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

IGARSS 2018
FERIA VALENcia | VALENcia | SPAIN
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**TABLE OF CONTENTS**

- Introduction
- Sentinel-2 mission / L2A processor Sen2Cor
- Current validation status of Sen2Cor v2.5
- Sen2Cor prototype using meteorological aerosol estimates
- Preliminary results
- Conclusion
SENTINEL-2 MISSION

- Optical mission for land and coastal region monitoring and emergency services
- Constellation of 2 satellites S2A and S2B
- Polar, Sun-synchronous orbit: altitude 786.13km with LTDN 10h30 AM
- Swath of 290km
- Global coverage with 5 days or less revisit period with both satellites

13 spectral bands
spatial resolution
10 m, 20 m, 60 m.
LEVEL-2A PROCESSING STEPS

- Two main modules: Scene Classification (SCL) and Atmospheric Correction (AC)
- Set of Look-Up Tables (LUTs) generated with libRadtran
- AOT derived at 550nm based on the DDV (Dense Dark Vegetation) algorithm
- WV retrieval based on the Atmospheric Pre-corrected Differential Absorption Algorithm (APDA)
Sentinel-2A product
Four tiles
North of Italy
22 April 2018
L2A PROCESSOR OUTPUTS

Sentinel-2A product
Four tiles
North of Italy
22 April 2018
Scatter plot of Sen2Cor WV output at 20 m resolution versus WV reference from AERONET stations. ACIX-1 data set (water sites excluded).

Accuracy requirement (solid lines): $|\Delta \text{WV}| \leq 0.1 \times \text{WV}_{\text{ref}} + 0.2$

Dashed line: Sen2Cor_output = Reference

Very good accuracy of WV estimation by Sen2Cor 2.5
L2A Validation Results Sen2Cor 2.5 Public: AOT Product

Scatter plot of Sen2Cor AOT$_{550}$ output at 20 m resolution versus AOT$_{550}$ reference from AERONET station. ACIX-1 data set (water sites excluded).

- Accuracy requirement (solid lines): $|\Delta \text{AOT}_{550}| \leq 0.1 \times \text{AOT}_{550,\text{ref}} + 0.03$
- Dashed line: $\text{Sen2Cor}_{\text{output}} = \text{Reference}$
- Green triangles: Results for DDV-algorithm
- Orange triangles: Results for fall-back processing with configured start VIS=40 km

- DDV-algorithm slightly overestimates AOT$_{550}$
- Current fall-back processing gives many large outliers
Fall back solution when DDV pixels are missing in the image.

- ECMWF-CAMS Total AOD at 550 nm short term forecast (< 12 hours)
- Data available on Operational FTP with short-term rolling archive (~ 3 days)
- CAMS data is collected daily
- CAMS data quality is controlled above L2A calibration test sites.

Sen2Cor CAMS prototype developed by TPZ F

First validation performed by DLR on ACIX dataset

Copernicus Atmosphere Monitoring Service (CAMS) website: https://atmosphere.copernicus.eu/
Example of CAMS product retrieved from operational FTP
0.4 x 0.4 deg lat-lon grid
L2A: ECMWF-CAMS AOD at 550 nm Assessment

Filtering using:

Aeronet quality (number of aeronet measurements around S2 acquisition time)

Nsamples: 547

Pearson's corr. Coeff R(all): 0.80

Slight overestimation for lower aerosol loads < 0.25
L2A PROTOTYPE: MAIN PROCESSING STEPS

- Sen2Cor CAMS prototype based on 02.05.05 (public version)
  - AOD inputs from CAMS NEAR_REALTIME (FTP) or MACC data from API server
  - CAMS AOD data used in AC processing only when not enough DDV are present
  - CAMS AOD converted to visibility (km) using the altitude of the CAMS DEM.
  - Visibility spatially and temporally interpolated to S2 geometry and S2 acquisition time.
  - Visibility parameter then used in the radiative transfer equations together with Sen2Cor Digital Elevation Model information (PlanetDEM for operational L2A)
  - Iterative negative reflectance check performed afterwards:
    - If too many negative surface reflectance pixels -> visibility slightly increased (\(\Leftrightarrow\) AOD decrease) to reduce the amount of negative reflectance pixels.
L2A Validation Results Sen2Cor 2.5 CAMS: AOT Product

Correlation plot of Sen2Cor AOT\textsubscript{550} output at 20 m resolution over AOT\textsubscript{550} reference from AERONET on basis of the ACIX-1 data set (water sites excluded).

Sen2Cor 2.5, fall-back solution = start VIS

Sen2Cor 2.5, fall-back solution = CAMS data

Using CAMS data as fallback solution in case there are no DDV-pixels in the image looks much better.
Sen2Cor 2.5 public in comparison to Sen2Cor 2.5 CAMS; ACIX (water sites excluded)

<table>
<thead>
<tr>
<th>AOT statistics</th>
<th>noDDV set 2.5 public</th>
<th>noDDV set 2.5 CAMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of products</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>Products within requ.</td>
<td>27%</td>
<td>36%</td>
</tr>
<tr>
<td>$R^2$ (Coefficient of variation)</td>
<td>0.19</td>
<td>0.60</td>
</tr>
<tr>
<td>$r$ (Pearson’s correlation coeff.)</td>
<td>0.43</td>
<td>0.77</td>
</tr>
<tr>
<td>MA (Median Accuracy value)</td>
<td>-0.08</td>
<td>0.04</td>
</tr>
<tr>
<td>MD (Median deviation)</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>MP (Median Precision value)</td>
<td>0.25</td>
<td>0.16</td>
</tr>
<tr>
<td>U (Uncertainty)</td>
<td>0.25</td>
<td>0.17</td>
</tr>
<tr>
<td>Max AOT$_{550}$ difference</td>
<td>0.77</td>
<td>0.48</td>
</tr>
<tr>
<td>95.4% Quantile</td>
<td>0.14</td>
<td>0.26</td>
</tr>
<tr>
<td>68.3% Quantile</td>
<td>0.07</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Median Deviation = median (|Sen2Cor - reference|)

Much higher correlations, remarkable lower MP, U and Max AOT$_{550}$ difference, lower A
More products within requirement
L2A CAMS FALLBACK: Sen2COR 2.5 ORIGINAL

Sentinel-2B product
Four tiles
Naples, Italy
9 March 2018

Overlap region in red: 980 x 980 pixels
L2A CAMS FALLBACK: Sen2cor 2.5 CAMS PROTOTYPE

Sentinel-2B product
Four tiles
Naples, Italy
9 March 2018

Overlap region in red : 980 x 980 pixels
CONCLUSION AND OUTLOOK

- Sen2Cor CAMS prototype based on public Sen2Cor version 2.5
- Promising results for the improvement of AOT retrieval in case DDV pixels are missing in the image
- CAMS data quality monitoring over L2A calibration sites to be continued
- Further investigations foreseen:
  - using CAMS forecasts for different aerosol types
  - merging CAMS forecasts with Sen2Cor AOT estimates (in case DDV are present in the image)
ACKNOWLEDGEMENTS

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L2A CALIBRATION ACTIVITIES: CAMS-ECMWF AOT

CAMS geopotential used to calculate elevation
elevation = surface geopotential / 9.80665

Resolution 0.4 x 0.4 deg
L2A: ECMWF-CAMS AOD at 550 nm Assessment

No direct correlation between cloud coverage and CAMS aod uncertainty.

Qualitative analysis of outliers shows that these are often related to a large weather front approaching the aeronet site.
VALIDATION PROCEDURE

• AOT & WV validation procedure:
  ➢ direct comparison with AERONET as reference
  ➢ AERONET: satellite overpass time ±30 min
  ➢ Sentinel-2: average over
    ➢ 9km x 9km area around sunphotometer of all vegetated and not-vegetated pixels

• SR validation procedure:
  ➢ Pixel-by-pixel comparison with AERONET corrected (surface reflection) data as reference
  ➢ SR reference computed from [Eric Vermote]
    ➢ Sentinel-2 L1C (TOA) data with
    ➢ 6S radiation transport model using
    ➢ aerosol parameters from AERONET as input
  ➢ AERONET: satellite overpass time ±30 min
  ➢ Sentinel-2:
    ➢ 9km x 9km area around sunphotometer with
    ➢ only non-saturated, non-cloudy and non-missing pixels considered
VALIDATION PROCEDURE

• Statistical metrics:
  - $X_i = SR_{i\lambda}, AOT^{550}_i, WV_i$  
  - $\Delta X_i = X_i,_{SEN2COR} - X_i,_{reference}$
  - **Median Accuracy value** (median difference to reference value)
    
    $$MA = \text{Median}_{i=1}^{n}(\Delta X_i)$$
  - **Median absolute Deviation**:
    
    $$MD = \text{Median}_{i=1}^{n}(|\Delta X_i|)$$
  - **Median Precision value** (rms around MA)
    
    $$MP = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n}(\Delta X_i - MA)^2}$$
  - **Uncertainty U** (rms around reference value)
    
    $$U = \sqrt{\frac{1}{n} \sum_{i=1}^{n}(\Delta X_i)^2}$$
  - **SR per band**:
    - MA, MP and U are computed per 0.02-SR-bins and
    - overall values for entire SR range