thereby leaving the data physically at VITO to avoid data transfer. They need a fast access to the data and need powerful tools to develop EO-applications or information extraction tools, suitable for their purpose. The solution should act as a platform towards the scientists, where they can develop and execute their own EO-processing applications. This will allow them to iteratively develop and test prototypes, which can be released as near-real-time operational services after validation. Of course this involves some complexity and therefore requires a specific expertise of these users.
- Another community is interested in **operational services**, with a high quality of service and fast response time. These services should be easy to use, but still allow a number of interactions by users to query the information they need and to visualize it in the format they prefer. These services should present at anytime the most recent information, whereby the information is tailored towards the needs of the individual user.

In the previous years, VITO prepared these services by introducing innovative ICT-technologies in the ground segment, notably GRID-computing and prototype Web-based platforms using open standards such as the Web Processing Service (WPS) and Sensor Observation Service (SOS).

Today, VITO designs an integrated end-to-end solution for the on-demand processing of EO-data. EO-data from different providers (VITO, ESA, and others) are used, where the data can be accessible in the processing environment of a provider or on a public cloud resource. Since the EO-sensors of the near future will produce petabytes of data yearly and often data from different EO-sensors are required for a single application, we need solutions to cope with data that are geographically spread and cannot be transferred to one processing centre. We will integrate data access, data processing, data visualization, and data analysis in one solution. As much as possible, existing solutions are integrated, and the use of widely accepted open standards is maximized, e.g. WMS (Web Map Service), WFS (Web Feature Service), WCS (Web Coverage Service), WPS (Web Processing Service), CSW (Catalogue Service for the Web), and WCPS (Web

Coverage Processing Service). This approach ensures an easy integration in a wider infrastructure and allows benefiting from services from third parties.

Hadoop will be used as a framework for the distributed processing of large datasets. Hadoop is a software framework that is derived from Google's MapReduce (e.g. Dean and Ghemawat 2004) and Google File System GFS (e.g. Ghemawat, Gobioff, and Leung 2003). The system will be demonstrated on both private and public cloud resources, to prove the scalability of the solution. Array database technology will be assessed to offer fast access to raster data for real-time analyses and an existing business intelligence solution will be used to provide dynamic maps, graphs, and dashboards towards end-users. Another key requirement of the solution is supporting e-collaboration: the vision is to create a framework where both scientists and decision-makers can collaborate by sharing and discussing results in a virtual environment. This research will demonstrate that the results can facilitate and yet boost the scientific exploitation of the EO-data and that the solution offers a framework that can be deployed at different EO-data providers in Europe. It is clear that the new developments will be integrated with existing solutions at VITO, such as the processing distribution facility and the existing processing facilities.

5. SPOT-VEGETATION as GMES contributing mission

The European Space Agency (ESA) is preparing a constellation of EO missions in the GSC, to supply data from space-based observations in response to the GMES Service needs. VITO contributes to SPOT-VEGETATION as a Third Party Mission. In the GSC Data Access Portfolio (DAP) (Hoersch and Amans 2012), the products from SPOT-VEGETATION are offered within the core dataset for optical worldwide low-resolution coverage towards the GMES services. As such, VITO contributes to the systematic delivery of SPOT-VEGETATION data to fulfil the needs of, e.g., the GEOLAND2 (Operational Monitoring Services for our Changing Environment) project (<http://www.gmes-geoland.info>).

The GSCDA Web portal (<http://gmesdata.esa.int>) is a public portal provided by ESA and is the unique access point towards the GMES Services, to find information about data availability and accessibility. Initially, GMES services that requested SPOT-VEGETATION data were redirected from the GSCDA portal to the native SPOT-VEGETATION catalogue at VITO. Today, the SPOT-VEGETATION products can be queried directly using the catalogue client of the ESA GSCDA portal.

To realize this, VITO successfully completed in 2011 the development activities for interfacing the SPOT-VEGETATION Ground Segment with the Coordinated Data Access System (CDS) of ESA. The core part of this activity was the implementation of machine-to-machine HMA catalogue interoperability (OGC 06–080, OGC 06–131), allowing users to browse the SPOT-VEGETATION native collections via the GSCDA Client. Additionally, as a global systematic mission, VITO developed interfaces to support semi-automated reporting to the CDS, as well as automated ordering via HMA (OGC 06–141) for CDS operators: these features are expected to partially relieve manual operations and to improve the overall system integration.

The HMA catalogue and ordering interfaces were added to the existing infrastructure without disrupting the daily service. The acquired experience is of great value, also beyond the GSCDA project. The outcomes will be used for PROBA-V, which will join the GCM constellation from 2013 onwards.

6. Conclusions

The SPOT-VEGETATION missions were the first European truly operational global missions. Since 1998 they have been providing a daily snapshot of the status of the world's vegetation cover, resulting in a valuable time series of products that are used in the fields of land-use/land-cover mapping, agricultural yield prediction, impact monitoring of climate change, etc. Thanks to an open data policy (all products are freely available three months after acquisition), more than 14,000 users could benefit from the 50 terapixels of data that have been distributed. The entire archive covers the equivalent of 11,000 times the Earth's surface and is stored in one unique archive. The latter distinguishes the VEGETATION missions and archive from other global missions.

Specific attention was also paid to users in the developing world, first in Africa and later on also in South and Central America. To reach these users a custom website and the EUMETCast satellite broadcast service, operated by EUMETSAT, were used as dissemination channels. These channels offer 100+ subcontinent (country or economic region scale) coverages, and reach out, train, and support a growing community of users. Although this makes VEGETATION part of a larger, global dissemination service, it remains clear that, among the 10 VEGETATION-based products disseminated today, the basic VEGETATION 10-day NDVI synthesis (S10 NDVI) still remains the most desired product.

Although the original dissemination tools are still in use, an entirely new product distribution facility (PDF) was developed in the frame of the PROBA-V user segment. This new distribution facility will guarantee access to VEGETATION products after the end of the acquisitions. The new PDF supports the consultation, viewing, download, ordering, subscription, and delivery of EO products. The system is designed to distribute products from many different collections and will be used as such. Another important improvement in the SPOT-VEGETATION processing facility is the processing-on-demand capability, building on the philosophy that the ever-increasing amounts of EO-data should not be copied to the local disk of each and every user but should be accessible in one performant processing centre. Using standardized Web access, users can process data remotely and on-demand using algorithms provided by VITO, its partners, or applying their own algorithms.

The new PDF, the processing-on-demand capacity, and a new archiving system ensure that the SPOT-VEGETATION processing facility remains state of the art, even after 15 years of operation.

Finally, it is important to mention that, after the near-real-time acquisitions end in 2014, a reprocessing of the entire archive is planned to correct for a few known errors and to ensure full consistency with the processing chain of PROBA-V, scheduled to be launched early 2013.

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