Haze compensation and atmospheric correction for Sentinel-2 data

Aliaksei Makarau, Rudolf Richter, Viktoria Zekoll, and Peter Reinartz
German Aerospace Center (DLR), Münchnerstr. 20, Weßling, D-82234 (aliaksei.makarau@dlr.de)

Intro. The Sentinel-2 high spatial resolution and a wide swath requires a per granule analysis. A high variation of the aerosol optical thickness (AOT) across the granules, especially in case of haze, cause the atmospherically corrected and mosaicked product to show border effects. A dehazing prior to the atmospheric correction compensates for the haze thickness keeping the AOT fraction for further estimation and compensation. This results in a smoother AOT map and bottom of atmosphere (BOA) reflectance with reduced border artifact. Digital elevation model (DEM) is employed for a higher accuracy of the dehazing. The DEM analysis rejects high elevation areas where bright surfaces might erroneously be classified as haze. An example of a numeric evaluation of the atmospheric correction products (AOT and BOA reflectance) is given. It demonstrates a smoother transition between the granules in the AOT map leading to a proper estimate of the BOA reflectance data.

Haze model. Haze additive model is:

$$L^{sensor} = L_0 + HR$$

L^{sensor} is the acquired radiance, L_0 is the sum of path radiance and surface reflected radiance, and *HR* is the haze contribution. A linear relationship of the DN to radiance:

$$DN_i^{sensor}(x,y) = DN_i(x,y) + HR_i'(x,y)$$

Spatial thickness. The dark pixels are searched using a local non-overlapping window (*w*×*w* pixels) and the *HTM*(*x*,*y*) is estimated.

$$HTM_i'(x,y) = DARK\_PIX\_SEARCH(Band_i(x,y), w)$$

Spectral thickness. Per band *HTMi* thickness:

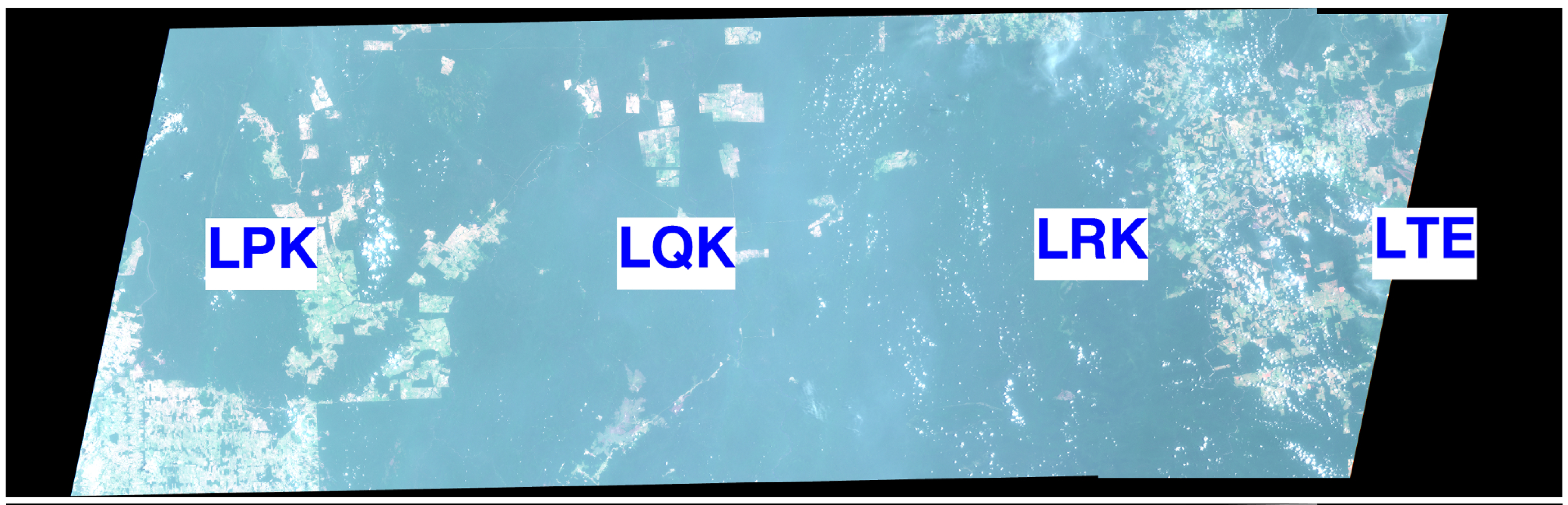
$$k_i = SLOPE(HTM(x,y), HTM_i'(x,y))$$
$$HTM_i(x,y) = HTM_i'(x,y) * k_i, \quad k_i \in \mathbf{K}$$

Dehazing.

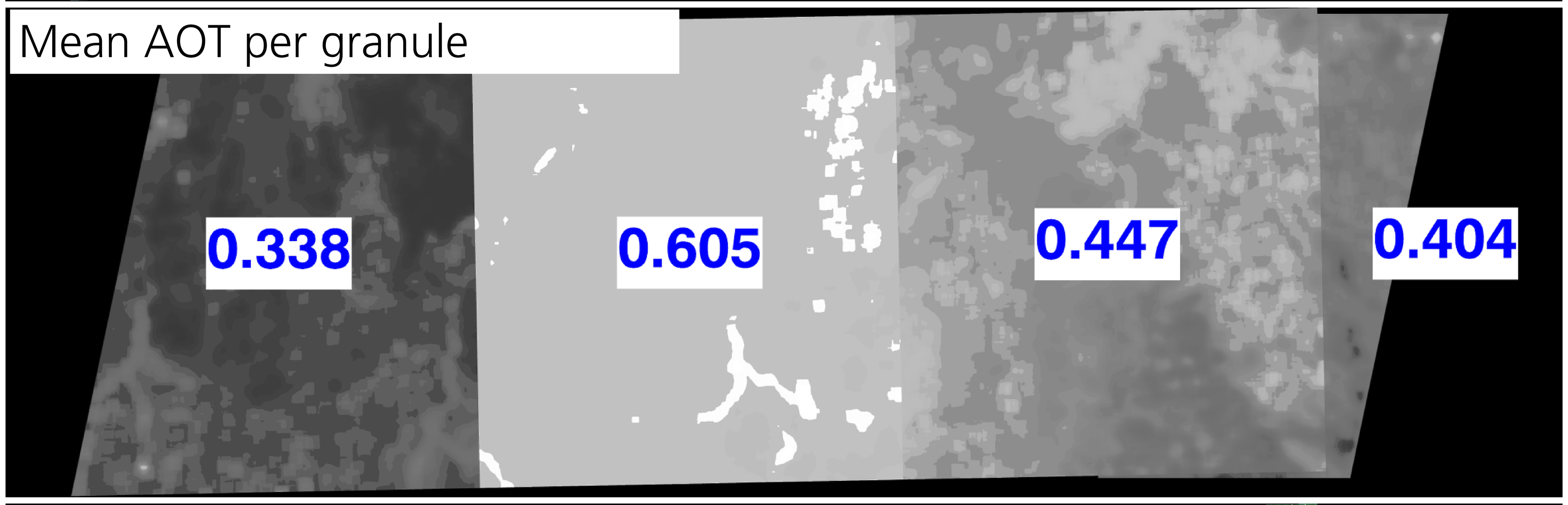
$$DN_i(x,y) = DN_i^{sensor}(x,y) - HTM_i(x,y)$$

The subtraction removes the HTM (haze plus possibly a fraction of the clear scene aerosol) thickness and the data are also compensated for the clear scene aerosol fraction.

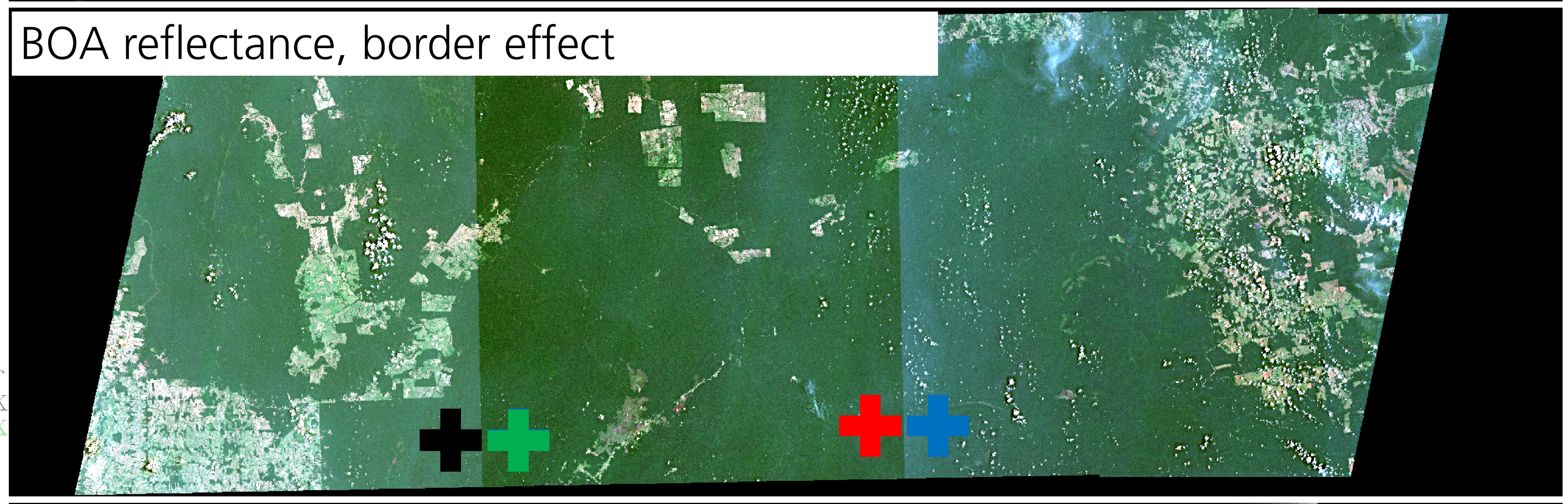
The Sentinel-2 L1C scene (S2A_OPER_PRD_MSIL1C_PDMC_20151022T110044_R010_V20151021T143100_20151021T143100.SAFE, 21 Oct 2015) consisting of 12 granules (scene total size is > 361 megapixel). Four granules are presented here for an illustration: S2A_OPER_MSI_L1C_TL_SGS__20151021T193835_A001723_T20**LRK**_N01.04, *T20**LPK**_N01.04, *T21**LTE**_01.04, *T20**LQK**_N01.04. The scene is covered by haze and small areas have cirrus (LRK).



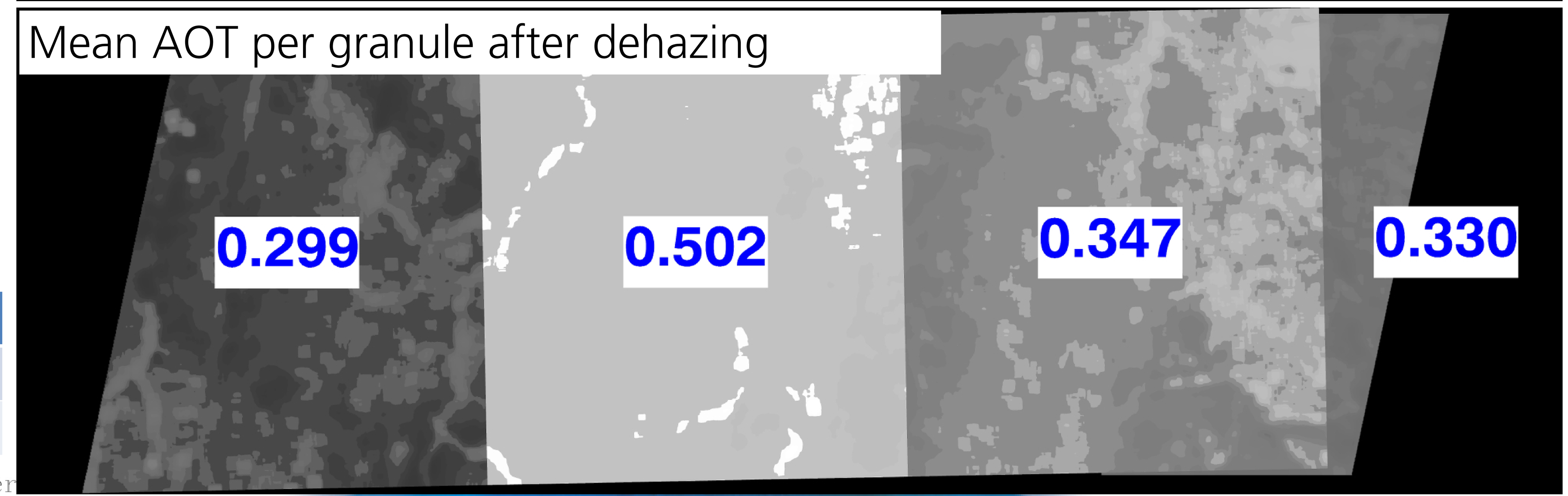
AOT estimaton and atmospheric correction are performed per granule. DLR ATCOR is used. The estimated AOT maps have the value offset at a granule border which is expected. Haziness over the whole scene increases the AOT level. The mean AOT value per granule is marked by blue color and has relatively high variation.



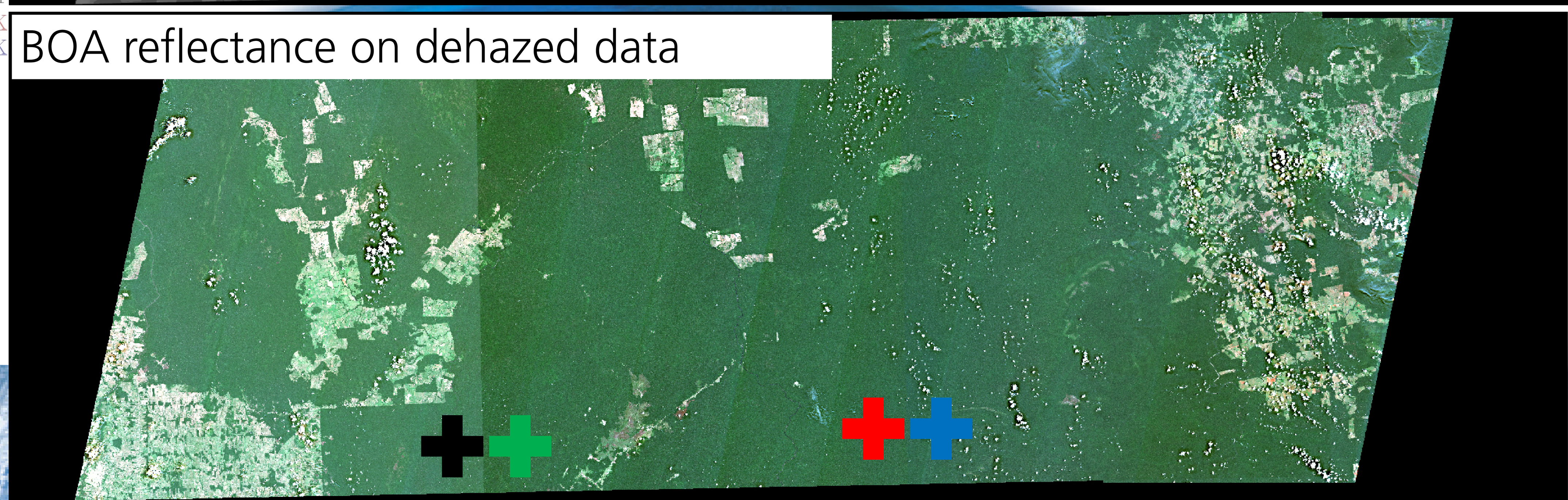
The AOT border offset leads to a border effect in the BOA reflectance. Further products estimated using the BOA reflectance data are expected to have inconsistency on the border.

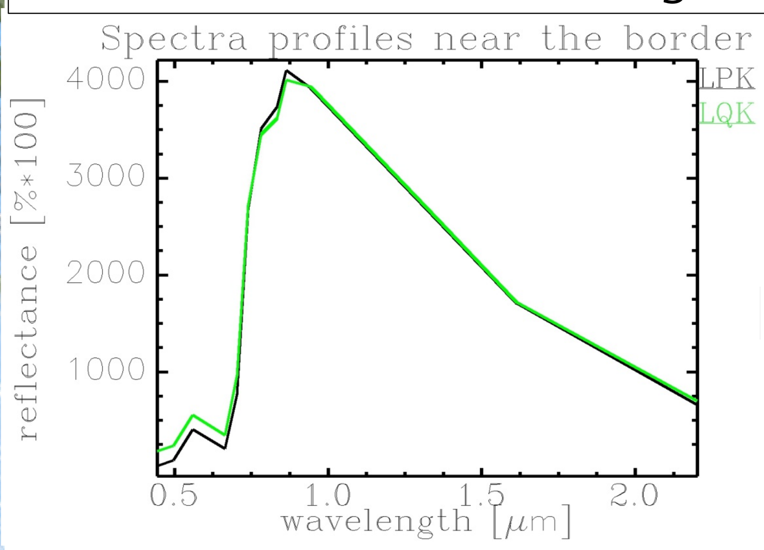


The AOT maps are estimated on the dehazed* ** granules. AOT variation among the granules decreased. Nevertheless, granule LQK still has a higher AOT compared to the other granules. The employment of the S2 water absorption band as well as DEM data increase the accuracy of the dehazing.



Eliminated border effect for granules LQK-LRK, LRK-LTE.
Reduced border effect for granules LPK-LQK.





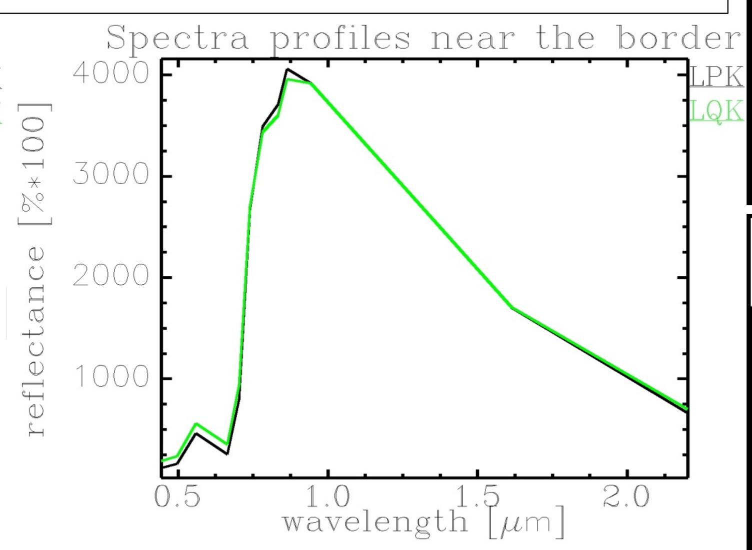
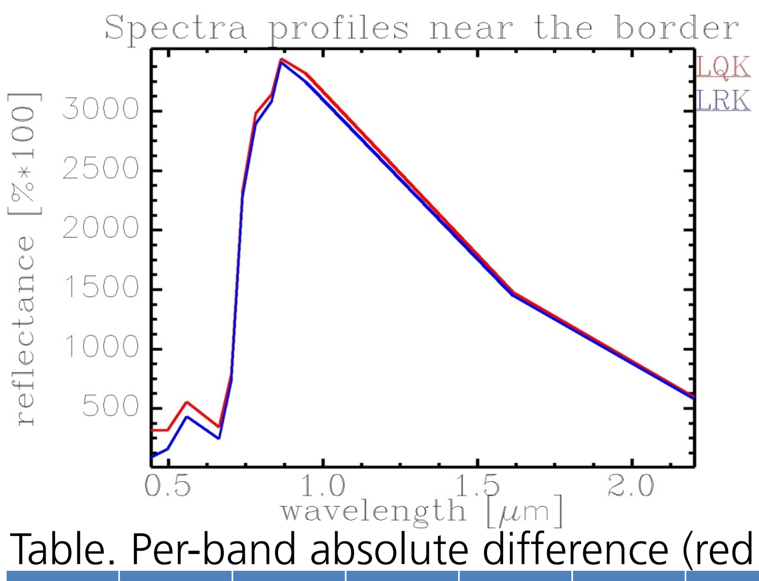


Table. Per-band absolute difference (black & green cross)

B1	B2	B3	B4	B5	B6	B7	B8	B8a	B9	B10	B11	B12
1.56	1.48	1.48	1.4	1.96	0.41	0.59	1.19	1.02	0.17	0.13	0.1	0.4
0.68	0.77	0.97	0.98	1.46	0.31	0.27	1.08	1.02	0	0	0.02	0.37



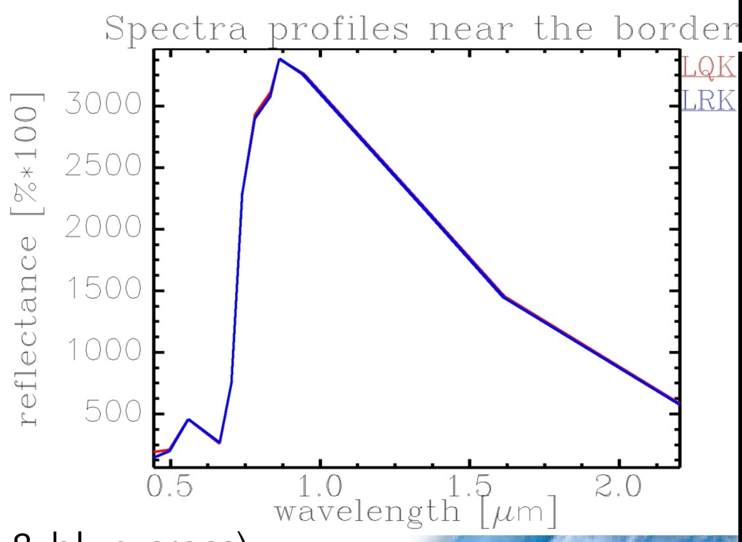


Table. Per-band absolute difference (red & blue cross)

B1	B2	B3	B4	B5	B6	B7	B8	B8a	B9	B10	B11	B12
2.2	1.52	1.03	0.94	0.48	0.26	0.02	0.02	0.12	1.13	0.45	0.08	0.03
0.34	0.05	0.21	0.12	0.15	0.32	0.1	0.02	0.1	0.1	0.2	0.05	0.02

* A. Makarau, R. Richter, D. Schläpfer, and P. Reinartz, "Combined haze and cirrus removal for multispectral imagery", IEEE GRSL, Vol 13, No 3, PP 379-383
** A. Makarau, R. Richter, R. Müller, and P. Reinartz, "Haze Detection and Removal in Remotely Sensed Multispectral Imagery", IEEE TGRS, Vol 59, No 9, PP 5895-5905

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