# ESA Climate Change Initiative
# Aerosol_cci+

## Algorithm development plan (ADP)

### Version 3.0

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# EXECUTIVE SUMMARY

This report briefly summarizes the achieved and planned developments and improvements to each of the two algorithms under development during the Aerosol_cci+ project:

- SU algorithm (Swansea)
- CISAR algorithm (Rayference)

For each algorithm a short overview, the planned work in each project contractual year and the achieved work in the previous project year are summarized. This document is based on section 3.5 of the proposal.

This update of the ADP at the end of Year 3 of Aerosol_cci+ contains the third summary of achieved work and a summary of the work proposed for a follow-up project.

This report contains in section 2 a selection of gaps relevant for aerosol retrieval algorithm development identified within the Copernicus Climate Change Service (C3S) contract C3S_312b_Lot2 for Atmospheric Composition ECVs including aerosols. In section 3 the two algorithms under development in Aerosol_cci+ are briefly introduced with the overall work plan for this project and then for the previous project year achieved work and updated plans for the subsequent year are summarized.

| Issue | Date | Modified Items / Reason for Change |
|---|---|---|
| 0.9 | 04.03.2020 | Document structure and first draft |
| 1.0 | 10.03.2020 | Input by algorithm development partners<br>Review by science lead |
| 2.0 | 31.03.2021 | Input by algorithm development partners<br>Integration by science lead |
| 3.0 | 06.05.2022 | Update at the  end of the project |

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# 1 INTRODUCTION

Algorithm development is one major part of Aerosol_cci+ activities. Based on findings of earlier product evaluations in Aerosol_cci2, two existing pre-cursor algorithms are adapted to improve their outputs for subsequent evaluation (valdiatrion and user assessment). A continuous exchange between project partners forms the basis to identify and implement for each algorithm potential improvements in following ways:

- by exchange of modules
- by improvement of modules
- by agreement on common modules (or auxiliary datasets)
- by development of new synergetic approaches

## 1.1 Scope

This document describes the developments and improvements to each of the two algorithms at the end of the second year of Aerosol_cci+.

### 1.1.1 Applicable Documents

[AD1] The Statement of Work, reference ESA-CCI-EOPS-PRGM-SOW-18-018, issue 1, revision 6, dated May 31st, 2018, and its specific annex C.

[AD2] The Contractor's Proposal reference 3022091 revision 1.1 , dated 10 December 2018

### 1.1.2 Reference Documents

[RD1] Govaerts, Y. and Luffarelli, M.: Joint retrieval of surface reflectance and aerosol properties with continuous variation of the state variables in the solution space – Part 1: theoretical concept, Atmos. Meas. Tech., 11, 6589–6603, https://doi.org/10.5194/amt-11-6589-2018, 2018.

[RD2] Luffarelli, M. and Govaerts, Y.: Joint retrieval of surface reflectance and aerosol properties with continuous variation of the state variables in the solution space – Part 2: application to geostationary and polar-orbiting satellite observations, Atmos. Meas. Tech., 12, 791–809, https://doi.org/10.5194/amt-12-791-2019, 2019.

[RD3] Bevan, S., North, P., Los, S. & Grey, W. (2012). A global dataset of atmospheric aerosol optical depth and surface reflectance from AATSR. *Remote Sensing of Environment* 116, 199-210.

[RD4] North, P. and Heckel, A. (2018). SU-SLSTR ATBD, C3S Ref: C3S_D312a_Lot5_201811_SU_SLSTR_ATBD_v1.1.

[RD4] North, P. and Heckel, A. (2018). SU-ATSR ATBD, C3S Ref: C3S_D312a_Lot5_201811_SU_ATSR_ATBD_v4.32.

[RD5] *Preparation and Operations of The Mission Performance Centre (MPC) For The Copernicus Sentinel-3 Mission, Technical note: Assessment of Visible and Short Wavelength Radiometric Calibration, S3MPC.RAL.TN.010*. Version 1.0, 24/01/2020.

# 2 GAPS IDENTIFIED BY C3S RELEVANT TO AEROSOL_CCI+

We analysed the gaps identified by the Copernicus Climate Change Service (C3S) contract C3S_312b_Lot2 for Atmospheric Composition ECVs including aerosols. In table 1 a selection of those gaps relevant for aerosol retrieval algorithm development are listed and the possible contribution of this project Aerosol_cci+ is indicated.

**Table 1:** *List of identified gaps for aerosol ECVs*

| C3S service component covered by the AER component of project C3S_312b_Lot2 (satellite-derived aerosol ICDRs / CDRs and related services): **List of identified gaps and recommendations on how to improve** *(not ordered by priority)* | | | | |
|---|---|---|---|---|
| **GAP ID** | **Type** | **Gap** | **Recommendation** | **Aerosol_cci+ response** |
| **General gaps of all sensor lines: FCDRs and reference data** | | | | |
| **GAP_INP _1** | Input data | Partial lack of FCDR consistency across missions (subsequent sensors) | Assign responsibility for multi-mission FCDRs | Work of this project aims at improving consistency of ATSR-2 / AATSR / SLSTR data records to be produced in C3S (both algorithms). |
| **General gaps per sensor lines: FCDRs** | | | | |
| **GAP_INP _3** | Input data | Inconsistency in ATSR vs. SLSTR viewing geometry, possible problem for consistency | Further research is needed to reduce uncertainties of the retrieval algorithms for all instruments of the dual view sensor line. | Work to assess and improve this inconsistency is planned (SU algorithm) |
| **Algorithm gaps / general aspects** | | | | |
| **GAP_ALG _2** | R&D | Lack of information on speciated aerosols | Further research is needed to develop algorithms for the inversion of aerosol type information from combinations of different sensors. | This project contributes with Fine Mode AOD retrievals to this task (both algorithms). |
| **GAP_ALG _3** | R&D | Accuracy targets are not (yet) fully met. | Ongoing algorithm improvement needed to meet | This project aims at improving the accuracy of the inversions (both |

| | | | | |
|---|---|---|---|---|
| | | | accuracy requirements | algorithms). |
| **Algorithm gaps / specific aspects per sensor line** | | | | |
| **GAP_ALG _8** | R&D | Dual view sensor line: reduced accuracy for higher AOD (> 0.2) | Further algorithm development is needed. | This project aims at improving the accuracy of the inversions (both algorithms). Evaluation will try to separate AOD>0.2 cases. |
| **GAP_ALG_11** | R&D | Dual view sensor line: reduced quality under several specific conditions | improve quality over bright deserts, of fine mode AOD, correct overestimates near dust sources, improve uncertainty estimates | This project aims at improving the inversion algorithm based on earlier identified deficits (SU algorithm).<br>This project aims at improving uncertainty estimates (both algorithms; esp. RF algorithm). |
| **Gaps in uncertainties** | | | | |
| **GAP_ALG_20** | R&D | Propagated uncertainties so far neglect effects due to cloud masking | develop methods to estimate uncertainties due to cloud contamination, including their validation | This project tests possibilties for avoiding cloud masks (RF algorithm). |

# 3 OVERVIEW FOR PRE-CURSOR ALGORITHMS

In this project we focused on one sensor line, namely dual view radiometers operated since 1995 on a series of platforms (ERS-2 1995 - 2003 and ENVISAT 2002 – 2012) in research context and since 2016 on board Sentinel-3 operational platforms (A and B). We developed and assessed two algorithms, which are complementary in their maturity. One of them has been the leading algorithm throughout the period of the Aerosol_cci projects and has benefitted largely through open / collaborative competition with and comparison to other algorithms for the same sensor in this timeframe. The other one has been developed first for a much weaker geostationary instrument (SEVIRI on board Meteosat Second Generation) which required mathematically powerful constraining and recently been adapted and demonstrated for SLSTR. As we have seen the benefit of competing algorithms in the last decade, we hoped to achieve further improvements by continuing on lowest level (i.e. with two algorithms) this concept.

## 3.1 SU dual view algorithm (Swansea)

Current algorithm status: The main components of the current SU algorithm for (A)ATSR and SLSTR are (i) radiative transfer modelling of TOA reflectance to generate lookup tables for a range of aerosol optical depths and aerosol model types, (ii) definition of parameterised models of land and ocean surface spectral and angular reflectance, (iii) an inversion algorithm to estimate the optimal atmospheric profile, and (iv) post-processing to remove residual cloud contamination. An aerosol retrieval is attempted at 'superpixel' resolution (9 km for (A)TSR and 4.5km for SLSTR) for all regions over land and ocean free of snow/ice cover, and excluding high cloud fraction. Two parameters describing the aerosol content are directly retrieved during the inversion: AOD at 550nm and fine mode fraction, while further aerosol parameters are constrained by a climatology giving likely seasonal and spatial sources of aerosol. Estimation of per-retrieval AOD uncertainty is also provided by propagating the known or estimated uncertainties of surface model, radiative transfer and observational uncertainties directly into the optimisation procedure. The SLSTR algorithm implementation to date has minor adaptation to account for changed solar/view geometry and spectral channels. Following evaluation under CCI, a version of the retrieval based on the AATSR ATBD 4.3 developed during Aerosol_cci has been developed into an operational product for SLSTR under separate funding, to provide part of the Copernicus Atmospheric Monitoring Service. However further development is needed to optimise the retrieval for SLSTR, and to ensure continuity with (A)ATSR record, and this development is not currently funded elsewhere. Global patterns of annual mean AOD and uncertainty retrieved from AATSR and SLSTR are shown in Figure 1.

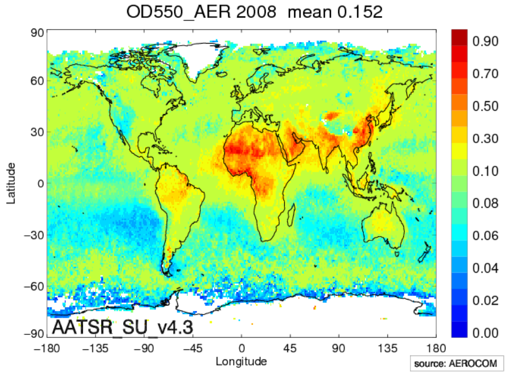
Priority issues to be addressed under Aerosol_cci+: The aerosol retrieval algorithm for AATSR has been extensively evaluated in ESA Aerosol CCI (e.g. Popp et al., 2016). While overall evaluation shows favourable retrieval in comparison to other available satellite datasets, especially in overall low bias and good retrieval of aerosol size distribution, a number of issues have been identified to target improvement. These include regions of high cloud, especially over ocean, where plumes may be confused with cloud, and retrieval of dust over bright surfaces. Existing absorption for dust plumes appears high in the current retrieval, potentially leading to high bias in AOD over desert surfaces.

Initial testing of SLSTR retrieval under Aerosol cci bridging funding showed overall similar pattern of retrieval to AATSR, but with a high bias (Figure 1 a-b). This bias may be explained by use of initial poorly calibrated data in the test, and preliminary radiative transfer look-up tables. In addition the spatial pattern of estimated retrieval uncertainty is very different to AATSR (Figure 1, c-d). The changed geometry of SLSTR leads to lower uncertainty in the southern hemisphere, at the expense of higher uncertainty in the northern hemisphere. Further work is needed to calibrate absolute values of uncertainty retrieval, to reduce bias and provide continuity with AATSR record. Of critical importance also is research to improve retrieval over northern land surfaces.

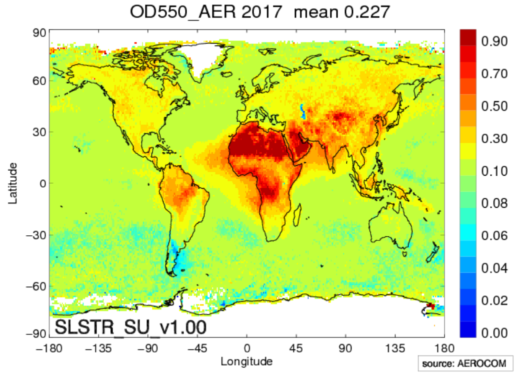
Algorithm development plan: Phase 1: We will focus with priority on SLSTR since the error is currently greatest. However algorithm improvements will be included in revision to (A)ATSR. The first iteration will include revised radiative transfer model adapted for SLSTR wavebands, and use of improved calibration. Further research will seek to understand regions of high bias, and tuning of surface model and cloud screening to optimise retrieval, and improved propagation of uncertainty. To date testing of SLSTR has only been carried out on S3A. Data from revised algorithms for 4 months for each of four instruments (ATSR-2, AATSR, SLSTR on S3A and S3B) will be produced in CCI format to allow full inter-comparison by the Aerosol_cci+ validation team.

Phase 2: Retrieval over bright surface for both AATSR and SLSTR shows largest error, and requires additional research to improve retrieval. Under Aerosol_cci bridging funding, reduced error has been demonstrated using an experimental priori constraint on optical depth. The focus of this research will be to adapt the surface model to provide constraint over bright desert surfaces by multi-temporal analysis of reflectance, taking advantage of typically stable reflectance spectra in these regions. In addition use of updated climatology of aerosol properties will be tested. Global data will be provided for testing as for Phase 1. SU will process for month 21 already one full year of one SLSTR sensor as test dataset for the user case studies.

Phase 3: Research priorities during phase 3 will depend on analysis of results and feedback from the CCI validation team from Phase 1 and 2 developments. The focus will be on areas of high bias apparent in either sensor, focussing on achieving climate quality time series with well characterised error in level 2 and 3 products, and documentation of all changes in final ATBDs, allowing transfer of results to other programmes (e.g. CAMS, C3S).




(a)

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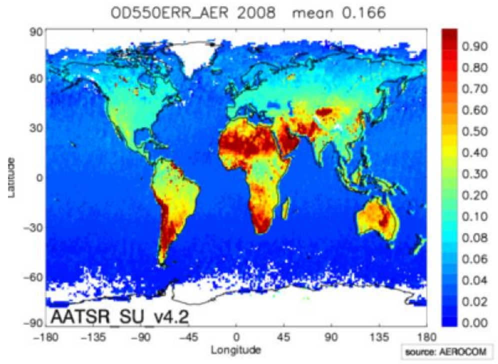


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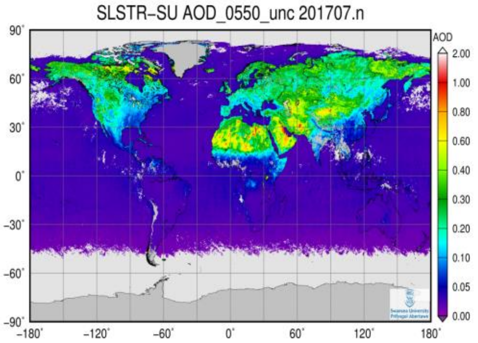



(d)

**Figure 1: SU algorithm example results for AATSR and SLSTR**

(a) Global AOD estimation for AATSR for 2008 from the SU algorithm; (b) AOD from SLSTR on Sentinel 3a for July-Dec 2017. Annual mean of estimated retrieval uncertainty for AATSR and SLSTR AOD are shown in figures (c) and (d) respectively.

### 3.1.1 Year1 developments: SU algorithm

Research has focussed on Sentinel-3 development as planned. The algorithm has been implemented and tested for processing of both Sentinel-3A and Sentinel-3B data. The key new dataset was for 4-month processing of Sentinel-3B. This has been achieved, and following initial verification extended to processing the entire record (Nov 2018-Feb 2020) and submission to CCI for testing. Level 2 testing against Aeronet has been performed, with results showing similar pattern (Figure 2a, 2b) and accuracy as for Sentinel-3A (Figure 2c, 2d). Correlation for S3B over the year shows R=0.79 for both, with RMS= 0.104 for S3A and 0.111 for S3B. Analysis suggests the pattern of error compared with AERONET corresponds to the projected uncertainty, with highest errors in N. hemisphere land, especially during winter months, corresponding to unfavourable back-scattering viewing conditions for the oblique view. Further analysis of the results is guiding ongoing development.

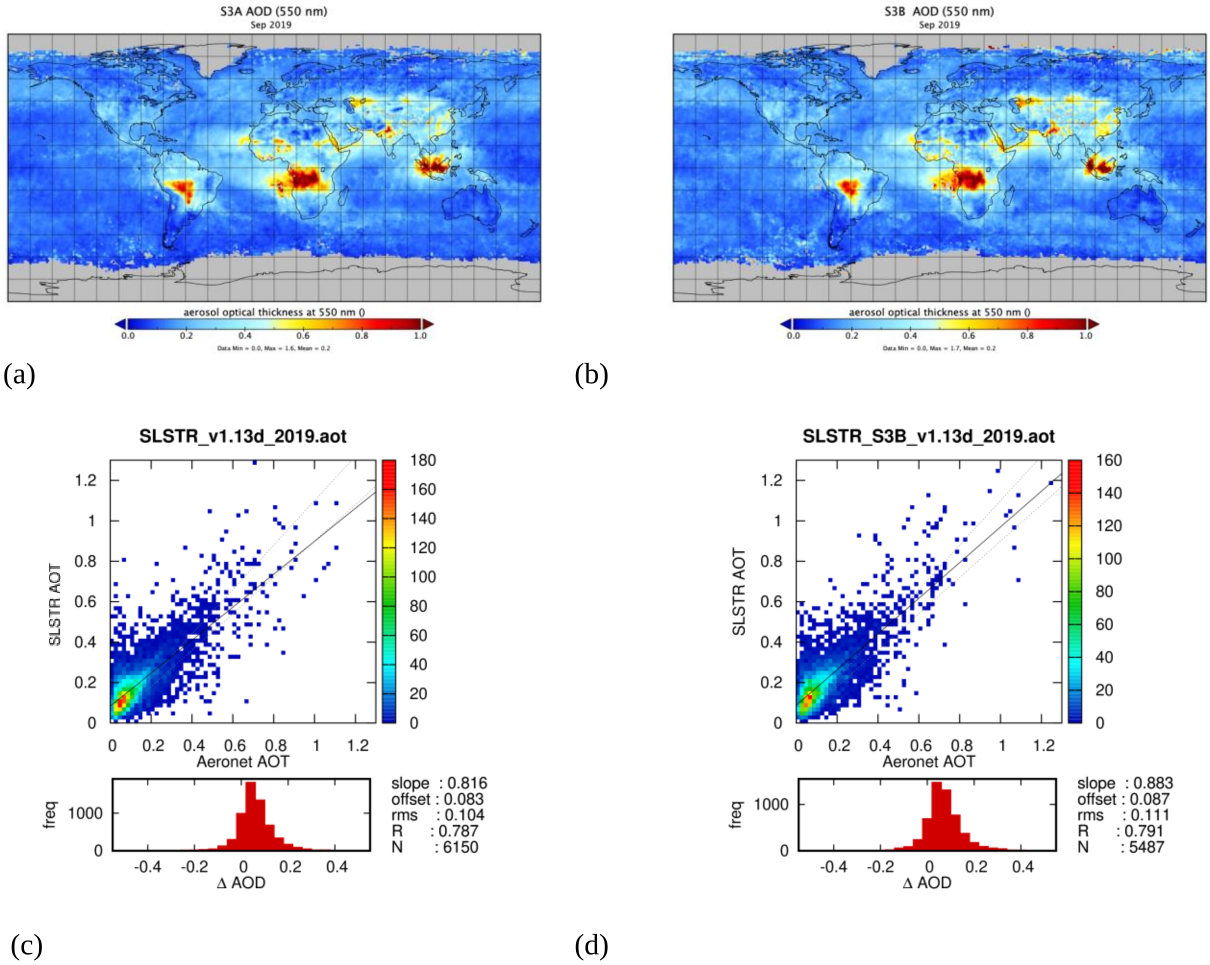
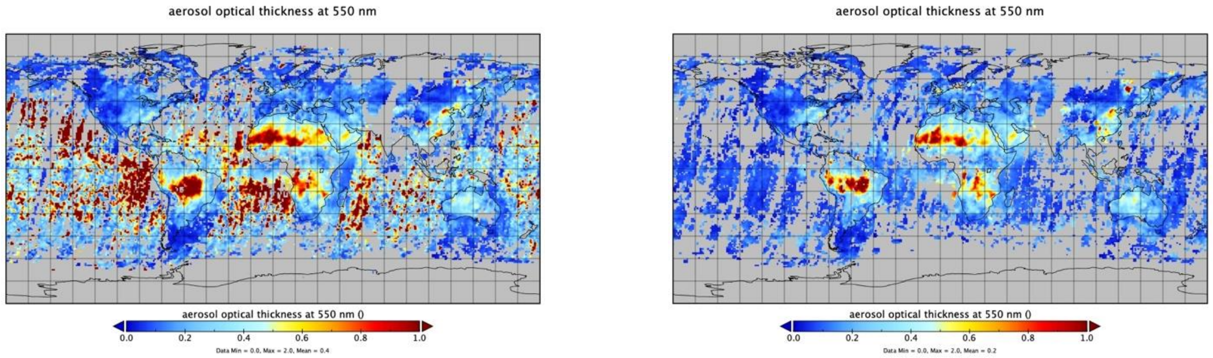



**Figure 2: SU algorithm results for SLSTR3A and 3B**

(a) Global AOT estimation for SLSTR on S3A for Sep 2019 from the SU algorithm (v1.11), and (b) AOT from SLSTR on S3B for the same period. Aeronet comparison at L2 over all matches for 2019 for S3A (c) and S3B (d).

Previous results at the end of Aerosol_cci2 (bridging option) had shown poor retrieval of AOD for ATSR-2 over the ocean in version 4.32. This was explored, and problems were traced to treatment of cloud flagging in parts of orbit which were downloaded at reduced resolution due to interference with scatterometer data. This has been corrected and a revised ATSR-2 dataset was produced for testing over the whole time series in the period between Aerosol_cii2 and Aerosol_cci+. In addition problems were indicated with absorbing AOD in (AAOD) in the AATSR product; this was a minor error in code writing output, and has been corrected and this field replaced in the period between Aerosol_cii2 and Aerosol_cci+. When the Aerosol_cci+ contract started a major review and enhanced documentation of code was undertaken, corresponding with change of key personnel, and appointment of Dr Kevin Pearson at Swansea. The corrected files produced in the interim period were then thoroughly evaluated and the intended improvements could be proven (as shown in figure 3 for the ATSR-2 cloud masking). Subsequently, those positively evaluated AATSR and ATSR-2 files of v4.32 were uploaded to the ftp server in February 2020 over-writing the erroneous files with wrong cloud masks and absorbing AOD fields.




(a) (b)

**Figure 3: SU algorithm update for ATSR-2** (a) Version 4.32 of ATSR-2 AOD submitted under CCI Continuation had erroneous implementation of cloud screening, leading to high error, illustrated for Sep 1998. (b) This has been replaced with a new version for testing, correcting this issue.

### 3.1.2 Year2 developments: SU algorithm

Research during Phase 2 targeted enhancement of the S3A and S3B retrieval, focussing on issues identified by the initial processing and CCI evaluation feedback. These are

(i) Calibration of SLSTR channels, in particular channels S5 and S6, were known to be uncertain during early mission phases. We have explored the impact of the calibration, and used the revised calibration factors detailed in [RD5] to produce an improved retrieval included in version 1.14.

(ii) Examination of the SLSTR datasets indicated greatest error was apparent in N. hemisphere land surfaces, and especially over bright surfaces and high latitudes. This corresponds to the high retrieval uncertainty caused by the relatively weak aerosol back-scatter compared to surface scatter in these regions, and reduced contrast of aerosol scattering strength between the two views. Research during year 2 addressed this by developing an improved spectral constraint within the surface model, and included in the inversion over land surfaces in addition to the angular constraint. This follows a similar formulation to the dark target approach used in MODIS and the Synergy aerosol retrievals developed by SU for MERIS/AATSR and SLSTR/OLCI. The constraint links the surface reflectance terms in the model at channels S2 (0.66 μm) and S6 (2.25 μm).

(iii) Revised ATBDs for SLSTR (v1.14) and (A)ATSR v4.33 were produced for Aerosol CCI, and test datasets for (A)ATSR, Sentinel-3A and -3B delivered.

### 3.1.3 Year3 developments: SU algorithm

(i) The spectral model developed for SLSTR was further explored and it was adapted to apply to the (A)ATSR instruments also. Since the model makes use of the S6 channel (2.25 µm), which does not exist on (A)ATSR, the formulation was adjusted on use of the 1.6 µm channel. Wit this a new ATSR-2 / AATSR algorithm version was developed (v4.35) which is more consistent with the latest vesino for SLSTR (v1.14).

(ii) With this improvement of the consistency between retrievals produced by (A)ATSR(-2) and SLSTR , we achieved a slight reduction of the (A)ATSR(-2) bias. The full consistency of the combined record can only be assessed when more than the 1-year datasets are processed.

(iii) 12-month / full test datasets were produced with the latest algorithm versions for ATSR-2 (1998) and AATSR (2008) as well as both SLSTR instruments (2020, in addition to the earlier 2019). Those 12-month datasets went into the validation and inter-comparison exercises.

### 3.1.4 Proposed follow-up developments: SU algorithm

The Swansea algorithm improvement, based on identified deficiencies and user needs, has as its highest priority ti achieve full consistency of the full CDR from (A)ATSR(-2) and SLSTR records, and with improved fine mode discrimination. This required a reduced bias and rms in the Northern hemisphere over land for SLSTR, and (less severe) in the Southern hemisphere for (A)ATSR(-2). Also, further improvement in uncertainty propagation is needed. This priority should be addressed by

(i) further improvement of spectral land surface model, especially considering compatibility of (A)ATSR and SLSTR retrievals
(ii) integration of spectral and angular approaches, improve error propagation considering modelling error in spectral model
(iii) optimization of FMF retrieval, re-examine aerosol components, spatial coherence, prior climatology (link to additional task 1b below)
(iv) Understanding of reasons for differing ocean AOD between (A)ATSR and SLSTR, and targeted improvement for consistency

## 3.2 CISAR dual view algorithm (Rayference)

Cloud contamination is a major issue for the retrieval of aerosol properties. Data sets derived from a same instrument but using different cloud masks can exhibit large differences. In the framework of the CIRCAS SEOM project (www.circas.eu), Rayference has improved the Combined RetrIeval of Surface and AeRosol (CISAR) algorithm (Govaerts and Luffarelli, 2017, Luffarelli and Govaerts, 2018) used within Aerosol_cci2 to include the possibility to jointly retrieve aerosol and thin cloud properties over any type of surfaces. Such approach should limit the impact of cloud mask on aerosol retrieval. One of the major assets of the CISAR algorithm is the possibility to retrieve surface reflectance and aerosol or cloud properties with continuous variations of the state variables in the solution space. To achieve this, the radiative transfer equation solution is not pre-calculated for a limited number of possible solutions but solved on the fly during the inversion process. Though very efficient in an optimal estimation framework, the method is very demanding in terms of CPU times.

The CISAR algorithm implements an estimation of the retrieval uncertainties for each processed pixel, providing insight on the coupling between the various variables as a function of the observation and prior information uncertainties. This method accounts thus for the observation uncertainties, propagating them on the retrieval uncertainties as required by QA4EO principles (http://www.qa4eo.org/) and ISO standard such as the Guides to the expression of uncertainty in measurement (http://www.iso.org/sites/JCGM/GUM-introduction.htm). So far the CISAR algorithm has been successfully applied for:

- the generation of a surface reflectance test data set from the SEVIRI HRVIS, VIS0.6 and VIS0.8 bands in the framework of the QA4ECV FP7 project;
- the derivation of an hourly aerosol data set from MSG / SEVIRI data in the framework of the ESA Aerosol_cci2 project;
- the derivation of surface reflectance from PROBA-V observations within the ESA PV-LAC project;
- the generation of a long-term aerosol CDR from the MVIRI instrument in the framework of the FIDUCEO H2020 project;
- the consistent surface reflectance, downward flux, aerosol and cloud properties from SLSTR in the framework of the ESA CIRCAS project (see fig. 4).

Within the Aerosol_cci+ project, the CISAR algorithm will be used to support the innovative approach for the processing of SLSTR data. This algorithm already includes all the TR-9 requirements to the exception of the spatial regularization of the cloud and aerosol properties. The possibility to include spatial regularization within the CISAR algorithm will be developed during the Aerosol_cci+ project.

The use of the CISAR algorithm within the FIDUCEO project has revealed some limitations in uncertainty estimation due to assumption on the shape of the observation and prior uncertainty covariance matrices. Currently, these matrices are assumed diagonal, neglecting thereby possible error correlation between observations or prior information. Such assumptions reduce the CPU time and simplify the assemblage of these matrices. However, uncertainty propagation assuming non diagonal matrices is expected to have an important impact on the estimated uncertainty of the retrieved solution. Such additional development will allow the innovative algorithm to fully cope with requirement TR-10.

In summary, the following two developments are foreseen with the innovative algorithm:

- use of spatial regularization method for the retrieval of cloud and aerosol properties
- analysis of observation and prior covariance uncertainties on the estimated uncertainties of the retrieved state variables.

This improved version of CISAR will be used for the processing of one year of SLSTR data for the consistent estimation of the following variables:

- aerosol optical depth including fine and coarse mode ratio and AOD;
- aerosol single scattering albedo and asymmetry parameter;
- thin cloud optical depth and phase;
- land surface reflectance.

Europe and North Africa regions will be processed in priority for evaluation purposes. SLSTR data will be processed globally using the same superpixel resolution as the mature algorithm to foster direct comparison. For processing of global data we will seek collaboration with other activities available at no / low cost.

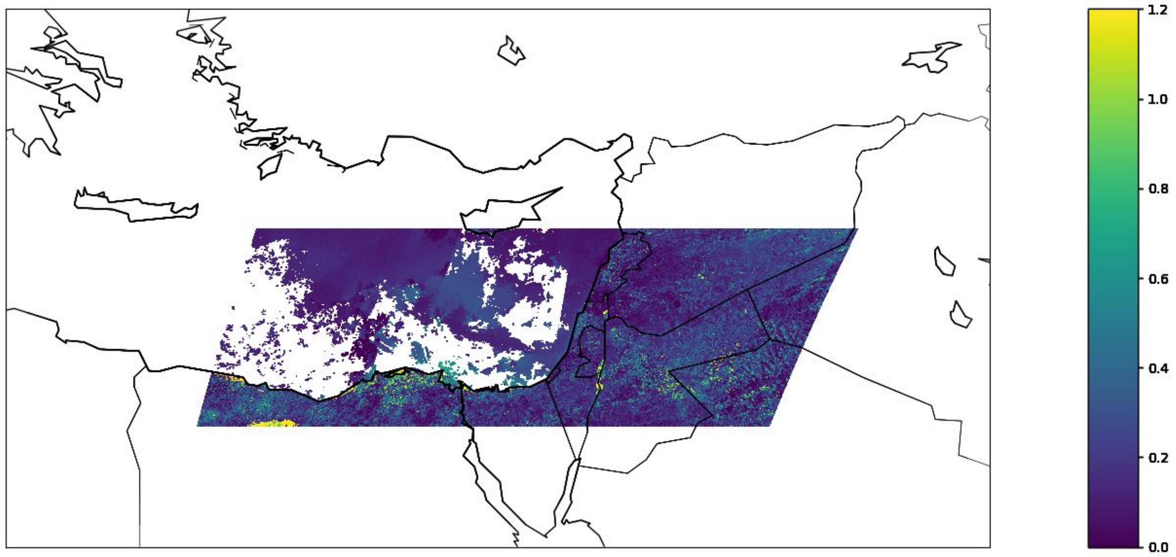



**Figure 4: Example S3A/SLSTR AOD550 with CISAR / CIRCAS algorithm**

Example of AOD retrieval at 0.55 on 15/11/2016 from S3A/SLSTR data with the CISAR algorithm from the CIRCAS project.

### 3.2.1 Year1 developments: CISAR algorithm

In the framework of the CIRCAS ESA SEOM project, CISAR has been applied to SLSTR onboard S3A acquisition from March 2017 to May 2018 over 16 AERONET stations. The satellite observations are aggregated at 5 km resolution. The newly developed version of the algorithm, after a so-called training period, perform the retrieval of surface reflectance, aerosol and cloud single scattering properties without the use of the SLSTR cloud mask. During the training period, defined by at least two successful inversions (usually achieved within 16 days), CISAR only processes cloud-free observations in order to get a reliable prior information on the surface reflectance. This is necessary in order to process cloudy observations as in those conditions the surface contribution to the signal at the satellite is minimum and the retrieval will mostly rely on the prior information. Once the surface is correctly retrieved, CISAR processes all SLSTR cloudy and coud free observations to retrieve surface reflectance, aerosol and cloud single scattering properties only relying on the

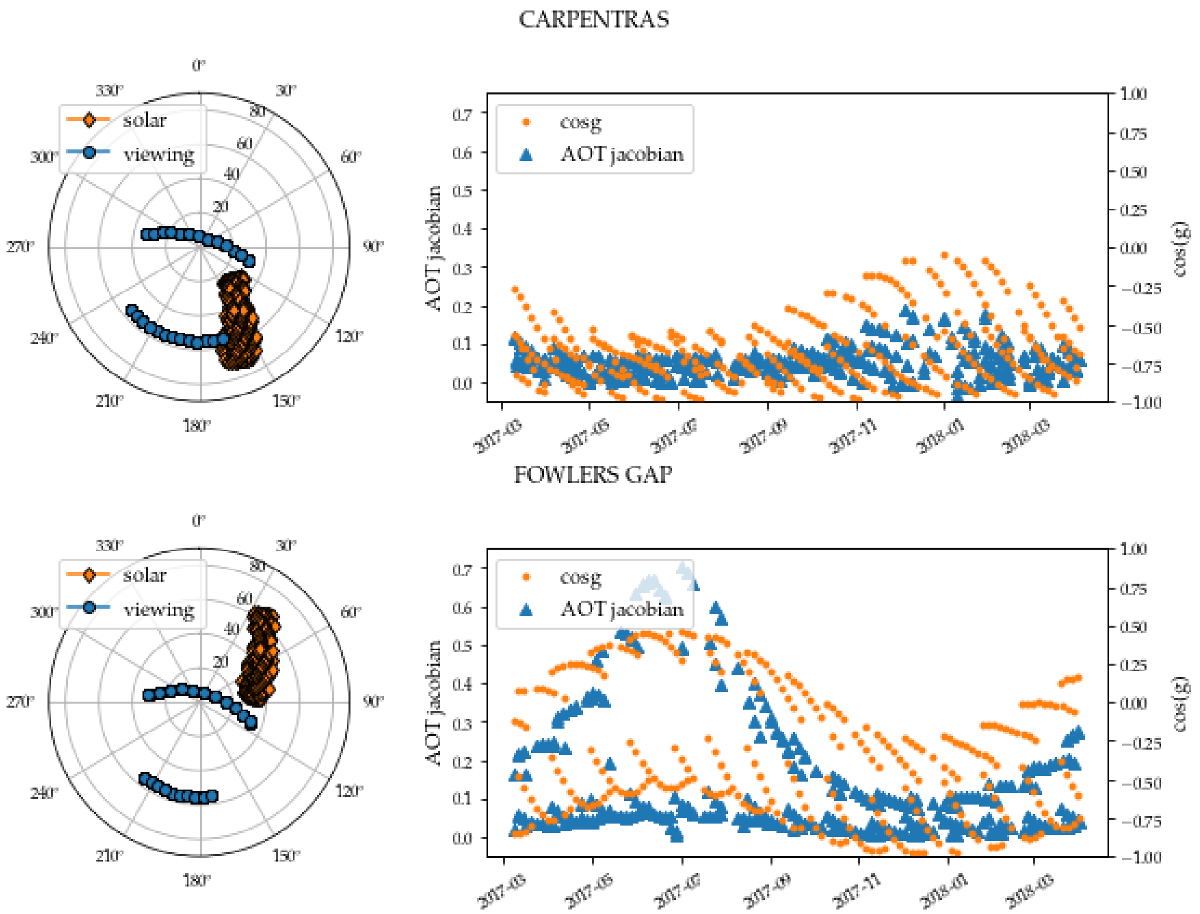



**Figure 5:** The left panels show the polar plot of the viewing (blue dots) and illumination (orange diamonds) geometries. Circles represent the zenith angles and polar angles represent the azimuth angles with zero azimuth pointing to the North. The right panels show the timeseries of the Jacobian associated to the AOT (blue triangles) and the cosine of the scattering angle (orange dots). The top panel refers to Carpentras, Northern Hemisphere, the bottom one refers to Fowlers Gap, Southern Hemisphere.

information coming from the observations and the prior information. In addition to the 4 sources of prior information defined in [RD2], the prior information on the cloud optical thickness (COT) takes full advantage of the SLSTR spectral response and the cloud spectral response. One of the challenges encountered processing SLSTR observations is related to the predominantly backward scattering geometry of the oblique view in the northern hemisphere, as the information associated to the aerosol particles is strongly dependent on the observation direction. Figure 5 shows the viewing and illumination geometries and the Jacobian and scattering angle timeseries for Carpentras, located in the Northern Hemisphere, and Fowlers Gap, located in the Southern Hemisphere. It can be seen that over Carpentras (backward scattering) the Jacobian associated to the aerosols is much lower than over Fowlers Gap (forward scattering). For this reason, the prior information and its associated uncertainty play a fundamental role in the inversion process.

The aerosol optical thickness (AOT) retrieved by CISAR in the band S1 has been evaluated against the AERONET product, showing a correlation higher than 0.7 and a RMSE < 0.12 (Fig. 6). The new version of the CISAR algorithm is currently being deployed on Calvalus to produce maps over the Nile delta.

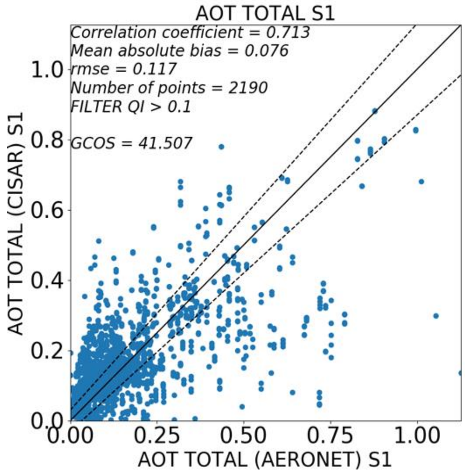



**Figure 6:** Scatterplot between CISAR (y axis) and AERONET (x axis) AOT in the band S1 (0.55um). The statistics show good correlation and a low RMSE (<0.12). Only retrieval with a Quality Indicator (QI) higher than 0.1 are considered in this evaluation.

### 3.2.2 Year2 developments: CISAR algorithm

CISAR is based on the accumulation of satellite observations during the so-called accumulation period, which for SLSTR lasts 16 days. The inversion takes place at the end of this accumulation. The accumulation period, however, are shifted by 8 days, meaning that there is an 8-days overlap between two successive accumulation periods.

Within CISAR, each pixel is processed independently, to allow for a complete parallelisation of the inversion. However, it is possible to introduce spatial smoothing by exploiting the prior information and the temporal overlap between two consecutive accumulation periods. This feature has been implemented for the aerosol retrievals, as aerosols are expected to be spatially smooth at a few kilometer scale. In particular, for each solution retrieved during the period $P_i$ at pixel p the median value is computed over the surrounding 5 x 5 pixels (i.e. over 25x25 km) and used as prior information for the same pixel at the period $P_{i+1}$. Figure 7 visually shows the implementation of the spatial smoothing.

The uncertainty associated with this prior information is defined as follows:

$\sigma_{Xb} = 25 * x_b(t) * y(t_d)$

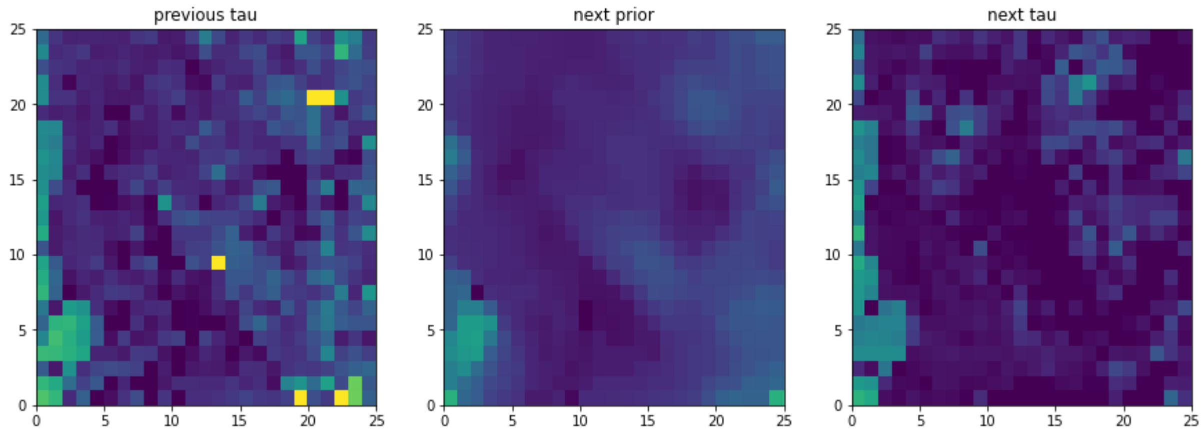



Figure 7 Example of the spatial smoothing implementation. The left panel shows the retrieved AOT at the period $P_i$, the central panel the smoothed prior information obtained from the solution at period $P_i$ and used for the period $P_{i+1}$, and the right panel shows the retrieved AOT at period $P_{i+1}$. The colorscale ranges from 0 to 1.

The TileMaker to generate the SLSTR Input Tiles in the GEDAP format has been developed. S3A/SLSTR Level-1 RBT products are organised in fixed geographical tiles, each Input Tile corresponding to one acquisition time.

Also, the hardware at Rayference has been upgraded for a total of 184 cores. To exploit the hardware at best, a new scheduler has been developed to distribute the processing of the tiles among the available servers.

The globe has been divided in 6 areas: Australia, Europe, Africa, Asia, South America and North America. Four months of products over Australia, Europe and Africa have been delivered. Figure 8 shows an example of the retrieved CISAR product over Australia during the 6th September 2019.

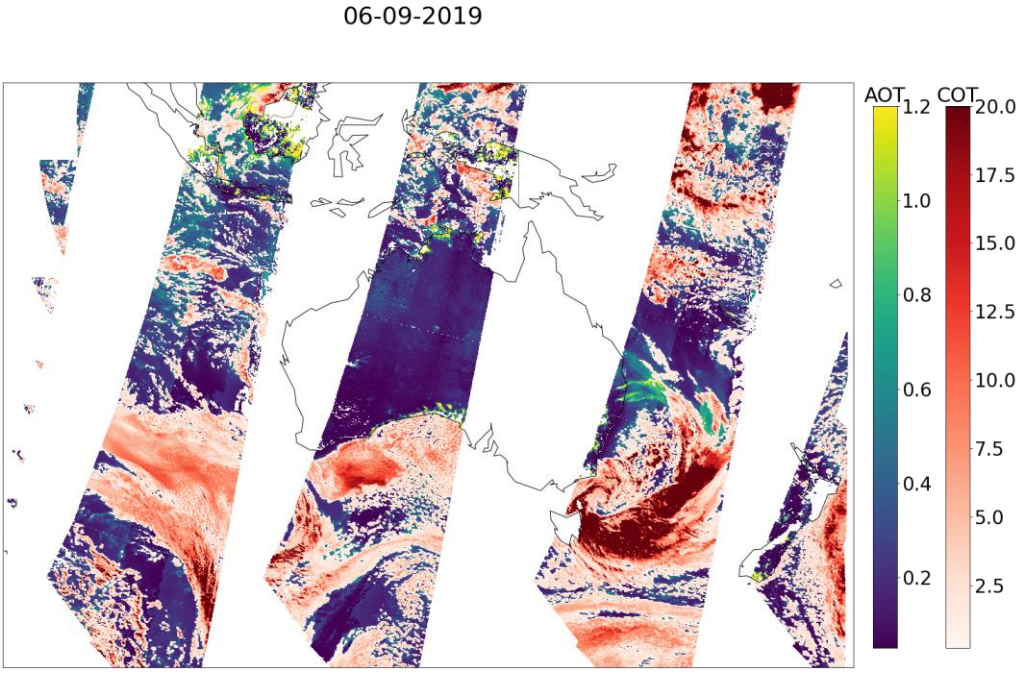



**Figure 8 CISAR combined aerosol-cloud product over Australia for SLSTR obsevations acquired on the 6th of September 2019.**

From a first quick evaluation of CISAR performances shows a good agreement between CISAR product and AERONET data (correlation of 0.7 over Australia and 0.5 over Europe) and similar temporal evolution. CISAR succeeds to process pixels independently from the cloud mask and thick clouds are correctly identified.

A web story has been prepared showing the results over Australian fires in September 2019. The web story has been published on ESA CCI website.

### 3.2.3 Year3 developments: CISAR algorithm

The distribution mechanism implemented at Rayference correctly exploits all the available resources. However, it could be improved by implementing a quantitative analysis of the processing statisics (e.g. number of iterations, processing time, quality indicator, etc.).

The evaluation of the first test products showed that more effort was needed to discriminate between fine/coarse aerosol particles and ice/liquid clouds. The discrimination between aerosol and cloud for low optical thickness should also be improved, especially over land surfaces where retrieved surface reflectance is affected by cloud retrieval. Given these needs for improvements, a new version of the CISAR algorithm addressing the current issues and limitations was implemented during Year 3 and used for the global processing of 1 year of data. With this, an improvement of the aerosol-cloud discrimination was achieved;

altogether this led to a significant reduction of the bias and noise in the results (over land and ocean), but also to an apparent suppression of high AOT values over land.

### 3.2.4 Proposed follow-up developments: CISAR algorithm

Future CISAR algorithm improvements based on identified deficiencies and user needs, focus on the priority to improve in coastal areas, and further optimize aerosol-cloud discrimination for high AOT. This priority should be addressed by

(i) Account for the ocean colour variation effects: With the current version of the algorithm, a constant chlorophyll content is assumed everywhere and all the time. For this reason, CISAR mistakenly attributes the differences due to the chlorophyll content to aerosols, leading to AOT overestimation along the coast. Accounting for spatial and temporal variability should improve the results over coastal areas. Two options will be explored: using an ocean colour climatology or directly using OLCI products

(ii) Improve the use of the surface wind speed over water: Differences appear for the various satellite-based aerosol products over sea. The importance of the surface wind speed should be further investigated

(iii) Explore synergies with Cloud-cci, to discuss how to fully exploit CISAR combined AOT/COT product

# CONCLUSIONS

The most critical elements of any aerosol retrieval algorithm are known in principal: cloud clearing, surface brightness and bi-directionality of its reflectance, micro-physical / optical aerosol models. Earlier valdiation results have provided wide analysis of strengths and weaknesses of the involved algorithms – this has been used to identify priorities for algorithm development. One other major element of Aerosol_cci+ algorithms is their error propagation so that products contain uncertainties on pixel level.

This report contains the analysis of gaps identified within the Copernicus Climate Change Service relevant for aerosol retrieval algorithm development, and the planned contribution to the reponse in this project.

In the main part of this report, (ongoing) recent updates are discussed of two algorithms involved in the Aerosol_cci+ project, for which test dataset processing in several versions is planned (in the first two versions 4 months global data for March June, September, December of one chosen year per sensor; in the final version one full global year per sensor). After three iterations within the project, test dataset versions were produced for each algorithm with two versions of the respective algorithms (Swansea for ATSR-2 and AATSR in 198 and 2008 and both SLSTR instruments in 2019 and 2020, CISAR for SLSTR / 3A in 2019 and 2020) The validation of each version was conducted and summarized in the Product Validation and Intercomparison Report.