CCI Vegetation

Algorithm Development Plan

Christiaan Van der Tol, Simon Blessing, Else Swinnen,

October 2022

Distribution list

Author(s)	:	Else Swinnen
Reviewer(s)	:	Christiaan Van der Tol, Dennis Clarijs
Approver(s)	:	Clement Albergel
Issuing authority	:	VITO

Change record

Release	**Date**	**Pages**	**Description of change**	**Editor(s)/Reviewer(s)**
V1.0	2022/09/15	All	Algorithm Development Plan added in the Annex	Simon Blessing, Christiaan Van der Tol/Else Swinnen
V1.1	2022/10/05	All	Answer to RIDs on ADP implemented	Simon Blessing, Christiaan Van der Tol/Else Swinnen

Table of Contents

List of Acronyms 4
List of Tables 5
1 Introduction 6
1.1 Purpose of this document 6
1.2 Applicable documents 6
2 Algorithm Development Plan 7
2.1 Introduction 10
2.2 Discussion of user requirements 10
2.3 Adaption of outputs to user requirements 11
2.4 Cloud detection in multi-sensor retrieval 11
2.5 Snow detection 11
2.6 Previous retrieval as prior 12
2.7 Other opportunities 12
3 Referenties 12

LIST OF ACRONYMS

ADP	Algorithm Development Plan
ATBD	Algorithm Theoretical Basis Document
CCI	Climate Change Initiative
CCI+	The extension of CCI over the period 2017-2024
CRG	Climate Research Group
ECV	Essential Climate Variable
ESA	European Space Agency
FAPAR	Fraction of the photosynthetically active radiation absorbed by vegetation
GCOS	Global Climate Observing System
LAI	Leaf Area Index
URD	User Requirements Document
VITO	Flemish Institute for Technological Research
VP	Vegetation Parameters

LIST OF TABLES

Table 17: Development goals with risks and benefits 8

1 Introduction

1.1 Purpose of this document

This Algorithm Development Plan (ADP) describes an analysis of the technical feasibility to meet the user requirements. By analysing the trade-off between requirements and feasibility, a prioritisation is made of what ECV products should be developed to maximise benefits to the users.

1.2 Applicable documents

Reference	Document
AD-1	Climate Change Initiative Extension (CCI+) Phase 2 New ECVs: Vegetation Parameters (ESA-EOP-SC-CA-2021-7)

2 Algorithm Development Plan

In the Algorithm Development Plan, an analysis is made of the technical feasibility to meet the user requirements. By analysing the trade-off between requirements and feasibility, we establish a prioritisation of what ECV products should be developed to maximise benefits to the users. We include a specification of the ECV products that are planned to be developed in the project. The Algorithm Development Plans are updated with the experiences and the user requirements from the previous cycles. This is the first of these plans for cycle 1. It is based on a first evaluation of the interviews with potential users and experts (D1.1 - User Requirements Document, URD), on the statement of work, and on the experiences with the implementation of the algorithms, assuming that, among others, temporal coverage, accuracy, and reliable uncertainty estimates are fundamental user requirements.

Innovations on the part of the atmospheric correction, such as the provision of full per pixel TOC reflectance covariance data, have to remain subject of minor test experiments (subject to capacity), since they would create an inconsistency with the brokered datasets. However, OptiAlbedo and OptiSAIL are already able to exploit and propagate such information by design.

Table 1 summarises the planned technical developments, their risks and their benefit to the user community. In the subsequent sections, the items of this table are described in more detail.

Table 1: Development goals with risks and benefits

Development goal/innovation	applicable to OptiAlbedo +TIP	applicable to OptiSAIL	technical risk	risk description	benefit for the community
Physically-based algorithm	+	+	none	implemented	users prefer physically-based over machine learning (61/100)
Joint multi-sensor retrieval with the same algorithm	+	+	medium	while technically implemented, the different combinations of sensors will carry different information content, potentially leading to discontinuities, possibly in retrieved values, and very probably in uncertainty levels. Without further measures, lowest resolution product dictates final resolution	Consistent product with similar interpretation over a long time series and a wide range of sensors, which is more important to users than high spatial resolution (70/100). Allows for low-latency operational line which uses only low-latency sensors.
Use previous retrieval as prior	+	+	low	temporal correlation in data, parallelisation only over spatial dimension	Faster processing; less noise at higher temporal resolution; higher temporal resolution <10 days required by users (70/100)

Development goal/innovation	applicable to OptiAlbedo +TIP	applicable to OptiSAIL	technical risk	risk description	benefit for the community
Extend cloud detection to multi-sensor		+	medium	requires introduction of additional parameters in the inversion which may adversely affect convergence	better coverage
Snow detection jointly with albedo retrieval	+		low	developed in cycle 1 based on regression	identification of snow-influenced backgrounds, better coverage and quality
Snow detection jointly with veg. ECV retrieval		+	none	included	identification of snow-influenced backgrounds, better quality retrievals
Adaption of outputs to user requirements	+	+	low	balance of preferences	improved usability
Retrieval of leaf pigments, leaf water content, surface soil moisture		+	none	implemented, but no validation foreseen	potentially useful data, more detailed regard of sources of uncertainty

2.1 Introduction

The main ECVs produced in the project are LAI and fAPAR. However, depending on the application, there are different preferences from the users' side, regarding the exact definition and way of computation of these quantities. Moreover, as stated in the technical proposal, OptiSAIL is both modular and highly efficient in the generation of ancillary outputs, which will be exploited in the project. For example, fAPAR for pigments is also an output and can be exploited, the scattering of fluorescence can be implemented with little additional computational effort thus adopting developments in the model SCOPE. Updates of the leaf radiative transfer model PROSPECT (such as PROSPECT-PRO) can be implemented with little effort. Based on the user requirements of Task 1, the configuration of OptiSAIL will be updated in cycle 2, provided that test inversions turn out encouraging. For a description of the present status of the algorithms and their correspondence to the project goals, please refer to the ATBD (VP-CCI_D6.2_ATBD_v1.1).

2.2 Discussion of user requirements

A first evaluation of the D1.1 - User Requirements Document (URD), confirms the choice of a physically based retrieval method over machine learning approach, which is applied to multi-sensors jointly. This allows for the retrieval of time series of maximum length with good consistency as preferred by users. It has to be noted, however, that different combinations of sensors carry different information content. Higher information content will allow the algorithms to retrieve values which are further away from prior assumptions, and thus introduce discontinuities in the statistics. The stability of the retrievals is evaluated in the validation part of this project.

Most users stress that a 'true LAI' is needed, following the definition of m2/m2 of ground surface. Many radiative transfer models assume that the leaves are homogenously distributed (turbid medium models or 1D models, such as OPTISAIL). If in reality, the leaf area is concentrated on parts of the surface within the 1-km footprint (for example in crowns with gaps in between), then a LAI retrieved from such 1-D model tends to underestimate the true LAI. This may well explain lower LAI values from TIP as compared to MODIS as reported by Feng et al., (2013).

At present, neither proposed algorithmic chain retrieves clumping or a land cover fraction. Further investigation is needed to whether (and how) an approximate land-cover specific or land surface model specific conversion can be derived from land-cover maps by the users. Given the coarse nature of the observations and with disregard of the land-cover maps, also no differentiation is made in the algorithms for pixels with mixed vegetation (e.g., Savannah). The retrieved values are for homogenous vegetation at the pixel level and consistent with the model assumptions of two-stream and PROSAIL, respectively.

This issue, combined with the user requirement of achieving physical consistency with land surface models (LSM), is a gordian knot. Most LSMs include a simplified radiative transfer scheme to calculate leaf photosynthesis, using a constant conversion from true to apparent LAI, but these approaches differ among LSMs. This implies that it is not possible to achieve physical consistency with all LSMs. The use of biome-specific radiative transfer models used by some existing products, which rely on additional assumptions on the structure of these biomes and a land cover classification map, has been identified as a major drawback by some users. Hence, biome specific parameterizations through land cover classification are uncertain, we take this as a confirmation to keep this set-up.

More sophistication on the model level would require more parameters to be estimated, with all the adverse consequences such as, worse performance, longer temporal aggregation window. It may also potentially lead to convergence problems due to under-determination. Furthermore, the use of a land-cover input layer may have adverse effects on the long-term consistency of the CDR, due to different qualities of historic land cover classifications and in case of land cover changes.

2.3 Adaption of outputs to user requirements

In order to allow the users to reconstruct the background spectrum, the spectral basis functions for the soil model shall be included in the metadata of the OptiSAIL retrievals. We are also hoping for feedback from the CRG on the presentation of the covariance data, which currently is given as correlations in individual data layers, once they had the opportunity to gain experience with the produced data sets. The computation of fAPAR based on the chlorophyll absorption or even split up by leaf pigments is an option which is still subject to evaluation in the dialogue with the CRG. Suitable extensions of PROSAIL have already been demonstrated in the literature (e.g. Zhang et al., 2005; Yang et al., 2021; Croft et al., 2020).

2.4 Cloud detection in multi-sensor retrieval

OptiSAIL cloud contamination detection currently uses one single cloud thickness parameter. For the use of observations that are made at different points of time, this cannot suffice, since clouds are highly variable in time. Currently, this problem is avoided by using the strictest possible choice of status flags in order to avoid cloudy observations. In cycle 2 of the vegetation CCI project, we foresee to test a set-up with multiple cloud contamination parameters, one per sensing geometry and time, in order to improve coverage in areas with frequent cloud-cover. This may also allow for a higher temporal resolution due to more observations being included in the retrieval.

2.5 Snow detection

OptiSAIL has sub-canopy snow detection by design by the inclusion of the snow reflectance model TARTES. For the base-line-algorithm however, snow detection had to be included in OptiAlbedo as described in the ATBD (VP-CCI_D6.2_ATBD_v1.1). For practical reasons, this was already done in cycle 1. Shall the validation exercise indicate the need for refinement, this will be part of cycle 2, but within the limits of the chosen technical approach (tuning and synergy with pixel classification). For both algorithmic chains the detection of snow is important because of its high impact on the radiative transfer in the canopy, thus affecting data quality in high latitudes and in winter.

2.6 Previous retrieval as prior

This technique has been demonstrated in the literature for related retrieval systems (e.g., SCOPE). It is technically feasible for both, the OptiAlbedo and for OptiSAIL. It has the potential to reduce noise, speed up the processing, improve the accuracy of the retrieved quantities, and/or allow for a higher temporal resolution. However, it requires changes in the operational implementation, since previously independent tasks get a sequential dependency. That means that parallelisation can only be done in the spatial domain, but no longer in the temporal domain. It also creates the need of a spin-up period in the processing and a careful choice of the strength of the constraint by the prior, based on the uncertainty estimate, its correlation with other parameters, and the temporal variability of the constrained parameter.

2.7 Other opportunities

OptiSAIL retrieves not only LAI and fAPAR, but also a number of other vegetation parameters, such as leaf pigments and leaf water content. Even if these quantities may not be well determined in all situations, taking them into account gives a more realistic estimate of the overall retrieval uncertainty. While the validation of these quantities is beyond the validation activities foreseen in this project, interest has been voiced from the CRG to study these data and to confront them with in situ observations in a suitably scoped project, which, if done in a timely fashion, could feed back into the algorithm development of the present project.

3 Referenties

Croft, H., Arabian, J., Chen, J. M., Shang, J., & Liu, J. (2020). Mapping within-field leaf chlorophyll content in agricultural crops for nitrogen management using Landsat-8 imagery. Precision Agriculture, 21(4), 856-880.

Feng, M. , J.O. Sexton, C. Huang, J.G. Masek, E.F. Vermote, F. Gao, R. Narasimhan, S. Channan, R.E. Wolfe, J.R. Townshend (2013) Global surface reflectance products from Landsat: Assessment using coincident MODIS observations, Remote Sens. Environ., 134, 276-293, 10.1016/j.rse.2013.02.031

Yang, P., Prikaziuk, E., Verhoef, W., & van Der Tol, C. (2021). SCOPE 2.0: A model to simulate vegetated land surface fluxes and satellite signals. Geoscientific Model Development, 14(7), 4697-4712.

Zhang, Q., Xiao, X., Braswell, B., Linder, E., Baret, F. and Moore III, B., 2005. Estimating light absorption by chlorophyll, leaf and canopy in a deciduous broadleaf forest using MODIS data and a radiative transfer model. Remote Sensing of Environment, 99(3), pp.357-371.)