Validation of atmospheric correction: Collaboration and exchange between Copernicus Sentinel-2 and Sentinel-3 teams?

SENTINEL 2 Mission Performance Centre

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Both Copernicus **Sentinel-2** and **Sentinel-3** missions provide data for global land monitoring. Future FLuorescence EXplorer (**FLEX**) mission will orbit in tandem with one Sentinel-3 satellite and quantify photosynthetic activity.
Synergistic data analysis involving FLEX, Sentinel-3 and Sentinel-2 missions is an upcoming topic which combines and exploits the spatial and spectral benefits of each of these missions. Even if different atmospheric correction algorithms are developed and used for Sentinel-2 and Sentinel-3 data and are being developed for FLEX-mission, there is a high synergy potential regarding validation. This poster shows the validation activities performed for Sentinel-2 atmospheric correction processor Sen2Cor and atmospheric correction tool ATCOR/PACO.

ATCOR(1) / PACO:

- **ATCOR** is a widely used multi-mission atmospheric correction tool developed by DLR which can process data of many sensors providing images in the VNIR to TIR spectral range.
- Main ATCOR modules are being migrated to Python-based Atmospheric COrrection chain **PACO**. It is designed for Big-Data solutions and will provide the same performance as ATCOR.

Sen2Cor(2):

- was implemented on basis of ATCOR by TPZ-D, TPZ-F and DLR on behalf of ESA
- Single mission atmospheric correction processor tailored to Sentinel-2 data.
- Is used for global L2A-processing by Sentinel-2 PDGS and can be obtained for user processing from http://step.esa.int/main/third-party-plugins-2/sen2cor/
- TPZ-F and DLR have teamed up in order to provide the calibration and validation of the Level-2A processor Sen2Cor.

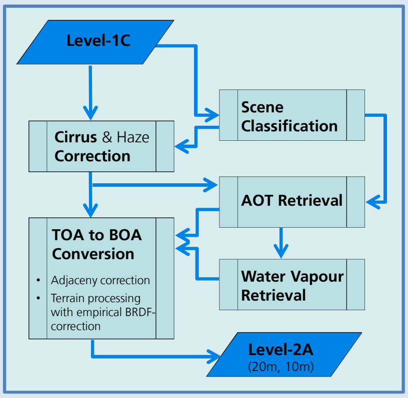

Figure 1: Sen2Cor / ATCOR/PACO processing
Haze correction is only implemented in ATCOR/PACO

Figure 2: Processing on granule level

(1) Richter, R. (1996). "A spatially adaptive fast atmospheric correction algorithm", Int. J. Remote Sensing, Vol. 17, 1201-1214

(2) Richter, R.; Louis, J.; Müller-Wilm, U. Sentinel-2 MSI—Level 2A Products Algorithm Theoretical Basis Document. 2012, S2PAD-ATBD-0001, Issue 2.0.

VALIDATION of SR (BOA product) on AERONET sites

Validation steps include:

- ➔Select Sentinel-2 acquisitions with AERONET data within ±15 min of satellite overpass time
- ➔Use radiation transport model with AERONET data as input for computation of SR reference from Sentinel-2 L1C data within 9x9 km² subset around sunphotometer location
- ➔Pixel-by-Pixel per band comparison of this „AERONET-corrected" SR as reference with SR from L2A-data within the same 9x9 km² subset around sunphotometer location, per 0.02 SR-bin
  [Claverie M. et al, 2015, Remote Sens. Environ., 169, 390–403]

- ➢ Advantage: many reference pixel available
- ➢ Disadvantage: additional uncertainty included with use of a model

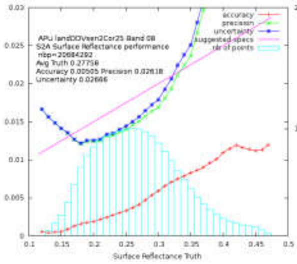

*Figure 5: Example APU-plot for Band 8 with SR specification |ΔSR|≤0.05*SRref+0.005*

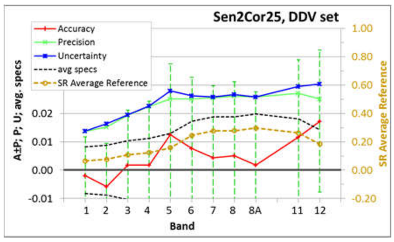

Figure 6: Plot of overall values of A, P and U per band for entire SR range relative to average SR per band

Accuracy (A)
mean difference to reference value

$$X = AOT_{550}\,;\, WV \qquad ;(\rho_{i,\lambda})$$

$$\Delta X = X_{SEN2COR} - X_{AERONET}$$

$$A = Median_{i=1}^{n}(\Delta X_i)$$

Precision (P)
rms around mean value

$$P = \sqrt{\frac{1}{(n-1)} \cdot \sum_{i=1}^{n} (\Delta X - A)^2}$$

Uncertainty (U)
rms around reference value

$$U = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\Delta X_i)^2}$$

CLOUD SCREENING & CLASSIFICATION VALIDATION

Validation steps include:

- ➔Stratified random sampling (minimum 50 samples per class)
- ➔Visual pixel/area labelling by validation expert (RGB⁸⁴³², CIR band composits, cirrus band, spectrum, confidence-images)
- ➔Creation of reference image, computation of confusion matrix, omission and commission errors …

More details: presentation "Validation of Sentinel-2 cloud masking and classification products – potential for Sentinel-3 validation?", M. Main-Knorn, et al.

VALIDATION of AOT and WV products

Validation based on direct comparison with AERONET data as reference

Validation steps include:

- ➔Select Sentinel-2 acquisitions with AERONET data within ±15 min of satellite overpass time
- ➔Spectral interpolation of AERONET AOT-spectra by a (geometric) fit to $AOT_{550} = a0 \cdot 0.55^{a1} + a2$
- ➔Temporal average of AOT_{550} and WV reference data
- ➔Spatial average of AOT_{550} and WV from Sentinel-2 data over 9x9 km² subset around sunphotometer location
- ➔Compute AOT-statistics / create plots with mask ('vegetation' or 'not vegetated') for summary over all test sites and for subsets per test site, per climate zone, per season …

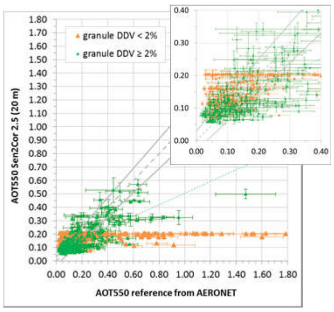

Figure 3: Correlation plot for AOT@550nm (20m)

- ›**solid lines**: Accuracy requirement
  *|ΔAOT550| ≤0.1*AOT550$_{ref}$+0.03*
  *|ΔWV| ≤0.1*WVref+0.2*
- ›**Dashed line**: Sen2Cor_output = Reference
- ›**Green triangles**: Results for **DDV**-algorithm
- ›**Orange triangles**: **fall-back** processing
- ›Linear trend lines for DDV and fall-back
- ›Error bars: have to use total uncertainties

$u_{total} = SQRT(u_{statistical}^2 + u_{systematic}^2)$

$u_{systematic} = \{0.1 \cdot AERONET;\ \sigma^{AOT}(Granule);\ 0.1 \cdot avg(WV(ROI))\}$

Table 1: Algorithm retrieval performance statistics

All test sites (20m product)	complete set	
	AOT_{550}	WV
Total no. of products	559	559
Products within requirement	41%	92%
R^2 (Coefficient of variation)	0.21	0.97
r (Pearson's correlation coeff.)	0.46	0.98
MD (Median deviation)	0.06	0.13 cm
MA (Median Accuracy value)	0.003	-0.13 cm
MP (Median Precision value)	0.24	0.22 cm
U (Uncertainty)	0.25	0.28 cm
Max AOT_{550} difference	1.59	1.63 cm

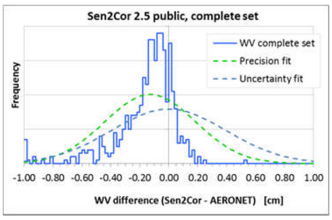

Figure 4: Histogram plot of WV difference (Sen2Cor – reference) in 0.02 cm bins

VALIDATION of SR (BOA product) with SR measurements

Validation steps include:

- ➔Processing SR measurements performed during ad-hoc campaigns
- ➔Upscaling of SR measurements performed on ground to Sentinel-2 pixels
- ➔Comparison

- ➢ Advantage: real measurements as reference, no additional model included
- ➢ Disadvantage: upscaling problem, only few reference pixels available

Table 2: Propagation of retrieval errors to Vegetation indices, example NDVI ; $(R_{865}-R_{665})/(R_{865}+R_{665})$

NDVI	Grass
Sen2Cor25	0.56
reference	0.53
Sen2Cor-reference	0.03

Example data: 04.05.2018, Lake Stechlin, Northern Germany (53.15°N, 13.03°E)

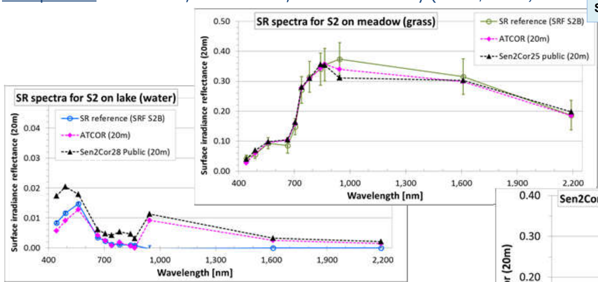

Figure 7: Satellite SR retrieval compared with SR measured on ground

Table 3: Shape and intensity correctness of SR retrieval relative to reference measurement on surface

	Sen2Cor25	water	grass
r	Pearson's correlation coefficient	0.897	0.973
	RMSD	0.005	0.022

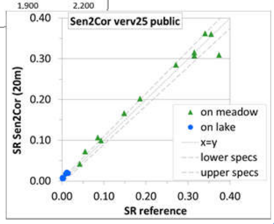

Figure 8: Correlation plot for SR

Outcome and credits

Tool developments and updates are ongoing for Sentinel-2 L2A-product validation together with discussions on better approximations for systematic uncertainties. More sources of systematic errors are to account for like L1C calibration uncertainty, masking errors, aerosol model and profile used, site altitude …

One aspect of potential synergy between Sentinel-2 and Sentinel-3 validation of atmospheric correction can cover sharing of campaign data and organization of joint ad-hoc campaigns. Discussion about user requirements / interests, the validation protocol, statistical metrics applied for reporting atmospheric correction performance and consideration of uncertainties is of high interest.

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