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PV-LAC

PROBA-V ATMOSPHERIC CORRECTION & COASTAL PRODUCTS

PV-LAC: Advanced Land, Aerosol and Coastal products for PROBA-V

PV-LAC: D-12-A2: Scientific Roadmap – Activity 2

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ATBD	Algorithm Theoretical Basis Document
BRF	Bidirectional Reflectance Factor
CCI	Climate Change Initiative
ESA	European Space Agency
ECV	Essential Climate Variable
MM	Man-Month
TOA	Top-Of-Atmosphere
WM	Working Month
CISAR	Combined Inversion of Surface and Aerosols
MEP	PROBA-V Mission Exploitation Platform
ECMWF	European Centre for Mid-Range Weather Forecasts
AOT	Aerosol Optical Thickness
BHR	Bi-Hemispherical Reflectance
C3S	Copernicus Climate Change Service
CNES	Centre d’Études Spatiales
AERONET	Aerosol Robotic Network
CPU	Central Processing Unit
ALE	Absolute Location Error
SZA	Solar Zenith Angle
SAA	Solar Azimuth Angle
VZA	Viewing Zenith Angle
VAA	Viewing Azimuth Angle
QA4EO	Quality Control Framework for Earth Observation
NIR	Near Infrared
SWIR	Short-Wave Infrared
MSG	Meteosat Second Generation
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SPOT-VGT	Satellite Pour l’Observation de la Terre - Vegetation
OLCI	Ocean and Land Cover Instrument
PMAp	Polar Multi-Sensor Aerosol Optical Properties

CHAPTER 1 INTRODUCTION

1.1. PURPOSE OF THE DOCUMENT

The Roadmap document discusses a number of elements that relate to the future application of the defined joint aerosol optical thickness and surface reflectance retrieval method.

1.2. LIST OF AVAILABLE DOCUMENTS

Govaerts, Y, Luffarelli M. and Damman A., (2016), CISAR-ATBD-V0.2, ESA Contract 4000114981/15/I-LG, deliverable D-2-A2 and D-3-A2.

CHAPTER 2 IMPLEMENTATION CONSTRAINTS FOR OPERATIONAL PROCESSING

2.1. INTRODUCTION

In the framework of the PV-LAC project Activity 2, the CISAR algorithm (Govaerts and Luffarelli 2017) has been applied to PROBA-V data for 2014 – 2015. This processing has permitted the adjustment of the prior values and associated uncertainties, as well as the definition of the threshold values for the Quality Indicator. It has demonstrated the algorithm's performance when applied to PROBA-V Level 2A observations. PROBA-V Level 2A data have been extracted by VITO for 5 x 5 pixels over a series of selected AERONET stations. The following data were made available for each observation:

- The illumination and observation geometries (SZA, SAA, VZA, VAA)
- The observation date and time
- The Top-Of-Atmosphere (TOA) Bidirectional Reflectance Factor (BRF) at 1 km resolution
- The total column water vapour – when available[1]
- The total column ozone concentration – when available[1]
- The geolocation Error per station/per observation – when available[2]
- The global mean Absolute Location Error (ALE) in meter (per band)
- The cloud mask (clear, cloud, cloud shadow, snow/ice)
- The pixel processing status
- The land/sea mask
- The pixel's altitude

These data were processed in the Rayference test environment, which has been designed to be flexible without considering CPU time aspects. Therefore it is difficult to provide an accurate estimation of the expected CPU time in an optimized operational environment. For the PROBA-V TOA BRF a radiometric uncertainty of 3%, constant in time and location, was assumed.

In order to perform an inversion of the PROBA-V observations with CISAR, data are accumulated in the four spectral bands during 16-day periods. It thus represents a multi-spectral and multi-angular observation vector processed by CISAR. In other words, one CISAR run is defined as the processing of this observation vector for one 1 km resolution pixel. In the Rayference test environment, one CISAR run as defined above takes about 6 seconds (Figure 1) of CPU time on a single-core processor (2,26 GHz Quad-Core Intel Xeon) for a mean number of 10 clear-sky observations per 16-day accumulation period.

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[1] In case where no ozone or water vapour data were available, Rayference used ECMWF re-analysis data.

[2] Due to internal storage limitations, the navigation accuracy per target and per observation unfortunately could not be provided for all segments. When this information was not available, the global mean Absolute Location Error values [which are reported in the PROBA-V Monthly Operations Reports (MOR)] were used.

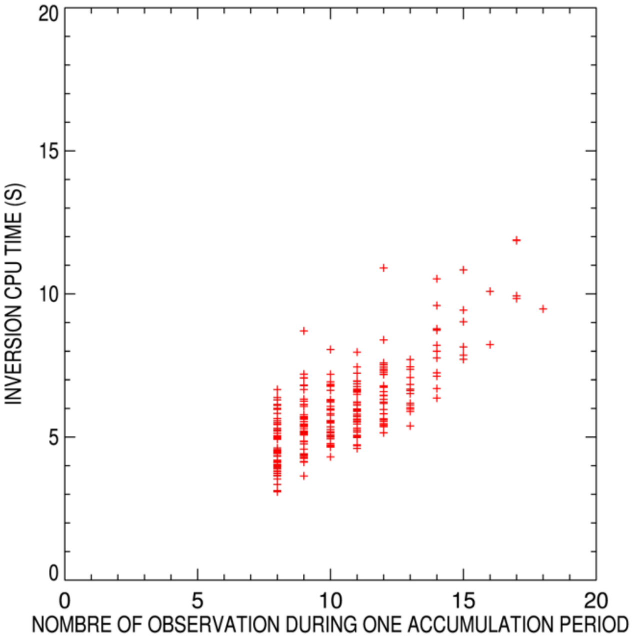

Figure 1: CPU time in seconds for the inversion of a single PROBA-V observation vector in the Rayference test environment.

2.2. CISAR OPERATIONAL PROCESSING

This Section describes the CISAR algorithm operations' concept. Such operations are pretty complex as:

- All the required input data need to be accumulated during a 16-day period prior to their processing.
- The algorithm uses a memory mechanism to update the prior information on surface properties.

In order to facilitate the time and space processing, these data are accumulated per tile. The processing includes the following major processing steps:

1. **Input data preparation**. All the input data required to perform the processing are extracted from various sources and stored in the so-called **input tiles**. One input tile is prepared for each observation, each day in the present case. This input information includes static and dynamic data. The static information includes for each pixel:
    - The pixel latitude and longitude
    - The pixel elevation
    - The pixel land/sea mask value
    - Aerosol layer height prior information, based on climatology data by Kinne et al. (2013)
    - Aerosol type prior information, based on climatology data provided by Kinne et al. (2013)

The dynamic information includes per pixel:

- Illumination and viewing geometry angles
- TOA BRF for all bands
- Radiometric and navigation[1] uncertainties
- Total column water vapour and ozone
- Surface pressure
- Wind speed and direction
- The surface prior information and associated uncertainties derived from the previous run

2. **Input data processing**
   For each pixel of an input tile, the corresponding observation vector and prior information is passed to CISAR that performs the inversion. The CISAR algorithm returns:
   - The estimated surface BHR value and its associated uncertainties for each processed spectral band.
   - The estimated aerosol optical thickness at 0.55 µm and its associated uncertainty.
   - The Quality Indicator value.

3. **Prior update**
   The new solution for the retrieved surface reflectance and associated uncertainties are analysed and the current surface prior information is updated accordingly. These values are stored in the **prior tile**.

4. **Solution tile generation**
   The retrieval values are saved in the **solution tile** for each processed pixels.

5. **Product generation**
   All the solution tiles are combined to generate the final product, the exact content of which is determined by the type of supported application.

A CISAR operational driver will have to be developed in order to perform these tasks efficiently and automatically in the operational PROBA-V processing environment.

2.3. EXPECTED ISSUES

During the development of an operational version of CISAR for the processing of PROBA-V images, it is critical to maintain the same accuracy as in the test environment. A series of issues will have to be faced during this development phase:

1. **Speed-up**
   The forward model and its inversion will have to be speeded-up with the objective to keep the inversion of one observation vector well below 1 second. In order to achieve this, the code (written in Fortran, C++, and Python) needs to be parallelized to take full advantage of the current distributed architecture. The PROBA-V Mission Exploitation Platform (MEP) is a suitable test bed for this code speed-up.

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[1] This information can be made available at the level of one PROBA-V tile.

2. **Evaluation**
   Currently, the retrieval evaluation has been performed only over the selected AERONET stations for the single pixels values that are currently retrieved. In order to get a better indication of the spatial consistency of full AOT and BHR images, evaluation with one or more satellite AOT and BHR datasets is required. In addition, especially for AOT the obtained results could be compared with dedicated atmospheric composition model output, such as the the MODIS AOT retrieval datasets and Copernicus Atmospheric Monitoring Service (CAMS) Near Real Time (NRT) AOT, the latter containing atmospheric composition forecasts and various assimilated satellite AOT datasets [the most recent version assimilates MODIS Deep Blue and Polar Multi-Sensor Aerosol Optical Properties (PMAp) AOT].

3. **Local emission**
   In case of local emissions, the evaluation of the CISAR AOT retrieval will become problematic, due to the time difference between satellite and ground-based retrievals, as well as due to different viewing geometries.

2.4. EFFORT ESTIMATE

The following Table summarizes the main tasks and a first estimate of the associated effort express in Working Months (WM).

Table 1: Effort estimates of the main tasks for the operational implementation of CISAR.

Task	Estimated effort [WM]
Input data preparation and verification	2
CISAR operational driver development and test	4
Code speed-up	6
Implementation in operational ground segment and documentation	2
Evaluation	4
Total	**18**

2.5. EXPECTED OUTCOME

The CISAR algorithm will provide state-of-the-art surface reflectance corrected for atmospheric effects. The retrieval uncertainty will also be calculated. Hence, this newly generated product will eventually fulfil current GCOS requirements for the generation of Essential Climate Variables (ECVs), such as surface albedo and aerosol optical thickness (being 5% and 10%, respectively). It will thus offer the possibility to support the needs of both the atmospheric and land surface research communities. Such data sets can directly contribute to Copernicus operational service or ESA Climate Change Initiatives (CCI) activities.

CHAPTER 3 UNCERTAINTY CHARACTERIZATION

3.1. RADIOMETRIC UNCERTAINTY

The radiometric random uncertainty needs to be provided on a pixel-basis per camera. Any systematic effects should be removed. At present, VITO provides the following radiometric uncertainties:

- BLUE strips all camera’s: 4 %
- RED strips all camera’s: 3 %
- NIR strips all camera’s: 3 %
- SWIR center camera: 4 %
- SWIR left and right camera: 5%

However, a pixel based uncertainty calculation should ideally be aimed for. This would mean that all the uncertainties in the radiometric model at the original pixel level in raw geometry (and at original resolution) have to be propagated to the projected L2 data at 1 km resolution, thus also the impact of resampling needs to be considered. It is clear that a pixel-based uncertainty budget calculation is not straightforward. Therefore in the framework of the PROBA-V Quality Working Group (QWG) a study is ongoing to define the overall strategy to be followed for the uncertainty calculations and to analyze the impact on the operational processing (e.g., increased processing time, increased data volume, etc.). One of the first actions is to participate to the Workshop "Uncertainties in Remote Sensing", which will be held in ESRIN in October 2017, in order to have a good knowledge about the state-of-the-art methodologies and their limitations.

3.2. GEOMETRIC UNCERTAINTY

The navigation accuracy should ideally be given for each acquisition cycle, possibly for each tile. This requires that the geolocation accuracy values are stored for all segments, which is currently not possible due to storage limitations in the geolocation processing environment. Therefore to fulfill this requirement, resources for implementing additional storage space and code adaptations should be allocated. The output of the segments will need to be redirected to several files. This implies that new code for this redirection needs to be written, tested, and validated.

The estimated effort for this modification amounts to **10 – 15 WD.**

CHAPTER 4 APPLICATION OF THE METHOD TO OTHER SENSORS

4.1. INTRODUCTION

In addition to PROBA-V data, the CISAR algorithm has already demonstrated its capacity to process Meteosat Second Generation (MSG)-Spinning Enhanced Visible and Infrared Imager (SEVIRI) data in the framework of the ESA aerosol_cci2 project. Therefore it should be possible to also apply it to SPOT-VGT and Sentinel-3 Ocean and Land Cover Instrument (OLCI) data.

4.2. PROBA-V 300 M AND 100 M RESOLUTION

It is noted that the current application of CISAR to 1 km PROBA-V data is the lower limit, as for the underlying FASTRE Radiative Transfer Model (RTM) the calculations become less accurate at these finer resolutions. This decrease in accuracy is among others connected to the increasing contribution of surface and atmosphere 3D effects (e.g. adjacency effects resulting from horizontal photon transport). In order to further extend the CISAR application to PROBA-V 300 m and 100 m data, additional research on the characterisation of these 3D effects in the radiative transfer calculations is required. It would be first necessary to quantity these effects, which represents about two or three years of research. All necessary tools to perform this research are not available yet and therefore need to be developed. Including these effects in the operational retrieval scheme requires an additional 3 - 4 years of research and development.

4.3. SPOT-VGT

The processing of SPOT-VGT data should be pretty straightforward because of the spectral similarities with PROBA-V. The radiometric and geometric uncertainties of SPOT-VGT will have to be carefully documented. For radiometric uncertainty, results from the uncertainty calculations performed within the Copernicus Climate Change Service (C3S) could be used as a first proxy.

As the SPOT-VGT swath and revisit cycle is similar to that of PROBA-V, the only major issue to be addressed for SPOT-VGT is related to SPOT-VGT's instrument configuration, which was different from that of PROBA-V. Regarding SPOT-VGT's orbital drift, this was only significant towards the mission's end, so only a limited research effort on the retrievals due to orbital drift is expected. Further, as the data covers a different time period, file format, etc., effort is needed to prepare and verify the input data. The product evaluation will also have to be carefully performed and the effort is somewhat compressible, as it can be performed using the already existing validation environment that was set up within this project.

A total effort of **3 – 5 WM**, excluding the radiometric uncertainty characterisation, should be foreseen for this activity. The input data quality would need to be carefully evaluated first in order to refine the actual effort needed.

4.4. SENTINEL-3 OLCI

Sentinel 3 OLCI offers much more spectral bands with better radiometric performance than PROBA-V. Consequently, it will be necessary first to re-assess the accuracy of the forward model and determine the need for some accuracy improvement that could cope with the new radiometric performance. In addition, the algorithm performance, prior setting, quality indicator evaluation, etc. will have to be evaluated in light of the additional spectral bands. Finally, as already indicated for PROBA-V in Chapter 4.1, the influence of 3D effects on the forward radiative transfer modelling needs to quantified for the 300 m OLCI data.

It is expected that it will be possible to define better spectral constraints concerning surface and aerosol properties. The duration of the accumulation period will have to be adjusted as a function of the orbital repeat cycle and the availability of Sentinel 3A and B data. A minimum effort of 6 WM should be foreseen to include the processing of Sentinel 3-OLCI data. An additional 2 WM should be foreseen for the combined processing of Sentinel-3A and -3B data, thus resulting in a **minimum total effort of 8 WM**, depending on the need for a 3D forward model.

LITERATURE

Govaerts, Y., and M. Luffarelli. 2017. ‘Joint Retrieval of Surface Reflectance and Aerosol Properties with Continuous Variations of the State Variables in the Solution Space: Part 1: Theoretical Concept’. *Atmos. Meas. Tech. Discuss.* 2017 (March): 1–27. doi:10.5194/amt-2017-29.

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