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Evaluation of the SPOT/VEGETATION Collection 3 reprocessed dataset: Surface reflectances and NDVI

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A B S T R A C T

After the end of the 'Satellite Pour l'Observation de la Terre' (SPOT) VEGETATION (SPOT/VGT) mission in May/2014, the SPOT/VGT data archive, consisting of raw data coming from both the VEGETATION 1 (VGT1) and VEGETATION 2 (VGT2) instruments, was reprocessed, aiming at improved cloud screening and correcting for known artefacts such as the smile pattern in the VGT2 Blue band and the Sun-Earth distance bug in Top-of-Atmosphere reflectance calculation, with the objective of improving temporal consistency. The aim of this paper is to inform the user community of the changes in and the evaluation of the new SPOT/VGT Collection 3 (VGT-C3). The evaluation of the reprocessing is based on (i) the relative comparison between SPOT/VGT Collection 2 (VGT-C2) and VGT-C3 surface reflectances and Normalized Difference Vegetation Index (NDVI), (ii) consistency analysis between VGT1-C3 and VGT2-C3, and (iii) the comparison of the archive with external datasets from METOP/Advanced Very High Resolution Radiometer (AVHRR) and TERRA/Moderate Resolution Imaging Spectroradiometer (MODIS). Surface reflectances are slightly higher after the reprocessing, with larger differences in July compared to January, caused by the corrected Sun-Earth distance modelling. For NDVI, the overall impact of the reprocessing is relatively small and differences show no seasonality. Trends in the differences over the years are related to changes in calibration coefficients. Systematic differences between VGT1-C3 and VGT2-C3 surface reflectance are well below 1%, with largest bias between VGT1 and VGT2 for the NIR band and the NDVI (VGT2 > VGT1, especially for larger NDVI values). Both the comparison with METOP/AVHRR (surface reflectance and NDVI) and TERRA/MODIS (NDVI) reveal trends over time: systematic bias between VGT2 and METOP/AVHRR tends to decrease over time, while comparison with TERRA/MODIS indicates an increasing bias between VGT2 and MODIS. VGT2 NDVI seems to be gradually evolving to slightly larger values, which is consistent with the change in overpass time of VGT2 and the different illumination conditions caused by the orbital drift of the sensor. Results demonstrate however the SPOT/VGT-C3 archive is more stable over time compared to the previous archive, although bidirectional reflectance distribution function (BRDF) normalization is recommended in order to correct for bidirectional effects.

1. Introduction

The VEGETATION programme, involving partners in France, Belgium, Sweden, Italy, and the European Commission, controlled and maintained the 'Satellite Pour l'Observation de la Terre' (SPOT) VEGETATION (VGT) sensors and distributed the imagery and products derived from them. For over 15 years, the Flemish Institute for Technological Research (VITO) hosted the prime user segment of both VEGETATION 1 (VGT1) and VEGETATION 2 (VGT2) multispectral instruments on board SPOT4, launched in March/1998 and SPOT5, launched in May/2002 (Deronde et al., 2014). The switch from VGT1 to VGT2 was made in February/2003, because the onboard star tracker of SPOT5 allowed for higher geometric performances for VGT2 in comparison to VGT1. The role of the SPOT/VGT processing facility at VITO (also called CTIV, 'Centre de Traitement d'Images VEGETATION') was to ingest, process and archive all SPOT/VGT data, and to distribute standard derived products to the user community (Passot, 2001).

SPOT/VGT data are widely used to monitor environmental change and the evolution of vegetation cover in different thematic domains such as: long-term, large-scale vegetation status monitoring and climate change studies (e.g. Atzberger and Eilers, 2011; Delbart et al., 2006; Fensholt et al., 2009; Lhermitte et al., 2011; Lupo et al., 2001; Tonini et al., 2012), agricultural monitoring and yield estimations (e.g. Durgun et al., 2016; Rembold et al., 2013; Vrieling et al., 2014), land cover/

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land use characterization (e.g. Bartholomé and Belward, 2005; Boles et al., 2004; Carreiras et al., 2006; Immerzeel et al., 2005; Kamthonkiat et al., 2005), monitoring of forest fires and burned areas (e.g. Fraser and Li, 2002; Lasaponara, 2006; Tansey et al., 2008; Zhang, 2003), and many other applications.

In the past years, several partial reprocessing campaigns have been implemented in order to improve calibration of both VGT1 and VGT2 (Bartholomé et al., 2006), resulting in VGT Collection 2 (VGT-C2), which was released in 2006 (for VGT2-C2) and 2010 (for VGT1-C2). After the end of the SPOT/VGT mission in May/2014, the complete data archive was reprocessed. The aim of the reprocessing was to apply an improved cloud screening algorithm and to correct for known artefacts such as the known smile pattern in the VGT2 Blue band (i.e. View Zenith Angle dependency of the Top-Of-Atmosphere (TOA) reflectance values) as observed by various authors (Bouvet, 2014; Sterckx et al., 2013) and the error in Sun-Earth distance modelling in TOA reflectance calculation, thereby improving consistency over time. All instrument calibration parameter updates and improved processing algorithms were provided by the VEGETATION Image Quality Centre (QIV) located at 'Centre National d'Études Spatiales' (CNES). The reprocessing of the complete VGT collection has led also, to some extent, to an improved consistency with the Project for On-Board Autonomy–Vegetation (PROBA-V) satellite (Swinnen and Toté, 2017). PROBA-V was launched in May/2013 and was designed to bridge the gap in space-borne vegetation measurements between the SPOT/VGT mission (March/1998–May/2014) and the Sentinel-3 satellites (from February/2016 onwards) (Dierckx et al., 2014; Sterckx et al., 2014).

This paper discusses the changes in and the evaluation of the new SPOT/VGT Collection 3 (VGT-C3). VGT-C3 products are distributed through the Product Distribution Facility (PDF) (http://www.vito-eodata.be/), supporting the consultation, viewing, download, ordering, subscription, and delivery of the SPOT/VGT, PROBA-V and Copernicus Global Land Service products. The Mission Exploitation Platform (MEP) (http://proba-v.vgt.vito.be/content/mep) provides tools to visualize and analyse large time series of PROBA-V and SPOT/VGT data (Goor et al., 2016).

This manuscript is organized as follows. First we describe the modifications in the SPOT/VGT processing chain and the materials and methods used. Then we evaluate VGT-C3 focusing on three aspects. In first instance, the entire new archive (VGT-C3) is compared against the previous version (VGT-C2), in order to quantify the effect of the changes applied in the reprocessing. Next, the consistency between data obtained from the VGT1 and VGT2 instruments within VGT-C3 (i.e. VGT1-C3 and VGT2-C3) is evaluated: although data derived from VGT1 and VGT2 are normally used as one single dataset, these datasets originate from two sensors with very similar but not identical characteristics. Finally, in order to evaluate the temporal consistency of the entire reprocessed archive, it is compared against two reference time series, i.e. TERRA/Moderate Resolution Imaging Spectroradiometer (MODIS) (Normalized Difference Vegetation Index, NDVI) and METOP/Advanced Very High Resolution Radiometer (AVHRR) (surface reflectance and NDVI).

2. Modifications in the SPOT/VEGETATION processing chain

2.1. Absolute and multi-angular calibration

This section describes the main updates to the instrument calibration parameters as provided by QIV. In VGT-C3, the absolute calibration parameters and multi-angular calibration (or equalization) coefficients were revised.

2.1.1. General description of SPOT/VEGETATION calibration processes

The optical imaging instrument design uses four independent cameras, one for each spectral band, with each one covering the whole Field Of View (FOV) thanks to a linear array of 1728 detectors (or pixels). In the calculation of the TOA radiance L_{TOA} from the observed digital number (*DN*), both the absolute and equalization coefficients need to be taken into account simultaneously:

$$L_{TOA,i,k} \sim \frac{DN_{i,k}}{A_k \cdot g_{i,k}} \tag{1}$$

where the subscripts *i* and *k* identify respectively the across track pixel (or detector) and the spectral band, *DN* is the raw digital output, *A* is the absolute calibration coefficient, *g* is the equalization coefficient. All these parameters vary over time.

For each spectral band, absolute calibration is thus the estimation of A_k, a global parameter independent of the considered pixel, whereas multi-angular calibration refers to variation of the instrument response with viewing angle or pixel, i.e., estimation of the equalization coefficients $g_{i,k}$.

Multi-angular calibration was performed for both VGT instruments before launch and regularly assessed in flight to monitor variations over the FOV, due mainly to heavy irradiations and aging of the different parts of the sensor (Fougnie et al., 2000). To allow these in-flight verifications, the coefficients $g_{i,k}$ were split into three terms according to the following equation:

$$g_{i,k} = P_{i,k} \cdot GLF_{i,k} \cdot GHF_{i,k} \tag{2}$$

GHF is a high-frequency term which refers to variation of the sensitivity of the elementary detector. *P* is a polynomial fit refering to variation of the optic transmission which slightly decreases when the viewing angle increases. *GLF* is a low-frequency term which refers mainly to smooth variations of the optic transmission that cannot be modeled by the polynomial function *P*.

To assess the in-flight absolute calibration parameters and the equalization coefficients, different vicarious calibration methods are applied, using the following natural targets: Rayleigh scattering, sun glint, deep convective clouds and desert sites (Henry and Meygret, 2001). The Rayleigh calibration is based on the idea that the apparent TOA radiance in Blue and Red observed over a clear ocean mainly results from atmospheric molecular scattering. This Rayleigh scattering is very well modeled and used for absolute and multi-angular calibrations. The calibration over sun glint allows to inter-calibrate the Blue, NIR and SWIR bands with respect to the Red band. It is similar to the Rayleigh scattering method, except that the geometrical viewing is set to observe the sun's reflection over the sea: because of the viewing constraints, this method cannot be used for multi-angular calibration. The calibration over clouds assumes that over thick clouds and under certain conditions of acquisition, cloud reflectance is the main contributor to the observed signal. The spectrally-independent properties of deep convective clouds in the visible and NIR bands allow calibration of the Blue and NIR bands with respect to the Red band. Finally, the principle of cross-calibration of sensors over desert sites is used to model the reflectance that the reference sensor (REF) would have measured in the same geometrical conditions and the same spectral bands as the sensor to calibrate (CAL). The signal acquired by CAL is then calibrated using the modeled radiance deduced from REF. Since desert sites are very stable targets in time, this method is also used for multi-temporal calibration, in particular to assess the temporal evolution of A_k (Lachérade et al., 2013).

Finally, all these vicarious calibration methods allow validation of the behavior and the stability of the on-board calibration lamp used to monitor the cameras sensitivity for the four spectral bands (Blue, Red, NIR and SWIR).

2.1.2. Multi-angular calibration

The combination of the on-board lamp, the calibration over clouds and the calibration over Rayleigh scattering allows characterization of the in-flight instrument angular response (i.e. the equalization coefficients) in the Blue, Red and NIR bands. In the SWIR band, only the on-