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Aerosol_cci+

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EXECUTIVE SUMMARY

The Climate Assessment Report evaluates test datasets processed with algorithms further developed under Aerosol_cci by conducting specific use cases. It aims to identify strengths and weaknesses of the algorithms / datasets and to prove their added value for climate science and applications.

In this first version of the Climate Assessment Report a light / visual initial user evaluation of the datasets is conducted and the setup of the planned user case studies is described.

The two planned use cases represent the two major application domains of Aerosol_cci datasets:

- Radiative forcing study as example for climate research
- Data assimilation study as example for reanalysis / long-term data records

Both user case studies will apply the test datasets processed in Aerosol_cci until end of 2020 (second climate research data package) and - as far as available and needed – can also include longer time series processed with the same algorithm version (Swansea algorithm) under the C3S_312b_Lot2 contract of the Copernicus Climate Change Service where a major reprocessing is scheduled for late 2020.

After definitions (sec. 1) and an introduction (sec. 2), this report summarizes the two user case studies on radiative forcing (sec. 3) and data assimilation (sec. 4) before concluding with a summary (sec. 5) and references (sec. 6)

Document change record

Issue	Date	Modified Items / Reason for Change
0.9	10.03.2020	First issue of the document
1.0	16.07..2020	Contributions by core users
1.1	28.07.2020	Review by science lead, final layout and editing

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1 DEFINITIONS AND ABBREVIATIONS

This section summarizes the major definitions relevant for the validation report.

AAOD (Absorption Aerosol Optical Depth) is the vertically normalized atmospheric column integrated aerosol absorption at a certain wavelength (usually at 550 nm, the reference wavelength in global modelling) [note, AAOD = AOD*(1-SSA)]

AeroCom is an open science initiative founded to inter-compare aerosol modules in global modelling and evaluate overall model performance as well as the treatment of specific aerosol processes against available (and trusted) observations.

AERONET represents a federated network of globally distributed ground-based CIMEL sun-/sky-photometers, which is maintained (calibration facility, data processing and aerosol and water vapor products access) by NASA (National Aeronautics and Space Administration) and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire)

AOD (Aerosol Optical Depth) is the vertically normalized atmospheric column integrated aerosol extinction at a certain wavelength or waveband (usually at 550nm, the reference wavelength in modelling). AOD is also often referred to as Aerosol Optical Thickness (AOT).

AODf (Fine-mode Aerosol Optical Depth) is the vertically normalized atmospheric column integrated aerosol extinction at a certain wavelength or waveband (usually at 550nm) of aerosol particles smaller than 0.5um in radius (or smaller 1um in diameter).

ATSR (Along Track Scanning Radiometer) was a multi-channel imaging radiometer (with dual view capabilities in the visible and near-IR solar spectrum). Two versions are used for aerosol retrieval: ATSR-2 on board of the European Space Agency's ERS-2 satellite (1995-2002) and the advanced ATSR (AATSR) on ESA's ENVISAT satellite (2002-2012).

CF (Climate and Forecast) naming convention metadata are designed to promote the processing and sharing of files created with the NetCDF API.

CMUG (Climate Model User Group) is a part of ESA's Climate Change Initiative (CCI) and is composed of members of major climate research institutes in Europe. The group is tasked to oversee the usefulness of new climate data records produced for CCI selected ECVs.

ECV (Essential Climate Variables) are geo-physical quantities of the Earth-Atmosphere-System that are technically and economically feasible for systematic (climate) observations.

ENVISAT ("Environmental Satellite") is a now inoperative ESA polar-orbiting (ca 10am local overpass) satellite, which supplied between 2002 and 2012 atmospheric data, including for aerosol remote sensing relevant AATSR, MERIS and GOMOS sensor data.

ESA (European Space Agency) is the European Organisation for Space Research with Headquarters in Paris.

FCDR (Fundamental Climate Data Records or simply **CDR**) represent long-term records of measurements or retrieved physical quantities from remote sensing. FCDRs require consistency across multiple platforms with respect to (1) calibration, (2) algorithms, (3) spatial and temporal resolution, (4) quantification of errors and biases and (5) data format. FCDRs also need to manifest applied ancillary data.

FMF (Fine Mode Fraction) is the fraction of the total AOD which is contributed by aerosol particles smaller than 1um in diameter. Due to their smaller size these aerosol particles are referred to as fine-mode aerosol, in contrast to (larger or) coarse mode aerosol particles.

GCOS (Global Climate Observing System), located at WMO in Geneve, is intended to be a long-term, user-driven operational system capable of providing the comprehensive observations required for (1) monitoring the climate system, (2) detecting and attributing climate change, (3) assessing impacts of, and supporting adaptation to, climate variability and change, (4) application to national economic development and (5) research to improve understanding, modelling and prediction of the climate system.

GRASP (Generalized Retrieval of Aerosol and Surface Properties) is an aerosol retrieval algorithm that processes properties of aerosol- and land-surface-reflectance. It infers nearly 50 aerosol and surface parameters including particle size distribution, the spectral index of refraction, the degree of sphericity and absorption.

CAMS (Copernicus Atmosphere Monitoring Service), operational service in the **Copernicus** program which monitors and predicts global distributions and long-range transports of greenhouse gases (carbon dioxide, methane), of aerosols that result from both natural processes and human activities and of reactive gases (tropospheric ozone, nitrogen dioxide). CAMS also evaluates how these constituents influence climate and estimates their sources and sinks.

MISR (Multi-angle Imaging Spectro-Radiometer) is a multi-spectral sensor on NASA's EOS Terra platform with (9) multi-directional view capabilities.

MODIS (Moderate Resolution Imaging Spectro-Radiometer) is a multi-spectral sensor on NASA's EOS Terra and Aqua platforms.

NASA (National Aeronautics and Space Administration), deutsch ist die 1958 gegründete zivile US-Bundesbehörde für Raumfahrt und Flugwissenschaft. Der Hauptsitz befindet sich in Washington, D.C.

POLDER (POLarization and Directionality of the Earth's Reflectances) is a passive optical imaging radiometer and polarimeter for studies on radiative and microphysical properties of clouds and aerosols on the French CNES PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar).

SLTSR (Sea and Land Surface Temperature Radiometer) on-board SENTINEL-3 is to maintain continuity with the (A)ATSR series of instruments. Additional new features include a wider swath, new channels (including two channels dedicated to fire detection), and higher resolution in some channels.

SSA (Single Scattering Albedo) quantifies the likelihood of scattering during an attenuation (or 'extinction') event by an atmospheric particle of given size and shape at a certain wavelength (most important at 550 nm, the reference wavelength in global modeling). The remaining fraction, 1-SSA referred to co-single scattering albedo, quantifies the likelihood of absorption during an attenuation (or extinction) event.

2 INTRODUCTION

One decade ago ESA's Aerosol_cci set out to develop and improve aerosol retrievals for European satellite sensors. These new products permitted new science studies. In order to demonstrate useful applications selected 'user-case' studies were supported. The results of these user case studies were summarized in the Climate Assessment Report (CAR) at the end of the Aerosol_cci2 project (Aerosol_cci2 CAR, v2.7, 08.01.2018) which contained eight different user case studies for the variety of Aerosol_cci2 datasets (e.g. AOD records from ATSR-2 / AATSR dual view sensors, stratospheric extinction record from GOMOS star occultation, dust AOD from IASI thermal infrared spectrometers, absorbing aerosol index from UV-VIS spectrometers).

The current extension of Aerosol_cci (under the name "Aerosol_cci+) focuses on only the instruments of the dual view sensor line (ATSR-2, AATSR, SLSTR) to optimize a data record covering the periods 1995 – 2012 (ATSR.2, AATSR) and extending it with the period since 2016 (SLSTR onboard SENTINEL-3A and SENTINEL-3B). Intensive validation of Aerosol_cci2 datasets was conducted by comparison to external reference datasets (AERONET ground-based sun photometers, other established satellite aerosol datasets) and documented in the Product Validation and Inter-comparison Reports (PVIR v3.41, 21.12.2017 and PVIR v4.2, 09.01.2019 after an small extension through a bridging option) which identified algorithm weaknesses and needs for further algorithm improvements. The goal of the Aerosol_cci+ project (2019 – 2022) is to achieve some of those intended improvements and evaluate them again through validation against external reference data and through conducting two user case studies listed in Tab. 2.1.

Table 2.1 *overview of planned user-case studies*

user case study	chapter	institute	lead author
Aerosol radiative forcing	3	MPI-Met	Stefan Kinne
Assimilation of SLSTR into CAMS model	4	ECMWF	Angela Benedetti

For both user case studies this first version of the Climate Assessment report contains in the following two sections an update of the study planning and an initial assessment of the first test datasets (from the mature Swansea algorithm applied to all 4 sensors) available under Aerosol_cci+ (at the end of its first year).

Further advanced dataset versions will become available by end of 2020 as 2nd climate research data package. These will include 4 months (one in each season) of global data processed with a new version of the Swansea algorithm (months March, June, September, December of 1998, 2008 and 2019) and also from a second innovative algorithm by Rayference (SLSTR test dataset covering a 4-month period in the summer, June – September 2019). Longer periods of the Swansea dataset will be processed until end of 2020 under the operational C3S_312b_Lot2 contract, so that both user case studies can also work with larger data volumes where needed.

3 RADIATIVE FORCING

Overview of the planned user case study

The user case study on radiative forcing plans the application of aerosol property retrieval products derived from ESA's SLSTR sensor data and its AATSR and ATSR2 predecessors. The underlying idea is that the satellite can offer much better spatial and temporal detail than any general climatology. With these satellite retrieval data there are plans to determine in an off-line radiative transfer scheme not only the 'direct' aerosol effects and the 'direct' aerosol forcing (from the aerosol presence) but also the 'indirect' aerosol effects through modified (brighter) water clouds. At this time, however, the required complementary cloud droplet number concentration (CDNC, iteration with the ESA's cloud-CCI project has started to identify the acquisition of possible datasets from them) for estimates of the aerosol indirect forcing are not available. Thus in this introductory contribution to the climate assessment report (CAR), both strengths and limitations of the Swansea aerosol retrieval are addressed. Aside from retrievals for the total aerosol amount (AOD at 550nm) and (retrieval model) diagnostics for the total aerosol absorption (AAOD at 550nm), also contributions by sub-micrometer particles to the AOD are retrieved (from the spectral dependence of AOD at different wavelengths). This so called fine-mode AOD (AODf at 550nm) is very important for estimates of the aerosol radiative forcing, because anthropogenic aerosol (since pre-industrial times) predominantly contributed with smaller sub-micron aerosol sizes and because sub-micrometer aerosol sizes define the number of available nuclei at condensation. Thus, by influencing the resulting cloud droplet number, AODf is most relevant for aerosol-cloud interactions and the aerosol indirect forcing.

Initial light dataset evaluation for this user case study

For an impression, how the SLSTR retrievals compare to mature retrievals by MISR (version 23) and MODIS (collection 6.1), year 2019 average maps for AOD, AODf, AODc and AAOD are compared in Figure 3.1 and seasonal differences to MISR and MODIS are displayed in Figure 3.2.

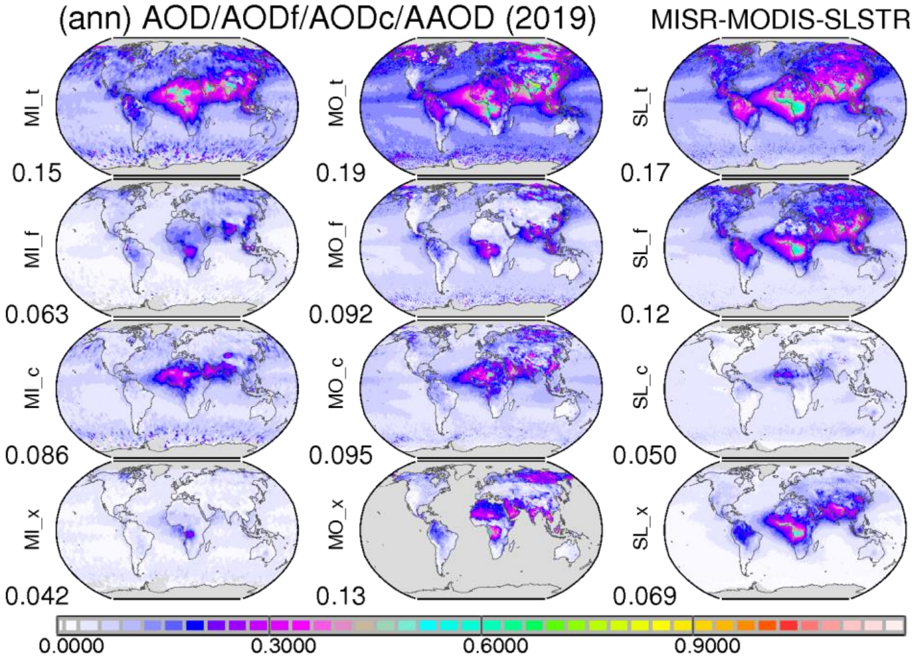

Figure 3.1 Comparisons of retrieval associated aerosol data between established NASA retrievals by MISR (column1) and MODIS (column2) and ESA's SLSTR. For the year 2019 annual average maps are presented for the total AOD (row 1), the AOD split into fine-mode (row2) and coarse-mode (row 3) and for the total AAOD (here multiplied by 10 to fit the common scale).

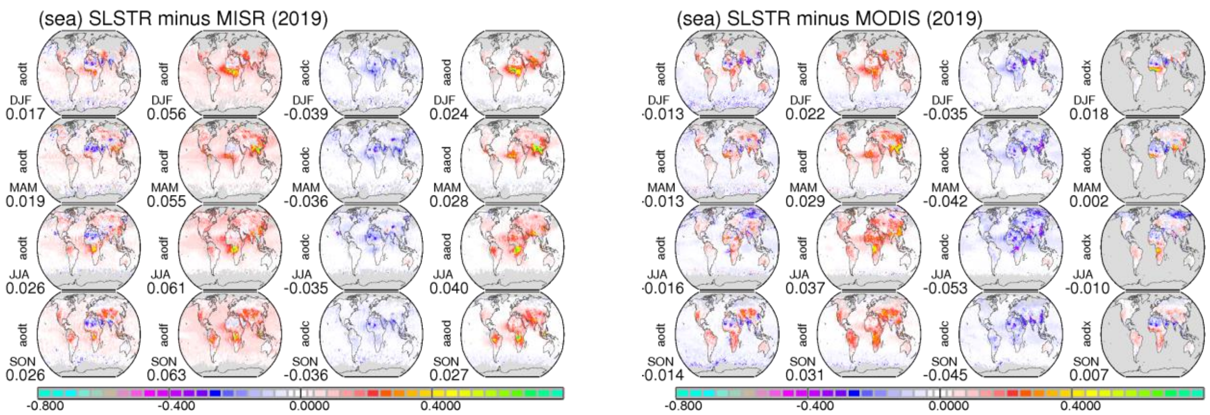

Figure 3.2 seasonal year 2019 differences of SLSTR aerosol retrieval products to MISR (left panel) and MODIS (right panel) for AOD (col1), AODf (col2), AODc (col3) and 10*AAOD (col4).

For total AOD, SLSTR appears to overestimate over (lower latitude) biomass and pollution source regions. Dust AOD of SLSTR is low - especially in winter and in comparisons to MISR. Background oceanic AOD is larger than for MISR but smaller than for MODIS. The major discrepancy of SLSTR is the AOD partitioning into AODf and AODc. SLSTR apparently assigns too much AOD to the fine-mode at the expense of the coarse mode AOD. (This bias has big consequences in a forcing application, yielding likely climate impact overestimates). The AAOD data comparison is more diagnostic in nature. MISR apparently underestimates aerosol absorption. SLSTR absorption over continents is overall similar to that of MODIS yet there are regional differences. The SLSTR absorption potential (1-SSA) seems too low over dust regions and boreal biomass regions, but too large over tropical biomass regions (which in part could explain AOD and AODf overestimates in that region). In the context of these biases (especially for relatively high AODf maps) it almost seems more appropriate in future forcing simulations not to use absolute values (of AODf and AODc) - but rather apply (monthly/regional) anomalies to the aerosol climatological data.

With the same Swansea retrievals applied to SLSTR / ATSR type sensors for 1998 (ATSR2), 2008 (AATSR) and SLSTR (2018) temporal regional changes to the retrieved aerosol properties (of AOD, AODf and AAOD) can be deduced - in the context of inter-annual and sensor variability. Annual average maps are presented in Figure 3.3 and associated differences with respect to the 2019 SLSTR-3a data are shown in Figure 3.4.

Compared to decadal changes, differences between SLSTR-3a and 3b and between 2018 and 2019 are small, so that larger differences potentially allow to address regional change. Changes are both positive or negative on a regional basis.

- Biomass AOD over tropical biomass / S.America was largest in the late 90ies
- Biomass AOD over equatorial Africa is now at maximum
- Pollution AOD over E.Asia was at a maximum in the late 00ies
- Pollution AOD over India is now at a maximum
- Dust AOD and AAOD over the Sahara has been declining over the decades

All of these tendencies are consistent with tendencies derived from MODIS and MISR time series.

While MODIS and MISR do not show any significant change in total AOD over the last two decades, total AOD with SLSTR is slightly up (by approximately 0.02) over ATSR retrievals. However, this also includes consistently larger AOD of SLSTR (vs ATSR) over continental N. America and Asia in particular. These apparent inconsistencies need to be understood before annual data trends can be derived from (smaller) regional differences between 1998, 2008 and 2018.

Note that the current validation of the datasets shows a clear positive bias of SLSTR AOD against AATSR AOD with a magnitude of ~0.025 (Aerosol_cci+ PVIR, v1.0, 28.07.2020: AATSR bias to AERONET is ~0.025 while for SLSTR it is ~0.05).

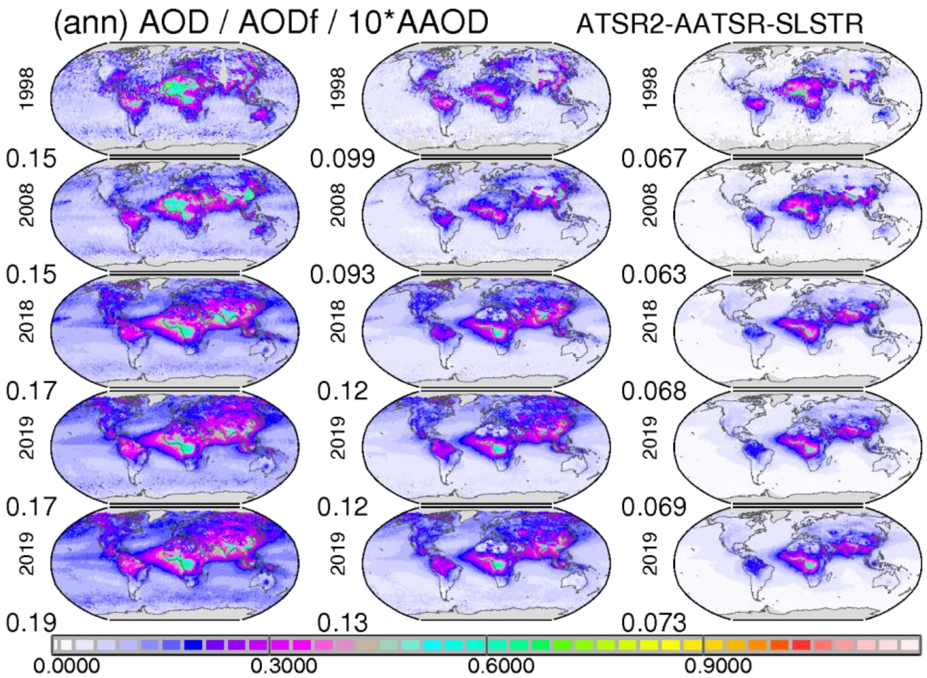

Figure 3.3 Comparisons for annual maps for AOD (left), AODf (center) and 10*AAOD (right) of retrievals by 1998 ATSR2 (row1), 2008 AATSR (row2) and 2018 SLSTR-3a (row3), 2019 SLSTR-3a (row4) and 2019 SLSTR-3b (row5).

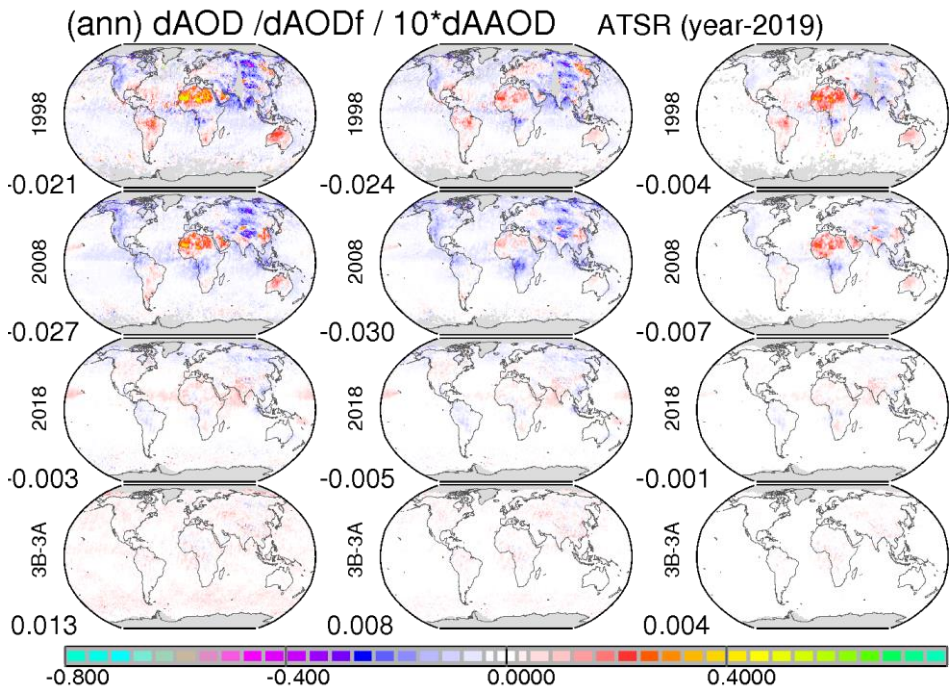

Figure 3.4 Maps of absolute differences for annual data of AOD (left), AODf (center) and 10*AAOD data (right) of 1998 ATSR2 (row1), 2008 AATSR (row2) and 2018 SLSTR-3a (row3) with respect to 2019 SLSTR-3a. Also shown are annual differences between 2019 SLSTR-3b and SLSTR-3a.

4 DATA ASSIMILATION

Overview of the planned user case study

In recent years significant progress of the CAMS modeling system has led to significant improvements of the modelling system and thus shown only weak impact of assimilating MODIS AOD (except for episodic high AOD cases such as autumn biomass burning). Therefore, expectations for the SLSTR AOD assimilation test should remain realistic, while future potential lies in exploiting more information than just AOD (e.g. PM at the surface, absorption SSA or AAOD, Fine Mode AOD) for verification or assimilation. MODIS assimilation proved more valuable where AERONET station density is low but also had still positive impact over Europe. In order to quantify the impact of SLSTR data, the assimilation user case study will focus on assessing and separating potential cases of high Aerosol_cci+ dataset impact (e.g. biomass burning events) and using the SLSTR Fine Mode AOD for verification.

The study will use level 2 data for the month of September 2019 when the biomass burning signal is strongest.

Assimilation experiments with ECMWF's IFS in the CAMS configuration will then be performed using Aerosol Optical Depth. Four one-month experiments are planned:

- a control experiments without any aerosol data in the assimilation
- one experiment with only SLSTR data
- one experiment with all other available AOD data (MODIS, PMAP) excluding SLSTR
- one experiment with all available data including SLSTR.

The impact of the various datasets will be assessed using the standard AERONET verification which is applied operationally in CAMS. Specific AERONET stations and regions will be looked at in more detail to understand the regional impact of the SLSTR dataset and its strength/weaknesses with respect to the other datasets.

Initial light dataset evaluation for this user case study

One year of level-3 SLSTR S3A and S3B Aerosol Optical Depth (AOD) monthly mean data were assessed. Qualitative comparisons were performed against AOD from the CAMS reanalysis (Inness, et al 2019). The agreement is generally good, although there are some differences highlighted below, month by month (Figures 4.1 – 4.12).

In January it is possible to see that the SLSTR AOD data show lower values over India and China whereas the biomass burning regions of Central Africa show values of AOD higher than the CAMS reanalysis. The global average for S3A is lower than S3B, but overall there is a large degree of consistency between the two SLSTR instruments. Both satellite datasets show a 30% difference in global average AOD. A similar behaviour is identifiable for the month of February 2019.

In March 2019, both SLSTR AOD data show a larger contribution over China which seems to agree better with the CAMS reanalysis. The signal from central Africa is still larger in the SLSTR AOD than in the CAMS reanalysis. Over the Arabian Peninsula, however, the opposite is true. A similar behaviour is observed in April. In May good similarities are observed for AOD over the Sahara and generally East Asia. Central America also displays similar features between the three datasets.

In June, more dust signal is observed in the SLSTR datasets than in the CAMS reanalysis. Also, some high latitude high AOD episodes, possibly related to boreal fires, are visible in the SLSTR, but not to the same extent in the CAMS reanalysis. Overall, however, the global average for AOD remains lower for the satellite product than for the reanalysis. In July, the signal form the boreal forest fires is more pronounced in the CAMS reanalysis than the SLSTR datasets with patchy large AOD values at high latitudes. The dust signal over the Sahara is instead more pronounced in the SLSTR AOD than in the CAMS reanalysis AOD. The comparisons in August show a good degree of similarities, particularly in the Central Africa biomass burning and Indian Ocean dust signal. The latter is also very strong in July.

In September, the main features are the biomass burning in South America, Africa and Indonesia, well visible in all three datasets. For Central and East Asia, the AOD signal is larger in the SLSTR datasets than in the CAMS reanalysis. This continues into the month of October. The large AOD associated to biomass burning in Indonesia is well captured in all three datasets and persists into October. The month of November shows the worst agreement with large values of AOD in South America that are not captured by the reanalysis. Vice versa, the signal of anthropogenic aerosols over India and China is much lower in the SLSTR datasets than in the CAMS reanalysis. The global average for the CAMS reanalysis is more than double that of the SLSTR AOD datasets. A similar situation is visible in December. A general good agreement over Australia due to the signal of the bush fires is visible both in November and in December.

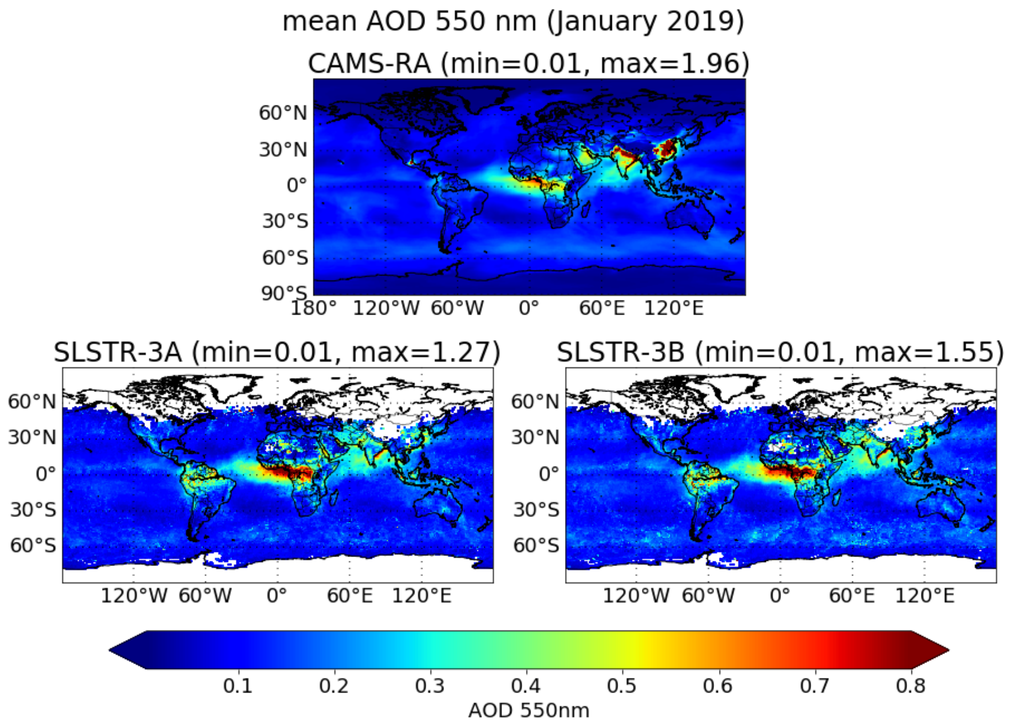

Figure 4.1 AOD comparisons for the month of January 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

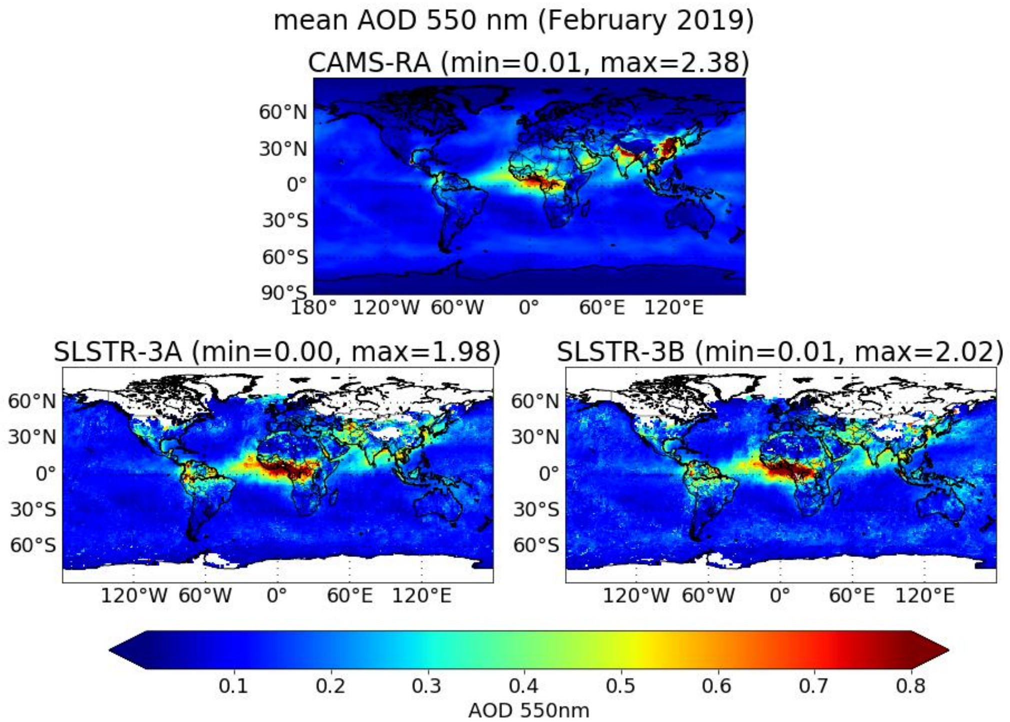

Figure 4.2 AOD comparisons for the month of February 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

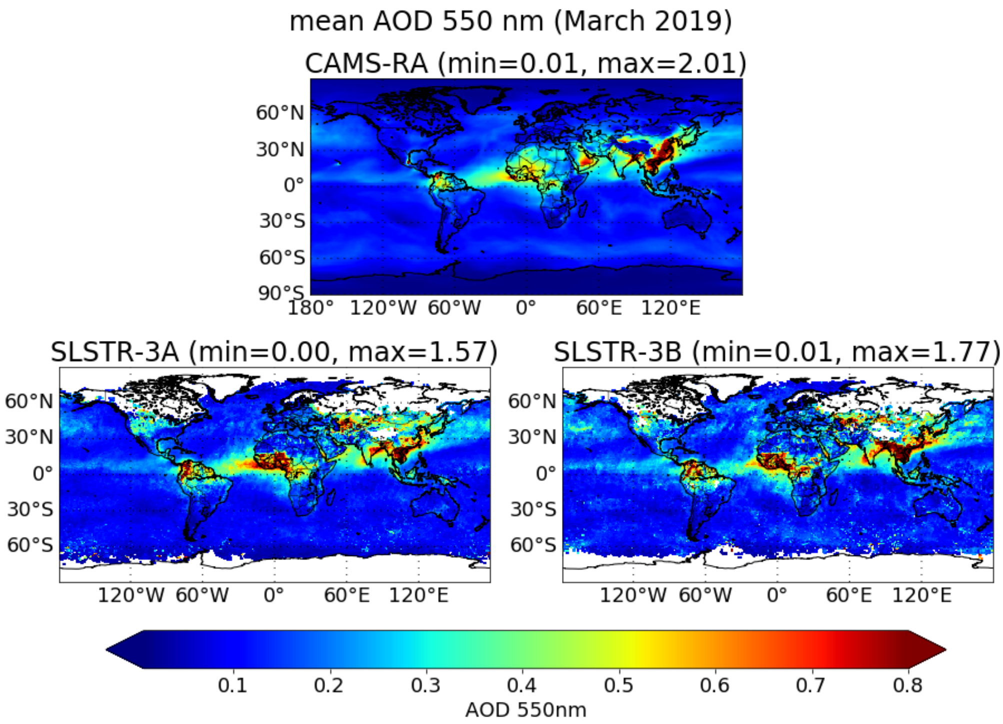

Figure 4.3 AOD comparisons for the month of March 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

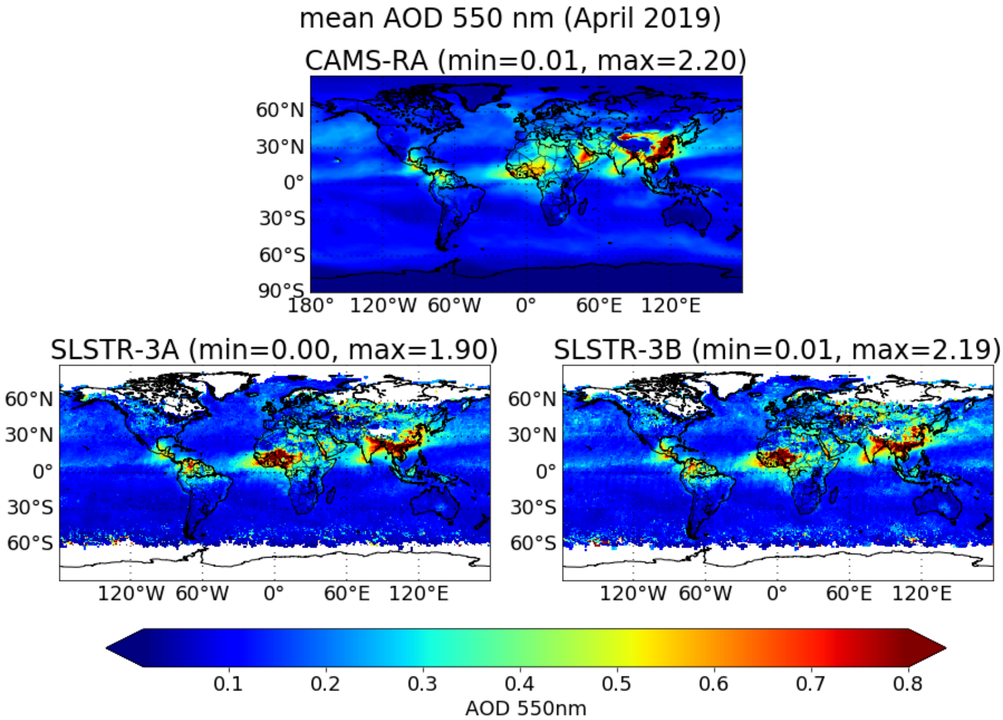

Figure 4.4 AOD comparisons for the month of April 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

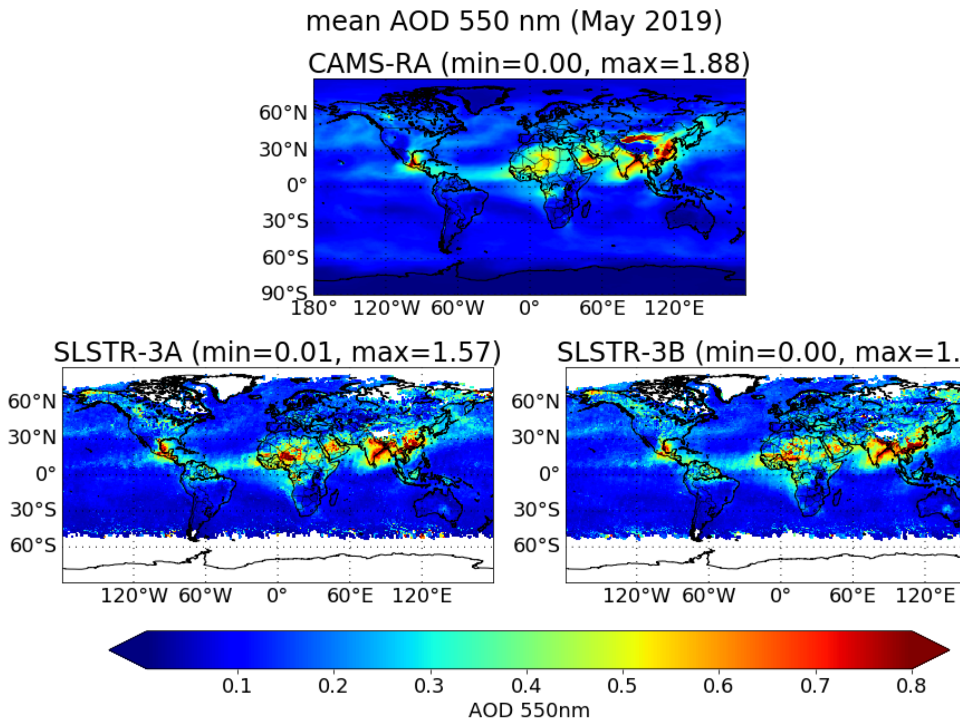

Figure 4.5 AOD comparisons for the month of May 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

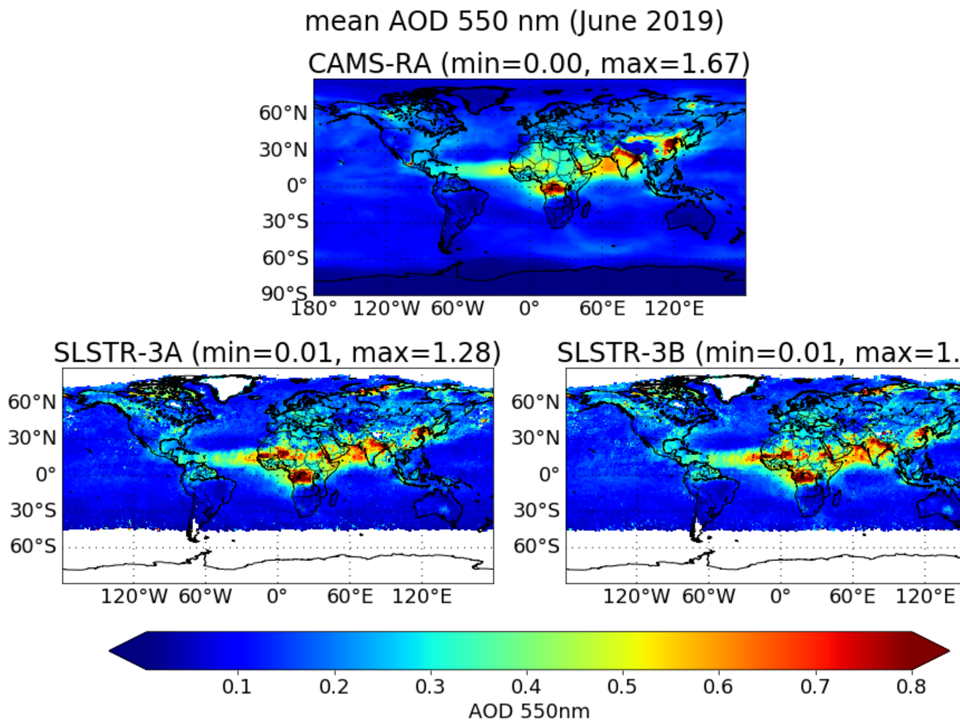

Figure 4.6 AOD comparisons for the month of June 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

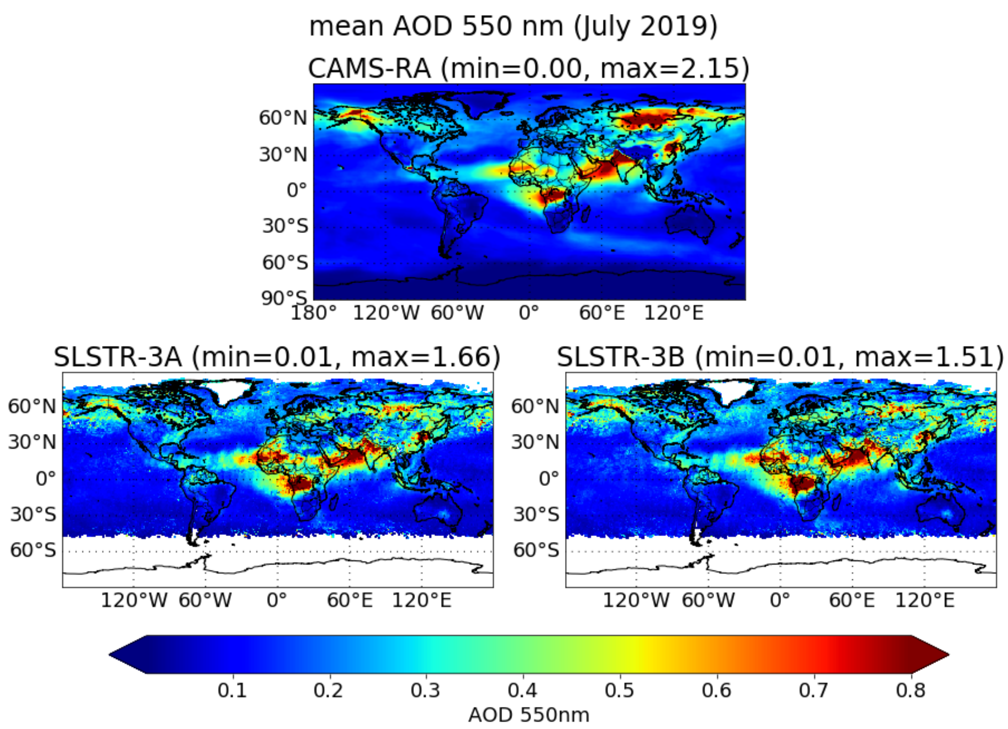

Figure 4.7 AOD comparisons for the month of July 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

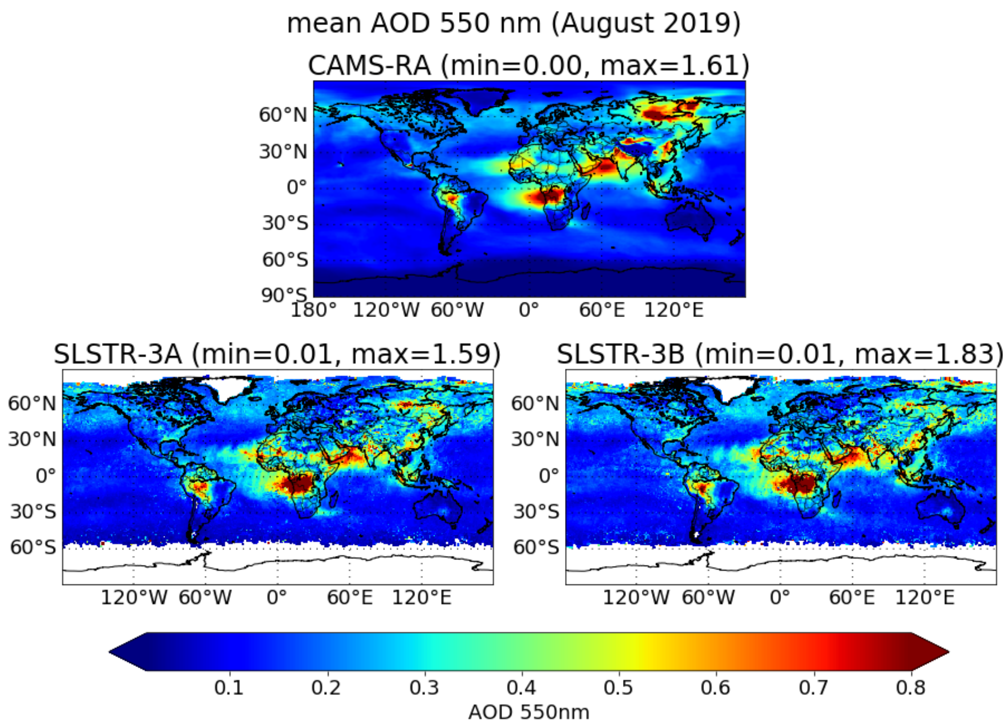

Figure 4.8 AOD comparisons for the month of August 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

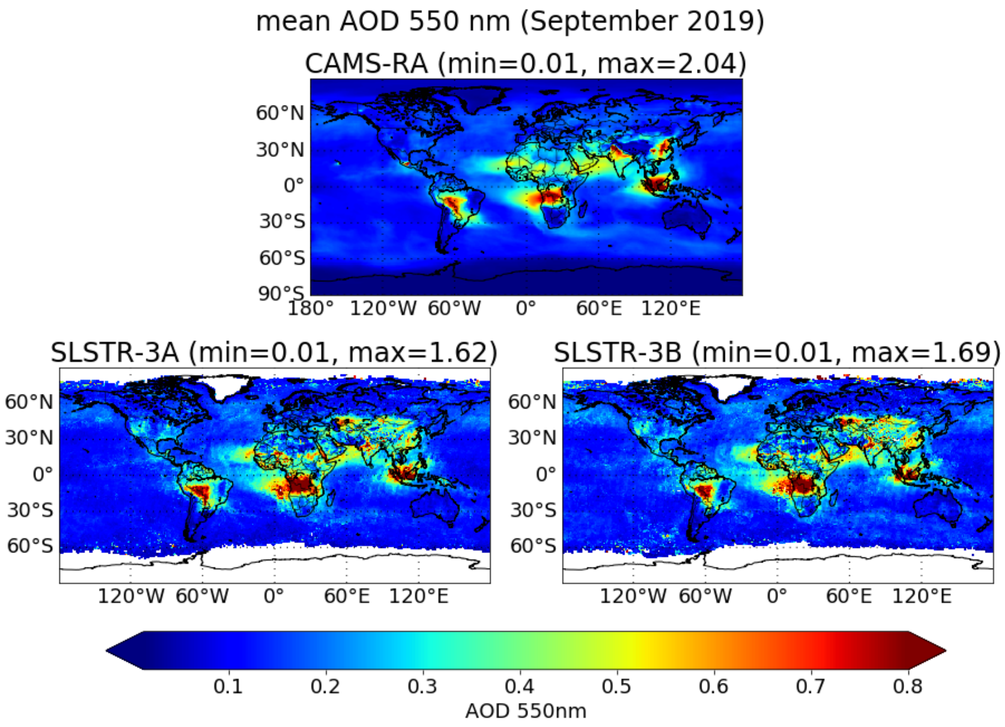

Figure 4.9 AOD comparisons for the month of September 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

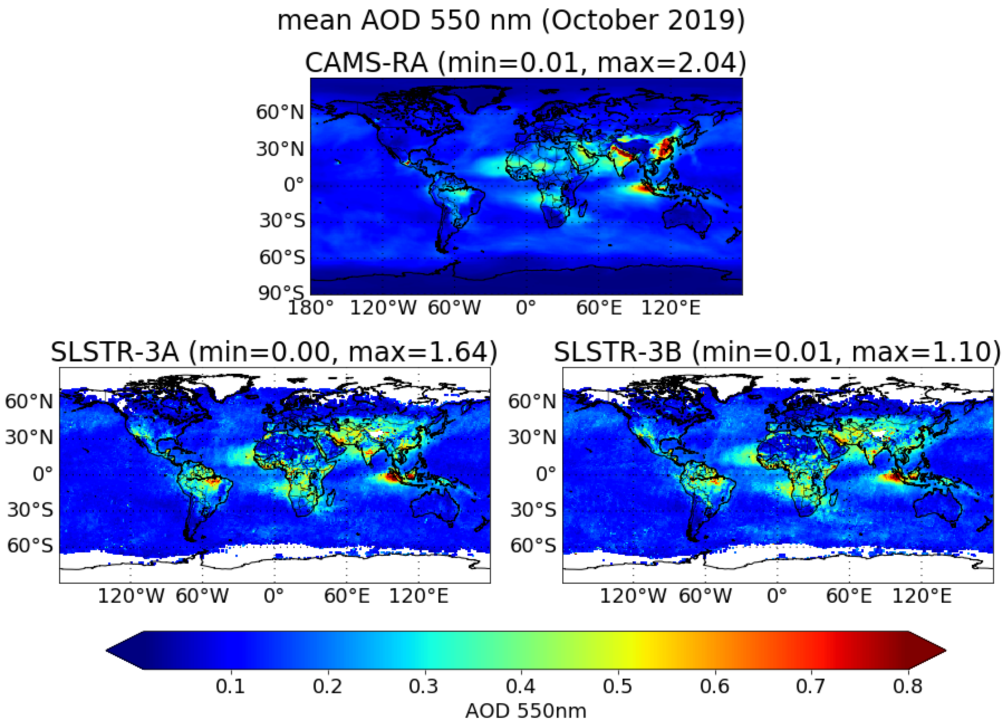

Figure 4.10 AOD comparisons for the month of October 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

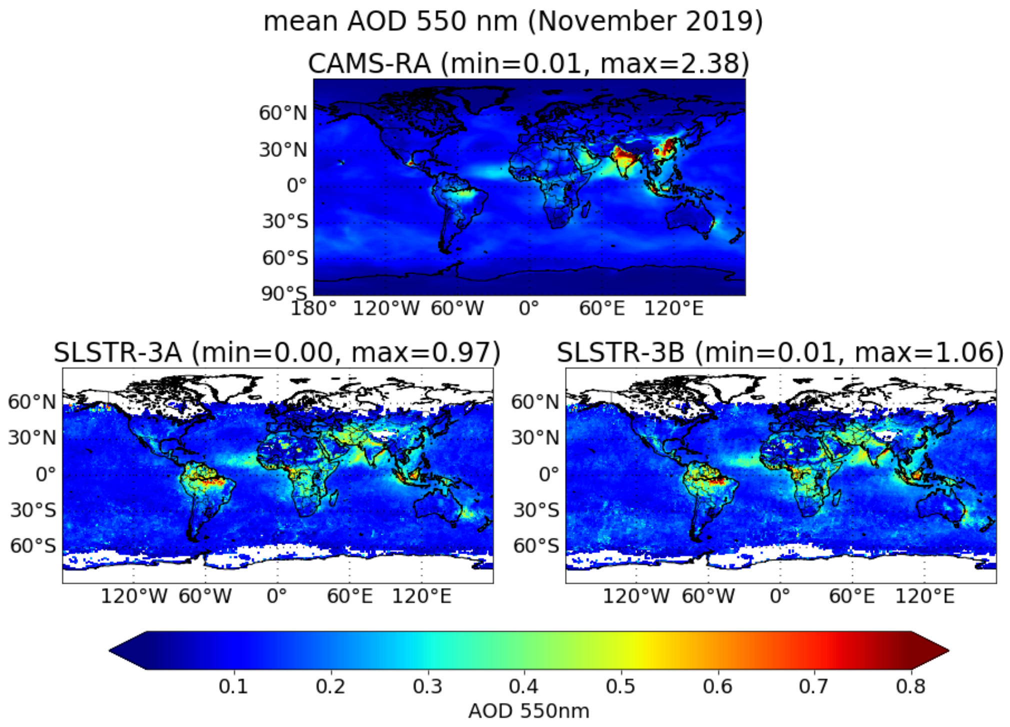

Figure 4.11 AOD comparisons for the month of November 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

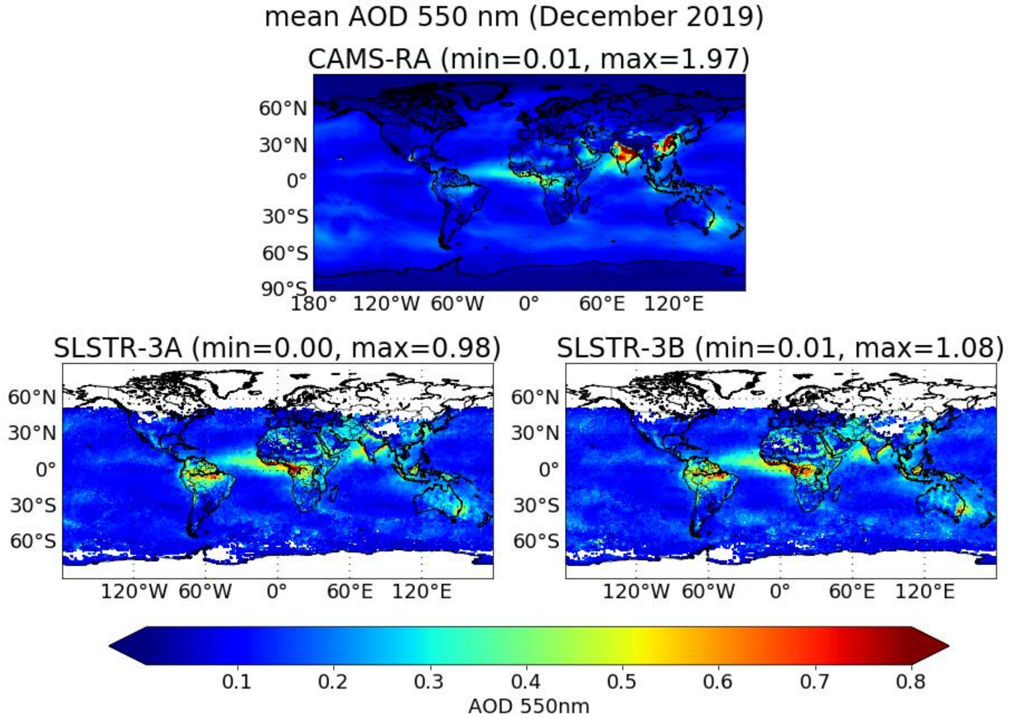

Figure 4.12 AOD comparisons for the month of December 2019: CAMS reanalysis (top panel), SLSTR SU product from Sentinel 3A (left) and SLSTR SU product from Sentinel 3B (right).

5 SUMMARY

Radiative forcing

A user case study will be conducted to analyse the radiative impact of AOD and FM-AOD of the test datasets in decadal steps (1998, 2008, 2019), where the dual view sensor satellite information will be used to provide the (relative) spatial context to model simulations.

Data assimilation

Several data assimilation experiments with and without using SLSTR data for September 2019 (with significant biomass burning episodes) will be conducted and compared to AEROENT reference to quantify the impact of assimilating SLSTR.

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