INTEGRATION AND ASSIMILATION OF METEOROLOGICAL (ECMWF) AEROSOL ESTIMATES INTO SEN2COR ATMOSPHERIC CORRECTION

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ABSTRACT

Sen2Cor is a Level-2A processor designed to correct Sentinel-2 Level-1C products from the effects of the atmosphere in order to deliver a Level-2A surface reflectance product. A key-parameter for accurate atmospheric correction is the knowledge of the spatially and temporally very variable aerosol content of the atmosphere The multi-spectral instrument on board Sentinel-2 has the appropriate spectral bands to derive the aerosol optical thickness (AOT) of the atmosphere, provided the image contains reference areas of known reflectance behavior, preferably dense dark vegetation (DDV). If the granule contains no DDV pixels, a fallback solution is required. The former solution was to generate an AOT map based on the start visibility set in the configuration file. In this updated Sen2Cor version, meteorological AOT estimates are retrieved from ECMWF ftp server and pre-processed. The integration and assimilation of ECMWF aerosol estimates into Sen2Cor atmospheric correction is described and recent validation results are presented.

Index Terms— Atmospheric correction, Sentinel-2, Sen2Cor, aerosol, meteorological, model

1. INTRODUCTION

The Sentinel-2 mission is fully operating since June 2017 with a constellation of two polar orbiting satellite units. Both Sentinel-2A and Sentinel-2B are equipped with an optical imaging sensor MSI (Multi-Spectral Instrument) which acquires high spatial resolution optical data products [1]. The Sentinel-2 mission is dedicated to land monitoring, emergency management and security. It serves for monitoring of land-cover change and biophysical variables related to agriculture and forestry, monitors coastal and inland waters and is useful for risk and disaster mapping [2].
Accurate atmospheric correction of satellite observations is a precondition for the development and delivery of high quality applications. Therefore the atmospheric correction processor Sen2Cor was developed on behalf of ESA. Sen2Cor is designed for mono-temporal processing of Sentinel-2 L1C data products providing Level-2A surface (Bottom-of-Atmosphere) reflectance product together with Aerosol Optical Thickness (AOT), Water Vapor (WV) and Scene Classification (SCL) maps. Sen2Cor can be downloaded from ESA website for individual processing by the users. In parallel, Sen2Cor is used by ESA for systematic L2A-processing of Sentinel-2 acquisitions over Europe since June 2017. ESA is preparing an operational global L2A-processing with the integration of Sen2Cor in Sentinel-2 ground segment (PDGS).
A key-parameter for accurate atmospheric correction is the knowledge of the spatially and temporally very variable aerosol content of the atmosphere. Sen2Cor estimates the aerosol optical thickness (AOT) at 550 nm using dark reference areas, most preferably dense dark vegetation (DDV) pixels. In case there are not enough DDV-pixels available in the granule, then a fallback solution is required. The former fallback solution was to generate an AOT map based on the start visibility set in the configuration file. This fallback solution is one of the limitations of Sen2Cor aerosol retrieval, because it can introduce large errors into the atmospheric correction [3]. Another limitation of this approach is a potential tile borders effect, which sometimes occurs due to the independent processing of neighboring granules (Figure 3). In this updated Sen2Cor version, meteorological AOT estimates from ECMWF are integrated and assimilated into Sen2Cor atmospheric correction to overcome these limitations.

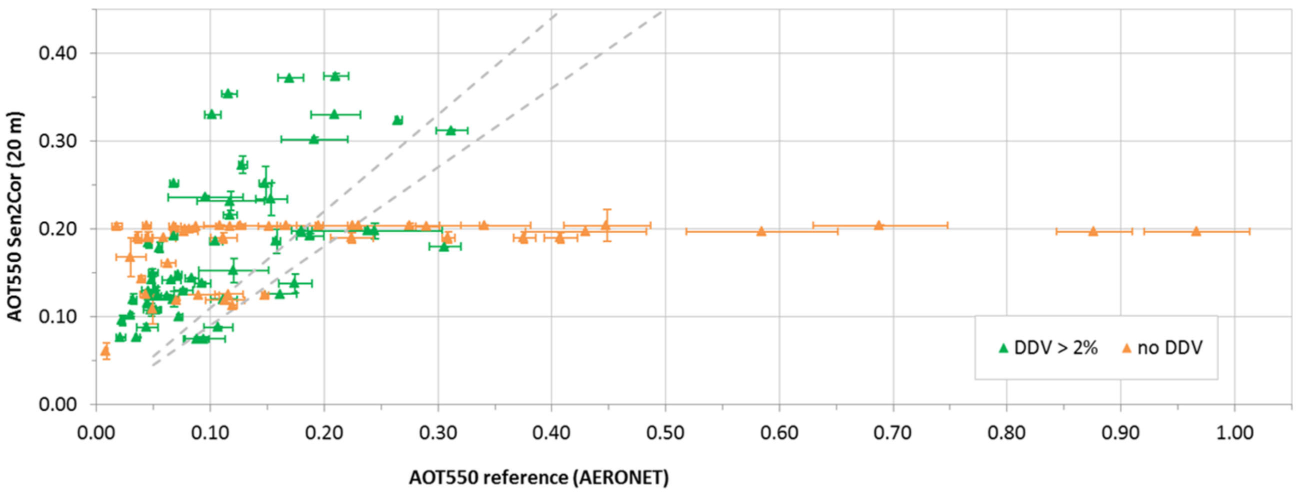

Figure 1: Comparison of Sen2Cor aerosol retrieval with reference from AERONET sunphotometers. Green points are for granules containing more than 2% DDV pixels allowing application of the DDV-algorithm. Orange points are for granules containing less than 2% DDV pixels. AOT is set to the start visibility configured for Sen2Cor processing for these granules.

2. METHOD OFAOT RETRIEVAL WITH THE DDV-ALGORITHM OF SEN2COR

Sentinel-2 MSI has the appropriate spectral bands to derive the aerosol optical thickness of the atmosphere, provided the scene contains reference areas of known reflectance behavior, preferably dense dark vegetation (DDV). A detailed explanation of the DDV-algorithm implemented in Sen2Cor is given in [4, 5]. Resulting AOT map is validated by direct comparison of Sen2Cor outputs with ground truth from AERONET [6] sunphotometer measurements. The average Sen2Cor output over all soil and vegetation pixels within 9 km × 9 km area around sunphotometer location is computed and compared with the time-average of sunphotometer data within ±30 min to satellite overpass time [3]. Figure 1 shows recent validation results of Sen2Cor aerosol retrieval based on the DDV-algorithm and the previous fallback solution which sets the AOT corresponding to the visibility configured for Sen2Cor processing. The figure clearly indicates the large AOT errors introduced by this fallback solution.

Accuracy represents the mean difference of Sen2Cor Aerosol retrieval to the reference value and uncertainty gives the root mean square (RMS) around the reference. Whereas both the full dataset and the reduced dataset (only granules with more than 2% DDV-pixels) provide similar accuracy of about 0.07, they largely differ for uncertainty. Uncertainty for the full dataset is about 0.19 and for the reduced dataset approximately 0.10.

3. METHOD OF AOT RETRIEVAL USING METEOROLOGICAL DATASET

Total aerosol optical thickness data at 550 nm (aod550) are provided globally by ECMWF through the Copernicus Atmosphere Monitoring Service (CAMS) [7]. A validation report of the CAMS near-real time global atmospheric composition service is issued each trimester by KNMI in charge of the validation [8]. In addition to this service validation reference, a monitoring of the quality of CAMS AOT estimates is performed for a list of AERONET test sites used for Sen2Cor calibration. An example of scatter plot for test site Capo Verde is shown in Figure 2. From our observations the CAMS AOT estimates are of good quality for test sites close to the sea with low topography.

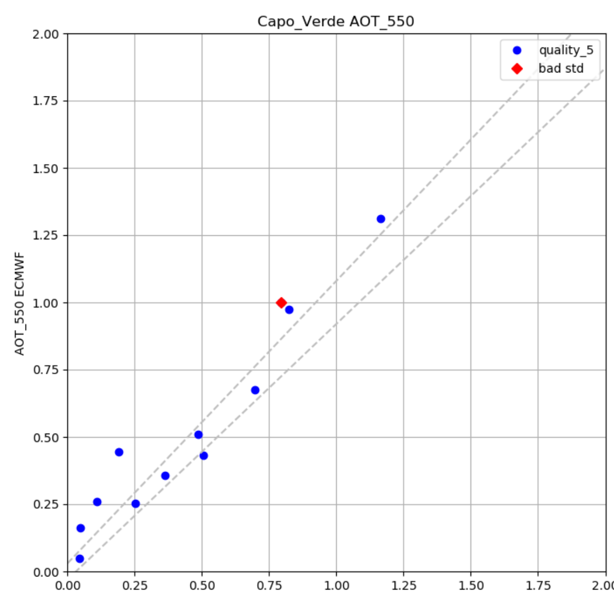

Figure 2: Comparison of AOT estimates for test site Capo Verde. Measurements period is from October 2016 to March 2018. Blue dots correspond to Aeronet AOT measurements of good quality. Red squares correspond to a CAMS AOT data with a large standard deviation (e.g. weather front).

Some details are provided hereafter concerning the format of the CAMS products. The native grid for the CAMS Global data is a reduced Gaussian Grid with 256 latitudes on each hemisphere [9]. The CAMS data is then disseminated in NetCDF format on a regular lat/lon grid with a spacing of 0.4 degree close to the native grid. The parameter of interest, aod550, is a column-integrated quantity from the surface of CAMS Earth model's topography to the top of the atmosphere (like e.g. total column water in meteorology). The data source for orography and surface geopotential in CAMS is primarily the SRTM DEM resampled on the same spatial grid.

In this Sen2Cor prototype version, the meteorological AOT is downloaded from the ECMWF operational ftp server and pre-processed. This pre-processing step includes spatial extraction and resampling to Sentinel-2 geometry (cubic spline) as well as a temporal interpolation (linear) to the Sentinel-2 acquisition time.

Inside the Sen2Cor atmospheric correction module, the CAMS AOT is converted to visibility (km) using the altitude of the CAMS DEM. The visibility obtained is then used in the radiative transfer equations with Sen2Cor Digital Elevation Model information (native resolution of 90 m) to compute the surface reflectance for Sentinel-2 bands. A further step is performed to check if negative reflectance values are obtained. If so, the visibility is slightly increased (corresponds to an AOT decrease) to reduce the amount of negative reflectance pixels.

Figure 3: Sentinel-2A L2A image composed of four tiles (from upper left to lower right: T18SUJ, T18SVJ, T18SUH, T18SVH). Lower right tile T18SVH appears brighter than the three others tile due to different AOT content estimates.

The use of meteorological AOT data can be configured within Sen2Cor either 1) to provide fallback solution for the DDV algorithm (when not enough DDV pixels are available within the image), 2) to replace entirely the DDV algorithm, or 3) to merge Sen2Cor AOT map obtained from DDV algorithm with ECMWF pre-processed AOT. Sen2Cor DDV AOT map has the advantage of higher spatial resolution than ECMWF pre-processed AOT map. It has the disadvantage of possible tile-edge border effects, like in Figure 3, due to the independent processing on granule level. Merging both AOT maps has the objective of removing any tile-edge border effect and still benefit from image-based, higher spatial resolution AOT retrieved by Sen2Cor with the DDV-algorithm.

The validation of Sen2Cor configured with the meteorological AOT data used as fallback solution for the DDV algorithm has started and first results will be presented at IGARSS.

4. DISCUSSION

For this first attempt of meteorological data usage in Sen2Cor, only the total aerosol optical thickness data at 550 nm (aod550) is used. A next step would be to implement an aerosol retrieval scheme including the information on the aerosol type. It will require the computation of additional Sen2Cor Look-Up-Tables generated with LibRadtran radiative transfer model [11] for different aerosol species. The impact of including or ignoring the aerosol type in the aerosol retrieval could then be assessed.

Concerning the potential limitation of this method in case of the presence of thin cirrus clouds, Sen2Cor delivers a Scene Classification map that flags cirrus clouds and informs the user that these areas should not be used for quantitative retrieval of geophysical variables.

In the first Atmospheric Correction Inter-Comparison Exercise (ACIX) [12] a former version of Sen2Cor was used for comparison with concurrent methods. A second edition of ACIX is foreseen in 2019 in which a version of Sen2Cor implementing the CAMS AOT fallback solution described in this paper will be presented.

If the results of the internal validation and ACIX are positive, there should not be any contraindication in terms of processing time or CAMS data availability to deploy this solution for operational processing of Sentinel-2 images at World scale.

5. CONCLUSION

An evolution of Sen2cor algorithm is presented in this paper. This evolution based on meteorological AOT estimates is designed to improve the atmospheric correction in case of missing DDV in most of the situations. Clearly the advantage of the integration and assimilation of CAMS aerosol estimates into Sen2Cor atmospheric correction strongly depends on the accuracy of CAMS aerosol data. Some additional filtering may be performed to limit the usage of CAMS data for some extreme cases. Monitoring of this data will therefore be continued over a selection of test sites as well as the validation of Sen2Cor outputs to decide if this solution could be used operationally at global scale.

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